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"Center for Excellence in Integrated Smart Sensor Surveillance System"

PI: Vir Phoha

Lead Institution: Louisiana Tech University

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II. Contract Work Plan
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Proposal Narrative (without appendices)

COVER PAGE FOR POST-KATRINA SUPPORT FUND INITIATIVE
PRIMARILY RESEARCH SUBPROGRAM PROPOSALS
BOARD OF REGENTS SUPPORT FUND, FY 2006-07

011PKSFI-R-07

1. Submission Discipline: G Biological Sciences G Information Technology G Materials Science (check only one)	(For BoR Use Only) Application Number:
2. Name(s) of Lead Submitting Institution of Higher Education: Louisiana Tech University (Include Branch/Campus/Other Components)	
3. Address of Lead Institution of Higher Education: (Include Dept/Unit, Street Address/P.O. Box Number, City, State, Zip Code)	Computer Science, College of Engineering and Science Nethken Hall, P.O. Box 10348, Arizona Ave., Louisiana Tech University Ruston, LA 71272
4. Title of Proposed Project:	Center of Excellence in Integrated Smart Sensor Surveillance System

5. Proposed Duration: (Circle # of Yrs.) 1 2 3 4 5	6. Funds Requested	P-KSFI Year 1:	ESIP:	Project Total:
		$ 384,663	$	$3,638,104

7. Name(s) of Partnering Institution(s)

LSU-Baton Rouge

8. Does This Proposal Contain Confidential or Proprietary Information Which Falls Into a Category Described in R.S. 44:4(16)?
G YES G NO X (NOTE: If YES, the proposal MUST be appropriately marked.)

By signing and submitting this proposal, the signators are certifying that: (1) the proposed project has not already been funded/is not currently being funded/has not been promised funding; (2) this proposal has been reviewed and approved by an Institutional Screening Committee; and (3) the institution and the proposed project are in compliance with all applicable Federal and State laws and regulations, including, but not limited to, the required certifications set forth in: (a) Grants for Research and Education in Science and Engineering, NSF Grant Proposals Guide (GPG), NSF 03-2, effective 10/1/02, and (b) 45CFR 620, Subpart F (Requirements for a Drug-Free Workplace).

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* If multiple deans from the lead institution are involved in project activities, the dean with authority over the primary submitting department will serve as signatory for all.

(Form 1-PKSFI-PRS, 1-2007)

2 PROJECT SUMMARY

Name of Lead Institution (Include Branch/Campus): Louisiana Tech University
Name(s) of Partnering Institution(s) (Include Branch/Campus): Louisiana State University, Baton Rouge
Principal Investigators: Vir V. Phoha, S.S. Iyengar, Gabrielle Allen, Peter Chen, Kody Varahramyan
Title of Project: Center of Excellence in Integrated Smart Cyber-Centric Sensor Surveillance Systems
Abstract (DO NOT EXCEED 250 WORDS):

This project will establish a center of excellence dedicated to education and research in cyber security, sensors, and networks with plans to achieve world-wide recognition, attract highly qualified information technology researchers to the State, and make lasting contributions to economic development. Eight eminently qualified computer scientists and engineers from Louisiana Tech University and Louisiana State University form the core of the center to conduct research addressing critical national issues related to cyberspace. The team will be supplemented by four new faculty, four post-doctoral fellows, and numerous support staff and students. The project builds upon existing well-funded research and education programs (ONR, DARPA SensIT, ARO, AFRL, NSF) of the research team. It capitalizes upon the convergence of recent State investments in information technology (LONI, CEnIT, CCT, I*f*M) with current federal investments in the U.S. Air Force's Cyberspace Command Center at Barksdale Air Force Base, which creates a unique and timely opportunity for establishing a *world-class* research center. The center will develop partnerships with local, national and international academic institutes and industries to support research and education. A robust commercialization infrastructure (Enterprise Center, LTTO, BTI) will support commercializing technologies and establish services that support secure cyber operations in the military and the private sector. An advisory board composed of leaders from academia, national laboratories, government, and industry will oversee the center. Successful execution of the project will result in a *self-sustained* center with a well-defined research agenda, demonstrable development, research opportunities for students, and a broad impact on Louisiana's economy.

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4 GOALS AND OBJECTIVES

The **ultimate goal** of this project is to establish a center of excellence dedicated to education and research in cyber security, sensors, and networks which will soon achieve world-wide recognition, attract highly qualified information technology researchers to the State, and make lasting contributions to economic and human resource development. This will be accomplished by achieving three objectives: (1) develop a set of core research foundations in evolvable sensor hardware/software for cyber security and the corresponding transformational information technologies for the early prediction, detection, and control of anomalous behavior in cyberspace; (2) develop a world-class multi-institutional, multi-disciplinary center of excellence in Louisiana to support this research; and (3) build strategic collaborative relationships between national and international academic and industrial partners, and with the Air Force's Cyberspace Command Center (AFCyber) at Barksdale Air Force Base (BAFB). Year-wise objectives follow.

During the first year, the research will focus on developing cyber grid structures, on socio-biological principles of territory formulation, and on adaptive sensing of non-stationary environments. These will lay the foundation for further, more narrowly focused programs in the future. The core group mentioned in the Project Summary will organize the first of a continuing series of conferences on cybersecurity-related topics. The invited participants, all accomplished scientists or high-level industry and government representatives, will facilitate the creation of the external Advisory Board for the proposed center.

The main objective in the second year will be to *formally establish the multi-institutional multi-disciplinary center of excellence (hereafter referred to as the Center).* A main research priority is expected to be energy-efficient survivable routing for the dissemination of sensor data to distributed cyber systems. Discussions currently in progress with the high-level administration of the BAFB are expected to lead to additional research projects in which the USAF will have a keen interest. A second objective will be to develop short courses and certificate programs to provide further training to professionals, thus contributing to the development of a technologically sophisticated workforce in the region. Such programs as well as university courses will be delivered to the BAFB, thus expanding Louisiana Tech's current academic program at the Base.

The objectives in years three to five will be to continue to build the Center by focused recruiting of faculty, continued pursuit of external funding, aggressive recruiting of highly qualified graduate students, and cultivation of relationships with local, national, and international industrial partners, national laboratories, and defense contractors. A combination of external support and institutional commitments that extend beyond the grant-period will make the Center self-sustaining at the end of this period.

The project will achieve the *next level of convergence in the technologies that interact directly with the physical world and with humans in dynamic and uncertain environments, cognizant of dynamic goals and the evolving physics, seamlessly spanning time and space to monitor change, and collaborating with humans to actuate purposeful distributed response.* Such an advance will not only be a significant contribution to information technology and a key component of the future national security apparatus, but will also have tremendous potential for direct and indirect economic impact and job creation in the region and State.

5 NARRATIVE

5.a PROJECT RATIONALE AND STRUCTURE

Real-time detection and identification of both normal and unusual patterns and rare patterns of activities (for example intrusions in cyber infrastructure, sudden movement of troops, or increases in communications traffic between areas of interest) are imperative for advancing early warning and response capabilities of modern surveillance systems. Deploying sensors to cover large areas, such as coastlines and land masses pose specific problems related to communication, maintenance, and collection of information. For example, heterogeneous sensors with limited sensing radii are individually prone to failure and noise contamination, and human oversight of so many sensors is not possible. In addition, real-time processing of the massive amount of data that these sensors generate has to be transmitted, interpreted; and if rare patterns are observed, has to be reacted to. The detection and identification methods must be robust and secure for persistent and pervasive operations under uncertainty, resource constraints, and known and unknown operational, environmental and adversarial perturbations. This necessitates the development of sensor networks that autonomously form collaborative clusters for reliable time critical response to natural and man-made disasters and to more general battlefield environments and are backed by strong processing power of cyber systems.

The computer science department and the Institute for Micromanufacturing (I*f*M) of Louisiana Tech University (LaTech), and the computer science department and the Center for Computation and Technology (CCT) of Louisiana State University (LSU) propose to *jointly* establish a Center of Excellence in Integrated Smart Cyber-centric Sensor Surveillance Systems. The proposal addresses the following objectives: (1) develop a set of core research foundations and transformational information technologies for the early prediction, detection, and control of anomalous behavior in cyberspace; (2) develop a world-class multi-institutional, multi-disciplinary center of excellence for the study and research of anomaly detection in cyberspace; and (3) build strategic collaborative relationships between national and international academic and industrial partners, and with the Air Force's Cyberspace Command Center (AFCyber) at Barksdale Air Force Base (BAFB), *just 65 miles* on I-20 from LaTech's main campus. LaTech has had a campus at BAFB for several decades which provides Air Force personnel and others in the community opportunities to access our educational programs.

The proposal will have significant impact on Louisiana's economy (see Section 5.b.2 PROJECT IMPACT, page 16 and the State of Louisiana's Secretary of Economic Development, Michael Olivier's *view of this proposal*; letter attached), and a world-wide impact on science and technology in terms of *significant scientific advances* that this center will produce.

Relative to other institutions in the country, we are in an enviable position to build a world-class research Center of Excellence because of having considerable key intellectual resources as well as major components of critical infrastructure already on hand. These include: (1) existing excellence in cyber security (Phoha, Chen), distributed data storage and grid computing (Allen, Kosar, Duncan), sensor networks (Iyengar, Varahramyan, Selmic), and economic feasibility and economic impact (Norris) at LaTech and LSU; (2) physical proximity of LaTech to AFCyber at BAFB in Shreveport; (3) LONI, a high-speed state-wide communications and grid computing infrastructure, which provides connectivity to the National LambdaRail and other national and international networks; (4) a real opportunity for acquiring resources through this proposal to establish a Tower of Excellence by building intellectual critical mass in cyber security and sensor

networks through additional hires in complementary areas of our research; and (5) a promise of existing and potential partnerships with leading institutions in the world.

5.a.1 DESCRIPTION OF RESEARCH GROUP

The research team is strategically organized to integrate the work of lead researchers in this project area. Participating lead researchers have extensive discipline-based long-term innovation credentials and laboratories for developing methods related to secure transmission of data to distributed cyber systems and building survivable communications routing and protocols for sensor data dissemination. They have accumulated expertise in developing methods for automatic sensor data fusion, sensor data processing, and tools for integrated prediction, detection, and estimation for disaster precursors. In addition, the team is supplemented by experts in visualization and experimental validation with simulated and actual sensor nodes.

Core Team Composition The core research team consists of five senior faculty members: Dr. Vir Phoha (PI) and Dr. Kody Varahramyan (Co-PI) from LaTech and Dr. S. S. Iyengar (Co-PI), Dr. Peter Chen (Co-PI), and Dr. Gabrielle Allen (Co-PI) from LSU. Phoha specializes in spatial-temporal pattern detection and event recognition, Varahramyan in microsensor fabrication and field testing, Iyengar in information sensing and fusion in sensor networks, Chen in data modeling, cyber forensics and cyber security, and Allen in high performance computing for grid based dynamic data-driven applications. The team is supplemented by three senior researchers: Dr. Christian Duncan and Dr. Rastko Selmic from LaTech and Dr. Tevfik Kosar from LSU. Dr. Duncan's expertise is in visualization and Dr. Selmic's expertise is in sensor placement and protocol development. Dr. Kosar's expertise is in distributed systems, grid and collaborative computing. Thus, the team brings a multifaceted approach to solve the problems posed in this proposal.

The team members will work in groups of three to four to solve research problems outlined in this proposal. (See Section 5.b.1 PROPOSED WORK, page 11.)

Existing and Prospective Partnerships The team has made substantial contributions to the broader impact of science and engineering. Collectively they have published fifteen books, 400 journal articles, and over 600 conference papers relevant to the proposed research. In addition to individual contributions, the PI Phoha has worked with the Co-PIs Iyengar, Chen, and Varahramyan and with senior researchers Selmic and Duncan; and many of the Co-PIs and senior researchers have worked with each other on previous projects, resulting in relevant joint publications. Phoha and Iyengar have also collaborated on patents related to cyber systems.

Existing Partnerships Phoha, Iyengar, Chen, Varahramyan, and Allen, each individually and in collaboration have substantial work in their research thrust areas which informs the direction of the proposed research activities of this proposal. Phoha, Iyengar and Chen have an NSF funded project on Cyber Security and Information Assurance [1] and another joint NSF project [2] to develop course and curriculum in information assurance and security under review. *The work developed under these two proposals will form the basis of security issues related to this project.* Phoha's work on anomaly detection in complex systems, supported by an Army Research Office Multi University Research Initiative (MURI) grant [3], involved four universities (Carnegie Mellon University, Penn State University, LaTech, and Duke University) and will form the foundation of rare pattern detection methods for this project.

Each of the core team members has substantial *current* federal research funding: Phoha (NSF, ARO, see for example [1, 3]), Iyengar (NSF, ARO, DoE, ORNL, see for example [4-8]),

Chen (NSF, AFOSR, see for example [9, 10]), Varahramyan (NSF, see for example [11-15]), and Allen (NSF, NIH, ONR, see for example [16-21]). The team members work collaboratively on many of these grants.

Many team members have collaborated on research (for *some* examples see [22-27]). Phoha and Selmic are program committee members and are jointly organizing and chairing a special session on intelligent sensor networks for the 2007 IEEE Conference on Wireless sensor networks to be held in London in April 2007. These examples only list the partnerships within the proposal team members. In addition, each team member has extensive research partnerships with national and international researchers such as those from ORNL, Penn State, MIT, Stanford, Duke, CMU, Max Planck Institute, etc.

Prospective Partnerships The Co-PI, Varahramyan brings significant interdisciplinary contributions to the existing team by building real artifacts and directing field experiments for validating the multimodal functionalities of real sensor systems integrated with cyber systems. The Co-PI Allen and senior researchers Kosar and Duncan add the much needed expertise in grid formulation, distributed massive data intensive scheduling, and visualization, respectively.

Many prospective partnerships are planned to assemble an expert group of talents from major universities and national laboratories (letters of support from Penn State and Oak Ridge National Laboratory attached), and private sector (letters of support attached).

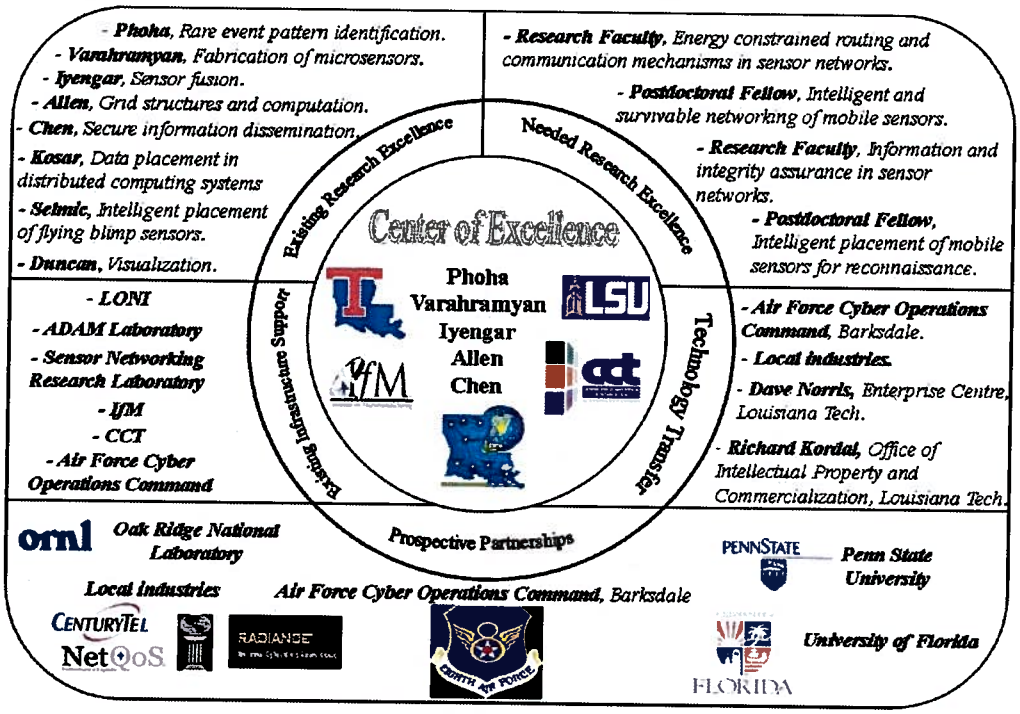

Figure 1. An overall view of the project.

Four Research Faculty and Four Postdoctoral Fellows Hired We will supplement the existing research excellence of the team with the expertise of four newly hired tenure-track research faculty members (two at LaTech and two at LSU) and four postdoctoral fellows (two at LaTech and two at LSU). Research faculty positions and postdoctoral fellowships will be advertised immediately after funding notification from BoR. The faculty and the post-docs will focus their work on sensor deployment, energy constrained communications in sensor networks,

protocol design and routing in sensor networks, information and integrity assurance in sensor networks and cyber systems, pattern analysis, machine learning, information fusion, and massive data-driven visualization. Figure 1 gives an overall view of the team structure and partnerships.

5.a.2 CONTEXT FOR PROJECT

The major task in Cyber-centric sensor networks is to process noisy intelligence data acquired by a collection of diverse sensors, to integrate the information, and to produce abstract interpretations of it. The team has been addressing many of the difficult research issues over the last ten years. In the following paragraphs, we list the team's recent history and directions in the most relevant research focus areas which inform the direction of the proposed research.

- *Distributed algorithms for integrated sensor networks*

The team's recent work in the area of distributed algorithms for integrated sensor networks focuses on reliable routing with arbitrary network topologies [28, 29], scalability issues in sensor networks [30], characterizing sensor fault modalities [31], tolerating faults while performing sensor integration [32], and tolerating faults while ensuring sensor coverage [33]. Building on our existing research and the ongoing research under our NSF and DoE-ORNL grants [6-8], we will address three proposed research tasks: *T.1.2*, *T.2.3*, and *T.2.4*. (See Table 1, Focus areas of the proposed research, page 11.)

- *Secure sensor data dissemination to distributed cyber systems*

Sensor data must be protected using secure and survivable protocols to prevent adversaries from accessing application-specific message contents or denial-of-service attacks. In this context, we propose to extend our research in securing sensor data transmission to cyber systems through attack detection and mitigation mechanisms [34, 35], randomized busing [36], online prediction [37], graph theoretical profiling [38, 39] and survivable and environment-aware sensor networks [40]. In addition, the ongoing research efforts under our currently funded MURI, NSF, and AFOSR grants [3, 6, 9, 10] will be used as a basis for addressing three proposed research tasks: *T.2.1, T.2.2,* and *T.3.3.*

- *Fabrication of micro/nano scale smart sensors*

Varahramyan's recent research in developing layer-by-layer nanoarchitecture assembled ultra thin films [41], polymeric field-effect transistors fabricated by reactive ion etching [42, 43], and thin film deposition of organic semiconductors by ink-jet printing [44] have a direct application in fabricating smart micro/nano scale sensors. Building on the existing research in micro/nano sensor fabrication as well as on the ongoing research under various NSF grants [11, 12, 14], we will address two proposed research tasks: *T.4.2* and *T.4.3*. In addition, the I*f*M's unique blend of world-class resources including electron beam nanolithography systems, dual chamber/micro reactive ion etching systems, wire bonding stations, and wafer dicing systems will be leveraged to address these tasks.

Selmic's background on intelligent control and design of small form-factor hardware modules [45, 46] gives much needed expertise in developing field testable sensor nodes with provision of interface to cyber systems (Task *T.4.2*). He will also bridge communications between the computer scientists of the team, to address placement and sensor fusion, and the I*f*M, to develop field realizable sensor fabrication technologies (Task *T.4.3*).

- *Automatic sensor data fusion, processing, and integrated event pattern detection, estimation, and prediction*

The team's recent research on data fusion in distributed sensor networks [47], information fusion for pattern analysis [48], multi-resolution data integration in sensor networks [49], cascading decision trees [35], parallel decision trees [50], quantitative language measures for decision and control [51], supervisory control [34], dependence trees [52] and the ongoing research efforts under MURI, NSF, and DoE/ORNL grants [3, 4, 6] will be used to address three proposed research tasks: *T.3.1, T.3.2,* and *T.3.4.*

- *Distributed and collaborative architectures, grid computation, and visualization*

The surveillance zone in the context of surface traffic analysis from spatially distributed sensors is viewed as a multi-dimensional grid with sensors being placed at grid points. Building on the team's research in distributed and collaborative architectures for modeling [53-55] and visualization [56], dynamic resource discovery and allocation in grids [57], parallel and distributed grid processing [58], data intensive computing [59], reliable and efficient data placement in dynamic grids [60-62], and on the ongoing research under various NSF, NIH, and DoE grants [17-21, 63], we will address three proposed tasks: *T.1.1, T.1.3*, and *T.4.1.*

5.a.3 EXISTING SCIENTIFIC EXCELLENCE

Professor Phoha (PI) has done fundamental and applied work in anomaly detection in network systems, in particular in the detection of rare events in network traffic. This work has been shared with the computer science community through significant archival quality publications in various IEEE Transactions publications (see for example [34, 35, 50, 64] which are specific to this research) and ACM and IEEE conferences [various] and by one allowed patent and four patent applications. His books [27, 65, 66] in these areas have been adopted in USA, Europe, China, and Australian universities and research institutes. He directs the Anomaly Detection and Mitigation Laboratory at LaTech.

Prof. Phoha has invented a resilient computer password protection technology using keystroke density neural networks, which has been licensed to *Biopassword Inc.*, a major company in the state of Washington, providing enterprise level user authentication systems and solutions. The technology is now the core of their major new product and has been employed to provide security in online bank transactions in major national and international banks. His mathematical tools and machine learning techniques for real-time detection of usual and rare patterns in massive data have been successfully applied to detect attacks on computer networks and detect and mitigate faults in software systems. In addition, Dr. Phoha has recently filed four invention reports in anomaly detection in computer networks and computer user access control through keystroke dynamics. These inventions support the proposed research in this proposal.

Professor Iyengar (Co-PI) is a world renowned authority in sensor fusion and has received numerous grants in sensor fusion from NSF, ARO, DARPA, and AFOSR. His book [67] on sensor fusion is one of the leading books in the field. He has authored over 400 papers in this field. He has been involved with research in high-performance algorithms, data structures, sensor fusion, data mining, and intelligent systems. *He is a fellow of the IEEE, ACM, and AAAS.*

Professor Chen (Co-PI) is the originator of the Entity-Relationship Model (ER Model) [68], which serves as the foundation of many systems analysis and design methodologies, computer-aided software engineering tools, and repository systems including IBM's Repository Manager/MVS and DEC's CDD/Plus. Prof. Chen is leading research teams on Profiling

Problems in Cyber Security and Anti-Terrorism. Recently, Prof. Chen was honored by the selection of his original ER model paper as one of the 38 most influential papers in Computer Science according to a survey of 1,000 computer science college professors. Prof. Chen received the *ACM/AAAI Allen Newell Award and is an ACM, IEEE, and AAAI Fellow.*

Professor Varahramyan (Co-PI) has pioneered the development of Layer-by-Layer assembly techniques for nanomanufacturing. These techniques form the basis of fabricating chemical/bio/thermal sensors with nanometer precision. He has several patents, more than 20 invention reports, and over 90 publications in micro/nano scale processes, materials, devices, and systems. He is Director of I*f*M, a world-class micro-fabrication facility for design and production of micron and submicron devices.

