Research Statement

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Introduction

My research interests are in the areas of wireless communication, security, UAV networks, and cross layer optimization. I am motivated by the unique challenges that the next generation wireless networks pose when they are empowered with autonomous, intelligent, and rational decision making. I have studied dynamic spectrum access, mission-centric tactical networks, UAV networks, spectrum fingerprinting, wireless honeypots, and adaptive beamforming. My current research is focused on how to empower autonomous wireless devices to make intelligent decisions on spectrum allocation, and avoid malicious activities to provide better end-to-end performance for wireless applications. My research philosophy is to investigate next generation wireless systems, identify their unique challenges, and apply inter-disciplinary knowledge to develop effective and efficient optimization strategies. The multidisciplinary approaches have been based on stochastic models, game theory, queuing theory, artificial intelligence, and multidimensional optimization. I have collaborated with subject experts from other fields to develop sophisticated models and protocols. Furthermore, I have developed a state-of-the-art testbed to evaluate the designed protocols on prototypes using off the shelf devices.

Research Projects

Frequency agile dynamic spectrum access testbed In this research, we have focused on intelligent wireless nodes that can adapt particular transmission parameters by sensing the environment to dynamically access the spectrum holes. As a first step, we provided a centralized solution with the use of dynamic programming. In this approach, a leader is elected who assign or allocate spectrum for other nodes. As the second step we provided a complete distributed spectrum acquirement policy for ad hoc networks. In the distributed spectrum acquirement policy, each transceiver sense the spectrum holes individually and apply a novel algorithm to acquire spectrum. We propose a novel approach in which the transmitter and receiver can coordinate on which spectrum holes to use for communication. The distributed approach is not as efficient as the centralized approach and goes through a lot of fluctuation in spectrum allocation. We propose a hybrid approach to use the benefits of both approach where a group of nodes periodically collaborate to defragment the spectrum usage with the election of a leader .

We have extended our study and developed a proof of concept testbed using high frequency agile software defined radio (SDR) devices. The testbed comprises of several USRP radio peripherals that are controlled by GNURadio. We have developed the protocol stacks for end-to-end communication. In the testbed each node is capable of sensing the spectrum holes and use non contiguous spectrum holes for communication. The nodes achieve duplex communication with better use of filtering mechanism.

Wireless security Cognitive Radio Networks (CRN) enable secondary users to borrow unused spectrum from the proprietary users in a dynamic and opportunistic manner (e.g., IEEE 802.22). Jamming-based denial of service (DoS) attacks pose serious threats to legitimate communications and packet delivery. In this research, inspired by the honeypot concept in cybercrime, we propose a honeynet -based defense mechanism which aims to deter the attacker from jamming legitimate communications. The CR-Honeynet passively learns the attackers strategy or its fingerprint from the past history of attacks, and actively adapts preemptive decoy mechanisms to prevent attacks on legitimate communications. We further seek to resolve the dilemma of dedicating nodes as honeynodes by dynamically selecting the honeynode for each transmission period. Initially, we developed the first comprehensive queuing model for CRNs, which posed unique modeling challenges due to their fixed periodic sensing and transmission cycles. In the second step, we introduced a series of strategies, keeping the CRN's performance optimal for different traffic scenarios. The decision is made by an optimization function that takes care of the current queue size, traffic load, and traffic type at each node to provide fairness among nodes.

In the battle over available spectrum, secondary users (SU) lack the means of identify whether disruption sensed on a band is intentional or unintentional. This problem is further intensified in the case of heterogeneous spectrum. A smart malicious agent can use this vulnerability to temporarily disrupt transmissions on certain bands and induce their unavailability on SU's. Our research investigated an adaptive strategy for robust dynamic spectrum access in the event of induced-attacks. Assuming rational players, and considering the notion of channel utility, the optimal strategy is established by modeling such scenarios as zero-sum games that lead to Nash equilibrium and can be extended to the case where utilities are subject to abrupt changes. Through concurrent estimation, learning, and optimal play, it is shown that the proposed mechanism performs robustly even in such dynamic environments.

