Understanding Energy Consumption of UHF RFID Readers for Mobile Phone Sensing Applications

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ABSTRACT

We argue that augmenting a mobile phone with an UHF RFID reader has the potential to expand the scope of mobile phone sensing applications. We investigate an important issue that arises when contemplating such integration — the energy consumption characteristics of state of the art compact UHF RFID readers collecting data from nearby sensor tags. Our experimental study shows that a typical operation using a compact UHF RFID reader consumes much less energy compared to sensors commonly present in mobile phones such as GPS, thereby supporting the case for UHF RFID reader integration with mobile phones.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless communication*

General Terms

Experimentation, Measurement, Performance, Reliability

Keywords

Mobile phone sensing, UHF RFID readers, Energy consumption

1. INTRODUCTION

In recent years, mobile phones have emerged as an attractive platform for sensing applications across several domains from transportation and environmental monitoring to health and social networking [1], chief reasons being their prevalence, built-in sensors (e.g., accelerometers, compasses), and ease of application development and deployment. Mobile phone sensing has also been a very active area of research addressing challenges such as energy-efficient continuous sensing [2] and incentive mechanisms to encourage user participation [3]. Even so, the kinds of sensing applications that can be realized with mobile phones are limited by sensors integrated into them. Form factor considerations and consumer nature of these devices determine the set of sensors that actually get added onto phones.

While researchers have developed specialized sensors to go with a consumer mobile phone for specific applications (e.g., CellScope[1], NETRA[2]), our motivation is to expand the scope of sensing applications on mobile phones in terms of type and scale. We observe that Radio Frequency IDentification (RFID) technology [4] offers an attractive solution to go some distance towards meeting this goal. Specifically, equipping mobile phones with RFID readers would allow phones to be turned into *generic* sensor data acquisition devices capable of reading data from a wide range of sensor tags deployed in the ambient environment. In fact, latest smartphones (e.g., Google Nexus S onwards for Android devices) have an integrated RFID reader that is based on the near field communication (NFC) technology. However, the main application driver for NFC reader on mobile phones is to enable mobile commerce applications and very short reader-tag separation required for NFC (in the order of few cm) makes it unsuitable for sensing applications.

A better RFID alternative for mobile phone based sensing applications is the UHF RFID technology based on the EPC Gen 2 standard [5] that can support larger read ranges (around a meter or more). The increasing availability of compact UHF RFID readers and sensor tags of the semi-passive type, that support reader-less sensing and substantial data storage, further strengthen the case for augmenting mobile phones with an UHF RFID reader. Recent research [6] has already demonstrated the feasibility of UHF RFID reader integration with mobile phones, in the process identifying various platform design related issues including antenna re-tuning, robustness to noise and USB based communication between reader and the phone operating system. The job of integration is now made a little easier with newer smartphones that support USB On-The-Go (OTG), allowing the reader and the phone to communicate with each other even though neither is a "host" in the USB sense.

In this paper, our goal is to understand the energy consumption impact of integrating a UHF RFID reader with a mobile phone. This is an important question that requires thorough investigation when contemplating such integration given that mobile phones run primarily on battery power and even more crucially, battery capacity remains the bottleneck resource on mobile phones. We address this question experimentally using state of the art compact UHF

[1]http://cellscope.berkeley.edu/
[2]http://web.media.mit.edu/~pamplona/NETRA/

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RFID readers, sensor tags and mobile phones. In particular, we relate the energy consumption of an UHF RFID reader with various types of sensors now common on modern mobile phones such as accelerometer, microphone and GPS. Our main finding is: while UHF RFID readers are expensive power consumption wise in the same region as the camera and the WiFi interface on a phone, they fair quite well in terms of energy consumed, the main metric of interest. Relatively shorter duration of RFID operations explains this discrepancy between power and energy consumption. Overall, our results show that UHF RFID reader integration with mobile phones is meaningful from an energy consumption perspective.

While there have been several recent studies on power consumption characteristics of mobile phones [7, 8, 9, 10], to the best of our knowledge, our work is the first one to look at UHF RFID reader energy consumption characterization in the context of a mobile phone. The only work that considers energy consumption of RFID readers focuses on the design of energy-aware MAC protocols for handling inter-tag collisions [11], whereas we measure energy consumption of currently available compact UHF RFID readers under different conditions and while doing different operations (inventory, read, write). Finally, note that the idea of using RFID for sensing has been around for sometime. See [12], for example. However the focus of that research is mainly oriented towards the design of energy harvesting sensor tags to permit reader less sensing (e.g., wisps [13]) and effective data collection from sensor tags by coping with the limited uplink (tag-to-reader) bandwidth (e.g., Flit [14], BLINK [15]). Our interest, on the other hand, is on quantifying reader energy consumption behavior.

