Research Statement

My research interests lie in the broad areas of mobile health and safety, wireless networking, wireless and mobile security, and algorithm design and analysis. My research vision is to exploit the algorithmic foundation behind the real-world problems and to provide practical designs to enable new levels of availability and performance. These two complementary research philosophies recursively propel my research with a balance in theory and applications. In this statement, I summarize my major research achievements and present my future research plan.

Past and Current Research

Resource Conservation and Information Processing in Wireless Sensor Networks (CAREER)
In this NSF CAREER project, I investigated novel approaches to both existing and newly proposed problems in sensor self-positioning, MAC control, and in-network data aggregation services for sensor network lifetime extension. These research activities are summarized as follows. 1) I studied the localizability problem in sensor networks and proposed a number of light-weight localization algorithms for both terrestrial and underwater sensor networks. We also proposed a novel problem, essential localization, to take into account the time needed for localizing a sensor network. 2) I designed two MAC protocols optimized for low power, low data-rate sensor networks. These protocols take a reservation-based approach to consider the key features of short-range links such as high bit error rate and low data-rate. 3) I developed multiple spatial data-mining based approaches to consider/re-consider data aggregation functions such as event detection and target counting. I have made significant contributions via this CAREER project to both theoretical foundations and algorithm design in sensor network research. A number of our proposed algorithms (papers) are highly cited.

The Design and Applications of Autonomous Mobile Underwater SEnsor networks
This is a collaborative research. We considered the design and applications of Autonomous Mobile Underwater SEnsor networks (AMUSE) consisting of a variable number of sonars (sensors) and vehicles that are deployed to perform collaborative tasks over a given area. The major tasks that have been explored include underwater sensor network (UWA-SN) self-organization and deployment, self-reconfiguring (MAC, physical layer, and cross-layer design), and mission-aware waveform design/diversity with applications to target recognition, target tracking, and event detection. Our proposed algorithms have tackled the following challenges: 1) the sensors in a UWA-SN are expensive and mobile, therefore sound self-organization and self-deployment algorithms are needed; 2) waveform design and diversity for UWA-SNs with active sonars are still in its infancy; 3) the transmit and receive data rates are highly asymmetric, which requires new MAC layer design; 4) the underwater channel is impaired by fading, multipath, and Doppler shift; 5) the GPS receivers do not work properly in underwater, thus new localization/navigation algorithms are required. For this project, we have presented a number of algorithms for underwater localization, target recognition, network self-organization, MAC control, etc.
**Key Management in Wireless Sensor Networks**
The central theme of this collaborative project is to build up KEYING SUITE, an open source library of keying mechanisms for sensor networks. The following research activities have been performed. 1) We designed a family of novel in-situ key establishment schemes that involve no communication overhead and no service sensor for sacrifice. 2) We designed a localized algorithm for inside attacker (compromised sensor) identification based on a robust “median” estimator and majority vote. 3) We developed two localized algorithms for clone attack detection in both static and mobile wireless networks to effectively identify the clones that possess the security information of legitimate nodes. 4) We set up a platform to systematically compare major existing keying schemes and scrutinizing their practicality. 5) We provided a library of keying mechanisms to satisfy different application requirements.

**Throughput Optimization in Wireless Mesh Networks**
This collaborative project investigated a number of fundamental problems that are very critical to wireless mesh network (WMN) throughput optimization. Wireless mesh networking is believed to be the most effective and efficient technology for the last-mile data connection to the Internet. We have investigated/designed various algorithms to target the following challenges. 1) Throughput optimization in MR-MC WMNs: the complexity of throughput-optimal scheduling, real-time logical topology characterization and inference, the joint exploitation of both rate diversity and channel diversity, and game theory based throughput optimization. 2) Non information theory based approaches to throughput optimization in multi-hop MIMO-enabled WMNs: stochastically modeling different aspects of the mesh network, constructing Network Utility Maximization formulations, and applying Information Geometric Programming to solve global optimization problems. 3) Biologically-inspired WMN design for throughput optimization.

**Opportunistic and Compressive Sensing in Wireless Sensor Networks (On-Going Research)**
This collaborative project investigates Opportunistic Sensing (OS) and Compressive Sensing (CS) in Wireless Sensor Networks (WSNs). OS refers to a paradigm in which a WSN can automatically discover and select sensor modalities and sensors based on an operational scenario, resulting in an adaptive network that automatically finds scenario-dependent, objective-driven opportunities with optimized performance. CS is a novel sensing/sampling paradigm that goes against the common wisdom in data acquisition. Both OS and CS help improve efficient operations and performance of WSNs significantly. In particular, OS aims at reduction from space by selecting a subset of sensors and modalities for efficient data fusion, whereas CS targets reduction in sampling by selecting a subset of samples non-uniformly. In this on-going project, we are investigating the theoretical foundations and algorithms for opportunistic and compressive sensing, which are essential for advancing the state of the art in wireless sensor networks that not only ensure effective utilization of sensing assets but also provide robust optimal performance. This project addresses fundamental research issues from information theoretic viewpoint to evaluate joint OS and CS distortions, develop OS
and collaborative CS schemes for better performance of WSNs, and cross-layer design to adapt to the non-uniform sampling in CS-based WSNs.

