A2PSM: Audio Assisted Wi-Fi Power Saving Mechanism for Smart Devices

Mostafa Uddin
Department of Computer Science
Old Dominion University
Norfolk, VA, USA
muddin@cs.odu.edu

Tamer Nadeem
Department of Computer Science
Old Dominion University
Norfolk, VA, USA
nadeem@cs.odu.edu

ABSTRACT

Wi-Fi is the most prominent wireless network interface in current smart devices. Due to its high power consumption, Power Saving Mode (PSM) schemes have been proposed to reduce power consumption. We show how the current popular PSM schemes implemented in nowadays smart devices are inefficient. In this paper, we propose A2PSM: an audio channel assisted power saving scheme for the Wi-Fi interface, which address the inefficiency of the existing power saving schemes in smart devices. In this scheme, we leverage the low power consumption of the audio interfaces (mic/speaker) to reduce the wakeup events of the Wi-Fi interface when it is in Power Saving Mode. In this paper, we develop a small-scale prototype testbed on real smartphones to evaluate the proposed A2PSM scheme. Experiments show that A2PSM could save up to more than 25% more power than the existing schemes. To the best of our knowledge, this is the first work to utilize the audio channel in optimizing the power consumption of Wi-Fi networks.

Categories and Subject Descriptors

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

General Terms

Design, Algorithms, Measurement, Performance

Keywords

WiFi, Constant Awake Mode, Power Saving Mode, Audio Interface

1. INTRODUCTION

Wi-Fi is becoming the prominent network interface for data communication in smart devices (e.g., smartphones) because of its low/free cost, high throughput, relatively large range, and ubiquitous accessibility. However, the WiFi network still has several inefficiencies in terms of high energy consumption, unfairness between co-located nodes, and poor bandwidth utilization. For example, the Wi-Fi transmitter has to finish the transmission of the packet even in the case when the receiver flags the packet as corrupted at early stage of the transmission. Another example is the overhead of the low rate transmission of Wi-Fi control packets (RTS/CTS/ACK).

Addressing the above problems, we introduce the idea of enhancing data communication performance over Wi-Fi networks by using the mic/speaker in smart devices as a parallel communication channel. More specifically, we envision a novel communication framework that utilizes the audio interface (i.e., mic/speaker) on smart devices in developing more efficient Wi-Fi networks. Unlike other interfaces in smart devices such as Bluetooth interface, audio interface (i.e., hardware and software) in current commodity smart devices are open and flexible that enable us to integrate it with Wi-Fi interface at the networking lower layers (i.e., MAC and PHY layers) to realize our vision.

In audio interface, we exploit the frequency band beyond the human ear's perception for audio communication. Nowadays, most of, if not all, smart devices are both capable of generating and discerning audio frequencies beyond the human perception. In this paper we develop and evaluate, as a part of our framework, an audio channel assisted Wi-Fi power saving mechanism for smart devices. To the best of our knowledge, this is the first work to utilize the audio channel in optimizing the power consumption of Wi-Fi networks.

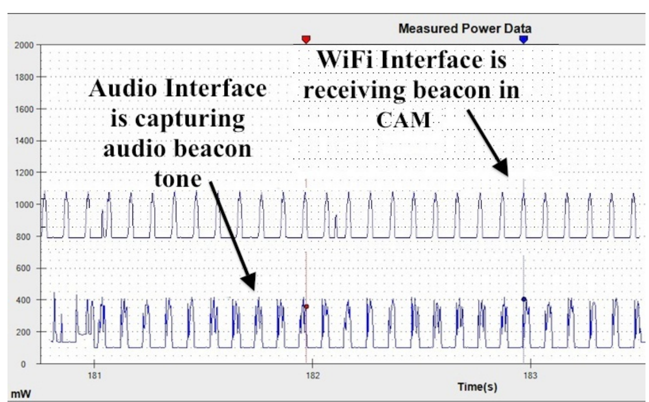

Figure 1: Monsoon Power monitoring result while audio interface is receiving audio beacon tone, and wifi interface is receiving beacon during CAM.