The rest of the paper is structured as follows. We describe our experimental methodology in the next section. Section 3 explains our energy consumption results for various compact UHF RFID readers in comparison with built-in phone sensors. In Section 4, we present our conclusions and outline some issues for future work.

2. METHODOLOGY

We take an experimental approach to characterize the energy consumption of compact UHF RFID readers in the context of a mobile phone.

We choose three representative readers for this purpose: A528 and R1230CB Quark readers from CAEN, and TagSense Nano UHF Reader. Since energy consumption of a reader will depend on its communication with tags in its vicinity, we consider three different types of tags: UPM Raflatac label tag, CAEN A918 passive universal mounting tag and CAEN RT0005 Easy2Log Semi-Passive UHF temperature sensor tag (shown from left to right in Figure 1(c)). All the above hardware conform to the EPC Class 1 Gen 2 standard and designed with multi-region operation obeying different regulatory restrictions in mind. However, we found that the TagSense reader implementation did not allow us to read all types of tags, so we mainly focus on A528 and Quark readers. For these two readers, we use the same type of antenna[3]: compact linearly polarized dipole antenna with 0.8dBi gain.

We use the HTC Magic mobile phone running Android 1.6 version. It has most of the sensors standard with smartphones today such as accelerometer, microphone, camera and GPS.

At the time of our study, there was no support in the Android system to communicate with an attached RFID reader[4], so we measure the energy consumption of readers separately from those of sensors on the phone but using a common measurement setup (Figure 2(a)). Readers as well as the phone are supplied a constant voltage using Agilent E3631A DC power supply; current measurements are then obtained by placing Agilent 34410A digital multimeter (DMM) in series. The DMM is connected to the PC via USB. Our custom PC application written in C# obtains remote current measurements from the DMM at 5KHz sampling rate; this application also has a GUI to view the data in real-time (Figure 2(b)).

Each of the readers is mounted on a CAEN A528ADAT service board through which the reader is powered. The board also has a USB interface for connection to a PC. We use a custom C# application on the PC to communication with and control each of the readers.

In order to measure the power consumption of the phone, we replaced the battery on the HTC Magic phone with a mock battery pack (as shown in Figure 1(d)) and power it using the DC power supply unit and measure the current using the DMM as described above. We use a custom Android app to control the use of built-in sensors on the phone. This app runs in the background and allows sampling different phone sensors (e.g., accelerometer) at a specified frequency and for a specified time period.

3. RESULTS

We first study reader energy consumption with different operating modes and varying reader-tag separation distances. Note that inventory is the key operation of a RFID reader to discover and identify nearby tags. Reading from and writing to tags are other important reader operations. Even though we conducted experiments with all three different readers (TagSense reader to a relatively lesser degree due to reasons stated in Section 2), for the sake of brevity, we mainly focus on the case of Quark reader with a temperature sensor tag in sight with reader transmit power set to 23dBm; other cases are qualitatively similar.

Figure 3 (a) shows the success ratio for key RFID reader operations (inventory, read and write) between a Quark reader and a temperature sensor tag in line of sight of each other as reader-tag separation distance is varied. We observe the success ratio falls off a sharp cliff near the fringe of reader range, which in this case is nearly 2m. There is no noticeable difference between different operations except near the reader range. Both of these behaviors match with observations made in previous RFID reader performance characterization studies.

Figure 3 (b) shows the energy consumption of the reader corresponding to Figure 3 (a). Here we not only include the basic operations (inventory, read and write), we also consider complete read and write operations (inventory+read and inventory+write, respectively) as a tag must be first

[3] http://www.caenrfid.it/rfid/syproduct.php?fam=antenna&mod=WANTENNAX008

[4] Very recently, an app was released for MTI's MINI ME UHF RFID reader for Android devices (http://www.mti.com.tw/_english/02_products/03products.php?MainID=12&SID=52&ID=169).