UAV networks The ecosystem of wireless communications is evolving towards distributed, self-confguring ad hoc architectures. Elimination of the need for central communications infrastructure appeals to many scenarios as it allows seamless and quick deployment of agile networks. Following the same trend, the concept of 3D mesh networks is envisioned, in which aerial nodes collaborate with ground nodes to allow wider, more dynamic ad hoc deployments while enhancing spectrum utilization by exploiting spatial reuse. Considering the advantages of ad hoc networking, it is envisioned that this paradigm will play a key role in future mission critical communications.

As the first step towards maintaining a 3D UAV mesh network, we explore the discovery of neighbors and maintenance of one hop links where high gain directional transceivers comprise radio or light wave communications. They provide benefits in terms of better throughput, enhanced spectrum utilization, and lower interference from unwanted sources. However, the stringent requirement of line-of-sight (LOS) communication makes it difficult for mobile nodes to maintain a link without a-priori information about its neighbor's position. In this research, we investigated neighbor discovery using full duplex directional transceivers in the absence of any localization device. We provided theoretical frameworks for both ground and UAV networks. The methodology has been is tested on a prototype developed using a robotic car, mechanically steerable head, and transceivers with free space optical communication.

In the second phase we looked into UAVs equipped with multiple heteregeneous radio interfaces. We presented a novel dynamic programming-based route aware dynamic channel scheduling approach that provides a conflict-free time slot transmission scheduling between neighbors. In the next phase we Then presented a framework for optimize paths to data streams in a mission-centric network that assigns paths using a link utility based on subtopologies of non-orthogonal frequencies. We use a graph coloring algorithm to calculate the utility of each link. We saw that routing data through multiple streams is useful in enhancing reliability, starvation, overload, and node lifetime.

In the third phase we built defense mechanisms against an autonomous moving jammer. With the advancement of software defined radios and antenna arrays, beamforming and the signal's direction measurements can be done online. This research investigates the performance of adaptive beam nulling as a mitigation technique against jamming. Considering a moving jammer, two different distributed beam nulling frameworks are proposed. Both of the the frameworks utilize periodic measurements from the RF environment to detect direction of arrival (DoA) of jamming signals and suppresses signals arriving from the current and predicted locations of the jammer. We use different filtering mechanism to reduce the effect of noise in direction of arrival estimation. Both algorithms use stochastic appraisal and optimization to create optimal beamnulls to enhance network performance.

Multimedia application over Mobile networks Wireless and Mobile communication is an essential part of modern telecommunications. With the increase in real time applications such as video streaming, video conferencing, Voice over IP, etc., the demand for wireless data rates is increasing exponentially. Due to stringent delay requirements, multimedia traffic poses some unique challenges to wireless communication. Unlike wired medium, wireless medium deals with congestion and delay due to interference, condition of wirelss environments, link failure, mobility etc. As a first step to improve the quality of service, we perform a rigorous study of modern cellular wireless systems such as WiMAX, WLAN, etc. We provided many cross layer optimization schemes for different wireless networks based on mobility and class of traffic. We also proposed schemes where intelligent applications can predict the wireless scenario and adapt multimedia traffic to provide optimal service quality at the application level.

Future Research Plan

My future research will continue to focus primarily on dynamic spectrum access, 3D mesh, multi-radio heterogeneous networks, and the security and vulnerability in such networks. I shall continue my research philosophy of applying knowledge from interdisciplinary subjects such as stochastic models, artificial intelligence, microeconomics, anthropology, and human and animal society inspired behavioral decision models to study evolutionary dynamics in autonomous wireless networks. My plan for collaboration with researchers from other disciplines will not only widen our opportunities for creating new paradigms, but also enrich mutual problem domains.

Brain Empowered Cognitive Radio Initially when Joseph Mitolla proposed the idea of cognitive radio, the intention was to develop a cognitive engine that could make decisions regarding several transmission characteristics. The advancement of high frequency agile software-defined radios have enabled transceivers to adapt to their environment. With further demand in wireless applications such as video surveillance and aerial monitoring, the demands on mobile 3D mesh networks is gaining popularity in mission-critical networks. Maintaining positions and links from a ground station is critical and are envisioned as becoming autonomous. Having autonomy in position, spectrum selection, transmission power selection, and beamforming, the nodes should be able to perform the duties while simultaneously maintaining network connectivity. The network should be capable of healing itself should some nodes or links fail. In cognitive radio technology such as IEEE 802.22 networks, secondary users are allowed to utilize unused spectrum in an opportunistic manner. The technological advancement of dynamically adapting transmission characteristics has enriched adversarial entities with enormous weaponry where the attackers can now choose the spectrum intelligently. I plan to study interdisciplinary methodologies based on microeconomics, artificial intelligence and sociological behavioral analysis that aid in the survivability of these networks. More specifically I would like to focus on: 1) Joint position control and routing mechanisms that change the position of autonomous nodes based upon traffic demand; 2) On the fly spectrum allocation model; 3) Constructing behavioral frameworks studying the evolutionary dynamics of defender and attacker.