**Exploring the Signal Sparsity in Sensor Networks Based on Compressing Sampling (On-Going Research)**

Traditionally, massive amounts of data are first collected and then discarded in large part at the compression stage to facilitate storage and transmission. This process of massive data acquisition followed by compression turns out to be extremely wasteful. Compressive sensing (CS), on the other hand, acquires just the important information about the data via nonadaptive random projections and then reconstructs the compressible signal via sparse signal recovery techniques. Notice that sensor networks are typically deployed to measure various natural signals that are usually compressible, we propose to investigate the signal sparsity in sensor networks based on CS. The major objective of this proposed research is to study the challenges and techniques of applying compressive sensing to various fundamental sensor network problems under typical network settings. In particular, I have been conducting research tackling the following research tasks: i) temporal and spatial compressive sampling to decrease the data volume for transmission while preserving the information level; ii) compressive data gathering to decrease the communication overhead while preserving the high fidelity data recovery at the data sink; and iii) employing compressing sensing theory in mission-critical applications such as targeting counting and outlier detection to enhance performance.

**Dynamic Spectrum Access in Cognitive Radio Networks (On-Going Research)**

Dynamic Spectrum Access (DSA) provides a promising solution approach to the spectrum scarcity problem resulted from FCC’s static spectrum assignment policy. In this collaborative project, we intend to investigate the challenges of enhancing cognitive radio network throughput, delay, and fairness via integrated DSA. In particular, we are conducting the following research activities: 1) Extended Spectrum Sensing. We intend to construct a PU activity map based on compressive sampling theory, and to maintain/update the map in real time via a message-passing method. 2) Spectrum Prediction. We propose to investigate game theory and Bayesian approaches for PU status prediction, and to explore statistical learning approaches for spectrum available-interval prediction. 3) Delay-Aware Spectrum Management. We investigate a novel delay model to accommodate all delay factors and then design delay-aware spectrum management algorithms. We also will investigate back-pressure facilitated delay-aware spectrum management and explore how it can support opportunistic routing. 4) Fair Spectrum Sharing. We will investigate fair inter-flow spectrum sharing based on minimum potential delay fairness, and multi-channel proportionally fair CSMA/CA protocols by jointly considering spectrum management and fair media access control. 5) Integrated DSA. We will explore the benefit of integrated DSA by investigating delay-aware fair routing for throughput optimization.

**Future Research Plan**

In the near future, I plan to perform the following research:

**Information Diffusion in Social Networks**
Information diffusion is an interesting problem in social networks. Such a problem assumes that a person will trust the diffusion of an information message if $K$ of its neighbors in the social network trust this information. Existing works either focus on how to speed up the diffusion when the set of initial influential nodes are given, or target the problem of how to select the initial influential set to influence all the network members in one round. I am interested in a more general problem that seeks how to select an optimal initial influential set, so that the entire network can be influenced in a given number of rounds. This problem is mathematically related to the time-bounded localization problem but is more general. I will study the problem’s complexity, and will design a polynomial time algorithm based on the previous results obtained from my localization study.

**RFID Systems on Roads**

On November 18, 2003, the “Zero Fatality, Zero Delay” safety philosophy was proposed at the World Congress on ITS (Intelligent Transportation Systems and Services) in Madrid, Spain. Nevertheless, eight years have been passed but no one knows how long we still need to go to reach this goal—the fatality in recent years is still unbearable. According to the vehicle traffic fatal crash report of FARS (Fatality Analysis Reporting System) and the analysis by BTS (Bureau of Transportation Statistics), the main factors in fatal vehicle crashes include traffic control, vehicle speed, road type, and road characteristics. The current transportation system cannot always provide drivers with accurate and real-time road information, which can help to protect well-behaved drivers. And there is no all day everywhere patrol who can prevent reckless drivers from violations. To address these problems, I propose the RFID System on Roads (RSR). RSR is an essential platform for future transportation systems. It can provide unique features that are missing from the current transportation system, including lane level position, reliable road traffic control information, vehicle distance estimation, electrical patrol, and so on. Several novel vehicular applications based on RSR are proposed, which can significantly improve the transportation safety and efficiency. I also propose the corresponding engineering/system and research challenges for implementing RSR and its applications, such as secure communication protocols, tag deployment, intrusion detection, and etc.

**mHealth Service Provisioning based on Wireless Networking and Mobile Computing**

Modernization is a double-edged sword. It not only brings convenience and efficiency but also causes stresses on human beings and pollutions in environments. Mobile health (mHealth) delivers wireless medical services via mobile communications and mobile computing. Under the paradigm of mHealth, human beings, especially those with disabilities and chronic diseases, and senior citizens, can easily get medical help even without visiting clinical facilities in person. Such services could be highly available by exploiting the advanced technologies in wireless networking and mobile computing. In my future research, I will develop methodologies to tackle the following problems: 1) Access control and privacy protection in body area sensor networks. 2) Earphone functionality enhancement for the deaf people based on smartphone devices. 3) Smartphone application development for the blinded human beings.
Transportation Safety Enhancement based on Smartphone Devices
Cell phone distractions have been an important factor in high-profile accidents and are associated with a large number of automobile accidents. Recent study indicates that handsfree phone operation does not help much as the driver still can not concentrate. Actively preventing phone calls to and from the driver seems to be a promising approach for transportation safety enhancement. As a future research, I intend to design and implement a smartphone based system to detect whether the driver is talking over a phone when the vehicle is moving.