Collaborative Communication and Sensing for Mobile Systems

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Bio of Student

Aaron Yi Ding is supervised by Prof. Sasu Tarkoma and Sr. Markku Kojo at the University of Helsinki, with Prof. Jon Crowcroft from University of Cambridge being his overseas research advisor. Currently Aaron is working in the Computer Laboratory, University of Cambridge. He obtained his MSc with distinction (5/5) in Computer Science from University of Helsinki in 2009. Since 2007, he has been employed to work on R&D projects collaborating with Nokia, NSN, Ericsson, and TeliaSonera with 6+ years experience. He is a recipient of the Nokia Foundation Scholarship and FIGS PhD Fellowship from the Academy of Finland. The tentative PhD graduation will be in Autumn 2014.

Abstract

The communication and sensing capabilities of mobile devices are improving dramatically in recent years together with the upgrading of wireless access infrastructure including the cellular and WiFi networks. However, the existing communication design is incapable of fully utilizing the resources offered by devices and networks, resulting in degraded service and user experience in terms of performance and battery life. My PhD research investigates this domain with a focus on developing solutions that can utilize the capability of networking interfaces and sensors collaboratively across devices and networks to achieve better performance and energy efficiency.

1 Introduction

Modern mobile systems are evolving at a tremendous speed. With powerful multi-core CPUs, fast memory, and smart sensors deployed on devices such as smartphones and tablets, mobile users are able to complete demanding tasks and enjoy convenient mobile services. At the same time, mobile operators are upgrading the infrastructure to LTE and LTE-advance (4G) for better access capacity and services. Unfortunately, for mobile users, the battery life is still a crucial bottleneck that affects the quality of user experience. On the other hand, the mobile operators are also suffering from the exponentially increase of data traffic generated by the bandwidth-hungry applications such as HD streaming.

In such fast evolving environment, there are several challenges that deserve our special attention and investigation:

- Overloaded networks and fast increase of mobile traffic: being a classic supply against demand problem, mobile offloading is sought as a promising direction but existing solutions are lack of considerations for device limitation and the complexity of network deployment.
- Power-hungry sensing tasks and limited battery life: for existing techniques to improve energy efficiency, the proposals tend to focus on the optimization of individual device at the cost of sensing accuracy.
- Network access performance in large social events: due to incompetent communication design, network congestion is common in events such as conferences and exhibitions. Although there is high demand for capacity, it is challenging and costly to install extra equipment merely for the needs of the event period.

The goal of my PhD research is to design solutions that utilize the capability of various interfaces and sensors on single device, and collaboratively unit the support from peer devices and network side for better performance and energy efficiency.

The rest of this paper is organized as follows. We present in Section 2 the main research questions and methodology. Section 3, 4 and 5 covers the major targets across my PhD research. We summarize in Section 6.

2 Research Questions and Methodology

My research seeks solutions to the following questions:

- What is the impact and implication of energy cost for communication design and why the existing design is incompetent for resource constrained mobile systems?
- How to improve the energy efficiency of sensing tasks while still maintaining a high level of accuracy?
- How to utilize available resources on mobile systems and particularly to benefit from the network side support?

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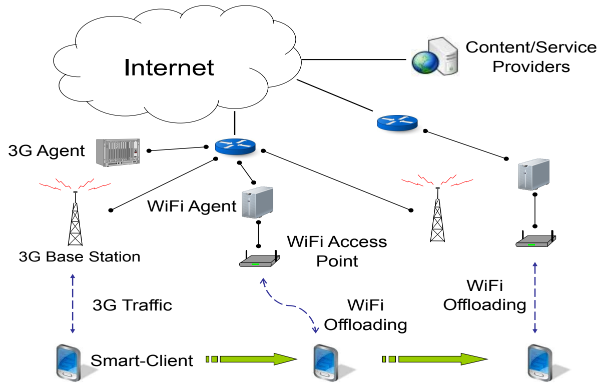

Figure 1. MADNet Offloading Architecture

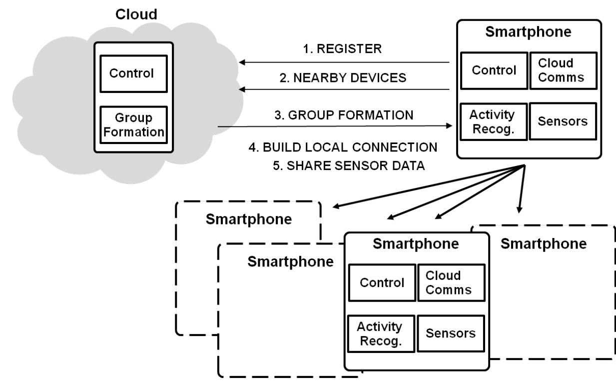

Figure 2. System architecture diagram.

- How to enable effective collaboration between peer mobile users and mobile networks, including cellular and WiFi providers?

My research style can be highlighted as *measurement-based*, *prototype-driven*, and *systems-oriented*. This is reflected in my research methodology that depends critically on three steps:

1. Measuring existing systems in real environment to understand their characteristics and limitations.
2. Designing protocols and system solutions by taking inputs from live measurement, combined with extensive simulations.
3. Implementing the most attractive design on prototype systems to uncover its complexity, and evaluating its performance in practice.

A common thread in my PhD research is to build systems that solve practical problems, as illustrated in the following sections.

