NATIONAL SCIENCE FOUNDATION
4201 WILSON BOULEVARD
ARLINGTON, VIRGINIA 22230

OFFICE OF THE
GENERAL COUNSEL

Case #06-285F

October 17, 2006

Ms. Marcia Hofmann
Staff Attorney
Electronic Frontier Foundation
1875 Connecticut Avenue, NW, Suite 850
Washington, DC 20009

Dear Ms. Hofmann:

This is in response to your September 26, 2006 emailed Freedom of Information Act (FOIA) request for copies of the NSF funded grants numbered 0423386, 0209190 and 0512976.

Records responsive to your request are enclosed. Personal information (individual salaries, bios, pending and non-Federal grants) has been withheld wherever it appears under the privacy protection of Exemption 6 of the FOIA. Reviewer identifying information in the proposal jacket is withheld under exemptions 5 and 6 of the Freedom of Information Act (5 U.S.C. 552(b)) that protect from disclosure the predecisional, deliberative process and personal information and exemption (k)(5) of the Privacy Act (5 U.S.C. 552a). Further, reviewer's comments/rankings are exempt from disclosure under the provisions of Exemption (b)(5) of the FOIA. Your right of administrative appeal is set forth in Section 612.9 of the NSF FOIA regulation (copy enclosed).

There is no fee for FOIA services in this instance in accordance with 5 U.S.C. 552 (a)(4)(A)(i) et seq.

Sincerely,

Leslie A. Jensen
FOIA/Privacy Act Officer

Enclosures

§612.9 Appeals.

(a) Appeals of denials. You may appeal a denial of your request to the General Counsel, National Science Foundation, 4201 Wilson Boulevard, Suite 1265, Arlington, VA 22230. You must make your appeal in writing and it must be received by the Office of the General Counsel within ten days of the receipt of the denial (weekends, legal holidays, and the date of receipt excluded). Clearly mark your appeal letter and the envelope "Freedom of Information Act Appeal." Your appeal letter must include a copy of your written request and the denial together with any written argument you wish to submit.

(b) Responses to appeals. A written decision on your appeal will be made by the General Counsel. A decision affirming an adverse determination in whole or in part will contain a statement of the reason(s) for the affirmance, including any FOIA exemption(s) applied, and will inform you of the FOIA provisions for court review of the decision. If the adverse determination is reversed or modified on appeal, in whole or in part, you will be notified in a written decision and your request will be reprocessed in accordance with that appeal decision.

(c) When appeal is required. If you wish to seek review by a court of any denial, you must first appeal it under this section.

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 04-23	FOR NSF USE ONLY
NSF 04-23	NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) OISE - AFRICA, NEAR EAST, & SO ASIA	0512976

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
12/09/2004	2	01090000 OISE	5976		09/27/2006 9:17am S

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS ☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
George Washington University	George Washington University 2121 Eye Street NW Washington, DC. 200372353
AWARDEE ORGANIZATION CODE (IF KNOWN) 0014449000	
NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE	ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE
PERFORMING ORGANIZATION CODE (IF KNOWN)	

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions) ☐ SMALL BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS ☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **Radio Frequency Microelecromechanical Systems (MEMS) Integration**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 30,000	24 months	01/01/05	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

- ☐ BEGINNING INVESTIGATOR (GPG I.A)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.1.d)
- ☐ HISTORIC PLACES (GPG II.C.2.j)
- ☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.D.1)
- ☐ VERTEBRATE ANIMALS (GPG II.D.5) IACUC App. Date ______
- ☐ HUMAN SUBJECTS (GPG II.D.6) Exemption Subsection ______ or IRB App. Date ______
- ☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j) ______
- ☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
Electrical and Computer Engineering	801 22nd street NW, Academic Center Electrical and Computer Engineering Dept Washington, DC 20052 United States
PI/PD FAX NUMBER 202-994-0227	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME Mona E Zaghloul	PhD	1975	202-994-3772	zaghloul@gwu.edu
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

Electronic Signature

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 04-23. Willful provision of false information in this application and its supporting documents or in reports required *under an ensuing award is a criminal offense* (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Drug Free Work Place Certification

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Appendix C of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Debarment and Suspension Certification contained in Appendix D of the Grant Proposal Guide.

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, "Disclosure of Lobbying Activities," in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME Helen Spencer	Electronic Signature	Dec 9 2004 11:49AM

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
202-994-6255	osr@gwu.edu	202-994-9137

*SUBMISSION OF SOCIAL SECURITY NUMBERS IS VOLUNTARY AND WILL NOT AFFECT THE ORGANIZATION'S ELIGIBILITY FOR AN AWARD. HOWEVER, THEY ARE AN INTEGRAL PART OF THE INFORMATION SYSTEM AND ASSIST IN PROCESSING THE PROPOSAL. SSN SOLICITED UNDER NSF ACT OF 1950, AS AMENDED.

This project focuses on designing and fabrication of microelectromechanical (MEMS) components for miniaturized RF wireless applications. The main target will be enabling a new class of low-power, low –cost, and high – performance of miniature RF MEMS devices, which offer significant space and time saving by replacing the off-chip passive components used in the current transceiver circuits. The technology referred to by the terms `microelectromechanical systems' (MEMS), is a multidisciplinary one which has generated a great deal of interest in numerous applications. This work will focus on the realization of RF-MEMS components on CMOS substrate that are suitable for integration for mobile and wireless communication system applications. In addition for their potential for integration and miniaturization, it is our goal to design low power and high Q devices integrated with CMOS circuits. The goal is the development of specific types of devices that will be integrated on the same substrate as Receiver/Transceiver The first objective is to review the status and prospects for high- Q, low power devices produced by the MEMS technology and to identify their applications in wireless communication. Examples of devices are Variable Capacitors, High Q Inductors, and Surface Acoustic Wave devices (Resonators and Filters) that are recently being developed on CMOS substrate. The integration of those devices with the control circuits on a monolithic substrate will be addressed in view of modified process and new materials to allow for integration. The next stage is the fabrication stage to produce a complete monolithic RF circuit with MEMS components on the same chip using combatable CMOS technology. Finally, the characterization and testing of the produced MEMS devices to assure the robustness and functionality on RF application will be done.

The main goal of the collaboration is to focus on the transfer of the microsystem technology, which involves design, modeling, and fabrication of micro-sensor and actuator in concert with different applications. This will help both of U.S and Egypt in establishing the new technology of micromachining in our institutes.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.C.

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

4. Background

Microelectromechanical systems (MEMS) are integrated micro devices or systems combining electrical and mechanical components fabricated using integrated circuit (IC) compatible batch-processing techniques and range in size from micrometers to millimeters. These systems can sense, control, and actuate on the micro scale and function individually or in arrays to generate effects on the macro scale. MEMS can be used to provide robust and inexpensive miniaturization and integration of simple elements into more complex systems. A few examples already built include accelerometers integrated into IC chips, tiny gear trains as small as dust mites, and electromechanical resonators for RF signal processing applications [1-3].

Extensive applications for these devices exist in both commercial and defense systems. MEMS are the next logical step in the silicon revolution. The silicon revolution began over three decades ago, with the introduction of the first integrated circuit. The integrated circuit has changed virtually every aspect of our lives. The hallmark of the integrated circuit industry over the past three decades has been the exponential increase in the number of transistors incorporated onto a single piece of silicon. This rapid advance in the number of transistors per chip leads to integrated circuits with continuously increasing capability and performance. As time has progressed, large, expensive, complex systems have been replaced by small, high performance, inexpensive integrated circuits. While the growth in the functionality of microelectronic circuits has been truly phenomenal, for the most part this growth has been limited to the processing power of the chip. The next step in the silicon revolution will be different, and more important than simply packing more transistors onto the silicon. It is believed that the hallmark of the next thirty years of the silicon revolution will be the incorporation of new types of functionality onto the chip; structures that will enable the chip to not only think, but to sense, act and communicate as well. This revolution will be enabled by MEMS.
In the most general form, MEMS consist of mechanical microstructures, microsensors, microactuators and electronics integrated in the same environment, the silicon chip. Miniaturization of mechanical systems promises unique opportunities for new directions of scientific and technological progress. MEMES are not only about miniaturization of mechanical systems; they are also a new paradigm for designing mechanical devices and systems. The microfabrication technology enables fabrication of large arrays of devices, which individually perform simple tasks but in combination can accomplish complicated functions. The field of solid-state transducers traditionally has been application driven and technology-limited, and it has emerged as an interdisciplinary field involving many areas of science and engineering. Microsensors and MEMES in general, have followed a similar trend. The realization of such complex microsystem on a chip, and the integration of these mechanical systems with on-chip control and communication electronics, will enables the creation of intelligent Microsystems which know where they are, and what is going on around them. Every day we're finding more applications for micromachine technology which focuses on a variety of defense and commercial applications.

A wide variety of MEMS devices have been built recently by using the VLSI processing techniques. Various MEMS devices applications can be found in [4-9]. During the designing process, it is very desirable to predict the effect of change of parameters. For some MEMS devices, it is tedious to derive analytic dynamic equations. Even if all equations are given, it is usually still tedious to solve them analytically to predict the dynamic behavior of the system. Therefore a general-purpose dynamic simulator would be an excellent tool to study the design. There exist now several MEMS simulators such as MEMSCAP, COVENTOR, and the traditional ANSYS tools. It is expected during the design of the proposed devices extensive simulation will be done using these tools.

4.1 Advantages offered by MEMS:

Obviously, MEMS are extremely small and can be built on the micron scale. These are only the beginning of their potential, however. The following advantages are grouped by their relevance to different applications.

Low Cost and Complexity (Ease of Manufacture)

- As mentioned, MEMS manufacturing processes piggyback off of the rest of the IC semiconductor industry, so they can be fabricated without extensive investment in new equipment.
- MEMS can be incorporated directly into the casing of an integrated circuit, operating off of its power supply and increasing the level of integration (thus reducing noise).
- Batch fabrication with sacrificial layers allows for automatic assembly of moving/connected parts.
- Also due to the sacrificial layers, MEMS parts are automatically self-aligned with high precision.
- All of these factors add up to significant cost savings on the manufacturing level, which is key to widespread use in everyday applications.

Improved Functionality as Sensors or Actuators

- Because MEMS are so small, they exhibit ultra-low mass and inertia.
- Low mass allows for both high actuator sensitivity (and accuracy) capable of measuring milli-G forces.
- At the same time, because they have virtually no mass, MEMS actuators avoid breaking under their own weight and can withstand thousands of G-forces.

- Without significant inertia, rotating parts in MEMS actuators can spin up to speed virtually instantaneously.
- Using photolithography, parts as big as a few millimeters can be built with ultra-high micron tolerances.
- Because MEMS sensors are so small and are relatively cheap, they can be used redundantly in arrays to improve robustness.

4.2 Proposed RF MEMS:

Recent efforts to apply micromachining technologies to the miniaturization and integration of frequency-selective devices are starting to bring passive device technology on par with that of transistors. In particular, micromachining technologies have successfully achieved miniaturized and integral versions of low loss, highly selective band pass filters covering a wide range of frequencies (from 20 kHz to 40 GHz); high-Q inductors and tunable capacitors for voltage-controlled oscillators and matching networks; micromechanical low-loss switches for phased arrays and configurable power amplifiers; and ultra-high-Q resonators for stable reference oscillators [10-16]. Figure 1 presents the typical block diagram for a super-heterodyne wireless transceiver, indicating the components that could greatly benefit from micromachined replacements. Current RF designs depend on off-chip components to implement key building blocks such as the low phase noise RF voltage-controlled oscillators (VCOs). In most systems the oscillator employs discrete inductor and varactor diode for frequency tuning. These off-chip devices rely on processing and materials that differ substantially from IC fabrication and consequently not suitable for monolithic integration, thus increasing cost, size and packaging complexity. On the other hand, quality factor (Q) of on-chip resonator is limited by the relatively poor Q of on-chip spiral inductor. A passive component such as high Q tunable capacitor, and high Q suspended inductor has been reported in [17-20]. In this collaborative work, we propose the design and fabrication of RF integrated CMOS-MEMS micro system. Backside Micromachined CMOS Inductors were introduced in [20], as well as variable capacitors [29]. Recently [31], [32], and [33] RF-Surface Acoustic Wave (SAW) components on CMOS substrate for mobile and wireless communication system were realized. The SAW device could be used as a resonator for filter and oscillator designs. In this entire devices novel method of integration with the monolithic CMOS RF circuits is required. It is proposed to study these RF-MEMS devices system as a part of this collaborative work using the MEMS technology to produce integrated devices compatible with a CMOS technology for the fabrication of monolithic Microsystems.

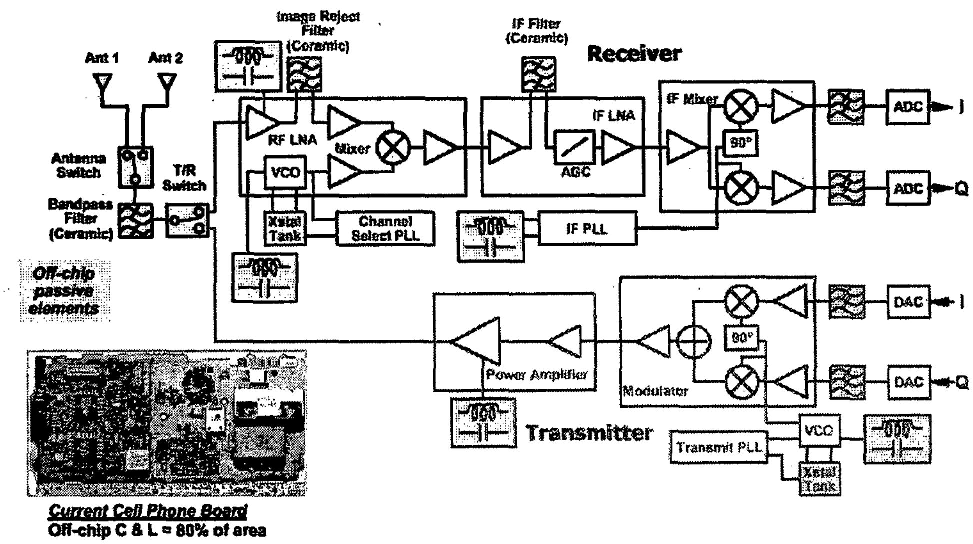

Fig. 1 Block diagram for a super-heterodyne wireless transceiver.

5. Statement of Technical Problem

In general, the main objective in this project is utilizing the MEMS technology to facilitate the integration of high Q components, low power MEMS devices and CMOS circuitry on IC scale substrate for monolithic fabrication. So the work will focus on the realization of RF MEMS components that are integrals with CMOS technology for mobile and wireless communication system. This will result in the development of specific types of devices with applications that will be specified during the implementation of the project.

The surface acoustic wave (SAW) devices on CMOS substrate are good example. These devices have applications such as band pass filters, resonators, voltage controlled oscillators (VCO) and converters operate in frequency range of 10 MHz to over 1 GHz [31-33].

The proposal will explore innovative design techniques to achieve the following:

1- Utilization of the MEMS technology to design and fabricate RF components such as high Q- factor inductors, capacitors that are combatable with CMOS substrate for RF circuits.
2- Design and fabrication of high Q RF-SAW devices using MEMS technology. Applications of those devices to the design of Voltage Controlled Oscillators(VCO), or band pass filter for wireless applications will be studied.
3- The integration of MEMS devices technology, with the required microelectronics interface circuitry results in new smart wireless system.

To achieve these goals, work on the system level, circuit and device level is proposed.. Innovation in interfacing MEMS and CMOS circuits and fabrication of SAW devices on IC scale substrate are needed. Low power, low voltage operation is an important prerequisite in such application. Achieving these goals simultaneously is a big challenge

The MEMS technology offers future solutions for complex problems facing the industry in the time being, a trend for the next century which will have its impact on different applications specially communications.
The main goal of this project to find an efficient way to produce integrated RF-MEMS components on monolithic substrate for wireless applications. This design will allow the integration of the MEMS devices with microelectronics circuits on a monolithic chip.

The team in Egypt and U.S. will study aspects related to currently available MEMS components for RF applications. While this work will be important to Egypt to build experience and knowledge in such areas, it will also give access to the U.S. team to manpower of graduate students and researchers to help with ongoing activities.

6. Project Description and detailed work plan

The work to be conducted in this project depends on knowledge of variety of important issues and of interdisciplinary nature. These issues involve the familiarity with the MEMS technology and CMOS circuit design. The work will involve the design of a MEMS components and fabrication and testing the fabricated device.
The MEMS components will be accomplished using standard CMOS Technology or modified extended CMOS technology. This work will allow the integration of MEMS components with the microelectronics circuit on the same chip. Monolithic communication transceivers are highly desirable for today's wireless communications. The key performance specifications are low voltage and low power consumption.

Thus the work will include four main parts:

1- Design and implement of high Q devices such as Inductors, Capacitors, SAW-CMOS Resonators, and using MEMS technology for RF application. The devices should be combatable with CMOS technology.
2- In the design of these components, the previous work and experience of the PI in realizing and implementing RF MEMS devices in CMOS technology will be used.
3- Using the realized components in 1) to implement RF circuit such as band pass filters or VCO.
4- Testing and characterization of the fabricated devices with their circuits interface.

6.1 The design of the RF-SAW filter

The SAW filters are widely used in the wireless communications industry and are found in many products including cellular phones, pagers, wireless LANs, and satellite receivers. The SAW filter is a relatively simple in structure [31-33]. It is consisting of a thin aluminum layer deposited on a piezoelectric medium. This metal layer is etched to form an array of interdigital transducer (IDT) that has geometrics on the scale of the acoustic wave lengths. The input and output IDTs convert the RF signals into mechanical surface wave and back into a filtered electrical signal. One of the most critical steps in SAW fabrication is the metal etch, the choice of the piezoelectric material deposition on silicon substrate is another challenge in design and fabrication of SAW device. Micromachining technology can be used to overcome of these challenges to fabricate SAW devices on CMOS substrate suitable for RF wireless applications. The resonators design will be the basic design for RF-Filters and Oscillators.

6.2 Plane of work

The following table summarizes the different tasks implied in this research project

No	Task name	Start Date	Duration	Responsibilities
1	Investigation of previous design and fabricated of MEMS components for RF applications	Month 1	3 m	ERI/GWU
2	Design, and Simulation of high Q devices . Design of RF CMOS circuit like VCO or filter including MEMS components.	Month 3	6 m	ERI/GWU
3	Fabrication Stage	Month 9	6 m	ERI/GWU
4	Test, measurements, and characterization.	Month 15	6 m	ERI/GWU
5	Documentation and Reporting	Month 21	3m	ERI/GWU

6.3 Deliverables from this work includes

First year: Development and design of RF MEMS devices and an integrating them in a system such as voltage controlled oscillator (VCO) or filters. Intensive simulation will also be conducted.

Second year: Fabrication of the design developed in the first phase, and then conducting evaluation and final testing, Characterization of the devices will be also presented. Comparative study will also be conducted. Documentation and dissemination of the results will be also available as an outcome of the project.

6.4 Impact of the proposed research

- Analysis, modeling, and characterization of MEMS based RF components will provide a framework for helping the designers to integrate these components into standard CMOS process.
- Enriching the experience for both the collaborating teams in the area of MEMS design for RF applications.
- Results of this research project will be published in Journals and Conferences proceedings, and will be available to industrial firms to benefit from it.

6.5 Previous work:

This work is a continuation for efforts done by the both collaborative working team in the area of designing MEMS components for RF wireless applications as depicted in references [23-30] and shown in the following figures. The Egyptian team has started already two years ago during a post doctor visit to the Analog VLSI Lab at Ohio Sate University. During this visit we have started the design of 1GHz CMOS VCO circuit for wireless application using MEMS technology. Through this work a VCO circuit has been designed, which has a tank circuit designed on MEMS technology. A MEMS tunable capacitor, and spiral inductor are implemented using bulk micromachining with all metal microstructure. We have used the clean room facility at the center of Integrated Microsystems (CISM) at OSU to accomplish some necessary step on the fabrication of the above-mentioned devices. We have also used the equipment available at the center to monitor the progress of the release of the microstructure of the devices.

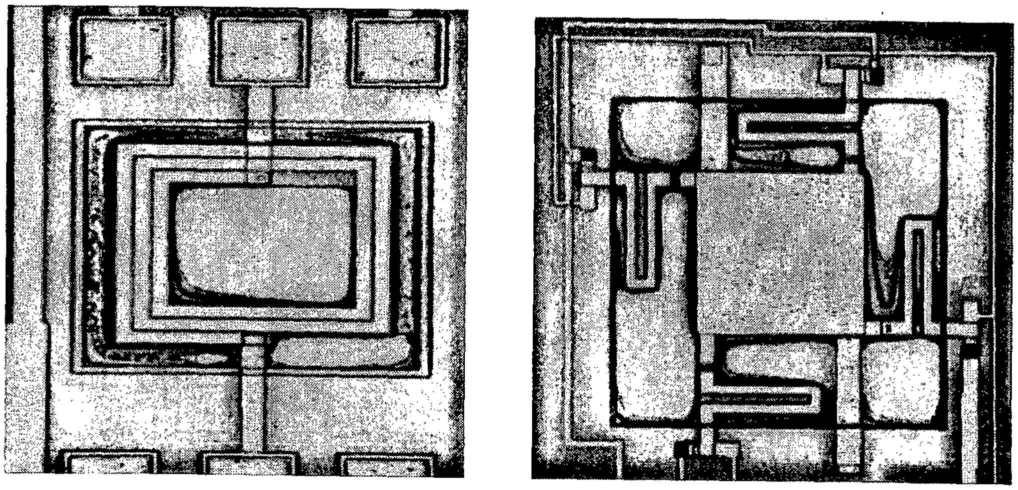

Fig. 2 The Fabricated spiral inductor and tunable capacitor during performing Post Processing procedures.

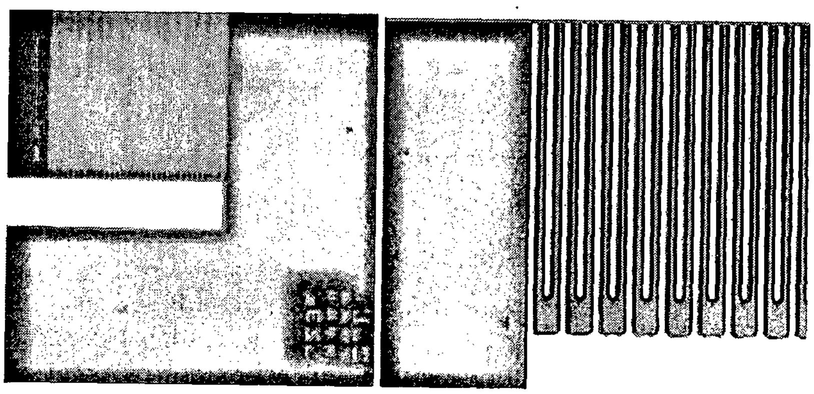

Fig. 3 A fabricated IDT with improved Lift-off process

The U.S PI has great experience of design and fabrication of MEMS devices for many applications. She has many publications and she involved in many projects in this field of

RF MEMS, also has work in the design and fabrication of SAW sensors on CMOS substrate [31], [33].

7. Role of each PI and nature of cooperation

The work in this project will involve both teams from Egypt and U.S. in all different phases of the project. Cooperation will include:

- Interchange of ideas and information.
- Collaboration in system design.
- Comparison between different technique for passive component fabrication and analysis.
- Fabrication
- Evaluation and testing.

The Egyptian team will lead the effort of the design and simulation of the proposed system, Egyptian research team will involve members from different departments of the ERI, with expertise in circuits and systems design, and communications. The U.S. team will lead the effort in fabricating the designed MEMS components in the fabrication facility available around George Washington University and may be in submitting the design to standard fabrication facility, and also in the evaluation and testing of the prototype chip. The team of the Institute of MEMS and VLSI Technologies at George Washington University works on closely related topics. The funding of this project may allow the researchers from Egypt to have some sort of training in the US in both the university and also in industry. Technology transfer of results will naturally follow as an integral part of the overall effort. The role of each PI can be summarized as follows

The US PI will be responsible for:

- Coordination between the US and Egyptian teams.
- The participation in the various tasks of the implementation process
- The participation in the evaluation of the technical results

The Egyptian PI will be responsible for:

- Coordination between the Egyptian and US teams.
- The participation in the various tasks of the implementation process.
- Supervising the Egyptian team in the Design, simulation of the proposed system.
- The participation in the evaluation of the technical results.

8. Statement of the Nature/Degree of collaboration

The collaboration required from the US is mainly needed for:

- Guidance and practical experience

- Provide access to expertise in RF MEMS components design, fabrication and testing.

- Applying the results of the accomplished work to real world application.

The outcomes of the research will be available to research and industrial entities interested in the design of MEMS devices and in the design of RF circuits using the proposed MEMS devices.

9. Statement on the participation of junior scientists:

One of the main objectives of the project is to involve the junior researchers in the different activities. As their motivation will help the project achieve it goal. Moreover they will enhance and enrich their experience through the work of the different phases of the project, and through the exchange of experience. They will be able to exchange of visits during the work of the project, so they can visit the laboratories of each others and integrate their work and exchange ideas.
Junior researchers will include the following names; however the project team may recruit others when needed.

-Eng. Sherief Saleh
Research Assistant.
-Eng. Hitham Azmi
Assistant Researcher

- While the other members are including the following:
Dr. Hamed Elsimary, CPI
Dr. Nivin Ghamry
Dr. Dalia Eldibe

10. List of facilities involved (available)

ERI Departments specially Microelectronics Dept., has the following

- Network of PCs, and printers
- Workstation (Sun station)
- EDA tools from Mentor Graphics & MEMSCAP Tools & ANSYS simulator.
- Testing equipment.

The Institute of MEMS and VLSI Technologies at George Washington University has the following facilities:

- Access to fabrication facilities and to post fabrication processing steps.
- Measuring & testing equipments.

References/Bibliographies:

1. M. Ozgur, and M.E. Zaghloul," MEMS Components for RF communication using CMOS technology", International Journal of RF and Microwave Computer – Aided Engineering, Special Issue on RF Applications of MEMS and Micromachining, Vol. 11, No. 5, PP 330-340, Ocober2001.

2. C. T Nguyen, and R. T. Howe, "An Integrated CMOS Micromechanical resonator High-Q Oscillator." IEEE Journal of solid state circuits, vol. 34, No. 4, April 1999.

3. V. Milanovic, E. Bowen, M. Zaghloul, N. Tea, J. Suehle, and M. Gaitan, "Micromachined Convector Accelerometers in Standard Integrated Circuits Technology," *Journal of Applied Physics Letters,* Vol 76(4), Jan. 2000, pp. 508-518.

4. Karl-Friedrich Bohringer, Bruce R. Donald, Robert Mihailovich, and NOel C. MacDonald. Sensorless manipulation using massively parallel micro-fabricated actuator arrays. In *IEEE International Conference on Robotics and Automation,* 1994.

1. Karl-Friedrich Borhinger, Bruce Randall Donald, and Noel C. MacDonald. Classification and lower bounds for mems arrays and vibratory parts feeders: What programmable vector fields can (and cannot) do - part 1. In *IEEE International Conference on Robotics and Automation,* 1996.

2. Brian Mirtich and John Canny. Impulse-based dynamic simulation. In K. Goldberg, D. Halperin, J.C. Latombe, and R. Wilson, editors, *The Algorithm Foundations of Robotics*. A. K. Peters, Boston, MA, 1995. Proceedings from the workshop held in February, 1994.

3. J. B. Sampsell. The digital micromirror device and it application to projection displays. In *Digest International Conference on Solid State Sensory and Actuators*, 1993.

4. C. T.-C. Nguyen, "Frequency-selective MEMS for miniaturized communication devices (invited)," *Proceedings,* 1998 IEEE Aerospace Conference, Snowmass, Colorado, March 21-28, 1998, pp. 445-460.

5. Rasmussen and M. E. Zaghloul, "CMOS Microfluidic Fabrication Technology for Biomedical Applications," *Proceedings of the Midwest Symposium for Circuits and Systems,* Aug. 1999.

10. D. J. Young, V. Malba, J.-J. Ou, A. F. Bernhardt, and B. E. Boser, "Monolithic high-performance three-dimensional coil inductors for wireless communication

applications," *Technical Digest*, IEEE International Electron Devices Meeting, Washington, D. C., Dec. 8-11, 1997, pp. 67-70.

11. D. J. Young and B. E. Boser, "A micromachined variable capacitor for monolithic low-noise VCOs," *Technical Digest*,1996 Solid-State Sensor and Actuator Workshop, Hilton Head Island, South Carolina, June 3-6, 1996, pp. 86-89.

12. C. Goldsmith, J. Randall, S. Eshelman, T. H. Lin, D. Denniston, S. Chen and B. Norvell, "Characteristics of micromachined switches at microwave frequencies," *IEEE MTT-S Digest*, June, 1996, pp. 1141-1144.

13. K. Wang, F. D. Bannon III, J. R. Clark, and C. T.-C. Nguyen, "Q-enhancement of micromechanical filters via low-velocity spring coupling," *Proceedings* of the 1997 IEEE International Ultrasonics Symposium, Toronto, Ontario, Canada, Oct. 5-8, 1997.

14. G Goldsmith, T H. Lin, B. Powers, W. R. WU, and B. Norvell, " Micro-mechanical Membrane Switches for Microwave Application." IEEE MTT-S Int. Symposium Dig., May 1995.

15. J. Young, V. Malba, J.J.OU, A. F. Bernhardt, B. Boser, " A low- Noise RF Voltage Controlled Oscillator Using On-Chip High.- Q Three- Dimensional Coil Inductor and Micromachined Variable Capacitor." IEEE Solid- State Sensor and Actuator Workshop, Hilton Head Island SC., June 1998.

16. Darrin J. Young, Bernahrd E. Boser, "A micromachine-Based RF Low-Noise Voltage Controlled Oscillator," Proc. Of the IEEE Custom Integrated Circuits Conference, 1997, pp. 431-434.

17. H. D. Wu, K. F. Harsh, R. S. Irwin, W Zangh, A. Michelson, C. Lee, "MEMS Design for Tunable Capacitors."IEEE MTT, Baltimore MD, June 1998.

18. J. Y.-C. Chang, A. A. Abidi, and M. Gaitna, "Large Suspended inductors on Silicon and their use in a 2 um CMOS RF Amplifier," IEEE Electron Device letter., vol. 14, pp. 246-248 May 1993.

19. Y.J. Kim and M. G. Allen, "Surface micromachined solenoid inductors for high frequency applications," IEEE Trans. Comp. Package and Manufact. Tech. Vol 21, no. 1m pp. 26-33.

20. Mehmet Ozgur, Mona Zaghloul, and Michael Gaitan, "Optimization of Backside Micromachined CMOS Inductors for RF Applications," IEEE International Symposium on Circuits and Systems, Geneva, Switzerland, May 2000, pp. V-185 – V-188.

21. Hamed Elsimary, Amal Mohamed, and Mohamed Ismail, "1 GHz CMOS VCO Design for Wireless Application Using MEMS Technology," Special Issue of International Journal of Analog Integrated Circuits and Signal Processing, Aug. 2000.

22. Amal Mohamed, Hamed Elsimary, and Mohammed Ismail, "Design of MEMS Tunable Capacitor with all Metal Microstructure for RF Wireless Applications, " Proceedings of the MSM'2000, San Diego, California, Mar. 2000., pp. 174-177.

23. Amal Mohamed, Hamed Elsimary, Mohammed Ismail, " Behavioral Modeling of RF VCO circuit with MEMS LC Resonator" proceeding of Design, Test, Integration and Packaging of MEMS/ MOEMS, DTIP01 France, April 2001.

24. V. Milanovic, M. Gaitan, E. Bowen, and M. E. Zaghloul, "Micromachining Microwave Transmission Lines in CMOS Technology," *IEEE Transactions on Microwave and Theory Techniques,* 45(5), May 1997, pp. 630-635.

25. N. Tea, V. Milanovic, C. Zincke, J. Suehle, M. E. Zaghloul, M. Gaitan, and J. Geist, "Hybrid Post-Processing Etching for CMOS-Compatible MEMS," *Journal of Microelectromechanical Systems, IEEE/ASME.* 6(4). Dec. 1997, pp. 363-372.

26. V. Milanovic, M. Gaitan, E. Bowen, and M.E. Zaghloul, "Micromachined Passive Filtering Elements in CMOS Technology," *Proceedings of Transducers 97,* Ninth International Conference on Solid-State Sensors and Actuation, Chicago, pp. 1007-1010, June 1997.

27. M. Ozgur, M. E. Zaghloul, and M. Gaitan, "High Q Backside Micromachined CMOS Inductors", *IEEE International Symposium on Circuits and Systems,* Orlando, FL, May 1999, pp. II-577—II-580.

28. V. Milanovic, M. Hopcroft, C. Zincke, M. Gaitan, and M. E. Zaghloul, "Optimization of CMOS MEMS Microwave Power Sensors," *IEEE International Symposium on Circuits and Systems,* Orlando, FL, May 1999, pp. V-144--V-147.

29. M.Ozgur and M.E.Zaghloul, " Rf MEMS Components using CMOS Technology"', IEEE Symposium on Antenna and Propagation, Boston, MA, July 2001.

30. Hamed Elsimary, Amal Mohamed, and Mohamed Ismail, "1 GHz CMOS VCO Design for Wireless Application Using MEMS Technology," proceeding of Design, Test, Integration and Packaging of MEMS/ MOEMS, DTIP France, May 2000.

31. S. Ahmadi, C.Korman, M.E.Zaghloul, "CMOS Implementation of Surface Accoustic Wave device for Gas Sensor", *The Proceedings of the IEEE International Symposium on Circuits and Systems,* Bangkok, Thailand, May 25-28, 2003.

32. S. Ahamadi, C. Korman, M.E.Zaghloul, " ZnO based CMOS Surface Acoustic Wave gas Sensor", the proceedings of the IEEE Sensors Conference , Toronto, Canada, October 2003.

33. S. Ahmadi, F. Hassani, C. Korman,M. Rahman, and M. Zaghloul, " Characterization of Multi and Single layer Structure SAW Sensor", to appear in IEEE Proceedings of IEEE-Sensors 2004, Vienna, October 2004.

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION George Washington University	FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Mona E Zaghloul	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Mona E Zaghloul - PI	0.00	0.00	0.00	$ 0	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.00	0	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (0) GRADUATE STUDENTS				0	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				0	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				0	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				0	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,000	
2. FOREIGN				3,500	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				7,658	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				7,658	
H. TOTAL DIRECT COSTS (A THROUGH G)				13,158	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				1,842	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				15,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 15,000	$

M. COST SHARING PROPOSED LEVEL $ Not Shown	AGREED LEVEL IF DIFFERENT $		
PI/PD NAME Mona E Zaghloul	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* Helen spencer	Date Checked	Date Of Rate Sheet	Initials - ORG

1 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 2

	FOR NSF USE ONLY		
ORGANIZATION George Washington University	PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Mona E Zaghloul	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Mona E Zaghloul - PI	0.00	0.00	0.00	$ 0	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.00	0	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (0) GRADUATE STUDENTS				0	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				0	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				0	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				0	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,000	
2. FOREIGN				3,500	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 0					
2. TRAVEL 0					
3. SUBSISTENCE 0					
4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				7,658	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				7,658	
H. TOTAL DIRECT COSTS (A THROUGH G)				13,158	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				1,842	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				15,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 15,000	$

M. COST SHARING PROPOSED LEVEL $ Not Shown	AGREED LEVEL IF DIFFERENT $	
PI/PD NAME Mona E Zaghloul	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION	
ORG. REP. NAME* Helen spencer	Date Checked / Date Of Rate Sheet	Initials - ORG

2 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

Cumulative

	FOR NSF USE ONLY			
ORGANIZATION **George Washington University**	PROPOSAL NO.	DURATION (months)		
		Proposed	Granted	
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Mona E Zaghloul**	AWARD NO.			