ACM HotMobile'13, February 26–27, 2013, Jekyll Island, Georgia, USA.

2. MOTIVATION AND CONTRIBUTION

Wi-Fi power management has an important impact on the battery endurability of smart devices. In this paper, we propose the Audio Assisted Wi-Fi Power Saving Mode (A2PSM) scheme that exploits both the audio interface hardware (mic/speaker) and the existing Wi-Fi power saving mechanism in smart devices. Given the wide adaptation of Wi-Fi in many types of smart devices and the corresponding spread of peer-to-peer applications and services (e.g., file sharing, multiplayer games, media streaming) between smart devices in home and office setting, Wi-Fi Direct (SoftAP) standard [3, 5] that allows direct communication between Wi-Fi peers is gaining more interests and spread. Wi-Fi Direct and the corresponding power saving mechanism works more like Wi-Fi infrastructure mode in which one device (e.g. smartphone, TV, laptop) acts as an access point (AP) while the others as client stations (STAs). Therefore and without loss of generality, we focus in this paper on using A2PSM in the Wi-Fi infrastructure mode that is equally applicable to Wi-Fi Direct.

Most smart devices have two main power management modes for Wi-Fi Infrastructure mode; Constant Awake Mode (CAM) and Power Saving Mode (PSM). In CAM mode, the device's Wi-Fi interface remains awake all the time while in PSM mode device's Wi-Fi interface awakes periodically to receive beacons from the access point (AP). Because of the importance of power management, several PSM schemes have been applied. The most common used PSM scheme in smart devices is Static PSM (SPSM). In SPSM, the sleeping duration is fixed and set at the association process between the device (STA) and the access point (AP). Since a STA needs to wake up periodically even if there is no data to exchange with the AP, SPSM is not optimal. In our proposed A2PSM, we try to mimic the optimal situation by using the audio interface as a parallel channel to the Wi-Fi interface in order to allow the STAÕs Wi-Fi interface sleep as long as there is no data to exchange between the AP and the STA.

To understand the power consumption of both the audio and Wi-Fi interfaces, we conducted a simple experiment with the use of Monsoon power monitoring tool [2]. In the experiment, the audio interface and the Wi-Fi interface receive an audio beacon (i.e., tone) and a Wi-Fi beacon respectively in a periodic pattern. Clearly, Figure 1 shows that the power consumption of the Wi-Fi interface is three times more than the audio interface. Such observation motivated us to consider a new mechanism to utilize the audio interface in enhancing the current PSM mechanism in the smart device to optimize its power consumption.

In the following, we summarize the contributions of this paper:

1. *Introduce the idea of using the audio communication channel to assist the Wi-Fi PSM mechanism.* This paper takes the first step to explore the feasibility and the future direction of our framework that utilizes the audio interface as an additional interface for the Wi-Fi interface.

2. *Design the A2PSM scheme for smart devices.* We describe in details about the design challenges of incorporating the audio channel with Wi-Fi.

3. *Implement the A2PSM scheme on commodity smart device.* We Implement our prototype of A2PSM on Nokia N900 phones.

4. *Evaluate the A2PSM scheme in real environments.* We evaluate the power efficiency of our implemented prototype using Monsoon power monitoring tool. We also identify several steps for future research.