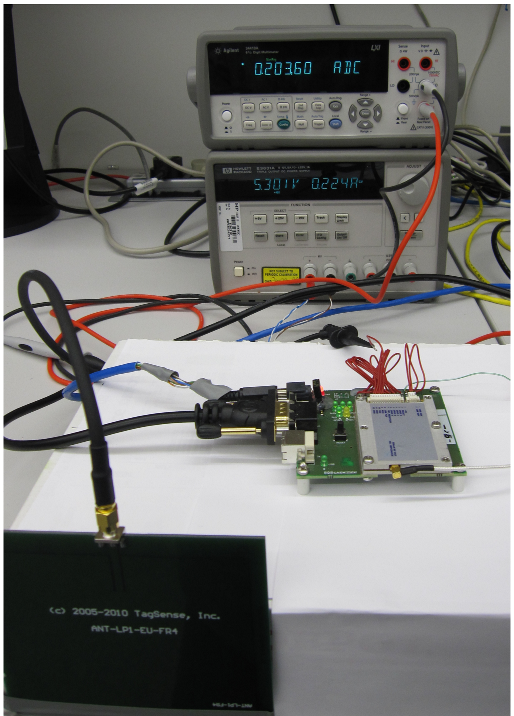
(a) A528 reader

(c) Tags

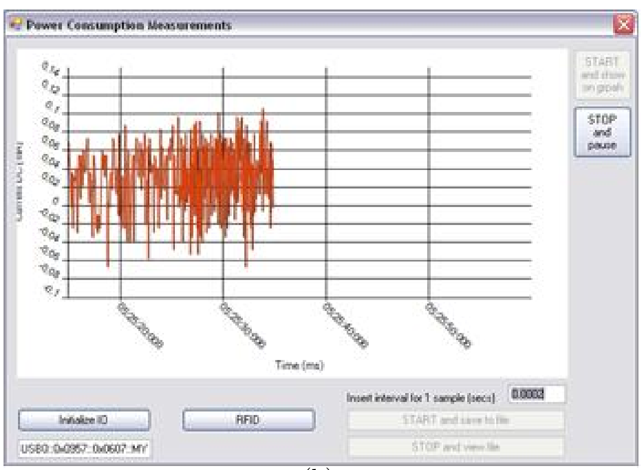
(b) Quark reader

(d) HTC Magic phone

Figure 1: RFID and mobile phone hardware used for energy consumption measurements.



(a)



(b)

Figure 2: (a) Power consumption measurement setup made up of a DC power supply and a digital multimeter. (b) Snapshot of PC application GUI to visualize power measurements from the multimeter in real-time.

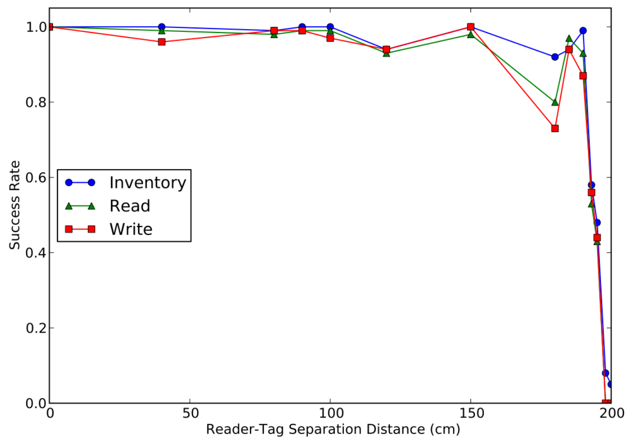
identified before it can be read from or written to. We note that for sensor tags inventory+read will be the typical operation. From Figure 3 (b), we observe that the behaviors of different curves are like those of success ratio curves in Figure 3 (a). Drop in energy consumption as tag is placed near the fringe of reader range is because operations keep failing as shown in Figure 3 (a) — unsuccessful operations end prematurely and consume lesser energy than successful ones. But unlike that of success ratio results, differences between curves showing energy consumption of different reader operations are much more noticeable. This can be explained by the fact that read and write operations are more involved (e.g., CRC checks) [5]. The write operations in addition requires a reader to wait for as long as 20ms while powering the tag as it writes the data into the tag memory. As a result, we find that write operations are most expensive in terms of energy consumption followed by read and then inventory. The energy consumption of combined operations is obtained by summing up the energy consumption for the underlying basic operations (e.g., energy consumption of inventory+read operation = energy consumption of inventory + energy consumption of read). Surprisingly, inventory+read is less energy consuming compared to just write operation alone.

In Figure 3 (c), we show the combined effect of success ratio and energy consumption using normalized energy consumption metric, which is the ratio of energy consumption to the success ratio. It is straightforward to explain the normalized energy consumption results given the results in Figures 3 (a) and (b). What is noteworthy though is that reader *effectively* consumes more energy for a given amount of useful work as tag location gets the near the fringe of reader range.