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Mona E Zaghloul - PI	0.00	0.00	0.00	$ 0	$
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.00	0	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (0) GRADUATE STUDENTS				0	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				0	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				0	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				0	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				4,000	
2. FOREIGN				7,000	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				15,316	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				15,316	
H. TOTAL DIRECT COSTS (A THROUGH G)				26,316	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				3,684	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				30,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 30,000	$

M. COST SHARING PROPOSED LEVEL $ **Not Shown**	AGREED LEVEL IF DIFFERENT $		
PI/PD NAME **Mona E Zaghloul**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Helen spencer**	Date Checked	Date Of Rate Sheet	Initials - ORG

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

Budget Justification Page

Travel Expenses:
Domestic Travel $2,000/year
{Airfare =1,000; Lodging/Meals =$600; Registration =$350; Ground Transportation =$50}

Foreign Travel $3,500/year
{Airfare =$1,500; Perdiem: 20 days visit * $125/day=$2,500}

Materials and supplies $7658/year
Costs for Chip Fabrication at US Foundries

Current and Pending Support

(See GPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Mona Zaghloul**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **(this proposal) Design Fabrication of RF-SAW Sensors using MEMS**

Source of Support: **NSF**
Total Award Amount: $ **15,000** Total Award Period Covered: **01/01/05 - 12/31/06**
Location of Project: **The George Washington University & Cairo, Egypt**
Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal T

Source of Support:
Total Award Amou
Location of Project:
Person-Months Per Ye

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **CMOS Integrated Bio-Sensors Array Chip Using SAW Technology**

Source of Support: **NSF**
Total Award Amount: $ **178,480** Total Award Period Covered: **09/15/02 - 08/31/05**
Location of Project: **The Geroge Washington University**
Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.75**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **IC Processing Phase III**

Source of Support: **DOC/NIST**
Total Award Amount: $ **54,040** Total Award Period Covered: **03/25/04 - 03/24/05**
Location of Project: **NIST**
Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.00**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Tit

Source of Support:
Total Award Amoun
Location of Project:
Person-Months Per

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

CMOS and MEMS Design and Fabrication Facility (available at The George Washington University):

The VLSI Testing Laboratory at the main engineering building of GWU, Tompkins Hall 307, has the following equipment installed:

- 1 – HP Color LaserJet 5 10/100 Network Printer
- 1 – Kiethley Model 2010 Digital Multimeter
- 1 – HP 54503 Digital Oscilloscope
- 1 – HP 8591E 9KHz to 1 GHz Spectrum Analyzer
- 1 – HP 8116 50 MHz Pulse/Function Generator
- 1 – HP 6622A System DC Power Supply
- 1 – Tektronix Model 7704A Analog Oscilloscope
- 1 – Epson Model 1240 Perfection Flat bed scanner
- 1 – Hi Level Model ETS 770/512 VLSI Test Set with computer and 17-inch monitor
- 1 – Summit Model 9500 Parametric Probe station with Olympus Microscope, Color Camera and Sony color monitor
- 1 – Networked Sun Solaris 8 with 17-inch monitor
- 1 – Networked Computer with 700 MHz Athlon CPU, 128 MB RAM, Maxtor 2GB HD, Viper II 32 MB Video Card, Zip 100 drive, Teac 1.44 drive, Asus 50X CD-ROM, 3Com 10/100 NIC, Win Vision Pro 32 Frame Grabber Card, Software: Adobe Reader, Adobe Photo Deluxe, Command Anti-virus, Disk Keeper Lite and IomegaWare,
- 1 - Networked Computer with 200 MHz Intel CPU, 128 MB RAM, Maxtor 2GB HD, Trident 2 MB Video Card, Zip 100 drive, Teac 1.44 drive, Asus 32X CD-ROM, National Instruments IEEE 488 PCI card and 3Com 10/100 NIC. Software: WaveStar, WinCal 2.2, Microtec 3.03, National Instruments CVI, National Instruments NI-488.2, Netscape 4.7, Internet Explorer 5.0, IomegaWare, Adobe Reader, and Command Anti-virus

Computer Equipment: The School of Engineering & Applied Science has an extensive network of PC and UNIX based engineering workstations available for general faculty and student use.

Computer Aided Tools for Design of IC and MEMS:

The George Washington University has several tools for the design and simulations of MEMS devices and Integrated Circuits, such as CADENCE, MEMSCAP, COVENTOR, ANSYS, and the Tanner Tools.

SCANNIG ELECTRON MICROSCOPE:

Recently the George Washington University acquired SEM for the characterizations of Microstructures. The SEM is located in School of Engineering and is accessible to all engineering students.

Results from Prior NSF Support

The Professor M.Zaghloul was PI of NSF Grant 0225431, entitled *"CMOS Integrated Gas Sensor Array Chip Using SAW Technology"* for the duration of September 15, 2002-August 31, 2004.

The effort and focus of this research is to fabricate, test and conduct performance analysis of thin film piezoelectric based surface acoustic wave gas sensors. In particular, we are currently focused on applications in miniaturized and highly integral chemical and biological surface acoustic wave (SAW) sensors integrated on a microchip substrate.

Through this NSF supported research, Professors Hamada, Koran and Zaghloul (PI of this project) at The George Washington University have developed a micro SAW gas sensor. The faculty and their graduate research assistants have characterized and compared the effect of different sputtered ZnO thin films. Interdigitated electrodes producing surface acoustic waves in the hundreds of MHz are developed by photolithography and metalization using Electron Beam Evaporation equipment (see Figure 7). The fabrication process is optimized for best yield and performance. In order to better understand the behavior of the surface acoustic wave sensors, a multilayer piezoelectric film simulator was developed. The simulator takes into account the mechanical (strain-stress relations), elastic constitutive constants, crystal structure and piezoelectric properties of the material systems. The simulator accounts for the multilayer interactions employing appropriate boundary condition for stress, strain, flux-density and electric fields. Surface acoustic wave properties such as wave-modes and velocities can be evaluated by the calculations. Currently the fabricated surface acoustic wave device is under testing for characteristic performance. Based on the initial test results, the fabrication process is being optimized. Device resonant frequency and its dependence on interdigitated electrodes parameters, thin film ZnO characteristics, temperature and external loading materials are being investigated. Currently, the silicon based die with on chip circuitry is fabricated and is ready to be integrated with the sensor.

As the result of this NSF supported research, several (five) technical papers have been published in major conferences such as IEEE Sensors 2003, IEEE ISCAS 2003, IEEE MWSCAS 2003 and MRS 2003.

S. Ahmadi, C. Korman, M. Zaghloul and K. H. Huang, "CMOS Integrated Gas Sensor Chip Using SAW Technology," ISCAS 2003, Bangkok, Thailand, May 2003.
F. Hassani, O. Tigli, S. Ahmadi, C. E. Korman and M. Zaghloul, "Integrated CMOS Surface Acoustic Wave Sensor: Design and Characteristics," IEEE Sensors 2003, Toronto, Canada, October 2003.
F. Hassani, S. Ahmadi, C. E. Korman, M. Zaghloul, S. Hullavarad, R. D. Vispute, T. Venkatesan, "ZnO Based SAW Delay Line: Thin Film Characteristics and IDT Fabrication," 2003 MRS Fall Meeting, Boston, MA, December 2003.
F. Hassani, S. Ahmadi, C. E. Korman and M. Zaghloul, "ZnO Based SAW Delay Line Sensor: Fabrication and Characteristics," The 46th IEEE Midwest Symposium on Circuits and Systems, Cairo, Egypt, December 2003.
A. N. Nordin, M. Zaghloul , S. Ahmadi and C. E. Korman, "Design and Implementation of CMOS Surface Acoustic Wave Resonators," The 46th IEEE Midwest Symposium on Circuits and Systems, Cairo, Egypt, December 2003.
S. Ahmadi, F. Hassani, C. Korman,M. Rahman, and M. Zaghloul, " Characterization of Multi and Single layer Structure SAW Sensor", to appear in IEEE Proceedings of IEEE-Sensors 2004, Vienna, October 2004.

NATIONAL SCIENCE FOUNDATION
Grant Letter

Award:0512976 **PI Name:**Zaghloul, Mona E.

Award Date:	August 17, 2005
Award No.	OISE-0512976
Proposal No.	OISE-0512976

Dr. Stephen Joel Trachtenberg
President
George Washington University
2121 Eye Street NW
Washington, DC 20037-2353

Dear Dr. Trachtenberg:

The National Science Foundation hereby awards a grant of $28,500 to George Washington University for support of the project described in the proposal referenced above as modified by revised budget dated July 26, 2005.

This project, entitled "U.S.-Egypt Cooperative Research: Radio Frequency Microelectromechanical Systems (MEMS) Integration," is under the direction of Mona E. Zaghloul.

This award is effective September 1 , 2005 and expires August 31, 2007.

This grant is awarded pursuant to the authority of the National Science Foundation Act of 1950, as amended (42 U.S.C. 1861-75) and is subject to NSF Grant General Conditions (GC-1), dated 6/15/05 available at http://www.nsf.gov/publications/pub_summ.jsp?ods_key=gc1605.

The grantee shall not change the scope of work or work plan, participant support costs, foreign travel costs, or major participants without prior consultation with and concurrence of the cognizant NSF Program Officer.

This project is supported under the cooperative program shown below. Your rights in inventions, writing, and data may be affected.

U.S. Egypt - Cooperative Research Program

Funds provided by this award include support from another Federal agency as noted below. Appropriate acknowledgement of this support should be included in reports or publications based on work performed under this award.

Department of State

The attached budget indicates the amounts, by categories, on which NSF has based its support.

The cognizant NSF program official for this grant is Osman Shinaishin, (703) 292-8707. The cognizant NSF grants official contact is Denise O. Young, (703) 292-8216.

Sincerely,

Anne C. Doyle
Grants and Agreements Officer

CFDA No. 47.079
osr@gwu.edu

NATIONAL SCIENCE FOUNDATION
Grant Letter

Award:0512976 **PI Name:**Zaghloul, Mona E.

OISE-0512976
000

SUMMARY PROPOSAL BUDGET

Person MOS	cal.	acad	sumr	Funds granted By NSF
A. (0.00) Total Senior personnel	0.00	0.00	0.00	$0
B. Other Personnel				
1. (0.00) Post Doctoral associates	0.00	0.00	0.00	$0
2. (0.00) Other professionals	0.00	0.00	0.00	$0
3. (0.00) Graduate students				$0
4. (0.00) Secretarial-clerical				$0
5. (0.00) Undergraduate students				$0
6. (0.00) Other				$0
Total salaries and wages (A+B)				$0
C. Fringe benefits (if charged as direct cost)				$0
Total salaries wages and fringes (A+B+C)				$0
D. Total permanent equipment				$0
E. Travel				
1. Domestic				$4,000
2. Foreign				$7,000
F. Total participant support costs				$0
G. Other direct costs				
1. Materials and supplies				$14,000
2. Publication costs/page charges				$0
3. Consultant services				$0
4. Computer (ADPE) services				$0
5. Subcontracts				$0
6. Other				$0
Total other direct costs				$14,000
H. Total direct costs (A through G)				$25,000
I. Total indirect costs				$3,500
J. Total direct and indirect costs (H+I)				$28,500
K. Residual funds / Small business fee				
1. Residual funds (if for further support of current projects GPM 252 and 253)				$0
2. Small business fee				$0
L. Amount of this request (J) or (J-K1+K2)				$28,500
M. Cost sharing				$0

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 01-2		FOR NSF USE ONLY
PD 98-6855	12/05/01	NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)		**0209190**
IIS - Information and Data Management		

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
12/05/2001	2	05020000 IIS	6855		09/28/2006 11:21am S

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS ☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYMS(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
University of Illinois at Chicago	University of Illinois at Chicago 1737 W. Polk Street Chicago, IL. 606127227
AWARDEE ORGANIZATION CODE (IF KNOWN) 0080010000	
NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE	ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE
PERFORMING ORGANIZATION CODE (IF KNOWN)	

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions) ☐ FOR-PROFIT ORGANIZATION ☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS

TITLE OF PROPOSED PROJECT **Geographic Management of Data Infrastructureless Environment**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PREPROPOSAL NO., IF APPLICABLE
$ 423,114	36 months	07/01/02	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

- ☐ BEGINNING INVESTIGATOR (GPG I.A)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.6)
- ☐ NATIONAL ENVIRONMENTAL POLICY ACT (GPG II.C.9)
- ☐ HISTORIC PLACES (GPG II.C.9)
- ☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.C.11)
- ☐ VERTEBRATE ANIMALS (GPG II.C.11) IACUC App. Date ____
- ☐ HUMAN SUBJECTS (GPG II.C.11) Exemption Subsection ____ or IRB App. Date ____
- ☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED ____
- ☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.E.1)

PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
Department of Computer Science	851 South Morgan, Room 1120 SEO Chicago, IL 606807053 United States
PI/PD FAX NUMBER 312-413-0024	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME Ouri Wolfson	PhD	1984	312-996-6770	wolfson@cs.uic.edu
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

 Electronic Signature

CERTIFICATION PAGE

Certification for Principal Investigators and Co-Principal Investigators:

I certify to the best of my knowledge that:

(1) the statements herein (excluding scientific hypotheses and scientific opinions) are true and complete, and
(2) the text and graphics herein as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or individuals working under their supervision. I agree to accept responsibility for the scientific conduct of the project and to provide the required progress reports if an award is made as a result of this proposal.

I understand that the willful provision of false information or concealing a material fact in this proposal or any other communication submitted to NSF is a criminal offense (U.S.Code, Title 18, Section 1001).

Name (Typed)	Signature	Social Security No.*	Date
PI/PD Ouri Wolfson	Signature Not Required	SSNs are confidential and are not displayed *ON FASTLANE SUBMISSIONS*	
Co-PI/PD			
Co-PI/PD			
Co-PI/PD			
Co-PI/PD			

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 01-2. Willful provision of false information in this application and its supporting documents or in reports required under an ensuring award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflict which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Debarment Certification (If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, "Disclosure Form to Report Lobbying," in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE		SIGNATURE	DATE
NAME/TITLE (TYPED) Paula M Means		Electronic Signature	Dec 5 2001 5:33PM
TELEPHONE NUMBER 312-996-4993	ELECTRONIC MAIL ADDRESS awards@uic.edu		FAX NUMBER 312-996-9005

*SUBMISSION OF SOCIAL SECURITY NUMBERS IS VOLUNTARY AND WILL NOT AFFECT THE ORGANIZATION'S ELIGIBILITY FOR AN AWARD. HOWEVER, THEY ARE AN INTEGRAL PART OF THE INFORMATION SYSTEM AND ASSIST IN PROCESSING THE PROPOSAL. SSN SOLICITED UNDER NSF ACT OF 1950, AS AMENDED.

Geographic Management of Data in Infrastructureless Environments

Ouri Wolfson
University of Illinois, Chicago

A. Project Summary

In this project we propose to study databases that are distributed among a set of possibly mobile sensors that communicate without a fixed network infrastructure. This architecture is motivated by new types of emerging wireless broadcast networks such as Mobile Ad-hoc Networks (see [8, 52])[1], and "smart dust" and sensor networks (see [51, 60]). Smart dust and sensor networks consist of processors that may be the size of a dust particle, and the processors may be parachuted or sprayed from an airplane.

We consider two environments. The first is a database distributed among a set of static sensors. The database may render a global picture of an unknown terrain from local images collected by individual sensors. The problem that arises here in processing queries is that a node in the network doesn't know exactly what other nodes are alive, their id, or their location. The second environment is a MANET, where the nodes' identifications are known, but the location of each node is unknown at any point in time. Our idea of processing queries in each one of the two cases is captured by the following "geographic dissemination of data" paradigm. It calls for partitioning the geographic area into cells. Each data item in the database is associated with a cell, and resides in that cell, i.e. in the processors that are located in the cell at a particular time. Each grid cell is considered a node of the distributed database, and queries are processed by sending them to the appropriate grid cell. In static sensor networks the sensors responding are the sensors in the cell. In MANET's each data item is associated with a grid cell, and is stored at some or all of the mobile nodes that are currently in the cell. Nodes are mobile, thus they may enter and exit a cell. Since the data belongs to a cell, a node that exits a cell hands-off the cell data to other mobile nodes that are currently in the cell. The nodes that are responding to a query arriving in a cell are the ones that are currently in the cell.

We evaluate this geographic partitioning idea on an application/database for each environment. In the static environment the database consists of sensor data (e.g. images) of the whole geographic area covered by the sensors, and a query may arrive at any sensor and request to view any part of the area. In the dynamic environment each mobile node stores its motion plan, or trajectory, and the queries issued by the mobile nodes are spatio-temporal range queries such as: "Display the mobile units (e.g. friendly helicopters) that are expected to enter region R within the next ten minutes".

[1]A Mobile Ad-hoc Network (MANET) is a system of mobile computers (or nodes) equipped with wireless broadcast transmitters and receivers which are used for communicating within the system. Such networks provide an attractive and inexpensive alternative to the cellular infrastructures when this infrastructure is unavailable (e.g. in remote and disaster areas), or inefficient, or too expensive to use (see [21]). Mobile Ad-hoc Networks are used to communicate among the nodes of a military unit, in rescue and disaster relief operations, in collaborative mobile data exchange (e.g the set of attendees at a conference), and other "micronetworking" technologies (see [20]).

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.C.

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

C. Project Description

C.1. Introduction

In this project we will study the problems of broadcast, replication, and data access in a wireless, possibly mobile environment without a fixed infrastructure. This lack of a fixed infrastructure is common in military battlefield applications, and in disaster management and recovery. After Sept. 11th, addressing the research issues in such environments became even more important. Even if the infrastructure exists, as we discuss below in the "traffic-reports" application, using it may not be efficient or cost effective. In the networking community, this architecture is common in Mobile Ad-Hoc Networks (MANET's), or in sensor and "smart dust" networks (see [51, 60]). Often in such networks the nodes collaborate to assemble a complete database from local fragments. For instance, in the case of sensors that are parachuted or sprayed from an airplane, the database renders a global picture of an unknown terrain from local images collected by individual sensors.

We model such applications using a "master" replication environment (see [9]), in which each node i "owns" the master copy of a data item D_i, i.e. it generates all the updates to D_i. For example, D_i may be the latest in a sequence of images taken periodically by the node i of its local surroundings. Each new image updates D_i. Or, in the MANET case, D_i may be the motion plan (or trajectory)[2] of the object i; D_i is updated when the Global Positioning System (GPS) on board i indicates a current location that deviates from D_i's current location by more than a prespecified threshold. The database of interest is $D = \{D_1,...,D_n\}$, where n is the number of nodes and also the number of items in the database. In case D_i is the motion plan of i, the database D is of interest in what are called Moving Objects Database (MOD) applications (see [14, 16, 44, 45, 43, 62, 63]). If D_i is the motion plan of object i in a battlefield situation, then a typical query may be: "Display the friendly helicopters that are currently in a given region R", or, "Display the friendly helicopters that are expected to enter region R within the next ten minutes". Each one of these queries can also represent a view of the locations database that is materialized on, say a command vehicle, and is periodically updated. Other MOD applications involve emergency (fire, police) vehicles and local transportation systems (e.g. a city bus system, a taxi cab company, a courier service).

Therefore, we consider two environments. The first is a database distributed among a set of static sensors. The problem that arises here in processing queries is that a node in the network doesn't know exactly what other nodes are alive, their id, or their location. Since each sensor is very unreliable, a (possibly inconsistent) copy of D is stored at each sensor[3]. This way, if any sensor is recovered D is accessible (see [60]).

The second environment is a MANET, where the nodes' identifications are known, but the location of each node is unknown at any point in time. Our idea of processing queries in each one of the two cases is captured by the following "geographic dissemination of data (gdd)" paradigm. It calls for dividing the geographic area into cells. Each data item in the database is associated with a cell, and resides in that cell, i.e. in the processors that are located in the cell at a particular time. Each grid cell is considered a node of the distributed database, and queries are processed by sending them to the appropriate grid cell. In static sensor networks the sensors responding are the sensors in the cell. In MANET's each data item is associated with a grid cell, and is stored at some or all of the mobile nodes that are currently in the cell. Nodes are mobile, thus they may enter and exit a cell. Since the data belongs to a cell, a node that exits a cell hands-off the cell data to other mobile nodes that are currently in the cell. The nodes that are responding to a query arriving in a cell are the ones that are currently in the cell.

For example, in the static sensors image application, the image of a cell resides in the sensors of that

[2] a trajectory is a sequence $(x_1,t_1),...,(x_k,t_k)$ of (location, time) points; it indicates that the object is at location x_1 at time t_1, at location x_2 at time t_2, etc. The location at each intermediate time point is found by interpolation. Thus, a trajectory is a piece-wise linear function in three dimensional time-space

[3] D is inconsistent if some data items do not contain the most recent version.

cell. In the Moving Objects Database each intersection of a trajectory and a cell is a data item stored in that cell. Thus data item A = "the trajectory of object 55 passes through cell number 20 between 5pm and 6pm" is stored in cell number 20, and data item B = "the trajectory of object 55 passes through cell number 21 between 6pm and 6:30pm" is stored in cell number 21. However, cells 21 and 22 do not have an infrastructure, which means that data item A may be stored on object 35 at 1pm (since 35 is in cell 20 at 1pm), and on object 102 at 9pm (since 102 is in cell 20 at 9pm). Data item A is updated whenever the trajectory of object 55 is updated, and it is retrieved, for example, when processing a query that requests all the trajectories that cross cell number 21 sometime.

Another example of an infrastructureless environment is the following "Traffic-reports" application. Consider the vehicles traveling on a highway in the same direction. Suppose that they constitute the nodes of MANET, and the database consists of data items of the form: "vehicle ACD123 took 11 minutes to travel between exits X and Y", where X and Y are two consecutive exits on the highway. The use of this database is to provide travel-time information to vehicles. Obviously the information can be transmitted to a centralized database, and vehicles requesting this information can transmit their queries to the central server, and get the results. However, the information would be cheaper and more timely if accessed on the traveling vehicles themselves. Thus, assume that we take the section of the highway between two consecutive exits to be a cell.. A vehicle v traveling through the cell calculates its travel time, t_v. t_v is a data item that belongs to the cell X-Y. When v exits the cell, it "hands-off" t_v to the cell. This means that v leaves t_v in the cell, i.e. it transmits t_v back to other vehicles in the cell X-Y. Another vehicle w that "picks up" t_v transmits it back when w exits the cell. Obviously, in this application there is a data aging process by which t_v becomes increasingly irrelevant as it ages, i.e. its weight in calculating the weighted average decreases as time passes. When a vehicle x queries the average travel time in the cell X-Y, the query is transmitted to the cell (via the MANET), i.e. to the vehicles that are currently in the cell. One vehicle, or all vehicles in the cell compute the weighted average of the travel times in the local database, and transmit the result back to x.

There are variants of this scheme which demonstrate the research issues of this proposal. When v transmits t_v back to the cell, is it transmitted to all the vehicles in the cell, or to any vehicle in the cell, or to some "leader" vehicle in the cell? Similarly, when a query is received at a cell, do all the vehicles in the cell respond, or only the leader? How is the data (t_v) handed off if there is no mobile unit (vehicle) in the cell to pick it up? Similarly, how is a query answered by a cell when there is no moving object in the cell?

Actually, the traffic reports application described above has the potential of providing drivers with detailed traffic information for every section of every road (at the beginning of the trip the car computer would be given the final destination, thus it would know what is the road ahead at any point in time). Observe that, in contrast, current radio reports provide only general traffic information (not for every section of the road) and only for the major highways. Furthermore, a company like GM could equip all its cars with transmitters/receivers that enable the MANET described above in a manner which is transparent to the drivers.

Summary of preliminary work

In our earlier works [14, 15], we proposed the maintenance of the location of a moving object as a dynamic attribute at the central server. In traditional databases, variables, tuples and attributes change only when explicitly updated. In contrast, a dynamic attribute is a variable that continuously changes over time, without being explicitly updated. In the case where the dynamic attribute represents the location of a moving object, the attribute was defined as a piece-wise linear function in three-dimensional space (two-dimensional geography plus time), i.e. a sequence of points (x1,y1,t1), (x2,y2,t2),..., (xn,yn,tn). indicating that the object was/will-be at point (xi,yi) at time ti, and it travels at constant speed between two consecutive points. If the the time points are in the future, one can think of this function as the motion plan (or trajectory) of the object. Using this plan, the central site is able to calculate the location of the object at any future time. If the time points are in the past, the function, or dynamic attribute, is a description of completed motion.

In case of the future motion plan, the above scheme avoids frequent transmission of the location information from the moving object, thus saving communication cost. Updates to the plan occur only when the deviation from the plan exceeds a *threshold value*; then the object will transmit the new location together with a revised plan; here we assume that the moving object can find its current location using Global Positioning System (GPS) or using any other means. Such a scheme is called a *dead reckoning* policy. Thus, there is an uncertainty in the location value, of the moving object, known to the central server; this uncertainty is bounded by the threshold value. By reducing the threshold value, we can decrease the uncertainty at the expense of increased message traffic from the moving object to the central server. In order to capture the trade off between communication and imprecision, we introduced a cost function that is the sum of communication cost and the imprecision cost. As part of future work, we plan to investigate various methods that dynamically change the threshold value so as to minimize the cost function.

Let us now discuss the inconsistency-communication tradeoff for sensor networks. Remember in this case updates to each nodes are disseminated throughout the network, so that each sensor has a complete but possibly inconsistent copy of the whole database. In order to quantify the tradeoff between consistency and communication we introduce the concept of the *inconsistency-cost* of a data item. This concept, in turn, is quantified via the notion of the cost difference between two versions of a data item D_i. In other words, the inconsistency cost of using an older version v rather than the latest version w is the distance between the two versions. If D_i is an image, existing algorithms that quantify the difference between a pair of images can be used (see for example [42]). If D_i is the quantity-on-hand of a widget, then the difference between the two versions is the difference between the quantities. Now, in order to quantify the tradeoff between inconsistency and communication one has to answer the question: what amount of bandwidth/energy/dollars am I willing to spend in order to reduce the inconsistency cost on a data item by one unit? In section C.3 we will demonstrate how we formalize this notion. In the same section we demonstrate a data dissemination policy that uses the inconsistency-communication tradeoff to optimize resource utilization.

Summary of the Proposed Research

We plan to study three problems in this project:

- The problem of data dissemination in static sensor networks.

- The problem of data allocation, and query and update processing in the MANET environment, in which the database is distributed among a set moving objects.

- We will apply and fine-tune the results of studying the second problem to the Moving Objects Database. In particular, our objective will be to develop efficient algorithms for processing queries and triggers of the form "Display the mobile units (e.g. friendly helicopters) that are expected to enter region R within the next ten minutes" in a distributed and mobile environment, in which the database is distributed among the moving objects.

The three research subjects constitute a natural succession from a traditional database in an infrastructureless static environment, to such a database in a mobile/distributed environment, to a special database in the mobile/distributed case. Our approach to finding efficient solutions to these problems is two-fold. First, we will apply the gdd idea to the three problems. Second, we will also apply the inconsistency-communication tradeoff idea. The reason is that in infrastructureless environments bandwidth and/or battery-power are in short supply, and naive solutions would use plenty of these resources.

C.2. Preliminary Work: Location Update Policies

Consider an object m moving along a prespecified route. The location of m is represented at the central server by storing m's starting time, starting location, and speed; these three sub-attributes define the plan of motion of the object. Thus the location of object m can be computed by the central server (CS) at any subsequent point in time using the plan of motion available to it. [4] This method of modeling the location was originally introduced in [14, 15] via the concept of a dynamic attribute; the method is modified in [18, 59] in order to handle uncertainty. In this method the actual location of a moving object m deviates from its location value known to the server due to the fact that m may not travel at exactly the speed given in the plan.

A *dead-reckoning update policy* for m dictates that there is an update threshold th, i.e. a deviation for which m should send a location/speed update to the central server. (Note that at any point in time, since m knows its actual location and its location at the central server, it can compute its current deviation.) *Speed dead-reckoning* [5] (sdr) is a dead-reckoning policy in which the threshold th is fixed for the duration of the trip.

In the dead-reckoning policies, the server is informed of the threshold value th. As explained earlier, at any point in time, the actual location of the object may be different from the location of the object known to the server (calculated from the object's plan of motion). This difference between the actual location and the known location is called the *deviation*. However, the server knows that the location of the object known to it may deviate by as much as th. This value th is called the uncertainty value.

We introduce another dead-reckoning update policy, called *adaptive dead reckoning(adr)*. Adr provides with each update a new threshold th that is computed using a cost based approach. The value th is chosen so as to minimize the total information cost, i.e. the sum of the communication cost, the deviation cost, and the uncertainty cost. At location update time, in order to compute the new threshold, m predicts the behavior of the deviation. The thresholds differ from update to update because the predicted behavior of the deviation is different.

A problem common to both sdr and adr is that the moving object may be disconnected or otherwise unable to generate location updates. In other words, although the server "thinks" that updates are not generated since the deviation does not exceed the update threshold, the actual reason is that the moving object is disconnected. To cope with this problem we introduce a third policy, "disconnection detecting dead-reckoning (dtdr)". The policy uses a novel technique that decreases the uncertainty threshold for disconnection detection. Thus, in dtdr the threshold continuously decreases as time since the last location update passes. It has a value K during the first time unit after the update, it has value $K/2$ during the second time unit after the update, it has value $K/3$ during the third time unit, etc. Thus, if the object is connected, it is increasingly likely that it will generate an update. Conversely, if the moving object does not generate an update, as time since the last update passes it is increasingly likely that the moving object is disconnected. The dtdr policy computes the K that minimizes the total information cost, i.e. the sum of the communication cost, the deviation cost, and the uncertainty cost.

To contrast the three policies, observe that for sdr the threshold is fixed for all location updates. For adr the threshold is fixed between each pair of consecutive updates, but it may change from pair to pair. For dtdr the threshold decreases as the period of time between a pair of consecutive updates increases.

Cost Function We introduce a cost function that allows us to measure how effective a particular policy is.

At each point in time during the trip the moving object has a deviation and an uncertainty, each

[4] Our simulation experiments show that, even when the speed fluctuates sharply, this temporal technique reduces the number of updates to 15% of the number used by the traditional, nontemporal method in which the server simply stores the latest known location for each object; this saves 85% of the location-updates overhead.

[5] We use the term *speed* dead-reckoning to contrast it with the plain dead-reckoning (pdr) policy in which the location at the central server is fixed until it is explicitly updated by the moving object; namely, pdr does not use dynamic attributes.

of which carries a penalty. Additionally the moving object sends location update messages. Thus the information cost of a trip consists of the cost of deviation, cost of communication, and cost of uncertainty.

Now we define the deviation cost. Observe first that the cost of the deviation depends both, on the size of the deviation and on the length of time for which it persists. It depends on the size of the deviation since decision-making is clearly affected by it. To see that it depends on the length of time for which the deviation persists, suppose that there is one query that retrieves the location of a moving object m per time unit. Then, if the deviation persists for two time units its cost will be twice the cost of the deviation that persists for a single time unit; the reason is that two queries (instead of one) will pay the deviation penalty. Formally, for a moving object m the cost of the deviation between two time points t_1 and t_2 is given by the *deviation cost function*, denoted $COST_d(t_1, t_2)$; it is a function of two variables that maps the deviation between the time points t_1 and t_2 into a nonnegative number. In this proposal we take the penalty for each unit of deviation during a unit of time to be one (1). Then, the cost of the deviation between two time points t_1 and t_2 is:

$$COST_d(t_1, t_2) = \int_{t_1}^{t_2} d(t)dt \qquad (1)$$

(Recall that $d(t)$ is the deviation as a function of time).

The *communication cost*, denoted C_1, is a nonnegative number representing the cost of a location-update message sent from the moving object to the server. The communication cost may differ from one moving object to another, and it may vary even for a single moving object during a trip, due for example, to changing availability of bandwidth. The communication cost must be given in the same units as the deviation cost. In particular, if the communication cost is C_1 it means the ratio between the communication cost and the cost of a unit of deviation per unit of time (which is one) is C_1. It also means that the moving object (or the system) is willing to use $1/C_1$ messages in order to reduce the deviation by one during one unit of time.

Now we define the uncertainty cost. Observe that, as for the deviation, the cost of the uncertainty depends both, on the size of the uncertainty and on the length of time for which it persists. Formally, for a moving object m the cost of the uncertainty between two time points t_1 and t_2 is given by the *uncertainty cost function*, denoted $COST_u(t_1, t_2)$; it is a function of two variables that maps the deviation between the time points t_1 and t_2 into a nonnegative number. Define the *uncertainty unit cost* to be the penalty for each unit of uncertainty during a unit of time, and denote it by C_2. Then, the cost of the uncertainty of m between two time points t_1 and t_2 is:

$$COST_u(t_1, t_2) = \int_{t_1}^{t_2} C_2 u(t)dt \qquad (2)$$

where $u(t)$ is the value of the uncertainty in the location of m as a function of time; note that this is equal to the threshold value which may change dynamically.

The uncertainty unit cost C_2 is the ratio between the cost of a unit of uncertainty and the cost of a unit of deviation. Consider an answer returned by the server; "the current location of the moving object m is (x,y), with a deviation of at most u units". C_2 should be set higher than 1 if the uncertainty in such an answer is more important than the deviation, and lower than 1 otherwise. Observe that in a dead-reckoning update policy each update message establishes a new uncertainty which is not necessarily lower than the previous one. Thus communication reduces the deviation but not necessarily the uncertainty.

Now we are ready to define the information cost of a trip taken by a moving object m. Let t_1 and t_2 be the time-stamps of two consecutive location update messages. Then the *information cost* in the interval $[t_1, t_2)$ is:

$$COST_I[t_1, t_2) = C_1 + COST_d[t_1, t_2) + COST_u[t_1, t_2) \qquad (3)$$

Observe that $COST_I[t_1, t_2)$ includes the message cost at time t_1 but not the cost of the one at time t_2. Observe also that each location update message writes the actual current location of m at the server thus it reduces the deviation to zero. The total information cost of a trip is computed by summing up $COST_I[t_1, t_2)$ for every pair of consecutive update points t_1 and t_2. Formally, let the time points of the update messages sent by m be $t_1, t_2, ..., t_k$. Furthermore, let 0 be the time point when the trip started and t_{k+1} the time point when the trip ended. Then the *total information cost* of a trip is

$$COST_I = COST_d[0, t_1) + COST_u[0, t_1) + \sum_{i=1}^{k+1} COST_I[t_i, t_{i+1}) \tag{4}$$

The objective of the dead reckoning policies that we introduce is to set the deviation threshold of a moving object, namely its th subattribute, such that the total information cost is minimized. An optimal value v for th can be established under the assumption that the deviation function between two consecutive update points in time is a linear function. For v the information cost per time unit is minimized between two consecutive location updates. For example, we have calculated that under certain assumptions (i.e. if the cost of a message is one cent, and if one is willing to spend 1/20th of a message to reduce the deviation by one during one time unit), the average information cost of a 80 mile trip for one of the policies is 70 cents, whereas for another is almost twice that.

C.3. Preliminary Work: Data Dissemination

In this subsection we illustrate our approach to data dissemination among a set of static sensors. Each node stores a possibly inconsistent copy of the whole database D. We use both, the gdd paradigm and the inconsistency-communication tradeoff to obtain a data dissemination policy, Adaptive Broadcast Replication (ABR), that can be proven optimal in an intuitive sense.

C.3.1. Operational model

The system consists of a set of n nodes that communicate by message broadcasting. all the nodes on the network. Each node i $(1 < i < n)$ has a data item D_i associated with it. Node i is called D_i's owner. This data item may contain a single numeric value, or an image of the local environment. Only i, and no other nodes, has the authorization to modify the state of D_i. A data item is updated at discrete time points. Each update creates a new version of the data item. In other words, the *kth version of* D_i, denoted $D_i(k)$, is generated by the kth update. We denote the latest version of D_i by $\overline{D_i}$. Furthermore, we use $v(D_i)$ to represent the version number of D_i, i.e. $v(D_i(k)) = k$.

For two versions $D_i(k)$ and $D_i(k')$, we say that $D_i(k)$ is *newer than* $D_i(k')$ if $k > k'$, and $D_i(k)$ is *older than* $D_i(k')$ if $k < k'$.

An owner i periodically broadcasts its data item D_i to the rest of the system. Each such broadcast includes the version number of D_i. Since the broadcast channel is unreliable, some broadcasts may be missed by some nodes, thus each node j has a version of each D_i which may be older than $\overline{D_i}$. The *local database* of node i at any given time is the set $< D_1^i, D_2^i, ..., D_n^i >$, where each D_j^i (for $1 \leq j \leq n$) is a version of D_j. Observe that since all the updates of D_i originate at i, then $D_i^i = \overline{D_i}$. Node i updates D_j^i $(j \neq i)$ in its local database when it receives a broadcast from j.