Dr. Allen (Co-PI) is leading several active Grid projects. Her NSF funded EnLIGHTened Computing project is developing advanced software and middleware that will provide a new generation of scientific applications to be aware of their network and Grid environment and to make dynamic, adaptive and optimized use of networks connecting various high end nodes. Her NSF supported Southeastern Coastal Ocean Observing and Prediction (SCOOP) project is being developed to archive and process coastal ocean observing and prediction data. Allen's group is developing state-of-the-art co-scheduling techniques bringing computational, data, and network resources together for the use of coastal modeling community. Allen has also taken a leading role in other NSF supported projects such as GridChem, which aims to build a computational chemistry Grid, and DynaCode: a general Dynamic Data Driven Application Systems (DDDAS) framework with coast and environment modeling applications.

Dr. Selmic's research (see [45, 46, 69, 70]) is in optimal sensor placement, control of sensor systems, intelligent sensors and actuators, control systems, failure detection in nonlinear systems, and neural networks. He currently serves as an Associate Editor for IEEE Transactions on Neural Networks. He is currently funded by the Air Force Research Lab for sensor networks and has been invited to be a Fellow at AFRL for the coming summer.

Dr. Duncan's expertise is geometric algorithms and information visualization. He is currently formulating problems for the simultaneous embedding of graphs and visualization of information. His work (see [71-77]) related to information visualization, geometric algorithms, planar graph-drawing, and balanced aspect ratio trees will lay the foundation for developing dynamic grid structures and visualization of information.

Dr. Kosar and his group have wide ranging experience in building blocks for Grid computing especially addressing the distributed data-handling problem. They have designed, and implemented the first prototype batch scheduler specialized in data placement, *Stork,* and introduced several possible scheduling strategies for data placement. Recently, Kosar has been awarded an NSF grant to develop an innovative distributed data archival, analysis and visualization cyberinfrastructure for data intensive collaborative research, called PetaShare. An initial prototype of this instrument will be deployed at LSU and four other Louisiana campuses, including LaTech. PetaShare will leverage the existing 40 Gbps LONI infrastructure to make the interconnections, fully exploiting high bandwidth low latency optical network technologies. This system will complement the high performance computing resources at the five interconnected campuses, and will boost the interdisciplinary research among them.

5.a.4 MULTI-INSTITUTIONAL FOCUS

Promoting collaboration between LaTech, LSU, AFCyber at BAFB, and other academic and industrial partners, the Center of Excellence *integrates* the best management and technical

expertise. The level of participation and commitments of the partnering institutions in support of this project follow.

The research team consists of representatives from LaTech and LSU. Researchers from both LaTech and LSU will work in groups of three to four on research problems (see Table 2, page 11). The groups represent the best match of expertise to each of the research topic and represent multi-institutional and multi-disciplinary focus of the project. For example, for network formulation, the research team includes Phoha (LaTech, CS), Allen (LSU, CCT), and Kosar (LSU, EE), and new faculty and post-docs (LaTech, LSU), represent both LaTech and LSU. Similar arrangements hold for other research areas.

Both LaTech and LSU have *each* committed half-time support of two research faculty (thus providing a total of four new faculty positions), and *will support these positions after the duration of the project.* In addition, both institutions have committed generous release time for the participating researchers and have contributed significant levels of matching funds for graduate students, support staff, travel, supplies, and equipment.

The advisory board includes the best management expertise from both institutions: LaTech (Les Guice, VP R&D, and Stan Napper, Dean, COES) and LSU (Harold Silverman, VC and interim Provost, and Brooks Keel, VC R&D). The advisory board includes nationally respected industrial leaders representing both Louisiana (CentruryTel, Praeses Corp, Barksdale Forward) and the nation (Radiance Technologies, NeTQoS and ATIC). These industrial leaders from both within and outside the state provide us with the knowledge, vision, and a non-invasive force to ensure relevance of our research agenda to Louisiana industries. In addition to serving on the board, many industrial partners have provided matching support. For example, Praeses Corporation has committed half-time of a technical person to support technology transition for the duration of the BoR funding.

The research team is further supplemented by international visionaries with distinguished records in sensor networks, cyber security, and allied areas representing prestigious national institutions: Professors Asok Ray and Bharat Madan (Penn State), Professor Sartaj Sahani (University of Florida), and Dr. Nagi Rao (UT-Battelle Corporate Fellow, Complex Systems Group, Oak Ridge National Laboratory). The research team will extend collaborations with other faculty members and universities both in state and nationally as the Center further develops and implements its research, education, and outreach programs.

5.b RESEARCH PLAN

5.b.1 PROPOSED WORK

The proposed work identifies the research focus of the Center of Excellence. The research focus is on four major research areas as delineated in Table 1, followed by a brief description of individual tasks.

Table 1. Focus Areas of the Proposed Research.

Research Areas	Task Description
Research Area #1 ***Investigate network formulation providing robust placement algorithms in uncertain environments and ill defined topologies.***	• T.1.1 Network Architectural Design Using Socio-Biological Principles • T.1.2 Adaptive Sensing in Non-stationary Environments. • T.1.3 Embedding of Sensor Information at Grid Locations.

Research Area #2 ***Develop secure transmission to distributed cyber systems and build energy-efficient survivable communications routing and protocols for sensor data dissemination;***	• T.2.1Develop Adaptive Attack Detection Mechanisms for Secure Transmission to Distributed Cyber Systems • T.2.2 Develop Resilience to Node Capture • T.2.3 Develop Robust Broadcast Routing Protocol for Sensor Networks • T.2.4 Develop Algorithms for Optimal Transmission Scheduling Under Power Constraints
Research Area #3 ***Develop automatic sensor data fusion, processing, and tools for integrated prediction, detection, and estimation for disaster precursors.***	• T.3.1 Rare Event Pattern Identification • T.3.2 Finding the Spatial-temporal Origins of Rare Events Based on Sensor Data • T.3.3 Secure Sensor Data Aggregation • T.3.4 Robust Sensor Data Fusion Using Dependence Tree Models
Research Area #4 ***Develop visualization software modules and perform experimental validation with simulated and actual sensors.***	• T.4.1 Develop Visualization Tools • T.4.2 Develop Smart Micro and Nano Scale Sensor Nodes • T.4.3 Validate Mathematical and Software Tools on Simulated and Actual Network of Sensors in the Center of Excellence

By converging these research areas, we aim to produce measurable advances in semantic fusion that enable fast, accurate, and dependable technology interacting purposefully with humans and the physical world. *This proposal addresses the fundamental deficiency in achieving this next level of convergence in technology that will interact directly with the physical world and with humans in dynamic and uncertain environments, cognizant of dynamic goals and the evolving physics, seamlessly spanning time and space to monitor change, and collaborating with humans to actuate purposeful distributed response.*

A brief description of the research tasks follows.

Research Area #1 Investigate network formulation providing robust placement algorithms in uncertain environments and ill defined topologies. (Phoha, Allen, Kosar, New Faculty, and Postdoctoral Fellow)

- *T.1.1 Network Architectural Design Using Socio-Biological Principles*

Tradeoffs of architectural design characteristics like number of nodes, node placement, routing, clustering, and resource constraints have been extensively studied in recent years [78-81]. We aim to engineer structure of sensor networks for operational dependability and performance under both expected and unexpected perturbations using principles derived from insect and animal behavior [82-87]. The approach based on insects and animal behavior provide an alternate way of designing sensor networks, in which autonomy, emergence, and distributed functioning replaces control, preprogramming, and centralization. Thus, these systems suit well for developing robust placement algorithms for sensor networks where mobile sensors (such as UAVs) are autonomous, the terrain is ill defined, and the operational environments are uncertain.

- *T.1.2 Adaptive Sensing*

Sensor density in large, low-density grids may vary wildly even for a regular grid (e.g., rectangular grids in two spatial dimensions). A promising approach to the problem of sensor networking with very low density regions is that of adaptive or targeted observations. This basic type of adaptive sensing approach has been successfully employed in weather prediction [88] and ocean sampling [89]. The proposed research will enhance the state-of-the-art of targeted/adaptive sensing for real-time pattern identification.

- *T.1.3 Embedding of Sensor Information*

Information extraction from observation of strategically placed sensor suites is critical for real-time pattern recognition in spatial-temporal processes. From this perspective, the research team will develop a theory of observation to address the following criteria: (1) Information collection over finite time from sensors at selected spatial locations; (2) separation of the relevant information from spurious data, including noise; and (3) validation of the extracted information. New mathematical tools will be developed to address this problem.

Research Area #2: Develop secure transmission to distributed Cyber systems and build energy-efficient survivable communications routing and protocols for sensor data dissemination. (Chen, Phoha, Iyengar, Selmic, New Faculty, and Postdoctoral Fellow)

- *T.2.1 Develop Adaptive Attack Detection Mechanisms for Secure Transmission to Distributed Cyber Systems*

Building on our earlier work in cascading decision trees [35], parallel decision trees [50], competitive learning networks [64], and intelligent control techniques [26, 34], we will develop *stateless, reliable* and *immediately deployable* attack detection mechanisms to secure transmissions to cyber systems. Figure 2 shows our two-stage attack detection method. In the first stage, data clustering algorithms will partition data and communication traffic measurements into heterogeneous clusters. In the second stage, decision trees will be constructed within each cluster.

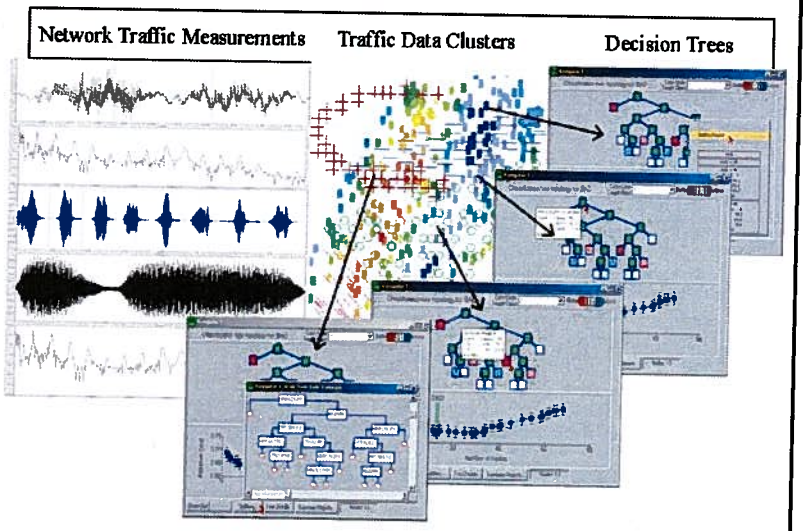

Figure 2. Cascading clustering algorithms with decision trees for robust attack detection in network traffic.

- *T.2.2 Develop Resilience to Node Capture*

The challenge here is to build wireless sensor networks that work reliably even if some nodes have been captured or compromised in the context of surface ship combat systems. Building on our earlier work [90-94], we will examine resilience problem by developing consistency checks on the information received. Further, we will spread the state information of sensor network over different regions and develop mechanisms, such as voting or polling to detect fraudulent activity and guess the correct information.

- *T.2.3 Develop Robust Broadcast Routing Protocol for Sensor Networks*

Building on our earlier work on adaptive routing specific to sensor networks [28, 95-99], we propose a near-optimal Broadcast Protocol for Sensor Networks (BPS) to enable a significant reduction on retransmissions and communication overhead. BPS uses geometric calculations in setting strategic locations for the next transmitting node, aiming for a maximal hop size. Four crucial issues: scalability, energy-efficiency, memory usage, and computational time, will be addressed in the proposed BPS research.

- *T.2.4 Develop Algorithms for Optimal Transmission Scheduling under Power Constraints*

Our goal is to develop optimal transmission scheduling algorithms for sensor nodes operating under load, duty-cycle, and power constraints. To obtain optimal transmission scheduling, we will solve the Minimum Energy Scheduling Problem (MESP) in which the objective function is to determine the schedule which minimizes the total energy. Since traditional optimization methods using Lagrange multipliers do not work well for MESP and are computationally expensive given the non-convex constraints, we will develop polynomial approximation schemes for finding optimal transmission schedules. For two fixed transmit power levels (0 and P), we will develop a 2-factor approximation for finding the optimal fixed transmission power level per time slot, that generates the minimum energy schedule.

Research Area #3 Develop automatic sensor data fusion, processing, and visualization tools for integrated prediction, detection, and estimation for disaster precursors. (Iyengar, Phoha, New Faculty, and Postdoctoral Fellow)

- *T.3.1 Rare Event Pattern Identification*

By treating the spatial-temporal structure in sensor observations as a generator of a formal language, we will develop methods to construct recognizers of this language to identify and localize the spread of rear events. The event-driven interactions between sensors are modeled as a deterministic finite state automaton (DFSA) of the plant, $G=(Q,\Sigma,\delta,q_0,Q_m)$, in which Q is a set of states, Σ is the alphabet of events causing the state transition, δ is the transition function, q_0 is the initial state, Q_m is the set of states of importance as determined by the designer. Event alphabet Σ is divided into two classes: recognizable events (Σ_c) and (rare) unrecognizable events (Σ_u). Our objective is to design a recognizer that matches event patterns in a way that the given spatial/temporal relationships in sensor observations behave in obedience to certain constraints. Figure 3 illustrates our ideas on rare event pattern recognition and spatial-temporal identification of events using sensor data. (See the next task for finding the origin of rare events as a sequel to this work.)

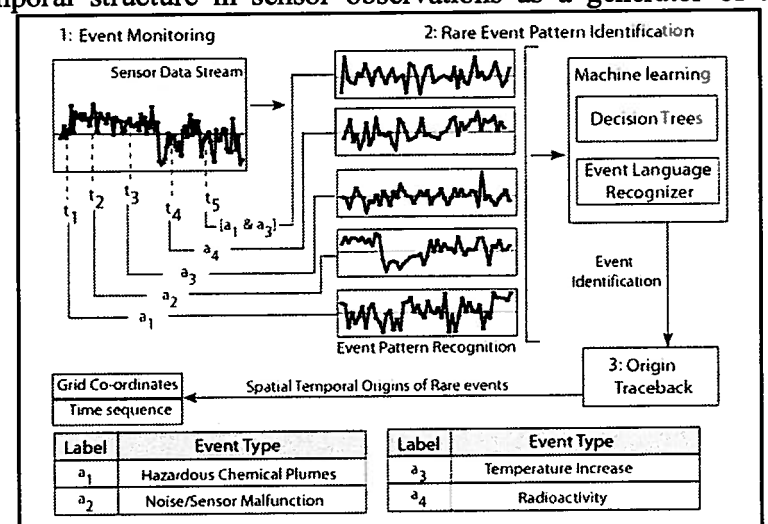

Figure 3. Event pattern recognition and spatial-temporal origin identification of rare events using sensor data.

- *T.3.2 Finding the Spatial-temporal Origins of Rare Events from Sensor Data*

We will use Bayesian inference methods in conjunction with language theoretic methods to find the spatial-temporal origins of unusual events. Formally, we will find $P(X_t/E_t)$, where X_t is a fast time scale stationary process representing state of the environment under surveillance; E_t is observation resultant of a rare non-stationary event. We have access to evidence E_t through

sensors as a continuous stream beginning at $t=1$. This problem translates to finding $P(X_{t+1}/E_{1:t+1}) = \alpha P(E_{t+1}/X_{1:t+1})P(X_{t+1}/E_{1:t})$, where α is a normalizing constant. Another task that we will address is the prediction of unusual event patterns from historical data, that is $P(F_{t+1}/E_{1:t+1}) = \alpha \sum_{F_{t+k}} P(F_{t+k+1}/F_{t+k})P(F_{t+k}/E_{1:t})$, where F_t is a multidimensional random variable representing event patterns, and k is the period for which we want to predict. We will explore the sequence of events that could most likely result in catastrophes or precursors to catastrophes. That means, in a recursive fashion, we are finding the most likely paths to state X_{t+1} and the most likely paths to each state X_t. In addition, using hidden Markov models [100] we will develop models of cause and effect and predict whether an event is a result of faults in a particular sensor.

- *T.3.3 Secure Sensor Data Aggregation*

Sensor nodes provide fine grain data, which must be aggregated to interpret information. Data aggregation can be compromised, for example, an adversary can disrupt the network's operation by broadcasting high energy signal; or some nodes can be physically removed, replaced, or destroyed. Many approaches show promise at conceptual level for secure data aggregation. For example, one can randomly sample some nodes to ensure their trustworthiness and detect many types of attacks. Building on our work in secure data aggregation [50, 91, 92, 101], fault tolerance [26, 102-106], and machine learning [22, 24, 35, 50, 52, 92, 93, 107], we will develop secure aggregation methods based on fusion using boosting and bagging approaches to provide security in data aggregation procedures.

- *T.3.4 Robust Data Fusion Using Dependence Tree Models*

Our approach to robust sensor data fusion draws on our earlier work on dependence trees [52]. Let $O = \{o_1,\ldots,o_n\}$ represent a vector of aggregated sensor observations from a set of sensors. Using tree dependence approximation [108] and Bayes' rule, we will estimate the state-conditional probability distribution $P(o/e)$ using second order component distributions of the type $P(o/e) = \prod_{i=1}^{n} P\left(o_{m_i}, o_{m_{j(i)}}/e\right)$ where e represents the evidence vector.

Research Area #4 Develop visualization software modules and perform experimental validation with simulated and actual sensors. (Varahramyan, Phoha, Kosar, Duncan, New Faculty, and Postdoctoral Fellow)

- *T.4.1 Develop Visualization Tools*

Visualization of the results of developed algorithms is an important software development activity of this research. Based on our earlier work [72, 109] we will develop multi-perspective dynamic real-time visualization of sensor nodes to help understand emergent trends and abrupt changes. The initial focus will be to visually represent the formation of ad hoc topologies and the detection of events with the ability to represent different views of the same information.

- *T.4.2 Develop Smart Micro and Nano Scale Sensor Nodes*

We propose to use Layer-by-Layer assembly in conjunction with lithography (see for example [110]) to fabricate ultrathin microcantilevers on a silicon wafer to develop chemical/thermal/bio sensor arrays. To provide *interface with cyber systems*, the sensors will be supplemented with a fractal antenna to interact with an external transceiver, an ID generating

circuit to modulate transceiver's query signal into a unique code characteristic, and a sensor switch to control the output code of the ID generating circuit. In addition, we will provide the sensor with solar cells or coat with piezoelectric and pyroelectric materials to generate energy.

- *T.4.3 Validate mathematical and software tools on simulated and actual network of sensors in the Center of Excellence*

Our earlier work in the MURI will form the basis for developing software validation tools of our research. We will model each sensor node as a separate processes running on Linux and Windows PCs and represented it as a separate instance of the Dynamic Space Time Coordinated (DSTC) tracking process [111, 112]. These processes receive sensory inputs from the sensors. Each sensor node has a sensor model and an associated Closest Point of Approach (CPA) event generator for running DSTC/CPA algorithm [113, 114]. The CPA generator uses inputs from the physical sensors to generate events for the grid of virtual sensor nodes and node positions to be displayed on screen.

5.b.2 PROJECT IMPACT

Partnership with the Air Force The opportunities for a state to attract a major military Command are indeed quite rare. It is even ***rarer*** when that Command is focused in an emerging area of great importance to the global knowledge economy. The fact that the focus of the AFCyber at BAFB is in the same domain (IT) in which Louisiana has been focusing its R&D investments over the past several years creates a convergence of actions that could have a dramatic impact on the future of the State of Louisiana.

This is what Secretary Michael Olivier, Economic Development, State of Louisiana has to say in support of this effort (letter of support attached): "***This project*** *serves as a very tangible thing that* General Elder can use to demonstrate to key decision makers that Barksdale is the best place to establish permanent headquarters for the Air Force's Cyberspace Command. While all indications are that this is going to happen...." (Emphasis by the research team writers of the proposal.)

Thus, there will be many new high-skilled military personnel moving to the State and the demands for the IT workforce to support these operations will rapidly grow. There will clearly be many other related impacts on the economy and vitality of the State. However, to truly capitalize upon the opportunities to harness the intellectual activities of AFCyber and ensure that they have maximum impact on Louisiana, it is critical that the academic community immediately engage in supporting the research, development, education, and innovation needs of the Air Force. In the absence of a meaningful engagement of Louisiana's leading cyber scientists and engineers, AFCyber will more aggressively seek support from R&D groups outside the State and the resulting long-term impacts on Louisiana's knowledge economy will be diminished. *Having this core center of excellence in cyber-security research will demonstrate the State's commitment and greatly enhance the overall impacts of and success of AFCyber in Louisiana.*

The proposed Center of Excellence will support economic development by providing a rich concentration of expertise and research capacity that creates technology commercialization opportunities and supports the operations of AFCyber in conjunction with the Cyberspace Innovation Center (CIC) at BAFB. The CIC is a 501(c)3 organization that has recently been established at the recommendation of Gen. Bob Elder, Commander of BAFB and AFCyber, to support cyberspace research, innovation, and education related to AFCyber. Gen. Elder recognizes that there will be many opportunities for private sector companies to partner with AFCyber in commercializing technologies and establishing services that support secure cyber

operations in the military and private sectors. The CIC will link our education institutions, the proposed Center of Excellence, and private sector partners with the activities and interests of AFCyber in a manner that enhances the success of the Command as well as generates significant economic benefits for the public and private partners.

Technology Commercialization Support The generation of commercially viable intellectual property (IP) leading to commercialization and economic development is not an automatic result of leading edge research. Consequently, the partners in this project will employ a robust and extensive commercialization process consisting of: (1) technology evaluation and assessment, (2) IP protection and marketing, and (3) venture formation and business development support. While these three components involve different activities and are led by different groups, they are all part of an integrated process that begins with pre-eminent scientific research informed by commercial applications and ends with public-private partnerships that deploy new technologies into the marketplace creating new economic activity, jobs, and wealth.

Secretary Olivier's letter noted: "We expect to see direct economic impact from the increases in highly skilled military personnel that will be deployed at the base.....Our research universities *must play a leadership role* to ensure that innovations flow out of the research and development opportunities and to ensure that we are meeting the major workforce needs. " (Emphasis by the research team writers of the proposal.)

The technology evaluation and assessment activities will be facilitated by LaTech's Center for Entrepreneurship and Information Technology (CEnIT), in collaboration with the Business Technology Incubator (BTI) at LSU and the Louisiana Technology Transfer Office (LTTO). LaTech has developed a novel commercialization infrastructure over the last several years resulting in rapid growth in IP development, business partnerships, and commercialization activities. This infrastructure is built around CEnIT which was launched in 2002 with $2 million per year in funding from the State's IT initiative. In 2003, CEnIT received a $600,000 NSF Partnerships for Innovation grant to establish the Innovative Venture Research (IVR) program for technology commercialization. Multidisciplinary teams of students, faculty, and business mentors evaluate new technologies developed at the university and recommend new products, services, and business models to deploy the technology profitably in the market. The recommendations are reviewed by a Triage Team of technology transfer experts. Some of these team members (Dr. Bob Mehalso, Senior VP, Microtec Associates; Ross Barrett, Partner, VCE Capital Partners; Joe Lovett, Manager, Louisiana Fund I; Bob Tucker, Partner, Jones Walker Law Firm) also serve as private sectors partners in state-wide commercialization activities, and will contribute to the commercialization process for IP resulting from the cyberspace project.