3 Collaborative Mobile Data Offloading

Searching for mobile data offloading solutions has become topical in recent years as cellular operators are suffering from the burden of mobile traffic growth. Owing to the maturity of WiFi technology and its vast deployment, WiFi-based mobile data offloading has been shown to be promising [1, 2, 3]. However, existing solutions are lack of considerations for the limitation of smartphone-alike devices in terms of battery life and hardware.

To understand the underlying problems, we conducted measurement study using smartphones in three cities of US and Europe, revealing that the number of open accessible WiFi APs is very limited and WiFi-based offloading can drain the battery faster than using cellular data access if energy awareness is missing from the offloading decision process [4]. Based on the observation, we design MADNet (as shown in Figure 1), a WiFi-based mobile data offloading architecture for smartphones that can harvest the collaboration among cellular operators, WiFi providers and mobile users to improve energy saving.

Targeting at enhancing the energy-awareness, we design a dedicated offloading decision algorithm for the MADNet architecture. We implement MADNet on our prototyped systems and conduct experiment in the wild to verify its feasibility. We show that the potential energy saving of traffic offloading depends on the throughput of cellular and WiFi networks, and also the amount of data we can offload. Our experiment results (in Table 1) reveal that MADNet is able to achieve more than 80% energy saving. The live measurement also show that MADNet can tolerate minor errors in localization, mobility prediction, and offloading capacity estimation.

To further extend the impact of research, we have also pushed our protocol design to IETF [5] based on our Linux kernel implementation and analysis in the real networks [6].

Table 1. Measurement Results and Energy Saving

	C_W	B_{3G}	B_W	E_{oo}	E_{3G}	E_W	Saving
	MB	Mbps	Mbps	Joule	Joule	Joule	%
East	27.2	0.8	3.5	3.4	292.8	39.3	85.42
West	22.9	0.8	3.2	3.5	256.4	38.9	83.46

4 Collaborative Sensing

The sensing capabilities of mobile devices have rapidly improved to enable complex sensing tasks being run on personal mobile devices. Unfortunately, these tasks tend to be power-hungry, significantly impacting the battery life of the device. While many techniques for improving energy-efficiency have been proposed, these tend to focus on optimizing resource consumption of individual devices and achieve power savings at the cost of sensing accuracy.

As our on-going research, we propose CoSense, a novel collaborative mobile sensing platform that distributes sensing tasks among familiar devices in close proximity of each other (shown in Figure 2). As people often travel with their

Table 2. Breakdown of energy consumption of CoSense.

Component	Consumption
Receiving data	14/17/20 mW
Sending data	40/45/50 mW
GPS sensing	205 mW
Bluetooth Scan	4.2 J
Reporting to Cloud	2.0 J
Master node initialization	1.9 J

friends or family members, and increasingly carry multiple mobile devices, there are potential opportunities for distributing sensing tasks between devices.

We use empirical energy measurements (indicated in Table 2) together with data collected from everyday transportation behavior to demonstrate that CoSense can achieve significant power savings (over 230% when 5 devices share GPS measurements for 5 minutes) compared to running sensing independently on devices, while at the same time maintaining best possible sensing accuracy.

Currently we are investigating related work [7] and working on improving the support for dynamic topology changes resulting from user mobility.

5 Collaborative Access in Large Social Events

In environments with many participants such as international conferences and exhibitions (e.g., Google I/O, Apple WWDC, MWC@Barcelona), one major challenge is to accommodate the traffic bursts occurring on the wireless links, especially on the opportunistically-formed hot spots where mobile users often experience poor network performance.

One interesting feature in such environments is that event attendants with shared interests are often willing to collaborate and exchange ideas on similar topics. It is possible to collaboratively utilize the various wireless interfaces across peer devices that form the clique to share content and coordinate wireless access to avoid congestion.

The related work in this domain include WiFox [8] which explores the asymmetric nature of uplink and downlink of WiFi traffic pattern and prioritize downlink channel for better download performance. The main issue with their proposal is its potential harm to uplink traffic such as VoIP. The work on Informed Prefetching [9] provides a goal-oriented adaptive prefetching optimized for single user, yielding reduced response time for web applications and predictable money cost. Catnap [10], CoolSpots [11] and proposal in [12] aim at exploit multiple interfaces to either save energy or achieve seamless connectivity and parallel download. COMBINE [13] proposed similar collaborative download but without efficient group detection and identification which could be assisted by cloud computation through cellular signaling. Yet COMBINE also lacks of caching of popular content in group and even requires WiFi periodically broadcasting for group formation. MAR [14] proposes a router design to aggregates bandwidth of various wireless accesses.

Earlier work tend to focus on certain specific access technology, or targeting at a single user scenario without exploiting the powerful support from the network side, nor the potential in-group communication with access coordination. We intend to adjust the proposal from [15] for our design to find the effective coordination user in the clique.

The main goal of this research is to design a collaborative group communication system that exploit the available communication channels via various interfaces deployed on smartphones (WiFi, Bluetooth, Cellular) dedicated for large social events. Our proposal utilizes the cellular link as a potential signaling channel with cloud support together with peer to peer channels over WiFi-direct/Bluetooth for coordinated wireless access, targeting at relatively fair improvement of performance for both TCP-based and real time traffic with potential energy saving.

6 Summary

My PhD work seeks solutions to collaboratively utilize available resources across devices and networks for better performance and energy efficiency. Following the philosophic guidance, my PhD research focuses on solving practical problems by building real systems and evaluating them in live environment. I believe it is critical to evaluate networked systems through working implementations because it can be extremely hard to capture the complexity of large-scale distributed systems through theoretical or simulation studies alone. In the longer term, this approach will continue to guide my research.

Acknowledgments

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