We model the network probabilistically. A broadcast message from a node i is received successfully and correctly by node j $(i \neq j)$ with probability p_{ij}. We call p_{ij} the *probability of reception* between i and j and we call $(p_{ij})_{1 \leq i \leq n, 1 \leq j \leq n}$ the *reliability matrix*. In a wireless network of static sensors, suppose that we divide the geographic area into a grid of square cells as in Figure 1. (Other partitioning schemes such as honeycomb/hexagon are possible). Consider all the sensors in a single cell as a single node; they presumably "cover" the same area, and each broadcast by one sensor of the cell is received by the other sensors in the cell with probability 1. The grid is preloaded in each processor, and using a gps each

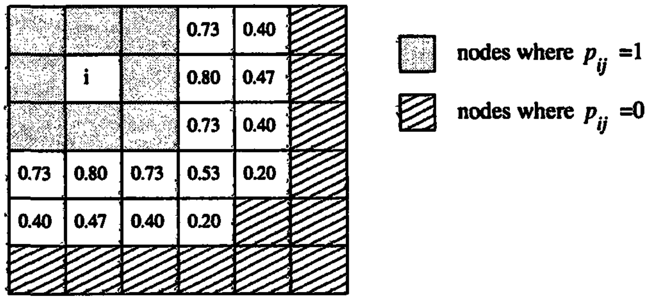

Figure 1: Reliability model of a wireless sensor network

processor knows to which cell it belongs. A method by which all processors in a cell can behave as a single node is for them to elect a leader before the data dissemination protocol starts.

The size of each cell depends on multiple factors including the power of the transmitter. The probability of reception between each pair of cells is determined by the Euclidean distance between the centers of the cells. For example, the distance between cell i and the cell to its north is 1, and the distance between i and the cell on its southeast is $\sqrt{2}$. For each cell i, there are three types of cells. The first type are cells that receive messages from i with probability 1. The second are cells that receive messages with probability 0, i.e. they are too far and do not receive any messages from i. And the third are cells that receive them with probability p ($p < 1$) where p is proportional to inverse of their square distance from i ([17]). Consider Figure 1 as an example. For each neighbor j of i, the probability of reception between i and j is 1 (see the shadowed cells). For each node j out of a certain range, p_{ij} is 0 (see the striped cells). For each j in the rest of the area, p_{ij} is proportional to the inverse of the square distance between i and j (see the numbers in the white cells).

C.3.2. Cost Model

In this subsection we introduce a cost function that quantifies the tradeoff between consistency and communication. The function has two purposes. First, to enable determining the items that will be included in each broadcast of the ABR policy, and second, to enable comparing the various policies.

Inconsistency cost

Assume that the distance between any two versions of a data item can be quantified. For example, the distance between two data item versions may be taken to be the Euclidean distance between two locations of an object. If D_i is an image, one of the many existing distance functions between images (e.g. the cross-correlation distance ([42])) can be used.

Formally, the *distance* between two versions $D_i(k)$ and $D_i(j)$, denoted $DIST(D_i(k), D_i(j))$, is a function whose domain is the nonnegative reals, and it has the property that the distance between two identical versions is 0. If the data item owned by each node consists of two or more types of logical objects, each with its own distance function, then the distance between the items should be taken to be the weighted averages of the pairwise distances.

We take the $DIST$ function to represent the cost, or the penalty, of using the older version rather than the newer one. More precisely, consider two consecutive updates on D_i, namely the kth update and the $(k+1)$st update. Assume that the kth update happened at time t_k and the $(k+1)$st update at time t_{k+1}. Intuitively, at time t_{k+1} each node j that did not receive the kth version $D_i(k)$ during the interval $[t_k, t_{k+1})$, pays a price which is equal to the distance between the latest version of D_i that j knows and $D_i(k)$. In other words, this price is the penalty that j pays for using an older version during the time in which j should have used $D_i(k)$. If j receives $D_i(k)$ sometime during the interval $[t_k, t_{k+1})$, then the price that j pays on D_i is zero. Formally, assume that at time t_{k+1} the latest version of D_i that j knows is v ($v \leq k$). Then *j's inconsistency cost on version k of* D_i is $COST\_INCO_j(D_i(k)) = DIST(D_i(v), D_i(k))$.

The *inconsistency cost of the system on* $D_i(k)$ is $COST\_INCO(D_i(k)) = \sum_{1 \leq j \leq n} COST\_INCO_j(D_i(k))$.

The *total inconsistency cost of the system on* D_i *up to* the *mth update of* D_i, denoted $COST\_INCO(i, m)$, is $\sum_{1 \leq k < m} COST\_INCO(D_i(k))$.

The *total inconsistency cost for the system up to time t* is $COST\_INCO(t) = \sum_{1 \leq i \leq n} COST\_INCO(i, m_i)$, where m_i is the highest version number of D_i at time t.

Communication cost

The cost of a message depends on the length of the Message. In particular, if there are m data items in a message, the cost of the message is $C_1 + m \cdot C_2$. C_1 is called the *message initiation cost* and C_2 is called the *message unit cost.* C_1 represents the cost of energy consumed by the CPU to prepare and send the message. C_2 represents the incremental cost of adding a data item to a message. The values of C_1 and C_2 are given in inconsistency cost units. They are determined based the amount of resource that one is willing to spend in order to reduce the inconsistency cost on a version by one unit. For example, if $C_1 = C_2$ and one is willing to spend one message of one data item in order to reduce the inconsistency by at least 50, then $C_1 = C_2 = 1/100$.

The *total communication cost up to time t* is the sum of the costs of all the messages that have been broadcast from the beginning (time 0) until t.

System cost

The *system cost up to time t*, denoted *COST_SYS(t)*, is the sum of the total inconsistency for the system up to t, and the total communication cost up to t. The system cost is the objective function optimized by the ABR policy. When comparing ABR with other broadcast policies, there are two additional costs which will come into play. They are the cost of memory to store the auxiliary data structures (e.g. the knowledge matrix), and the computation cost. Both have been included, but we omit the details.

C.3.3. The Adaptive Broadcast Replication Policy

In this section we describe the Adaptive Broadcast Replication policy. Intuitively, a node i executing the policy behaves as follows. When it receives an update to D_i node i constructs a broadcast message by evaluating the benefit of including in the message each one of the data items in its local database. [6] Specifically, the ABR policy executed by i consists of the following two steps.

(1) Benefit estimation: For each data item in the local database, estimate how much the inconsistency of the system could be reduced if that data item is included in the message.

(2) Message construction: Construct the message which is a subset of the local database so that the total estimated net benefit of the message is maximized (The net benefit is the difference between the inconsistency reduced by the message and the cost of the message). Observe that the set of data items to be broadcast may be empty. In other words, when D_i is updated, node i may estimate that the net benefit of broadcasting any data item is negative.

Each one of the above steps is executed by an algorithm which is described in one of the next two subsections.

[6] In this paper ABR is executed by node i when an update occurs on D_i. But this is not strictly necessary. The same policy can be executed periodically regardless of updates.

C.3.4. Benefit Estimation

Intuitively, the benefit to the system of including a data item D_j in a message that node i broadcasts is in terms of inconsistency reduction. This reduction depends on the nodes that receive the broadcast, and on the latest version of D_j at each one of these nodes. Node i maintains data structures that enable it to estimate the latest version of D_j at each node. Then the benefit of including a data item D_j in a message that i broadcasts is simply the sum of the expected inconsistency reductions at all the nodes.

In computing the inconsistency reduction for a node k we attempt to be as accurate as possible, and we do so as follows. Node i maintains a "knowledge matrix" which stores in entry (k, j) the last version number of D_j that node i received from node k (this version is called $v(D_j^k)$), and the time when it was received. Additionally, i saves in the "real history" for each D_j all the versions of D_j that i has "heard" from other nodes, the times at which it has done so, and from which node they were received[7]. The reason for maintaining all this information is that now, in estimating which version of D_j node k has, node i can take into consideration two factors: (1) the last version of D_j that i received from k at time, say t, and (2) the fact that since time t node k may have received updates of D_j by "third party" messages that were transmitted after time t, and "heard" by both, k and i. Node i also saves with each version v of D_j that it "heard", the distance (i.e. the inconsistency caused by the version difference) between v and the last version of D_j that i knows; this difference is the parameter necessary in order to compute the inconsistency cost reduction that is obtained if node i broadcasts its latest version of D_j.

In subsection C.3.4.1 we describe the data structures that are used by a node i in benefit estimation. In subsection C.3.4.2 we present i's benefit estimation method.

C.3.4.1 Data Structures

(1) The Knowledge matrix: For each data item D_j $(j \neq i)$, denote by $v(D_j^k)$ the latest version number of D_j that i received from k, and denote by $t(D_j^k)$ the last time when D_j^k was received at i. The *knowledge matrix* at node i is:

$$M_i = \begin{pmatrix} (t(D_1^1), v(D_1^1)) & (t(D_2^1), v(D_2^1)) & \dots & (t(D_n^1), v(D_n^1)) \\ (t(D_1^2), v(D_1^2)) & (t(D_2^2), v(D_2^2)) & \dots & (t(D_n^2), v(D_n^2)) \\ \vdots & \vdots & \ddots & \vdots \\ (t(D_1^n), v(D_1^n)) & (t(D_2^n), v(D_2^n)) & \dots & (t(D_n^n), v(D_n^n)) \end{pmatrix}$$

Node i updates the matrix whenever it receives a message. Specifically, when i receives a message from k that includes D_j, i updates the entry (k,j) of the matrix. In addition, if the version of D_j received is newer than the version in i's local database, then the newer version updates D_j in the local database.

(2) Version sequence: A version sequence records all the version numbers that i has ever known about a data item. Due to unreliability, it is possible that i has not received all the versions of a data item. In particular, the *version sequence of* D_j is $VS_j =< v_1, v_2, ..., v_h >$ where $v_1 < v_2 < ... < v_h$ are all the version numbers that i has ever known about D_j. For each $v \in VS_j$, i saves in the distance between $D_j(v)$ and $D_j(v_h)$.

(3) Replication history: For each version number v in each VS_j, i maintains a *replication history* $RH_j(v)$. In this history there is a record for every time point at which i received $D_j(v)$ from a node, along with the identification of that node. $RH_j(v)$ also contains a record for every time point at which i broadcast $D_j(v)$.

Observe that the lengths of each version sequence VS_j and replication history $RH_j(v)$ increases unboundedly as i receives more broadcasts. This presents a storage problem, and there are several ways of addressing it, but we omit this discussion here. Also, observe that the data structures change in the

[7] There is a potential storage problem here, which we address, but we postpone the discussion for now.

dynamic case, i.e. if a node can join or leave the system during operation. Again, there are ways of addressing this problem, but the discussion is omitted here.

C.3.4.2 The Benefit Estimation Method

When an update on D_i occurs, node i estimates the benefit of including its latest version of D_j in the broadcast message, for each D_j in the local database. Intuitively, i does so using the following procedure. For each node k compute the set of versions of D_j that k can have, i.e. the set of versions that were received at i after D_j^k was received. Assume that there are m such versions. Then, compute the set of broadcasts from which k could have learned each one of these versions. The computation of this set uses the data structures discussed in the previous subsection. Based on this set compute the probabilities $p_1, p_2, ..., p_m$ that k has each one of the possible versions $v_1, v_2, ..., v_m$. Finally, compute the expected benefit to k as the sum $p_1 \cdot DIST(v(D_j), v_1) + p_2 \cdot DIST(v(D_j), v_2) + ... + p_m \cdot DIST(v(D_j), v_m)$.

C.3.5. Message Construction Step

The objective of this step is for node i to select a subset S of data items from the local database for inclusion in the broadcast message. The set S is chosen such that the expected net benefit of the message (i.e. the total expected inconsistency-reduction benefit minus the cost of the message) is maximized.

First, node i sorts the estimated benefits of the data items in descending order. Thus we have the benefit sequence $B(D^i_{k_1}) \geq B(D^i_{k_2}) \geq ... \geq B(D^i_{k_n})$. Then i constructs the message as follows. If there is no number t between 1 and n such that the sum of the first t members in the sequence is bigger than $(C_1 + t \cdot C_2)$, then i will not broadcast a message.[8] Else, i finds the shortest prefix of the benefit sequence such that the sum of all the members in the prefix is greater than $(C_1 + m \cdot C_2)$, where m is the length of the prefix. i places the data items corresponding to the prefix in the broadcast message. Then i considers each member j that succeeds the prefix. If $B(D^i_j)$ is greater than or equal to C_2, then i puts D^i_j in the message.

This concludes the description of the ABR-s policy, which consists of the benefit estimation and message construction steps. It is easy to see that the time complexity of the policy is $O(n \cdot s)$.

C.4. Proposed Research

As as mentioned in the introduction, our research will address three problems. First, data dissemination in static sensor networks; second, data allocation, and query and update processing in the MANET environment, in which the database is distributed among a set moving objects; third, based on the previous results, develop efficient algorithms for processing queries and triggers of the form Q = "Display the mobile units (e.g. friendly helicopters) that are expected to enter region R within the next ten minutes" in a distributed and mobile environment, in which the Moving Objects Database is distributed among the moving objects themselves. Next we elaborate on the research issues related to each one of these problems.

• We will analyze variants of the ABR policy, devise alternatives, and conduct a comprehensive analysis of data dissemination options for static sensor networks. For example, as presented, the ABR policy may initiate a broadcast only when an update on the local data item is received. However, a broadcast can be initiated periodically; or a node may broadcast when the inconsistency cost of the system exceeds a certain threshold. Similarly, we will study if and how the geometric shape of the cell (e.g. square or hexagon) affects the algorithm.

[8] Remember that the cost of a message containing m data items is $(C_1 + m \cdot C_2)$.

One can also imagine a wide range of alternatives to ABR, that do not use the gdd paradigm, nor the inconsistency-communication tradeoff. For example, an alternative at one extreme end of the spectrum is to use reliable broadcast, i.e. rebroadcast each update until it is acknowledged by all the sensors. This will result in reliable broadcast. Another alternative is to broadcast the entire local database whenever an update on the local data item is received, or periodically. Another alternative is to use flooding, in which a sensor rebroadcasts each new update it receives, be it on its own data item, or on some other one. Another alternative is given in [60]. That work assumes large data items; each node that receives an update "advertises" it, and sends it to the nodes that request it.

The optimal broadcast algorithm depends on various parameters of the problem such as: the size of a data item, the cost of a message (which in tern depends on the available bandwidth), the update frequency, the inconsistency cost, the average distance between two consecutive versions of a data item, the reliability of the network. We will evaluate the algorithms analytically where possible, and by simulation. For example, we know how to analytically compare ABR with eager replication by reliable broadcast, and determine the parameters for which eager is superior to ABR, and vice versa.

We will build a simulation testbed in which a user selects a replication algorithm, a replication model, inputs cost functions, defines the cell geometric shape and the connection reliability parameters. A cost function has two components: inconsistency cost and communication-and-computation cost. Inconsistency cost, as stated before, is quantified via the notion of the cost difference between two versions of each data item D_i. The communication-and-computation cost is message based. The user is charged per message, and the exact charge depends on the length of the message. In particular, if there are m data items in a message, the cost of the message is $C_1 + m \cdot C_2$, where C_1 and C_2 can be determinated based on what amount of bandwidth/energy/dollars one is willing to spend in order to reduce the inconsistency cost on a data item by one unit.

A speculative way of validating our approach is to use a traffic monitoring scenario. In this scenario the system consists of n distributed computers, each monitoring a streets intersection in an urban environment. Each computer takes images of an intersection at various points in time (say every hour) and broadcasts it to the others.

We will validate our approach in this scenarios by instantiating the parameters of the simulation testbed such as C_1, C_2, and cost of inconsistency, and see how reasonable is the simulation prediction. We will use the algorithm in [42] to quantify the difference between two different images of an intersection.

• We will develop and evaluate algorithms for geographic dissemination of data in mobile ad hoc networks, and for query and trigger processing in this environment. The idea here is simple. Data items are associated with predefined geographic cells, and at each point in time each data item resides in moving objects that are in the geographic cell at that time. Queries about a the database on a particular moving object o are transmitted to o using the routing protocols in MANET's (quite a few papers in the recent Mobicom and Mobihoc conferences deal with such routing protocols). Range queries, such as the query Q above, are processed by transmitting them to the region R, i.e. to the moving objects that are currently in region R.

However, many details regarding this scheme need to be worked out, and this will the subject of our research. Consider for example a data item d that is associated with cell c, and consider a point in time t. Does d reside on all the moving objects that are in c at time t, or only in some, and if so, which ones?

One possibility is to have one or more leaders in each cell at any time, and have the data items of the cell replicated only at the leaders. When a leader leaves the cell a new leader is elected, and the data of the old leader is transferred to the new leader. What happens when the cell c does not contain any other moving objects at a time when a leader l moves out of cell c? One possible way of dealing with this problem is to transfer the data to a leader of a neighboring cell, for example, the leader of the cell into which l moves. Clearly that cell is not empty, since it has at least l.

Another possibility is that all the data items of the cell c are replicated at all the moving objects in c at any time. In this case we may also need a leader, in order to answer queries; clearly, to avoid wasting resources, we would like to prevent a situation in which all the moving objects in a cell transmit the (same) answer to a query.

What is the size of a cell, and how is the size related to the transmission range of each moving object? Clearly, all the moving objects in a cell must be within "hearing range" of each other, but what about moving objects in neighboring cells?

The answers to the above questions depend on the traffic patterns, the number of updates, the ratio of updates to queries, etc. Thus, we will evaluate the various gdd schemes by developing a simulation test bed. The simulation test bed will allow us to define traffic patterns in real maps, and compare the performance of various alternative answers to the above questions. We will strive to build our simulation testbed on top of existing environments for evaluating wireless protocols. A possible candidate is described in: http://www.ukans.edu/wsc96/htmfiles/mm121.htm

There are also several real network testbeds that we will consider utilizing for our research. For example, a group at CMU is designing, setting up and using a MANET testbed along the Monongahela River in Pittsburgh, including manet nodes operating in mobile vehicles (see http://www.ietf.org/proceedings/99mar/44th-99mar-ietf-92.html). Some other efforts which we may interface with are described at: http://www.darpa.mil/ato/programs/glomo/psum1999/D811-0.html, and http://www.cs.hut.fi/ mart/

We will also develop policies for maintaining a materialized view of the database on a moving object. For example, in the traffic reports application mentioned in the introduction, suppose that some vehicle needs a continuous view of the average travel time along some section of the highway. The consistency of the view needs to be balanced against the resources-cost of maintaining the view. Thus we will study view maintenance protocols that balance the imprecision of the local view against the communication-and-computation cost.

• We will investigate the gdd algorithms in the context of Moving Objects Database applications. We will store the locations and motion plans in a database that is distributed among a set of moving objects, in the absence of a fixed network infrastructure. As explained in the introduction, each intersection of a trajectory and a cell is a data item stored in that cell. Thus data item A = "the trajectory of object 55 passes through cell number 20 between 5pm and 6pm" is stored in cell number 20. This means that data item A may be stored on object 35 (which happens to be in cell 20) at 1pm, and on object 102 at 9pm. Consider now a query such as Q = "Display the mobile units (e.g. friendly helicopters) that are expected to enter region R within the next ten minutes" If the region R intersects two cells, 20 and 21, then the query will be sent to these two cells.

We will adapt our Moving Objects Database model to the mobile-distributed environment. Observe that each update of the locations database as a result of threshold violation will imply updating the timing information of the trajectory in all the cells that are crossed by the future trajectory. This will significantly increase the cost of communication, but not necessarily require changing the location update policies. However, in order to reduce the number of updates we will adapt the model, such that the uncertainty interval is an area (e.g. a circle around the current computed location), rather than a section of the road. This will avoid an update for every deviation from the predefined road. Additionally, we will adapt the model to allow for updates to the trajectory as a result of real-time traffic conditions. Thus, an update to the average travel time along a section of the highway may update timings along all the trajectories that traverse that section in the future.

We will adapt the location update policies adr and dtdr to the mobile-distributed environment. In the existing policies, the moving object and the central database have a common threshold at any point in time. This threshold is computed based on the cost of updating the central database. However, in the mobile-distributed environment the cost of updating the database changes continuously depending on the number of cells crossed by the future trajectory. Our policies have to be adapted accordingly.

Similarly, in this environment the moving objects are much more prone to disconnection, particularly to partial disconnection. Namely, they may be disconnected from one cell, but not from another. We propose to handle this case by devising an update policy in which the uncertainty interval increases as the time since the last update increases. Furthermore, each query such as Q will be associated with a maximal uncertainty interval, and the objects retrieved in response to the query Q will also be associated with their current uncertainty interval. If the current uncertainty interval of an object is higher than the maximum, then an attempt ot contact the object and obtain its exact location will be executed. This method trades off between push and pull of updates to the trajectories database. We will evaluate the new location management schemes by simulations, as in [18, 59]. For this purpose, we will also interface with existing work to evaluate MANET's (see references in the previous research item).

We will also study the view maintenance algorithms in the MOD context. For example, a moving object may define a local materialized view of all the objects that will enter a certain geographic region between 7 and 8pm. As traffic/weather conditions and unexpected delays occur, this set may change dynamically.

We will also study how trajectories in the moving objects database can be utilized and improve the efficiency of MANETs' routing protocols.

C.5. Research Plan

The three research subjects constitute a natural succession from a traditional database in an infrastructureless static environment, to such a database in a mobile/distributed environment, to a special database in the mobile/distributed case. Thus, we will roughly devote the first year to the first research subject, second year to the second subject, etc.

During the first year we will compare broadcast algorithms, build the simulation testbed, and validate our approach using the traffic monitoring scenario. Building parts of the simulation testbed will be offered as an optional course project in the graduate course taught by the PI. The validation necessitates obtaining a sequence of images at each one of a set of street intersections. We will approach the Chicago Transit Authority, with whom our computer science department has an ongoing relationship, for this purpose.

During the second year we will extend the simulation testbed and the analytical results of the first year to the mobile environment, with data handoff among moving objects. The simulation results will be validated in a real environment of handheld devices communicating using a mobile ad hoc network.

For the third year research we intend to use the Mobitrac Moving Objects Database system. This system is being developed for a centralized environment by Mobitrac Inc., a venture-funded, startup company founded by the PI, in which he serves as the Chief Scientific Officer.

The research will be conducted by the PI, Dr. Rishe from FIU who will serve as a consultant, and a Ph.D. student. Dr. Rishe will participate in the conceptual aspects of the project. He will interact with the team at UIC via quarterly face-to-face meetings and teleconferencing. The experimental aspects of the projects will be conducted at UIC. Based on past experience, we expect several M.Sc. students that are funded by other sources to do their thesis/project on the subject, and thus participate in the research.

C.6. Relevant Work

Work relevant to data dissemination in static sensor networks.

The problem of data dissemination in peer to peer broadcast networks has not been analyzed previously as far as we know. The data broadcasting problem studied in [13, 41, 40] is how to organize the broadcast and the cache in order to reduce the response time. The above works assume a centralized system with a single server and multiple clients communicating over a reliable network with large bandwidth. In contrast, in our environment these assumptions about the network do not always hold, and the environment is totally distributed and each node is both a client and a server.

Pagani et al. ([28]) proposed a reliable broadcast protocol which provides an exactly once message delivery semantics and tolerates host mobility and communication failures. Birman et al. ([29]) proposed three multicast protocols for transmitting a message reliably from a sender process to some set of destination processes. Unlike these works, we consider a "best effort" reliability model and allow copies to diverge.

Lazy replication by gossiping has been extensively investigated in the past (see for example [7, 6, 30]). Epidemic algorithms ([31, 32]) such as the one used in Grapevine ([33]) also propagate updates by gossiping. However, there are two major differences between our work and the existing works. First, none of these works considered the cost of communication; this cost is important in the types of novel applications considered in this paper. Second, we consider the tradeoff between communication and inconsistency, whereas the existing works do not. Alonso, Barbara, and Garcia-Molina ([34]) studied the tradeoff between the gains in query response time obtained from quasi-caching, and the cost of checking coherency conditions. However, they assumed point to point communication and a centralized (rather than a distributed) environment.

Let us now put the proposed project in the context of existing work on consistency in distributed systems. Our approach is new as far as we know. Although gossiping has been studied extensively in distributed systems and databases (see section 6), none of the existing works uses an inconsistency-communication tradeoff cost function in order to determine what gossip messages to send. Furthermore, in the emerging resource constrained environments (e.g. sensor networks, satellite communication, and MANET's) this tradeoff is crucial. Also our notion of consistency is appropriate for the types of novel applications discussed in this paper, and is different than the traditional notion of consistency in distributed systems discussed in the literature (e.g., [39, 35, 36, 37]. Specifically, in contrast to the traditional approaches, our notion of consistency does not mean consistency of different copies of a data item at different nodes, and it does not mean mutual consistency of different data items at a node. In this paper a copy of a data item at a node is consistent if it has the latest version of the data item. Otherwise it is inconsistent, and the inconsistency cost is the distance between the local copy and the latest version of the data item. Inconsistency of a local database is simply the sum of the inconsistencies of all data items. We employ gossiping to reduce inconsistency, not to ensure consistency as in using vector clocks ([35, 39]).

A recent work similar to ours is TRAPP (see [38]). The similarity is in the objective of quantifying the tradeoff between consistency and performance. However, the main differences are in the basic assumptions. First, the TRAPP system deals with numeric data in traditional relational databases. Second, it quantifies the tradeoff for aggregation queries. Actually, probably the most fundamental difference is that it deals with the problem of answering a particular instantaneous query, whereas we deal with database consistency. Specifically, we want the consistency of the whole database to be maximized for as long as possible. In other words, we maximize consistency in response to continuous queries that retrieve the whole database. Indeed, in our MOD scenario, a tank commander needs to continuously view the location of the other tanks in a platoon. Or, in sensor networks we want to view/examine the whole database at a particular sensor that we were able to access or recover.

Finally, let us discuss a large body of important work dealing with replication, consistency, and broadcasting (see for example [49, 50]). These works are concerned with transactional properties and attaining serializability, i.e. perfect consistency, at minimum cost. In contrast, in this paper we consider applications where inconsistency can be tolerated and transactional properties are not strictly required. However, a framework in which each update is a transaction can be easily incorporated in our model.

Work relevant to location management and Moving Objects Databases.

Most of existing works on MANET's are about routing management (see for example [55, 56, 58, 57]). They are concentrated on how to build and maintain a (dynamic) network topology via routers. Their protocols are used to exchange routing information. Our work is at a higher level in the sense that our data management protocols are application-layer protocols and can be built on top of the underlying MANET routing protocol.

Our problem is also related to mobile computing, particularly works on location management in the cellular architecture. These works address the following problem. When calling or sending a message to a mobile user, the network infrastructure must locate the cell in which the user is currently located. The network uses the location database that gives the current cell of each mobile user. The record is updated when the user moves from one cell to another, and it is read when the user is called. Existing works on location management (see, for example, [77, 71, 67, 72, 73, 66, 74]) address the problem of allocating and distributing the location database such that the lookup time and update overhead are minimized. Location management in the cellular architecture can be viewed as addressing the problem of providing uncertainty bounds for each mobile user. The geographic bounds of the cell constitute the uncertainty bounds for the user. Uncertainty at the cell-granularity is sufficient for the purpose of calling a mobile user or sending him/her a message. When it is also sufficient for MOD applications, the location database can be sold by wireless communication vendors to mobile fleet operators. However, often uncertainty at the cell granularity is insufficient. For example, in satellite networks the diameter of a cell ranges from hundreds to thousands of miles.

Finally, the present project extends the work on on Moving Objects Databases (see [14, 15, 44, 45, 62, 63] These works deal with language constructs and indexing of moving objects. None of these works addresses Moving Objects Databases in a mobile, distributed, and infrastructureless environment as we do in this proposal.

C.7. Results from Prior NSF Support

Ouri Wolfson was previously supported by NSF grants IRI-9408750, CCR-9816633, and CCR-9803974 which are related to the current proposal. As part of these projects we developed a prototype database system for tracking the location of mobile units, and a simulation testbed that can be used to evaluate the wireless network bandwidth used for tracking mobile units. The prototype was built on top of the Informix database management system, as a data-blade for tracking mobile units. The prototype is being commercialized by a startup company founded by Wolfson and UIC (www.mobitrac.com); the company received venture capital funding, and is in negotiation with Fedex for beta testing.

The publications resulting from this project are marked by * in the bibliography. The prototype database system for tracking mobile units and the simulation testbed are available for anonymous ftp at dbis.eecs.uic.edu in directory /pub/projects/domino. It can also be used by remote login to eagle.eecs.uic.edu with userid: informix and password: IUS91server.

D. Bibliography

References

[1] L. LAMPORT, *Time, clocks, and the ordering of events in a distributed system*, Commun. ACM, 21,7(July 1978),558-565.

[2] Jing, Elmagarmid, etc., *Bit-Sequences: An adaptive cache invalidation method in mobile client/server environments*, Mobile Networks and Applications, 2(1997).

[3] Shivakumar, Jannink and Widom, *Per-user profile replication in mobile environments: Algorithms, analysis, and simulation results*, Mobile Networks and Applications, 2(1997).

[4] Tsai and Lin, *A data request scheduling policy for PCS networks*, Mobile Networks and Applications, 2(1997).

[5] Dunham, Helal and Balakrishnan, *A mobile transaction model that captures both the data and movement behavior*, Mobile Networks and Applications, 2(1997).

[6] R. Ladin, B. Liskov, S. Ghemawat, *Providing High Availability Using Lazy Replication*, ACM Transactions on Computer Systems, Vol. 10, No. 4, November 1992.

[7] B. Liskov, R. Scheifler, E. Walker, and W. Weihl, *Orphan detection (extended abstract)*, Proceedings of the 17th International Symposium on Fault-Tolerant Computing, July 1987.

[8] J. P. Macker and M. S. Corson, Mobile Ad Hoc Networking and the IETF, Mobile Computing and Communications Review, Vol. 2, No. 1, January 1998.

[9] J. Gray, P. Helland, P. O'Neil, D. Shasha, The dangers of replication and a solution, Proc. ACM SIGMOD 96, pp. 173-182, Montreal, Canada, 1996.

[10] S. Acharya, M. Franklin, S. Zdonik, Balancing push and pull for data broadcast, Proc. ACM SIGMOD 97, pp. 183-194, Tucson, Arizona, 1997.

[11] S. Acharya, R. Alonso, M. Franklin, S. Zdonik, Broadcast disks: data management for asymmetric communication environments, Proc. ACM SIGMOD Conf., San Jose, CA, May, 1995.

[12] S. Acharya, M. Franklin, S. Zdonik, Disseminating updates on broadcast disks, Proc. 22nd VLDB Conf., Bombay, India, September, 1996.

[13] T. Imielinski, B. Badrinath, Mobile wireless computing: challenges in data management, CACM, 37(10), October, 1994.

[14] * P. Sistla, O. Wolfson, S. Chamberlain, S. Dao, *Modeling and Querying Moving Objects*, Proceedings of the Thirteenth International Conference on Data Engineering (ICDE13), Birmingham, UK, Apr. 1997.

[15] * O. Wolfson, S. Chamberlain, S. Dao, L. Jiang, G. Mendez, *Cost and Imprecision in Modeling the Position of Moving Objects*, Proceedings of the Fourteenth International Conference on Data Engineering (ICDE14), 1998

[16] * O. Wolfson, B. Xu, S. Chamberlain, L. Jiang, Moving Objects Databases: Issues and Solutions, Proceedings of the 10th International Conference on Scientific and Statistical Database Management (SSDBM98), Capri, Italy, July 1-3, 1998, pp. 111-122.

[17] W. Stallings, *Data and Computer Communications*, 5th ed., Prentice Hall, 1997.

[18] * O. Wolfson, L. Jiang, P. Sistla, S. Chamberlain, N. Rishe, M. Deng, Databases for Tracking Mobile Units in Real Time, in the Springer-Verlag Proceedings of the Seventh International Conference on Database Theory (ICDT), Jerusalem, Israel, Jan. 10-12, 1999.

[19] T. Imielinski, S. Viswanathan, B. Badrinath, Energy efficient indexing on air, Proc. ACM SIGMOD Conf., Minneapolis, MN, May, 1994.

[20] F. Bennett, D. Clarke, J. Evans, A. Hopper, A. Jones, and D. Leask, Piconet: Embedded Mobile Networking, IEEE Personal Communications, 4(5), October 1997.

[21] Z. J. Has, Panel Report on Ad Hoc Networks - MILCOM'97, Mobile Computing and Communications Review, Vol. 2, No. 1, January 1998.

[22] L. Kleinrock and J. A. Silvester, *Spatial reuse in multihop packet radio networks*, Proc. IEEE, vol. 75, pp. 116-134, Jan. 1987.

[23] H. Takagi and L. Kleinrock, *Optimal transmission ranges for randomly distributed packet radio terminals*, IEEE Trans. Comun., vol. COM-32, pp. 246-257, Mar. 1984.

[24] T. C. Hou and V. O. K. Li, *Transmission range control in multihop packet radio networks*, IEEE Trans, Communi., vol. COM-34, pp. 38-44, Jan. 1986.

[25] E. S. Sousa and J. A. Silvester, *Optimum transmission ranges in a direct-sequence spread-spectrum multihop packet radio network*, IEEE J. Select. Areas Commun., vol. SAC-8, pp. 762-771, June 1990.

[26] M. Zorzi and S. Pupolin, *Optimum transmission ranges in multihop packet radio networks in the presence of fading*, IEEE Trans. Commun., vol. 43, No. 7, pp. 2201-2205, July 1995.

[27] D. Agrawal, G. Alonso, A. El Abbadi, and I. Stanoi, *Exploiting atomic broadcast in replicated databases*, in Proceedings of the International Conference on EuroPar'97, 1997.

[28] E. Pagani and G. P. Rossi, *Reliable Broadcast in Mobile Multihop Packet Networks*, Proc. ACM MOBICOM'97, pp. 34-42, Budapest, Hungary, 1997.

[29] K. Birman, T. A. Joseph, *Reliable Communication in the Presence of Failures*, ACM Transactions on Computer Systems, Vol. 5, No. 1, Feb. 1987.

[30] D. B. Terry, K. Petersen, M. J. Spreitzer and M. M. Theimer, *The Case for Non-transparent Replication: Examples from Bayou*, Bulletin of the IEEE Computer Society Technical Committee on Data Engineering, Vol. 21, No.4, 1998.

[31] A. Demers, D. Greene, etc., *Epidemic algorithms for replicated database maintenance*, Operating Systems Review, vol. 22, No. 1, pp. 8-32, Jan. 1988.

[32] R. Golding, *A weak-consistency architecture for distributed information services*, Computing Systems, vol. 5, No. 4, 1992. Usenix Association.

[33] M. D. Schroeder, A. D. Birrell, R. M. Needham, *Experience with Grapevine: the growth of a distributed system*, ACM Transactions on Computer Systems, vol. 2, No. 1, pp. 3-23, Feb. 1984.

[34] R. Alonso, D. Barbara, and H. Garcia-Molina, *Data Caching Issues in an Information Retrieval System*, ACM Transactions on Database Systems, Vol. 15, No. 3, Sept. 1990.

[35] F. Mattern, Virtual time and global states of distributed systems, in the Proceedings of the International Workshop on Parallel and Distributed Algorithms, North-Holland, 1989.

[36] C. Fidge, *Timestamps in message-passing systems that preserve the partial ordering*, in Proceedings of the 11th Australian Computer Science Conference, 1988.

[37] A. Schiper, J. Eggli, and A. Sandoz, *A new algorithm to implement causal ordering*, in the Proceedings of the 3rd International Workshop on Distributed Algorithms, Lecture Notes on Computer Science 392, Springer-Verlag, New York, 1989.

[38] C. Olston, J. Widom, *Offering a precision-performance tradeoff for aggregation queries over replicated data*, http://www-db.stanford.edu/pub/papers/trapp-ag.ps.

[39] K. Birman, A. Schiper, P. Stephenson, *Lightweight Causal and Atomic Group Multicast*, ACM Transactions on Computer Systems, Vol. 9, No. 3, August 1991.

[40] S. Acharya, M. Franklin, and S. Zdonik, *Prefetching from a broadcast disk*, in 12th International Conference on Data Engineering, Feb. 1996

[41] S. Jiang, N. H. Vaidya, *Scheduling data broadcast to "impatient" users*, Proceedings of ACM International Workshop on Data Engineering for Wireless and Mobile Access, Seattle, Washington, August 1999.

