Enabling Opportunistic Resources Sharing on Mobile Operating Systems: Benefits and Challenges

Narseo Vallina-Rodriguez†, Christos Efstratiou†, Geoffrey Xie⋄, Jon Crowcroft†

† University of Cambridge
Cambridge
UK
name.surname@cl.cam.ac.uk

⋄ Naval Postgraduate School
Monterrey, California
USA
xie@nps.edu

ABSTRACT

The intense use of hardware resources by mobile applications has a significant impact on the battery life of mobile devices. In this paper we introduce a novel approach for the efficient use of mobile phone resources, by considering the coordinated sharing of resources offered by multiple co-located devices. Taking into account the social behaviour of users, there are frequent situations where similar resources are available by co-located mobile phones. In this work we discuss the feasibility of sharing such resources in an opportunistic way, the possible benefits and the research challenges that need to be addressed in order to implement a reliable and robust solution.

Categories and Subject Descriptors

D.4.7 [**Operating Systems**]: Organization and Design—*Distributed Systems*

General Terms

Design

Keywords

Mobile computing, operating systems, energy-awareness, resources management, resources sharing, opportunistic computing

1. INTRODUCTION

Modern mobile devices incorporate a rich collection of sensing and communication capabilities allowing the design of a diverse range of interactive context-aware applications. However, the intensive use of these resources can come at a cost, typically in the form of reduced battery life. Despite the recent efforts in improving the energy efficiency of both hardware and software (by utilising hardware more efficiently and adapting to battery status) on mobile phones, mobile handsets still suffer from severe energy limitations. As most of the energy consumption of a mobile phone can be attributed the use of particular hardware components, there is a clear need to discover new ways of reducing the use of such components, without compromising the user experience and services delivered by the mobile phone applications.

As most of the energy consumption of a mobile phone can be attributed the use of particular hardware components, there is a clear need to discover new ways of reducing the use of such components, without compromising the user experience and services delivered by the mobile phone applications. Typical software energy saving techniques aim at keeping hardware resources in low power mode for as long as possible. Moreover, transitions between power modes can imply an energy cost depending on the power modes of the resource (e.g. the FACH mode in cellular interfaces [1]) and they are typically related to the applications running on the device and the interaction patterns of the user [12]. Previous energy-aware systems also exploited adaptive QoS mechanisms and user behaviour prediction to save energy by constraining and reducing the use of specific hardware resources, albeit at the cost of the service quality and accuracy delivered to the end user [9].

However, by considering the social activity of mobile phone users, we can see that large portions of a user's daily life are spent in close proximity of other mobile phone users with devices that incorporate similar hardware resources. Indeed, if we consider a commuter travelling by bus and using a location-based service on her mobile phone, there is a high probability that a significant number of co-commuters are also using their phone's GPS and cellular networks to interact with similar services. Also, in social events such as music concerts or sport events, large numbers of co-located users may use their phone to access the internet simultaneously. Motivated by this observation, we believe that there is a clear opportunity for improving the energy efficiency of mobile phone usage while making acceptable compromises in the QoS, by trying to aggregate, share and coordinate resources of multiple users at close proximity.

In this paper we consider an extension to existing mobile phone operating systems that can allow the opportunistic sharing of resources, using low power short range communication (such as Bluetooth[1]). This is the key objective for the design of ErdOS [11], an energy-aware operating system that exploits opportunistic computing to extend the battery life of mobile handsets. We identify the transparent and secure support as a key features of such system so existing mobile phone applications can seamlessly interact with local and remote resources in an energy-efficient way. In the domain of cloud computing, works such as MAUI [7] and Cloudlets [10] aim to integrate the benefits of powerful wall-powered machines

[1]Bluetooth is a feasible option due to its wide availability on most modern handsets. However, the Bluetooth communication paradigm is not well suited for ad-hoc communication. Future short range technologies such as Qualcomm's Flashlinq [6] are expected to alleviate some of those problems.

S3'11, September 19, 2011, Las Vegas, Nevada, USA.

available in the cloud with mobile systems. We consider the opportunistic sharing of resources complementary to the integration of cloud computing with mobile devices. Such an approach can allow more flexibility and integration with resources that are location specific (such as the use of GPS).

2. MOTIVATION AND BENEFITS OF OPPORTUNISTIC RESOURCES SHARING.

Experiments on human mobility and social interaction, using Bluetooth for co-location tracking, show that there are frequent situations where users can establish opportunistic connections with mobile devices in close proximity [3]. The value of using such connections for resource sharing is directly related to the relative cost of using a resource locally versus the cost of the short range communication. In the general case, the break-down of the energy consumption of mobile devices depends on both hardware characteristics [8] and user behaviour [12]. Table 1 shows energy costs of Bluetooth communication along with the use of energy demanding resources such as radio communication and GPS on a modern smartphone [2]. As indicated by these values, there is a clear opportunity to save energy by avoiding the use of local resources and instead leverage data or resources from co-located devices in an opportunistic manner. Nevertheless, the device that is offering resources is actually spending more energy in the short term, to serve others as we will describe in Section 3.

