Preview of Award 1553395 - Annual Project Report

Cover

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Project Title:	CAREER: Interconnected Mobile Computing in Wireless Networks
PD/PI Name:	Wei Gao, Principal Investigator
Recipient Organization:	University of Tennessee Knoxville
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Submitting Official (if other than PD\PI):	Wei Gao Principal Investigator
Submission Date:	05/16/2017
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Wei Gao

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Accomplishments

* What are the major goals of the project?

Proliferation of mobile computing devices transforms the way people behave and access information in every aspect of their daily life. However, diverse manufacturing limits make current mobile devices far from ideal for being used anytime, anywhere. Instead, each device can only fit to a specific scenario. Traditional research strives to design individual mobile devices for different application scenarios by exploring tradeoffs among the various design perspectives, but cannot scale to the increasing complexity of future mobile applications and satisfy their requirements on the performance of mobile computing system.

The goal of this project is to develop key enabling technologies in wireless networks and mobile systems that realize Interconnected Mobile Computing (IMC). Instead of separately operating individual mobile devices, IMC fully interconnects multiple mobile devices owned by the same user via wireless networks, and allows these devices to complement each other via cooperative resource sharing. Hence, it fundamentally removes the physical boundary between devices and augments the mobile computing capability provided to user. The proposed research aims to ensure efficiency, adaptability and generality of IMC. First, we will design an extra communication channel in the wireless link that dedicates to resource sharing between mobile devices, hence minimizing the transmission latency of resource sharing and ensuring efficiency of IMC. Second, we will develop distributed network algorithms for resource sharing decisions, which adapt to frequent changes of network topology and maximize the efficiency of shared resource utilization. Third, a mobile middleware will be developed as the generic system interface to support mobile applications' remote access to shared system resources. The proposed designs will be implemented and evaluated over a medium-scale mobile testbed of software-defined radios and off-the-shelf mobile devices, and will also be validated by large-scale trace-based emulation.

*** What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?**

Major Activities:

This project outlines a career development plan addressing the fundamental challenges of IMC. Its research plan spans the network and system technologies that are vital to efficient, adaptable and generic interconnection among mobile devices. To efficiently address these fundamental challenges of IMC and satisfy the key requirements of IMC in practical wireless network scenarios, we had the following major activities in the past year.

First, we developed physical-layer wireless networking techniques that are able to ensure reliable and timely wireless transmissions across remote mobile devices, regardless of the specific traffic loads and patterns of the wireless network. Being different from traditional schemes which ensure network QoS via traffic scheduling or flow control but cannot scale to the amount of network traffic, our approach builds a separate wireless side channel that operates concurrently with the existing wireless channel over the same spectrum but dedicates for MCC. We built this side channel by exploiting the Signal-to-Noise Ratio (SNR) margin of a wireless channel, which is measured as the difference between the actual channel SNR and the required SNR for the configured channel operations. Our design is able to reach a throughput of up to 2.5 Mbps in the side channel without noticeably impairing the performance or reliability of the existing wireless channel. Therefore, it could be applied to support a large collection of practical mobile applications, ranging from mobile gaming and image processing to future emerging applications of Virtual Reality.

Second, we developed distributed network algorithms that make adaptive decisions of resource sharing with frequent changes of network topology, so as to maximize the efficiency of resource utilization and minimize the system cost. More specifically, our work reduced the computation and communication overhead when scheduling highly dynamic wireless networks with frequent changes of link status, by adaptively restricting the scope of network scheduling within the local proximity of where wireless link status changes. Being different from existing scheduling algorithms which will frequently reschedule the entire network in cases of network dynamics regardless of the actual network area being affected by these dynamics, we developed distributed algorithms that schedule wireless networks only within the limited scope where network dynamics occur.

Education Activities:

One PhD student has worked on the project. Some of the research results have been integrated with the education curricula at University of Tennessee, Knoxville. For example, we have added smartphone techniques to the contents of our undergraduate course "ECE455: Embedded System Design" and provided the students with the opportunity of working with the Android OS and off-the-shelf mobile devices.

Specific Objectives:

The proposed research aims to satisfy the following requirements for IMC. Existing mobile computing systems, however, have been considered incapable of addressing the core challenges in satisfying these requirements.

1. Efficiency: IMC should be highly efficient without degrading mobile system performance. For example, the smartphone's remote GPS access should not incur any additional delay compared to local GPS access. This requirement motivates fundamental redesign of wireless networks, which currently have a much larger transmission latency compared to local execution time of mobile programs. Response time of mobile applications, hence, will increase when they access remote resources shared by others.