[42] L. G. Brown, *A Survey of Image Registration Techniques*, ACM Computing Surveys, 24(4):325-376, December 1992.

[43] P. K. Agarwal, L. Arge, J. Erickson, *Indexing moving points*, in Proceedings of ACM PODS 2000.

[44] G. Kollios, D. Gunopulos and V. J. Tsotras, *On indexing mobile objects*, in Proceedings of ACM PODS 1999.

[45] G. Kollios, D. Gunopulos, and V. J. Tsotras, *Nearest Neighbor Queries in a Mobile Environment*, Workshop on Spatio-Temporal Database Management, 1999, Edinburgh, Scotland.

[46] I. Stanoi, D. Agrawal, and A. El Abbadi, *Using broadcast primitives in replicated databases*, Int. Conf. on Distributed Computing Systems (ICDCS98), Amsterdam, May 1998.

[47] Y. Breitbart, and H. F. Korth, *Replication and consistency being lazy helps sometimes* in Proceedings of ACM PODS'97, Tucson, AZ, May 1997.

[48] T. Anderson, Y. Breitbart, H. F. Korth and A. Wool, *Replication, consistency, and practicality: are these mutually exclusive?*, in Proceedings of ACM SIGMOD'98, Seattle, WA, June 1998.

[49] Y. Breitbart and H. F. Korth, *Replication and consistency in a distributed environment*, Journal of Computer and System Sciences, Vol 59, No. 1, Aug. 1999.

[50] Y. Breitbart, R. Komondoor, R. Rastogi, S. Seshadri, *Update propagation protocols for replicated databases*, in Proceedings of ACM SIGMOD'99, Philadelphia, PA, June 1999.

[51] J. M. Kahn, R. H. Katz and K. S. J. Pister, *Next century challenges: mobile networking for "Smart Dust"*, Proceedings of the fifth ACM/IEEE International Conference on Mobile Computing and Networking (MOBICOM99), Seattle, WA, August, 1999.

[52] Internet Engineering Task Force, *MANET WG Charter*, http://www.ietf.org/html.charters/manet-charter.html.

[53] S. Chamberlain, *Automated Information Distribution in Bandwidth-Constrained Environments* MILCOM-94 conference, 1994.

[54] S. Chamberlain, *Model-Based Battle Command: A Paradigm Whose Time Has Come,* 1995 Symposium on C2 Research & Technology, NDU, June 1995

[55] Y. B. Ko, N. H. Vaidya, *Location-aided routing (LAR) in mobile ad hoc networks*, The fourth annual ACM/IEEE International Conference on Mobile Computing and Networking, 1998, Dallas, TX.

[56] S. Basagni, I. Chlamtac, V. R. Syrotiuk and B. A. Woodward, *A distance routing effect algorithm for mobility (DREAM)*, The fourth annual ACM/IEEE International Conference on Mobile Computing and Networking, 1998, Dallas, TX.

[57] J. Broch, D. A. Maltz, et al., *A performance comparison of multi-hop wireless ad hoc network routing protocols*, The fourth annual ACM/IEEE International Conference on Mobile Computing and Networking, 1998, Dallas, TX.

[58] S. Singh, M. Woo and C. S. Raghavendra, *Power-aware routing in mobile ad hoc networks*, The fourth annual ACM/IEEE International Conference on Mobile Computing and Networking, 1998, Dallas, TX.

[59] * O. Wolfson, P. Sistla, S. Chamberlain, Y. Yesha, *Updating and Querying Databases that Track Mobile Units*, invited paper, special issue of the Distributed and Parallel Databases Journal on Mobile Data Management and Applications, 7(3), 1999, Kluwer Academic Publishers, pp. 257-287.

[60] W. R. Heinzelman, J. Kulik and H. Balakrishnan, *Adaptive protocols for information dissemination in wireless sensor networks*, Proceedings of the fifth ACM/IEEE International Conference on Mobile Computing and Networking (MOBICOM99), Seattle, WA, August, 1999.

[61] http://www.palm.net/myaccount/pricing.html

[62] R. H. Gueting, E. Nardelli, M. Schneider, *A data model and data structures for moving objects databases*, in Proceedings of ACM SIGMOD 2000.

[63] C. S. Jensen, S. T. Leutenegger, M. A. Lopez, *Indexing the positions of continuously moving objects*, in Proceedings of ACM SIGMOD 2000.

[64] A. Motro, *Management of Uncertainty in Database Systems*, In Modern Database Systems, Won Kim ed., Addison Wesley, 1995.

[65] S. Abiteboul, R. Hull, V. Vianu, *Foundations of Databases*, Addison Wesley, 1995.

[66] R. Alonso, H. F. Korth, *Database System Issues in Nomadic Computing*, Proceedings of the 1993 ACM SIGMOD International Conference on Management of Data, Washington DC, May 1993.

[67] B. R. Badrinath, T. Imielinski, A. Virmani, *Locating Strategies for Personal Communication Networks*, Workshop on Networking for Personal Communications Applications, IEEE GLOBECOM, December 1992.

[68] M. Baudinet, M. Niezette, P. Wolper, *On the representation of infinite data and queries*, ACM Symposium on Principles of Database Systems, May 1991.

[69] A. Brodsky, V. E. Segal, J. Chen, and R. A. Exarkhopoulo, The CCUBE Constraint Object-Oriented Database System, manuscript, 1997.

[70] J. Chomicki and T. Imielinski, *Temporal deductive databases and infinite objects*, ACM Symposium on Principles of Database Systems, March 1988.

[71] J. S. M. Ho, I. F. Akyildiz, *Local Anchor Scheme for Reducing Location Tracking Costs in PCN*, 1st ACM International Conference on Mobile Computing and Networking (MOBICOM'95), Berkeley, California, November 1995.

[72] R. Jain, Y.-B. Lin, C. Lo, and S. Mohan, *A Caching Strategy to Reduce Network Impacts of PCS*, IEEE Journal on Selected Areas in Communications, Vol(12), October 1994.

[73] T. Imielinski and H. Korth, *Mobile Computing*, Kluwer Academic Publishers, 1996.

[74] Lazoff, B. Stephens, Y. Yesha, *Optimal Location of Broadcast Sources in Unreliable Tree Networks*, IEEE International Conference on Computers and Communications Networks, Rockville, Maryland, 1996.

[75] S. Grumbach, P. Rigaux, M. Scholl, and L. Segoufin, DEDALE, A Spatial Constraint Database, manuscript, 1997.

[76] M. Goodchild and S. Gopal, editors, *Accuracy of Spatial Databases*, Taylor and Francis, 1989

[77] N. Shivakumar, J. Jannink and J. Widom, *Per-User Profile Replication in Mobile Environments: Algorithms, Analysis, and Simulation Results*, ACM/Baltzer Journal on Special Topics in Mobile Networks and Applications, special issue on Data Management, 1997.

[78] P. Kanellakis, *Constraint programming and database languages*, ACM Symposium on Principles of Database Systems, May 1995.

[79] M. Abadi and Z. Manna, *Temporal logic programming*, Journal of Symbolic Computation, 8, 1989.

[80] Y. Yesha, K. Humenik, P. Matthews, B. Stephens, *Minimizing Message Complexity in Partially Replicated Databases on Hypercube Networks*, accepted for publication in Networks

[81] J. Paradaens, J. van den Bussche, D. Van Gucht, *Towards a theory of spatial database queries*, ACM Symposium on Principles of Database Systems, May 1994.

[82] * O. Wolfson, S. Jajodia, *An Algorithm for Dynamic Data Allocation in Distributed Systems*, Information Processing Letters (IPL), Vol. 53, 1995, pp. 113-119.

[83] * P. Sistla, O. Wolfson, *Temporal Triggers in Active Databases*, IEEE Transactions on Knowledge and Data Engineering (TKDE), Vol. 7(3), June 1995, pp. 471-486.

[84] * L. Russell, O. Wolfson, C. Yu, *Beyond Database Managers - Information Flow Managers*, Special Issue on Workflow Management Systems of the IEE Distributed Systems Engineering Journal (DSEJ), Vol. 3(4), Dec. 1996, pp. 263-275.

[85] * O. Wolfson, *Infrastructure and cost models for digital libraries* ACM Computing Surveys (Electronic Version), Vol. 28(4es), Dec. 1996. http://www.acm.org/pubs/citations/ journals/surveys/ 1996-28-4es/a113-wolfson

[86] * N. Adam, Y. Yesha, et al., *Strategic Directions in Electronic Commerce and Digital Libraries: Towards a Digital Agora*, ACM Computing Surveys, Vol. 28(4), Dec. 1996, pp. 818-835.

[87] * O. Wolfson, S. Jajodia, and Y. Huang, *An Adaptive Data Replication Algorithm*, ACM Transactions on Database Systems (TODS), Vol. 22(2), June 1997, pp. 255-314.

[88] * O. Wolfson, *Data Management in Mobile Computing*, ACM/Baltzer Journal on Special Topics in Mobile Networks and Applications (MONET), Vol. 2, No. 2, Oct. 97 (guest editor's introduction).

[89] * O. Wolfson, Y. Huang, *Competitive Analysis of Caching in Distributed Databases*, IEEE Transactions on Parallel and Distributed Systems, 9(4), Apr. 1998, pp. 391-409.

[90] * P. Sistla, O. Wolfson, Y. Huang, *Minimization of Communication Cost Through Caching in Mobile Environments*, IEEE Transactions on Parallel and Distributed Systems, 9(4), Apr. 1998, pp. 378-390.

[91] * J. Tayeb, O. Ulusoy, O. Wolfson, *A Quadtree Based Dynamic Attribute Indexing Method*, Computer Journal, Vol. 41(3).

[92] * P. Sistla, O. Wolfson, Y. Yesha, R. Sloan *Towards a Theory of Cost Management for Digital Libraries*, ACM Transactions on Database Systems (TODS), Vol. 23(3), Sept. 1998.

[93] * O. Wolfson, *Mobile Computing in a Reservation Application*, Proceedings of the 2nd International Conference on Information and Communications Technology in the Field of Tourism (ENTER'95), Springer Verlag, Innsbruck, Austria, Jan. 95.

[94] * P. Sistla, O. Wolfson, *Temporal Conditions and Integrity Constraints in Active Database Systems*, Proceedings of the ACM-SIGMOD 1995, International Conference on Management of Data, San Jose, CA, May 1995, pp. 269-280.

[95] * M. Deng, P. Sistla, O. Wolfson, *Temporal Conditions with Retroactive and Proactive Updates*, Proceedings of the International Workshop on Active and Real-Time Database Systems (ARTDB-95), M. Berndtsson and J. Hansson (Eds), Springer Workshops in Computing Series, Skovde, Sweden, June 1995, pp. 122-141.

[96] * P. Sistla, O. Wolfson, S. Dao, K. Narayanan, R. Raj, *An Architecture for Consumer-Oriented Online Database Services* Proceedings of the 6th International Workshop on Research Issues in Data Engineering: Interoperability of Nontraditional Database Systems (RIDE-NDS'96), New Orleans, LA, Feb. 1996, pp. 50-60.

[97] * O. Wolfson, S. Chamberlain, S. Dao, L. Jiang, *Location Management in Moving Objects Databases,* Proceedings of The Second International Workshop on Satellite-Based Information Services (WOSBIS'97), Budapest, Hungary, Oct. 97, pp. 7-14.

[98] * O. Wolfson, *Location Management for Moving Objects Databases,* invited paper, Proceedings of The First Intensive Workshop on Spatio-Temporal Database Systems, Austria, Nov. 97.

[99] * O. Wolfson, B. Xu, S. Chamberlain, L. Jiang, *Challenges and Approaches in Motion Databases*, Proceedings of the 14th International Conference on Advanced Science and Technology (ICAST98), Naperville, IL, Apr. 98, pp. 182-194.

[100] * O. Wolfson, S. Chamberlain, P. Sistla, B. Xu, J. Zhou, *DOMINO: Databases fOr MovINg Objects tracking*, the Proceedings of the ACM-SIGMOD 1999, International Conference on Management of Data, Philadelphia, PA, June 1999.

[101] * O. Wolfson, P. Sistla, B. Xu, J. Zhou, S. Chamberlain, N. Rishe,Y. Yesha, *Tracking Moving Objects Using Database Technology in DOMINO*, Springer-Verlag Lecture Notes in Computer Science, number 1649, Proceedings of NGITS'99, The Fourth Workshop on Next Generation Information Technologies and Systems, Zikhron-Yaakov, Israel, July 1999, pp. 112-119.

[102] * O. Wolfson, B. Xu, S. Chamberlain, *Location Prediction and Queries for Tracking Moving Objects*, in the Proceedings of the 16th International Conference on Data Engineering, San Diego, CA, Feb. 2000.

[103] * B. Xu, O. Wolfson, S. Chamberlain, *Cost based data dissemination in broadcast networks*, in the Proceedings of the 8th International Conference on Database Theory (ICDT), 2001.

[104] * G. Trajcevski, O. Wolfson, F. Zhang, S. Chamberlain, *The Geometry of Uncertainty in Moving Objects Databases* accepted to appear, International Conference on Extending Database Technology (EDBT), 2002.

[105] * O. Wolfson, P. Sistla, S. Dao, K. Narayanan, R. Raj, *View maintenance in Mobile Computing* (invited), SIGMOD RECORD, Association of Computing Machinery Press, Dec. 1995.

P. Sistla, O. Wolfson, S. Chamberlain, S. Dao,

[106] * O. Etzion, S. Jajodia, S. Sripada, eds., *Querying the Uncertain Position of Moving Objects*, (invited) Temporal Databases: Research and Practice Springer-Verlag, 1998.

[107] * Naphtali Rishe, Khaled Naboulsi, Ouri Wolfson, *Report Generators*, Wiley Encyclopedia of Electrical and Electronics Engineering, John Webster ed., Feb. 1999.

SUMMARY PROPOSAL BUDGET

YEAR 1

FOR NSF USE ONLY

ORGANIZATION	PROPOSAL NO.	DURATION (months) Proposed	Granted
University of Illinois at Chicago			
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR	AWARD NO.		
Ouri Wolfson			

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Ouri Wolfson - Professor					
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES					
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (1) GRADUATE STUDENTS					
4. (1) UNDERGRADUATE STUDENTS					
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (0) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) 3 Laptops at $2,000 each $ 6,000					
TOTAL EQUIPMENT				6,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				2,000	
2. FOREIGN				3,500	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 0					
2. TRAVEL 0					
3. SUBSISTENCE 0					
4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				700	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				700	
3. CONSULTANT SERVICES				20,000	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				6,520	
TOTAL OTHER DIRECT COSTS				27,920	
H. TOTAL DIRECT COSTS (A THROUGH G)				93,299	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				45,690	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				138,989	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 138,989	$

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $		
PI / PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY	
Ouri Wolfson		INDIRECT COST RATE VERIFICATION	
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked / Date Of Rate Sheet	Initials - ORG
Paula means			

SUMMARY PROPOSAL BUDGET

YEAR 2

ORGANIZATION **University of Illinois at Chicago**				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Ouri Wolfson**				AWARD NO.	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUM	Funds Requested By Proposer	Funds granted by NSF (if different)
1. **Ouri Wolfson - Professor**					
2.					
3.					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (**1**) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES					
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (**1**) GRADUATE STUDENTS					
4. (**1**) UNDERGRADUATE STUDENTS					
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (**0**) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **Hand held computers** $ **4,500**					
TOTAL EQUIPMENT				4,500	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				2,000	
2. FOREIGN				3,500	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
(**0**) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				700	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				700	
3. CONSULTANT SERVICES				20,000	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				6,796	
TOTAL OTHER DIRECT COSTS				28,196	
H. TOTAL DIRECT COSTS (A THROUGH G)				94,768	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				47,195	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				141,963	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 141,963	$
M. COST SHARING PROPOSED LEVEL $ **0**	AGREED LEVEL IF DIFFERENT $				
PI / PD TYPED NAME & SIGNATURE* **Ouri Wolfson**	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION			
ORG. REP. TYPED NAME & SIGNATURE* **Paula means**	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG	

SUMMARY PROPOSAL BUDGET — YEAR 3

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Illinois at Chicago

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Ouri Wolfson

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Ouri Wolfson - Professor					
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES					
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (1) GRADUATE STUDENTS					
4. (1) UNDERGRADUATE STUDENTS					
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (0) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				2,000	
2. FOREIGN				3,500	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				700	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				700	
3. CONSULTANT SERVICES				20,000	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				7,086	
TOTAL OTHER DIRECT COSTS				28,486	
H. TOTAL DIRECT COSTS (A THROUGH G)				93,387	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				48,775	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				142,162	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 142,162	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
Ouri Wolfson		INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG
Paula means				

NSF Form 1030 (10/98) Supersedes all previous editions

 *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG II.B)

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION **University of Illinois at Chicago**	FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Ouri Wolfson**	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SU	Funds Requested By Proposer	Funds granted by NSF (if different)
1. **Ouri Wolfson - Professor**					$
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES					
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (3) GRADUATE STUDENTS					
4. (3) UNDERGRADUATE STUDENTS					
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (0) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ 10,500					
TOTAL EQUIPMENT				10,500	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				6,000	
2. FOREIGN				10,500	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 0					
2. TRAVEL 0					
3. SUBSISTENCE 0					
4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				2,100	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,100	
3. CONSULTANT SERVICES				60,000	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				20,402	
TOTAL OTHER DIRECT COSTS				84,602	
H. TOTAL DIRECT COSTS (A THROUGH G)				281,454	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				141,660	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				423,114	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 423,114	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE* **Ouri Wolfson**	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE* **Paula means**	DATE	Date Checked / Date Of Rate Sheet / Initials - ORG

Budget Justification Page

Year 1

Equipment:

3 Laptops at $2,000 each=$6,000

*****G-6 Other:**

General Servcies=$1,000
Tuition Remission: RA salary ($16,000*34.5%)=$5,520

Total Other =$6,520

Indirect Cost:

Total Direct Cost $93,299-$6,000(equipment)-$5,520(tuition remission)*55.87%=%45,690

Total Year 1 =$138,989

Year 2

Equipment:

Hand held computers=$4,500
*****G-6 Other:**

General Servcies=$1,000
Tuition Remission: RA salary ($16,800*34.5%)=$5,796

Total Other =$6,796

Indirect Cost:

Total Direct Cost $94,768-$4,500(equipment)-$5,796(tuition remission)*55.87%=%47,195

Total Year 2=$141,963

Year 3

*****G-6 Other:**

General Servcies=$1,000
Tuition Remission: RA salary ($17,640*34.5%)=$6,086

Total Other =$7,086

Indirect Cost:

Total Direct Cost $93,387-$6,086(tuition remission)*55.87%=%48,775

Total Year 3 =$142,162

Cummulative:

Equipment:

3 Laptops at $2,000 each=$6,000
Hand held computers=$4,500

Total equipment=$10,500

*****G-6 Other:**

General Servcies=$3,000
Tuition Remission: RA salary ($50,440*34.5%)=$17,402

Total Other =$20,402

Indirect Cost:

Total Direct Cost $281,454-$10,500(equipment)-$17,402(tuition remission)*55.87%=%141,660

Total Project=$423,114

SUMMARY YEAR 1
PROPOSAL BUDGET

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Illinois at Chicago

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Ouri Wolfson

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Ouri Wolfson - Professor					
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES					
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (0) GRADUATE STUDENTS					
4. (0) UNDERGRADUATE STUDENTS					
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (0) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				1,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				152	
TOTAL OTHER DIRECT COSTS				152	
H. TOTAL DIRECT COSTS (A THROUGH G)				25,663	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				14,338	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				40,001	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 40,001	$

M. COST SHARING PROPOSED LEVEL $ 0 | AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
Ouri Wolfson		INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG
Paula means				

NSF Form 1030 (10/98) Supersedes all previous editions

1 *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)

Revised Proposal Budget Revision # 1 for 0209190 Submitted On Apr 30 2002 10:27AM Electronic Signature

SUMMARY PROPOSAL BUDGET

YEAR 2

ORGANIZATION University of Illinois at Chicago		FOR NSF USE ONLY		
		PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Ouri Wolfson		AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUM	Funds Requested By Proposer	Funds granted by NSF (if different)
1. Ouri Wolfson - Professor					
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES					
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (0) GRADUATE STUDENTS					
4. (0) UNDERGRADUATE STUDENTS					
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (0) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) 2 handheld computers @ $500 each $ 1,000					
TOTAL EQUIPMENT				1,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				1,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 0					
2. TRAVEL 0					
3. SUBSISTENCE 0					
4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				516	
TOTAL OTHER DIRECT COSTS				516	
H. TOTAL DIRECT COSTS (A THROUGH G)				29,228	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				15,771	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				44,999	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 44,999	$

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $			
PI / PD TYPED NAME & SIGNATURE* Ouri Wolfson	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE* Paula means	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG

NSF Form 1030 (10/98) Supersedes all previous editions

2 *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)

SUMMARY PROPOSAL BUDGET — YEAR 3

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Illinois at Chicago

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Ouri Wolfson

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Ouri Wolfson - Professor					
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES					
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (0) GRADUATE STUDENTS					
4. (0) UNDERGRADUATE STUDENTS					
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (0) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) 2 laptop computers at $2,000 each $ 4,000					
TOTAL EQUIPMENT				4,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				1,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 0					
2. TRAVEL 0					
3. SUBSISTENCE 0					
4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				465	
TOTAL OTHER DIRECT COSTS				465	
H. TOTAL DIRECT COSTS (A THROUGH G)				33,512	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				16,488	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				50,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 50,000	$

M. COST SHARING PROPOSED LEVEL $ 0 — AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
Ouri Wolfson		INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG
Paula means				

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION University of Illinois at Chicago	FOR NSF USE ONLY PROPOSAL NO. / DURATION (months): Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Ouri Wolfson	AWARD NO.

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SU	Funds Requested By Proposer	Funds granted by NSF (if different)
1. Ouri Wolfson - Professor					$
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES					
2. (3) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (0) GRADUATE STUDENTS					
4. (0) UNDERGRADUATE STUDENTS					
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (0) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ 5,000					
TOTAL EQUIPMENT				5,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				3,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				1,133	
TOTAL OTHER DIRECT COSTS				1,133	
H. TOTAL DIRECT COSTS (A THROUGH G)				88,403	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				46,597	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				135,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 135,000	$

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $	
PI / PD TYPED NAME & SIGNATURE* Ouri Wolfson	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE* Paula means	DATE	Date Checked / Date Of Rate Sheet / Initials - ORG

NSF Form 1030 (10/98) Supersedes all previous editions

C*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)

Budget Impact Statement

Year 1

Travel=$1,000

PI will attend one conference

Indirect Cost:

Total Direct Cost$25,663*55.87%=$14,338

Total Year 1=$40,001

Year 2

Equipment:

2 Handheld computers at $500 each

Total Equipment=$1,000

Travel=$1,000

PI will attend one conference

Indirect Cost:

Total Direct Cost$29,228-$1,000(equipment)*55.87%=15,771

Total Year 2=$44,999

Year 3

Budget Impact Statement

Equipment:

2 laptop computers at $2,000 each

Total Equipment=$4,000

Travel=$1,000

PI will attend one conference

Indirect Cost:

Total Direct Cost$33,512-$4,000(equipment)*55.87%=16,488

Cummulative

Equipment:
2 Handheld computers at $500 each
2 laptop computers at $2,000 each

Total Equipment=$5,000

Travel=$3,000

PI will attend one conference per year

Indirect Cost:

Total Direct Cost:$88,403-$5,000(equipment)*55.87%=46,597

Total Project=$135,000

SUMMARY PROPOSAL BUDGET

YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Illinois at Chicago

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Ouri Wolfson

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By Proposer	Funds granted by NSF (if different)
1. Ouri Wolfson - Professor					
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES					
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (0) GRADUATE STUDENTS					
4. (0) UNDERGRADUATE STUDENTS					
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (0) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				1,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 0					
2. TRAVEL 0					
3. SUBSISTENCE 0					
4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				152	
TOTAL OTHER DIRECT COSTS				152	
H. TOTAL DIRECT COSTS (A THROUGH G)				25,663	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				14,338	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				40,001	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 40,001	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
Ouri Wolfson		INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG
Paula means				

Revised Proposal Budget Revision # 2 for 0209190 Submitted On May 1 2002 11:37AM Electronic Signature

SUMMARY PROPOSAL BUDGET

YEAR 2

ORGANIZATION University of Illinois at Chicago	FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Ouri Wolfson	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUM	Funds Requested By Proposer	Funds granted by NSF (if different)
1. Ouri Wolfson - Professor					
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES					
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (0) GRADUATE STUDENTS					
4. (0) UNDERGRADUATE STUDENTS					
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (0) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					

D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) 2 handheld computers @ $500 each $ 1,000		
TOTAL EQUIPMENT	1,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)	1,000	
2. FOREIGN	0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0		
(0) TOTAL PARTICIPANT COSTS	0	
G. OTHER DIRECT COSTS		
1. MATERIALS AND SUPPLIES	0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION	0	
3. CONSULTANT SERVICES	0	
4. COMPUTER SERVICES	0	
5. SUBAWARDS	0	
6. OTHER	516	
TOTAL OTHER DIRECT COSTS	516	
H. TOTAL DIRECT COSTS (A THROUGH G)	29,228	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)		
TOTAL INDIRECT COSTS (F&A)	15,771	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	44,999	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)	0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)	$ 44,999	$

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $			
PI / PD TYPED NAME & SIGNATURE* Ouri Wolfson	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE* Paula means	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET

YEAR 3

FOR NSF USE ONLY

ORGANIZATION University of Illinois at Chicago	PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Ouri Wolfson	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SU	Funds Requested By proposer	Funds granted by NSF (if different)
1. Ouri Wolfson - Professor					$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES					
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (0) GRADUATE STUDENTS					
4. (0) UNDERGRADUATE STUDENTS					
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (0) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) 2 laptop computers at $2,000 each $ 4,000					
TOTAL EQUIPMENT				4,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				1,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				465	
TOTAL OTHER DIRECT COSTS				465	
H. TOTAL DIRECT COSTS (A THROUGH G)				33,512	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				16,488	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				50,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 50,000	$

M. COST SHARING PROPOSED LEVEL $ 0 | AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
Ouri Wolfson		INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG
Paula means				

SUMMARY PROPOSAL BUDGET

Cumulative

				FOR NSF USE ONLY	
ORGANIZATION **University of Illinois at Chicago**				PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Ouri Wolfson**				AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds	Funds granted by NSF (if different)
1. Ouri Wolfson - Professor					
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES					
2. (3) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (0) GRADUATE STUDENTS					
4. (0) UNDERGRADUATE STUDENTS					
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (0) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ 5,000					
TOTAL EQUIPMENT				5,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				3,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 0					
2. TRAVEL 0					
3. SUBSISTENCE 0					
4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				1,133	
TOTAL OTHER DIRECT COSTS				1,133	
H. TOTAL DIRECT COSTS (A THROUGH G)				88,403	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				46,597	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				135,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 135,000	$

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $		
PI / PD TYPED NAME & SIGNATURE* **Ouri Wolfson**	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION	
ORG. REP. TYPED NAME & SIGNATURE* **Paula means**	DATE	Date Checked / Date Of Rate Sheet	Initials - ORG

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)

Budget Impact Statement

Year 1

Travel=$1,000

PI will attend one conference

Indirect Cost:

Total Direct Cost $25,663*55.87%=$14,338

Total Year 1 =$40,001

Year 2

Equipment:

2 Handheld computers at $500 each

Total Equipment=$1,000

Travel=$1,000

PI will attend one conference

Indirect Cost:

Total Direct Cost $29,228-$1,000(equipment)*55.87%=$15,771

Total Year 2 =$44,999

Year 3

Budget Impact Statement

Equipment:

2 laptop computers at $2,000 each

Total Equipment=$4,000

Travel=$1,000

PI will attend one conference

Indirect Cost:

Total Direct Cost $33,512-$4,000(equipment)*55.87%=$16,488

Total Year 3 =$50,000

Cummulative:

Equipment:
2 handheld computers at $500 each
2 laptop computers at $2,000 each

Total Equipment=$5,000

Travel=$3,000

PI will attend one conference per year

Indirect Cost:

Total Direct Cost $88,403-$5,000(equipment)*55.87%=$46,597

Total Project: $135,000

RESEARCH PLAN:

Budget Impact Statement

**The research will address two problems.
First, data dissemination in static sensor networks;
second, data allocation, and query and update processing
in the MANET environment,
in which the database is distributed among a set moving objects.**

**We will devote the first year to the first research subject,
and the second and third year to the second one.
During the first year we will compare broadcast algorithms
in a static environment, and build the simulation testbed.
Building parts of the simulation testbed
will be offered as an optional project in the graduate course taught
by the PI.**

During the second year we will extend the simulation testbed and the analytical results of the first year to the mobile environment, with data handoff among moving objects. In the third year the simulation results will be validated in a real environment of handheld devices communicating using a mobile ad hoc network.

**The research will be conducted by the PI and Dr. Rishe from
Florida International University.
The interaction between the researchers will be via teleconferencing.
Based on past experience, we expect several
M.Sc. students that are funded by other sources to do
their thesis/project on the subject, and thus participate in the research.**

**Due to budget cuts, the experimental part of the project will be curtailed. In particular, we will not be able to validate our results using Chicago Transit Authority data.
We will also not be able to validate our results in the
Mobitrac Moving Objects Database system.**

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Ouri Wolfson**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Design of Dynamic Adaptable Network Architecture Using Intelligent Agents (2 PI)**

Source of Support: **NSF**
Total Award Amount: $ **194,020** Total Award Period Covered: **09/01/98 - 08/31/02**
Location of Project: **UIC**
Person-Months Per Year Committed to the Project. Cal:**0.00** Acad: **0.00** Sumr: **0.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Triggers and Queries in Distributed Software Systems**

Source of Support: **NSF**
Total Award Amount: $ **260,000** Total Award Period Covered: **08/01/98 - 07/31/02**
Location of Project: **UIC**
Person-Months Per Year Committed to the Project. Cal:**0.00** Acad: **0.00** Sumr: **0.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Dynamic Negotiation Agents in Mobile Computing**

Source of Support: **NSF**
Total Award Amount: $ **66,203** Total Award Period Covered: **09/01/00 - 08/31/03**
Location of Project: **UIC**
Person-Months Per Year Committed to the Project. Cal:**0.00** Acad: **0.00** Sumr: **0.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Data Replication in peer to peer broadcast networks**

Source of Support: **NSF**
Total Award Amount: $ **66,000** Total Award Period Covered: **10/01/00 - 09/30/02**
Location of Project: **UIC**
Person-Months Per Year Committed to the Project. Cal:**0.00** Acad: **0.00** Sumr: **0.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Dynamic Data Allocation in Distributed Systems**

Source of Support: **NSF**
Total Award Amount: $ **12,000** Total Award Period Covered: **02/15/99 - 01/30/02**
Location of Project: **UIC**
Person-Months Per Year Committed to the Project. Cal:**0.00** Acad: **0.00** Summ: **0.00**

---

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Ouri Wolfson**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **ITR/IM: Real - Time Capture, Management and REconstruction of Spatio - Temporal Events**

Source of Support: **NSF**
Total Award Amount: $ **649,837** Total Award Period Covered: **09/01/00 - 08/31/03**
Location of Project: **UIC**
Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.00**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: :
Location of Project: :
Person-Months Per Yea

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

H. Facilities, Equipment, and other Resources

The proposed research will be conducted in two co-located labs at UIC, i.e. the Databases and Mobile Computing Laboratory and the Database and Information Systems Laboratory. The resources in these labs include Sun Enterprise Servers, several Sun Ultra machines, and PCs. In addition, we have several mobile and hand held computers, which communicate using a subscription to one of the Palm.net wireless data.

NATIONAL SCIENCE FOUNDATION

PROPOSAL BUDGET

ORGANIZATION **University of Illinois at Chicago**				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Wolfson, Ouri**				AWARD NO. **0209190**		
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each seperately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUM	Funds Requeste propos	Funds granted	
1.				$		
2.						
3.						
4.						
5.						
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)						
7. (1) TOTAL SENIOR PERSONNEL (1-6)						
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. (0) POST DOCTORIAL ASSOCIATES						
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)						
3. (0) GRADUATE STUDENTS						
4. (0) UNDERGRADUATE STUDENTS						
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)						
6. (0) OTHER						
TOTAL SALARIES AND WAGES (A + B)						
C. FRINGE BENIFITS (IF CHARGED AS DIRECT COSTS)						
TOTAL SALARIES, WAGES AND FRINGE BENIFITS (A + B + C)						
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5000.) 1 $ 2 $ 3 $ Others: (see budget comment page ...) $ TOTAL EQUIPMENT						
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)						
2. FOREIGN						
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 2. TRAVEL 3. SUBSISTENCE 4. OTHER						
(0) TOTAL PARTICIPANT COSTS						
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES						
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION						
3. CONSULTANT SERVICES						
5. COMPUTER SERVICES						
5. SUBAWARDS						
6. OTHER						
TOTAL OTHER DIRECT COSTS						
H. TOTAL DIRECT COSTS (A THROUGH G)						
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)						
TOTAL INDIRECT COSTS (F&A)						
J. TOTAL DIRECT AND INDIRECT COSTS (A THROUGH G)						
K. RESIDUAL FUNDS (0 + 0)						
L. AMOUNT OF THIS REQUEST(J) OR (J MINUS K)				$		
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $					
PI/PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION				
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials - ORG		

NSF Form 1030 (10/99) Supersedes all previous editions

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)

From: Maria Zemankova
To: U of Illinois Chicago [awards@uic.edu]; Wolfson, Ouri
Cc: Michele R. Johnson; Maria Zemankova
Subject: NSF Approval of Continuing Grant Increment - Wolfson
Sent: 06/18/2004 01:00 PM

Notification of NSF Approval of Additional Funding Support

Award No. IIS - 0209190
Amendment No. 002
Release Date: 06/18/2004
Released By: Maria Zemankova
Amount: $50,000
New Expiration Date: 07/31/2005

As authorized by the original award, the National Science Foundation hereby releases $50,000 for additional support of the award referenced above. The award, with this amendment, now totals $147,000 and will expire on 07/31/2005.

The attached budget indicates the amounts, by categories, on which NSF has based its continued support.

The award is subject to the conditions available at http://www.nsf.gov/home/grants/grants_fdp.htm.

Any technical or programmatic questions regarding this notification should be addressed to the cognizant NSF Program Officer: Maria Zemankova, (703) 292-8918, mzemanko@nsf.gov.

Any award specific questions of an administrative or financial nature should be addressed to the grants official at http://www.nsf.gov/bfa/dga/liaison.htm. The cognizant grants official can be identified by associating the three-letter division identifier in the above-referenced award number with the grants official for that division on the liaison website.

NATIONAL SCIENCE FOUNDATION

PROPOSAL BUDGET

	FOR NSF USE ONLY		
ORGANIZATION **University of Illinois at Chicago**	PROPOSAL NO.	DURATION (months)	
		Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Wolfson, Ouri**	AWARD NO. **0209190**		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each seperately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUM	Funds Requested by proposer	Funds granted by NSF (if different)
1.				$	$
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (1) TOTAL SENIOR PERSONNEL (1-6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORIAL ASSOCIATES					
2. (2) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (0) GRADUATE STUDENTS					
4. (0) UNDERGRADUATE STUDENTS					
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (0) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENIFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENIFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5000.) 1 $ 2 $ 3 $ **Others: (see budget comment page ...)** $ TOTAL EQUIPMENT					
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)					
2. FOREIGN					
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 2. TRAVEL 3. SUBSISTENCE 4. OTHER					
(0) TOTAL PARTICIPANT COSTS					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES					
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION					
3. CONSULTANT SERVICES					
5. COMPUTER SERVICES					
5. SUBAWARDS					
6. OTHER					
TOTAL OTHER DIRECT COSTS					
H. TOTAL DIRECT COSTS (A THROUGH G)					
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)					
J. TOTAL DIRECT AND INDIRECT COSTS (A THROUGH G)					
K. RESIDUAL FUNDS (0 + 0)					
L. AMOUNT OF THIS REQUEST(J) OR (J MINUS K)				$	

M. COST SHARING PROPOSED LEVEL $ 0		AGREED LEVEL IF DIFFERENT $		
PI/PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
		INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials - ORG

NSF Form 1030 (10/99) Supersedes all previous editions

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)

NATIONAL SCIENCE FOUNDATION
Grant Letter

Award Date:	August 2, 2002
Award No.	IIS-0209190
Proposal No.	IIS-0209190

Ms. Paula M. Means
Director, Grants and Sponsored Programs
University of Illinois at Chicago
1737 W. Polk Street
Chicago, IL 60612

Dear Ms. Means:

The National Science Foundation hereby awards a grant of $85,000 to University of Illinois at Chicago for support of the project described in the proposal referenced above as modified by revised budget dated May 1, 2002.