Lightweight UAV security for tactical networks An exciting new area of research is the problem of maintaining security and privacy in 3D UAV networks. Unlike conventional wireless networks, 3D mesh networks are constrained by battery life and very limited amounts of bandwidth. To facilitate normal operation, the security of this kind of network is kept at very minimal level. Based upon my past research I outline a few directions in the security if 3D mesh networks that I intend to pursue.

The first approach would be to change the sequence of parallel to serial conversion in OFDM transmitters. Each pair of nodes can use a pseudo random sequence that can be exchanged at the starting of their flight. I would like to design the protocol for exchanging those sequences in a secure way, and then work on an optimization mechanism on the time period to change the sequence and length of the sequence.

A big challenge in 3D mesh with DSA is allocating spectrum on the fly, since the spectrum opportunities change with location. A group based spectrum sensing may be used to reduce the ripple effect,however the data fusion will be more challenging in presence of a malicious agent. In this scope, I want to use trust mechanisms coupled with location information to decide on spectrum allocation. My earlier work on leader election based spectrum defragmentation would be meaningful in this kind of network. However the protocol has to be optimized with respect to multiple variables. Reducing the overhead of trust based security with spectrum decision making would be challenging field of research.

Interoperability among heterogeneous networks To accommodate enormous variations in traffic nature, bandwidth, reliability, and demand, wireless service providers are forced to move from the fixed nature of spectrum access to heterogeneous and on-demand access technologies. The overly fashioned deployment of different radio access technologies poses unique changeless for coexistence due to intra channel and cross channel interference. Also, to further meet the demand of different applications, the networks intend to use the unlicensed spectrum. For example, the LTE-Unlicensed mechanism allows LTE providers to operate on the free ISM bands at 5GHz and 60 GHz. However, it is not well defined how fairness is to guarantee an LTE network which relies on central controller for spectrum access and WiFi which relies on distributed coordination function. Maintaining Quality of Service (QoS) in the battle of coexistence with heterogeneous radio access technologies becomes very challenging. Many decisions are left open. In the case of a collision, which network should change its spectrum or stop its transmission? How to distinguish between interference and deliberate jamming? How to ensure fairness among different networks? How to ensure end-to-end QoS for wireless applications? Who is responsible for scheduling? I want to apply my earlier knowledge in real time application, congestion control, game theory and stochastic analysis to attack these questions. I also plan to collaborate with researchers from microeconomics, behavioral analysis, biological networks to build models that enhances the performance of heterogeneous networks in the battle of coexistence

Cyber-physical system security Advancements in wireless technology has led civilization towards the connection of all physical devices to the cyber world, which we commonly refer as the Internet of Things (IoT). Unlike conventional Internet architecture, data can now travel over heterogeneous protocol stacks, different wireless structures, and varying environments. Due to the vast nature of connectivity and geographical coverage, cyber-physical systems are vulnerable to threats from both cyber attacks as well as physical attacks such as jamming based attacks. In the fist phase, I want to investigate localization-based intrusion detection system by mining large scale sensing data from the devices in a region. Provided the limited power constraint in IoT, I want to extend my study towards power constrained distributed data mining models. In the next phase, I want to investigate interdisciplinary pharmaceutical, biomedical and graphical learning research models that deal with determining possible causes of disease in any region, and build a model to find out source of malicious activities in IoT.

Research Funding

I plan to submit research proposals based on the directions highlighted above. My target will include government agencies such as NSF (e.g., CAREER, NeTS and EARS programs), Air Force Office of Scientific Research (AFSOR), Department of Defense Young Investigator Program (DoD YIP), and Defense Advanced Research Projects Agency (DARPA), as well as private industrials companies such as Qualcom, Intel, IBM, Microsoft, NEC laboratories, etc.