2. Adaptability: IMC should efficiently adapt to network and system dynamics, including user mobility, wireless channel fluctuations and mobile application behaviors. When the interconnection among mobile devices changes due to these dynamics, shared resources may become unavailable and IMC should be reconfigured accordingly, so as to avoid system performance degradation due to such resource unavailability and minimize additional system cost when switching to other shared resources. Such reconfiguration, however, is challenging due to the lack of centralized coordination among distributed devices.

3. Generality: Mobile devices should access the heterogeneous hardware and software resources shared by others via a generic suite of system interfaces, hence scaling to the increasing complexity of mobile systems. For example, the same interface should be applied for accessing GPS, body sensors and computational resources. Existing system designs, however, are limited to providing resource-specific interfaces.

Significant Results:

We have developed a practical high-throughput design of the wireless side channel that efficiently supports real-time wireless traffic for MCC, by exploiting the unique properties of modern digital modulation methods, particularly OFDM which will be the technical foundation of next-generation high-speed wireless networks (e.g., LTE-A and 5G). The key insight of such a side channel is that the SNR of a wireless channel is usually higher than the SNR required to support the data rate being used, due to inaccurate SNR estimation and conservative rate adaptation in wireless networks. This in-band SNR margin can be exploited to encode data as patterned interference over the main channel. The impact of such a side channel on packet decoding over the main channel, on the other hand, could be efficiently eliminated by limiting the amount of additional patterned interference within the scope of the main channel's SNR margin. As a result, our basic idea of the side channel design is to encode data as patterned interference by erasing the energy of specific subcarriers in the main channel's OFDM symbols. Since such energy erasure does not increase the RF transmit power, it can be used to encode data into every OFDM symbol in the main channel, hence dramatically increasing the side channel throughput. On the other hand, since OFDM modulates data into separate subcarriers in both time and frequency domains, the amount of patterned interference could be efficiently controlled by interfering only a small portion of OFDM subcarriers, without affecting the packet decoding in the main channel and its resistance to channel contention. We have implemented the proposed system design over practical Software-Defined Radio (SDR) hardware platforms, and evaluated the effectiveness of our design over realistic VoIP applications. The experimental results show that our system can provide a side channel throughput of up to 2.5 Mbps, which is 10 times higher than existing work with minimal impairment to the main channel performance. It also reduces the data transmission delay in commodity 802.11 networks by up to 90%, and significantly eliminates the chance of delay jitters in such networks.

We developed distributed algorithms that schedule dynamic wireless networks only within the limited scope where network dynamics occur. More specifically, existing scheduling algorithms are designed to provide approximations to global optimality of solving the Maximum Weighted Independent Set (MWIS) problem over a network conflict graph via distributed operations in wireless networks, but will frequently reschedule the entire network in cases of network dynamics regardless of the actual network area being affected by these dynamics. To efficiently reduce the overhead of network scheduling over highly dynamic wireless networks, we experimentally investigated the wireless network dynamics in different types of practical application scenarios, and we observe that these dynamics in wireless networks usually affect only a small portion of the network at any specific moment, when the rest major portion of the network remains stable and unaffected. Based on this observation, our proposed algorithms combine the scheduling results from such limited operations with the previous scheduling results over the remaining portions of the network, hence still providing guaranteed network throughput with much lower overhead.

Key outcomes or Other achievements:

The results of our work “Scheduling Dynamic Wireless Networks with Limited Operations,” has been accepted by the highly competitive *IEEE International Conference on Network Protocols (ICNP 2016)*, which has an acceptance ratio of 20.1%.

The results of our work “Supporting Real-Time Wireless Traffic through A High-Throughput Side Channel,” has been accepted by the highly competitive *ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc 2016)*, which has an acceptance ratio of 18%.

*** What opportunities for training and professional development has the project provided?**

One PhD student has worked on the project, and the research results have been published at various academic conferences.

*** How have the results been disseminated to communities of interest?**

Our research work in this project has resulted in two conference papers. These publications will help people better understand our novel techniques on enabling interconnected mobile computing in wireless networks, and further apply these techniques to overcome the fundamental limitations on the performance and energy efficiency of mobile devices. We have also given seminar and summer camp talks to high school students to stimulate their interest in engineering majors.

*** What do you plan to do during the next reporting period to accomplish the goals?**

In the next year, we will build on our existing techniques and further investigate techniques to satisfy the requirements of efficiency and adaptability in IMC. First of all, we plan to further extend our wireless side channel design to concurrent data transmissions among multiple mobile devices with heterogeneous types and traffic patterns, so as to enable emerging application paradigms in future Internet of Things (IoT) and smart systems. More specifically, we will allow these multiple devices to flexibly share the available wireless spectrum according to their traffic demands, and further optimize the power efficiency of their transmissions at the same time. Second, we will further explore the theoretical insights of resource sharing decisions over highly dynamic wireless networks with frequent link status changes, to ensure the adaptability of IMC over highly volatile mobile computing scenarios.

