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).

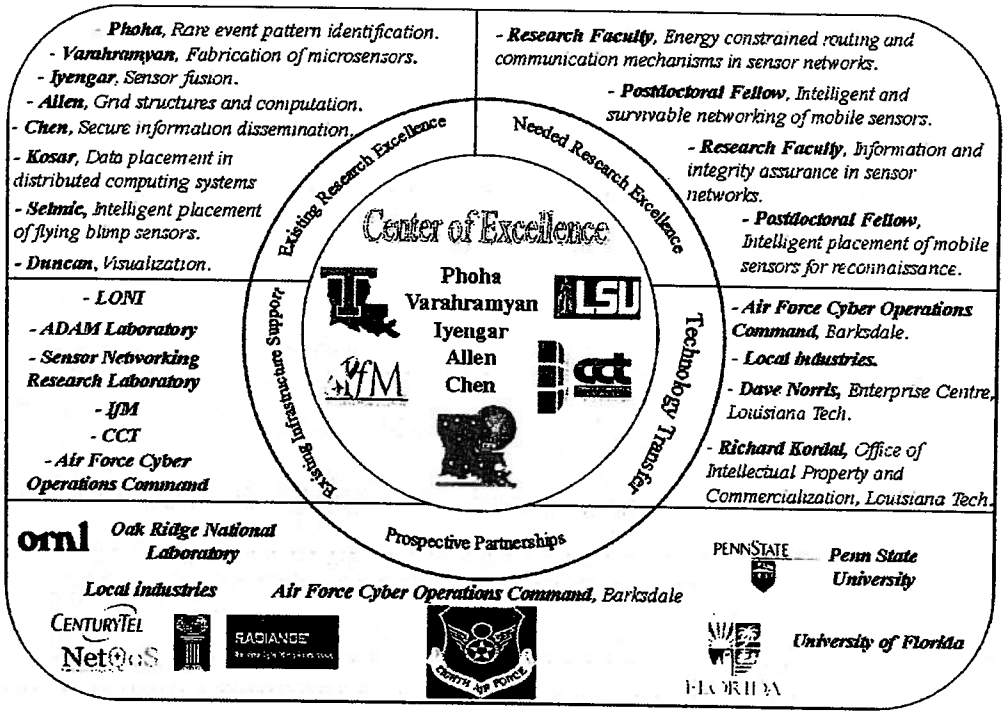

Figure 1. An overall view of the project.

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.

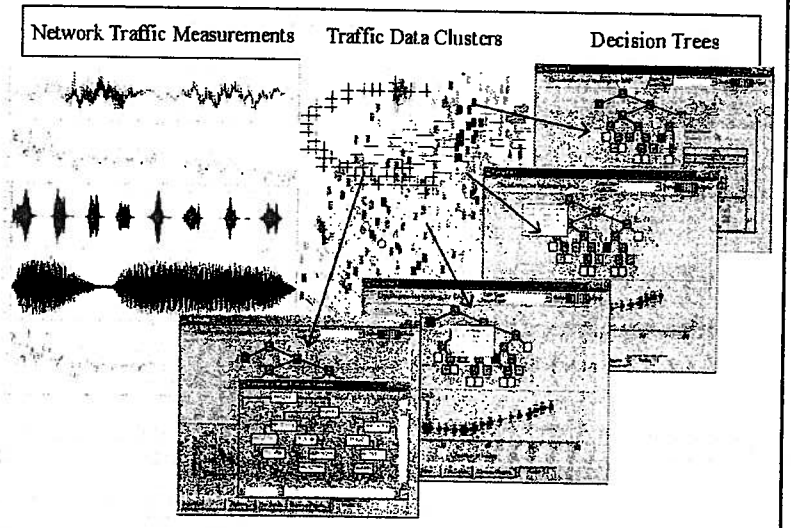

Figure 2. Cascading clustering algorithms with decision trees for robust attack detection in network traffic.

- *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.)

