Research Statement

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My research focuses on networking, with an emphasis on wireless networks. I use algorithmic techniques in my work and support my work through experimental and simulation based evaluation. Here is an overview of the current active projects in my group in the areas of renewable energy, distributed wireless channel access protocols, femto-cells and vehicular networks.

- **Smart Use of Renewable Energy: Networking and Beyond:** Recent advances in sensor networks have resulted in a unique capability to remotely sense the environment. These networks can be used to sense natural as well as human-created phenomena (e.g., earthquake, fires, troop movements, radioactive substances). These systems could be deployed in remote or hard-to-reach areas, hence, it is critical that such networks operate unattended for long durations. To that end, new developments in the areas of renewable energy sources suggest that this is feasible. However, the design and control of sensor networks with the added dimension of renewable energy makes the problem of managing these networks challenging and substantially different from their non-replenishment counterparts. The goal of the project is to understand the performance limits of sensor networks with replenishment, to develop simple distributed algorithms and protocols that approach these limits, and validate and fine-tune the results based on experimentation. This ambitious endeavor will be accomplished by a team that brings in expertise that spans physical layer communications, distributed algorithms, control theory, resource allocation, sensor networking, and implementation.

  We have studied the problem of energy management in the context of sensor networks [1, 2, 3, 4, 5]. More recently, we have begun exploring how such dynamics can be exploited in the context of scheduling delay-tolerant tasks in the consumer's premises in a smart grid [6, 7, 8]. Also, we have investigated the problem of MAC layer design in the context of CSMA for devices with ability to harvest renewable energy [9]. This work is partially supported by NSF through a collaborative grant with Ness. B. Shroff (osu) and Can Emre Koksal (OSU).

- **Leveraging Physical Layer Advances for the Next Generation Distributed Wireless Channel Access Protocols:** This project aims at addressing the fundamental problem of how to maximize the efficiency of access to the wireless medium. In recent years, new information-theoretic solutions have emerged, some of which can now be implemented due to technological advances. Also, long engrained notions, such as half duplex, are being challenged. It has been shown that through a combination of strategies at the physical layer and signal processing, full duplex systems are indeed feasible. These developments have radically altered the very notion of what a spatio-temporal resource is. These developments have necessitated a thorough redefinition and appraisal of the problem of efficient access as addressed in this project.

  Over the years, developments have taken place in parallel and somewhat in isolation in the physical layer community and in the protocol community. By bringing together a broad-spectrum of expertise from both areas, this project envisages fundamental advances in wireless networking at the access layer. The core challenge is how to use the scarce resources of "space" and "time" as efficiently as possible. In addition, distributed operation, channel fading, time-varying channel conditions, and fast time-scales of transmission opportunities and decisions, exacerbate the problem. This project has the potential of making a transformative advancement in the science of medium access.

Our prior work on full-duplex communication [10] laid the foundations for this project. We have developed a novel solution for efficient medium access in presence of full-duplex nodes [11], a mechanism for supporting downlink scheduling without requiring time-synchronization [12] and a novel scheduling algorithm that leverages available capacity in the wired backbone for extracting information from collided packets in the uplink [13]. This project is supported by NSF through a collaborative grant with Kannan Srinivasan (OSU) and P. R. Kumar (TAMU). The information-theoretic aspect of the project is being carried out at TAMU and the practical and experimental aspects at OSU.

- **Enabling Cellular Services over Unplanned Femto-Cell Deployments:** The objective of this project is to develop the foundations for resource allocation in femtocell networks, and evaluate the performance of the solutions using real testbeds. Wireless resource allocation in femtocell-based networks is particularly challenging due to four main reasons: (1) interference between femtocells and between femto- and macro-cells; (2) variable and unpredictable delays in signaling and data communication between each femtocell and the operator's network; (3) limited bandwidth for signaling over a wireless channel to a large number of femtocells; and, (4) involvement of three parties with differing priorities: the operator, the users, and the femtocell owners. The specific research tasks in this project are: (1) For legacy systems, develop distributed solutions for both downlink and uplink scheduling and handover under co-deployment of macro- and femto-cells that do not require any changes to existing hardware and standards; (2) Develop distributed, adaptive and self-organizing solutions (unconstrained by legacy requirements) for resource allocation by using a powerful tool from statistical physics, called Glauber dynamics; and (3) Design mechanisms to facilitate offline truthful auctions in practical settings involving the end-users, the femtocell owners, and the operator. The proposed research has the potential to significantly impact the cellular industry and end-users. Given the high penetration rates of cell-phones worldwide, this research has an immediate and widespread impact.

  We have studed the dynamic OFDMA sub-channel assignment problem while jointly considering power assignment and association control to provide max-min fairness [14]. This project is supported by NSF through a collaborative grant with Kang G. Shin (UMich) and R. Srikant (UIUC). The primary focus at OSU is truthful auctions, at UIUC is non-legacy systems and at Umich is legacy systems.

- **Vehicles as First Class Citizens of Tomorrow's Internet:** Current cellular technologies fail to provide services with data rates that are anywhere close to the speeds available over typical Wireless LANs (WLANs). Large-scale deployments of WLANs have the potential to provide ubiquitous high data rate coverage, but the cost of deployment and management of a large number of WLAN access-points for providing full coverage is prohibitive. On the other hand, scattered deployments of WLAN hotspots are useful but they fail to provide any level of service assurance to mobile users. This project aims at developing the foundations for a system that will provide assured data services over a wide-area to data-intensive applications for mobile users using an economically scalable infrastructure consisting of heterogeneous technologies, and to demonstrate it with a prototype implementation. The project involves the following research objectives: 1) to develop solutions for hotspot deployment that enable the best possible services for mobile users through a limited number of hotspots; and, 2) to design solutions for meeting the needs of delay tolerant applications using dynamic resource control. The proposed research will build the foundations for bringing high-speed data services to mobile users through scattered hotspots and it has the potential to open up new research avenues along the lines of assured but interruptible services. A number of applications covering the entertainment, industrial and commercial sectors will get impacted by this research. Special efforts will be made to recruit women and minority students for this project.

  Our work on intermittent coverage [15, 16, 17, 18, 19] has laid the foundations for this project. This work is supported by NSF. More lately, we have begun exploring interactions between vehicles and aggregation of information across vehicles to achieve better relative localization of vehicles on the road [20, 21]. This work is partially supported by Toyota InfoTechnology Center.

In addition, I always like to explore new research directions. I am quite excited about some recent results on three exploratory projects, on data center design [22], scheduling within data centers [23] and on cognitive radios [24, 25].

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