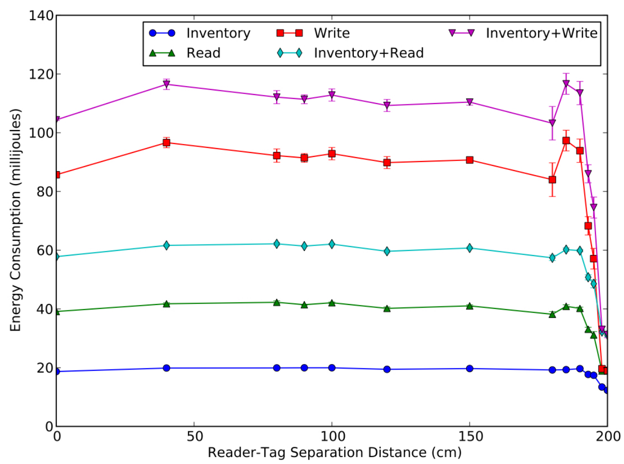
An important parameter in the reader configuration is the "Q" parameter, which specifies the range of slots (0 to $2^Q - 1$) for randomized tag responses to mitigate tag-tag collisions. Figure 4 shows the normalized energy consumption (as described above) with different Q values and different numbers of tags[5]. In the single tag case, we compare the effect of using different Q values and observe that using a bigger Q value increases the energy consumption as it has the effect of prolonging the tag response on average. As noted in [16], the optimum value of Q from a success ratio viewpoint is to set it to closely match the number of tags within the reader range, which in the single tag case is 0. Single tag results in Figure 4 in essence show that setting the reader Q value without consideration to number of tags in its range causes higher energy consumption due to the longer Query Cycle. For comparison, we also show results using optimum Q values for 3 and 5 tags cases — 2 and 3, respectively. We find that the effect of setting the same Q value for different numbers of tags is different because with multiple tags inter-tag collisions are still possible even with the optimum setting of Q value, thereby increasing the amount of effort involved and energy consumed for successfully identifying all tags within reader range.

Figure 5 (a) and (b) show the power consumption in watts and energy consumption in joules, respectively, for different readers doing the typical reader operation in sensing applications — inventory+read — in comparison with built-in sensors on the HTC Magic phone. For each of the sensors,

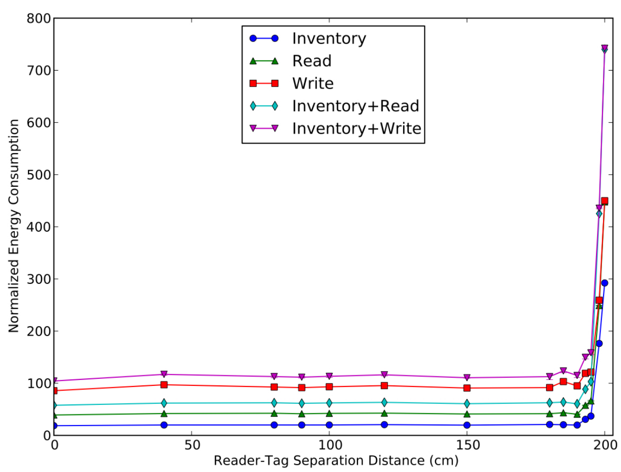
[5]For the results in Figure 3, Q was set to 0 as there is only one tag in the vicinity of reader.



(a)



(b)



(c)

Figure 3: The success rate, energy consumption and normalized energy consumption of a Quark reader for different reader operations with a temperature sensor tag as a function of reader-tag separation distance.

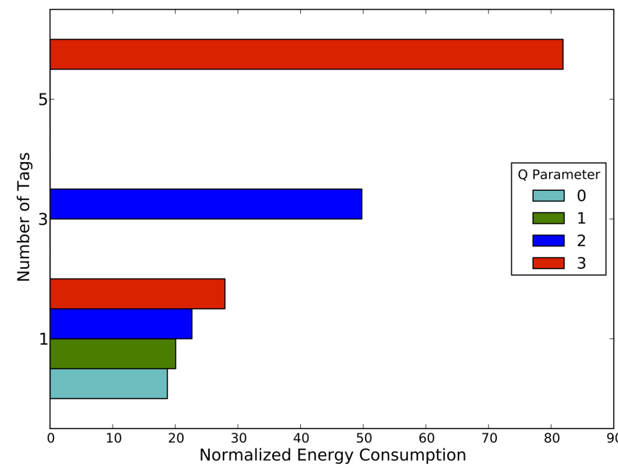


Figure 4: Impact of reader Q parameter on normalized energy consumption for the inventory operation between a Quark reader and one or more temperature sensor tags.