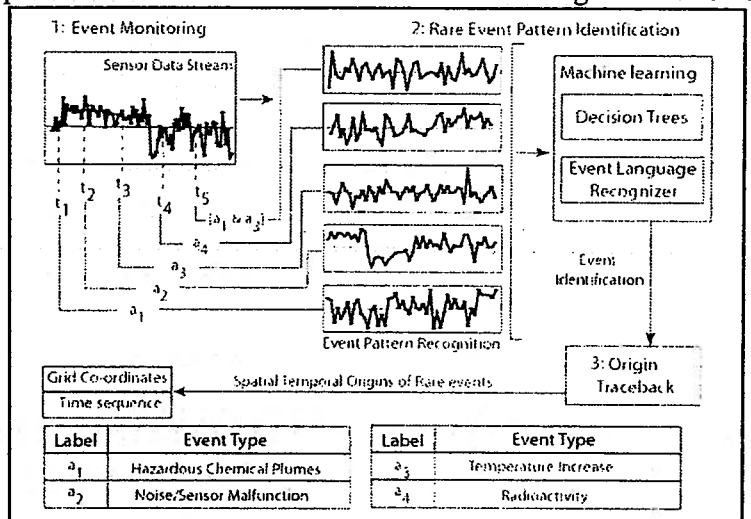

Figure 3. Event pattern recognition and spatial-temporal origin identification of rare events using sensor data.

- *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.

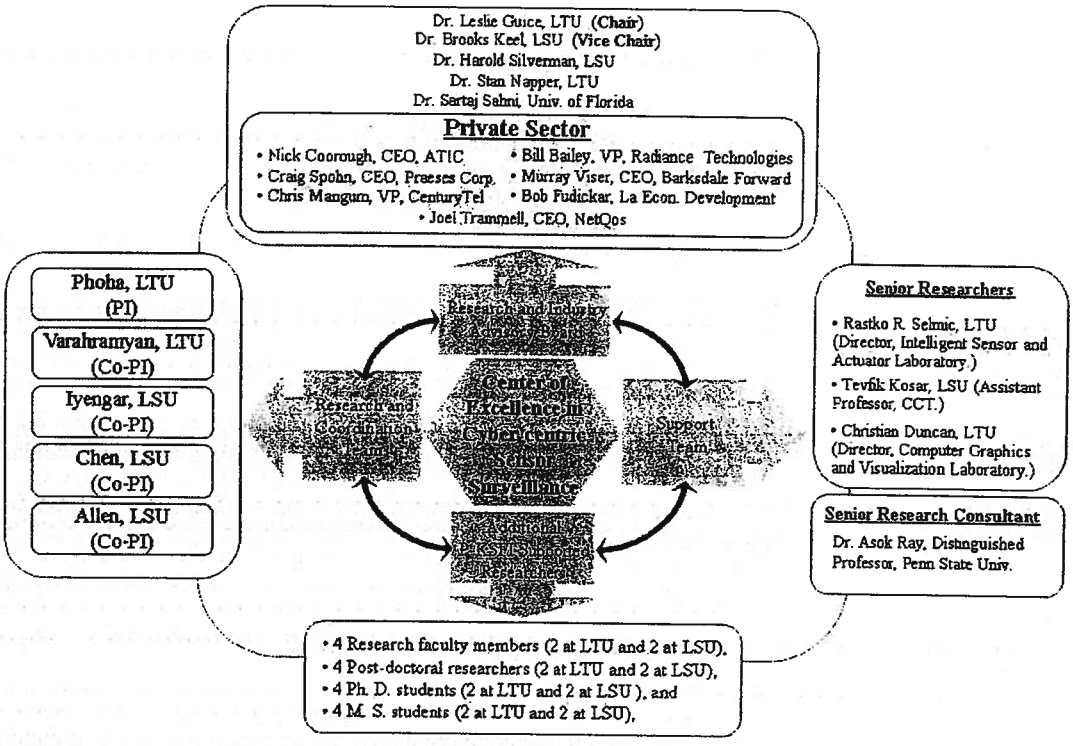

Figure 4. Project organization.

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.*