Intellectual Property Management The IP protection and marketing activities will be facilitated by the Office of Intellectual Property and Commercialization (OIPC) at LaTech in collaboration LSU's Office of Intellectual Property and other partners. The OIPC has seen significant growth in IP activity over the last few years, negotiating six new licenses and options, receiving 31 reports of invention (ROIs), and filing 17 patent applications in fiscal year 2006. Fiscal year 2007 productivity is on a similar pace. The OIPC actively provides professional development outreach for faculty and engages research productive faculty members in dialogue about applications and IP. These activities will contribute significantly to the increased volume of disclosures, patented inventions and licenses resulting from the cyberspace project. We project at least 10 new ROI's, five patent applications, and three licenses for commercialization over the first five years of research and development.

Business Development Support The business development activities will be facilitated

by the Enterprise Center at LaTech in collaboration with partners including the LTTO and the BTI at LSU. The Enterprise Center is the lead external business development arm of LaTech and offers a comprehensive set of resources for early stage and growing technology companies across the I-20 corridor in north Louisiana. These resources include two technology business incubators and a full set of targeted support services through its Technology Business Development Center. The primary support services include entrepreneurial development, pre-venture counseling, and equity and grant fundraising assistance, financial and strategic management consulting, and business networking. It is expected that over the next five years, through cyberspace research projects, the Enterprise Center will host another five startup companies with well over 50 employees in high-paying, quality technology jobs.

The Enterprise Center Director and Senior Investigator, Dr. Dave Norris, will commit 10% of his time to this project. LaTech proposes to hire one new Technology Coordinator to facilitate the integration of the Cyberspace project activities with AFCyber, the Cyberspace Innovation Center, and the overall university commercialization infrastructure. The funding for this position would be $50,000/year, with a 50% match from LaTech.

External partners, public and private, have been essential to recent commercialization successes at LaTech and LSU, and those partnerships will be enhanced and extended through this project. The Enterprise Center has established an extensive network of regional entrepreneurs, investors, mentors, and business leaders as part of the Regional Innovators Network. The Network, with Director John Buske, will serve as another private sector partner helping to facilitate the commercialization of new technologies.

Liaison With Industry The Research and Industry Advisory Board (RIAB) for this project will consist of key technology companies and research entities in the region, as well as major industry players from across the country. The RIAB will facilitate partnerships that drive the development of cyberspace products of common interest to industry and the military, and develop new relationships with leading technology companies to enhance technology transfer and economic development in the state. Eventually, industrial and government organizations that are represented in the RIAB will be asked to contribute in-kind or cash resources to support the operations of the Center. LaTech has employed such a model quite successfully for its Trenchless Technology Center for 15 years.

As a result of the AFCyber's role in a federal governmental agency, multiple contracting opportunities will be created. Contracting for general supplies will provide new procurement opportunities for businesses throughout the region, and the specific and technical needs of AFCyber will stimulate greater activity in SBIR/SSTR grants that enhance the research and development sector of the state's economy. As the AFCyber grows, more jobs will become available for Louisiana's highly skilled and educated citizens, and the region's business climate will be positively influenced by the introduction of new business services and products that meet the needs of this highly sophisticated governmental operation.

Education and Training Impacts The Center's research will be integrated into the academic programs of LaTech and LSU through advanced courses and research projects. It is expected that some common courses will be developed that can be team taught and delivered/received by both campuses using LONI's powerful high-definition multi-conferencing capabilities. Short courses and certificate programs will be developed to support cyberspace workforce development. We will conduct an annual national conference and focused workshops involving participants from national laboratories, industry, DoD laboratories, and students. The Advanced Technology Intelligence Center (ATIC) in Dayton, Ohio, has indicated interests in

partnering with this project for supporting educational needs in the intelligence community.

5.b.3 MANAGEMENT PLAN

Research and Coordination Team Dr. Phoha, the PI, will lead the overall project, coordinate the research thrusts, and coordinate interactions with the Research and Industry Advisory Board. Phoha and Co-PIs Varahramyan, Iyengar, Chen and Allen will serve as the Research and Coordination Team (RCT). They are responsible for directing the project-specific thrust areas and overseeing the overall research and economic development activities. The RCT will meet semi-annually. One of those meetings will be an annual workshop for dissemination of the research results.

Research and Industry Advisory Board To ensure effective cross-institutional interactions and the efficient transfer of research knowledge and experience into the industry, a Research and Industry Advisory Board (RIAB) will be established. The Vice President for Research and Development at LaTech, Dr. Les Guice, will chair the RIAB. Dr. Brooks Keel, Vice Chancellor for Research and Economic Development at LSU, will serve as the Vice Chair. In addition to their roles on the RIAB, Guice and Keel will facilitate interactions between researchers at the two campuses. They will coordinate the establishment of technology transfer policies and inter-institutional agreements.

Other academic members of the RIAB include Dr. Stan Napper, Dean of College of Engineering and Science at LaTech, Dr. Harold Silverman, Executive Vice Chancellor at LSU, and Dr. Sartaj Sahni, Distinguished Professor and Chair of Computer and Information Science and Engineering Department at University of Florida. The RIAB includes several representatives from the private sector including: Murray Viser, CEO of Barksdale Forward (Shreveport), Craig Spohn, CEO of Praeses Corporation (Shreveport), Joel Trammell, CEO of NetQos (Austin), Chris Mangum, VP of Centurytel (Monroe), Bill Bailey, VP of Radiance Technologies (Huntsville, AL), and Bob Fudickar of Louisiana Economic Development. (letters of support in the Appendix.) Other members will be added to the RIAB as appropriate. It is expected that there will be significant overlap in memberships of the RIAB and the Board of the Cyberspace Innovation Center (see paragraph 2 of Section 5.b.2 PROJECT IMPACT on page16).

The RIAB will meet semi-annually with the RCT. The RIAB will annually review the research progress of the project, act as a resource for applications and technology transfer to industry, and will support the establishment of industrial partnerships. They will also provide input into educational needs for academia, the military, and the private sector. The RIAB will provide valuable industrial feedback to researchers in the project. *In addition, Dr. Asok Ray, University Distinguished Professor at Penn State University will be a senior research consultant and offer his expertise in anomaly detection, mitigation, and control of environmental characteristics perceived through sensor networks* (letter of support attached). Dr. Nick Coorough, CEO of the Advanced Technology Intelligence Center (ATIC), will serve as an advisor on workforce development and as a liaison with Wright Patterson Air Force Base in Dayton, Ohio.

Research Project Management The research of this project will be closely monitored by the PI, Co-PIs, and senior researchers. The qualifications and expertise of the research team are addressed in Section 5.a.3. The research faculty, post-docs and students will be organized by teams to support the Research Focus Areas of this project as given in Table 2.

Table 2. Research focus areas and team participants.

Research Areas	Team Participants
#1 Network Formulation	• Phoha (lead), Allen, Kosar, 1 new faculty, and 1 post-doc.
#2 Distributed Systems	• Chen (lead), Phoha, Iyengar, Selmic, 1 new faculty, and 1 post-doc.
#3 Sensor Data Fusion	• Iyengar (lead), Phoha, 1 new faculty, and 1 post-doc.
#4 Field Testing	• Varahramayan (lead), Phoha, Kosar, Duncan, 1 new faculty, and 1 post-doc.

We have planned coordination mechanisms to cover both cross–disciplinary and cross-institutional scientific integration. The coordination mechanisms consist of at least two mandatory face-to-face review meetings every year, biweekly *phone/access grid* conference calls, development of joint Web repositories, identified points-of-contact for virtual laboratory integration across universities, and meetings organized at commonly attended conferences/workshops for addressing coordination issues in a timely fashion.

Dr. Phoha will be responsible for organizing biweekly *access grid conferencing* meetings with all participants at LaTech and LSU to discuss project progress, laboratory integration issues, and educational developments. A formal agenda will be circulated before the meeting and meeting minutes will be posted on the web. An annual workshop with all Co-PIs, interested industry participants, and students will be organized to share research results. Travel support is allocated in the budget for the annual workshop.

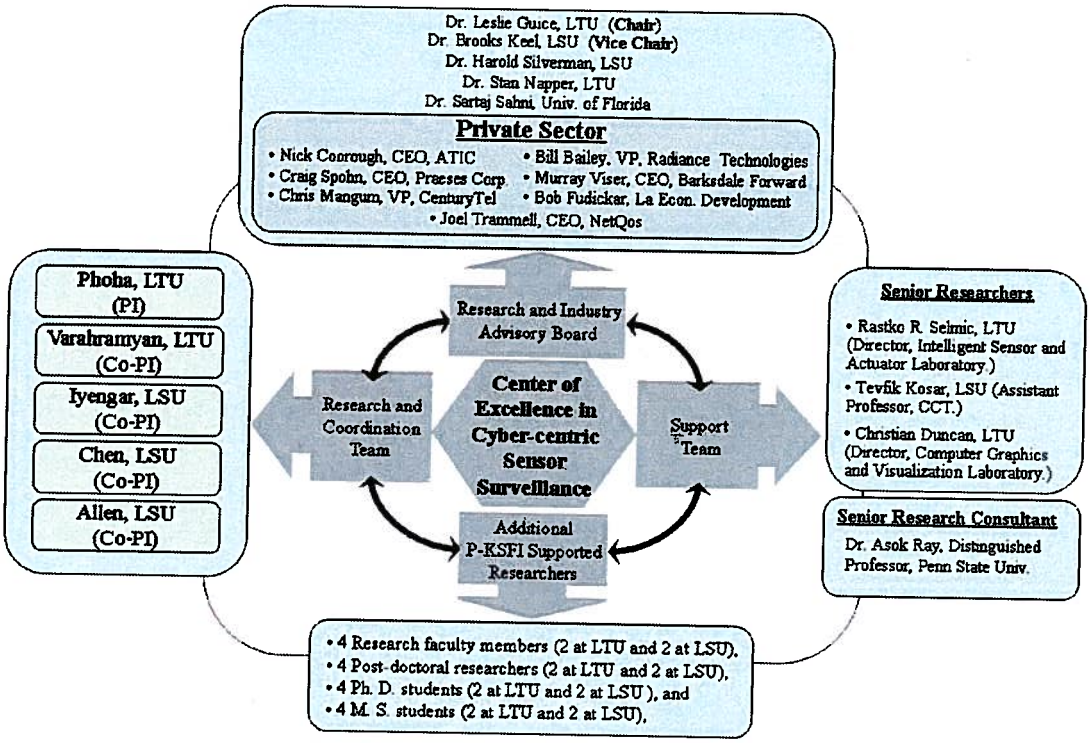

Figure 4. Project organization.

Figure 4 shows the organization and relationships between RCT, RIAB, and the researchers.

5.b.4 PERFORMANCE MEASURES AND OBJECTIVES

Our yearly plans for benchmarking performance and progress in infrastructure, research, and statewide impacts are summarized below. Contingency plans contain adjustments to accommodate unexpected developments.

Table 3: Key Performance Measures and Expectations (Years 1 and 2).

	Performance Measures	Expectations
Year 1		
Infrastructure	Faculty hiring	By May 31, 2008
	Post–doc hiring	One by Aug 2007 and second by October 2007
	Link with LONI resources	By December 2007
	Link with Labs	By March 2008
	Recruit initial graduate students	By December 2007
Research Activity	Major publications, presentations & invited lectures	3 publications, 3 presentations
	Research Milestones	Grid Formulation
Statewide Impact	Establish links with RIAB companies	March 2008
	Support for Cyberspace Command	March 2008
Contingency Plans	LaTech and LSU have a stream of high quality Ph.D. graduates each year. Thus, if we are not able to hire post-docs and faculty through open advertisements, we will recruit post-docs from our graduates. We plan to hire the best expertise in the world.	
Year 2		
Infrastructure	Securing additional external funding	Newly hired faculty will submit at least two research proposals to sustain and extend the current research.
	Build strategic collaborations with national and international academic and industrial partners	December 2008
Research Activity	Publications, presentations, lectures	6 publications, 6 presentations
	Research Milestones	Initiate research specific to needs of the AF. Initiate research on energy-efficient survivable routing for the dissemination and transmission of sensor data to distributed cyber systems.
Statewide Impact	Reports of Invention	3
	Increase presence of RIAB companies	March 2009
	SBIR grant applications	2
Contingency Plans	Core faculty members are active in research and expect no problems in submitting research proposals in collaboration with newly hired post-docs and research faculty. We expect no problems in meeting the objectives of the year 2.	

Table 4: Key Performance Measures and Expectations for Years 3-5

	Performance Measures	Expectations
Year 3		
Infrastructure	Support for more research faculty, grad students, and lab equipment	Submission of at least 3 multi-institutional research and infrastructure proposals
	Strengthened ties with the Air Force	Integration of the Center's research to Tech's BAFB Program
Research Activity	Major publications & presentations	4 publications, 5 presentations
	Research Milestones	Focus on developing sensor data fusion and visualization tools for integrated prediction, detection and estimation of disaster precursors.
Statewide Impact	ROI's, Patent applications, SBIRs	2 ROI's, 1 patent applications, 2 SBIRs
	First new start-up company	1 company, 4-5 employees
Contingency Plans	Could experience delays in integrating our research and education with Barksdale AF program. We will seek collaboration with other national and international partners.	
Year 4		
Infrastructure	3 Ph.D. students to graduate	By May 31, 2010
Research Activity	Major publications & presentations	6 publications, 8 presentations
	Research Milestones	Technology for collaborative viz by different stakeholders having multiple persp. Submit 3 multi-institutional proposals to extend research goals.
Statewide Impact	ROI's Patent Apps, Licenses, SBIRs	3 ROI's, 2 patent apps, 2 licenses, 2 SBIR
	New start-up companies	2 companies, 8-10 employees
	Recruited companies	2 companies, 40-50 employees
Contingency Plans	Assessment of sustainability may require additional focus on this activity year.	
Year 5		
Infrastructure	Center should be self-sustainable	May 31, 2012
	Continuous stream of grad students, post-docs, and visiting positions	Research agenda should have matured and plans for next agenda in place.
Research Activity	Major Publications & presentations	8 publications, 8 presentations
	Research Milestones	Final prototype of system in the field will be demonstrated by end of year.
Statewide Impact	ROI's Patent Applications, Licenses	2 ROI's, 2 patent applications, 2 licenses
	SBIR applications	3
	New start-up companies, employees	3 companies, 35 employees
	Recruited companies, employees	3 companies, 40-50 employees
Contingency Plans	If the Center is not financially self-sustainable, both LaTech and LSU will support the additional post-docs and faculty.	

5.b.5 SUSTAINABILITY

This project lays the foundation for a multi-institutional Center of Excellence in Integrated Smart Cyber-Centric Sensor Surveillance Systems. It brings together a team of eminently qualified computer scientists and engineers to work on integrated and reliable hardware, software and computer systems to address critical national issues related to communications and sensor networks. The research team has a proven record of collaborative research as demonstrated through funded grants, publications, and patents. This P-KSFI grant will provide the team with the resources required to establish a sustained research program focused in an area of importance to the nation and State of Louisiana.

The team will immediately pursue other funding opportunities through their existing extensive connections with the Department of Defense, Department of Homeland Security, and Department of Energy. The team will also pursue major grant opportunities with the National Science Foundation and other agencies. Given their track record, it is most likely that the PI and Co-PIs will be successful in our pursuit of major grants. Through mentorship, it is expected that the national competitiveness of the junior faculty will be enhanced to sustain and expand the Center's research program over the longer term.

This project will establish a research relationship between Louisiana's academic research community and the AFCyber at BAFB. In November of 2006, as Commander of the Eighth Air Force and the Air Force Cyberspace Command, General Bob Elder was charged with leading the planning for a full Cyberspace Command to integrate the Air Force's total capabilities in offensive and defensive operations in the electronics and electromagnetics spectrum (i.e., Cyberspace). General Elder has led discussions with the academic and private sectors to establish public/private partnerships with AFCyber. Further, he encouraged the academic community to begin to develop research programs that would support the Air Force's efforts in this area. The proposed project demonstrates a tangible commitment of Louisiana's top cyber scientists to work with General Elder and AFCyber in advancing its mission and *lays the groundwork for sustained research with the Air Force in cyber-related activities*.

This new initiative will have major economic development implications on the State of Louisiana. Our model for the Cyberspace project is designed to support AFCyber as well as leverage the partnerships that will be formed between academics, industry and the military, to sustain this project indefinitely. The project team will interact with the Cyberspace Innovation Center and other entities to foster the development of new cyber technologies that can be applied in the private sector as well as the military. The ultimate success in developing the new Cyberspace Command to its maximum potential is highly dependent upon the establishment of strong linkages of the Air Force to the regional academic and business community. The RIAB will provide an interface for this project that will generate partnerships to sustain our project for the longer term.

The two participating institutions of higher education will ensure the sustainability of the Center of Excellence by absorbing the new faculty positions into the institutional budgets, continuing to provide matching funds for proposals written by Center members, and allocating doctoral assistantships available to the Center faculty on an ongoing basis as long as they are active in supporting the Center's research. As the Center's needs for space grows, the institutions will identify opportunities for facility expansion that can maximize the impact of the research, education and outreach activities.

5.c LEVERAGING OF RESOURCES

This project capitalizes upon the significant investments that the State has made in IT research and education over the past several years. Louisiana's 2001 IT Initiative has served as a catalyst for elevating Louisiana's research universities to support research productivity and economic development. Both LaTech and LSU made major investments in their IT personnel, facilities and programs as a result of the IT initiative. As a result of this initiative, LSU established the Center for Computation and Technology (CCT) that has already garnered considerable national and international recognition. Two core members of the CCT's research team (Allen and Kosar) are participants in this project. Varahmayan and Selmic bring considerable resources from the world-class I/M laboratories, developed from federal and state funding, to support the sensor network development activities of the project.

Perhaps the most significant development for Louisiana in advancing its IT capabilities was initiated in 2005 with the establishment of the Louisiana Optical Network Initiative (LONI) as part of the new national scale research network called the National LambdaRail (NLR). The NLR provides a high-speed optical network backbone that spans the US, connecting numerous major research institutions and government laboratories. LONI connects the state's major research institutions with high-speed optical fibers capable of delivering up to 40 Gbps. The network connects five IBM P5-575 supercomputers acting in a grid environment with a total computational capability of approximately 5 Tflops. Most recently, the Governor committed $10M to enable LONI to expand its supercomputing capacity by adding 80 Tflops distributed around the grid. *This provides Louisiana researchers with the most powerful distributed supercomputing grid infrastructure in the nation.* LONI's high-performance computing resources will be extensively used in the proposed project. LONI's optical network capabilities will be used to support communications between the researchers and will provide a test bed for cyber security research.

The project capitalizes upon the investments the State has made in its technology commercialization and business support efforts at LaTech (CEnIT, Enterprise Center, Technology Business Development Center), LSU (BTI) and the Louisiana Technology Transfer Office. These entities have collaborated on several projects over the past two years. Together, they form a robust mechanism for leveraging the impacts of the research in the private sector.

The project leverages significant new investments that both LaTech and LSU are making to build a world-class Center of Excellence in cyber security. Each institution has committed two faculty positions, paid ½ by the grant with the commitment that the university picks them up 100% at the end of the grant. The universities are committing to two post-docs (paid ½ by the grant), 12 graduate students, a technology business liaison, and other supporting funds. Other costs such as start-up packages for the new faculty members will also be provided by the institutions and are not reflected in the budget.

Finally, the project leverages a major investment of the Department of Defense in establishing a Cyberspace Command in Louisiana. *The opportunities for leveraging these resources to elevate Louisiana's IT research community to national prominence in an area of national priority are truly unique and timely.*

Contract Work Plan

5 NARRATIVE

5.a PROJECT RATIONALE AND STRUCTURE

Real-time detection and identification of both normal and unusual patterns and rare patterns of activities (for example intrusions in cyber infrastructure, sudden movement of troops, or increases in communications traffic between areas of interest) are imperative for advancing early warning and response capabilities of modern surveillance systems. Deploying sensors to cover large areas, such as coastlines and land masses pose specific problems related to communication, maintenance, and collection of information. For example, heterogeneous sensors with limited sensing radii are individually prone to failure and noise contamination, and human oversight of so many sensors is not possible. In addition, real-time processing of the massive amount of data that these sensors generate has to be transmitted, interpreted; and if rare patterns are observed, has to be reacted to. The detection and identification methods must be robust and secure for persistent and pervasive operations under uncertainty, resource constraints, and known and unknown operational, environmental and adversarial perturbations. This necessitates the development of sensor networks that autonomously form collaborative clusters for reliable time critical response to natural and man-made disasters and to more general battlefield environments and are backed by strong processing power of cyber systems.

The computer science department and the Institute for Micromanufacturing (I*f*M) of Louisiana Tech University (LaTech), and the computer science department and the Center for Computation and Technology (CCT) of Louisiana State University (LSU) propose to *jointly* establish a Center of Excellence in Integrated Smart Cyber-centric Sensor Surveillance Systems. The proposal addresses the following objectives: (1) develop a set of core research foundations and transformational information technologies for the early prediction, detection, and control of anomalous behavior in cyberspace; (2) develop a world-class multi-institutional, multi-disciplinary center of excellence for the study and research of anomaly detection in cyberspace; and (3) build strategic collaborative relationships between national and international academic and industrial partners, and with the Air Force's Cyberspace Command Center (AFCyber) at Barksdale Air Force Base (BAFB), *just 65 miles* on I-20 from LaTech's main campus. LaTech has had a campus at BAFB for several decades which provides Air Force personnel and others in the community opportunities to access our educational programs.

The proposal will have significant impact on Louisiana's economy (see Section 5.b.2 PROJECT IMPACT, page 16 and the State of Louisiana's Secretary of Economic Development, Michael Olivier's *view of this proposal*; letter attached), and a world-wide impact on science and technology in terms of *significant scientific advances* that this center will produce.

Relative to other institutions in the country, we are in an enviable position to build a world-class research Center of Excellence because of having considerable key intellectual resources as well as major components of critical infrastructure already on hand. These include: (1) existing excellence in cyber security (Phoha, Chen), distributed data storage and grid computing (Allen, Kosar, Duncan), sensor networks (Iyengar, Varahramyan, Selmic), and economic feasibility and economic impact (Norris) at LaTech and LSU; (2) physical proximity of LaTech to AFCyber at BAFB in Shreveport; (3) LONI, a high-speed state-wide communications and grid computing infrastructure, which provides connectivity to the National LambdaRail and other national and international networks; (4) a real opportunity for acquiring resources through this proposal to establish a Tower of Excellence by building intellectual critical mass in cyber security and sensor

networks through additional hires in complementary areas of our research; and (5) a promise of existing and potential partnerships with leading institutions in the world.

5.a.1 DESCRIPTION OF RESEARCH GROUP

The research team is strategically organized to integrate the work of lead researchers in this project area. Participating lead researchers have extensive discipline-based long-term innovation credentials and laboratories for developing methods related to secure transmission of data to distributed cyber systems and building survivable communications routing and protocols for sensor data dissemination. They have accumulated expertise in developing methods for automatic sensor data fusion, sensor data processing, and tools for integrated prediction, detection, and estimation for disaster precursors. In addition, the team is supplemented by experts in visualization and experimental validation with simulated and actual sensor nodes.