Energy consumption per hardware module		
Bluetooth	Near (30 cm)	36.0 mW
	Far (10 m)	44.9 mW
WiFi	Idle	8.0 mW
	Full Capacity	720.0 mW
GSM	Idle	58.0 mW
	Full Capacity	620.0 mW
GPS		143.1 mW

Table 1: Detailed break-down of the power consumption on a modern smartphone (Openmoko Neo Freerunner) with an external multimeter and with access to the hardware schematics of the device. The measurements were also validated for HTC Dream and Google Nexus One handsets

Considering the case of sharing radio communication, it is known that radio channels are unreliable with high variations in quality of service [4]. The energy consumption and the quality of cellular network interfaces depends on the receiving signal strength. As the *signal-to-noise ratio* (SNR) increases, more retransmissions at the link layer are required and therefore, more energy is consumed. The signal strength is in fact, context-dependent. It depends on the network deployment, the location of the user, whether the node is indoors or outdoors, mobility, radio obstacles, and the impact of any destructive interference effects [5]. Considering that co-located mobile phone users may experience significantly different GSM communication quality, opportunistic sharing could allow users to access the internet through links with higher SNR, reducing the overall energy consumed. In fact, as we can see in Figure 1, co-located nodes can collaborate to aggregate their traffic through the node with the better connectivity and enough energy resources (especially if they use different mobile operators with different network coverage and quality). Consequently, multiple mobile devices in a cluster can benefit from a better network connection while also collectively saving energy.

Moreover, we can consider situations where mobile devices could have local resources unavailable or in the wrong power mode, having an impact on both energy and user experience. For example, a local GPS receiver that is in the *"cold-start"* phase, can take up to 30 seconds to fully power up the component, thus imposing a significant penalty in terms of energy consumption in addition to the delay in serving a user application. Opportunistic sharing can significantly reduce the energy consumption is such cases while improving the responsiveness of the user applications. Specifically, performing a Bluetooth scan and connecting with a nearby device takes 11.5 seconds on average, while retrieving the first position from the local GPS receiver can take from 4 seconds to the order of minutes depending on the availability of the orbital data from the GPS satellites and the current power state of the GPS receiver.

In any case, in addition to the energy and usability benefits, we envision that opportunistic resources sharing at the operating system level can enable the eclosion of new types of applications and services based on nodes collaboration and crowd-sourcing. Mobile applications no longer need to rely exclusively on resources available in the local device. They can access remote resources seamlessly if the operating system provides this feature. They can collaborate to enable richer mobile applications (e.g. aggregate videocameras for a multipoint recording of an event), for sensing (e.g. inferring the speed of a vehicle using the information sensed by all the accelerometers from the passengers) or even for collaborative filtering (e.g., reducing the noise of an audio recording by aggregating data from several microphones).

3. RESEARCH CHALLENGES

In order to realise a transparent system that allows opportunistic sharing of mobile phone resources, several key challenges need to be addressed.

- *Adaptive resources discovery*. The use of an additional wireless interface such as Bluetooth to discover and communicate with nearby devices (and also to allow being discovered by them) comes at an energy cost for each node. The system must smartly decide when to discover nearby resources in order to minimise the Bluetooth energy overhead while maximising the chances of accessing remote resources and sharing local ones. Contextual and historic information can play an important role here.

- *Selecting the right node*. A cluster of co-located mobile nodes can provide a rich diversity of computing resources. In order to optimise usability while reducing the energy cost, it is necessary to apply appropriate device selection policies, considering the state of their resources and the availability of expendable energy (i.e. enough remaining battery capacity).

- *Collaboration and efficient aggregation of resources*. Mobile devices must collaborate to satisfy both the local demands and the sharing of resources with other nodes in the cluster. Fair allocation dictates that the energy cost of resource sharing is distributed among participating devices as equally as possible. Access control must be based on the availability of enough local resources to satisfy future own needs. As a consequence, multiplexing efficiently the resources is fundamental to guarantee the efficient operation of the system.

- *IPC mechanisms*. Accessing different shared resources may require different communication paradigms. Resources such as GPS reads can be broadcasted taking advantage of the properties of wireless interfaces while they can also be accessed by Remote Procedure Calls. Using the wrong communication mechanism can reduce the efficiency of the system, or even cancel any possible energy savings.

(a) Operator 1

(b) Operator 2

Figure 1: Signal strength perceived by two identical co-located handsets in several locations in west and centre of Cambridge (UK) with different network operators. Lighter points indicate better signal strength.