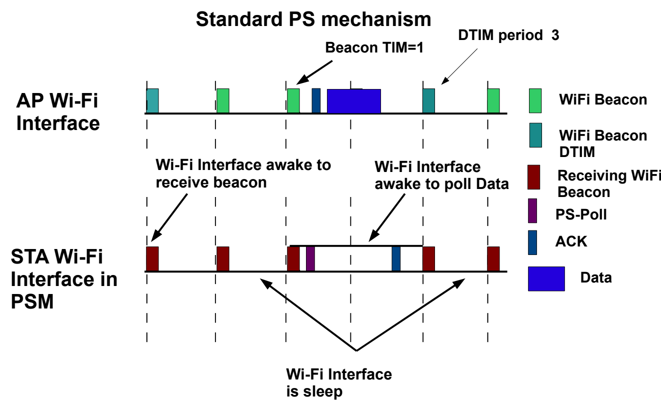

Figure 2: Standard PSM scheme for Wi-Fi infrastructure networks

3. BACKGROUND: PSM OVERVIEW

In standard PSM, the STA's Wi-Fi interface awake periodically to receive beacons from the AP. A beacon message from the AP with the STA's TIM bit set indicates that AP has buffered data for the STA. Consequently, the STA's Wi-Fi interface switches from PSM to CAM and poll the data from AP. In case of a broadcast frame, AP transmits a special kind of beacon message; DTIM, periodically every certain beacon intervals. Figure 2 gives an overview of the standard PSM scheme for Wi-Fi infrastructure networks. Unlike PSM, A2PSM scheme keeps the STAÕs Wi-Fi interface in sleep until there is a data to exchange with the AP and the STA needs to switches from PSM to CAM. While the STA is in sleep, the communication between the AP and the STA happens thru the audio interface. In our schema, we assume both the AP and the STA have an audio interface (mic/speaker). In section 5 we describe details of our A2PSM scheme.

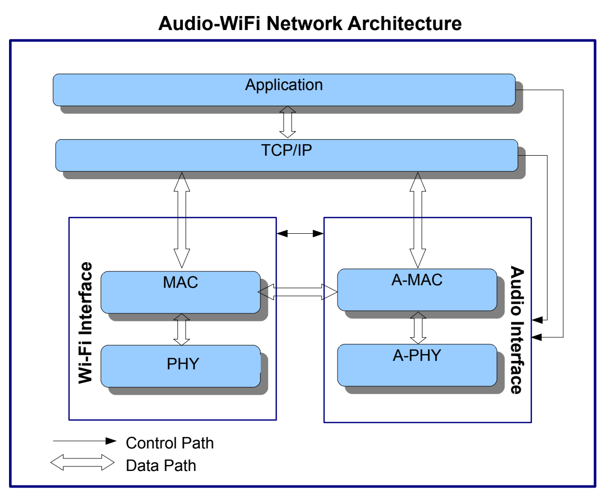

Figure 3: Preliminary Audio-WiFi Framework Architecture.

4. AUDIO-WIFI ARCHITECTURE

Figure 3 shows the preliminary architecture of our Audio-WiFi framework vision. The audio interface in this framework has two layers: 1) A-PHY layer: responsible for signal processing and signal transmission/ reception using speaker/microphone hardware. 2) A-MAC layer: responsible for sending/receiving audio signals over audio channels. In this framework, Wi-Fi MAC and upper layers (e.g., TCP/IP and applications) utilize the audio interface to send control frames (e.g. beacon frame) using the A-MAC layer. In a similar way, A-MAC could receive control frames over audio channel and send it to Wi-Fi MAC and upper layers. In addition, the framework defines the cross-layer interactions (e.g. control path) between the different layers and the audio interface to facilitate the data flows between the different components. In the implementation section we describe, how we use this architecture to implement our prototype of the proposed A2PSM scheme in Linux-based Nokia N900 smartphones.

5. A2PSM DESIGN

The scope of this paper is to design and implement the A2PSM scheme for unicast transmissions in Wi-Fi infrastructure networks. We will discuss the broadcast transmissions later in Section 9. In designing A2PSM scheme, we need to fulfill the following requirements: (1) The use of the audio interface with the PSM should cost less energy than the traditional Wi-Fi interface. (2) The audio interface needs to generate and receive the audio beacon within the same time limit of the Wi-Fi beacon, in order not to increase the data transmission latency. In this section, we describe in details the design of A2PSM scheme that fulfill the above requirements