This project, under the direction of Ouri Wolfson, is entitled:

"Geographic Management of Data Infrastructureless Environment."

This award is effective August 1 , 2002 and expires July 31, 2004.

This is a continuing grant which has been approved on scientific / technical merit for approximately 3 years. Contingent on the availability of funds and the scientific progress of the project, NSF expects to continue support at approximately the following level:

FY 2004	$50,000

This grant is awarded pursuant to the authority of the National Science Foundation Act of 1950, as amended (42 U.S.C. 1861-75) and is subject to NSF Grant General Conditions (GC-1), dated 07/02 .

The attached budget indicates the amounts, by categories, on which NSF has based its support.

The cognizant NSF program official for this grant is Bhavani Thuraisingham (703) 292-8930. The cognizant NSF grants official contact is Laura A. Buckley (703) 292-8212.

Sincerely,

Rochelle D. Ray
Grants Officer

CFDA No. 47.070
awards@uic.edu

IIS-0209190
000

SUMMARY PROPOSAL BUDGET

Person MOS	cal	acad	sumr	Funds granted By NSF
A. (1.00) Total Senior personnel				
B. Other Personnel				
1. (0.00) Post Doctoral associates				
2. (2.00) Other professionals				
3. (0.00) Graduate students				
4. (0.00) Secretarial-clerical				
5. (0.00) Undergraduate students				
6. (0.00) Other				
Total salaries and wages (A+B)				
C. Fringe benefits (if charged as direct cost)				
Total salaries wages and fringes (A+B+C)				
D. Total permanent equipment				$1,000
E. Travel				
1. Domestic				$2,000
2. Foreign				$0
F. Total participant support costs				$0
G. Other direct costs				
1. Materials and supplies				$0
2. Publication costs/page charges				$0
3. Consultant services				$0
4. Computer (ADPE) services				$0
5. Subcontracts				$0
6. Other				$668
Total other direct costs				$668
H. Total direct costs (A through G)				$54,891
I. Total indirect costs				$30,109
J. Total direct and indirect costs (H+I)				$85,000
K. Residual funds / Small business fee				
1. Residual funds (if for further support of current projects GPM 252 and 253)				$0
2. Small business fee				$0
L. Amount of this request (J) or (J-K1+K2)				$85,000
M. Cost sharing				$0

Annual Report for Period: 08/2002 - 08/2003
Principal Investigator: Wolfson, Ouri .
Organization: U of Illinois Chicago
Title:
Geographic Management of Data Infrastructureless Environment

Submitted on: 06/24/2003
Award ID: 0209190

Project Participants

Senior Personnel

Name: Wolfson, Ouri
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Name: Xu, Bo
Worked for more than 160 Hours: Yes
Contribution to Project:

Graduate Student

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities:

We have studied resource discovery in mobile ad-hoc networks where moving objects communicate with each other via multi-hop wireless transmission. We considered resources that are location specific and time sensitive, e.g. free parking spots, traffic condition within a certain area, etc. We explored two approaches to resource discovery. The first is opportunistic exchange, where two objects exchange their resources when they encounter each other. The second approach is on-demand query, where an object explicitly sends out a query to a specific area and waits for the answer.

We have studied performance issues in moving objects tracking by conducting experiments on real data, including a map of the Chicago metropolitan area, and GPS updates of a centralized database that stores location information. The updates were transmitted via the Palmnet network from moving vehicles.

We also researched the application of line-simplification (a technique used in computer graphics) on the size of typical trajectories. We researched the semantics of location updates in moving objects databases. We also researched the incorporation of traffic into moving objects databases, particularly the update of trajectories based on such reports.

We have evaluated exprimentally three time series prediction approaches in terms of their performance on real-time traffic prediction. These approaches are, neuro-fuzzy networks, moving averages, and exponential smoothing. The experiments use real travel speeds collected on an expressway of a major U.S. metropolitan area. We explored the application of traffic prediction to query processing in Moving Objects Databases.

On the education side, the PI taught graduate courses related to this project in Spring 2003. The courses dealt with databases and mobile computing, and the PI brought research related to this project into the class material.

Findings:

We created a mathematical model for describing resource propagation in opportunistic exchange. With this model, we found that the opportunistic exchange algorithm provides a balance between the availability of resources and the cost of spreading and storing them. This finding was verified by simulations.

For on-demand query, we developed routing algorithms for query dissemination and answer delivery. These algorithms use the mobility of nodes to aid in message delivery, and therefore allow routing even though the network is diconnected.

We developed a new location update policy for maintaining the current location of a large number of moving objects while minimizing the number of updates. The experimental results show that it is superior than traditional approaches. We also developed a method of generating realistic synthetic spatio-temporal information.

Our experiments with different metrics and tolerances show that line simplification is very efficient in reducing the size of trajectories, i.e. obtaining trajectory-approximations. We postulated the desiderata for distance-metrics that are used in trajectory-approximations. Some metrics are sound in the sense that they satisfy these desiderata, others are not. Interestingly, the Euclidean metric proves not to be sound in this sense. We introduced an aging mechanisms based on the line simplification technique. The mechanism gradually shrinks the size of trajectories as time progresses. We also considered the querying of simplified trajectories, and developed a set of operators with uncertainty quantifiers to address this problem.

Our experiments on traffic speed prediction indicates that exponential smoothing is better than neuro-fuzzy networks and moving averages, and neuro-fuzzy networks better than moving averages.

Training and Development:

The postdoc supported by this project has been exposed to research efforts in this area. He has become skillful on developing, testing and validating concepts, writing papers, and developing sophisticated geographic real-time software.

Outreach Activities:

The PI is serving as the Chief Scientist and a member of the Board of

Directors of Mobitrac, a company that commercializes some of the technology.

Journal Publications

P. Agarwal, L. Guibas, H. Edelsbrunner, Erickson, M. Isard, S. Har-Peled, J. Hershberger, C. Jensen, L. Kavraki, P. Koehl, M. Lin, D. Manocha, D. Metaxas, B. Mirtich, D. Mount, S. Muthukrishnan, D. Pai, E. Sacks, J. Snoeyink, S. Suri, O. Wolfson, "Algorithmic Issues in Modeling Motion", ACM Computing Surveys, p. 550, vol. 34, (2002). Published

G. Trajcevski, O. Wolfson, S. Chamberlain, "Managing Uncertainty in Moving Objects Databases", ACM Transactions of DAtabase Systems, p. , vol. , ( ). conference paper being revised

Books or Other One-time Publications

G. Trajcevski, O. Wolfson, B. Xu and P. Nelson, "Real-Time Traffic Updates in Moving Objects Databases", (2002). Conference proceedings, Published
Bibliography: Proc. of the 5th International Workshop on Mobility in Databases and Distributed Systems, Aix-en-Provence, France, Sept. 2-6, 2002

J. Dillenburg, O. Wolfson and P. Nelson, "The Intelligent Travel Assistant", (2002). Conference proceedings, Published
Bibliography: Proc. of the Intelligent Transportation Symposium, Singapore, Sept. 2002

O. Wolfson, S. Chamberlain, K. Kalpakis, Y. Yesha, "Modeling Moving Objects for Location Based Services", (2002). Book, Published
Editor(s): B. K÷nig-R ies, K. Makki, S.A.M. Makki, N. Pissinou, P. Scheuermann
Bibliography: invited, in Developing an Infrastructure for Mobile and Wireless Systems, Springer, Lecture Notes in Computer Science number 2538, 2002, pp. 46 -58.

Birgitta K÷nig-Ries, Kia Makki, S.A.M. Makki, Charles E. Perkins, Niki Pi ssinou, Peter Reiher, Peter Scheuermann, Jari Veijalainen, Alexander Wolf, and Ouri Wolfson, "Research Direction for Developing an Infrastructure for Mobile and Wireless Systems", (2002). Book, Published
Editor(s): B. K÷ni g-Ries, K. Makki, S.A.M. Makki, N. Pissinou, P. Scheuermann
Bibliography: in Developing an Infrastructure for Mobile and Wireless Systems, Springer, Lecture Notes in Computer Science number 2538, 2002, pp. 1-37.

O. Wolfson, H. Yin, "Accuracy and Resource Consumption in Tracking Moving Object", (2003). Book, Accepted
Bibliography: Springer Verlag Lecture Notes in Computer Science, the Proceedings of the 8th International Symposium on Spatial and Temporal Databases, Santorini Island, Greece, July, 2003.

Web/Internet Site

URL(s):
http://www.eecs.uic.edu/~wolfson/html/mobile.html
Description:

Other Specific Products

Product Type: Software (or netware)
Product Description:
Domino-- platform for the development of location based applications.
Sharing Information:
N/A

Product Type: Data or databases

Product Description:

Personal Trajectory Data - records the daily trajectory of a person since 5/30/03.

Sharing Information:

Will be published on the website.

Product Type: Software (or netware)

Product Description:

Software for generating synthetic trajectories that can be used in experiments.

Sharing Information:

Will be published through the web site.

Contributions

Contributions within Discipline:

We are building DOMINO, a platform for location based services and moving-objects applications.

Contributions to Other Disciplines:

Contributions to Human Resource Development:

A postdoctoral student, Dr. Bo Xu, is being trained in this area. We have also taught courses where materials from this research effort have been introduced.

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Unobligated funds: less than 20 percent of current funds

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Organizational Partners

Contributions: To Any Other Disciplines

Contributions: To Any Resources for Research and Education

Contributions: To Any Beyond Science and Engineering

Annual Report for Period: 08/2003 - 08/2004
Principal Investigator: Wolfson, Ouri .
Organization: U of Illinois Chicago
Title:
Geographic Management of Data Infrastructureless Environment

Submitted on: 06/18/2004
Award ID: 0209190

Project Participants

Senior Personnel

Name: Wolfson, Ouri
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Name: Xu, Bo
Worked for more than 160 Hours: Yes
Contribution to Project:

Graduate Student

Undergraduate Student

Technician, Programmer

Other Participant

Name: Rishe, Naphtali
Worked for more than 160 Hours: Yes
Contribution to Project:

Research Experience for Undergraduates

Organizational Partners

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities:

We have studied resource discovery in infrastructureless environments where moving objects communicate with each other via multi-hop wireless transmission. We considered resources that are location specific and time sensitive, e.g. free parking spots, traffic condition within a certain area, etc. We explored two approaches to resource discovery. The first is opportunistic exchange, where two objects exchange their resources when they encounter each other. The second approach is on-demand query, where an object explicitly sends out a query to a specific area and waits for the answer.

We studied incentive mechanisms that stimulate a moving objects to participate as suppliers of resource information and/or intermediaries for information propagation.

We analyzed by simulations the information accuracy provided by the opportunistic dissemination approach. We also developed a method to determine the optimal size of the local database at a moving object such that a certain accuracy level is reached.

We also researched the application of line-simplification (a technique used in computer graphics) on the size of typical trajectories. We researched the semantics of location updates in moving objects databases. We also researched the incorporation of traffic into moving objects databases, particularly the update of trajectories based on such reports.

We have evaluated experimentally three time series prediction approaches in terms of their performance on real-time traffic prediction. These approaches are, neuro-fuzzy networks, moving averages, and exponential smoothing. The experiments use real travel speeds collected on an expressway of a major U.S. metropolitan area. We explored the application of traffic prediction to query processing in Moving Objects Databases.

We studied how to match a GPS-generated trajectory to the roads on the map. This issue arises because the locations reported by a GPS is imprecise. We developed a weight-based map matching method to solve the problem.

On the education side, the PI taught graduate courses related to this project in Spring 2004. The courses dealt with databases and mobile computing, and the PI brought research related to this project into the class material.

Findings:
We created a mathematical model for describing resource propagation in opportunistic exchange. With this model, we found that the opportunistic exchange algorithm provides a balance between the availability of resources and the cost of spreading and storing them. This finding was verified by simulations.

We theoretically and experimentally quantified the benefit of information dissemination in mobile sensor networks, where the benefit is measured in terms of the amount of time saved in resource discovery. We also developed strategies for a consumer to use the received information, such that the time needed for discovering and capturing a resource is minimized. We found that with information the resource discovery time can be reduced by up to 75% than without information.

We identified the requirements generated by the characteristics of mobile sensor networks to an economic solution, we provided the solution that satisfies the requirements. The models are based circulation of virtual currency among mobile sensors. The incentive mechanism addresses the issues of who pays, who charges, and how much is paid or charged.

For on-demand query, we developed routing algorithms for query dissemination and answer delivery. These algorithms use the mobility of nodes to aid in message delivery, and therefore allow routing even though the network is disconnected.

We developed a new location update policy for maintaining the current location of a large number of moving objects while minimizing the number of updates. The experimental results show that it is superior than traditional approaches. We also developed a method of generating realistic synthetic spatio-temporal information.

Our experiments with different metrics and tolerances show that line simplification is very efficient in reducing the size of trajectories, i.e. obtaining trajectory-approximations. We postulated the desiderata for distance-metrics that are used in trajectory-approximations. Some metrics are sound in the sense that they satisfy these desiderata, others are not. Interestingly, the

Euclidean metric proves not to be sound in this sense. We introduced an aging mechanisms based on the line simplification technique. The mechanism gradually shrinks the size of trajectories as time progresses. We also considered the querying of simplified trajectories, and developed a set of operators with uncertainty quantifiers to address this problem.

Our experiments on traffic speed prediction indicates that exponential smoothing is better than neuro-fuzzy networks and moving averages, and neuro-fuzzy networks better than moving averages.

Our experiments on map matching show that, for the offline situation, on average, our weight-based map matching algorithm can get up to 94% correctness depending on the GPS sampling interval. Compared to the straightforward method which snaps a GPS point ot the closest road segment, our method improves correctness by tens of percentage points.

Training and Development:

The postdoc supported by this project has been exposed to research efforts in this area. He has become skillful on developing, testing and validating concepts, writing papers, and developing sophisticated geographic real-time software.

Outreach Activities:

The PI is serving as the Chief Scientist and a member of the Board of Directors of Mobitrac, a company that commercializes some of the technology.

Journal Publications

P. Agarwal, L. Guibas, H. Edelsbrunner, Erickson, M. Isard, S. Har-Peled, J. Hershberger, C. Jensen, L. Kavraki, P. Koehl, M. Lin, D. Manocha, D. Metaxas, B. Mirtich, D. Mount, S. Muthukrishnan, D. Pai, E. Sacks, J. Snoeyink, S. Suri, O. Wolfson, "Algorithmic Issues in Modeling Motion", ACM Computing Surveys, p. 550, vol. 34, (2002). Published

G. Trajcevski, O. Wolfson, K. Hinrichs, S. Chamberlain, "Managing Uncertainty in Moving Objects Databases", ACM Transactions on Database Systems, p. , vol. , ( ). Accepted, scheduled to appear in Sept. 2004.

T. Kian-Lee, O. Wolfson, "Mobile and Wireless Data Management (guest editors introduction)", Kluwer Academic Publishers, Mobile Networks and Applications (MONET), p. 315, vol. 8, (2003). Published

Books or Other One-time Publications

G. Trajcevski, O. Wolfson, B. Xu and P. Nelson, "Real-Time Traffic Updates in Moving Objects Databases", (2002). Conference proceedings, Published
Bibliography: Proc. of the 5th International Workshop on Mobility in Databases and Distributed Systems, Aix-en-Provence, France, Sept. 2-6, 2002

J. Dillenburg, O. Wolfson and P. Nelson, "The Intelligent Travel Assistant", (2002). Conference proceedings, Published
Bibliography: Proc. of the Intelligent Transportation Symposium, Singapore, Sept. 2002

O. Wolfson, S. Chamberlain, K. Kalpakis, Y. Yesha, "Modeling Moving Objects for Location Based Services", (2002). Book, Published
Editor(s): B. K÷nig-R ies, K. Makki, S.A.M. Makki, N. Pissinou, P. Scheuermann
Bibliography: invited, in Developing an Infrastructure for Mobile and Wireless Systems, Springer, Lecture Notes in Computer Science number 2538, 2002, pp. 46 -58.

Birgitta K÷nig-Ries, Kia Makki, S.A.M. Makki, Charles E. Perkins, Niki Pi ssinou, Peter Reiher, Peter Scheuermann, Jari Veijalainen, Alexander Wolf, and Ouri Wolfson, "Research Direction for Developing an Infrastructure for Mobile and Wireless Systems", (2002). Book, Published
Editor(s): B. K÷ni g-Ries, K. Makki, S.A.M. Makki, N. Pissinou, P. Scheuermann
Bibliography: in Developing an Infrastructure for Mobile and Wireless Systems, Springer, Lecture Notes in Computer Science number 2538, 2002, pp. 1-37.

O. Wolfson, H. Yin, "Accuracy and Resource Consumption in Tracking Moving Object", (2003). Book, Accepted
Bibliography: Springer Verlag Lecture Notes in Computer Science, the Proceedings of the 8th International Symposium on Spatial and Temporal Databases, Santorini Island, Greece, July, 2003.

H. Cao, O. Wolfson, G. Trajcevski, "Spatio-temporal Data Reduction with Deterministic Error Bounds", (2003). conference proceedings, Published
Bibliography: Proc. of the ACM DIALM-POMC Joint Workshop on Foundations of Mobile Computing, San Diego CA, Sept. 2003, pp. 33-42

B. Xu, O. Wolfson, "Time-Series Prediction with Applications to Traffic and Moving Objects Databases", (2003). conference proceedings, Published
Bibliography: Proc. of the MobiDE'03, 3rd ACM International Workshop on Data Engineering for Wireless and Mobile Access, San Diego CA, Sept. 2003, pp. 56-60

O. Wolfson, A. Ouksel, B. Xu, "Resource Discovery in Disconnected Mobile Ad-Hoc Networks", (2003). Book, conference proceedings
Bibliography: Proc. of the international Workshop on Next Generation Geospatial Information, Cambridge, MA, Oct. 2003.

B. Xu, A. Ouksel, O. Wolfson, "Opportunistic Resource Exchange in Inter-vehicle Ad Hoc Networks", (2004). conference proceedings, Published
Bibliography: Proc. of the Fifth IEEE International Conference on Mobile Data Management, Berkeley, CA, Jan. 2004, pp. 4-12

O. Wolfson, B. Xu, "Data-on-the-Road in Intelligent Transportaion Systems", (2004). conference proceedings, Published
Bibliography: Proc. of the IEEE International Conference on Networking, Sensing, and Control (ICNSC 2004), Taipei, Taiwan, Mar. 2004.

J. Dillenbrug, P. Nelson, O. Wolfson, O. Yu, P. Sistla, S. McNeil, A. Ouksel, B. Xu, J. Ben-arie, "Applications of a Transportation Information Architecture", (2004). conference proceedings, Published
Bibliography: Proc. of the IEEE International conference on networking, Sensing, and Control (ICNSC 2004), Taipei, Taiwan, Mar. 2004.

G. Trajcevski, P. Scheuermann, O. Wolfson, N. Nedungadi, "CAT: Correct Answers of Continuous Queries Using Triggers, (demonstration paper)", (2004). conference proceedings, Published
Bibliography: Proceeding of the International Conference on Extending Database Technology (EDBT04), Heraklion, Greece, March 2004, pp. 837-840.

O. Wolfson, B. Xu, P. Sistla, "An Economic Model for Resource Exchange in Mobile Peer-to-Peer Networks", (2004). conference proceedings, Accepted
Bibliography: Proceedings of the 16th International Conference on Scientific and Statistical Database Management (SSDBM'04), Santorini Island, Greece, June 2004.

H. Yin, O. Wolfson, "A Weight-Based Map Matching Method in Moving Objects Databases (Poster paper)", (2004). conference proceedings, Accepted
Bibliography: Proceedings of the 16th International Conference on Scientific and Statistical Database Management (SSDBM'04), Santorini Island, Greece, June 2004.

O. Wolfson, B. Xu, "Opportunistic Dissemination of Spatio-Temproal Resource Information in Mobile Peer-to-Peer Networks", (2004). conference proceedings, Accepted
Bibliography: 1st International Workshop on P2P Data Management, Security and Trust (PDMST'04), Zaragoza, Spain, Sept. 2004.

O. Wolfson, E. Mena, "Applications of Moving Objects Databases", (2004). Book, Accepted
Bibliography: Spatial Databases: Technologies, Techniques and Trends, M. Vassilakopoulos, A. Papadopoulos and Y. Manolopoulos(eds.), Idea group Co., (in press) the Idea Group Inc.

Web/Internet Site

URL(s):

http://www.cs.uic.edu/~wolfson/html/p2p.html
Description:

Other Specific Products

Product Type: Software (or netware)
Product Description:
Domino-- platform for the development of location based applications.
Sharing Information:
N/A

Product Type: Data or databases
Product Description:
Personal Trajectory Data - records the daily trajectory of a person since 5/30/03.
Sharing Information:
Will be published on the website.

Product Type: Software (or netware)
Product Description:
Software for generating synthetic trajectories that can be used in experiments.
Sharing Information:
Will be published through the web site.

Product Type: Intellectual Property Disclosure
Product Description:
Intellectual Property Disclosure: Opportunistic Resource Dissemination in Mobile Peer-to-Peer Networks, disclosure number CX056 (Ouri Wolfson, Bo Xu, Prasad Sistla, Aris Ouksel).
Sharing Information:
Intellectual Property Disclosure

Product Type: Provisional Patent
Product Description:
O. Wolfson, B. Xu, A. Ouksel, P. Sistla, Opportunistic Resource Dissemination in Mobile Peer-to-Peer Networks, provisional patent filed 1/04
Sharing Information:
Provisional Patent

Product Type: Software (or netware)
Product Description:
Simulation system for mobile sensor networks

Sharing Information:
Will be published through the web site

Contributions

Contributions within Discipline:
We are building DOMINO, a platform for location based services and moving-objects applications.

Dr. Ouri Wolfson the PI was invited to give a Key-note speech

on 'Data-on-the-Road in Intelligent Transportation Systems'
in the 2004 IEEE International Conference on Networking, Sensing, and
Control (ICNSC 2004), Taipei, Taiwan, March 23, 2004.

Our paper 'Opportunistic Resource Exchange in Inter-vehicle Ad Hoc Networks' won the Best Paper award for the paper in
Fifth IEEE International Conference on Mobile Data
Management, Berkeley, CA, Jan. 2004,

Contributions to Other Disciplines:

Contributions to Human Resource Development:
A postdoctoral student, Dr. Bo Xu, is being trained in this area. We have also taught courses where materials from this research effort have been introduced.

Contributions to Resources for Research and Education:
We implemented a software system that simulates the dissemination of
context and resource information in mobile sensor networks. The system is able to generate various test scenarios that differ in the number of resources in the system, the traffic density and speed, and other parameters that dictate the amount of storage, processing power, and bandwidth that should be allocated to each disseminated data item.

Contributions Beyond Science and Engineering:

Special Requirements

Special reporting requirements: None
Change in Objectives or Scope: None
Unobligated funds: less than 20 percent of current funds
Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Organizational Partners
Contributions: To Any Other Disciplines
Contributions: To Any Beyond Science and Engineering

Annual Report for Period: 08/2004 - 08/2005
Principal Investigator: Wolfson, Ouri .
Organization: U of Illinois Chicago
Title:
Geographic Management of Data Infrastructureless Environment

Submitted on: 07/25/2005
Award ID: 0209190

Project Participants

Senior Personnel

Name: Wolfson, Ouri
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Name: Xu, Bo
Worked for more than 160 Hours: Yes
Contribution to Project:

Graduate Student

Undergraduate Student

Technician, Programmer

Other Participant

Name: Rishe, Naphtali
Worked for more than 160 Hours: Yes
Contribution to Project:

Research Experience for Undergraduates

Organizational Partners

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities:

We have studied resource discovery in infrastructureless environments where moving objects communicate with each other via multi-hop wireless transmission. We considered resources that are location specific and time sensitive, e.g. free parking spots, traffic condition within a certain area, etc. We explored two approaches to resource discovery. The first is opportunistic exchange, where two objects exchange their resources when they encounter each other. The second approach is on-demand query, where an object explicitly sends out a query to a specific area and waits for the answer.

We studied incentive mechanisms that stimulate a moving objects to participate as suppliers of resource information and/or intermediaries for information propagation.

We analyzed by simulations the information accuracy provided by the opportunistic dissemination approach. We also developed a method to determine the optimal size of the local database at a moving object such that a certain accuracy level is reached.

We explored a peer-to-peer broadcast approach to resource discovery in infrastructureless environments, in which each moving object periodically selects the k most relevant resource reports and queries in its local database and broadcasts them to its neighbors. By disseminating both queries and resource reports, our approach is a hybrid between push and pull. We studied strategies that are used by moving objects to determine when to broadcast and what to broadcast so as to maximize the number of answers delivered to information consumers given the bandwidth constraint. We evaluated the approach by comparing it with existing resource discovery and publish/subscribe methods.

We also researched the application of line-simplification (a technique used in computer graphics) on the size of typical trajectories. For the transportation environment, we proposed an alternative representation of motion, called nonmaterialized trajectory, which takes advantage of the a priori knowledge that the motion occurs on a transport network. We researched the semantics of location updates in moving objects databases. We also researched the incorporation of traffic into moving objects databases, particularly the update of trajectories based on such reports.

We have evaluated experimentally three time series prediction approaches in terms of their performance on real-time traffic prediction. These approaches are, neuro-fuzzy networks, moving averages, and exponential smoothing. The experiments use real travel speeds collected on an expressway of a major U.S. metropolitan area. We explored the application of traffic prediction to query processing in Moving Objects Databases.

We studied how to match a GPS-generated trajectory to the roads on the map. This issue arises because the locations reported by a GPS is imprecise. We developed a weight-based map matching method to solve the problem.

On the education side, the PI taught graduate courses related to this project in Spring 2004 and Spring 2005. The courses dealt with databases and mobile computing, and the PI brought research related to this project into the class material.

Findings:

We created a mathematical model for describing resource propagation in opportunistic exchange. With this model, we found that the opportunistic exchange algorithm provides a balance between the availability of resources and the cost of spreading and storing them. This finding was verified by simulations.

We theoretically and experimentally quantified the benefit of information dissemination in mobile sensor networks, where the benefit is measured in terms of the amount of time saved in resource discovery. We evaluated for both the pair-wise exchange paradigm and the local broadcast paradigm. We also developed strategies for a consumer to use the received information, such that the time needed for discovering and capturing a resource is minimized. We found that with information the resource discovery time can be reduced by up to 75% than without information.

We identified the requirements generated by the characteristics of mobile sensor networks to an economic solution, we provided the solution that satisfies the requirements. The models are based circulation of virtual currency among mobile sensors. The incentive mechanism addresses the issues of who pays, who charges, and how much is paid or charged.

For on-demand query, we developed routing algorithms for query dissemination and answer delivery. These algorithms use the mobility of nodes to aid in message delivery, and therefore allow routing even though the network is disconnected.

We optimized the parameters used by the peer-to-peer broadcast algorithm such as the ratio between the queries space and the reports space in broadcast messages. We conducted experiments and determined that disseminating queries in addition to resource reports is indeed beneficial. We experimentally compared peer-to-peer broadcast with periodic flooding and PSTree, a publish/subscribe algorithm. We compared the algorithms in terms of how many reports (or how much total relevance) are delivered to each information consumer. We compared the three algorithms in high mobility (simulating a vehicular application) and low mobility (simulating a pedestrian application); for different resource types, including both spatio-temporal and non-spatio-temporal resources; and for different wireless technologies including 802.11 and Bluetooth. The experimental results show that in most cases peer-to-peer broadcast performs far better than periodic-flooding and PSTree. In many cases peer-to-peer broadcast outperforms the other two by two orders of magnitude.

We developed a new location update policy for maintaining the current location of a large number of moving objects while minimizing the number of updates. The experimental results show that it is superior than traditional approaches. We also developed a method of generating realistic synthetic spatio-temporal information.

Our experiments with different metrics and tolerances show that line simplification is very efficient in reducing the size of trajectories, i.e. obtaining trajectory-approximations. We postulated the desiderata for distance-metrics that are used in trajectory-approximations. Some metrics are sound in the sense that they satisfy these desiderata, others are not. Interestingly, the Euclidean metric proves not to be sound in this sense. We introduced an aging mechanisms based on the line simplification technique. The mechanism gradually shrinks the size of trajectories as time progresses. We also considered the querying of simplified trajectories, and developed a set of operators with uncertainty quantifiers to address this problem.

Our experiments on traffic speed prediction indicates that exponential smoothing is better than neuro-fuzzy networks and moving averages, and neuro-fuzzy networks better than moving averages.

Our experiments on map matching show that, for the offline situation, on average, our weight-based map matching algorithm can get up to 94% correctness depending on the GPS sampling interval. Compared to the straightforward method which snaps a GPS point ot the closest road segment, our method improves correctness by tens of percentage points.

Training and Development:

The postdoc supported by this project has been exposed to research efforts in this area. He has become skillful on developing, testing and validating concepts, writing papers, and developing sophisticated geographic real-time software.

Outreach Activities:

The PI is serving as the Chief Scientist and a member of the Board of Directors of Mobitrac, a company that commercializes some of the technology.

Journal Publications

P. Agarwal, L. Guibas, H. Edelsbrunner, Erickson, M. Isard, S. Har-Peled, J. Hershberger, C. Jensen, L. Kavraki, P. Koehl, M. Lin, D. Manocha, D. Metaxas, B. Mirtich, D. Mount, S. Muthukrishnan, D. Pai, E. Sacks, J. Snoeyink, S. Suri, O. Wolfson, "Algorithmic Issues in Modeling Motion", ACM Computing Surveys, p. 550, vol. 34, (2002). Published

G. Trajcevski, O. Wolfson, K. Hinrichs, S. Chamberlain, "Managing Uncertainty in Moving Objects Databases", ACM Transactions on Database Systems, p. 463, vol. 29, (2004). Published

T. Kian-Lee, O. Wolfson, "Mobile and Wireless Data Management (guest editors introduction)", Kluwer Academic Publishers, Mobile Networks and Applications (MONET), p. 315, vol. 8, (2003). Published

H. Cao, O. Wolfson, G. Trajcevski, "Spatio-Temporal Data Reduction with Deterministic Error Bounds", The VLDB Journal, p. , vol. , ( ). Accepted

Books or Other One-time Publications

G. Trajcevski, O. Wolfson, B. Xu and P. Nelson, "Real-Time Traffic Updates in Moving Objects Databases", (2002). Conference proceedings, Published
Bibliography: Proc. of the 5th International Workshop on Mobility in Databases and Distributed Systems, Aix-en-Provence, France, Sept. 2-6, 2002

J. Dillenburg, O. Wolfson and P. Nelson, "The Intelligent Travel Assistant", (2002). Conference proceedings, Published
Bibliography: Proc. of the Intelligent Transportation Symposium, Singapore, Sept. 2002

O. Wolfson, S. Chamberlain, K. Kalpakis, Y. Yesha, "Modeling Moving Objects for Location Based Services", (2002). Book, Published
Editor(s): B. K÷nig-R ies, K. Makki, S.A.M. Makki, N. Pissinou, P. Scheuermann
Bibliography: invited, in Developing an Infrastructure for Mobile and Wireless Systems, Springer, Lecture Notes in Computer Science number 2538, 2002, pp. 46 -58.

Birgitta K÷nig-Ries, Kia Makki, S.A.M. Makki, Charles E. Perkins, Niki Pi ssinou, Peter Reiher, Peter Scheuermann, Jari Veijalainen, Alexander Wolf, and Ouri Wolfson, "Research Direction for Developing an Infrastructure for Mobile and Wireless Systems", (2002). Book, Published
Editor(s): B. K÷ni g-Ries, K. Makki, S.A.M. Makki, N. Pissinou, P. Scheuermann
Bibliography: in Developing an Infrastructure for Mobile and Wireless Systems, Springer, Lecture Notes in Computer Science number 2538, 2002, pp. 1-37.

O. Wolfson, H. Yin, "Accuracy and Resource Consumption in Tracking Moving Object", (2003). Book, Accepted
Bibliography: Springer Verlag Lecture Notes in Computer Science, the Proceedings of the 8th International Symposium on Spatial and Temporal Databases, Santorini Island, Greece, July, 2003.

H. Cao, O. Wolfson, G. Trajcevski, "Spatio-temporal Data Reduction with Deterministic Error Bounds", (2003). conference proceedings, Published
Bibliography: Proc. of the ACM DIALM-POMC Joint Workshop on Foundations of Mobile Computing, San Diego CA, Sept. 2003, pp. 33-42

B. Xu, O. Wolfson, "Time-Series Prediction with Applications to Traffic and Moving Objects Databases", (2003). conference proceedings, Published
Bibliography: Proc. of the MobiDE'03, 3rd ACM International Workshop on Data Engineering for Wireless and Mobile Access, San Diego CA, Sept. 2003, pp. 56-60

O. Wolfson, A. Ouksel, B. Xu, "Resource Discovery in Disconnected Mobile Ad-Hoc Networks", (2003). Book, conference proceedings
Bibliography: Proc. of the international Workshop on Next Generation Geospatial Information, Cambridge, MA, Oct. 2003.

B. Xu, A. Ouksel, O. Wolfson, "Opportunistic Resource Exchange in Inter-vehicle Ad Hoc Networks", (2004). conference proceedings, Published
Bibliography: Proc. of the Fifth IEEE International Conference on Mobile Data Management, Berkeley, CA, Jan. 2004, pp. 4-12

O. Wolfson, B. Xu, "Data-on-the-Road in Intelligent Transportaion Systems", (2004). conference proceedings, Published
Bibliography: Proc. of the IEEE International Conference on Networking, Sensing, and Control (ICNSC 2004), Taipei, Taiwan, Mar. 2004.

J. Dillenbrug, P. Nelson, O. Wolfson, O. Yu, P. Sistla, S. McNeil, A. Ouksel, B. Xu, J. Ben-arie, "Applications of a Transportation Information

Architecture", (2004). conference proceedings, Published
Bibliography: Proc. of the IEEE International conference on networking, Sensing, and Control (ICNSC 2004), Taipei, Taiwan, Mar. 2004.

G. Trajcevski, P. Scheuermann, O. Wolfson, N. Nedungadi, "CAT: Correct Answers of Continuous Queries Using Triggers, (demonstration paper)", (2004). conference proceedings, Published
Bibliography: Proceeding of the International Conference on Extending Database Technology (EDBT04), Heraklion, Greece, March 2004, pp. 837-840.

O. Wolfson, B. Xu, P. Sistla, "An Economic Model for Resource Exchange in Mobile Peer-to-Peer Networks", (2004). conference proceedings, Published
Bibliography: Proceedings of the 16th International Conference on Scientific and Statistical Database Management (SSDBM'04), Santorini Island, Greece, June 2004, pp. 235-244.

H. Yin, O. Wolfson, "A Weight-Based Map Matching Method in Moving Objects Databases (Poster paper)", (2004). conference proceedings, Published
Bibliography: Proceedings of the 16th International Conference on Scientific and Statistical Database Management (SSDBM'04), Santorini Island, Greece, June 2004, pp. 437-438

O. Wolfson, B. Xu, "Opportunistic Dissemination of Spatio-Temproal Resource Information in Mobile Peer-to-Peer Networks", (2004). conference proceedings, Published
Bibliography: 1st International Workshop on P2P Data Management, Security and Trust (PDMST'04), Zaragoza, Spain, Sept. 2004, pp. 954-958.

O. Wolfson, E. Mena, "Applications of Moving Objects Databases", (2005). Book chapter, Published
Bibliography: Spatial Databases: Technologies, Techniques and Trends, M. Vassilakopoulos, A. Papadopoulos and Y. Manolopoulos(eds.), Idea group Co., (in press) the Idea Group Inc.

O. Wolfson, B. Xu, H. Yin, "Dissemination of Spatial-Temporal Information in Mobile Networks with Hotspots", (2004). conference proceedings, Published
Collection: Springer Verlag Lecture Notes in Computer Science vol. 3367
Bibliography: Proc. of the 2nd International Workshop on Databases, Information Systems, and Peer-to-Peer Computing (DBISP2P'04), Toronto, Canada, Aug. 2004, pp. 185-199.