Core Team Composition The core research team consists of five senior faculty members: Dr. Vir Phoha (PI) and Dr. Kody Varahramyan (Co-PI) from LaTech and Dr. S. S. Iyengar (Co-PI), Dr. Peter Chen (Co-PI), and Dr. Gabrielle Allen (Co-PI) from LSU. Phoha specializes in spatial-temporal pattern detection and event recognition, Varahramyan in microsensor fabrication and field testing, Iyengar in information sensing and fusion in sensor networks, Chen in data modeling, cyber forensics and cyber security, and Allen in high performance computing for grid based dynamic data-driven applications. The team is supplemented by three senior researchers: Dr. Christian Duncan and Dr. Rastko Selmic from LaTech and Dr. Tevfik Kosar from LSU. Dr. Duncan's expertise is in visualization and Dr. Selmic's expertise is in sensor placement and protocol development. Dr. Kosar's expertise is in distributed systems, grid and collaborative computing. Thus, the team brings a multifaceted approach to solve the problems posed in this proposal.

The team members will work in groups of three to four to solve research problems outlined in this proposal. (See Section 5.b.1 PROPOSED WORK, page 11.)

Existing and Prospective Partnerships The team has made substantial contributions to the broader impact of science and engineering. Collectively they have published fifteen books, 400 journal articles, and over 600 conference papers relevant to the proposed research. In addition to individual contributions, the PI Phoha has worked with the Co-PIs Iyengar, Chen, and Varahramyan and with senior researchers Selmic and Duncan; and many of the Co-PIs and senior researchers have worked with each other on previous projects, resulting in relevant joint publications. Phoha and Iyengar have also collaborated on patents related to cyber systems.

Existing Partnerships Phoha, Iyengar, Chen, Varahramyan, and Allen, each individually and in collaboration have substantial work in their research thrust areas which informs the direction of the proposed research activities of this proposal. Phoha, Iyengar and Chen have an NSF funded project on Cyber Security and Information Assurance [1] and another joint NSF project [2] to develop course and curriculum in information assurance and security under review. *The work developed under these two proposals will form the basis of security issues related to this project.* Phoha's work on anomaly detection in complex systems, supported by an Army Research Office Multi University Research Initiative (MURI) grant [3], involved four universities (Carnegie Mellon University, Penn State University, LaTech, and Duke University) and will form the foundation of rare pattern detection methods for this project.

Each of the core team members has substantial *current* federal research funding: Phoha (NSF, ARO, see for example [1, 3]), Iyengar (NSF, ARO, DoE, ORNL, see for example [4-8]),

Chen (NSF, AFOSR, see for example [9, 10]), Varahramyan (NSF, see for example [11-15]), and Allen (NSF, NIH, ONR, see for example [16-21]). The team members work collaboratively on many of these grants.

Many team members have collaborated on research (for *some* examples see [22-27]). Phoha and Selmic are program committee members and are jointly organizing and chairing a special session on intelligent sensor networks for the 2007 IEEE Conference on Wireless sensor networks to be held in London in April 2007. These examples only list the partnerships within the proposal team members. In addition, each team member has extensive research partnerships with national and international researchers such as those from ORNL, Penn State, MIT, Stanford, Duke, CMU, Max Planck Institute, etc.

Prospective Partnerships The Co-PI, Varahramyan brings significant interdisciplinary contributions to the existing team by building real artifacts and directing field experiments for validating the multimodal functionalities of real sensor systems integrated with cyber systems. The Co-PI Allen and senior researchers Kosar and Duncan add the much needed expertise in grid formulation, distributed massive data intensive scheduling, and visualization, respectively.

Many prospective partnerships are planned to assemble an expert group of talents from major universities and national laboratories (letters of support from Penn State and Oak Ridge National Laboratory attached), and private sector (letters of support attached).

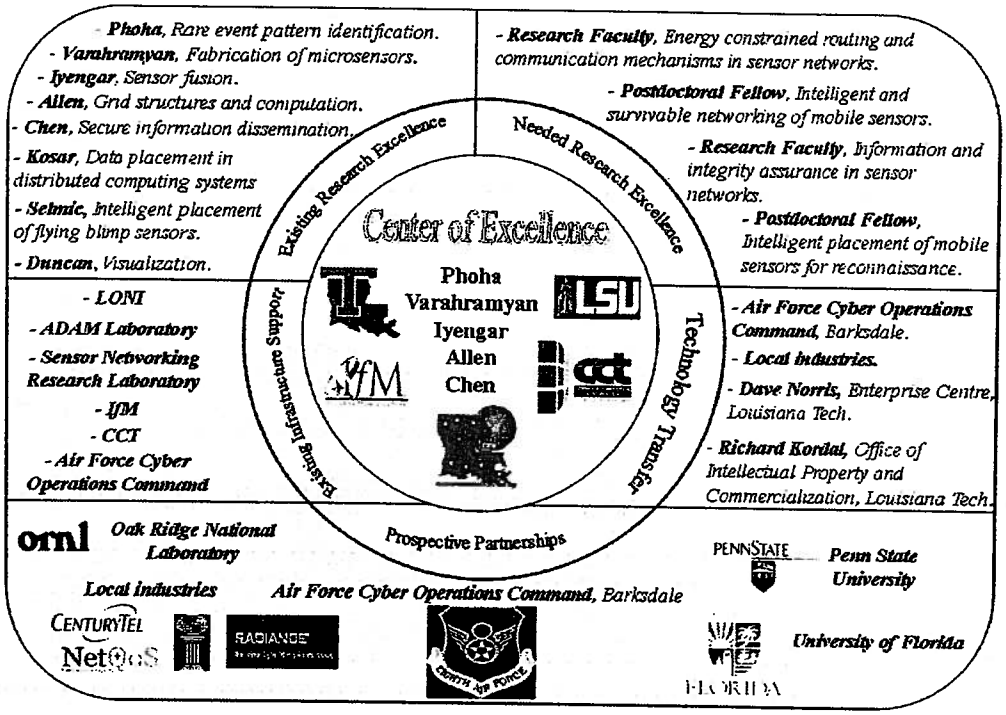

Figure 1. An overall view of the project.

Four Research Faculty and Four Postdoctoral Fellows Hired We will supplement the existing research excellence of the team with the expertise of four newly hired tenure-track research faculty members (two at LaTech and two at LSU) and four postdoctoral fellows (two at LaTech and two at LSU). Research faculty positions and postdoctoral fellowships will be advertised immediately after funding notification from BoR. The faculty and the post-docs will focus their work on sensor deployment, energy constrained communications in sensor networks,

protocol design and routing in sensor networks, information and integrity assurance in sensor networks and cyber systems, pattern analysis, machine learning, information fusion, and massive data-driven visualization. Figure 1 gives an overall view of the team structure and partnerships.

5.a.2 CONTEXT FOR PROJECT

The major task in Cyber-centric sensor networks is to process noisy intelligence data acquired by a collection of diverse sensors, to integrate the information, and to produce abstract interpretations of it. The team has been addressing many of the difficult research issues over the last ten years. In the following paragraphs, we list the team's recent history and directions in the most relevant research focus areas which inform the direction of the proposed research.

- *Distributed algorithms for integrated sensor networks*

The team's recent work in the area of distributed algorithms for integrated sensor networks focuses on reliable routing with arbitrary network topologies [28, 29], scalability issues in sensor networks [30], characterizing sensor fault modalities [31], tolerating faults while performing sensor integration [32], and tolerating faults while ensuring sensor coverage [33]. Building on our existing research and the ongoing research under our NSF and DoE-ORNL grants [6-8], we will address three proposed research tasks: *T.1.2*, *T.2.3*, and *T.2.4*. (See Table 1, Focus areas of the proposed research, page 11.)

- *Secure sensor data dissemination to distributed cyber systems*

Sensor data must be protected using secure and survivable protocols to prevent adversaries from accessing application-specific message contents or denial-of-service attacks. In this context, we propose to extend our research in securing sensor data transmission to cyber systems through attack detection and mitigation mechanisms [34, 35], randomized busing [36], online prediction [37], graph theoretical profiling [38, 39] and survivable and environment-aware sensor networks [40]. In addition, the ongoing research efforts under our currently funded MURI, NSF, and AFOSR grants [3, 6, 9, 10] will be used as a basis for addressing three proposed research tasks: *T.2.1, T.2.2,* and *T.3.3.*

- *Fabrication of micro/nano scale smart sensors*

Varahramyan's recent research in developing layer-by-layer nanoarchitecture assembled ultra thin films [41], polymeric field-effect transistors fabricated by reactive ion etching [42, 43], and thin film deposition of organic semiconductors by ink-jet printing [44] have a direct application in fabricating smart micro/nano scale sensors. Building on the existing research in micro/nano sensor fabrication as well as on the ongoing research under various NSF grants [11, 12, 14], we will address two proposed research tasks: *T.4.2* and *T.4.3*. In addition, the I*f*M's unique blend of world-class resources including electron beam nanolithography systems, dual chamber/micro reactive ion etching systems, wire bonding stations, and wafer dicing systems will be leveraged to address these tasks.

Selmic's background on intelligent control and design of small form-factor hardware modules [45, 46] gives much needed expertise in developing field testable sensor nodes with provision of interface to cyber systems (Task *T.4.2*). He will also bridge communications between the computer scientists of the team, to address placement and sensor fusion, and the I*f*M, to develop field realizable sensor fabrication technologies (Task *T.4.3*).

- *Automatic sensor data fusion, processing, and integrated event pattern detection, estimation, and prediction*

The team's recent research on data fusion in distributed sensor networks [47], information fusion for pattern analysis [48], multi-resolution data integration in sensor networks [49], cascading decision trees [35], parallel decision trees [50], quantitative language measures for decision and control [51], supervisory control [34], dependence trees [52] and the ongoing research efforts under MURI, NSF, and DoE/ORNL grants [3, 4, 6] will be used to address three proposed research tasks: *T.3.1, T.3.2,* and *T.3.4.*

- *Distributed and collaborative architectures, grid computation, and visualization*

The surveillance zone in the context of surface traffic analysis from spatially distributed sensors is viewed as a multi-dimensional grid with sensors being placed at grid points. Building on the team's research in distributed and collaborative architectures for modeling [53-55] and visualization [56], dynamic resource discovery and allocation in grids [57], parallel and distributed grid processing [58], data intensive computing [59], reliable and efficient data placement in dynamic grids [60-62], and on the ongoing research under various NSF, NIH, and DoE grants [17-21, 63], we will address three proposed tasks: *T.1.1, T.1.3*, and *T.4.1.*

5.a.3 EXISTING SCIENTIFIC EXCELLENCE

Professor Phoha (PI) has done fundamental and applied work in anomaly detection in network systems, in particular in the detection of rare events in network traffic. This work has been shared with the computer science community through significant archival quality publications in various IEEE Transactions publications (see for example [34, 35, 50, 64] which are specific to this research) and ACM and IEEE conferences [various] and by one allowed patent and four patent applications. His books [27, 65, 66] in these areas have been adopted in USA, Europe, China, and Australian universities and research institutes. He directs the Anomaly Detection and Mitigation Laboratory at LaTech.

Prof. Phoha has invented a resilient computer password protection technology using keystroke density neural networks, which has been licensed to *Biopassword Inc.*, a major company in the state of Washington, providing enterprise level user authentication systems and solutions. The technology is now the core of their major new product and has been employed to provide security in online bank transactions in major national and international banks. His mathematical tools and machine learning techniques for real-time detection of usual and rare patterns in massive data have been successfully applied to detect attacks on computer networks and detect and mitigate faults in software systems. In addition, Dr. Phoha has recently filed four invention reports in anomaly detection in computer networks and computer user access control through keystroke dynamics. These inventions support the proposed research in this proposal.

Professor Iyengar (Co-PI) is a world renowned authority in sensor fusion and has received numerous grants in sensor fusion from NSF, ARO, DARPA, and AFOSR. His book [67] on sensor fusion is one of the leading books in the field. He has authored over 400 papers in this field. He has been involved with research in high-performance algorithms, data structures, sensor fusion, data mining, and intelligent systems. *He is a fellow of the IEEE, ACM, and AAAS.*

Professor Chen (Co-PI) is the originator of the Entity-Relationship Model (ER Model) [68], which serves as the foundation of many systems analysis and design methodologies, computer-aided software engineering tools, and repository systems including IBM's Repository Manager/MVS and DEC's CDD/Plus. Prof. Chen is leading research teams on Profiling

Problems in Cyber Security and Anti-Terrorism. Recently, Prof. Chen was honored by the selection of his original ER model paper as one of the 38 most influential papers in Computer Science according to a survey of 1,000 computer science college professors. Prof. Chen received the *ACM/AAAI Allen Newell Award and is an ACM, IEEE, and AAAI Fellow.*

Professor Varahramyan (Co-PI) has pioneered the development of Layer-by-Layer assembly techniques for nanomanufacturing. These techniques form the basis of fabricating chemical/bio/thermal sensors with nanometer precision. He has several patents, more than 20 invention reports, and over 90 publications in micro/nano scale processes, materials, devices, and systems. He is Director of I*f*M, a world-class micro-fabrication facility for design and production of micron and submicron devices.

Dr. Allen (Co-PI) is leading several active Grid projects. Her NSF funded EnLIGHTened Computing project is developing advanced software and middleware that will provide a new generation of scientific applications to be aware of their network and Grid environment and to make dynamic, adaptive and optimized use of networks connecting various high end nodes. Her NSF supported Southeastern Coastal Ocean Observing and Prediction (SCOOP) project is being developed to archive and process coastal ocean observing and prediction data. Allen's group is developing state-of-the-art co-scheduling techniques bringing computational, data, and network resources together for the use of coastal modeling community. Allen has also taken a leading role in other NSF supported projects such as GridChem, which aims to build a computational chemistry Grid, and DynaCode: a general Dynamic Data Driven Application Systems (DDDAS) framework with coast and environment modeling applications.

Dr. Selmic's research (see [45, 46, 69, 70]) is in optimal sensor placement, control of sensor systems, intelligent sensors and actuators, control systems, failure detection in nonlinear systems, and neural networks. He currently serves as an Associate Editor for IEEE Transactions on Neural Networks. He is currently funded by the Air Force Research Lab for sensor networks and has been invited to be a Fellow at AFRL for the coming summer.

Dr. Duncan's expertise is geometric algorithms and information visualization. He is currently formulating problems for the simultaneous embedding of graphs and visualization of information. His work (see [71-77]) related to information visualization, geometric algorithms, planar graph-drawing, and balanced aspect ratio trees will lay the foundation for developing dynamic grid structures and visualization of information.

Dr. Kosar and his group have wide ranging experience in building blocks for Grid computing especially addressing the distributed data-handling problem. They have designed, and implemented the first prototype batch scheduler specialized in data placement, *Stork,* and introduced several possible scheduling strategies for data placement. Recently, Kosar has been awarded an NSF grant to develop an innovative distributed data archival, analysis and visualization cyberinfrastructure for data intensive collaborative research, called PetaShare. An initial prototype of this instrument will be deployed at LSU and four other Louisiana campuses, including LaTech. PetaShare will leverage the existing 40 Gbps LONI infrastructure to make the interconnections, fully exploiting high bandwidth low latency optical network technologies. This system will complement the high performance computing resources at the five interconnected campuses, and will boost the interdisciplinary research among them.

5.a.4 MULTI-INSTITUTIONAL FOCUS

Promoting collaboration between LaTech, LSU, AFCyber at BAFB, and other academic and industrial partners, the Center of Excellence *integrates* the best management and technical

expertise. The level of participation and commitments of the partnering institutions in support of this project follow.

The research team consists of representatives from LaTech and LSU. Researchers from both LaTech and LSU will work in groups of three to four on research problems (see Table 2, page 11). The groups represent the best match of expertise to each of the research topic and represent multi-institutional and multi-disciplinary focus of the project. For example, for network formulation, the research team includes Phoha (LaTech, CS), Allen (LSU, CCT), and Kosar (LSU, EE), and new faculty and post-docs (LaTech, LSU), represent both LaTech and LSU. Similar arrangements hold for other research areas.

Both LaTech and LSU have *each* committed half-time support of two research faculty (thus providing a total of four new faculty positions), and *will support these positions after the duration of the project.* In addition, both institutions have committed generous release time for the participating researchers and have contributed significant levels of matching funds for graduate students, support staff, travel, supplies, and equipment.

The advisory board includes the best management expertise from both institutions: LaTech (Les Guice, VP R&D, and Stan Napper, Dean, COES) and LSU (Harold Silverman, VC and interim Provost, and Brooks Keel, VC R&D). The advisory board includes nationally respected industrial leaders representing both Louisiana (CentruryTel, Praeses Corp, Barksdale Forward) and the nation (Radiance Technologies, NeTQoS and ATIC). These industrial leaders from both within and outside the state provide us with the knowledge, vision, and a non-invasive force to ensure relevance of our research agenda to Louisiana industries. In addition to serving on the board, many industrial partners have provided matching support. For example, Praeses Corporation has committed half-time of a technical person to support technology transition for the duration of the BoR funding.

The research team is further supplemented by international visionaries with distinguished records in sensor networks, cyber security, and allied areas representing prestigious national institutions: Professors Asok Ray and Bharat Madan (Penn State), Professor Sartaj Sahani (University of Florida), and Dr. Nagi Rao (UT-Battelle Corporate Fellow, Complex Systems Group, Oak Ridge National Laboratory). The research team will extend collaborations with other faculty members and universities both in state and nationally as the Center further develops and implements its research, education, and outreach programs.

5.b RESEARCH PLAN

5.b.1 PROPOSED WORK

The proposed work identifies the research focus of the Center of Excellence. The research focus is on four major research areas as delineated in Table 1, followed by a brief description of individual tasks.

Table 1. Focus Areas of the Proposed Research.

Research Areas	Task Description
Research Area #1 ***Investigate network formulation providing robust placement algorithms in uncertain environments and ill defined topologies.***	• T.1.1 Network Architectural Design Using Socio-Biological Principles • T.1.2 Adaptive Sensing in Non-stationary Environments. • T.1.3 Embedding of Sensor Information at Grid Locations.

Research Area #2 ***Develop secure transmission to distributed cyber systems and build energy-efficient survivable communications routing and protocols for sensor data dissemination;***	• T.2.1Develop Adaptive Attack Detection Mechanisms for Secure Transmission to Distributed Cyber Systems • T.2.2 Develop Resilience to Node Capture • T.2.3 Develop Robust Broadcast Routing Protocol for Sensor Networks • T.2.4 Develop Algorithms for Optimal Transmission Scheduling Under Power Constraints
Research Area #3 ***Develop automatic sensor data fusion, processing, and tools for integrated prediction, detection, and estimation for disaster precursors.***	• T.3.1 Rare Event Pattern Identification • T.3.2 Finding the Spatial-temporal Origins of Rare Events Based on Sensor Data • T.3.3 Secure Sensor Data Aggregation • T.3.4 Robust Sensor Data Fusion Using Dependence Tree Models
Research Area #4 ***Develop visualization software modules and perform experimental validation with simulated and actual sensors.***	• T.4.1 Develop Visualization Tools • T.4.2 Develop Smart Micro and Nano Scale Sensor Nodes • T.4.3 Validate Mathematical and Software Tools on Simulated and Actual Network of Sensors in the Center of Excellence

By converging these research areas, we aim to produce measurable advances in semantic fusion that enable fast, accurate, and dependable technology interacting purposefully with humans and the physical world. *This proposal addresses the fundamental deficiency in achieving this next level of convergence in technology that will interact directly with the physical world and with humans in dynamic and uncertain environments, cognizant of dynamic goals and the evolving physics, seamlessly spanning time and space to monitor change, and collaborating with humans to actuate purposeful distributed response.*

A brief description of the research tasks follows.

Research Area #1 Investigate network formulation providing robust placement algorithms in uncertain environments and ill defined topologies. (Phoha, Allen, Kosar, New Faculty, and Postdoctoral Fellow)

- *T.1.1 Network Architectural Design Using Socio-Biological Principles*

Tradeoffs of architectural design characteristics like number of nodes, node placement, routing, clustering, and resource constraints have been extensively studied in recent years [78-81]. We aim to engineer structure of sensor networks for operational dependability and performance under both expected and unexpected perturbations using principles derived from insect and animal behavior [82-87]. The approach based on insects and animal behavior provide an alternate way of designing sensor networks, in which autonomy, emergence, and distributed functioning replaces control, preprogramming, and centralization. Thus, these systems suit well for developing robust placement algorithms for sensor networks where mobile sensors (such as UAVs) are autonomous, the terrain is ill defined, and the operational environments are uncertain.

- *T.1.2 Adaptive Sensing*

Sensor density in large, low-density grids may vary wildly even for a regular grid (e.g., rectangular grids in two spatial dimensions). A promising approach to the problem of sensor networking with very low density regions is that of adaptive or targeted observations. This basic type of adaptive sensing approach has been successfully employed in weather prediction [88] and ocean sampling [89]. The proposed research will enhance the state-of-the-art of targeted/adaptive sensing for real-time pattern identification.

- *T.1.3 Embedding of Sensor Information*

Information extraction from observation of strategically placed sensor suites is critical for real-time pattern recognition in spatial-temporal processes. From this perspective, the research team will develop a theory of observation to address the following criteria: (1) Information collection over finite time from sensors at selected spatial locations; (2) separation of the relevant information from spurious data, including noise; and (3) validation of the extracted information. New mathematical tools will be developed to address this problem.

Research Area #2: Develop secure transmission to distributed Cyber systems and build energy-efficient survivable communications routing and protocols for sensor data dissemination. (Chen, Phoha, Iyengar, Selmic, New Faculty, and Postdoctoral Fellow)

- *T.2.1 Develop Adaptive Attack Detection Mechanisms for Secure Transmission to Distributed Cyber Systems*

Building on our earlier work in cascading decision trees [35], parallel decision trees [50], competitive learning networks [64], and intelligent control techniques [26, 34], we will develop *stateless, reliable* and *immediately deployable* attack detection mechanisms to secure transmissions to cyber systems. Figure 2 shows our two-stage attack detection method. In the first stage, data clustering algorithms will partition data and communication traffic measurements into heterogeneous clusters. In the second stage, decision trees will be constructed within each cluster.

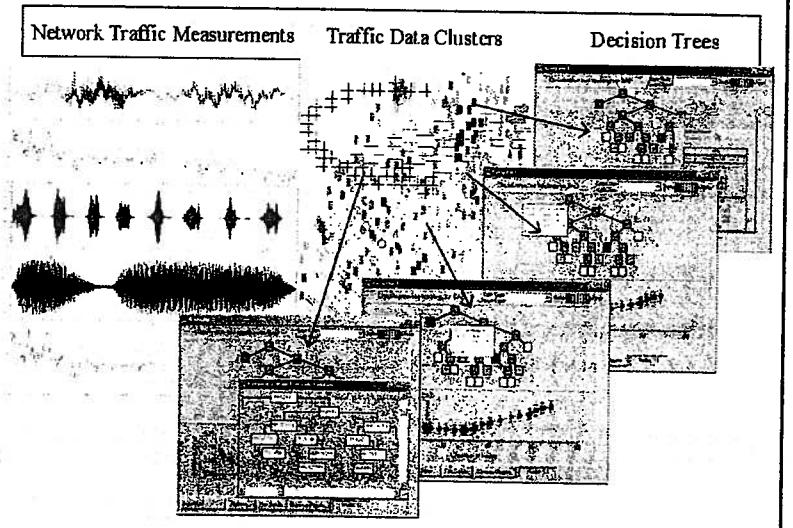

Figure 2. Cascading clustering algorithms with decision trees for robust attack detection in network traffic.