5.1 Audio Beacon

In A2PSM, in addition to the Wi-Fi beacons, the AP needs to generate audio beacons synchronized with the Wi-Fi beacons. The audio beacon is an audio signal that has one or more high frequency ($\geq$ 18kHz) sinusoidal signal components. In 802.11 standards, the AP assigns a unique Association Id (AID) to each STA during the association process. In A2PSM, similarly, each STA is assigned a unique audio frequency corresponding to its unique AID. Figure 4 shows the overall power saving mechanism of the A2PSM. As shown, when the AP has a buffered data for a STA or more, the AP includes in the audio beacon, transmitted along with the Wi-Fi beacon, the frequency components that are corresponding to these STAs. This audio beacon structure mimics the Wi-Fi beacon with TIM bits. In A2PSM, while the STA is in PSM, the audio interface awakes periodically to capture the audio beacons from the AP. When a STA receives an audio beacon with including its audio frequency, it puts its audio interface to sleep and then awakes the Wi-Fi interface to poll its buffered data from the AP. Note that, the duration of the awake periods of the audio interface should be short enough to capture the audio beacon while minimizing the energy consumption. In our implementation, we set this period to 20ms, which is the average duration of the Wi-Fi interface being awake to receive the Wi-Fi beacon.

5.2 Relative position

In Figure 4, there is a time difference between the generation and the reception of the audio beacon tone by the AP and the STA respectively. This time difference is due to the slow propagation speed of the audio. The observed time difference depends on the relative distance between the STA and the AP. The STA and the AP can use one of the existing ranging schemes such as Beepbeep [10] to estimate the relative distance between them. Knowing the relative distance to the AP, the STA could calculate the exact time to awake its audio interface just right before the reception of the audio beacon. Therefore, STAs with different distances to the AP turn their audio interfaces at different times.For example, in Figure 5, while *STA2* has not received the audio beacon yet, *STA1* started to receive the audio beacon.

To satisfy our second design requirement, the farthest STA from the AP needs to receive the audio beacon within the typical Wi-Fi beacon interval time (e.g. 100ms). Such requirement is necessary to minimize the data latency between STAs and the AP. Devices in Wi-Fi Direct scenarios are in close proximity (e.g. 5-10 meter) to each other. For the indoor Wi-Fi networks (e.g., home and office settings), the typical average Wi-Fi range is within 30 meter [6]. Given the speed of sound in air, the farthest STA would start receiving the audio beacon within 60ms after its transmission for the 30meter range. This allows the farthest STA to capture the audio beacon within the typical Wi-Fi beacon interval (e.g., 100ms). This requirement is more challenging in case of broadcast transmissions. We describe this challenge in section 9.

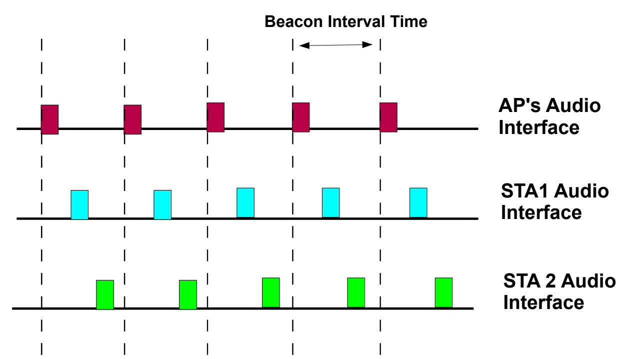

Figure 5: Audio beacon communication between two STAs and AP. In the scenario, STA2 is further away from the AP compare to STA1.

6. IMPLEMENTATION

We have implemented our prototype of A2PSM on two Nokia N900 smartphones. We use one phone as an AP and the other as a STA. In the prototype, we implement the followings: (1) The audio interface for both the STA and the AP. (2) The interaction between the Wi-Fi Interface and the audio Interface for both the STA and the AP.

6.1 Audio Interface

In the audio interface, we implement a simple prototype of the A-PHY layer. Figure 6 shows the original components of the Linux sound driver (e.g. ALSA) and the Wi-Fi driver(e.g. wl12xx) (shown as dotted boxes) in Linux-based smart devices (e.g. Android, Memo etc.). Our additional A-PHY and A-MAC modules of the audio interface are shown in the figure as shaded solid boxes. The A-PHY of the audio interface is responsible to transmit/receive the audio beacon. In our implementation, the A-PHY module in the AP only generates the audio beacon synchronized with the Wi-Fi