- *Fairness and privacy-energy tradeoff*. Using opportunistic sharing can offer an overall reduction in energy consumption when considering a whole cluster of co-located mobile devices. However, a key challenge for the success of the system, is to offer a balanced and fair distribution of the cost amongst users. Moreover, users can be selfish, preferring not to share their resources in order to avoid the short term energy overhead despite the potential benefits in the long term. Therefore, it is important to investigate appropriate incentive schemes that can help users act in a more altruistic manner and also to better understand the security and sharing policies they might require. Users might prefer different strategies to share their resources with members of their social network instead of sharing with everyone. We need to investigate the viability of different techniques to encourage resources sharing, as well as the fairness of different sharing strategies such as *tit-for-tat*, *dictator game* or *social capital*.

- *Dealing with mobility*. Nodes can dynamically join and leave a cluster because of their mobility. Consequently, it is possible that an ongoing transaction is disrupted. This can have a serious impact on the users' experience. Key challenges include mechanisms to predict the duration of co-location as well as the possible demand on certain resources. Such predictions can assist in evaluating whether establishing a connection and sharing a resource would actually lead to an overall reduction in energy and improvement of the user experience.

4. CONCLUSIONS

Opportunistic resources sharing at the operating system level can provide both energy and usability benefits for mobile users. Computation off-loading from energy-scarce mobile nodes to wall-powered machines in the cloud has been a quite well explored research topic in recent years. However, opportunistic resources sharing using low range wireless interfaces has not yet been investigated in a thorough and pragmatic way despite the potential bennefits that this approach can offer. This paper highlights the potential of opportunistic resources sharing in terms of energy and usability while also describing open research challenges in this field. This work is under the umbrella of ErdOS [11], an energy-aware opperating system that tries to extend the battery life of mobile devices by understanding how users interact with their devices and also by leveraging opportunistic resources sharing between co-located handsets.

Acknowledgements

We would like to thank our sheperds Daniel Halperin (University of Washington) and Hossein Falaki (UCLA) for their useful feedback and suggestions.

References

[1] N. Balasubramanian, A. Balasubramanian, and A. Venkataramani. Energy consumption in mobile phones: a measurement study and implications for network applications. In *Proceedings of ACM IMC'09*, pages 280–293, New York, NY, USA, 2009. ACM.

[2] A. Carroll and G. Heiser. An analysis of power consumption in a smartphone. In *Proceedings of USENIXATC'10*, pages 21–21, Berkeley, CA, USA, 2010. USENIX Association.

[3] A. Chaintreau, P. Hui, J. Crowcroft, C. Diot, R. Gass, and J. Scott. Impact of Human Mobility on Opportunistic Forwarding Algorithms. *IEEE Transactions on Mobile Computing*, 6:606–620, June 2007.

[4] R. Chakravorty, S. Katti, J. Crowcroft, and I. Pratt. Flow Aggregation for Enhanced TCP over Wide-Area Wireless. In *Proceedings IEEE INFOCOM'03*, pages 1754–1764, 2003.

[5] X. Chen, H. Zhai, J. Wang, and Y. Fang. A Survey on Improving TCP Performance over Wireless Networks. In *Resource Management in Wireless Networking*, pages 657–695. Kluwer Academic Publishers, 2005.

[6] M. Corson, R. Laroia, J. Li, V. Park, T. Richardson, and G. Tsirtsis. Toward proximity-aware internetworking. *IEEE Wireless Communications*, 17(6):26 –33, december 2010.

[7] E. Cuervo, A. Balasubramanian, D.-k. Cho, A. Wolman, S. Saroiu, R. Chandra, and P. Bahl. MAUI: making smartphones last longer with code offload. In *Proceedings MobiSys'10*, pages 49–62, New York, NY, USA, 2010. ACM.

[8] M. Dong and L. Zhong. Self-constructive high-rate system energy modeling for battery-powered mobile systems. In *Proceedings of MobiSys '11*, pages 335–348, New York, NY, USA, 2011. ACM.

[9] B. D. Noble and M. Satyanarayanan. Experience with adaptive mobile applications in Odyssey. *Mobile Networks and Applications*, 4:245–254, December 1999.

[10] M. Satyanarayanan, P. Bahl, R. Caceres, and N. Davies. The Case for VM-Based Cloudlets in Mobile Computing. *IEEE Pervasive Computing*, 8:14–23, October 2009.

[11] N. Vallina-Rodriguez and J. Crowcroft. ErdOS: achieving energy savings in mobile OS. In *Proceedings ACM MobiArch '11*, pages 37–42, New York, NY, USA, 2011. ACM.

[12] N. Vallina-Rodriguez, P. Hui, J. Crowcroft, and A. Rice. Exhausting battery statistics: understanding the energy demands on mobile handsets. In *Proceedings ACM MobiHeld '10*, pages 9–14, New York, NY, USA, 2010. ACM.