- *T.2.2 Develop Resilience to Node Capture*

The challenge here is to build wireless sensor networks that work reliably even if some nodes have been captured or compromised in the context of surface ship combat systems. Building on our earlier work [90-94], we will examine resilience problem by developing consistency checks on the information received. Further, we will spread the state information of sensor network over different regions and develop mechanisms, such as voting or polling to detect fraudulent activity and guess the correct information.

- *T.2.3 Develop Robust Broadcast Routing Protocol for Sensor Networks*

Building on our earlier work on adaptive routing specific to sensor networks [28, 95-99], we propose a near-optimal Broadcast Protocol for Sensor Networks (BPS) to enable a significant reduction on retransmissions and communication overhead. BPS uses geometric calculations in setting strategic locations for the next transmitting node, aiming for a maximal hop size. Four crucial issues: scalability, energy-efficiency, memory usage, and computational time, will be addressed in the proposed BPS research.

- *T.2.4 Develop Algorithms for Optimal Transmission Scheduling under Power Constraints*

Our goal is to develop optimal transmission scheduling algorithms for sensor nodes operating under load, duty-cycle, and power constraints. To obtain optimal transmission scheduling, we will solve the Minimum Energy Scheduling Problem (MESP) in which the objective function is to determine the schedule which minimizes the total energy. Since traditional optimization methods using Lagrange multipliers do not work well for MESP and are computationally expensive given the non-convex constraints, we will develop polynomial approximation schemes for finding optimal transmission schedules. For two fixed transmit power levels (0 and P), we will develop a 2-factor approximation for finding the optimal fixed transmission power level per time slot, that generates the minimum energy schedule.

Research Area #3 Develop automatic sensor data fusion, processing, and visualization tools for integrated prediction, detection, and estimation for disaster precursors. (Iyengar, Phoha, New Faculty, and Postdoctoral Fellow)

- *T.3.1 Rare Event Pattern Identification*

By treating the spatial-temporal structure in sensor observations as a generator of a formal language, we will develop methods to construct recognizers of this language to identify and localize the spread of rear events. The event-driven interactions between sensors are modeled as a deterministic finite state automaton (DFSA) of the plant, $G=(Q,\Sigma,\delta,q_0,Q_m)$, in which Q is a set of states, Σ is the alphabet of events causing the state transition, δ is the transition function, q_0 is the initial state, Q_m is the set of states of importance as determined by the designer. Event alphabet Σ is divided into two classes: recognizable events (Σ_c) and (rare) unrecognizable events (Σ_u). Our objective is to design a recognizer that matches event patterns in a way that the given spatial/temporal relationships in sensor observations behave in obedience to certain constraints. Figure 3 illustrates our ideas on rare event pattern recognition and spatial-temporal identification of events using sensor data. (See the next task for finding the origin of rare events as a sequel to this work.)

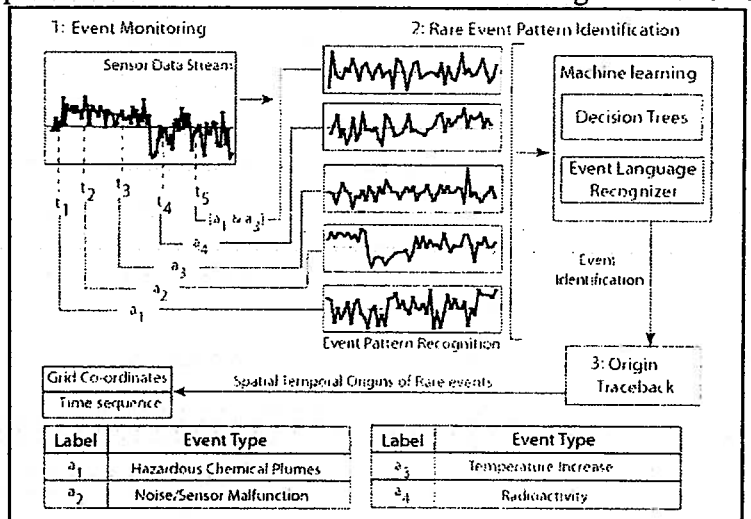

Figure 3. Event pattern recognition and spatial-temporal origin identification of rare events using sensor data.

- *T.3.2 Finding the Spatial-temporal Origins of Rare Events from Sensor Data*

We will use Bayesian inference methods in conjunction with language theoretic methods to find the spatial-temporal origins of unusual events. Formally, we will find $P(X_t/E_t)$, where X_t is a fast time scale stationary process representing state of the environment under surveillance; E_t is observation resultant of a rare non-stationary event. We have access to evidence E_t through

sensors as a continuous stream beginning at $t=1$. This problem translates to finding $P(X_{t+1}/E_{1:t+1}) = \alpha P(E_{t+1}/X_{t+1})P(X_{t+1}/E_{1:t})$, where α is a normalizing constant. Another task that we will address is the prediction of unusual event patterns from historical data, that is $P(F_{t+1}/E_{1:t+1}) = \alpha \sum_{F_{t+k}} P(F_{t+k+1}/F_{t+k})P(F_{t+k}/E_{1:t})$, where F_t is a multidimensional random variable representing event patterns, and k is the period for which we want to predict. We will explore the sequence of events that could most likely result in catastrophes or precursors to catastrophes. That means, in a recursive fashion, we are finding the most likely paths to state X_{t+1} and the most likely paths to each state X_t. In addition, using hidden Markov models [100] we will develop models of cause and effect and predict whether an event is a result of faults in a particular sensor.

- *T.3.3 Secure Sensor Data Aggregation*

Sensor nodes provide fine grain data, which must be aggregated to interpret information. Data aggregation can be compromised, for example, an adversary can disrupt the network's operation by broadcasting high energy signal; or some nodes can be physically removed, replaced, or destroyed. Many approaches show promise at conceptual level for secure data aggregation. For example, one can randomly sample some nodes to ensure their trustworthiness and detect many types of attacks. Building on our work in secure data aggregation [50, 91, 92, 101], fault tolerance [26, 102-106], and machine learning [22, 24, 35, 50, 52, 92, 93, 107], we will develop secure aggregation methods based on fusion using boosting and bagging approaches to provide security in data aggregation procedures.

- *T.3.4 Robust Data Fusion Using Dependence Tree Models*

Our approach to robust sensor data fusion draws on our earlier work on dependence trees [52]. Let $O = \{o_1,\ldots,o_n\}$ represent a vector of aggregated sensor observations from a set of sensors. Using tree dependence approximation [108] and Bayes' rule, we will estimate the state-conditional probability distribution $P(o/e)$ using second order component distributions of the type $P(o/e) = \prod_{i=1}^{n} P\left(o_{m_i}, o_{m_{j(i)}}/e\right)$ where e represents the evidence vector.

Research Area #4 Develop visualization software modules and perform experimental validation with simulated and actual sensors. (Varahramyan, Phoha, Kosar, Duncan, New Faculty, and Postdoctoral Fellow)

- *T.4.1 Develop Visualization Tools*

Visualization of the results of developed algorithms is an important software development activity of this research. Based on our earlier work [72, 109] we will develop multi-perspective dynamic real-time visualization of sensor nodes to help understand emergent trends and abrupt changes. The initial focus will be to visually represent the formation of ad hoc topologies and the detection of events with the ability to represent different views of the same information.

- *T.4.2 Develop Smart Micro and Nano Scale Sensor Nodes*

We propose to use Layer-by-Layer assembly in conjunction with lithography (see for example [110]) to fabricate ultrathin microcantilevers on a silicon wafer to develop chemical/thermal/bio sensor arrays. To provide *interface with cyber systems*, the sensors will be supplemented with a fractal antenna to interact with an external transceiver, an ID generating

circuit to modulate transceiver's query signal into a unique code characteristic, and a sensor switch to control the output code of the ID generating circuit. In addition, we will provide the sensor with solar cells or coat with piezoelectric and pyroelectric materials to generate energy.

- *T.4.3 Validate mathematical and software tools on simulated and actual network of sensors in the Center of Excellence*

Our earlier work in the MURI will form the basis for developing software validation tools of our research. We will model each sensor node as a separate processes running on Linux and Windows PCs and represented it as a separate instance of the Dynamic Space Time Coordinated (DSTC) tracking process [111, 112]. These processes receive sensory inputs from the sensors. Each sensor node has a sensor model and an associated Closest Point of Approach (CPA) event generator for running DSTC/CPA algorithm [113, 114]. The CPA generator uses inputs from the physical sensors to generate events for the grid of virtual sensor nodes and node positions to be displayed on screen.

5.b.2 PROJECT IMPACT

Partnership with the Air Force The opportunities for a state to attract a major military Command are indeed quite rare. It is even ***rarer*** when that Command is focused in an emerging area of great importance to the global knowledge economy. The fact that the focus of the AFCyber at BAFB is in the same domain (IT) in which Louisiana has been focusing its R&D investments over the past several years creates a convergence of actions that could have a dramatic impact on the future of the State of Louisiana.

This is what Secretary Michael Olivier, Economic Development, State of Louisiana has to say in support of this effort (letter of support attached): "***This project*** *serves as a very tangible thing that* General Elder can use to demonstrate to key decision makers that Barksdale is the best place to establish permanent headquarters for the Air Force's Cyberspace Command. While all indications are that this is going to happen...." (Emphasis by the research team writers of the proposal.)

Thus, there will be many new high-skilled military personnel moving to the State and the demands for the IT workforce to support these operations will rapidly grow. There will clearly be many other related impacts on the economy and vitality of the State. However, to truly capitalize upon the opportunities to harness the intellectual activities of AFCyber and ensure that they have maximum impact on Louisiana, it is critical that the academic community immediately engage in supporting the research, development, education, and innovation needs of the Air Force. In the absence of a meaningful engagement of Louisiana's leading cyber scientists and engineers, AFCyber will more aggressively seek support from R&D groups outside the State and the resulting long-term impacts on Louisiana's knowledge economy will be diminished. *Having this core center of excellence in cyber-security research will demonstrate the State's commitment and greatly enhance the overall impacts of and success of AFCyber in Louisiana.*

The proposed Center of Excellence will support economic development by providing a rich concentration of expertise and research capacity that creates technology commercialization opportunities and supports the operations of AFCyber in conjunction with the Cyberspace Innovation Center (CIC) at BAFB. The CIC is a 501(c)3 organization that has recently been established at the recommendation of Gen. Bob Elder, Commander of BAFB and AFCyber, to support cyberspace research, innovation, and education related to AFCyber. Gen. Elder recognizes that there will be many opportunities for private sector companies to partner with AFCyber in commercializing technologies and establishing services that support secure cyber

operations in the military and private sectors. The CIC will link our education institutions, the proposed Center of Excellence, and private sector partners with the activities and interests of AFCyber in a manner that enhances the success of the Command as well as generates significant economic benefits for the public and private partners.

Technology Commercialization Support The generation of commercially viable intellectual property (IP) leading to commercialization and economic development is not an automatic result of leading edge research. Consequently, the partners in this project will employ a robust and extensive commercialization process consisting of: (1) technology evaluation and assessment, (2) IP protection and marketing, and (3) venture formation and business development support. While these three components involve different activities and are led by different groups, they are all part of an integrated process that begins with pre-eminent scientific research informed by commercial applications and ends with public-private partnerships that deploy new technologies into the marketplace creating new economic activity, jobs, and wealth.

Secretary Olivier's letter noted: "We expect to see direct economic impact from the increases in highly skilled military personnel that will be deployed at the base.....Our research universities *must play a leadership role* to ensure that innovations flow out of the research and development opportunities and to ensure that we are meeting the major workforce needs. " (Emphasis by the research team writers of the proposal.)

The technology evaluation and assessment activities will be facilitated by LaTech's Center for Entrepreneurship and Information Technology (CEnIT), in collaboration with the Business Technology Incubator (BTI) at LSU and the Louisiana Technology Transfer Office (LTTO). LaTech has developed a novel commercialization infrastructure over the last several years resulting in rapid growth in IP development, business partnerships, and commercialization activities. This infrastructure is built around CEnIT which was launched in 2002 with $2 million per year in funding from the State's IT initiative. In 2003, CEnIT received a $600,000 NSF Partnerships for Innovation grant to establish the Innovative Venture Research (IVR) program for technology commercialization. Multidisciplinary teams of students, faculty, and business mentors evaluate new technologies developed at the university and recommend new products, services, and business models to deploy the technology profitably in the market. The recommendations are reviewed by a Triage Team of technology transfer experts. Some of these team members (Dr. Bob Mehalso, Senior VP, Microtec Associates; Ross Barrett, Partner, VCE Capital Partners; Joe Lovett, Manager, Louisiana Fund I; Bob Tucker, Partner, Jones Walker Law Firm) also serve as private sectors partners in state-wide commercialization activities, and will contribute to the commercialization process for IP resulting from the cyberspace project.

Intellectual Property Management The IP protection and marketing activities will be facilitated by the Office of Intellectual Property and Commercialization (OIPC) at LaTech in collaboration LSU's Office of Intellectual Property and other partners. The OIPC has seen significant growth in IP activity over the last few years, negotiating six new licenses and options, receiving 31 reports of invention (ROIs), and filing 17 patent applications in fiscal year 2006. Fiscal year 2007 productivity is on a similar pace. The OIPC actively provides professional development outreach for faculty and engages research productive faculty members in dialogue about applications and IP. These activities will contribute significantly to the increased volume of disclosures, patented inventions and licenses resulting from the cyberspace project. We project at least 10 new ROI's, five patent applications, and three licenses for commercialization over the first five years of research and development.

Business Development Support The business development activities will be facilitated

by the Enterprise Center at LaTech in collaboration with partners including the LTTO and the BTI at LSU. The Enterprise Center is the lead external business development arm of LaTech and offers a comprehensive set of resources for early stage and growing technology companies across the I-20 corridor in north Louisiana. These resources include two technology business incubators and a full set of targeted support services through its Technology Business Development Center. The primary support services include entrepreneurial development, pre-venture counseling, and equity and grant fundraising assistance, financial and strategic management consulting, and business networking. It is expected that over the next five years, through cyberspace research projects, the Enterprise Center will host another five startup companies with well over 50 employees in high-paying, quality technology jobs.

The Enterprise Center Director and Senior Investigator, Dr. Dave Norris, will commit 10% of his time to this project. LaTech proposes to hire one new Technology Coordinator to facilitate the integration of the Cyberspace project activities with AFCyber, the Cyberspace Innovation Center, and the overall university commercialization infrastructure. The funding for this position would be $50,000/year, with a 50% match from LaTech.

External partners, public and private, have been essential to recent commercialization successes at LaTech and LSU, and those partnerships will be enhanced and extended through this project. The Enterprise Center has established an extensive network of regional entrepreneurs, investors, mentors, and business leaders as part of the Regional Innovators Network. The Network, with Director John Buske, will serve as another private sector partner helping to facilitate the commercialization of new technologies.

Liaison With Industry The Research and Industry Advisory Board (RIAB) for this project will consist of key technology companies and research entities in the region, as well as major industry players from across the country. The RIAB will facilitate partnerships that drive the development of cyberspace products of common interest to industry and the military, and develop new relationships with leading technology companies to enhance technology transfer and economic development in the state. Eventually, industrial and government organizations that are represented in the RIAB will be asked to contribute in-kind or cash resources to support the operations of the Center. LaTech has employed such a model quite successfully for its Trenchless Technology Center for 15 years.

As a result of the AFCyber's role in a federal governmental agency, multiple contracting opportunities will be created. Contracting for general supplies will provide new procurement opportunities for businesses throughout the region, and the specific and technical needs of AFCyber will stimulate greater activity in SBIR/SSTR grants that enhance the research and development sector of the state's economy. As the AFCyber grows, more jobs will become available for Louisiana's highly skilled and educated citizens, and the region's business climate will be positively influenced by the introduction of new business services and products that meet the needs of this highly sophisticated governmental operation.

Education and Training Impacts The Center's research will be integrated into the academic programs of LaTech and LSU through advanced courses and research projects. It is expected that some common courses will be developed that can be team taught and delivered/received by both campuses using LONI's powerful high-definition multi-conferencing capabilities. Short courses and certificate programs will be developed to support cyberspace workforce development. We will conduct an annual national conference and focused workshops involving participants from national laboratories, industry, DoD laboratories, and students. The Advanced Technology Intelligence Center (ATIC) in Dayton, Ohio, has indicated interests in

partnering with this project for supporting educational needs in the intelligence community.

5.b.3 MANAGEMENT PLAN

Research and Coordination Team Dr. Phoha, the PI, will lead the overall project, coordinate the research thrusts, and coordinate interactions with the Research and Industry Advisory Board. Phoha and Co-PIs Varahramyan, Iyengar, Chen and Allen will serve as the Research and Coordination Team (RCT). They are responsible for directing the project-specific thrust areas and overseeing the overall research and economic development activities. The RCT will meet semi-annually. One of those meetings will be an annual workshop for dissemination of the research results.

Research and Industry Advisory Board To ensure effective cross-institutional interactions and the efficient transfer of research knowledge and experience into the industry, a Research and Industry Advisory Board (RIAB) will be established. The Vice President for Research and Development at LaTech, Dr. Les Guice, will chair the RIAB. Dr. Brooks Keel, Vice Chancellor for Research and Economic Development at LSU, will serve as the Vice Chair. In addition to their roles on the RIAB, Guice and Keel will facilitate interactions between researchers at the two campuses. They will coordinate the establishment of technology transfer policies and inter-institutional agreements.

Other academic members of the RIAB include Dr. Stan Napper, Dean of College of Engineering and Science at LaTech, Dr. Harold Silverman, Executive Vice Chancellor at LSU, and Dr. Sartaj Sahni, Distinguished Professor and Chair of Computer and Information Science and Engineering Department at University of Florida. The RIAB includes several representatives from the private sector including: Murray Viser, CEO of Barksdale Forward (Shreveport), Craig Spohn, CEO of Praeses Corporation (Shreveport), Joel Trammell, CEO of NetQos (Austin), Chris Mangum, VP of Centurytel (Monroe), Bill Bailey, VP of Radiance Technologies (Huntsville, AL), and Bob Fudickar of Louisiana Economic Development. (letters of support in the Appendix.) Other members will be added to the RIAB as appropriate. It is expected that there will be significant overlap in memberships of the RIAB and the Board of the Cyberspace Innovation Center (see paragraph 2 of Section 5.b.2 PROJECT IMPACT on page16).

The RIAB will meet semi-annually with the RCT. The RIAB will annually review the research progress of the project, act as a resource for applications and technology transfer to industry, and will support the establishment of industrial partnerships. They will also provide input into educational needs for academia, the military, and the private sector. The RIAB will provide valuable industrial feedback to researchers in the project. *In addition, Dr. Asok Ray, University Distinguished Professor at Penn State University will be a senior research consultant and offer his expertise in anomaly detection, mitigation, and control of environmental characteristics perceived through sensor networks* (letter of support attached). Dr. Nick Coorough, CEO of the Advanced Technology Intelligence Center (ATIC), will serve as an advisor on workforce development and as a liaison with Wright Patterson Air Force Base in Dayton, Ohio.

Research Project Management The research of this project will be closely monitored by the PI, Co-PIs, and senior researchers. The qualifications and expertise of the research team are addressed in Section 5.a.3. The research faculty, post-docs and students will be organized by teams to support the Research Focus Areas of this project as given in Table 2.

Table 2. Research focus areas and team participants.

Research Areas	Team Participants
#1 Network Formulation	• Phoha (lead), Allen, Kosar, 1 new faculty, and 1 post-doc.
#2 Distributed Systems	• Chen (lead), Phoha, Iyengar, Selmic, 1 new faculty, and 1 post-doc.
#3 Sensor Data Fusion	• Iyengar (lead), Phoha, 1 new faculty, and 1 post-doc.
#4 Field Testing	• Varahramayan (lead), Phoha, Kosar, Duncan, 1 new faculty, and 1 post-doc.

We have planned coordination mechanisms to cover both cross–disciplinary and cross-institutional scientific integration. The coordination mechanisms consist of at least two mandatory face-to-face review meetings every year, biweekly *phone/access grid* conference calls, development of joint Web repositories, identified points-of-contact for virtual laboratory integration across universities, and meetings organized at commonly attended conferences/workshops for addressing coordination issues in a timely fashion.

Dr. Phoha will be responsible for organizing biweekly *access grid conferencing* meetings with all participants at LaTech and LSU to discuss project progress, laboratory integration issues, and educational developments. A formal agenda will be circulated before the meeting and meeting minutes will be posted on the web. An annual workshop with all Co-PIs, interested industry participants, and students will be organized to share research results. Travel support is allocated in the budget for the annual workshop.

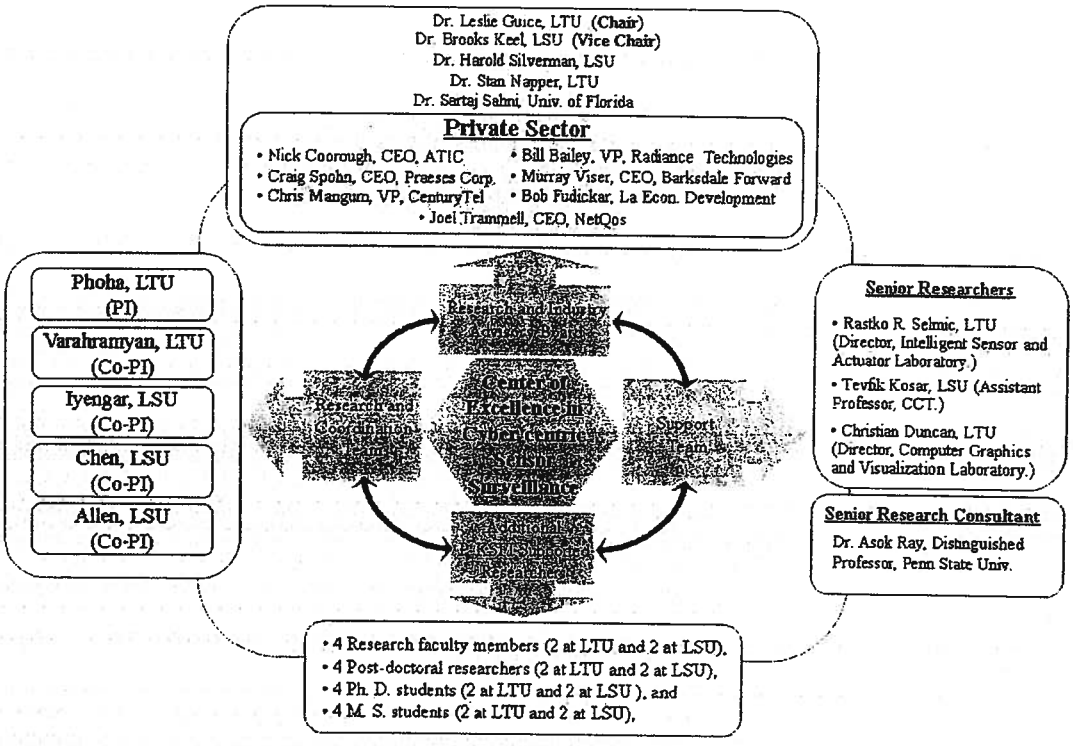

Figure 4. Project organization.