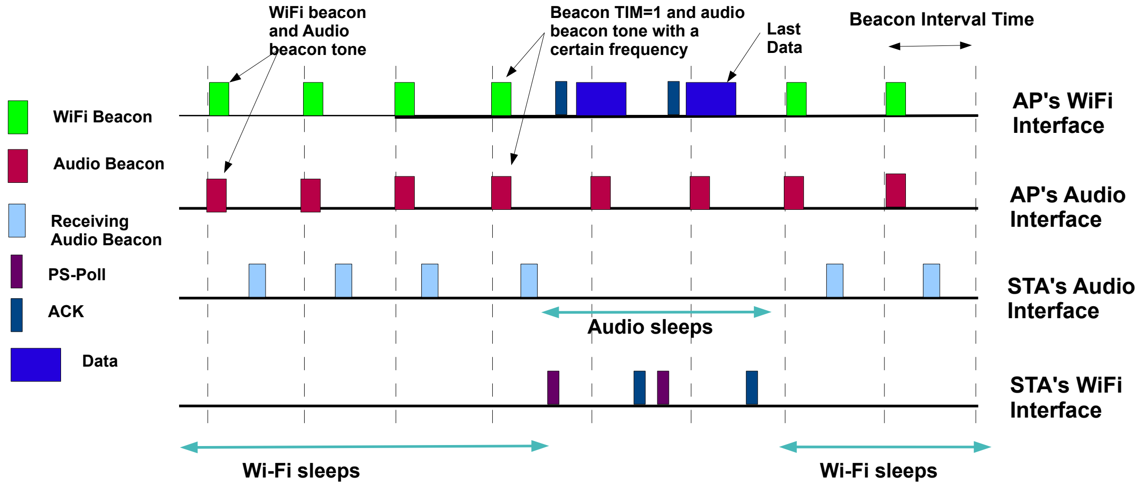

Figure 4: Overview of unicast transmissions from an AP to a STA using A2PSM scheme.

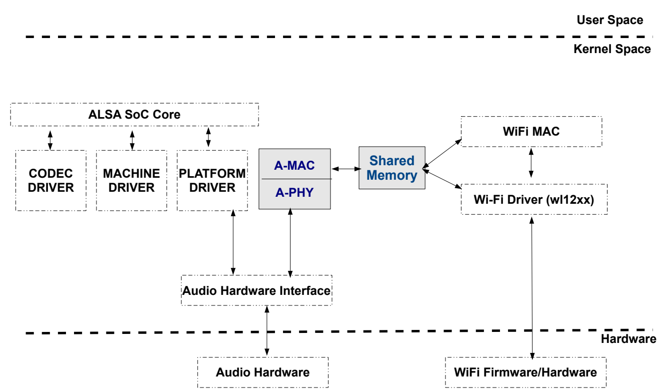

Figure 6: Implementation architecture of A2PSM scheme.

beacon transmission. On the other hand, the A-PHY module in the STA is responsible to capture the audio beacon and to detect whether its corresponding frequency component is included in the beacon. Initially, the A-PHY module in the STA applies a high pass filter to extract only the high frequency component of the captured audio signal. Followed by the filtering, the A-PHY module uses cross-correlation technique to detect whether the captured signal contains a certain frequency component corresponding to the STA's AID. Given that the background noises have very minimal effects in the high frequency range (18kHz-21kHz), it is easy to detect certain frequency components within the captured beacon with high accuracy.

The A-MAC module in the AP interacts with the A-PHY module to transmit periodic audio beacons aligned with the Wi-Fi beacons. In addition, the A-MAC module is responsible to define the frequency components in the audio beacon based on the AIDs of the STAs those have buffered data at the AP. Therefore, the A-MAC module in AP needs to communicate with the Wi-Fi MAC to identify those STAs. In the STA, the A-MAC module notifies the Wi-Fi MAC only when it has data to poll from the AP.