Products

Books

Book Chapters

Inventions

Journals or Juried Conference Papers

Haoyang Lu and Wei Gao (2016). Scheduling Dynamic Wireless Networks with Limited Operations. *Proceedings of the IEEE International Conference on Network Protocols (ICNP)*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Haoyang Lu and Wei Gao (2016). Supporting Real-Time Wireless Traffic through A High-Throughput Side Channel. *Proceedings of the ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc)*. . Status =

PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Licenses

Other Conference Presentations / Papers

Other Products

Other Publications

Patents

Technologies or Techniques

Thesis/Dissertations

Websites

Website for NSF Project "CAREER: Interconnected Mobile Computing in Wireless Networks"
http://web.eecs.utk.edu/~weigao/reporting/career.html

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Gao, Wei	PD/PI	1
Lu, Haoyang	Graduate Student (research assistant)	3

Full details of individuals who have worked on the project:

Wei Gao
Email: weigao@utk.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Manage the project and the research team. Design and evaluate the high-throughput wireless side channel for delay-sensitive IMC traffic. Design the distributed wireless network scheduling protocols with limited operations.

Funding Support: This grant.

International Collaboration: No
International Travel: No

Haoyang Lu
Email: hlu9@vols.utk.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Design, implement and evaluate the high-throughput wireless side channel for delay-sensitive IMC traffic. Design, implement and evaluate the distributed wireless network scheduling protocols with limited operations.

Funding Support: This grant

International Collaboration: No
International Travel: Yes, Germany - 0 years, 0 months, 8 days

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What other organizations have been involved as partners?
Nothing to report.

What other collaborators or contacts have been involved?
Nothing to report

Impacts

What is the impact on the development of the principal discipline(s) of the project?

Proliferation of mobile computing devices greatly extends the information that we can access anytime, and enables us to track, control and manage our bodies and the surrounding environment anywhere. The proposed research in this project aims at a complete rethink of how mobile computing systems are designed from the ground up, ranging from designs of wireless links and network algorithms to development of mobile system interfaces. We will study how potentials of heterogeneous mobile devices can be fully unleashed by being interconnected, so as to inspire novel theoretical and systematic studies that open up new research frontiers in emerging areas such as wearable computing and IoTs. If successful, such interconnection among mobile devices will provide a solid foundation to future development of pervasive and cognitive mobile applications, which persistently monitor human behavior and adaptively meet humans' needs.

Further, each task of the proposed research can potentially revolutionize wireless networking and mobile computing system designs. First, the extra wireless channel could greatly reduce the transmission latency of resource sharing and avoid degradation of mobile system performance. Second, distributed network algorithms that coordinate resource sharing and ensure efficient utilization of shared resources would greatly improve the efficiency and adaptability of mobile computing systems. Third, mobile system interfaces that support runtime access to heterogeneous remote resources are crucial to generality of IMC. The proposed techniques will have applications in a broader scope of cyber-physical systems such as industry control, remote sensing and connected healthcare by allowing seamless interconnection between disparate system components.

What is the impact on other disciplines?

The proposed research could be the critical factor to lay the foundation of realizing future large-scale smart connected systems, such as the Internet of Things. These smart systems, in turn, will serve as the key enabler of many cyber-physical systems, which will impact a large collection of different science and engineering disciplines. In particular, being able to precisely characterize the system instability and appropriately adapt to various types of system dynamics is critical to improve the mobile system efficiency and adaptability, and has a direct and immediate impact on a large variety of ubiquitous computing and cyber-physical systems.

What is the impact on the development of human resources?

Many of the research results have been integrated into the undergraduate curricula at the University of Tennessee, by adopting many perspectives of the research results for undergraduate students' course projects and senior design topics. The project has supported one PhD student working on his dissertation. The involvement of the graduate and undergraduate students into this research will prepare them for leadership roles in computer science research, academia, and industry.

What is the impact on physical resources that form infrastructure?
Nothing to report.

What is the impact on institutional resources that form infrastructure?
Nothing to report.

What is the impact on information resources that form infrastructure?
Nothing to report.

What is the impact on technology transfer?
Nothing to report.

What is the impact on society beyond science and technology?
Nothing to report.

Changes/Problems

Changes in approach and reason for change
Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them
Nothing to report.

Changes that have a significant impact on expenditures
Nothing to report.

Significant changes in use or care of human subjects
Nothing to report.

Significant changes in use or care of vertebrate animals
Nothing to report.

Significant changes in use or care of biohazards
Nothing to report.

Special Requirements

Responses to any special reporting requirements specified in the award terms and conditions, as well as any award specific reporting requirements.