Figure 4 shows the organization and relationships between RCT, RIAB, and the researchers.

5.b.4 PERFORMANCE MEASURES AND OBJECTIVES

Our yearly plans for benchmarking performance and progress in infrastructure, research, and statewide impacts are summarized below. Contingency plans contain adjustments to accommodate unexpected developments.

Table 3: Key Performance Measures and Expectations (Years 1 and 2).

	Performance Measures	Expectations
Year 1		
Infrastructure	Faculty hiring	By May 31, 2008
	Post–doc hiring	One by Aug 2007 and second by October 2007
	Link with LONI resources	By December 2007
	Link with Labs	By March 2008
	Recruit initial graduate students	By December 2007
Research Activity	Major publications, presentations & invited lectures	3 publications, 3 presentations
	Research Milestones	Grid Formulation
Statewide Impact	Establish links with RIAB companies	March 2008
	Support for Cyberspace Command	March 2008
Contingency Plans	LaTech and LSU have a stream of high quality Ph.D. graduates each year. Thus, if we are not able to hire post-docs and faculty through open advertisements, we will recruit post-docs from our graduates. We plan to hire the best expertise in the world.	
Year 2		
Infrastructure	Securing additional external funding	Newly hired faculty will submit at least two research proposals to sustain and extend the current research.
	Build strategic collaborations with national and international academic and industrial partners	December 2008
Research Activity	Publications, presentations, lectures	6 publications, 6 presentations
	Research Milestones	Initiate research specific to needs of the AF. Initiate research on energy-efficient survivable routing for the dissemination and transmission of sensor data to distributed cyber systems.
Statewide Impact	Reports of Invention	3
	Increase presence of RIAB companies	March 2009
	SBIR grant applications	2
Contingency Plans	Core faculty members are active in research and expect no problems in submitting research proposals in collaboration with newly hired post-docs and research faculty. We expect no problems in meeting the objectives of the year 2.	

Table 4: Key Performance Measures and Expectations for Years 3-5

	Performance Measures	Expectations
Year 3		
Infrastructure	Support for more research faculty, grad students, and lab equipment	Submission of at least 3 multi-institutional research and infrastructure proposals
	Strengthened ties with the Air Force	Integration of the Center's research to Tech's BAFB Program
Research Activity	Major publications & presentations	4 publications, 5 presentations
	Research Milestones	Focus on developing sensor data fusion and visualization tools for integrated prediction, detection and estimation of disaster precursors.
Statewide Impact	ROI's, Patent applications, SBIRs	2 ROI's, 1 patent applications, 2 SBIRs
	First new start-up company	1 company, 4-5 employees
Contingency Plans	Could experience delays in integrating our research and education with Barksdale AF program. We will seek collaboration with other national and international partners.	
Year 4		
Infrastructure	3 Ph.D. students to graduate	By May 31, 2010
Research Activity	Major publications & presentations	6 publications, 8 presentations
	Research Milestones	Technology for collaborative viz by different stakeholders having multiple persp. Submit 3 multi-institutional proposals to extend research goals.
Statewide Impact	ROI's Patent Apps, Licenses, SBIRs	3 ROI's, 2 patent apps, 2 licenses, 2 SBIR
	New start-up companies	2 companies, 8-10 employees
	Recruited companies	2 companies, 40-50 employees
Contingency Plans	Assessment of sustainability may require additional focus on this activity year.	
Year 5		
Infrastructure	Center should be self-sustainable	May 31, 2012
	Continuous stream of grad students, post-docs, and visiting positions	Research agenda should have matured and plans for next agenda in place.
Research Activity	Major Publications & presentations	8 publications, 8 presentations
	Research Milestones	Final prototype of system in the field will be demonstrated by end of year.
Statewide Impact	ROI's Patent Applications, Licenses	2 ROI's, 2 patent applications, 2 licenses
	SBIR applications	3
	New start-up companies, employees	3 companies, 35 employees
	Recruited companies, employees	3 companies, 40-50 employees
Contingency Plans	If the Center is not financially self-sustainable, both LaTech and LSU will support the additional post-docs and faculty.	

5.b.5 SUSTAINABILITY

This project lays the foundation for a multi-institutional Center of Excellence in Integrated Smart Cyber-Centric Sensor Surveillance Systems. It brings together a team of eminently qualified computer scientists and engineers to work on integrated and reliable hardware, software and computer systems to address critical national issues related to communications and sensor networks. The research team has a proven record of collaborative research as demonstrated through funded grants, publications, and patents. This P-KSFI grant will provide the team with the resources required to establish a sustained research program focused in an area of importance to the nation and State of Louisiana.

The team will immediately pursue other funding opportunities through their existing extensive connections with the Department of Defense, Department of Homeland Security, and Department of Energy. The team will also pursue major grant opportunities with the National Science Foundation and other agencies. Given their track record, it is most likely that the PI and Co-PIs will be successful in our pursuit of major grants. Through mentorship, it is expected that the national competitiveness of the junior faculty will be enhanced to sustain and expand the Center's research program over the longer term.

This project will establish a research relationship between Louisiana's academic research community and the AFCyber at BAFB. In November of 2006, as Commander of the Eighth Air Force and the Air Force Cyberspace Command, General Bob Elder was charged with leading the planning for a full Cyberspace Command to integrate the Air Force's total capabilities in offensive and defensive operations in the electronics and electromagnetics spectrum (i.e., Cyberspace). General Elder has led discussions with the academic and private sectors to establish public/private partnerships with AFCyber. Further, he encouraged the academic community to begin to develop research programs that would support the Air Force's efforts in this area. The proposed project demonstrates a tangible commitment of Louisiana's top cyber scientists to work with General Elder and AFCyber in advancing its mission and *lays the groundwork for sustained research with the Air Force in cyber-related activities*.

This new initiative will have major economic development implications on the State of Louisiana. Our model for the Cyberspace project is designed to support AFCyber as well as leverage the partnerships that will be formed between academics, industry and the military, to sustain this project indefinitely. The project team will interact with the Cyberspace Innovation Center and other entities to foster the development of new cyber technologies that can be applied in the private sector as well as the military. The ultimate success in developing the new Cyberspace Command to its maximum potential is highly dependent upon the establishment of strong linkages of the Air Force to the regional academic and business community. The RIAB will provide an interface for this project that will generate partnerships to sustain our project for the longer term.

The two participating institutions of higher education will ensure the sustainability of the Center of Excellence by absorbing the new faculty positions into the institutional budgets, continuing to provide matching funds for proposals written by Center members, and allocating doctoral assistantships available to the Center faculty on an ongoing basis as long as they are active in supporting the Center's research. As the Center's needs for space grows, the institutions will identify opportunities for facility expansion that can maximize the impact of the research, education and outreach activities.

5.c LEVERAGING OF RESOURCES

This project capitalizes upon the significant investments that the State has made in IT research and education over the past several years. Louisiana's 2001 IT Initiative has served as a catalyst for elevating Louisiana's research universities to support research productivity and economic development. Both LaTech and LSU made major investments in their IT personnel, facilities and programs as a result of the IT initiative. As a result of this initiative, LSU established the Center for Computation and Technology (CCT) that has already garnered considerable national and international recognition. Two core members of the CCT's research team (Allen and Kosar) are participants in this project. Varahmayan and Selmic bring considerable resources from the world-class I/M laboratories, developed from federal and state funding, to support the sensor network development activities of the project.

Perhaps the most significant development for Louisiana in advancing its IT capabilities was initiated in 2005 with the establishment of the Louisiana Optical Network Initiative (LONI) as part of the new national scale research network called the National LambdaRail (NLR). The NLR provides a high-speed optical network backbone that spans the US, connecting numerous major research institutions and government laboratories. LONI connects the state's major research institutions with high-speed optical fibers capable of delivering up to 40 Gbps. The network connects five IBM P5-575 supercomputers acting in a grid environment with a total computational capability of approximately 5 Tflops. Most recently, the Governor committed $10M to enable LONI to expand its supercomputing capacity by adding 80 Tflops distributed around the grid. *This provides Louisiana researchers with the most powerful distributed supercomputing grid infrastructure in the nation.* LONI's high-performance computing resources will be extensively used in the proposed project. LONI's optical network capabilities will be used to support communications between the researchers and will provide a test bed for cyber security research.

The project capitalizes upon the investments the State has made in its technology commercialization and business support efforts at LaTech (CEnIT, Enterprise Center, Technology Business Development Center), LSU (BTI) and the Louisiana Technology Transfer Office. These entities have collaborated on several projects over the past two years. Together, they form a robust mechanism for leveraging the impacts of the research in the private sector.

The project leverages significant new investments that both LaTech and LSU are making to build a world-class Center of Excellence in cyber security. Each institution has committed two faculty positions, paid ½ by the grant with the commitment that the university picks them up 100% at the end of the grant. The universities are committing to two post-docs (paid ½ by the grant), 12 graduate students, a technology business liaison, and other supporting funds. Other costs such as start-up packages for the new faculty members will also be provided by the institutions and are not reflected in the budget.

Finally, the project leverages a major investment of the Department of Defense in establishing a Cyberspace Command in Louisiana. *The opportunities for leveraging these resources to elevate Louisiana's IT research community to national prominence in an area of national priority are truly unique and timely.*

Annual Report for Year 3 (ending 6/30/2010)

LOUISIANA TECH UNIVERSITY
AND
LOUISIANA STATE UNIVERSITY

2009-2010: ANNUAL REPORT

LOUISIANA BOR PKSFI
CENTER FOR SMART CYBER CENTRIC SENSOR SURVEILLANCE SYSTEMS
GRANT# LEQSF (2007-12)-ENH-PKSFI-PRS-03

PI: Dr. Vir V. Phoha
Co-PIs: Dr. S. S. Iyengar, Dr. Gabrielle Allen, Dr. Peter Chen

Chair of Research and Industrial Advisory Board: Dr. Les Guice

June 15, 2010

1. PERSONNEL: LIST ALL KEY PERSONNEL AND OTHER STAFF WHO PROVIDED *SIGNIFICANT* CONTRIBUTIONS TO THE PROJECT. PROVIDE INFORMATION ABOUT THE TYPES OF CONTRIBUTIONS MADE BY EACH LISTED PARTICIPANT AND CONTROLS IN PLACE TO ENSURE THAT THESE CONTRIBUTIONS ARE ADEQUATE TO THE PROJECT'S REQUIREMENTS.

1.1. Key Personnel and Their Contributions

1.1.1. Project Team

Dr. Vir V. Phoha, (La Tech), PI; Dr. S. S. Iyengar, (LSU), Co-PI; Dr. Peter Chen, (LSU), Co-PI; Dr. Gabrielle Allen, (LSU), Co-PI; Dr. Rastko Selmic, (La Tech), Sr. Researcher; Dr. Tevfik Kosar, (LSU), Sr. Researcher; Dr. Christian Duncan, (La Tech), Sr. Researcher; Dr. Asok Ray, (Penn State University), Sr. Consultant.

1.1.2. Core Research Team

Dr. Vir V. Phoha, (LA Tech), PI; Dr. S.S. Iyengar, (LSU), Co-PI; Dr. Peter Chen, (LSU), Co-PI; Dr. Gabrielle Allen, (LSU), Co-PI; Dr. Asok Ray, (Penn State University), Sr. Consultant.

Tenured/Tenure-track Faculty: Dr. Travis Atkison, (La Tech); Dr. Christian Duncan, (LA Tech); Dr. Jean Gourd, (La Tech); Dr. Jinko Kanno, (La Tech); Dr. Tevfik Kosar, (LSU); Dr. Supratik Mukhopadhyay, (LSU); Dr. Rastko Selmic, (La Tech); Dr. Jian Zhang, (LSU);

Research Assistant Professors: Dr. Kiran Balagani, (La Tech) and Dr. Md Enamul Karim, (La Tech). *Research Associates:* Mr. Vasanth Iyer, (LSU) and Mr. Noureddine Boudriga (LSU).

1.1.3. Research Team Contributions

Collectively as a team and individually, the investigators have produced significant research results supported by the P-KSFI grant. Overall, for the 2010 reporting period, the research team has to its credits ***34*** research papers (***25*** published and ***9*** under review), ***2*** issued US patents, ***1*** US patent application, ***6*** book chapters, ***2*** books, and ***11*** funded grants.

The Core Research Team and their students have collaboratively worked on rare and event pattern detection, intelligent placement of sensors, visualization of graphics, malware and malicious executables, anomaly detection, system security, cyber forensics, sensor fusion, secure information dissemination, grid structures and computation, data placement in distributed computer systems, sensor data modeling, information-theoretic feature selection, sensor network programming, statistical machine learning, and network security.

A summary of key contributions made by the core research team members for the 2010 reporting period follows:

Dr. Vir Phoha and Dr. Kiran Balagani were the key personnel involved in developing fusion algorithms for keystroke based biometric user authentication. Fusion algorithms and related codes were transferred to our industry partner, Assured Information Security Inc., Rome, NY, under the "Cyber Weapons" project effort. In partnership with Air Force Research Laboratory (AFRL), Dr. Phoha and Dr. Balagani led a campus wide effort to collect keystroke patterns to facilitate large-scale evaluations of keystroke based biometric authentication systems. The data collection effort has been very successful, and has attracted more than 1,500 unique participants. The keystroke database resulting from the data collection effort currently has more than 117,000 fixed-text typing samples, and 2,500 free-text typing samples, making it the most comprehensive evaluation database available in keystroke authentication field. Efforts toward analyzing the keystroke data and publishing key insights from the analysis are ongoing.

Dr. Balagani, Dr. Phoha, and Dr. S. S. Iyengar have collaboratively worked on developing mathematical proofs, relating Bayes error bounds to several information-theoretic feature selection criteria. The developed proofs validate the lower-order dependency assumptions of the feature selection criteria, and justify their utility by relating to Bayes classification error. This research has been published in *2* journal papers: IEEE Transactions on PAMI, 2010, and IEEE Transactions on SMC - Part A, 2010.

Dr. Balagani and Dr. Phoha, in collaboration with Dr. Asok Ray from Penn State University, have developed a novel theoretical framework to analyze the discriminability of keystroke features for authentication. Findings from the analysis have indicated strong connections between the inherent discriminability in keystroke features, the correlation structure of keystroke features, and the lengths of reference phrases. A manuscript reporting this work is currently under review in the journal Pattern Recognition Letters.

Dr. Iyengar has been addressing various problems in sensor fusion, sensor data aggregation, and source localization from sensor network data. Together with students and collaborators, he has published 2 journal papers: IEEE Transactions on Wireless Communications, and ACM Transactions on Sensor Networks, 2010. In addition, Dr. Iyengar has received a $284,413 NSF grant to research intelligent and uncertainty-resilient tracking sensor networks. Dr. Peter Chen and his students have developed algorithms applicable to counter-terrorism, learning, and conceptual modeling.

Dr. Enamul Karim and Dr. Phoha, in collaboration with Dr. Keesook Han (AFRL), have developed a new framework and software prototype for identifying malicious botnet traffic through local manipulation of packets and for effective white-listing of IPs. To research botnet detection and mitigation, Dr. Karim has recieved $84,000 funding from Air Force Office of Scientific Research.

Dr. Rastko Selmic, in collaboration with AFRL researchers Lt. R. Carr and A. K. Mitra, are addressing problems related to cooperative control of Micro-Aerial Vehicles (MAVs) for localization of unknown or hidden electromagnetic sources. Dr. Christian Duncan, Dr. Rastko Selmic, and Dr. Vir Phoha are collaboratively working on problems related to sensor placement, sensor coverage, applications of socio-biology to task allocation in sensor networks, and other associated problems.

Dr. Travis Atkison has been working on malicious application detection algorithms. Dr. Atkison has developed data-slicing methodologies, and has proposed a randomized projection algorithm to create a low-order embedding of the high-dimensional malware data.

Dr. Jean Gourd has developed a theoretical model of a mobile agent framework in API-S calculus. His research on mobile agents has earlier appeared in the journal: The Journal of Management and Engineering Integration. Another paper is under review in the same journal.

Dr. Tevfik Kosar and his students have been working on high performance data transfer models. Specifically, his team has developed new models to adaptively approximate optimal number of parallel streams in wide-area network data transfers. Dr. Kosar has published his work in the IEEE Transactions on Parallel and Distributed Computing, 2010. In addition, Dr. Kosar and Dr. Gabrielle Allen together are working on problems related to failure prediction in data-aware scheduling and meta-data management.

Dr. Supratik Mukhopadhyay has been developing modeling techniques for capturing failure semantics in workflow systems, and for rapidly deploying adaptable situation-aware secure service-based systems. Dr. Jian Zhang is developing new stochastic machine learning algorithms and Bayesian methods for early prediction of Cyber attacks. In this area, he has published 1 journal and 2 conference papers, 1 book chapter, and has received $152,462 NSF funding to research multi-perspective Bayesian learning methods for detecting advanced malware.

1.1.4. Research and Industrial Advisory Board

The Research and Industry Board (RIAB) for this project consists of key technology companies and research entities in the region, as well as major industry players from across the country. Dr. Les Guice (La Tech), is the Chair of the Research and Industrial Advisory Board and VP for Research and Development.

The RIAB will facilitate partnerships that drive the development of relationships with leading technology companies, to enhance technology transfer and economic development in the state. Eventually, industrial and government organizations that are represented in the RIAB, will be asked to contribute in-kind or cash resources to support the operations of the Center. Louisiana Tech has employed such a model quite successfully for its Trenchless Technology Center for 15 years.

1.1.5. Research and Industrial Advisory Board Contributions

Dr. Les Guice, Louisiana Tech Vice President for Research and Development, has been a major resource and motivator to make this project a success. The project has established a Research and Industrial Advisory Board (RIAB) consisting of industry leaders, and has helped develop important contacts with the Air Force National Laboratories such as Air Force Research Laboratory, Air Force Office of Scientific Research, Sandia National Labs, and industry partners such as NetQoS, Radiance Technologies, and Assured Information Security Inc, etc.

The RIAB consists of the following members:

Doris Carver, Associate Vice Chancellor, Research & Economic Development, Louisiana State University; Stan Napper, Dean, College of Engineering & Science, Louisiana Tech University; Joel Trammell, Chairman of the Board, CEO, Co-Founder, NETQoS, Inc.; Chris Mangum, CenturyLink, Inc.; Craig Spohn, Executive Director/President, Cyber Innovation Center; Bob Fudickar, Director, Technology, Louisiana Office of Economic Development; Bill Bailey, Radiance Technologies, Inc.

1.1.6. New Hires Supported By PKSFI Funding

- Tenure-track assistant professor Dr. Travis Atkison began his duties at Louisiana Tech University in September 2009.
- Tenure-track assistant professor Dr. Supratik Mukhopadhyay began his duties at Louisiana State University in July 2009.
- Research Associates: Mr. Vasanth Iyer (LSU) and Mr. Noureddine Boudriga (LSU).

1.1.7. Technical and Administrative Support Team

Dr. Scott Forrest (La Tech), Director of the Technology Transfer Center Shreveport, LA, Ms. Brenda S. Brooks (La Tech), Administrative Assistant.

Dr. Scott Forrest has been the Director of the Technology Transfer Center (T2C) in Shreveport. He has been representing Louisiana Tech in his research activities in the development of micro and nano technologies with military, homeland defense, and aerospace applications. Dr. Forrest facilitates the integration of the Cyberspace project activities with the Air Force, the Cyber Innovation Center, Barksdale Air Force Base, and the overall university commercialization infrastructure. As Technology Coordinator, Dr. Forrest maintains a relationship with the 8th Air Force. Dr. Forrest attends monthly meetings at the Cyber Innovation Center (CIC), and meets biweekly with Craig Spohn, Director of the Cyber Innovation Center. Dr. Forrest utilizes all initiative and funding opportunities with constant interaction and coordination. Through AFCEA, Louisiana Tech CEnIT, Louisiana Tech Enterprise Center, Louisiana Tech Technology Business Development Center, LSU BTI, and the Louisiana Technology Transfer Center, Dr. Forrest exercises the opportunity to capitalize on business support efforts, and integrate project activities with academia and industry.

Dr. Forrest has formed an initiative toward Remote Sensing Platforms with the Air Force and Louisiana Tech University using the LONI network. The Business of Airborne Remote Sensing Research and Development (AARecon), comprised of three employees, is the first small business to be located at the CIC. This company services a contract with the Louisiana Department of Wildlife and Fisheries to supply helicopter support for video recon on Lake Bistineau. The contract was awarded to help them track the spread of the invasive plant species, Giant Salvinia. Dr. Forrest has recently submitted a whitepaper to the CIC highlighting some of

his promising unmanned Aircraft (UA) technologies. Consequently, his technologies are under consideration for seed funding from the CIC to expedite these new technologies to the market place.

Dr. Forrest has partnered with Business Collaborators in Bossier City to form a new company called Precision Aerial Reconnaissance (PAR). AARecon will continue as a separate entity with a research and development emphasis, especially on UA technologies. PAR will provide manned aircraft remote sensing services while integrating the UA capabilities that AARecon can provide. Precision Aerial Reconnaissance will be moving into spaces at the CIC on August 1, 2010, and will be working closely with AARecon on related projects.

Ms. Brenda S. Brooks (La Tech), Grants Administrative Assistant, was hired in November 2008, replacing Tina Allen, to provide administrative support for the Center. She is responsible for all administrative functions required in the day-to-day operations of the center. This includes account monitoring, purchasing, travel, and assisting the faculty with submitting proposals and research publications. She monitors grant status on a daily basis. She is responsible for the CSC Newsletter that is released quarterly and is a means of providing research updates and information on the activities at the Center for Secure Cyberspace at Louisiana Tech. Ms. Brooks is also responsible for maintaining the Center's website and continued composition of the quarterly newsletter. She also assisted in the organization and planning of the Second Annual Cyberspace Workshop held in connection with Cyber Innovation Center's Air Force Symposium held in June, and Cyberstorm 2010 held in May.

1.2. Controls in Place to Ensure Project Requirements

The PIs, Co-PIs, and senior researchers have met and discussed research progress and directions of research during the project period. The coordination mechanisms include face-to-face meetings, phone and conference calls, and quarterly newsletters.

The PI Phoha, and the LSU lead Co-PI Iyengar, and Senior Consultant Ray meet every week by phone to discuss progress of the project and overcome deficiencies in research. In addition, almost all the researchers have had frequent face-to face meetings.

Details of the meetings in which all (or most of the PKSFI team) were present follow:

Cyberspace Research Workshop

(June 15, 2009): This workshop was held in Shreveport, Louisiana. It provided a venue to share eleven peer reviewed research papers with peers across the country, and coincided with the Air Force Cyberspace symposium. The conference received high attendance and extensive media coverage.

(November 15, 2010) The 3rd Cyberspace Research Workshop is slated for mid November in Shreveport, LA in conjunction with the Cyber Innovation Center and the Global Strike Command.

Research and Industrial Advisory Board Meetings

(June 15, 2009): The second meeting of the RIAB was held at the Hilton Convention Center in Shreveport, Louisiana.

