Research Statement

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In science and engineering, there is an endless array of diverse and important problems yet to be uncovered and solved. In particular, within the field of Computer Science, the advent of the Internet and the ever growing availability of resources like computing power offer the opportunity for amazing innovations. Consequently, these changes are fundamentally redefining the intertwining relationship between users, developers, and suppliers. As a researcher in the midst of this unforgiving force of change, I have been, and will continue to seek out meaningful questions and answers.

During my Ph.D. study, I was exposed to many research projects sponsored by National Science Foundation and industry companies. Participation in these projects allowed me to hone my research skills and to gain an appreciation for the value of theory and its true implication when integrated in practical applications. My dissertation research arises from real-world problems. The backbone of my solutions stems from sound theoretical foundations. My dissertation research is stated next followed by my research plan.

There are many different wireless network technologies in existence today - 3G/4G, WLAN, WiMAX, WPAN, etc. - with their own unique strengths and weaknesses. These radio access technologies are being overlapped to satisfy the demand and goals of users and service providers. In such heterogeneous wireless environment, radio resource management is a big issue because of the capacity-constrained and highly dynamic nature of wireless networks. In my Ph.D. dissertation research, I have analyzed a new traffic usage pattern in 3G Data Networks and brought up switching overhead issue in multi-radio multi-channel resource allocation problem.

1. UGC and Uplink Traffic in Mobile Data Networks.

Fast growth in cellular usage with emerging multimedia applications have led to the requirement for new 3G cellular telecommunication networks. To deal with this requirement, two new partnership projects, 3GPP and 3GPP2, are developing 3G/4G standards. 3GPP is developing GSM based system such as WCDMA and 3GPP2 is focusing on IS-95 based CDMA system such as CDMA2000. As high data rate services such as video transmission and other data services became popular, both 3GPP and 3GPP2 introduced downlink/uplink enhancement technologies of each 3G system, which are HSPA and EvDO respectively.

Furthermore 4G systems, 3GPP LTE and WiMAX (IEEE 802.16e) wireless broadband access standard, are being developed. Along with these mobile network evolutions, we need to consider a recent trend in Internet usage, which exhibits growth in data traffic from user-generated content (UGC) with the potential to create a huge amount of uplink traffic for wireless operators.

UGC, also known as user-created content (UCC), refers to various kinds of media contents that are produced by end users. As the reality of UGC's scope and power is becoming crystallized (e.g., YouTube, Facebook, Wikipedia, MySpace, and Flickr), modeling and analysis of uplink traffic has just begun to receive attention in the wireless research community.

In my research, I have analyzed live uplink traffic traces obtained by monitoring 3G networks of a mobile data service provider (SK Telecom in Korea, the world's first to commercialize HSDPA). My statistical analysis showed that this trace exhibits a certain degree of self-similarity. In order to evaluate the impact of this traffic characteristic on 3G/4G mobile data networks, I used the WiMAX module available in OPNET software. My trace-driven simulation results indicate burstiness in the aggregated traffic received at a base station as well as in the traffic generated at each subscriber station (SS). The impact of the data burst at SSs is shown to be negligible when the overall traffic load is relatively small but becomes significant when a large volume of delay-sensitive traffic is generated in many SSs even if the overall network load is less than the network capacity.

2. Switching Overhead in Multi-radio Multi-channel Environments

As another interesting and essential resource management problem, channel assignment and scheduling methods in multi-radio multi channel wireless mesh networks are considered.

In order to increase the network capacity, we can equip the wireless mesh routers with multiple radios operating in multiple non-overlapping channels. By assigning different channels to radio interfaces in the interference range, multiple channel-interface pairs can be served simultaneously, and this leads to higher network capacity. In this multi-radio multi-channel environment, a proper assignment of channels to interfaces is a critical factor of resource allocation problem. However, none of the existing algorithms consider the overhead incurred from switching radios dynamically from one channel to another into account. The algorithms simply assume that the switching delay can be reduced and made negligible by improving hardware technology and refining protocols. However, my simulation results showed that the actual performance of these algorithms can be much lower than expected when actual switching delays are injected into time slots.