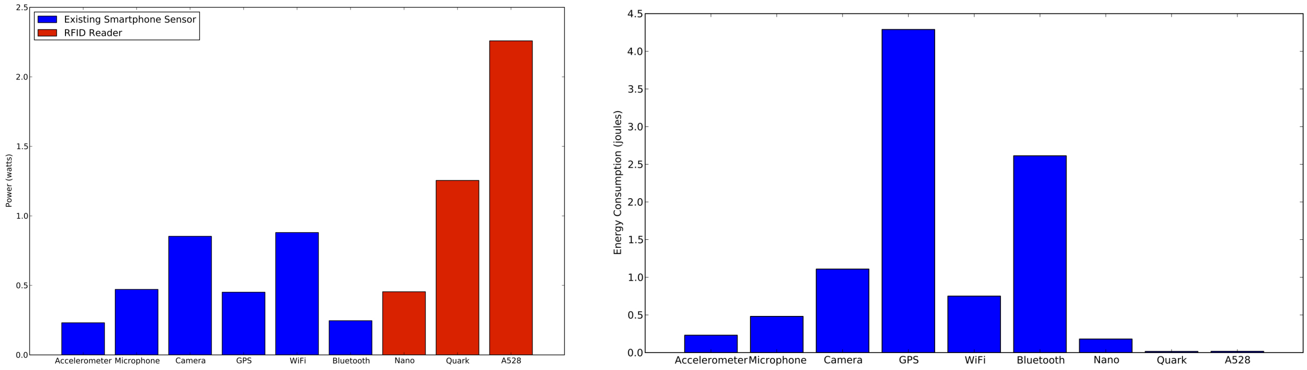
we consider a typical operation. For accelerometer and microphone, it is 5 seconds of continuous sampling. With the camera, it is taking a picture. For WiFi and Bluetooth, we consider AP scan and device scan, respectively. We view getting a single location fix as the typical operation for GPS. We observe that power consumption of various RFID readers can be higher compared to some of the phone sensors. But the short duration of RFID operations (in the order of few tens of milliseconds) result in negligible reader energy consumption relative to phone sensors (e.g., GPS can take several seconds to get a fix). While the comparisons in Figure 5 are based on measurements of sensor energy consumption on a specific phone (HTC Magic Android phone), we expect similar results with other phones. Validation of the latter assertion is left for future work.

Figure 6 presents the result from Figure 5 in a different and more informative form. It shows that the several tens of inventory+read operations can be carried out with the energy consumption budget for typical operations of each of the built-in phone sensors. For example, with the Quark reader around 65 inventory+read operations can be carried out with the energy budget of acquiring a GPS location fix on phone.

Although not presented here, we have also considered the effect of reader transmit power and environmental factors on reader energy consumption. We find that increased transmit power expectedly increases the energy consumption, but only marginally. Having obstacles blocking the line of sight between reader and tag makes the reader take longer to achieve the same success rate as in the line-of-sight case, leading to increased energy consumption. Nevertheless, comparative results shown in Figures 5 and 6 still hold in a qualitative sense even for non-line-of-sight scenarios.

4. DISCUSSION AND CONCLUSIONS

Our experimental study on energy consumption of compact UHF RFID readers supports the case for their integration with mobile phones as they consume no more energy



(a) (b)

Figure 5: (a) Average power consumed (in watts) and (b) energy consumed (in joules) by integrated smartphone sensors and RFID readers for typical operations. Readers consume much less energy because most reader operations finish in fractions of a second while tasks for some of the phone sensors can take several seconds.

than any of the built-in sensors on modern mobile phones. This observation needs to be validated with a integrated mobile phone – UHF RFID reader system such as MTI's MINI ME and with different phones. It remains to be seen how user mobility and placement of phone on the user (holding in hand vs. pocket or handbag) affect reader success ratio and energy consumption. An interesting question for future work in this space is the design of reader duty cycling techniques that balance high fidelity tag sensor data collection with energy efficiency. Energy efficient reader behavior can also be obtained with assistance from other phone sensors (e.g., accelerometer detecting motion). Finally, it is important to evaluate the UHF RFID technology against other alternative technologies such as Bluetooth Low Energy (BLE)[6] and ANT[7] in terms of their pros and cons for expanding the scope of mobile phone sensing applications.