(November 15, 2010): The third meeting of the RIAB is slated for mid November in Shreveport, LA in conjunction with the 3rd Cyberspace Research Workshop.

Meetings at LSU

(July 2009): The most recent meeting of the PKSFI research team was held in on the campus of Louisiana Tech to discuss the progress of the PKSFI research. Those present were PI Phoha and Co-PI Iyengar.

The above meetings are in addition to the regular meetings that PI Phoha has with individual researchers and Co-PI Iyengar has with LSU on part of the PKSFI team.

Bi-weekly Multidisciplinary Cyberspace Meetings (at La Tech)

The bi-weekly multidisciplinary cyberspace meeting brings together 12 faculty members and 13 graduate students from several disciplines including cyber security, computer science, electrical engineering, mathematics, psychology, business, and entrepreneurship. The purpose of the bi-weekly meetings is to generate new ideas for research, to explore synergistic cross-disciplinary collaborations, and to create a forum to openly discuss and critique works in progress. The bi-weekly meetings are conducted in the Center for Secure Cyberspace (Nethken Hall, Room 248) at Louisiana Tech University. Guest speakers are invited to discuss leading topics at their departments/universities to encourage continued progress in other fields interrelated with Cyberspace. During the Spring 2010 Quarter, Dr. K. R. Rao, Professor of Electrical Engineering at the University of Texas at Arlington was invited as the guest speaker.

Newsletters

A newsletter is designed every quarter to compile recent events and accomplishments from the team. This newsletter is circulated via campus email, and posted the CSC website.

2. ACTIVITIES AND FINDINGS

2.1. Major Research and Educational Activities Undertaken

2.1.1. Research Activities

Table 1. A description of four major research activities and their status. Check mark indicates that work on the task is ongoing or has started.

Research Activities	Task Description	Status
Research Area #1 ***Investigate network formulation providing robust placement algorithms in uncertain environments and ill defined topologies.***	• T.1.1 Network Architectural Design Using Socio-Biological Principles • T.1.2 Adaptive Sensing in Non-stationary Environments. T.1.3 Embedding of Sensor Information at Grid Locations.	☑ ☑ ☑
Research Area #2 ***Develop secure transmission to distributed cyber systems and build energy-efficient survivable communications routing and protocols for sensor data dissemination.***	• T.2.1 Adaptive Attack Detection Mechanisms for Secure Transmission to Distributed Cyber Systems • T.2.2 Network Centric Behavioral Biometrics and Remote Suspect Identification • T.2.3 Botnet, Malware, and Rogue Application Detection and Mitigation • T.2.4 Algorithms for Optimal Transmission Scheduling	☑ ☑ ☑ ☑
Research Area #3 ***Develop automatic sensor data fusion, processing, and tools for integrated prediction, detection, and estimation for disaster precursors.***	• T.3.1 Rare Event Pattern Identification • T.3.2 Finding the Spatial-temporal Origins of Rare Events Based on Sensor Data • T.3.3 Secure Sensor Data Aggregation • T.3.4 Robust Sensor Data Fusion and Decision Fusion	☑ ☑ ☑ ☑
Research Area #4 ***Develop visualization software modules and perform experimental validation with simulated and actual sensors.***	• T.4.1 Develop Visualization Tools • T.4.2 Develop Smart Micro and Nano Scale Sensor Nodes • T.4.3 Validate Mathematical and Software Tools in the Center of Excellence	☑ ☑ ☑

2.1.2. Educational Activities

2.1.2.1. Cyber Discovery Camp

In its third year, Louisiana Tech University welcomed 20 area high school teachers, and 60 of their students are now better cyber-citizens after completing the College of Engineering and Science's annual Cyber Discovery Camp. Faculty members from the College of Engineering and Science, including Professors Jean Gourd, Travis Atkison, and Christian Duncan of the Center for Secure Cyberspace (CSC), teamed with the College of Liberal Arts to develop a residential camp experience aimed at high school teachers and students.

During the camp, lasting a full week on campus with teachers and students, facilitators demonstrated how to help rather than hinder security efforts by making participants aware of the benefits and dangers of cyberspace. This goal was defined by full immersion of all participants in the issues of cyberspace - from basic programming of a 'BOE-bot' machine to the architectural design of a cyber fort - to writing essays on legal and policy issues (enabling in the development of a story-line for the camp's Final Cyber Challenge).

The camp introduced to teachers how to integrate cyber into every element of the classroom. Whether they are teaching mathematics, history, ethics, engineering, or the arts, awareness in technology and cyberspace should be omnipresent.

Benton High School took top honors for the 2010 Cyber Discovery Camp. Ruston High School came in second, and Parkway High School came third. These teams received awards donated by the Cyber Innovation Center. This year's awards included funds available to enhance their school's technology, and 20 computers, donated by Dell, which were used during the camp.

The Cyber Discovery Camp is funded by a U.S. Department of Education grant, with support from the Cyber Innovation Center in Bossier City, Louisiana. The first Cyber Discovery Camp was held in the summer of 2008. Since that time, the Cyber Innovation Center has partnered with Louisiana Tech on this new model for teacher professional development.

2.1.2.2. Cyber Storm 2010

CSC member Dr. Jean Gourd introduced the first 'Cyber Storm 2010' event held at Louisiana Tech University in May of 2010. Dr. Gourd developed the Cyber Storm competition coinciding with Tech's 400-level cyber security course, the first of its kind, designed to provide students with practical cyber security experience, while expanding theoretical foundations. Throughout the event, students focused on computer network defense and computer network attack. Two teams used a variety of equipment taken from class lectures and labs and placed in a day long "hackfest". The students worked in groups and had remote virtualized access to isolated environments that assisted them in completing their projects.

2.1.2.3. Computer Forensics Course

CSC member Dr. Travis Atkison has developed the first Computer Forensics course for Louisiana Tech University. This 400-level class for upper level undergraduates and graduate students majoring in computer science or cyber security is a research-oriented course working with live incident response, network based forensics, forensics analysis techniques, online and mobile based forensics, and creating forensics toolkits.

2.1.2.4. Computer Forensics Cyber Crime Initiative

A proposal has been submitted in which Louisiana Tech University proposes to enter into a collaborative arrangement with the Louisiana State Police under Cyber Crime Initiative. This collaborative project will significantly benefit both parties' goals of increasing the knowledge and capabilities of the Louisiana State Police in the use of tools, methods and techniques for cyber crime investigations. Long-term success of this collaboration will increase knowledge and capabilities of both parties in developing methodologies to fight cyber crime. If the proposal receives funding, the first stage of the process will begin in February, 2011 with the engagement of an onsite Investigator and CSC researcher, Dr. Atkison, working together to establish a Problem-Based Learning Approach. During that process, a training course will be developed for the summer of 2011 for Federal, State and Local Law Enforcement Community.

2.2. Describe and Provide Data Supporting Major Findings

The research team has met or exceeded the goals promised in the project proposal. Research funded by the PKSFI grant has resulted in ***25*** scholarly publications (published/accepted), ***2*** issued US patents, ***1*** US patent application, ***6*** book chapters, and ***2*** books.

Table 2. Research Activity: performance measures, expectations promised in the PKSFI proposal, and achievements for Year 3 (1 July 2009 – 30 June 2010).

Year 3			
	Performance Measures	**Expectations promised in the PKSFI Proposal**	**Achievements**
Research Activity	Major publications and presentations	4 publications & 5 presentations	***13*** journal papers published & ***12*** conference papers presented ***2*** books & ***6*** book chapters ***6*** journal papers & ***3*** conference papers are under review
	Research Milestones	Focus on developing sensor data fusion and visualization tools for integrated detection and estimation of disaster precusors.	Data fusion algorithms and related codes for keystroke based user authentication were transfered to industry partner, Assured Information Security Inc., for integration with US Air Force's Host Based Security System. Dr. Phoha, Dr. Selmic, and Dr. Duncan together are working on the integration of disaster-precursor detection algorithms with visualization tools.

Table 3. Infrastructure and Statewide Impact: performance measures, expectations promised in the PKSFI proposal, and achievements for Year 3 (1 July 2009 – 30 June 2010).

Year 3			
	Performance Measures	**Expectations promised in the PKSFI Proposal**	**Achievements**
Infrastructure	Support for more research faculty, grad students, and laboratory equipment	Submission of atleast 3 multi-institutional research and infrastructure proposals	▪ Multi-instiutional proposals: ***4*** submitted, of which ***3*** received funding and ***1*** is under review. ▪ Individual proposals: ***15*** submitted, of which ***8*** received funding; ***2*** proposals are under review. ▪ Total ***19*** proposals submitted, ***11*** received funding and ***3*** are under review.
	Strengthened ties with the US Air Force	Integation of the Center's research to Tech's BAFB program.	▪ A new B. S. program in Cyber Engineering is under development in collaboration with Dr. Kamal Jabbour, Information Directorate, AFRL, Rome, NY. ▪ A new $2.84M Secure Cyberspace Laboratory is under development with funding from AFOSR. ▪ Multiple partnerships between the Center for Secure Cyberspace researchers and researchers at Air Force Research Laboratory, Rome, NY and AFRL, Wright-Patternson AFB, OH.
Statewide Impact	ROIs, Patent Applications, & SBIRs	2 ROIs, 1 Patent Application, & 2 SBIRs	▪ ***2*** US patents issued, ***1*** US patent application submitted, and ***2*** SBIRs submitted.
	Startup company	1 company, 4-5 employees	▪ A start-up company 'AARecon' for airborne remote sensing R&D has been established. AARecon currently has 3 employees and has been awarded a contract from Louisiana Department of Wildlife and Fisheries.

2.3. Describe the Opportunities for Faculty Recruitment, Retention, and Development, as well as Post-doc, Graduate, and Undergraduate Student Training;

Using PKSFI funds, La Tech recruited one tenure-track assistant professor and LSU recruited one tenure-track assistant professor and two research associates. After a comprehensive national selection process, we have the following new faculty members and research associates in place:

1. Travis Atkison, Tenure-Track Assistant Professor, La Tech

2. Supratik Mukhopadhyay, Tenure-Track Assistant Professor, LSU

3. Vasanth Iyer, Research Associate, LSU

4. Noureddine Boudriga, Research Associate, LSU

Visiting Scholars: La Tech has supported Associate Professor Remzi Sekar from the University of Arkansas at Little Rock during 1 July 2009 through 31 July 2009. La Tech is supporting Professor Joseph Kizza from the University of Tennessee Chattanooga during 1 June 2010 through 30 June 2010.

Both La Tech and LSU have supported graduate and undergraduate students. Most publications produced by the the core research team have students as co-authors. A list of students supported during this reporting period are:

Graduate Students (La Tech): Jun Dong Chen, Md. Shafaeat Hossain, David Irakiza, Ankunda Kiremire, Abena Primo, Khandaker Abir Rahman, Abdul Serwada, Md. Arafat Sultan, and Zibo Wang.

Graduate Students (LSU): Srini Srivasta, Ismail Akturk, and Huy Phamg.

Undergraduate Students (La Tech): William Ryan Lockwood, Chuka Okoye, and Stephan White.

2.4. Describe the Nature and Scope of Partnership Activities

CSC researchers have made considerable progress in connecting major Air Force Research Laboratories, industry and government partners, and universities.

CSC team members Dr. Vir Phoha and Dr. Kiran Balagani have partnered with Air Force Research Laboratory and industry (Assured Information Security (AIS) Inc., Rome, NY, Booz Allen Hamilton, McLean, VA, and Praeses LLC, Shreveport, LA) to design and field-adapt keystroke based authentication technologies. Prototype level software codes implementing Hidden Markov Model based and 'similarity metric' based authentication algorithms were

delivered to AIS Inc. to mature and field-adapt them to address the operational needs of the USAF. To support large-scale evaluations of text keystroke authentication algorithms, CSC researchers, in collaboration with AIS and Air Force Research Laboratory, undertook a major campus-wide data collection effort in two phases, Phase I was undertaken in October 2009 and Phase II was undertaken in April 2010. In these efforts, approximately 1500 participants provided more than 20,000 keystroke typing patterns. To further support large scale evaluation of keystroke authentication algorithms, CSC researchers are planning to undertake another keystroke data collection effort. The keystroke database resulting from the data collection effort currently has more than 117,000 fixed text typing samples, and 2,500 free text typing samples, making it the most comprehensive evaluation database in keystroke authentication field.

Louisiana Tech and Air Force Research Laboratory (AFRL) have signed Education Partnerships Agreement (EPA). Under this agreement, CSC members Dr. Vir Phoha and Dr. Md Karim, are collaborating with Dr. Keesook Han and her team from AFRL to research anti-botnet technologies. Dr. Keesook Han directs CSC's anti-botnet research from an Air Force perspective and has agreed to facilitate access to beneficial resources. A recent outcome of the partnership has been the development of a prototype-level network traffic analyzer.

CSC researchers Dr. Vir Phoha and Dr. Enamul Karim have partnered with researchers Dr. Arun Lakhotia and Dr. Andrew Walenstein from University of Louisiana at Lafayette, to conduct malware research and share expertise and resources (e.g., datasets and tools) in this area. The two teams jointly have won a Louisiana DEPSCOR grant to conduct research on obfuscation and de-obfuscation games for malware analysis. The teams at both universities have been working closely with an initial focus towards understanding the attacker and victim strategies from game-theoretic perspective and efficient interpretation of obfuscated codes.

CSC researchers Dr. Iyengar (LSU) and Dr. Jian Zhang (LSU) have partnered with researchers from University of Florida, Gainesville, and Purdue University, West Lafayette, to develop intelligent and uncertainty resilient sensor networks for identification and tracking of chemical, biological, radiological, nuclear, and explosive plumes. Recently, the joint partnership has received $284,413 NSF funding to collaboratively solve research problems pertaining to: 1) network formation by sensor selection, placement, and coverage; 2) sensor tasking protocols with temporal and spatial uncertainty management; and 3) protocols for reliable sensor-cyber communication.

CSC researcher Dr. Iyengar (LSU) has been collaborating with Dr. Nagi S. V. Rao, Oak Ridge National Laboratory (ORNL), Dr. Qishi Wu, University of Memphis, and Dr. Mengxia Zhu, Southern Illinois University, Carbondale, to develop fusion algorithms for target detection using sensor networks. Their recent research results appear in the ACM Transactions on Sensor Networks. As a result of the partnership with ORNL, Dr. Iyengar and his students at LSU have access to the state-of-the-art sensor network testbeds at ORNL.

Table 4. below summarizes ongoing major research activities of the Center and the collaborating units associated with the research activities.

Table 4. A list of the ongoing major research activities and the collaborating units associated with the research activities.

CSC Research Activities (Tasks)	Collaborating Units
Network-centric Behavioral Biometrics	Louisiana Tech University, Air Force Research Laboratory, Rome, NY, Assured Information Security Inc., Rome, NY, Booz Allen Hamilton, McLean, VA, & Praeses, LLC, Shreveport, LA
Insider Threat Detection	
Remote Suspect Identification	
Rare Event Pattern Identification	Louisiana Tech University & Penn State University Louisiana State University & SRI International
Finding Spatial/Temporal Origins of Anomalies	
Adaptive Attack Detection Mechanisms	
Mobile Agent Framework for Intelligent Attack Response	
Feature Discovery and Selection	
Botnet Detection	Louisiana Tech University & Air Force Research Laboratory, Rome, NY
Adversarial Code Detection	
Malware and Rogue Application Detection	
Sensor Coverage and Hole Detection	Louisiana Tech University & Air Force Research Lab, Wright-Patterson, OH Louisiana State University, University of Florida, & Purdue University
Sensor Networks for MAVs	
Applications of Socio-biological Principles in Sensor Networks	
Robust Routing Protocols for Sensor Networks	Louisiana State University & Oak Ridge National Laboratory, TN
Optimal Transmission Scheduling Algorithms for Sensor Networks	
Information and Decision Fusion Algorithms and Applications	Louisiana State University, Louisiana Tech University, & Penn State University

2.5. Describe any Problems Encountered During the Last Year of Project Activities;

None.

3. CONTRIBUTIONS: SUMMARIZE EFFORTS MADE TO BUILD RESEARCH AND EDUCATION CAPACITY, SECURE EXTERNAL FEDERAL AND PRIVATE-SECTOR FUNDING, BUILD INFRASTRUCTURE, CONTRIBUTE TO ECONOMIC DEVELOPMENT, AND ENSURE PROJECT SUSTAINABILITY OVER THE LONG TERM.

The team has submitted ***19*** proposals (and a whitepaper) for funding; ***11*** of the proposals have been funded; ***3*** proposals are in review. Details follow.

3.1. Funded Proposals

[1] " Cyber Weapons," PI: **Vir V. Phoha**; 1 July 2009 through 30 May 2010; Air Force Research Laboratory through Assured Information Security Inc., has been funded for $400,000.

[2] **(Multi institutional proposal)** "Science of Autonomy," PI: **Asok Ray** (Penn State University), Co-PI: **Vir V. Phoha**; 1 June 2009 through 31 May 2014; Office of Naval Research/$1.7M for the first 3 years + $1.5M for 2 optional years (subject to results of review after first 3 years).

[3] "Cyber K-12: Building a Foundation for Cyber Education in North Louisiana," PI: Galen Turner (Louisiana Tech University), Co-PI: **Christian Duncan**; Department of Education/$951,000 has been funded.

[4] **(Multi institutional proposal)** "Obfuscation and De-obfuscating of Intent in Computer Programs," PI: Arun Lakhotia (University of Louisiana at Lafayette), Co-PI: **Vir Phoha**, Co-PI: Andrew Walenstein (University of Louisiana at Lafayette); 1 November 2009 through 31 September 2012; Louisiana Board of Regents/DEPSCoR/$232,544 has been funded.

[5] "STCI: Development of Stork Data Scheduler for Mitigating the Data Bottleneck in Petascale Distributed Computing Systems," PI: **Tevfik Kosar**; 1 September 2009 through 31 August 2012; NSF - STCI Program/ $495,514 has been funded.

[6] "Collaborative Research: Community Infrastructure for General Relativistic MHD," PI: **Tevfik Kosar**, Co-PI: **Gabrielle Allen**; 1 October 2009 - 30 September 2012; NSF-PIF Program/ $400,000 has been funded.

[7] "Recruitment of Superior Graduate Fellows in Computer Science," PI: **Tevfik Kosar**, Co-PI: **S. S. Iyengar**; 21 August 2010 through 15 May 2013; Louisiana Board of Regents - Graduate Fellows Program/ $100,000 has been funded.

[8] "Remote Suspect Identification - Improvements and Optimization," PI: **Vir V. Phoha**, Co-PI: **Kiran S. Balagani**; July 2010 through May 2011; Air Force Research Laboratory through Assured Information Security/$400,000 has been funded.

[9] "A Composite Scheme for Detection and Disruption of Botnets," PI Md. Enamul Karim; 1 November 2009 through 31 October 2010; Air Force Research Laboratory/ $83,198 has been funded.

[10] **(Multi-institutional proposal)** "NeTS: Medium: Collaborative Research: Building an Intelligent, Uncertainty-Reslient Detection and Tracking Sensor Network," PI: **S. S. Iyengar**, Co-PI: **Dr. J. Zhang** , Dr. H.C. Wu (LSU); PI: S. Sahani (University of Florida); PI: D. Yau (Purdue University); 1 June 2010 – 31 May 2011; NSF/ $284,413 has been funded.

[11] "LA Tech Proposal for the Cybersecurity Research Program at the Cyberspace Research Laboratory," PI: **Les Guice**, Co-PI: **Vir V. Phoha**, Co-PI: **Md. Enamul Karim**, Co-PI: **Jean Gourd**, Co-PI: **Travis Atkison**, Co-PI: **Sumeet Dua**, Co-PI: **Rastko Selmic**; Air Force Office of Scientific Research/ $1,189,458 has been funded.

3.2. Other Proposals

[1] Cyber Crime Initiative Proposal with Department of Public Safety and Corrections
Agency: Office of State Police, State of Louisiana
Duration: 8 months
Total Budget: $40,000
Investigator: Travis Atkison, PI
Status: Pending

[2] Exposing the Netprint
Agency: DARPA (Cyber Genome Program)
Duration: March 2010
Total Budget: $1,565,738
Investigators: Travis Atkison, Co-PI; Jean Gourd, Co-PI
Status: Pending

[3] **(Multi-institutional proposal)**. Virtual Organization for Collaboration and Advancement of Learning Institutes (VOCAL) Agency: NSF (Cyber Enabled Discovery and Innovation)
Collaborating Institutions: University of Southern Mississippi, University of Southern Illinois at Carbondale, and Marshall University
Duration: February 2010
Louisiana Tech's Share: $431,470
Investigator: Jean Gourd, PI
Status: Pending

[4] CYEN: A Roadmap to Creating and Deploying Cyber Engineering at Louisiana Tech University (Whitepaper)
Agency: US Department of Homeland Security
Duration: January 2010
Total Budget: $69,484
Investigator: Jean Gourd, PI
Status: Not funded

[5] Mobile Agent Framework for Intelligent Attack Response (**SBIR**)
Agency: US Army Research, Development, and Engineering Command
Partnering Industry: Radiance Technologies Inc., Huntsville, AL
Duration: January 2010
Total Budget: $36,000
Investigator: Jean Gourd, PI
Status: Not funded

[6] Contained Automated Software Environment (**SBIR**)
Agency: Intelligence Advanced Research Projects Activity
Duration: November 2009
Total Budget: $1,280,618
Investigator: Jean Gourd, PI
Status: Not funded

[7] Identifying Vulnerabilities from Binary Executable Code Characteristics
Agency: Intelligence Advanced Research Projects Activity
Duration: November 2009
Total Budget: $904,712
Investigator: Jean Gourd, PI
Status: Not funded

[8] Algorithms and Foundations for Robust Intelligence in Autonomous Sensor Networks
Agency: NSF (Information & Intelligent Systems: Robust Intelligence)
Duration: September 1, 2010 - August 31, 2013
Total Budget: $487,877.00
Investigator: Vir V. Phoha, PI and Kiran S. Balagani, Co-PI
Status: Not funded

[9] Cyber Actor Characterization and Modeling
PI: John Bay (AIS Inc.); Co-PIs (Louisiana Tech): Vir V. Phoha, Kiran S. Balagani, and Md Enamul Karim
Agency: DARPA Cyber Genome Program (Technical Area 2: Cyber Anthropology and Sociology)
Duration: January 1, 2011 - December 31, 2014
Requested Funding: Total: $6.52M, Louisiana Tech's Share: $1.66M
Status: Not funded

3.3. Infrastructure

3.3.1. Cyberspace Research Laboratory

The Center for Secure Cyberspace with the support of a ***$2.84M*** Air Force Office of Scientific Research grant (received in April 2009), is establishing a Cyberspace Research Laboratory (CRL) to support a wide spectrum of novel cyber-centric research activities and experiments. CRL is composed of an Internet Replica Lab, a Compressed Sensor Network (CSN)/Micro Aerial Vehicle (MAV) laboratory, a High Performance Computing (HPC) lab, a Visualization laboratory, a Field Programmable Gate Array (FPGA) laboratory, and a Human Factors laboratory. The Internet Replica Laboratory is the core component and is a reconfigurable virtualization facility with high end network infrastructure that can support various cyber-centric experiments as well as serve as a cyber range. In this reporting period, we have acquired proof-of-concept virtualization infrastructure, full FPGA infrastructure, and CSN/MAV equipment. CSC also purchased high end work stations and various software tools. The rest of the equipment are under procurement. CRL is temporarily located at Nethken Hall and the Enterprise Center and Engineering Annex Building of Louisiana Tech. It is expected that the CSL will soon relocate to a new Louisiana Tech Enterprise Campus facility which is currently under construction.