Motivated by this observation, I developed multi-radio multi-channel scheduling algorithms with switching overhead explicitly considered. I model the delay overhead that is incurred during channel switching, and use that delay in the design of algorithms. As a theoretical support, I showed that when the switching overhead is non-negligible, finding a schedule that achieves the maximum throughput capacity is NP-complete for tree networks even under 2-hop interference model. This problem is, by contrast, solvable in polynomial time in tree networks under the k-hop interference model if switching overhead is not considered.

Future Research Plan

I envision each of my previous results as an incremental building block that constitutes the foundation of a comprehensive set of tools for heterogeneous wireless networking. I will continue my efforts to explore the mobile computing and wireless communication problems from theoretical aspects, design and improve efficient algorithms, and search for new applications as well as the possibility of interdisciplinary collaboration.

1. Heterogeneous Sensor and Computational RFIDs Networks

As the computing capability of tiny wireless devices including sensors and computational RFIDs becomes stronger and faster, the level of heterogeneity in wireless networks rapidly increases. A sensor node can sense its immediate environment, process its sensing data, communicate its results to other nodes over a wireless link, and possibly take an action in response. Computational RFID tags (CRFIDs) are battery-less computers that harvest all of their operating power from an interrogating reader. A network of these tiny, smart nodes can be deployed in wide geographical areas for a low price with various applications such as health care, manufacturing, military, etc. In particular, cyber-physical systems (CPS), which the US NSF has identified as a key area of research[1], are considered a new application domain of heterogeneous sensor/CRFIDs networks. For future work, I am interested in the following topics:

- Heterogeneous sensor and CFRIDs networks modeling and cooperating issues with current 3G/4G and wireless LANs.
- Various optimization issues in heterogeneous wireless networks

2. Information Processing for CPS in Heterogeneous Sensor Networks

While computing becomes faster and more pervasive, human information processing capability lags behind. This leads to an increasing gap between the ability of computing devices to collect information and the ability of humans to consume it. Thus computing devices will collectively

[1] http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503286

need to become more autonomous and more embedded. In heterogeneous sensor networks, predicting physical attributes (keeping an accurate representative view of present and future) is important for optimal decision making. Most CPS applications have a module that is focused on monitoring certain system attributes. For example, many environment-aware technologies monitor temperature, light and moisture. Autonomous cars must constantly monitor speed, location, road conditions, weather, distance from other cars, etc. in order to prevent accidents and optimize fuel efficiency. In this field, I could expand my traffic monitoring and analysis research to time series analysis in CPS applications. I also plan to consider the problem of service distribution for CPS in a distributed heterogeneous environment. Service partitioning and service distribution are other algorithmic and foundational issues to address.

3. Security in Heterogeneous Sensor Networks and Secure Computing

Finally, as part of my future research, I would like to concentrate on security issues in heterogeneous wireless networks, systems and data processing. As the demands of safety-critical applications grow and more devices and systems involve heterogeneous environments, security issues gain an increasing amount of attention from the community. I believe security is a major open field where my strong heterogeneous network background can be used. The following are interesting issues:

- **Various security issues in heterogeneous wireless networks and systems**
    - Heterogeneous networks, systems and Internet Security, e.g., intrusion detection, detection and defense against attacks, and secure routing
    - Fault and security management in networks and distributed systems
- **Security aware resource management schemes** in heterogeneous wireless networks
    - Secure and energy-efficient resource management schemes
- **Security and Privacy issues in information processing**
    - Protect private data during data collection from distributed data provider in heterogeneous sensor networks

I would like to develop my research interests further and welcome the opportunity to collaborate with your faculty in their ongoing projects in wireless networks, resource management, network security, information retrieval, and information management.