B. Xu, O. Wolfson, "Data Management in Mobile Peer-to-Peer Networks", (2004). conference proceedings, Published
Collection: Springer Verlag Lecture Notes in Computer Science, Vol. 3367
Bibliography: Proc. of the 2nd International Workshop on Databases, Information Systems, and Peer-to-Peer Computing (DBISP2P'04),} Toronto, Canada, Aug. 2004 pp. 1-15.

H. Cao, O. Wolfson, "Nonmaterialized Motion Information in Transport Networks", (2005). conference proceedings, Published
Bibliography: Proc. of the 10th International Conference on Database Theory (ICDT'05), Edinburgh, UK, Jan. 2005, pp. 173-188.

P. Sistla, O. Wolfson, B. Xu, "Opportunistic Data Dissemination in Mobile Peer-to-Peer Networks", (2005). conference proceedings, Accepted
Bibliography: Accepted, to appear in the Proceedings of the 8th International Symposium on Spatial and Temporal Databases, Angra dos Reis, Brazil, August 2005.

O. Wolfson, B. Xu, H. Yin, "Reducing Resource Discovery Time by Spatio-temporal Information in Vehicular Ad-Hoc Networks (Poster)", (2005). conference proceedings, Accepted
Bibliography: Proceedings of the Second ACM International Workshop on
Vehicular Ad Hoc Networks (VANET), Cologne, Germany, Sept. 2005.

B. Xu and O. Wolfson, "Privacy solutions by mobile peer-to-peer communication", (2004). online proceedings, Published
Bibliography: In Center for Intellectual Property Law and Info. Tech., (CIPLIT) Symposium, Chicago, Illinois, October 2004.

Naphtali Rishe, Malek Adjouadi, Maxim Chekmasov, Dmitry Vasilevsky, Scott Graham, Dayanara Hernandez, Ouri Wolfson, "XML-Based

Semantic Database Definition Language
", (2005). conference proceedings, Published
Bibliography: Proceedings of the Seventh International Conference on Enterprise Information Systems, Miami, USA, May 25-28, 2005, pp. 197-202.

Naphtali Rishe, Armando Barreto, Maxim Chekmasov, Dmitry Vasilevsky, Scott Graham, Sonal Sood, Ouri Wolfson, "Object ID Distribution and Encoding in the Semantic Binary Engine", (2005). conference proceedings, Published
Bibliography: Proceedings of the Seventh International Conference on Enterprise Information Systems, Miami, USA, May 25-28, 2005, pp. 279-284

Naphtali Rishe, Armando Barreto, Maxim Chekmasov, Dmitry Vasilevsky, Scott Graham, Sonal Sood, Ouri Wolfson, "Semantic Database Engine Design", (2005). conference proceedings, Published
Bibliography: Proceedings of the Seventh International Conference on Enterprise Information Systems, Miami, USA, May 25-28, 2005, pp. 433-436

Naphtali Rishe, Malek Adjouadi, Maxim Chekmasov, Dmitry Vasilevsky, Scott Graham, Dayanara Hernandez, Ouri Wolfson, "Storage Types in the Semantic Binary Database Engine", (2005). conference proceedings, Published
Bibliography: Proceedings of the Seventh International Conference on Enterprise Information Systems, Miami, USA, May 25-28, 2005, pp. 437-440

Web/Internet Site

URL(s):
http://www.cs.uic.edu/~wolfson/html/p2p.html
Description:

Other Specific Products

Product Type:
Software (or netware)
Product Description:
. Domino -- platform for the development of location based applications.

. Software for generating synthetic trajectories that can be used in experiments.

. Simulation system for mobile sensor networks.

. Prototype system for mobile peer-to-peer query and data dissemination
Sharing Information:
All the above softwares/netwares will be published through the web site.

Product Type:
Data or databases
Product Description:
Personal Trajectory Data - records the daily trajectory of a person since 5/30/03.
Sharing Information:
Will be published on the website.

Product Type:
Invention Disclosure

Product Description:

Invention Disclosure: Opportunistic Resource Dissemination in Mobile Peer-to-Peer Networks, disclosure number CX056 (Ouri Wolfson, Bo Xu, Prasad Sistla, Aris Ouksel).

Sharing Information:

Invention Disclosure

Product Type:

Provisional Patent

Product Description:

O. Wolfson, B. Xu, A. Ouksel, P. Sistla, Opportunistic Resource Dissemination in Mobile Peer-to-Peer Networks, provisional patent filed 1/04

Sharing Information:

Provisional Patent

Product Type:

Patent

Product Description:

O. wolfson, Method and System for Tracking Moving Objects, US patent number 6,801,850 awarded Oct. 2004.

Sharing Information:

The description of the patent is available online at http://www.uspto.gov/

Contributions

Contributions within Discipline:

We are building DOMINO, a platform for location based services and moving-objects applications.

Dr. Ouri Wolfson the PI was invited to give a Key-note speech on 'Data-on-the-Road in Intelligent Transportation Systems' in the 2004 IEEE International Conference on Networking, Sensing, and Control (ICNSC 2004), Taipei, Taiwan, March 23, 2004.

Dr. Ouri Wolfson was invited to give a Key-note speech on 'Data Management in Mobile Peer-to-Peer Networks' in the 2nd International Workshop on Databases, Information Systems, and Peer-to-Peer Computing (DBISP2P'04), Toronto, Canada, August 29, 2004.

Our paper 'Opportunistic Resource Exchange in Inter-vehicle Ad Hoc Networks' won the Best Paper award for the paper in Fifth IEEE International Conference on Mobile Data Management, Berkeley, CA, Jan. 2004,

Wolfson served as Program Committee co-Chairman in the 6th ACM International Conference on Mobile Data Management, Cyprus, May 2005, and in the Second ACM International Workshop on Mobile Commerce, Atlanta, GA, Sept. 2002.

Wolfson will server as Program Committee vice-Chairman, The 22nd International Conference on Data Engineering, Atlanta, GA, Apr. 2006.

Wolfson served as a program committee member in DASAA'04, ICSS'04, CCNC'04, SAC'04, MDM'04, ICDCS'04, ICDE'04, IADIS'04, PIM'04, DBISP2P'04, ICDE'05, ICDCS'05, CCNC'05, HICSS'05, VLDB'05, MOBIDE'05, MDDS'05, NetDB'05, SIGMOD'05, SSTD'05, ACM-GIS'05, DBISP2P'05, W2GIS'05.

Contributions to Other Disciplines:

Contributions to Human Resource Development:

A postdoctoral student, Dr. Bo Xu, is being trained in this area. We have also taught courses where materials from this research effort have been introduced.

Contributions to Resources for Research and Education:

We implemented a software system that simulates the dissemination of
context and resource information in mobile sensor networks. The system is able to generate various test scenarios that differ in the number of resources in the system, the traffic density and speed, and other parameters that dictate the amount of storage, processing power, and bandwidth that should be allocated to each disseminated data item.

We have implemented the communication layer on the Pocket PC PDA platform, which allows mobile PDA's to conduct 802.11 peer-to-peer communication without any base station. We also have a demonstration that includes two transportation applications, and matchmaking at a convention.

Contributions Beyond Science and Engineering:

Special Requirements

Special reporting requirements:

During the extension period we will *extend our*
simulation testbed with a wireless network simulator which may be a research prototype such as ns2 or a commercial product such as Qualnet) and with real traffic data. Then we will run experiments to fine-tune our moving objects peer-to-peer dissemination algorithm. Parameters to fine-tune include the rank-penalty for each resource report broadcasted.

We expect to complete this within the next 3-6 months.
The reason for the delay is that it took longer than anticipated to obtain realistic traffic information for the experiments.

Change in Objectives or Scope: None

Unobligated funds: less than 20 percent of current funds

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Organizational Partners

Contributions: To Any Other Disciplines

Contributions: To Any Beyond Science and Engineering

From: Maria Zemankova
To: U of Illinois Chicago [awards@uic.edu]; Wolfson, Ouri
Cc: Michele R. Johnson; Maria Zemankova
Subject: NSF Approval of Continuing Grant Increment - Wolfson
Sent: 06/18/2004 01:00 PM

Notification of NSF Approval of Additional Funding Support

Award No. IIS - 0209190
Amendment No. 002
Release Date: 06/18/2004
Released By: Maria Zemankova
Amount: $50,000
New Expiration Date: 07/31/2005

As authorized by the original award, the National Science Foundation hereby releases $50,000 for additional support of the award referenced above. The award, with this amendment, now totals $147,000 and will expire on 07/31/2005.

The attached budget indicates the amounts, by categories, on which NSF has based its continued support.

The award is subject to the conditions available at http://www.nsf.gov/home/grants/grants_fdp.htm.

Any technical or programmatic questions regarding this notification should be addressed to the cognizant NSF Program Officer: Maria Zemankova, (703) 292-8918, mzemanko@nsf.gov.

Any award specific questions of an administrative or financial nature should be addressed to the grants official at http://www.nsf.gov/bfa/dga/liaison.htm. The cognizant grants official can be identified by associating the three-letter division identifier in the above-referenced award number with the grants official for that division on the liaison website.

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 04-2	FOR NSF USE ONLY
NSF 01-100 02/02/04	NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) CNS - CISE RESEARCH INFRASTRUCTURE	0423386

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
02/02/2004	5	05050000 CNS	2885		09/27/2006 9:15am S

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS ☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
University of Missouri-Columbia	University of Missouri-Columbia Office of Sponsored Prgm Admin Columbia, MO. 652110000
AWARDEE ORGANIZATION CODE (IF KNOWN) 0025163000	
NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE	ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE
PERFORMING ORGANIZATION CODE (IF KNOWN)	

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions) ☐ SMALL BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS | ☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **Wireless Sensor Networks: Middleware and Applications**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 406,881	24 months	08/01/04	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

- ☐ BEGINNING INVESTIGATOR (GPG I.A)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.1.d)
- ☐ HISTORIC PLACES (GPG II.C.2.j)
- ☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.D.1)
- ☐ VERTEBRATE ANIMALS (GPG II.D.5) IACUC App. Date ________
- ☐ HUMAN SUBJECTS (GPG II.D.6) Exemption Subsection ____ or IRB App. Date ____
- ☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.g.(iv).(c)) ________
- ☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.E.1)

PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
Computer Engineering/Computer Science	201 Engineering Building West Columbia, MO 65211 United States
PI/PD FAX NUMBER 573-882-8318	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME Yi Shang	PhD	1997	573-884-7794	shangy@missouri.edu
CO-PI/PD Sheila A Grant	PhD	1994	573-884-9666	grantsa@missouri.edu
CO-PI/PD Haibin Lu	PhD	2003	573-882-3371	luhaibin@missouri.edu
CO-PI/PD Hongchi Shi	PhD	1994	573-882-3088	shih@missouri.edu
CO-PI/PD Wenjun Zeng	PhD	1997	573-882-4480	zengw@missouri.edu

Electronic Signature

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 04-2. Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Drug Free Work Place Certification

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Appendix C of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Debarment and Suspension Certification contained in Appendix D of the Grant Proposal Guide.

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, "Disclosure of Lobbying Activities," in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME Dona R McKinney	Electronic Signature	Feb 2 2004 2:43PM

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
573-882-9592	grantsdc@missouri.edu	573-884-4078

*SUBMISSION OF SOCIAL SECURITY NUMBERS IS VOLUNTARY AND WILL NOT AFFECT THE ORGANIZATION'S ELIGIBILITY FOR AN AWARD. HOWEVER, THEY ARE AN INTEGRAL PART OF THE INFORMATION SYSTEM AND ASSIST IN PROCESSING THE PROPOSAL. SSN SOLICITED UNDER NSF ACT OF 1950, AS AMENDED.

Wireless Sensor Networks: Middleware and Applications

Project Summary

The remarkable increase in computing power together with the fast growing capabilities of sensors and actuators is revolutionarily changing how systems sense and interact with their physical environment. Significant efforts have been made in recent years in building sensor networks from computing devices with integrated sensing and wireless communicating capabilities. There are two categories of sensing devices: One is characterized as resource-lean (low-cost, low-power) sensing devices such as motes and smart dust developed in UC Berkeley, and the other is represented by resource-rich multimedia sensors such as video camera and microphone. There are exciting opportunities and challenges in developing system support that allows the co-existence of various types of sensors and the use of multiple sensing modalities to achieve coordinated system capabilities and performance.

The overall goal of the proposed collaborative research is to develop middleware for building wireless sensor networks (WSNs), which are highly heterogeneous in nature, in an integrated fashion and supporting the development, maintenance, deployment, and execution of sensing-based applications. This includes mechanisms for formulating complex sensing tasks, communicating the tasks to wireless sensor networks, coordinating sensor nodes to divide and distribute the tasks to individual sensor nodes, merging and processing low-level sensor readings from the individual sensor nodes to obtain desired high-level results, and reporting the results back to the user, designing energy-efficient distributed compression and transmission techniques, designing efficient network architectures, routing protocols, and adaptive cross layer optimization techniques, and developing network-friendly media security solutions. Heterogeneous sensor networks and related software will be developed for three important applications: environmental monitoring for countering agro-terrorism, surveillance for homeland security, and patient monitoring for improved healthcare.

The requested resources include Berkeley Motes and related hardware and software, video cameras, PDAs and notebooks acting as mobile nodes, gateways or access points, and data servers for storing, analyzing, and streaming sensing data. These resources will enable a versatile experimental platform of heterogeneous sensor networks for prototyping and demonstrating the middleware and applications to be developed in the proposed collaborative research.

Intellectual merit of the proposed activity. The proposed research work addresses the key technical issues related to utilization and deployment of WSNs in real-world applications. It is an innovative and creative attempt to develop fundamental technologies for heterogeneous wireless sensor networks. The testbed developed with the equipment acquired in the project will provide a state-of-the-art experimental environment that will facilitate the collaborative work on WSN research and development. This research will lead to deeper understanding of the performance, limitations, implications, and trade-offs in WSN systems and applications. Our proposed cross-fertilization approach has the potential of significantly improving the continuity, robustness, and good end-to-end performance in WSNs. The PIs have extensive experience researching wireless sensor networks, multimedia communication, and related areas, and their works are well received by the research community.

Broader impacts of the proposed activity. The equipment acquired will be the first major resource on WSNs at MU that will significantly enhance the collaborative research, development, and education capabilities of the Computer Science Department and other departments at the University. The middleware developed will become important building blocks in WSN infrastructures and can support a broad range of WSN applications. The applications developed will be of significant importance to the national security. The proposed research will have tremendous impact on US agriculture, economy, defense, homeland security, and healthcare. The project results will be disseminated through the Web, professional conferences, and journal articles.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.C.

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

Project Description

1 Overview

1.1 Resources to be Acquired, Developed, and Maintained

The resources to be acquired for the wireless sensor networks (WSNs) research and development include 200 Berkeley Motes and related hardware and software, 40 video cameras, 20 PDAs, 30 notebook computers, one data and computing server, and a set of Ultra-wideband evaluation kit. The Motes have a rich set of sensing capabilities, including light, temperature, sound, humidity, barometric pressure, seismic, and GPS. The cameras with microphones built-in are used as audio/video sensors. The PDAs and notebooks act as mobile nodes and/or access points of the heterogeneous WSNs. The servers are used for storing and analyzing sensing data, and controlling sensor networks.

We will develop a new wireless sensor network laboratory (WSNL) with the necessary equipment for WSN research and development. We will build a testbed using the equipment, and on top of the testbed develop several middleware services and important WSN applications. The lab will be mainly maintained and supported by PhD level graduate students under supervision of the PIs.

1.2 Need and Impact of Proposed Resources

The requested resources will enable a versatile experimental platform of heterogeneous sensor networks for prototyping and demonstrating the middleware and applications to be developed. The equipment will be the first major resource on wireless sensor networks at MU and will significantly enhance the collaborative research/development and education capabilities of the Computer Science Department and other departments at the University as well.

The platform of Motes forms a medium-scale testbed of resource-lean WSNs. This testbed will consist of about 200 Berkeley Motes with various sensing capabilities and 10 notebook computers acting as access points. It will be used to analyze the performance and usability of the middleware in such networks for the proposed anti-agro-terrorism applications. The prototypical WSN based on the testbed will be deployed on the campus and connected to a server for data archiving and analysis. Accordingly, software will be developed for processing data and controlling sensor nodes.

The platform of cameras, PDAs and notebook computers forms another medium-scale testbed of multimedia mobile ad hoc sensor networks. This testbed will consist of about 40 wireless cameras, a media/data server (for data archiving, analysis, and streaming to wireless clients), and a number of wireless handheld devices (Laptops, PDAs) serving as wireless clients. It will be used to analyze the performance and usability of such networks in the proposed multimedia delivery applications. In analysis, we will quantitatively measure the impact of the proposed multimedia delivery research on the end-to-end system performance. In addition, we will acquire a software processing/streaming server system based on which to develop the image/video analysis and synthesis software that fuses video streams from multiple cameras, performs scene analysis, and streams the processed videos to the wireless clients live or on demand.

The platforms of Motes and cameras will be combined to form a large-scale testbed of heterogeneous WSN (HMSN). Software will be developed to integrate sensing information from both Motes and cameras. The multi-modal sensing information will improve the system performance for the proposed applications.

The combined sensor network testbed is reconfigurable, accommodating different research and development projects. Once established, it will become an integrated part of the proposed collaborative research platform and significantly enhance/facilitate future research/development and education on WSNs at MU.

1.3 Overall Goals of the Collaborative Research

The overall goal of the proposed collaborative research is to develop middleware for building WSNs, which are highly heterogeneous in nature, in an integrated fashion and supporting development, maintenance, deployment, and execution of sensing-based applications. This includes mechanisms for formulating complex high-level sensing tasks, communicating the tasks to WSNs, coordinating sensor nodes to divide and distribute the tasks to individual sensor nodes, merging and processing low-level sensor readings from the individual sensor nodes to obtain desired high-level results, and reporting the results back to the task issuer, designing energy-efficient distributed compression and transmission techniques, designing efficient network architectures, routing protocols, and adaptive cross layer optimization techniques, and developing network-friendly media security solutions. Middleware should also support appropriate abstractions and mechanisms for dealing with the heterogeneity of sensor nodes.

Heterogeneous sensor networks and related software will be developed for three important applications: 1) environmental monitoring for countering agro-terrorism, 2) surveillance for homeland security, and 3) patient monitoring for improved healthcare.

The PIs have diverse expertise that complements each other which will allow research/development on WSNs. The testbed set up with the equipment acquired in the project will provide a state-of-the-art experimental environment that will facilitate their collaborative work on WSN research and development.

2 Resources Description

2.1 Unique Equipment and Software Systems to be Acquired

Resource-lean sensor devices and related computing environment

Berkeley Motes and related hardware and software will be purchased from Crossbow, Inc. Crossbow ships three Mote Processor Radio module families – MICA (MPR300), MICA2 (MPR400), and MICA2-DOT (MPR500). All of these modules provide a processor that runs TinyOS based code. TinyOS is an efficient and modular embedded software platform for the Motes, and it is an open-source software platform and tool-chain, developed by UC Berkeley and actively supported by a large community of users. In addition, the STARGATE modules will be purchased to interface the Motes to the Internet. Crossbow's STARGATE products run Linux and host standard Internet protocols including TCP/IP (Wired and WiFi), HTTP, and FTP.

Part No.	*Description*	*Unit Price*	*Units*	*Cost*
MPR500CA	FM Multi-Channel MICA2DOT Processor/Radio Board (868/916 MHz)	$115	100	$11,500
MPR400CB	FM Multi-Channel MICA2 Processor/Radio Board (868/916 MHz)	$161	100	$16,100
MTS310CA	MICA/MICA2 Sensor Board with light, thermistor, acoustic sensor, acoustic actuator, accelerometer, magnetometer	$175	50	$8,750
MDA500CA	MICA2DOT Prototype/Data Acquisition Board	$26	10	$260
MIB510CA	MICA, MICA2, MICA2DOT PC Interface Board	$80	10	$800
MTS420CA	MICA2 Sensor Board (light, temp, humidity, barometric pressure, seismic, GPS)	$317	10	$3,170
MTS400CA	MICA2 Sensor Board (light, temp, humidity, barometric pressure, seismic)	$212	40	$8,480
SP-KIT420	Advanced Stargate Developer's Kit	$1,195	1	$1,195
SPB400CA	Stargate Processor Board	$440	10	$4,440
SDC400CA	Stargate Daughter Card – 10/100 Ethernet, Serial, USB	$122	10	$1,220
SENSICAST SOFTWARE		$195	10	$1,950

	Notebooks as mobile nodes and access points	$2000	10	$20,000
		Subtotal:		$77,865

Multimedia sensor devices and related computing environment

Part No.	*Description*	*Unit Price*	*Units*	*Cost*
HP9000 L2000	ENTERPRISE SERVER W/RAID Scalable 80 GB to 4 TB Up-to (16) IDE hard disk drives	$9,000	1	$9,000
Toshiba IK-WB11A Webcam	802.11b wireless cameras	$600	40	$24,000
Helix Universal Server (S)	An entry-level RealNetworks server with throughput capacity of 4Mbps delivers all major media formats within small organizations.	$2,100	1	$2,100
	Notebook computers as mobile nodes	$2,000	20	$40,000
	PDA as mobile nodes	$500	20	$10,000
	Wireless access point	$60	10	$600
		Subtotal:		$85,700

Health sensors and Ultra-wideband wireless evaluation kit

Part No.	*Description*	*Unit Price*	*Units*	*Cost*
ProComp 2™	EEG sensor and the peripherals for PC connection www.biof.com	$1,750	2	$3,500
Time Domain's	PulsON 200 UWB evaluation kit	$32,000	1	$32,000
Additional Time Domain's UWB radios		$14,900	1	$14,900
Time Domain's EVK Standard Support 10 hour block		$2,000	2	$4,000
		Subtotal:		$54,400
		Total Equipment Cost:		$217,965

2.2 Development, Deployment, and Maintenance Plan

The PI will coordinate the project. He will make decisions jointly with the other five investigators. The proposed activities will be undertaken in two years. The timelines for the activities are listed and briefed as follows:

Year 1

- Purchase the equipment for building resource-lean and resource-rich WSNs.
- Investigate the integration of resource-lean and resource-rich WSNs.
- Design and develop the adaptive optimization middleware for resource-lean WSNs.
- Design and develop efficient localization and routing services based on the adaptive optimization middleware on resource-lean WSNs.
- Design and develop efficient and secure multimedia delivery methods for resource-rich WSNs.
- Design and develop energy-efficient Ultra-wideband protocol architecture specific for wireless patient monitoring.
- Design and develop multi-modal WSN techniques for three target applications: environmental monitoring for countering agro-terrorism, surveillance for homeland security, and patient monitoring for improved health care.

Year 2

- Construct an integrated WSN platform consisting of both resource-lean and resource-rich sensing devices.
- Implement the adaptive optimization middleware and the localization and routing services on the WSN platform.
- Implement the secure multimedia delivery methods on the WSN platform.
- Implement and integrate Ultra-wideband module with patient monitoring devices.
- Implement multi-modal WSN techniques for the three target applications.
- Conduct experiments to measure the system performance.
- Evaluate the outcomes of all project activities, disseminate the project results, and collect feedback.

2.3 Existing Resources

The general facilities and equipment are supported by a combination of resources from the Computer Science Department and Campus Computing at the University of Missouri-Columbia. The University has been awarded an NSF grant that partially supports establishing high performance network connectivity under the Next Generation Internet "Connections to the Internet" program to the Very High Performance Backbone Network Service (vBNS). The CS department was the principal lead on the NSF vBNS proposal and has already installed a direct OC-3 connection to the campus ATM backbone via an IBM 8285 ATM switch and an IBM 8274 Ethernet edge switch (10BaseT/100Base/TX).

The following three research laboratories were founded by PIs in the past 6~7 years: (1) Distributed Computing Laboratory (Yi Shang and Hongchi Shi) has two Linux servers, eight Windows XP workstations, one Sun Enterprise server, twelve Sun workstations, and one RAID storage system, all funded by NSF. (2) Mobile Networking and Multimedia Communications Laboratory (Wenjun Zeng and Haibin Lu) currently has five Windows XP workstations, two Laptops, two PDAs, high speed Ethernet and wireless LAN, and Linux servers. (3) Multimedia Communications and Visualization Laboratory (Zhuang) has equipment worth $1.8 million funded by grants from NASA, NSF, and SCI. It currently hosts fifteen Silicon Graphics workstations (eight R 10000 O2-s, four dual processor Octanes, two Indogo2s, and one Onyx2 four processor Infinity Reality supercomputer with 80 GB disk array storage system). The Octane and Onyx2 workstations are all stereo capable and can be used to develop 3-D display using the StereoGraphic CrystalEyes stereo hardware. The distributed cluster of workstations contains a total of over 2 gigabytes of memory (RAM), 162 gigabytes of disk storage, over 25 CPUs, a variety of graphics capabilities, 100BseT network connectivity and ATM capable. In addition, five high performance PCs (three Dell PIV 1.2 GHz with 512MB RAM, two Dell 1.8G with 512M RAM) have been recently added to the Lab facilities for developing PC-based Videoconferencing over IP and Spoken Language Processing technologies.

2.4 Rationale for the Specific Selections Proposed

For resource-lean WSNs, the platform provided by Berkeley Motes and TinyOS is the best and currently available. Motes and TinyOS have been used to form the designated hardware and software experimental platforms for several advanced research programs on WSNs, including the DARPA NEST program. The hardware system has a rich set of sensor options, and it is stable and reasonably priced. The software environment is open-source and has been improved constantly by scientists all over the world.

For resource-rich WSNs, IEEE 802.11 family is currently the most popular wireless LAN. Toshiba IK-WB11A Webcam has its own built-in web server and built-in microphone. It incorporates the 802.11b wireless antenna so it does not need any additional modules connected to it. It has dynamic DNS and multiple resolution support. It is easy to deploy, and it is perfect for security surveillance, education, and many other quality-sensitive applications. Helix Universal Server is an entry-level RealNetworks server that delivers all major media formats. More importantly, it is an open-source platform that would allow enhancement and adaptation for specific research objectives. HP9000 L2000 is a scalable server that achieves high-end mission critical availability and manageability at an entry-level price.

For wireless patient monitoring, our goal is to develop communication modules that are energy-efficient (< 1mW) and can coexist with current wireless services such as WiFi and Bluetooth. Ultra-wideband (UWB) technology is the best candidate. Time Domain's PulsON 200 UWB evaluation kit contains 2 UWB radios and 2 complete software modules designed to provide performance-based information and allow users to build custom applications. It has lower price than the evaluation kit from xtremespectrum.com ($50,000). We plan to build a prototype including 2 sensor sources and 1 base station. We will need 2 EEG sensors and 3 UWB radios. ProComp 2™ contains a built-in EEG sensor for generating EEG data, and it has the peripherals for easily connecting with a PC.

3 Proposed Research

3.1 Project Context

3.1.1 Wireless Sensor Networks (WSNs)

Wireless sensor networks (WSNs) are an increasingly attractive means to monitor environmental conditions and bridge the gap between the physical and the virtual world (Kahn et al., 1999; Akyildiz et al., 2002; Ganesan et al., 2002). According to the resources on the sensor nodes, WSNs can be classified as resource-lean or resource-rich. The former uses resource-lean sensing devices such as motes and smart dust, which are low-cost and low-power devices. The latter uses resource-rich devices such as multimedia (video/audio) sensors.

A resource-lean WSN usually consists of a large number of cooperating small-scale nodes each capable of limited computation, wireless communication, and sensing. When properly networking these nodes and intelligently correlating/fusing their outputs, a WSN as a whole will provide functionality far beyond an individual node can. A resource-rich WSN has more powerful but fewer sensor nodes. Its communication scope is more constrained and deployment more costly. A heterogeneous WSN consists of both resource-lean and resource-rich sensing devices that could achieve much better performance than either a resource-lean WSN or resource-rich WSN by using multi-modal sensing information.

Application areas for WSNs include geophysical monitoring, precision agriculture, habitat monitoring, traffic monitoring, military systems, business processes, and in the future, possibly cooperating smart everyday devices. The basic operation of WSNs is significantly different from traditional computer networks, due to their ties with the physical world. The characteristics of resource-rich and resource-lean WSNs are quite different. Thus, their integration poses a challenging task. In addition, sensor networks have many unique characteristics that must be taken into account while developing any non-trivial applications.

Deployment of a WSN in a target area can be a continuous process, for example, nodes with depleted batteries or destroyed due to environmental influences need to be replaced (Beigl et al., 2001, Howard et al., 2002). Due to the number of sensor nodes being potentially large, nodes have to operate unattended after deployment. Once a sufficient number of nodes are properly deployed, the sensor network should be capable of accomplishing its designated task, which may be issued by an external entity connected to the sensor network, such as a user with a PDA, an aircraft flying by, or some device on the Internet.

3.1.2 Unique Characteristics of WSNs

Although sharing many commonalities with traditional *ad hoc* computer networks, WSNs have a number of unique characteristics as follows.

- *Application Specific Design.* Due to a large number of possible combinations of sensing, computation, and communication technologies, many different application scenarios are possible. It is unlikely that there will be "one-size-fits-all" solutions for all these applications.

- *Close Environment Interaction.* Since WSNs closely interact with the environment, their traffic characteristics can be expected to be very different from traditional computer networks.
- *Large Scale.* Potentially, WSNs have to scale to a much larger number (thousands, hundreds of thousands) of elements than current *ad hoc* networks that would require different and more scalable solutions.
- *Scarce Energy.* In WSNs, energy supply is scarce and hence energy consumption is of primary concern. Since sensor nodes are often powered by batteries, the need to prolong the lifetime of a sensor node would have a deep impact on the system and networking architecture.
- *Self-Configurability.* Similar to normal *ad hoc* networks, WSNs will most likely be required to self configure into connected networks. However, the differences in traffic, energy trade-offs, and computation and communication constraints would require new solutions.
- *Dependability and QoS.* WSNs exhibit very different concepts of dependability and quality of service than traditional computer networks.
- *Data-Centric Architecture.* The low cost and low energy supply in typical WSNs require, in many application scenarios, redundant deployment of wireless sensor nodes. As a result, the importance of any one particular node is considerably reduced as compared to traditional networks. The data that the nodes can observe is more important.
- *Simplicity.* Since sensor nodes are small and energy is scarce, the operating and networking software must be kept orders of magnitude simpler compared with traditional desktop computers. This simplicity also requires breaking away from conventional layering rules for networking software, since abstractions typically cost time and space.
- *Heterogeneity.* WSNs may consist of a large number of rather different nodes in terms of sensors, computing power, communication bandwidth, and memory.

3.2 Project Activities

3.2.1 Middleware Development for Wireless Sensor Networks

Middleware sits between the operating system and the applications. On traditional desktop computers and portable computing devices, operating systems are well established, both in terms of functionality and systems. However, for sensor nodes, particularly resource-lean nodes, the identification and implementation of appropriate operating system primitives is a challenging issue (Festrin et al., 1999; Hill et al., 2000). In many existing WSN projects, applications are executed on the bare hardware without a separate operating system component.

In this project, we will develop middleware to support development, maintenance, deployment, and execution of sensing-based applications of WSNs. Classical networking mechanisms and infrastructures are typically not well suited for peculiar WSNs. Middleware designed in traditional networks often does not use application knowledge and hence can accommodate a wide variety of applications. In contrast, middleware for WSNs has to provide mechanisms facilitating the use of application knowledge due to resource constraints, and it may even be necessary to execute resource-intensive functions or store large amounts of data in external components. Thus, communication and application specific data processing is much more integrated in WSN middleware. Data-centric communication in WSNs mandates a communication paradigm that more closely resembles content-based messaging than traditional RPC-style communication. Time and location of sensed real-world events in WSNs play a much more important role since they are crucial to fusing individual sensor readings for high-level sensing results. Some WSN applications might even pose real-time requirements. Therefore, support for time and location management should be tightly integrated into a WSN middleware infrastructure.

There are some projects underway to develop middleware for WSNs. The Cougar Project at Cornell University adopts a database approach where sensor readings are treated like "virtual" relational database tables, and uses an SQL-like query language to issue tasks to the WSN. The Smart Messages Project at

Rutgers University is based on agent-like messages containing code and data, which migrate through the sensor network. The NEST Project at the University of Virginia provides so-called micro-cells, which are similar to operating system tasks with support for migration, replication, and grouping, as a basic abstraction. The SCADDS Project at USC ISI is based on a paradigm called Directed Diffusion, which supports robust and energy-efficient delivery and in-network aggregation of sensor events. Most of the projects are in an early stage focusing on developing algorithms and components for WSNs, which are aimed at serving as a foundation for middleware in the future. Furthermore, most of current results are based on simulations or small-scale experiments in laboratory settings (Ganesan et al., 2002).

3.2.2 Adaptive Optimization as Middleware Service for WSNs

Future sensor networks promise unprecedented reconfigurability, flexibility, and robustness. However, software is lagging behind hardware. Model-based software technology, using generic constraints and optimization techniques, can be used to achieve this promise, but it must move beyond the scope of traditional off-line algorithms executed on a central computer. Many sensor network applications require combining distributed optimization techniques with complexity analysis and learning techniques.

Nonlinear constrained and unconstrained optimization is at the core of many applications in sensor networks such as node localization, routing, topology control, anchor placement, and target tracking. The common synthesis task in these applications is to (repeatedly) find a solution for a given objective, a solution that is achievable within the time bound and consistent with the constraints. Currently, a synthesis solution is typically hand-coded using analysis on a fixed set of configurations and tasks. In order to fulfill the promise of dynamic reconfiguration and fault-tolerant behaviors of future sensor networks, many synthesis operations must be done in a real-time fashion

This adaptive optimization research is to enable essential capabilities of reconfigurable, fault-tolerant, and long-lived sensor networks by providing time-bounded optimization techniques that combine problem analysis, adaptation, and distribution. Based on our experience with embedded optimization techniques in real-time networked embedded systems, we have identified several places where distributed adaptive techniques would greatly improve the ability to provide a time-bounded synthesis service to WSN applications. We will develop novel adaptive optimization services for several important middleware components in WSNs, including node localization and position estimation, routing and clustering, target tracking and pursuing, etc.

<u>Technical Approaches</u>

We will develop techniques and software to provide distributed adaptive optimization services for WSN applications in the following key areas:

- Modeling and analysis techniques to estimate quality of synthesis solutions and computational complexity of optimization problems and algorithms, assess on-line performance of optimization solvers, and provide time-bounded synthesis with required feasibility, average and worst case behaviors for specific applications. This research will provide the necessary performance information for the following two research components.
- Adaptive optimization techniques, including complexity-directed algorithm synthesis for continuous and discrete optimization, time-aware balancing of constraint propagation and search in discrete constraint solvers, dynamic problem adaptation, and a closed-loop control architecture to manage low-level operations of a solver. These techniques will result in time-bounded synthesis software for an individual embedded solver.
- Distributed constraint-solving methods, consisting of problem decomposition and configuration-adaptive solver distribution and coordination techniques. These techniques will enable the distribution and solution of large-scale optimization problems.

Together, these components will provide three key capabilities needed by time-bounded solver synthesis. That is, the capabilities to assess the complexity of a problem, dynamically adapt to the problem characteristics and application requirements, and decompose and distribute the solving task in a networked computing environment. The proposed techniques are designed to address both continuous and discrete optimization problems, enable on-line and off-line analysis, study algorithmic and problem issues, and improve the performance of individual and multiple interacting solvers for sensor networks.

Using these building blocks, we will construct a versatile toolbox providing optimization services in sensor networks for several important WSN problems, particularly for node localization and routing. At the core is a dynamic feed-back-control loop between performance analysis and adaptive solving, designed to proactively consider performance and resources in the solver. On the performance analysis side, complexity analysis provides information about the average complexity of a given problem, which is complemented by online performance monitoring and off-line average and worse case analysis to achieve solution timeliness and quality. On the solving side, the adaptive synthesis of optimization algorithms provides robust results for problems of various complexities. Finally, distributed processing techniques will enable the efficient implementation of our approach to WSNs.