3.3.2. Louisiana Tech Enterprise Campus and Tech Pointe Building

Louisiana Tech University has received ***$25M*** in funding from the State of Louisiana to build its new research park to be called as the Louisiana Tech Enterprise Campus. Additional efforts are underway to raise another ***$10M*** in federal and private funds to complete the Enterprise Campus. The Enterprise Campus will provide floor-space for high-tech companies to commercialize intellectual property, and to strengthen their research with Tech faculty and students. A multi-tenant building, called Tech Pointe, will be the first building in the Enterprise Campus. Tech Pointe is envisioned to be the new home of the Center for Secure Cyberspace and the Cyberspace Research Laboratory, and will house private and government entities that endeavor to partner with Louisiana Tech in the areas of research, education, and training, while developing business activities.

4. PROJECT REVISION: PROVIDE A LISTING OF AND EXPLANATION FOR ANY SIGNIFICANT CHANGES IN THE WORK PLAN FOR UPCOMING YEAR, INCLUDING ANY CHANGES IN THE AMOUNT OF INVESTIGATORS' TIME DEVOTED TO THE PROJECT. IF YOU MADE SIGNIFICANT CHANGES TO THE PROJECT DESIGN AS OUTLINE IN THE PROPOSAL DURING THE PAST YEAR, PLEASE LIST AND EXPLAIN THE CHANGES, THE PURPOSES FOR THE CHANGES, AND THE RESULTS.

None.

Annual Report for Year 2 (ending 6/30/2009)

Annual Report for Year 1 (ending 6/30/2008)

LOUISIANA TECH UNIVERSITY
AND
LOUISIANA STATE UNIVERSITY

2007-08 ANNUAL REPORT

LOUISIANA BOR PKSFI
CENTER FOR SMART CYBER CENTRIC SENSOR SURVEILLANCE SYSTEMS
GRANT# LEQSF (2007-12)-ENH-PKSFI-PRS-03

PI: Dr. Vir V. Phoha
Co-PIs: Dr. S. S. Iyengar, Dr. Kody Varahramyan, Dr. Peter Chen, and Dr. Gabrielle Allen

Chair of Research and Industrial Advisory Board: Dr. Les Guice

1. PERSONNEL: LIST ALL KEY PERSONNEL AND OTHER STAFF WHO PROVIDED *SIGNIFICANT* CONTRIBUTIONS TO THE PROJECT. PROVIDE INFORMATION ABOUT THE TYPES OF CONTRIBUTIONS MADE BY EACH LISTED PARTICIPANT AND CONTROLS IN PLACE TO ENSURE THAT THESE CONTRIBUTIONS ARE ADEQUATE TO THE PROJECT'S REQUIREMENTS.

1.1. Key Personnel and Their Contributions

1.1.1. Core Research Team

Dr. Vir V. Phoha (LA TECH), PI; Dr. S.S. Iyengar (LSU), Co-PI; Dr. Kody Varahramyan (LA TECH), Co-PI; Dr. Peter Chen (LSU), Co-PI; Dr. Gabrielle Allen (LSU), Co-PI; Dr. Asok Ray (Penn State University), Senior Consultant

Senior Researchers: Dr. Rastko Selmic (LA TECH), Dr. Christian Duncan (LA TECH), Dr. Tevfik Kosar (LSU)

Collectively the team and individually the investigators have produced significant research results supported by the PKSFI grant. Overall, the research team has to its credit more than *32* research papers (*21* published and *11* under review of publication), *4* patent applications, and *1* report of invention (see the attached document containing a list of publications). PI Phoha's new authentication technology has been licensed to ZEH Graphics software of Houston, Texas. Details follow.

Dr. Mangilal Agarwal, Dr. Vir Phoha, and Dr. Kody Varahramyan have been the key personnel associated with developing a chipless RFID sensor system platform consisting of passive chipless RFID sensor tags and specialized reader for cyber centric monitoring applications. Dr. Agarwal is a postdoctoral scholar who oversaw the daily implementation of the project. Dr. Phoha oversaw the computer system and internet communications parts of the project, and Dr. Varahramyan oversaw the overall aspects of the project, making sure that all the computer, sensor, wireless, and other components of the project progressed well and were successfully integrated and tested.

Dr. Phoha, Dr. Iyengar, Dr. Ray, and their students have collaboratively worked on anomaly detection in non-stationary environments, sensor fusion, and secure data aggregation problems. Together Dr. Iyengar and Dr. Phoha have successfully received $761,000 of DEPSCoR funding, have published two journal papers, and are working on many additional topics (see the attached list of publications). Dr. Peter Chen and his students have developed algorithms applicable to counterterrorism, learning, and conceptual modeling.

Dr. Phoha, Dr. Selmic, and Dr. Duncan have been addressing issues to solve sensor placement, finding holes in coverage, and other associated problems.

Dr. Kosar, Dr. Allen, and their students have been working on applying grid and distributed computing technologies to state-wide scientific applications, including sensor networking, coastal modeling, and reservoir simulations. They have developed novel distributed data management techniques and applied them in a new data-aware distributed batch scheduler that has been developed. These techniques include prediction models for tuning the optimal number of parallel streams in end-to-end data transfers across wide area data networks.

1.1.2. Research and Industrial Advisory Board

Dr. Les Guice (LA TECH), Chair of the Research and Industrial Advisory Board and VP for Research and Development.

Dr. Guice has been a major resource and motivator to make this project a success. He has established a Research and Industrial Advisory Board (RIAB) consisting of industry leaders, and has helped develop important contacts with AF Cyber Command, national laboratories such as Sandia National Labs, and industry partners such as NetQoS, Radiance Technologies, etc. The RIAB consists of the following members:

- Brooks Keel, Vice Chancellor, Research & Economic Development, Louisiana State University
- Doris Carver, Associate Vice Chancellor, Research & Economic Development, Louisiana State University
- Stan Napper, Dean, College of Engineering & Science, Louisiana Tech University
- Joel Trammell, CEO, NETQoS, Inc.
- Chris Mangum, Vice President, Strategic Planning, CenturyTel, Inc.
- Craig Spohn, Executive Director/President, Cyber Innovation Center
- Bob Fudickar, Director, Technology, Louisiana Office of Economic Development
- Bill Bailey, Vice President, Intelligence Systems, Radiance Technologies, Inc.
- Frank Auer, CEO, Praeses, LLC

1.1.3. New hires from support from PKSFI funding

Post-doctoral scientists (research assistant professor): Dr. Enam Karim (LA TECH), Dr. Kiran Balagani (LA TECH)

The new post-doctoral hires have submitted four research papers. In addition, Dr. Karim has submitted one Major Research Instrumentation Grant proposal to NSF and one research proposal to NSF.

Both the researchers have started collaboration with Co-PIs Iyengar (LSU) and Senior Consultant Ray in addition to collaborating with PI Phoha. As their research progresses, more team collaboration including other members of the PKSFI team will be added.

1.1.4. Technical and Administrative Support Team

Mr. Stan Finley (LA TECH), Technology Coordinator, Ms. Tina Allen (LA TECH), Administrative Assistant.

Stan Finley was hired on an interim basis to fill the position of Technology Coordinator. He has been representing Louisiana Tech in numerous meetings with the Air Force and industry partners. Stan has been meeting regularly with Air Force, industry, and Cyber Innovation Center personnel in the Bossier area. Stan has also researched and documented a number of potential contracting mechanisms that would be valuable to us in working with Air Force, government and industry partners. Finally, Stan has been working with Chris Womack, Coordinator of Technology at CEnIT and others to establish a Secure Information Sharing laboratory facility at the Cyber Innovation Center that will enable industry partners to demonstrate and test certain cyber security software resources. Stan has worked closely with Davy Norris, Director of Enterprise Center and Kathy Wyatt, Director Of Business Development in understanding the business development resources that the university has to support emerging businesses.

Tina Allen was hired in March 2008, replacing Kristin Martin, to provide administrative support for the Center. She is responsible for all administrative functions required in the day-to-day operation of the Center. This includes purchasing, travel, and assisting the faculty with submitting proposals and research publications. She played a major role in preparing the first edition of the CSC Newsletter released in April 2008. This newsletter will be released quarterly and is a means of providing research updates and information on the activities at the Center for Secure Cyberspace at Louisiana Tech. Tina also has responsibility for maintaining the Center's website. She also assisted in the organization and planning of the first Research and Industry Advisory Board held in April.

1.2. Controls in Place to Ensure Project Requirements

The PIs, Co-PIs, and senior researchers, as well as newly hired scientists, have met and discussed research progress and directions of research during the whole year. The control mechanisms include face-to-face meetings, Access Grid meetings, and phone and conference calls.

PI Phoha (LA TECH) LSU lead-Co-PI Iyengar, and Senior Consultant Ray (Penn State University) meet by telephone *at least once every week* to discuss progress of the project and overcome deficiencies in research. In addition, almost all the researchers have had frequent face-to face meetings; our goal is to have at least two face-to-face meetings per six months.

The following is a summary of the details of the meetings in which all (or most of the PKSFI team) were present.

PKSFI Project Kickoff Meeting (August 20, 2007): The kickoff meeting was held at Beau Rivage Hotel, Biloxi, MS, which was the same venue as the Post-Katrina Gulf Coast Network Science Forum. Those present were Les Guice, Vir Phoha, S. S. Iyengar, Peter

Chen, Kody Varahramyan, Gabrielle Allen, Tevfik Kosar, Christian Duncan, and Rastko Selmic (via phone), as well as observers Daryush Ila, Raymond Sterling, and Sumanth Yenduri. The minutes of the meeting are on record.

Access Grid Meetings (First on October 8, 2007 and second on November 12, 2007): Two Access Grid meetings of LA TECH and LSU researchers were held to discuss progress report. The minutes of the meeting are on record.

Cyberspace Research Workshop (November 27, 2007): This workshop, which was held in Shreveport, Louisiana, provided a venue to share fifteen peer reviewed research papers with peers across the country and coincided with the Air Force Cyberspace symposium. The conference was very well attended (136 participants) and received extensive media coverage.

Research and Industry Advisory Board Meeting (April 28, 2008): The first meeting of the RIAB was held at the LA TECH Technology Transfer Center in Shreveport, Louisiana. During the first half of the meeting PI Phoha updated the RIAB on the progress made so far; the feedback from the RIAB will help improve the teams' activities. During the second half of the meeting the researchers presented their work.

Meeting at LSU (May 27, 2008): The most recent meeting of the PKSFI research team was held in Coates Hall on the campus of LSU to discuss the progress of the PKSFI research. Those present were PI Phoha, Co-PIs Iyengar, Chen, Allen, and senior researcher Kosar. For logistics convenience, PI Phoha (LA TECH) met with the LA TECH team separately in Ruston.

The above meetings are in addition to the regular meetings that PI Phoha has with individual researchers.

2. ACTIVITIES AND FINDINGS:

2.1. Describe major research and educational activities undertaken in this reporting period;

The team, collectively and individually, has successfully addressed various research tasks outlined in the proposal. The research has resulted in *21* scholarly publications published or accepted for publication; *4* patents applications and *1* report of invention filed; and *11* research papers submitted and under review for publication.

Table 1 outlines the research activities outlined in the proposal and their status by the end of the first year of funding.

Table 1. A description of the four major research tasks and their status. Check mark indicates the task has started and the filled concentric circle indicates task has not yet started.

RESEARCH TASK #1

Investigate network formulation providing robust placement algorithms in uncertain environments and ill defined topologies.

TASK	*STATUS*
• Network Architectural Design Using Socio-Biological Principles	☑
• Adaptive Sensing in Non-stationary Environments	☑
• Embedding of Sensor Information at Grid Locations.	◉

RESEARCH TASK #2

Develop secure transmission to distributed cyber systems and build energy-efficient survivable communications routing and protocols for sensor data dissemination.

TASK	*STATUS*
• Develop Adaptive Attack Detection Mechanisms	☑
• Develop Resilience to Node Capture	◉
• Develop Robust Broadcast Routing Protocol for Sensor Networks	☑
• Develop Algorithms for Optimal Transmission Scheduling Under Power Constraints	☑

RESEARCH TASK #3

Develop automatic sensor data fusion, processing, and tools for integrated prediction, detection, and estimation for disaster precursors.

TASK	*STATUS*
• Rare Event Pattern Identification	☑
• Finding the Spatial-temporal Origins of Rare Events Based on Sensor Data	☑
• Secure Sensor Data Aggregation	◉
• Robust Sensor Data Fusion Using Dependence Tree Models	☑

RESEARCH TASK #4

Develop visualization software modules and perform experimental validation with simulated and actual sensors.

TASK	*STATUS*
• Develop Visualization Tools	☑
• Develop Smart Micro and Nano Scale Sensor Nodes	☑
• Validate Mathematical and Software Tools on Simulated and Actual Network of Sensors in the Center of Excellence	◉

2.2. Describe and provide data supporting the major findings resulting from these activities;

The research team has met or exceeded the goals promised in the project proposal. Table 2 outlines goals set for the first year of the project and the status at the end of the first year. Since the project built on the existing strength of the key researchers, the table also contains milestones achieved during the last three years.

Table 2. Milestones as promised in the proposal and the status. Checked indicates the milestone has been achieved and a checked and filled solid circle indicates the performance has exceeded the milestone.

Performance Measures and Expectations

	Since Funding	Year 1 Promised	Status	Last 3 years
Research Activity				
Research Milestones	Grid Formulation	Grid Formulation	☑	Various
Publications	21	6	☑ ●	over 32
Patents	4 filed; 1 ROI submitted	-	☑ ●	7 filed 1 issued
Grants	3 new funded	-	☑ ●	
Infrastructure				
Faculty Hiring	4 offered and 3 accepted	4	☑	4
Post-doc hiring	4 in place	4	☑	4
Labs	Sandia, Penn State, and LSU	Various	☑	Sandia, Penn State, LSU
Students	8 graduate and 4 undergraduates	6	☑ ●	
State-wide Impact				
Technology transfer	1 transferred ; 1 open	-	☑ ●	3 Technology transfer licenses; 1 open
Link with companies	2	No # specified	☑ ●	3
Support for AFCyber	Extensive		☑ ●	Initiated this year
Conferences	CSC, IRA-DSN	CSC	☑	

2.3. Describe the opportunities for faculty recruitment, retention and development, as well as post-doc, graduate and undergraduate student training provided by your project;

All the positions[1] are filled as requested except one faculty position at LA TECH where the candidate declined after a prolonged period of negotiations. We will re-advertize and hope to fill this position soon. The post-doctoral scientists are already in place at LA TECH and postdoctoral scientists at LSU have accepted the position with a start date of fall 2008. Details follow.

2.3.1. LA TECH

After a comprehensive national selection process, LA TECH has now in place the following:

1. Dr. Jean Gourd hired as a tenure-track assistant professor. He will start his duties effective July 1, 2008.
2. Dr. Enam Karim hired as research assistant professor (post-doctoral scientist), effective January 7, 2008.
3. Dr. Kiran Balagani hired as research assistant professor (post-doctoral scientist), effective March 1, 2008.

In addition, Dr. Mangilal Agarwal, a post-doctoral researcher (working with Co-PI Varahramyan) has been partially supported from PKSFI funds.

2.3.2. LSU

After a comprehensive national selection process the following faculty members and post-doctoral scientists have been hired and supported in part from the grant:

1. Dr. Jiang Zhang hired as tenure-track assistant professor (YALE, Assistant Professor who is currently at Stanford Research Institute).
2. Dr. Claire Montelini hired as tenure-track assistant professor (MIT, who is currently at University of California, San Diego, Machine Learning).
3. Dr. Gregory Vert (University of Nevada, Postdoctoral Scientist).
4. Dr. N. Parmeswaran (Visiting Faculty, Australia).

[1] *In the proposal, the PIs requested the faculty positions at both universities start in the fall of 2008. The post-doctoral positions at LA TECH were requested to start during the first year (2007-08) and at LSU to start during the second year (2008-09).*

Both LA TECH and LSU have supported graduate and undergraduate students. Most publications produced by the research team have students as co-authors. A list of students supported by PKSFI grant follows.

Graduate Students: Sudhir Shresha, Mercyma Balachandran, Shrijit Joshi, Kiran Balagani, Fayaz Baig, Jie Liu, Raja Mannam, Azaluddin Mohammad, Siuaroop Peesapati, and Ismail Akturk.

Undergraduate Students: Thomas Goodwin, Christina Foye, and Cyrus Robinson.

2.4. Describe the nature and scope of partnership activities; and

There have been considerable efforts to connect Center personnel with the Air Force Cyber Command (AFCYBER), the Cyber Innovation Center (CIC), and other industry and government partners (see details in Section 3.2, page 11). In addition to the existing collaborative activities, close research collaboration with Penn State University's Applied Research Laboratory is likely to result in new joint publications in sensor deployment in urban warfare environment. In addition, research collaboration of the PKSFI supported Center with Mississippi State University and the University of Tennessee, Chattanooga are being explored. Professor Bin Mai of Northwestern State University, Louisiana has visited LA TECH on numerous occasions for joint research activities resulting in a joint proposal to National Science Foundation (see *Proposals Under Consideration*, Section 10, page 10). PI Phoha and VP R & D Les Guice (LA TECH) have given presentations at Sandia National Labs, and C-PI Iyengar (LSU) collaborated with researchers from Oak Ridge National Labs.

2.5. Describe any problems encountered during the last year of project activities.

None

3. CONTRIBUTIONS: SUMMARIZE EFFORTS MADE TO BUILD RESEARCH AND EDUCATION CAPACITY, SECURE EXTERNAL FEDERAL AND PRIVATE-SECTOR FUNDING, BUILD INFRASTRUCTURE, CONTRIBUTE TO ECONOMIC DEVELOPMENT, AND ENSURE PROJECT SUSTAINABILITY OVER THE LONG TERM.

3.1. Efforts made to Build Research and Education Capacity, and Secure External Funding

The core research team has been complemented by seven new Ph.D. hires with one more faculty expected soon to make 18 doctoral-level research positions (eight core members of the team + seven new hires + 1 senior consultant who is deeply involved in the Center activities + 1 new post-doctoral position from newly received funding). Each of these seven hires will submit research proposals to build research and education capacity and secure external funding. Both LA TECH and LSU have made it a priority to hire the best talent. Three new faculty position offers have been accepted, and one more will be recruited through a national search. Two new faculty members will join LSU in the fall of 2008, and one new faculty member will start July 1, 2008 at Louisiana Tech. In addition, two new post-doctoral fellows have already joined Louisiana Tech and two new post-doctoral scientists will join LSU in the fall of 2008.

The Center is helping to co-sponsor a Cyber Discovery Camp for high school teachers and students June 9-14, 2008. There are approximately 35 students and 5 teachers participating in the event. The project is being organized and instructed by five Louisiana Tech faculty. The purpose is to support K-12 outreach and to enhance interactions in support of the Cyber Innovation Center and AFCYBER.

The team has already submitted six new proposals for funding, three of these proposals have been successful, one is in the final stages of negotiations, and two are pending. Details follow.

Funded proposals

1. "Secure and Survivable Cyber-Centric Sensor Networks: Algorithms and Architecture Research" PI S. S. **Iyengar**, Co-PI V. **Phoha**, Wu, and Park funded by DEPSCoR in the amount of $761,000 for the period July 1, 2008 – June 30, 2011.
2. "SURA Coastal Ocean Observing and Prediction Program (SCOOP)", PI G. **Allen**, Co-PI T. **Kosar** funded by NOAA/SURA in the amount of $50,000 (LSU share) for the period December 31, 2007 – April 30, 2008.
3. “Fault Detection and Isolation in Leader-Follower Networks,” PI R. **Selmic** funded by LaSPACE NASA in the amount of $38,211 for the period May 2008 – April 2009.
4. A proposal to build keystroke based authentication systems is in the final stages of being funded by AFRL, PI Vir **Phoha**.

Proposals Under Consideration

1. "MRI: Development of SensorPreter: an Instrument for Sensor-Sensor and Human-Sensor Dialogue," submitted to NSF on 01/24/2008 by Enam **Karim**, Vir **Phoha**, and Rastko **Selmic**; pending.
2. "CT-ER: Game Theoretic Strategies under Socio-economic Dynamics in Cyberspace," submitted to NSF on 03/24/2008 by Enam **Karim**, Vir **Phoha**, Jeffrey Walczyk, and Bin Mai; pending.

3.2. Build Infrastructure, contribute to economic development, and ensure project sustainability over the long term

The project team has demonstrated strong initiatives and success in pursuing additional grants to support the Center over the longer term. There have also been considerable efforts to connect Center personnel with the Air Force Cyber Command (AFCYBER), the Cyber Innovation Center (CIC), and other industry and government partners. As described earlier, two research workshops have been held this past year with representatives from the Center, the Air Force, the CIC, and industry partners present. Dr. Phoha, Dr. Chen, and Dr. Guice have also had numerous interactions with AFCYBER and AFRL to explore research needs and opportunities for collaboration. These interactions are leading to new contracts and grants. LA TECH has also been pursuing additional federal funding which could lead to new support for the Center's research program and infrastructure enhancements. Louisiana Tech has filed for three patents and has licensed one technology to ZEH Graphics software in Houston, Texas.

Louisiana Tech has also received money from the State of Louisiana to establish a multi-tenant building in its new research park (called the Louisiana Tech Enterprise Campus). The University has committed to provide 4,000 to 5,000 square feet of space in that building to house the Cyber Center. This will not only provide more effective space for the researchers, but it will provide ample room to develop a specialized laboratory that will advance the research activities and foster collaborations with some of the industry partners who are expected to occupy the building with the Center faculty.

4. PROJECT REVISION: PROVIDE A LISTING OF AND EXPLANATION FOR ANY SIGNIFICANT CHANGES IN THE WORK PLAN FOR UPCOMING YEAR, INCLUDING ANY CHANGES IN THE AMOUNT OF INVESTIGATORS' TIME DEVOTED TO THE PROJECT. IF YOU MADE SIGNIFICANT CHANGES TO THE PROJECT DESIGN AS OUTLINE IN THE PROPOSAL DURING THE PAST YEAR, PLEASE LIST AND EXPLAIN THE CHANGES, THE PURPOSES FOR THE CHANGES, AND THE RESULTS.

The project team has changed the name of the Center to the *Center for Secure Cyberspace*, which replaces the name *Center for Smart Cybercentric Sensor Surveillance Systems* as proposed in the project. The reason for this name change is to make it easier to communicate to the external public and potential industry partners. The structure of the Center as outlined in the PKSFI proposal will remain the same.

One of the Co-PIs, Kody Varahramyan, Director of the I*f*M, is leaving Louisiana Tech effective July 1, 2008. The new director of the I*f*M will replace Dr. Varahramyan in the PKSFI project. In the interim, Dr. Varahramyan will delegate his research responsibilities to his post-doctoral associate Dr. Mangilal Agarwal. Dr. Varahramyan will continue to be affiliated with Louisiana Tech and the *Center for Secure Cyberspace*, and involved in its' research activities.