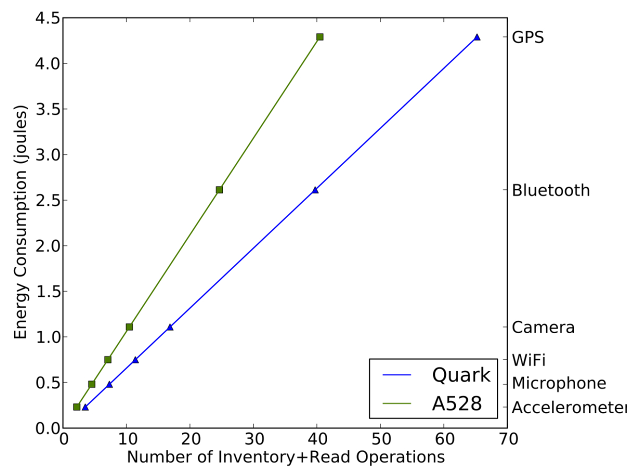


Figure 6: The number of inventory+read operations for the Quark and A528 readers with a temperature sensor tag relative to the energy consumed (in joules) by each of the built-in phone sensors to do their typical operation.

5. REFERENCES

[1] N. D. Lane et al. A Survey of Mobile Phone Sensing. *IEEE Communications*, 48(9):140–150, Sep 2010.

[2] B. Priyantha, D. Lymberopoulos, and J. Liu. LittleRock: Enabling Energy-Efficient Continuous Sensing on Mobile Phones. *IEEE Pervasive Computing*, 10(2):12–15, Apr 2011.

[3] S. Reddy, D. Estrin, M. Hansen, and M. Srivastava. Examining Micro-Payments for Participatory Sensing Data Collections. In *Proc. ACM UbiComp*, 2010.

[4] R. Want. An Introduction to RFID Technology. *IEEE Pervasive Computing*, 5(1):25–33, Jan 2006.

[5] EPCglobal Specification for RFID Air Interface. EPC Radio-Frequency Identity Protocols Class-1 Generation-2 UHF RFID Protocol for Communications at 860 MHz - 960 MHz Version 1.2.0, Oct 2008.

[6] J. T. Savolainen, H. Hirvola, and S. Iraji. EPC UHF RFID Reader: Mobile Phone Integration and Services. In *Proc. IEEE Consumer Communications and Networking Conference (CCNC)*, 2009.

[7] N. Balasubramanian, A. Balasubramanian, and A. Venkataramani. Energy Consumption in Mobile Phones: A Measurement Study and Implications for Network Applications. In *Proc. ACM Internet Measurement Conference (IMC)*, 2009.

[8] A. Shye, B. Scholbrock, and G. Memik. Into the Wild: Studying Real User Activity Patterns to Guide Power Optimizations for Mobile Architectures. In *Proc. IEEE/ACM Int'l Symp. on Microarchitecture (MICRO)*, 2009.

[9] A. Rice and S. Hay. Decomposing Power

[6] `http://en.wikipedia.org/wiki/Bluetooth_low_energy`
[7] `http://www.thisisant.com/technology`

Measurements for Mobile Devices. In *Proc. IEEE PerCom*, 2010.

[10] A. Carroll and G. Heiser. An Analysis of Power Consumption in a Smartphone. In *Proc. USENIX Annual Technical Conference*, 2010.

[11] V. Namboodiri and L. Gao. Energy-Aware Tag Anticollision Protocols for RFID Systems. *IEEE Transactions on Mobile Computing*, 9(1):44–59, Jan 2010.

[12] M. Buettner et al. Revisiting Smart Dust with RFID Sensor Networks. In *Proc. ACM HotNets*, 2008.

[13] M. Philipose et al. Battery-Free Wireless Identification and Sensing. *IEEE Pervasive Computing*, 4(1):37–45, Jan 2005.

[14] J. Gummeson, P. Zhang, and D. Ganesan. Flit: A Bulk Transmission Protocol for RFID-Scale Sensors. In *Proc. ACM MobiSys*, 2012.

[15] P. Zhang, J. Gummeson, and D. Ganesan. BLINK: A High Throughput Link Layer for Backscatter Communication. In *Proc. ACM MobiSys*, 2012.

[16] M. Buettner and D. Wetherall. An Empirical Study of UHF RFID Performance. In *Proc. ACM MobiCom*, 2008.