In recent years, we have worked on several important WSN problems, particularly node localization and data-centric routing, and developed several novel optimization-based methods. For localization, we have developed the MDS-MAP method (Shang et al., 2003; Shang and Ruml, 2004; Shang et al., 2004) based on multi-dimensional scaling techniques. MDS-MAP outperforms existing multilateration-based methods significantly when the number of anchor nodes is small, particularly for irregular networks. Furthermore, MDS-MAP is able to perform relative position estimation much more accurately than existing methods, given noisy distance information. For data-centric routing in sensor networks, we have developed a message-initiated constraint-based routing method (Fromherz et al., 2003). The method is more general and flexible than existing methods. It separates the routing objectives from routing strategies and provides a general message specification mechanism to explicitly encode the routing destinations, constraints, and objectives. In addition, we have developed routing strategies based on online reinforcement learning techniques for improved performance. We have also developed a routing strategy for time-bounded applications. We have had promising initial results of developing adaptive optimization techniques for specific WSN applications.

We will further develop and test our proposed research projects on adaptive optimization as middleware services. To achieve our goals, we need to build a testbed of medium- to large-scale WSNs to analyze the performance and usability of the middleware on such networks for the proposed applications. The testbed will consist of a medium-scale WSN (about 200 Berkeley Motes and 10 notebook acting as access points) deployed over the campus, a hardware media/data server for data archiving and analysis. In addition, we will develop software for processing data and controlling sensor nodes of the WSN. One graduate student is needed to help set up, develop, and maintain the testbed. The Motes-based sensor network testbed, once established, will serve as an important component of the proposed collaborative research platform.

3.2.3 Optimizing Multimedia Delivery over WSNs

Multimedia communication over advanced ad hoc WSNs is expected to be critical for many military and homeland security applications. For example, an important application is wireless security surveillance where wireless delivery of video sources from multiple wireless cameras will enable security personnel to monitor and analyze the situation from anywhere, and react promptly and appropriately to the emergency.

Multimedia over advanced WSNs, however, remains a very challenging problem, due to the battery-driven, power constrained diverse multimedia sensors and client devices, the time-varying nature of the wireless networks, data loss, heterogeneity of networks, as well as the stringent real-time constraint of the multimedia applications. As a result, energy-aware multimedia processing and transmission, the design of the topology/architecture of the ad hoc WSNs, the corresponding routing protocols, and the adaptability of each layer of the network protocol stack are some critical issues for achieving reliable and quality multimedia communication over WSNs.

An important aspect of our research work is to address power efficiency in a wireless multimedia sensor network. Typically data transmission is significantly more costly than computation in the wireless sensors. Therefore it is desirable to reduce the data rate of the video sources for transmission. In a dense wireless camera network with overlapping fields of view, distributed image/video compression can be used to exploit the correlation between camera views to lower the power expenditure (Pradhan et al., 2002, Wagner et al, 2003). In such scenarios, a lower (spatial and temporal) resolution image can be captured and compressed at each wireless camera site, then transmitted to the service center or receivers. The service center or receiver can then generate a super-resolution image/video by fusing multiple received low resolution images/video from different sensors. One significant advantage of such approach is that the computational complexity and transmission power cost can be shifted from low power cameras to potentially high power service center or receivers. Another significant advantage for security surveillance applications is the possibility it provides to enhance the spatial or temporal resolution of the video for zooming in "regions/events of interest". Initial study on distributed image compression using super-resolution approach has been reported recently (Wagner et al, 2003).

Another important aspect of our research is to address efficient and reliable delivery of multimedia over ad hoc WSNs. Some initial work on advanced ad hoc multimedia sensor networks using wireless LAN as the building block in a cluster-based multi-hop network architecture has been studied (Ban and Gharavi, 2002). Cross-layer optimization of the network protocol stack has also been considered as an important solution for multimedia wireless networks (SNRC, 2004). The variability and volatility of wireless networks can be addressed by adapting to the wireless link, network, and application dynamics, in preferably a distributed manner. A combination of novel network architecture and an adaptive cross layer optimization would be a very powerful approach for addressing QoS and cost effectiveness in mobile multimedia ad hoc networks.

Media security (privacy, authentication, data integrity, etc) is a critical issue in wireless security surveillance applications. It faces a number of new challenges in the resource-constrained, error prone WSN environment. We were the first to recognize that, for many applications such as streaming media, it is required that content encryption provides error resiliency, scalability, network friendliness and capability of performing signal processing *directly* on the encrypted bitstream, just as is required for unencrypted content formats (Wen et al., 2002, Zeng and Lei, 2003). In addition, for wireless multimedia delivery from power constrained sensors to low-power devices, a particularly desirable feature is low processing overhead, which can usually be achieved through selective encryption and/or some lightweight encryption techniques. Similarly, we believe that for other security techniques such as media authentication, the requirements described above are equally desirable for wireless multimedia sensor network applications. The last aspect of our research work is to investigate network-friendly media security solutions for WSNs.

Technical Approaches

We have previously explored the idea of incorporating an interpolator at the receiver to help improve the coding efficiency in block-based low bit rate coding over conventional codecs that do not fully exploit the inter-block correlations (Zeng and Liu, 1996, Zeng and Liu, 1999a). Using a geometric structure based directional interpolation scheme, our proposed system was able to faithfully reconstruct a large percentage of image blocks at the decoder that are intentionally not coded/sent by the encoder to save bits. The directional interpolation scheme is capable of preserving the edge structures of the images well, which allows many blocks containing edge information to be thrown away (which otherwise take a lot of bits to code). We will extend the idea to distributed image compression for WSNs where the correlation between multiple images of the same scene from different views can be similarly exploited to reduce the total transmitted bits. In addition, we will adopt an *image-region- or video-segment- adaptive subsampling and interpolation approach* based on the spatial and temporal complexity of each image region or video segment, to further reduce the transmission redundancy (thus power cost) in the correlated images/videos. We also believe that by incorporating information extracted by content-analysis of video

(Chang et al., 1996) into the distributed image compression/transmission system will result in reduced bit rate. For example, to reduce power consumption, a smart surveillance system can transmit only extracted key frames (scene change or motion-detected frames), or suspected scenes.

For efficient and quality multimedia delivery over wireless networks, we have been working on joint optimization of source and network modules (a cross-layer adaptive approach) to improve the end-to-end system performance (Zeng and Wen, 2002, Xie and Zeng, 2004). In particular, we have recently been working on dynamic rate control combined with dynamic bitstream switching for streaming video over bandwidth varying wireless networks, using an integrated end to end virtual network buffer management approach (Xie and Zeng, 2004). We proposed a *server based* rate-distortion optimized solution that incorporates feedback from the client through RTCP (Real-Time Control Protocol) reports to estimate the network condition *proactively*. Our preliminary study have shown that, with such approach, the delay can be controlled appropriately to tailor to changing network conditions, thereby avoiding player rebuffing and packet loss and making sufficient use of the available network bandwidth. This end-to-end approach, however, may have some inherent limitation, especially for streaming over a mixed wired and wireless network where packet loss can be attributed to both network congestion and random bit error (Cen et al., 2002). In a mixed network scenario, we believe that by using a proxy server located at the gateway between the wired and wireless networks, we can deal with the heterogeneous networks more efficiently, using an approach tailored to both networks. Similarly, we envision that by intelligently placing appropriate streaming agents throughout a large scale ad hoc wireless network to enhance the network adaptation capability, we will be able to improve the overall network performance. This is one of the most important issues that we would like to investigate in the context of a mobile ad hoc network environment.

For media security, we have developed a framework of performing selective encryption and spatial shuffling of compressed video that maintains syntax compliance to the compression format after content has been secured (Wen et al., 2002, Zeng et al., 2002). With such a *joint design of encryption and compression*, we can achieve the various aforementioned network-friendly functionalities, which is extremely helpful for multimedia delivery over power constrained, error prone channels with dynamic bandwidth such as the WSNs. This format compliant selective encryption framework has been adopted into the MPEG-4 IPMP Extension standard (MPEG4 IPMP FPDAM, 2002). We are currently investigating a semi-format compliant encryption approach for improved network-friendliness, as well as network-friendly content authentication using semi-fragile watermarks, e.g., a variation of (Zeng and Liu, 1999b).

We have developed a software-based high performance IP multi-point videoconferencing system VCLAN at the Multimedia Communications and Visualization Laboratory at University of Missouri-Columbia. We will extend and tailor that system for use as a security surveillance system in WSNs, based on which we will develop and test our proposed research projects on secure optimized multimedia delivery over WSNs. To achieve our goals, we need to build a test-bed of medium to large scale mobile multimedia ad hoc sensor networks to analyze the performance and usability of such networks for multimedia delivery, and to quantify the practical impact of the proposed research work. The test-bed will consist of a medium scale wireless security camera networks (about 40 wireless cameras) deployed over the campus, a hardware media/data server for data archiving, analysis, and streaming, and a number of wireless handheld devices serving as wireless clients. In addition, we will acquire a software processing and streaming server system based on which we can develop the image/video analysis and fusing center that fuses multiple video streams from the camera networks, performs scene analysis streams the processed videos to the wireless clients. One graduate student is also needed to help setup, develop, and maintain the testbed, including extending and tailoring the current video conferencing system VCLAN for use as a security surveillance system in wireless ad hoc sensor networks. The multimedia ad hoc sensor network test-bed, once established, will serve as another important component of the proposed collaborative research platform.

3.2.4 Ultra-wideband (UWB) for Wireless Patient Monitoring (WPM)

Wireless patient monitoring (WPM) is an important research area in healthcare applications. For example, using wireless network patients with cardiac diseases can be monitoring at home or on road. Cardiac arrhythmia does not happen regularly so it may not be captured when a patient is at a hospital. With wireless sensors the patient wears, it is possible to capture cardiac arrhythmia when it happens. Wireless sensors communicate with wireless home gateway when the patient is at home or cellular data network (Paulopoulos et al., 1998) when the patient is on road. Even when the patient is at hospital wards the wearable wireless sensors allow the patient to move around without disrupting monitoring.

Wireless sensors are driven by battery power. Thus, wearable devices should be compact and consume as little battery power as possible (Rollins et al., 2000). The commercially available WLAN (wireless LAN) parts were primarily designed for general use and not optimized for low-power applications. The power consumption becomes even more serious when patients wear several small sensors powered by button batteries, for example, EEG sensor, blood pressure sensor, ECG sensor, and speedometer. These small sensors communicate with smart monitoring devices wirelessly and form a wireless personal area network. Although smart monitoring devices (bigger) have more computational power and battery power to run a full set of monitoring functions, both the sensing function and wireless communication function are still done by small sensors. So, low power consumption becomes a real challenge. Andreasson et al. (Andreasson et al., 2002) proposed a remote patient monitoring system using Bluetooth of lower power consumption. Although being more power-efficient than 802.11 WLAN, Bluetooth operates on unlicensed 2.4 GHz ISM band as WLAN does. This coexistence of Bluetooth and 802.11 WLAN on 2.4 GHz causes interference that may prevent the network from operation (Ennis, 1998; Golmie et al., 2001) and a good solution thus needs to be found (Cordeiro et al., 2003; Cordeiro and Agrawal, 2002; Kamerman, 2000; Chiasserini and Rao, 2001).

Ultra-wideband (UWB) uses extremely short duration pulses, typically a few tens of picoseconds to a few nanoseconds in duration, with very low duty cycle to transmit information (Fontana, 2000; Siwiak, 2002). The pulse has extremely wide bandwidth with noise-like power spectral density so that UWB devices can safely operate on spectrum already occupied by existing wireless applications such as Bluetooth, WiFi, etc. FCC recently legalized unlicensed use of UWB technology (FCC, 20002). The benefits of UWB include very low transmission energy, low energy density, very high bandwidth within short range (several hundreds Mbps within 10m) and low cost hardware. According to staccatocommunications.com (2004), 802.11a uses 200mW at 50 meters, 802.11b uses 200mW at 100 meters, and Bluetooth uses 1mW at 10 meters, while UWB needs only 0.2 mW at 10 meters. The low energy density minimizes interference with other wireless devices, thus enabling UWB devices to coexist with 802.11a, 802.11b, or Bluetooth. Another advantage of UWB is the ability for accurate localization using short impulse based delay estimation. Accurate localization is very important in finding patients in emergency.

We propose to adapt UWB technology for wireless patient monitoring (WPM). The low power, low cost, interference resistance, ability to coexist with other wireless devices, and accurate localization capability all are important for a wide deployment of WPM services. Current UWB research aims at ultra-high data rate design with reasonable power consumption. For example, the Trinity chip set by xtremespectrum.com offers a data rate at 25, 50, 75, and 100 Mbps with 200mW power consumption that is far too high for WPM applications. Although the data rate necessary for patient monitoring is usually less than 1Mbps, low-power design is not as simple as trading power with data rate. In fact, it is an issue that has to be addressed at every layer of the protocol architecture. While energy-efficient wireless MAC layer design for 802.11, Bluetooth, and WSNs has been heavily investigated, energy-efficient MAC design for UWB has not. Boudec et al. (Boudec et al., 2004) used dynamic channel coding in dealing with varying channel conditions to reduce energy dissipation. The contention mechanism with low probability of collision and error control schemes with low overhead are alternative ways to save power at the link layer. Although being investigated by other wireless standards, these ideas need an adaptation and performance evaluation when applied to UWB. Power-efficient design also includes power-aware *ad* *hoc* routing algorithms and low-power transport protocols. Moreover, the power-efficient protocol architectures are application-specific. Heinzelman (Heinzelman, 2000) studied low-energy adaptive clustering hierarchy for remote sensor network and unequal error protection for MPEG-4 delivery. We propose to investigate the energy-efficient protocol architecture specific for patient monitoring application and an integration of UWB transceivers with some existing patient monitoring systems.

3.2.5 WSN Applications for Homeland Security and HealthCare

The design and development of middleware and WSNs continue to emerge as one of the exciting research areas in the 21st century, while detection-based devices represent another rapidly growing technology for homeland security and healthcare. The integration of these technologies offers the potential to develop state-of-the-art detection networks that could (1) detect biological and chemical threats in the environment, (2) provide surveillance for homeland security, and (3) monitor patients for improved healthcare.

<u>(1) Detect biological and chemical threats in the environment</u>: An area of increasing importance is anti-agro-terrorism. Agro-terrorism is the use of biological or chemical agents against the agricultural industry and the food supply. The potential hazards include the release of known and unknown agents that cause animal diseases and plant diseases. It is not a question of if, but when, a plant or animal disease will be purposefully introduced into the U.S. While an attack on crops or livestock may not cause massive human casualties, the economic impact could be devastating. Infecting cattle with diseases such as foot and mouth or mad cow would likely erode public confidence in food safety and destroy the agricultural industry. Significant new investments in infrastructure and resources are necessary to reduce vulnerability from bioterrorist attacks and protect animal health. Detection and surveillance systems for agrosecurity must be capable of operating within a relatively large geographical area in order to monitor animal herd health as well as detect the (intentional or unintentional) release and migration of pathogens.

Additionally, water quality is a growing concern in the United States. For example, 50 million pounds of antibiotics are produced each year with about 40 percent going to treat animals. Unfortunately much of that goes through the animals' digestive systems and eventually into ground and surface water (Fackelmann, 2002). There is a move by the EPA to consider limiting antibiotics fed to animals in confined animal-feeding operations due to the unknown human health risks of drinking contaminated water. Since more than 50 percent of the people in the United States depend on groundwater for their drinking water, there is fear that even low levels of antibiotics fouling the nation's water supply may help create microorganisms that are antibiotic-resistant (Beeman, 2002). In fact, an increase in bacteria resistance to antibiotics has been a growing problem over the past several years. WHO (World Health Organization) approximates 14,000 Americans die each year due to drug-resistant infections (Mitchell, 2002).

It is clear that wireless detection and surveillance networks are ideally suited for such applications. The detection and/or surveillance systems would be placed in a distributed environment. For example, an array of sensors could be placed at strategic locations along susceptible streams and rivers and information could be transmitted remotely to a multi-channel receiver and processed. Video surveillance cameras could be placed in a number of feed barns along with sensors to monitor animal herd health. As the sensor and surveillance systems need to be powered by batteries, it is clearly necessary that the sensor data collection, processing, and transmission should all be operated with low energy consumption so that the lifetime of such networks can be maximized. When fully operational, the network systems could in real-time monitor biological and chemical threats in the environment.

<u>(2) Provide surveillance for homeland security</u>: Bioterrorism in the form of infectious organisms threatens the health of the world population (Beck et al., 2000; Armstrong et al., 1999; Berkelman et al., 1994). According to the Center for Disease Control and Prevention (CDC), diagnostic detection systems for disease surveillance as well as for clinical management of patients with infectious diseases are crucial (Shalala, 1999; CDC, 1998). For example, these devices might be capable of quickly reporting the

presence of infectious airborne, waterborne, or blood borne microrganisms or microorganism produced toxins (e.g. viruses: HIV, hepatitis, emerging virulent influenzas; bacteria: Clostridium, Anthracis, E. coli; parasites: malaria, Cryptosporidium; toxins: ricin, enterotoxins). Surveillance of microorganisms (and toxins) that harm people or cause human disease requires advancement in middleware and wireless systems so that these systems could be deployed throughout the civilian population such as subways, airports, and sporting events. Such sensors would rapidly identify the introduction of a bioterrorist agent into the civilian population. Furthermore, video security surveillance at borders, airports, federal buildings, schools, etc., has played and will continue to play a significant role in homeland security. An intelligent, secure, and efficient video surveillance system over WSNs would significantly extend the reach and enhance the homeland defense capability.

(3) Monitor patients for improved healthcare: Wireless applications in patient monitoring are becoming an important area of research due to the focus of the healthcare market to reduce costs and provide better care without significantly interrupting the daily schedules of physicians and/or patients. High-quality, wireless, wearable health monitoring products in the form of handheld PDA devices can be utilized by hospitals for inpatient monitoring as well as monitoring outpatients with chronic illness. Additionally, intensive care units could utilize wireless PDA monitoring systems that warn the medical team of potentially life-threatening situations remotely. There are a plethora of medical applications due to such factors as an aging population and an increased incidence of heart disease. For example, wireless networks can be utilized to remotely monitor blood oxygen content and pulse readings. Sufferers of chronic illnesses such as diabetes, asthma, renal disease, etc., could also utilize wireless applications to ensure enhanced disease monitoring. For example, diabetic patients could send their glucose level data to an online electronic medical record by utilizing a touch-tone phone. Additionally, wireless sensing and video monitoring can be applicable to livestock. Sick or pregnant animals could be monitored in real-time to decrease animal mortality and reduce morbidity.

3.2.6 Collaborative Aspects

The development of the middleware and applications of heterogeneous WSNs proposed in this project involves research expertise from many fields, such as wireless networking, multimedia communication, *ad hoc* networks, distributed computing, adaptive optimization, security, and biosensor technologies. The investigators have been working in these fields and have sufficient expertise to carry out the project successfully.

Many aspects of the project are collaborative in nature. The heterogeneity of the WSNs to be developed requires expertise in both resource-lean and resource-rich WSNs. For example, the security surveillance system can have both cameras and Motes as sensors. The wireless security camera system can be combined with other sensors (e.g., fire detectors, temperature sensors, special sound detectors, etc.) attached to Motes for some specific target applications. A smart wireless sensor/camera system can provide protocol access point for interested clients to register for events and monitor for events at its site. When an event (e.g., fire, shooting) is detected, instant messages together with the position information will be sent to specific clients (e.g., firefighters, security personnel), who can access either archived site sensor video data or stream live video from the sensor site.

For resource-lean WSNs, there is a lack of efficient middleware across the network protocol stacks. Even within advanced multimedia WSNs, it is recognized that the variability and volatility of wireless networks can be better addressed by adapting to the wireless link, network, and application dynamics, in preferably a distributed manner, using a cross-layer design approach. This is a highly complex design problem that requires multiple levels of expertise across the network protocol stack. We believe that substantial cross-fertilization across disciplines will result in broad new ideas for the development of the middleware and applications of heterogeneous WSNs.

4 Impact of the Proposed Research

The proposed research will significantly impact research and development in the area of WSNs. First, the proposal will lead to a state-of-the-art training program for graduate students in the area of WSN research. It will significantly enhance the graduate programs in terms of laboratory capabilities, expanding interdisciplinary research among graduate students and professors.

Second, the proposed work will have a significant impact on the research and development of the middleware and applications of heterogeneous WSNs. We expect that the research effort on optimized data and multimedia delivery in WSNs will result in a power-friendly, high performance, and secure real-time data and multimedia delivery system, which will significantly advance the state of art in secure communication over WSNs. This research will lead to deeper understanding of the performance, limitations, implications, and trade-offs in WSN systems and applications. Our proposed cross-fertilization approach has the potential of significantly improving the continuity, robustness, and good end-to-end performance in WSNs.

Finally, the proposed research work addresses the key technical issues related to utilization and deployment of WSNs in real-world applications. To our knowledge the proposed work is among the first attempts in developing optimization-based middleware services, optimizing multimedia delivery in WSNs and targeting significant applications of WSNs in anti-agroterrorism, security surveillance, and patient monitoring. Therefore, the proposed research will have tremendous impact on US agriculture, economy, defense, homeland security, and healthcare. Specifically, it will expand the science and technology in detection and surveillance systems, thereby leading to critical advances in not only animal pathogen detection, but also plant pathogen detection. It will enrich and enhance the security in agriculture and thus, stabilize consumer confidence and the economy. Additionally, it will significantly accelerate the prototyping and deployment of detection and surveillance technologies into commercial products.

MU is in a unique position to provide such an innovative research. MU is one of the rare major research campuses in the nation with agriculture, engineering, medicine, and veterinary medicine programs on the same campus. The richness of our education and research programs are of great benefit for innovated WSN research.

5 Unique Capabilities of Key Team Members

We believe the depth and breadth of our research team makes us well positioned to develop and analyze strategies for middleware and application design techniques for wireless *ad hoc* sensor networks.

Yi Shang has extensive research experience on WSNs and related fields. He has been supported by grants from federal agencies including NSF and DARPA. His research is at the leading edge and is well received by the research community. As a member of the innovative Smart Matter project at the Palo Alto Research Center (PARC), he developed novel methods of adaptive constrained optimization for controlling large-scale networked embedded systems (Fromherz et al., 2001; Shang et al., 2001a; Shang et al., 2002; Shang and Fromherz, 2003). When working in the DARPA NEST project at PARC, he developed novel methods for position estimation and routing in WSNs, two fundamental problems in WSNs (Shang et al., 2003; Fromherz et al., 2003; Shang and Ruml, 2004; Shang et al., 2004). He also has extensive experience on distributed systems and intelligent systems.

Hongchi Shi has done research on parallel and distributed computing for many years (Shi et al., 2002; Shi and Li, 2001; Li and Shi, 2000; Li and Shi, 1999; Shi et al., 1998; Shi et al., 1997; Shi et al., 1995; Shi and Ritter, 1995; Shi and Ritter, 1994). In recent years, he has been working on several NSF projects and obtained extensive research and education results on distributed systems, intelligent systems, and educational innovation (Shang et al., 2004; Shi et al., 2000a; Shang and Shi, 1999; Shang et al., 2000, Shi et al., 2000b). With the support of three NSF grants, they have established a Distributed Systems

Laboratory in the CS Department for teaching and research on distributed computing, and developed innovative adaptive asynchronous learning technologies for Web-based distance learning (Shang and Shi, 2000; Shang et al., 2001b; Shi et al., 2003).

Wenjun Zeng has made significant contributions to the fields of wireless multimedia communication, multimedia security and digital watermarking, multimedia compression and content analysis. A number of his works in these areas have been widely cited. He has also made significant contributions to the development of international standards. Four of his proposals have been adopted by the JPEG2000 and MPEG4 IPMP (Intellectual Property Management and Protection) standards. He has extensive industrial R&D experience, including three years with PacketVideo Corporation, a recognized leader in standard-compliant end-to-end wireless multimedia technology and embedded solutions. He has 9 granted patents and a number more pending in the areas of multimedia compression, transmission, and security.

Haibin Lu has conducted significant research on Internet routing. His research on Internet packet forwarding and classification resulted in 5 patents (pending). In 2003 he created a wireless networking course for graduate students in the CS Department. He also participated in developing NIH-sponsored medical informatics system for oncologists and radiologists nationwide to share and review voluminous clinical imaging and patient treatment planning data. Wenjun Zeng and Haibin Lu started the Mobile Networking and Multimedia Communications Lab in the CS Department.

Dr. Sheila Grant has over ten years of biophotonic experience and over seven years of sensor fabrication experience and will help the team in the area of the diagnostic detection for homeland and agriculture security and environmental monitoring. She has designed fluorescence, absorption, and reflectance-based sensing schemes, and has extensive knowledge in optical sensing methods. Her background and expertise will be crucial in the development of diagnostic instruments. Dr. Grant has one patent (U.S.#5938595) with two patent applications pending. Her work has been featured in international journals such as *Biophotonics International* (Jan/Feb 1998), *AIDS ALERT* (June 2000), *Molecular Medicine Today* (July 2000), and *USA Weekend* (Jan13, 2001). She was also awarded an R&D 100 Award in 1995.

Xinhua Zhuang is renowned for his contributions in the field of computer vision, image processing, image/video coding/communication, etc. He has published over 250 solid journal/conference papers and eight book chapters in these fields. He is the founder of the Multimedia Communications and Visualization Laboratory (MCVL) at University of Missouri. He has been directing several funded research projects in multimedia communications and networking in recent years in the areas of (1) high performance wavelet-based image coding; (2) scalable, multicast, multi-resolution, error resilient video transmission over IP; (3) low complexity, scalable, multi-resolution, error resilient wireless video; (4) distributed multipoint control for application-layer multicast. He has developed one of the best wavelet-based image codecs, SLCCA, in the world (Feng and Zhuang, VCLAN TR-2001). In the past five years, MCVL has been awarded over $5M federal funding from NASA, NIH, NSF, Army, DARPA, etc.

6 Project Evaluation and Dissemination

The project will be evaluated based upon the research output of the project including new method developed and technical papers published, the utilization of the testbed in terms of both research and education/training, and the performance of the software developed. One particular criterion for measuring the success is the collaborative aspect of the established platform/testbed and its impact on the performance of the developed middleware and applications. For example, we will measure how it enhances the graduate programs in terms of laboratory capabilities, expanding interdisciplinary research among graduate students and professors. The testbed built in the proposed project will also be evaluated by our graduate students who will use the testbed as a unique platform for their course projects. The project results including software and technical reports will be disseminated through the Web, publications in technical journals, and presentations at professional conferences.

7 Results from Prior NSF Support in the Last Five Years

(1) **Yi Shang** and **Hongchi Shi**

- "ILI: Distributed Systems Laboratory," NSF DUE-9851485, $41,960, 6/1/1998 - 5/31/2000.
- "Incorporating Agent-Based Computing into Computer Science and Engineering Curriculum," NSF DUE-9980375, $74,327, 1/1/2000 - 12/31/2001.
- "CISE Educational Innovation: Integrating Agent Technology into CISE Curriculum Using Lecturelets," NSF EIA-0086230, $419,998, 9/15/2000 - 8/31/2004.

The first project established a dedicated laboratory for teaching in the distributed computing areas. The laboratory consists of one SUN server and twelve SUN workstations connected via a CISCO ATM switch. Courses supported by the laboratory include object-oriented design, operating systems, software engineering, compilers, programming language principles, artificial intelligence, networks, science and engineering of WWW, and parallel and distributed computing (Shi et al., 2000b). In the second project, we investigate how to incorporating agent technology into computer science and engineering curriculum. After a comprehensive study of the benefits of having agent technology as part of the curriculum, we develop a modular approach of organizing material related to agent technology and integrating them into various courses (Shang et al., 2000, Shi et al., 2000a). In the third project, we further develop a set of "smart" instructional components on agent technology that can be integrated across the CISE curriculum (Rodriguez et al., 2002, Shang et al., 2001b). We also develop new Web-based learning techniques by integrating advanced methods in Web technology, machine learning, and educational technology (Chen et al., 2001, Shang et al., 2001b, Shang and Shi, 2000, Shi et al., 2001, Shi et al., 2002a, Shi et al., 2002b).

(2) **Xinhua Zhuang**

- "Advanced Human-Computer Interface for Biomedicine," NSF EIA 9911095, $200,000, 1/1/00 - 12/31/03
- "QoS Guaranteed VTC for Telemedicine over Broadband IP Networks," NSF SBIR Phase I 0232943, $100,000, 1/1/03-12/31/03

In the first project, two systems have been developed: a real-time, interactive multimedia communication system supporting lip-reading and sign language and a multi-channel speech processing system with real-time captioning capability. In the second project, a certain level of needed QoS has been developed for telemedicine oriented video teleconferencing (VTC) (over broadband IP networks) that requires certain QoS guarantees from the network service, no matter what standard application-level protocol is used.

(3) **Sheila Grant**:

- "Engineering Research Center on Wireless Integrated Microsystems," NSF EEC-9986866A, 9/1/2000- . PI: Dr. Kenneth Wise, University of Michigan.
  My involvement spanned from 09-01-00 to 08-31-01 at $150k. We developed chemical sensor patterning strategies (Xu et al., 2002a, Xu et al., 2002b). Laser Based Guidance is a noncontact method that was being used to manipulate and precisely align reactive molecules on a treated substrate. Optical forces generated by a laser were used to trap the reactive molecules and guide them through a hollow tube onto a substrate.
- Prior Equipment Grant
  MRI: "The Acquisition of Instrumentation for Microstructural Characterization of Materials that are Non-Conductive or Include Volatile Phases". PI(s): Thomas Van Dan, Lawrence Sutter, Laurent Matuana, Sheila Grant, and Julia King. Michigan Technological University, Award 0079469, $490,820.00, 09/01/00-.

References

Akyildiz, I. F., Su, W., Sankarasubramaniam, Y., and Cayirci, E. (2002). Wireless sensor networks: A survey. *Computer Networks*, 38(4):393–422.

Andreasson, J., Ekstrom, M., Fard, A., Castano, J. G., and Johnson T. (2002). P1-30: Remote system for patient monitoring using Bluetooh. *The First IEEE International Conference on Sensors.*

Armstrong, G. L., Conn, L. A., and Pinner, R. E. (1999). Trends in infectious disease mortality in the United States in the 20th century. *JAMA*, 281:61-66.

Ban, K. and Gharavi, H. (2002). IEEE 802.11 FHSS receiver design for cluster-based multihop video communications. *Journal of Wireless Communications and Mobile Computing,* vol. 2, issue 6, pp. 595-605.

Beck, L.R., Lobitz, B.M., and Wood B.L. (2000). Remote sensing and human health: New sensors and new opportunities. *Emerging Infectious Diseases*, 6:217-227.

Berkelman, R. L., Bryan, RT, Osterholm, MT, LeDuc, JW, and Hughes, JM. (1994) Infectious disease surveillance: a crumbling foundation. *Science*, 264:368-370.

Beeman, P. (2002). Drugs in animal feed pollute food, lakes, and rivers. *The Des Moines Register*, Sunday, 8/4/02.

Beigl, M., Gellersen, H., and Chmidt, A. (2001). Mediacups: Experience with design and use of computer-augmented everyday objects. *Computer Networks, Special Issue on Pervasive Computing*, 25(4):401–409.

Boudec, J.L., Merz, R., Radunovic, B., and Widmer, J. (2004). A MAC protocol for UWB very low power mobile ad-hoc networks based on dynamic channel coding with interference mitigation, *EPFL Technical Report* ID: IC/2004/02.

Cen, S., Cosman, P. and Voelker, G. (2002). End-to-end differentiation of congestion and wireless losses. *SPIE Multimedia Computing and Networking (MMCN2002).*

Center for Disease Control and Prevention (CDC). *Preventing Emerging Infectious Diseases: A Strategy for the 21st Century.* Atlanta, GA http://www.cdc.gov/ncidod/emergplan/plan98.pdf.

Chang, Y., Zeng, W., Kamel, I. and Alonso, R. (1996). Integrated image and speech analysis for content-based video indexing. *IEEE Inter. Conf. Multimedia Computing and Systems,* Japan.

Chiasserini, C.F., and Rao, R.R. (2001). A comparison between collaborative and non-collaborative coexistence mechanisms for interference mitigation in ISM Bands. *IEEE Vehicular Technology Conference (VTC).*

Cordeiro, C., Abhyankar, S., Toshiwal, R., and Agrawal, D. (2003). A novel architecture and coexistence method to provide global access to/from Bluetooth WPANs by IEEE 802.11 WLANs. *IEEE IPCCC.*

Cordeiro, C., and Agrawal, D. (2002). Employing dynamic segmentation for effective co-located coexistence between Bluetooth and IEEE 802.11 WLANs. *IEEE Globecom.*

Crawford, L., Fromherz, M., Guettier, C., and Shang, Y. (2001). A framework for on-line adaptive control of problem solving. In *Proc. CP'01 Workshop on On-line Combinatorial Problem Solving and Constraint Programming.*

Ennis, G. (1998). Impact of Bluetooth on 802.11 direct sequence. *IEEE P802.11-98/319.*

Estrin, D., Govindan, R., Heidemann, J., and Kumar, S. (1999). Next century challenges: Scale coordinations in sensor networks. In *Proc. ACM MobiComm*, pages 263–270, Seattle, WA.

Fackelmann, K. (2000). Drugs found in tap water. *USA Today Health*. http://www.usatoday.com/life/health /general/lhgen115.htm.

FCC (2002), FCC's UWB First Report & Order.

Fontana, R. (2000). Ultra wideband technology - the wave of the future? *ITC/USA* 2000.

Fromherz, M., Hoeberechts, M., and Jackson,W. (1999). Towards constraint-based actuation allocation for hyper-redundant manipulators. In *CP'99 Workshop on Constraints in Control (CC'99)*, Alexandria, VA.

Fromherz, M., Hogg, T., Shang, Y., and Jackson, W. (2001). Modular robot control and continuous constraint satisfaction. In *Proc. IJCAI-01 Workshop on Modelling and Solving Problems with Constraints*, pages 47–56, Seattle, WA.

Fromherz, M., Shang, Y., Zhang, Y., and Crawford, L. (2003). Constraint-based routing for ad-hoc networks. In *IEEE Int'l Conf. on Information Technology: Research and Education (ITRE)*, pages 306–310, Newark, NJ.

Ganesan, D., Krishnamachari, B., Woo, A., Culler, D., Estrin, D., and Wicker, S. (2002). Complex Behavior at Scale: An Experimental Study of Low-Power Wireless Sensor Networks. Tech. Rep. CSD-TR 02-0013, UCLA.

Glance, N., Snowdon, D., and Meunier, J.- L. (2001). Pollen: using people as a communication medium. *Computer Networks 35*(4), 429–442.

Golmie, N., Dyck, R.E., and Soltanian, A. (2001). Bluetooth and 802.11b interference: simulation model and system result. *IEEE 802.15/195r0.*

Heinzelman, W.B. (2000). Application-specific protocol architecture for wireless networks. Ph.D. dissertation, MIT.

Hill, J., Szewczyk, R., Woo, A., Hollar, S., Culler, D., and Pister, K. (2000). System Architecture Directions for Networked Sensors. In *ASPLOS 2000* (Cambridge, USA).

Howard, A., Mataric, M. J., and Sukhatme, G. S. (2002). Mobile sensor network deployment using potential fields: A distributed, scalable solution to the area coverage problem. In *DARS*, Fukuoka, Japan.

Jackson, W., Fromherz, M., Biegelsen, D., Reich, J., and Goldberg, D. (2001). Control of real time large-scale systems: Airjet object movement system. In *Proc. Fortieth Conference on Decision and Control*, Orlando, FL.

Kahn, J. M., Katz, R. H., and Pister, K. S. J. (1999). Next century challenges: Mobile networking for smart dust. In *Proc. ACM MobiComm*, Seattle, WA.

Kamerman, A. (2000). Coexistence between Bluetooth and IEEE 802.11 CCK solutions to avoid mutual interference, *IEEE 802.11-00/162.*

Li, H. and Shi, H. (2001). Identity-plus-row decomposition and its application in design of parallel projection algorithms. *Journal of Electronic Imaging*, 10(3):814-824.

Li, H. and Shi, H. (2000). A parallel algorithm for volume projections on mesh-connected computers. *The Journal of Supercomputing*, 17(1):5-22.

Li, H. and Shi, H. (1999). A fast algorithm for reconstructing motion compensated blocks in compressed domain. The Special Issue on Distributed Multimedia Information Retrieval, *International Journal of Visual Languages and Computing*, 10(6):607-623.

Mitchell, S. (2002). Antibiotics in animal feed debate heats up in the USA. http://www.organicsconsumers.org/toxic/aniimalfeed051302.cfm.

Pradhan, S.S., Kusuma, J., and Ramchandran, K. (2002). Distributed compression in a dense microsensor network. *IEEE Signal Processing Magazine*, vol. 19, pp. 51-60.

Paulopoulos, S., Kyraicou, E., Berler, A., and Koutsouris, D. (1998). A mobile system for emergency health care provision via telematics support — AMBULANCE. *IEEE Int. Conf. on Information Technology Applications in Biomedicine* (ITAB), pp. 150–154.

Rollins, D. L., Killingsworth, C. R. , Walcott, G. P., Justice, R. K., Ideker, R. E., and Smith, W. M. (2000). A telemetry system for the study of spontaneous cardiac arrhythmias. *IEEE Transactions on Biomedical Engineering*, Vol 47, No. 7, pp. 887 – 892.

Savvides, A., Han, C. C., and Srivastava, M. (2001). Dynamic fine-grained localization in ad hoc networks of sensors. In *ACM/IEEE Int'l Conf. on Mobile Computing and Networking (MOBICON)*.

Shalala, D.E. (1999). Bioterrorism: How prepared are we? *Emerging Infectious Diseases*, 5. http://www.cdc.gov/ncidod/EID/vol5no4/shalala.htm.

Shang, Y. and Fromherz, M. (2003). Experimental complexity analysis of continuous constraint satisfaction problems. *Information Sciences*, (153):1–36.

Shang, Y., Fromherz, M., and Crawford, L. (2002). Efficient cooperative solvers for nonlinear continuous constraint problems. In *Proc. Int. Congress on Mathematical Software (ICMS'02)*, Beijing, China.

Shang, Y., Fromherz, M., Hogg, T., and Jackson, W. (2001a). Complexity of continuous, 3-SAT-like constraint satisfaction problems. In *Proc. IJCAI-01 Workshop on Stochastic Search Algorithms*, pages 49–54, Seattle, WA.

Shang, Y. and Li, L. (1999a). Intelligent agents for designing filter banks in image compression. In *Proc. Parallel and Distributed Methods for Image Processing, SPIE Int'l Symposium on Optical Science, Engineering and Instrumentation*, pages 98–107.

Shang, Y. and Li, L. (1999b). Optimization design of filter banks in subband image coding. In *Proc. IEEE Symposium on Application-Specific Systems and Software Engineering and Technology*, pages 112–119.

Shang, Y. and Li, L. (2002). Precision evaluation of search engines. *World Wide Web*, 5(2):159–173.

Shang, Y., Meng, J., and Shi, H. (2004 (to appear)). Relative localization in wireless sensor networks. In *IEEE Int'l Parallel and Distributed Processing Symposium (IPDPS)*.

Shang, Y. and Ruml, W. (2004, to appear). Improved MDS-based localization. In *IEEE InfoCom*.

Shang, Y., Ruml, W., Zhang, Y., and Fromherz, M. (2003). Localization from mere connectivity. In *ACM MobiHoc*, pages 201–212, Annapolis, MD.

Shang, Y. and Shi, H. (1999). A web-based multi-agent system for interpreting medical images. *World Wide Web*, 2(4):209–218.

Shang, Y. and Shi, H. (2000). IDEAL: An integrated distributed environment for asynchronous learning. In *Proc. ACM Workshop on Distributed Communities on the Web. Lecture Notes in Computer Science.*, volume 1830, pages 182–191.

Shang, Y., Shi, H., and Chen, S. (2000). Agent technology in computer science and engineering curriculum. In *Proc. 5th ACM Annual Conf. on Innovation and Technology in Computer Science Education*, pages 120–123, Helsinki, Finland.

Shang, Y., Shi, H., and Chen, S. (2001b). An intelligent distributed environment for active learning. *ACM Journal on Educational Resources In Computing*, 1(2):1–17.

Shang, Y. and Wah, B.W. (1996). Global optimization for neural network training. *IEEE Computer*, 29:45–54.

Shang, Y. and Wah, B. W. (1997). Discrete lagrangian-based search for solving max-sat problems. In *Proc. 15th Int'l Joint Conf. on Artificial Intelligence*, pages 378–383.

Shang, Y. and Wah, B. W. (1998). A discrete lagrangian-based global-search method for solving satisfiability problems. *Journal of Global Optimization*, 12(1):61–99.

Shang, Y., Wan, Y., Fromherz, M., and Crawford, L. (2001c). Toward adaptive cooperation between global and local solvers for continuous constraint problems. In *Proc. CP'01 Workshop on Cooperative Solvers in Constraint Programming.*

Shi, H. and Ritter, G.X. (1995). A new parallel binary image shrinking algorithm. *IEEE Transactions on Image Processing*, 4(2):224-226.

Shi, H. and Ritter, G.X. (1994). A fast algorithm for image component labeling with local operators on mesh connected computers. *Journal of Parallel and Distributed Computing*, 23(3):455-461.

Shi, H., Ritter, G.X., and Wilson, J.N. (1997). A fast general algorithm for extracting image features on SIMD mesh-connected computers. *Pattern Recognition*, 30(7):1205-1211.

Shi, H., Ritter, G.X., and Wilson, J.N. (1995). Simulations between two reconfigurable mesh models. *Information Processing Letters*, 55:137-142.

Shi, H., Rodriguez, O., Chen, S., and Shang, Y. (2003). Open learning objects as an intelligent way of organizing educational material. *International Journal on E-Learning.*

Shi, H., Rodriguez, O., Shang, Y., and Chen, S. (2002b). Integrating adaptive and intelligent techniques into a web-based environment for active learning. In Leondes, C. T., editor, *Intelligent Systems: Technology and Applications*, volume 4, pages 229–260. CRC Press, Boca Raton, FL.

Shi, H., Shang, Y., and Chen, S. (2000a). A multi-agent system for computer science education. In *Proc. 5th ACM Annual Conf. on Innovation and Technology in Computer Science Education*, pages 1–4, Helsinki, Finland.

Shi, H., Shang, Y., and Chen, S. (2001). Smart instructional component based course content organization and delivery. In *Proc. 6th ACM Annual Conf. on Innovation and Technology in Computer Science Education*, Canterbury, UK.

Shi, H., Shang, Y., Joshi, A., and Jurczyk, M. (2000b). Laboratory-oriented teaching in web and distributed computing. In *Proc. 2000 ASEE Annual Conference & Exposition*, St. Louis.

Shi, H. Zhao, Y., Zhuang, X., and Ren, F. (2002). GAM: A general auto-associative memory model. *EICE Transactions on Information and Systems*, 85-D(7):1153-1164.

Shi, H., Zhao, Y., and Zhuang, X. (1998). A general model for bidirectional associative memories. *IEEE Transactions on Systems, Man and Cybernetics, Part B: Cybernetics*, 28(4):511-519.

Siwiak, K. (2002). Ultra-Wide Band Radio: a new PAN and positioning technology, *IEEE Vehicular Technology Society News*, pp. 4-9.

staccatocommunications (2004). FAQ at http://www.staccatocommunications.com.

Stanford Networking Research Center (SNRC, 2004). A multilayered approach to mobile networking. http://systems.stanford.edu/projects/snrc.html.

Wagner, R., Baraniuk, R., and Nowak, R. (2003). Distributed image compression for sensor networks using correspondence analysis and super-resolution. *Proc. IEEE Inter. Confer. Image Proc.*

Wah, B. W. and Shang, Y. (1996). A new global optimization method for neural network training. In *Proc. Int'l Conf. on Neural Networks*, Washington, DC. (Plenary Speech).

Wah, B. W., Shang, Y., and Wu, Z. (1999). Discrete lagrangian method for optimizing the design of multiplierless qmf filter banks. *IEEE Transactions on Circuits and Systems II*, 46(9):1179–1191.

Wah, B. W., Wang, T., Shang, Y., and Wu, Z. (2000). Improving the performance of weighted Lagrange-multiplier methods for nonlinear constrained optimization. *Information Sciences*, 124:241–272.

Wen, J., Severa, M., Zeng, W., Luttrell, M. and Jin, W. (2002). A format compliant configurable encryption framework for access control of video. *IEEE Tran. Circuits & Systems for Video Technology, Special Issue on Wireless Video*, pp. 545-557.

Xie, B. and Zeng, W. (2004). Rate-distortion optimized dynamic bitstream switching for scalable video streaming. Submitted to *IEEE Inter. Confer. Multimedia & Expo.*

Xu, J., Grant, S., and Pastel, R. (2002a). Patterning of bio-molecules by laser guidance in hollow-core optical fibers. *IEEE Transaction in Biomedical Engineering.*, 49(12):1475-1478.

Xu, J., Zhou, C., Grant, S., Nadgorny, E., and Drelich, J. (2002b). Laser guidance deposition technique for patterning 3D microstructures made of nanoparticles with varying surface functionality. *Proc. MRS Spring Conference.*

Zhang, Y. and Fromherz, M. (2004). Message-initiated constraint-based routing for wireless ad-hoc sensor networks. In *Proc. IEEE Consumer Communications and Networking Conference.*

Zeng, W. and Liu, B. (1996). Directional spatial interpolation for DCT-based low bit rate coding. *Proc. IEEE International Conf. Acoustic, Speech, and Signal Processing*, Atlanta.

Zeng, W. and Liu, B. (1999a). Geometric-structure-based error concealment with novel applications in block-based low bit rate coding. *IEEE Trans. on Cir. and Sys. for Video Technology*, pp. 648-665.

Zeng, W., Wen, J., and Severa, M. (2002). Fast self-synchronous content scrambling by spatially shuffling codewords of compressed bitstreams. *IEEE Inter. Conf. Image Proc.*

Zeng, W. and Lei, S. (2003). Efficient frequency domain selective scrambling of digital video. In *IEEE Tran. Multimedia*, vol. 5, no. 1, pp. 118-129.

MPEG4 IPMP FPDAM (2002). ISO/IEC 14496-1:2001/ AMD3, *ISO/IEC JTC 1/SC 29/WG11 N4701.*

Zeng, W. and Liu, B. (1999b). A statistical watermark detection technique without using original images for resolving rightful ownerships of digital images. *IEEE Trans. Image Processing* , vol. 8, no. 11, pp. 1534-1548.

Zeng, W. and Wen, J. (2002). 3G wireless multimedia: technologies and practical issues. Invited paper, *Journal of Wireless Communications and Mobile Computing, Special Issue on Multimedia over Mobile IP*, vol. 2, issue 6, pp. 563-572.

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION University of Missouri-Columbia	FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Yi Shang	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Yi Shang - Assistant Professor					
2. Sheila A Grant - Assistant Professor					
3. Haibin Lu - Assistant Professor					
4. Hongchi Shi - Associate Professor					
5. Wenjun Zeng - Associate Professor					
6. (1) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (6) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES					
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (3) GRADUATE STUDENTS					
4. (0) UNDERGRADUATE STUDENTS					
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (0) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) Wireless Sensor Networks $ 200,000					
TOTAL EQUIPMENT				200,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				4,500	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (5) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				2,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				1,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				3,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				274,470	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				27,441	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				301,911	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 301,911	$
M. COST SHARING PROPOSED LEVEL $ Not Shown	AGREED LEVEL IF DIFFERENT $				

PI/PD NAME Yi Shang	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* Dona mckinney	Date Checked	Date Of Rate Sheet	Initials - ORG

1 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET COMMENTS - Year 1

Other Senior Personnel Name - Title	Cal	Acad	Sumr	Funds Requested

SUMMARY PROPOSAL BUDGET

YEAR 2

FOR NSF USE ONLY			
ORGANIZATION: University of Missouri-Columbia	PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: Yi Shang	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months ACAD	SUN	Funds Pequested By	Funds granted by NSF (if different)
1. Yi Shang - Assistant Professor				
2. Sheila A Grant - Assistant Professor				
3. Haibin Lu - Assistant Professor				
4. Hongchi Shi - Associate Professor				
5. Wenjun Zeng - Associate Professor				
6. (1) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)				
7. (6) TOTAL SENIOR PERSONNEL (1 - 6)				
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)				
1. (0) POST DOCTORAL ASSOCIATES				
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)				
3. (3) GRADUATE STUDENTS				
4. (0) UNDERGRADUATE STUDENTS				
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				
6. (0) OTHER				
TOTAL SALARIES AND WAGES (A + B)				
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)				
TOTAL EQUIPMENT			0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)			4,635	
2. FOREIGN			0	
F. PARTICIPANT SUPPORT COSTS				
1. STIPENDS $ 0				
2. TRAVEL 0				
3. SUBSISTENCE 0				
4. OTHER 0				
TOTAL NUMBER OF PARTICIPANTS (5) TOTAL PARTICIPANT COSTS			0	
G. OTHER DIRECT COSTS				
1. MATERIALS AND SUPPLIES			2,060	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION			1,030	
3. CONSULTANT SERVICES			0	
4. COMPUTER SERVICES			0	
5. SUBAWARDS			0	
6. OTHER			0	
TOTAL OTHER DIRECT COSTS			3,090	
H. TOTAL DIRECT COSTS (A THROUGH G)			76,705	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)				
TOTAL INDIRECT COSTS (F&A)			28,265	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)			104,970	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)			0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)			$ 104,970	$

M. COST SHARING PROPOSED LEVEL $ Not Shown — AGREED LEVEL IF DIFFERENT $

PI/PD NAME: Yi Shang	FOR NSF USE ONLY — INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*: Dona mckinney	Date Checked	Date Of Rate Sheet	Initials - ORG

2 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET COMMENTS - Year 2

Other Senior Personnel Name - Title	Cal	Acad	Sumr	Funds Requested

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION: **University of Missouri-Columbia**	FOR NSF USE ONLY — PROPOSAL NO.	DURATION (months): Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Yi Shang**	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Yi Shang - Assistant Professor**					
2. **Sheila A Grant - Assistant Professor**					
3. **Haibin Lu - Assistant Professor**					
4. **Hongchi Shi - Associate Professor**					
5. **Wenjun Zeng - Associate Professor**					
6. (**1**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (**6**) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES					
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (**6**) GRADUATE STUDENTS					
4. (**0**) UNDERGRADUATE STUDENTS					
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (**0**) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ **200,000**					
TOTAL EQUIPMENT				**200,000**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**9,135**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**10**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**4,060**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**2,030**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**0**	
TOTAL OTHER DIRECT COSTS				**6,090**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**351,175**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**55,706**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**406,881**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **406,881**	$
M. COST SHARING PROPOSED LEVEL $ **Not Shown**	AGREED LEVEL IF DIFFERENT $				

PI/PD NAME: **Yi Shang**	FOR NSF USE ONLY — INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*: **Dona mckinney**	Date Checked	Date Of Rate Sheet	Initials - ORG

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

Budget Justification

Personnel

Tuition charges. The University of Missouri-Columbia has an educational fee remission program in which tuition for graduate students who are working on grant/contract projects is paid directly from the grant/contract. Estimates are based on 9 credit hours per semester (winter/fall) and 4 hours (summer) for each student. The fee per student credit hour will be $243.70 in 2004-2005 and $251.01 in 2005-2006.

Medical insurance coverage at a cost of $1,218 for academic year 2004-2005 is provided for Graduate Research Assistants with a 3% yearly increase thereafter.

Travel

University meal expenses are limited to $10.00 - breakfast; $10.50 - lunch; $21.50 - dinner. Airfare and ground transportation for trips to conferences, meetings, and site visits, etc. will be at the lowest possible rate available at time of travel. Mileage reimbursement for use of one's personal vehicle is $0.375/mile. Cost estimates provided are based on previous travel. A 3% increase is applied each year thereafter.

Materials and Supplies

Funds requested for materials and supplies that include reference materials, paper, diskettes, library costs, laboratory supplies and other incidental supplies that are principally expendable in nature. A 3% increase is applied each year thereafter.

Publication Costs

Funds allocated for publication include those costs necessary for the dissemination of results from this work. These costs include, among other things, reproduction costs, mailing costs, expenses directly associated with producing reports, and costs for placing research results into the public domain. A 3% increase is applied each year thereafter.

Facilities and Administrative Costs

The University of Missouri has finalized negotiations with its cognizant agency (DHHS) concerning F&A rates. The research rate for on campus research projects changes to 47% in July 2004. Documentation is in the signature process and is not available for distribution at this time. When available, a copy will be forwarded to you for your files.

Modified Total Direct Costs. Equipment valued over $5,000, and tuition costs are exempt from F&A costs. F&A charges are applied on the first $25,000 of subcontracts.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Yi Shang**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **CISE Educational Innovation: Integrating Agent Technology into CISE Curriculum Using Lecturelets**

Source of Support: **NSF**

Total Award Amount: $ **420,000** Total Award Period Covered: **09/01/00 - 08/31/04**

Location of Project: **University of Missouri-Columbia**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **1.00**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Wireless Sensor Networks: Middleware and Applications**

Source of Support: **NSF**

Total Award Amount: $ **406,881** Total Award Period Covered: **08/01/04 - 07/31/06**

Location of Project: **University of Missouri-Columbia**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.00**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title

Source of Support:

Total Award Amount:

Location of Project:

Person-Months Per Y

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

---

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Sheila A. Grant

Other agencies (including NSF) to which this proposal has been/will be

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Person-Months Per

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Pro

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project

Sou

To

Lo

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Projec

Sour

Total

Loca

Pers

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title NIH Fellowship: Biocompatibility and Function in a Troponin-T Biosensor.

Source of Support: NIH

Total Award Amount: $172,540,937 Total Award Period Covered:07/03/03-07/02/08

Location of Project: University of Missouri

Person-Months Per Year Committed to the Project. 0.0 Cal: Acad: Sumr: 0.0

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Sheila A. Grant

Other agencies (including NSF) to which this proposal has been/will be

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Pr

Sou

Tot

Lc

Person-Mon

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project

Source

Total A

Locatio

Persor

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Person-Months

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. 0 Cal: Acad: Sumr: 0.0

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. 0.0 Cal: Acad: Sumr: 0.0

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Sheila Grant**	Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **Wireless Sensor Networks: Middleware and Applications**

Source of Support: **NSF**
Total Award Amount: $ **406,881** Total Award Period Covered: **08/01/04 - 07/31/06**
Location of Project: **University of Missouri-Columbia**
Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.00**

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

---

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

 USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Haibin Lu**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **Wireless Sensor Networks: Middleware and Applications**

Source of Support: **NSF**
Total Award Amount: $ **406,881** Total Award Period Covered: **08/01/04 - 07/31/06**
Location of Project: **University of Missouri-Columbia**
Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.00**

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Hongchi Shi**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **CISE Educational Innovation: Integrating Agent Technology into CISE Curriculum Using Lecturelets**

Source of Support: **NSF**

Total Award Amount: $ **420,000** Total Award Period Covered: **09/01/00 - 08/31/04**

Location of Project: **University of Missouri-Columbia**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **1.00**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Wireless Sensor Networks: Middleware and Applications**

Source of Support: **NSF**

Total Award Amount: $ **406,881** Total Award Period Covered: **08/01/04 - 07/31/06**

Location of Project: **University of Missouri-Columbia**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.00**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal

Source of Supp

Total Award Am

Location of Proje

Person-Months P

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

 USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Wenjun Zeng**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **Wireless Sensor Networks: Middleware and Applications**

Source of Support: **NSF**
Total Award Amount: $ **406,881** Total Award Period Covered: **08/01/04 - 07/31/06**
Location of Project: **University of Missouri-Columbia**
Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.00**

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

 USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Xinhua Zhuang**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Wireless Sensor Networks: Middleware and Applications**

Source of Support: **NSF**

Total Award Amount: $ **406,881** Total Award Period Covered: **08/01/04 - 07/31/06**

Location of Project: **University of Missouri-Columbia**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Enhanced Multimedia Telehealth for Hearing Disabilities**

Source of Support: **NIH**

Total Award Amount: $ **1,781,132** Total Award Period Covered: **08/01/01 - 07/31/06**

Location of Project: **University of Missouri-Columbia**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **1.00**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal

Source of Support·

Total Award Amou

Location of Project:

Person-Months Per Yє

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

FACILITIES, EQUIPMENT & OTHER RESOURCES

FACILITIES: Identify the facilities to be used at each performance site listed and, as appropriate, indicate their capacities, pertinent capabilities, relative proximity, and extent of availability to the project. Use "Other" to describe the facilities at any other performance sites listed and at sites for field studies. USE additional pages as necessary.

Laboratory: **The general facilities and equipment are supported by a combination of resources from the Computer Science Department and Campus Computing at the University of Missouri-Columbia. The University has been awarded an NSF grant that partially supports establishing high performance network**

Clinical:

Animal:

Computer:

Office:

Other:

MAJOR EQUIPMENT: List the most important items available for this project and, as appropriate identifying the location and pertinent capabilities of each.

OTHER RESOURCES: Provide any information describing the other resources available for the project. Identify support services such as consultant, secretarial, machine shop, and electronics shop, and the extent to which they will be available for the project. Include an explanation of any consortium/contractual arrangements with other organizations.

LABORATORY FACILITIES (continued):

connectivity under the Next Generation Internet "Connections to the Internet" program to the Very High Performance Backbone Network Service (vBNS). The CS department was the principal lead on the NSF vBNS proposal and has already installed a direct OC-3 connection to the campus ATM backbone via an IBM 8285 ATM switch and an IBM 8274 Ethernet edge switch (10BaseT/100Base/TX).
The following three research laboratories were founded by PIs in the past 6~7 years: (1) Distributed Computing Laboratory (Yi Shang and Hongchi Shi) has two Linux servers, eight Windows XP workstations, one Sun Enterprise server, twelve Sun workstations, and one RAID storage system, all funded by NSF. (2) Mobile Networking and Multimedia Communications Laboratory (Wenjun Zeng and Haibin Lu) currently has five Windows XP workstations, two Laptops, two PDAs, high speed Ethernet and wireless LAN, and Linux servers. (3) Multimedia Communications and Visualization Laboratory (Zhuang) has equipment worth $1.8 million funded by grants from NASA, NSF, and SCI. It currently hosts fifteen Silicon Graphics workstations (eight R 10000 O2-s, four dual processor Octanes, two Indogo2s, and one Onyx2 four processor Infinity Reality supercomputer with 80 GB disk array storage system). The Octane and Onyx2 workstations are all stereo capable and can be used to develop 3-D display using the StereoGraphic CrystalEyes stereo hardware. The distributed cluster of workstations contains a total of over 2 gigabytes of memory (RAM), 162 gigabytes of disk storage, over 25 CPUs, a variety of graphics capabilities, 100BseT network connectivity and ATM capable. In addition, five high performance PCs (three Dell PIV 1.2 GHz with 512MB RAM, two Dell 1.8G with 512M RAM) have been recently added to the Lab facilities for developing PC-based Videoconferencing over IP and Spoken Language Processing technologies.

From: rrodrigu@nsf.gov
Reply-To: rrodrigu@nsf.gov
To: shangy@missouri.edu; grantsdc@missouri.edu; shangy@missouri.edu
CC: rrodrigu@nsf.gov; dhutchin@nsf.gov
Subject: NSF Approval of Continuing Grant Increment - Award ID - 0423386
Status: Sent on Mon 06/05/2006 06:38 PM

Notification of NSF Approval of Additional Funding Support

Award No. CNS - 0423386
Amendment No. 002
Release Date: 06/05/2006
Released By: Rita V. Rodriguez
Amount: $96,630
New Expiration Date: 08/31/2007

As authorized by the original award, the National Science Foundation hereby releases $96,630 for additional support of the award referenced above. The award, with this amendment, now totals $298,184 and will expire on 08/31/2007.

The attached budget indicates the amounts, by categories, on which NSF has based its continued support.

The award is subject to the conditions available at http://www.nsf.gov/home/grants/grants_fdp.htm.

Any technical or programmatic questions regarding this notification should be addressed to the cognizant NSF Program Officer: Rita V. Rodriguez , rrodrigu@nsf.gov, (703)292-8950.

Any award specific questions of an administrative or financial nature should be addressed to the grants official at http://www.nsf.gov/bfa/dga/docs/liaison.pdf. The cognizant grants official can be identified by associating the three-letter division identifier in the above-referenced award number with the grants official for that division on the liaison website.

Annual Report for Period: 09/2004 - 09/2005
Principal Investigator: Shang, Yi .
Organization: U of Missouri Columbia
Title:
CISE-RR: Wireless Sensor Networks: Middleware and Applications

Submitted on: 05/26/2005
Award ID: 0423386

Project Participants

Senior Personnel

Name: Shang, Yi
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Shi, Hongchi
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Grant, Sheila
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Zeng, Wenjun
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Lu, Haibin
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Zhuang, Xinhua
Worked for more than 160 Hours: No
Contribution to Project:
Dr. Zhuang is working on multimedia communication over wireless networks. His students have access to the wireless equipment, PCs, and computing and storage servers purchased using this grant.

Post-doc

Graduate Student

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities:

The major research and education activities are as follows:

ò Purchase equipment for building resource-lean and resource-rich WSNs. For the resource-lean sensor network, we bought 30 MICA2 Motes, the wireless sensor nodes, and associated sensing and programming boards from Crossbow. For resource-rich sensors, we bought both wired and wireless cameras to form wireless video networks. In addition, we bought one 4-CPU Dell Linux computing server, one Dell storage server with an 800 GB RAID system, 6 Windows XP workstations, and 6 laptops.

ò Investigate the integration of resource-lean and resource-rich WSNs. We have programmed and experimented with the Mote sensor networks that have light, temperature, and acoustic sensors, and started to develop software to connect it with the wireless video sensor network.

ò Design and develop the adaptive optimization methods for resource-lean WSNs. Using node localization problem as an example, we analyze the theoretical bounds and the computational complexity of existing optimization methods. We are developing adaptive, hybrid, and distributed methods.

ò Design and develop efficient localization and routing methods based on the adaptive optimization on resource-lean WSNs. Localization and routing problems are formulated into optimization problems of various forms and solved by different optimization-based algorithms.

ò Design efficient distributed source coding (DSC) algorithms for use in wireless video sensor networks, and develop wireless video conferencing and streaming system based on peer-to-peer network architecture. We explore efficient joint source-channel coding methodologies in distributed source coding. We also explore emerging network architecture in improving the performance of wireless video conferencing/streaming systems, and expect to use the system to be developed for distance learning applications. Some media security issues in wireless video sensor networks have also been studied.

ò In biosensor development, we are developing portable diagnostic systems to detect a pathogen that infects swine herds in the U.S. Porcine Reproductive and Respiratory Syndrome Virus (PRRSV) is a devastating and highly contagious disease that causes dramatic losses in swine production. The mortality rate of piglets can be approximately one piglet surviving per litter. This high mortality rate accompanied with some swine showing no signs of infection has created a desperate need for tests for PRRS detection that is fast, accurate, wireless, and portable. We have been working on the development of two diagnostic kits. One kit is a PCR-on-a-Chip, and the other is a FRET Immunosensor.

Findings:

The following findings have been obtained from our research using the newly purchased equipment.

ò We have used the pursuer and evader games as the driving application to integrate the resource-lean and resource-rich WSNs. In the application, the pursuers, such as Unmanned Aerial Vehicles (UAVs) or Unmanned Ground Vehicles (UGVs), search and capture evaders, with the help of wireless sensor networks. Through the work, we have better understanding of the technical issues such as target detection by sensors, message communication in wireless networks, purser decision making and commanding the sensor networks, etc.

ò We have investigated light-weighted optimization techniques for managing WSNs and studied machine learning methods for selecting appropriate optimization methods. In order to address large-scale problems, we have developed methods to adaptively decompose a large non-uniform network into smaller uniform sub-nets, extract important features of the sub-nets and select appropriate optimization methods for the sub-nets.

ò We have several new node localization methods and topology control methods and demonstrated their promising results through extensive simulation. We have developed methods based on the estimation theory for analysis of localization errors to better understand the behavior of localization systems.

ò In non-binary DSC, we found that symbol-domain correlation cannot be losslessly projected to binary-domain for channel coding. By quantization indice remapping using Gray codes, we can make the source quantization/coding adapted to the channel properties, making the binary domain statistical correlation more consistent with the symbol domain correlation. We expect that the more general idea of joint source-channel coding can be further exploited to improve the performance of DSC systems. Our preliminary results also showed that cross-layer optimization can significantly improve the streaming media performance in time-varying networks such as wireless sensor networks, and that media security architecture needs to be specifically designed for WSN.

ò We have concluded that the FRET immunosensor is a feasible method to detect PRRS. The technique utilizes the chemical transduction method of Fluorescence Resonance Energy Transfer (FRET). Antibody/protein complexes are labeled with FRET fluorophores (donor and acceptor fluorophores). When antibodies bind to the specific antigen, the Fab region of the antibody undergoes a conformational change which causes the distance between the donor and the acceptor fluorophore to change. Thus, we can achieve high sensitivity with a low incidence of false positives. Our other diagnostic kit is a PCR-on-a-Chip. This micro-fluidic assay will be utilized to quickly analyze microscopic samples of DNA for field applications. The DNA microanalyzer consists of a micro-PCR chamber, micropumps, and microheaters. Additional components of the device that will be fabricated include gel electrophoresis micro-channels and solid core waveguide fluorescence collectors. The intended analyzer is a micro-fluidic platform that is principally based on the three-step polymerase chain reaction (PCR) mechanism. Our findings have indicated that the micro-PCR chamber had comparable amplification to conventional PCR equipment and that the chip is extremely durable and can be thermally cycled without any damaging thermal stresses.

Training and Development:

Three PhD students are working on the wireless sensor network localization, topology control, and message routing tasks. One PhD student and two MS student are working on wireless video sensor networks and cross layer optimization. One PhD student and one MS student are working on solving the pursuer and evader application using heterogeneous sensor networks. One PhD student and one MS student are working on the field diagnostic test kits.

The students are learning basic research methodologies, multidisciplinary tasks, sensor and network design, statistical methods, computation and complexity analysis, algorithm development, embedded software implementation, experimental design, and empirical approaches.

Outreach Activities:

1. Wireless Sensor Network Lab exhibits during the College of Engineering Open House at the University of Missouri-Columbia in March 2005. Over 1200 K-9 students attended the open house.

2. Poster presentations at the 2005 Computer Science Department Graduate Student Research Exhibition at the University of Missouri-Columbia in May 2005.

3. Poster presentations at the 2005 Life Sciences Week at the University of Missouri. Honorary Mention: A FRET Immunosensor for PRRS.

4. Poster presentation at the 2005 Institute of Biological Engineering conference (Athens, GA): Detection of PRRS Using a FRET Immunosensor, Brian Heits, Darcy Lichlyter, Steven Kleiboeker, and Sheila A. Grant.

Journal Publications

X. Li, H. Shi, and Y. Shang, "Sensor Network Localization Based on Sorted RSSI Quantization", Int?l Journal of Ad Hoc and Ubiquitous Computing, p. , vol. , (2005). Accepted

Y. Shang and H. Shi, "Flexible Energy Efficient Density Control on Wireless Sensor Networks", Ad Hoc Networks Journal, p. , vol. , ( ). Submitted

S. Bhattacharya, V. Korampally, Y. Gao, SA Grant, S. Kleiboeker, K. Gangopadhyay, S. Gangopadhyay, "A novel on-chip platform for amplification of DNA", Biotechnology Process, p. , vol. , ( ). Submitted

W. Zeng, J. Lan, and X. Zhuang, "Security for Multimedia Adaptation: Architectures and Analysis", IEEE Multimedia Magazine, p. , vol. , ( ). Submitted

B. Xie and W. Zeng, "A Fast Bitstream Switching Algorithm for Real-time Adaptive Multicasting of Video", IEEE Trans. Circuits & Systems for Video Technology, p. , vol. , ( ). Submitted

Books or Other One-time Publications

H. Shi, X. Li, Y. Shang, and D. Ma, "Cramer-Rao Bound Analysis of Quantized RSSI Based Localization in Wireless Sensor Networks", (2005). Proceedings, Accepted
Collection: Proc. IEEE/IFIP Int'l Workshop on Parallel and Distributed Embedded Systems
Bibliography: Fukuoka, Japan, July 2005.

B. Yin, H. Shi, and Y. Shang, "A Two-level Strategy for Topology Control in Wireless Sensor Networks", (2005). Proceedings, Accepted
Collection: Proc. 1st IEEE Int'l Workshop on Heterogeneous Wireless Sensor Networks
Bibliography: Fukuoka, Japan, July 2005.

Y. Shang and H. Shi, "Coverage and Energy Tradeoff in Density Control on Sensor Networks", (2005). Proceedings, Accepted
Collection: Proc. 11th IEEE Int'l Conf. Parallel and Distributed Systems
Bibliography: Fukuoka, Japan, July 2005.

A. Ahmed, Y. Shang, and H. Shi, "Variants of Multidimensional Scaling for Node Localization", (2005). Proceedings, Accepted
Collection: Proc. 11th IEEE Int'l Conf. Parallel and Distributed Systems
Bibliography: Fukuoka, Japan, July 2005.

X. Li, H. Shi, and Y. Shang, "A Sorted RSSI Quantization Based Algorithm for Sensor Network Localization", (2005). Proceedings, Accepted
Collection: Proc. 11th IEEE Int'l Conf. Parallel and Distributed Systems
Bibliography: Fukuoka, Japan, July 2005.

A. Ahmed, H. Shi, and Y. Shang, "SHARP: A New Approach to Relative Localization in Wireless Sensor Networks", (2005). Proceedings, Accepted
Collection: Proc. 2nd IEEE International Workshop on Wireless Ad Hoc Networking
Bibliography: Columbus, OH, June 2005.

Y. Shang, J. Shen, and H. Shi, "A New Density Control Algorithm for Sensor Networks", (2004). Proceedings, Published
Collection: Proc. 1st IEEE Int'l Workshop on Embedded Networked Sensors
Bibliography: Tampa, FL, Nov. 2004.

M. Sullivan and W. Zeng, "A Protocol for Simultaneous Real Time Playback and Full Quality Storage of Streaming Media", (2005). Proceedings, Published
Collection: Proc. IEEE Inter. Confer. Communications
Bibliography: Seoul, Korea, May 2005.

B. Xie and W. Zeng, "On the rate-distortion performance of dynamic bitstream switching mechanisms", (2005). Proceedings, Accepted
Collection: Proc. IEEE Inter. Confer. Multimedia and Expo
Bibliography: July 2005.

W. Liu and W. Zeng, "Non-Binary Distributed Source Coding Using Gray Codes", (2005). Proceedings, Submitted
Collection: IEEE Workshop on Multimedia Signal Processing
Bibliography: Shanghai, China, Nov. 2005

P. Zhu, W. Zeng, and C. Li, "Joint Design of Source Rate Control and QoS-Aware Congestion Control for Streaming Video over the Internet", (2005). Proceedings, Submitted
Collection: IEEE Workshop on Multimedia Signal Processing
Bibliography: Shanghai, China, Nov. 2005

Web/Internet Site

URL(s):
http://dcsn.cs.missouri.edu/
Description:
It is the Web site of the Distributed Computing & Sensor Networks Research Laboratory. The lab is supported by this award.

Other Specific Products

Contributions

Contributions within Discipline:

The techniques we developed will contribute to more efficient and effective middleware for building wireless sensor networks (WSNs). The adaptive optimization methods can be applied to a number of networking problems. The improved localization, data-centric routing, and topology control methods can be applied to many important sensor network applications. The new cross-layer optimization techniques for streaming media enable high quality video delivery using bandwidth-limited channels. The effective integration of resource-lean and resource-rich sensor nodes is important in developing heterogeneous sensor networks. In bio-sensor development, the discovery we are making in lab-on-a-chip platforms can be applied to other analytes of interest. The FRET immunosensor for field sensing can also be applied to other analytes of interest.

Contributions to Other Disciplines:

The development of sensors and special-purpose sensor networks requires multidisciplinary teams. The sensor development is being inputted into wireless, remote sensing. The sensor network technologies are being used in real-time blast-resistant applications.

Contributions to Human Resource Development:

The project enables us to train 6 PhD and 4 MS students.

Contributions to Resources for Research and Education:

The purchased equipment enables us to establish a research lab for our faculty, PhD students, and MS students to conduct research in wireless sensor networks. The equipment provides a state-of-the-art experimental environment that facilitates research collaboration.
We taught a graduate-level topic course on wireless sensor networks in the Department of Computer Science, Univ. of Missouri-Columbia, in the winter semester of 2005. The course was supported by the purchase equipment and received very positive feedback from the students.

Contributions Beyond Science and Engineering:

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Unobligated funds: less than 20 percent of current funds

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Organizational Partners

Any Product

Contributions: To Any Beyond Science and Engineering