One main question we need to address in our implementation is: how long we need to keep the audio interface awake in the STA to capture the audio beacon properly? Our objective in the implementation is to minimize the duration needed by the audio interface in the STA to stay awake to capture the audio beacon. Since the duration of capturing an audio beacon at the STA is tightly coupled with the duration of the generated audio signal at the AP, we studied how audio signal is generated. In general, the generation of an audio signal depends on three main parameters of the sound driver; sampling period, buffer size and period size [8]. In our implementation, we tune these parameters to limit the duration of the audio beacon signal to 10ms, which is large enough to be detected at the STA side. Therefore, the audio interface at the STA needs to keep awake for at least 10ms in order to capture the audio beacon from the AP. This duration period is identical to the period the Wi-Fi interface stays awake in the SPSM scheme to receive a Wi-Fi beacon.

6.2 Audio-WiFi Interaction

Another important issue we have to address in our implementation is to minimize the miss-alignment between the transmissions time of the audio beacons and the WiFi beacons at the AP. In doing this, fast interaction between the audio and the Wi-Fi interfaces is needed to guarantee lower miss-alignment between the audio and Wi-Fi beacons. In our implementation, we use a simple shared memory to facilitate the interaction between the two interfaces thru sharing certain information that control the operation of the interfaces. For example, the Wi-Fi driver uses the shared memory to signal the audio driver about a Wi-Fi beacon transmission. Similarly, the Wi-Fi drive uses the shared memory to inform the audio driver about changing its PSM mode.

7. EXPERIMENT AND EVALUATION

In this section we evaluate the performance of our proposed A2PSM scheme by answering the following two questions: (1) How much energy is saved by the A2PSM scheme compared to the standard power saving mechanism under different traffic loads? and (2) Does the A2PSM has any effect on the network throughput?

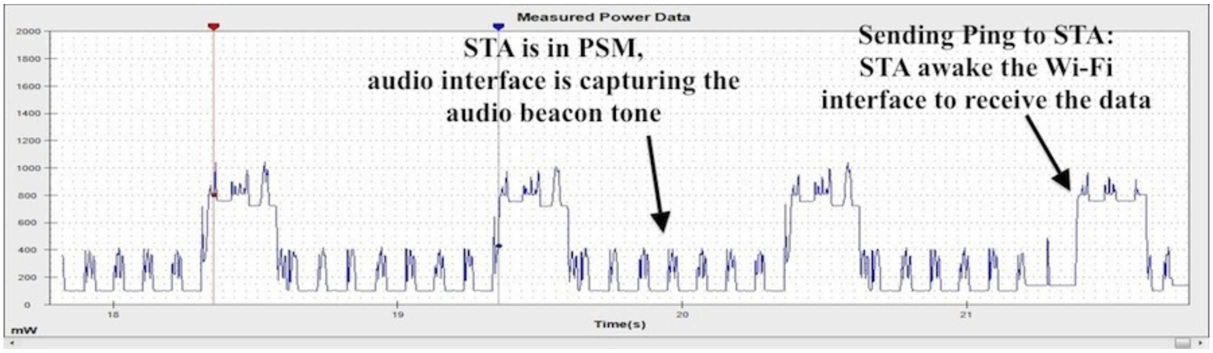

Figure 7: Monsoon Power Monitoring observation of A2PSM schema while STA is receiving ping message during PSM.

In our experiments, we use two Nokia N900 phones running our implemented A2PSM scheme in which one phone act as a STA and the other as an AP. We connect the STA with the Monsoon Solution Power Monitor [2] to measure its energy consumption. We conducted a simple experiment to validate the proper implementation of the A2PSM. In this experiment, we send a periodic ping command through the AP to the STA. Figure 7 shows the power consumption that is corresponding to the activities of the audio and Wi-Fi interfaces in the STA in response to the ping commands. This plot validates the proper operation of A2PSM scheme in receiving the audio beacon and in switching between the audio interface and the Wi-Fi interface.

To evaluate the energy efficiency of A2PSM scheme, we run iperf [1] tool on both the STA and the AP in server mode and client mode respectively. We send UDP data from iperf client to the iperf server under different traffic loads for duration of 20 seconds. We replicate this experiment 10 times for each traffic load setting. During the experiment, we fix the distance between the STA and the AP to 3 meter. We compare the power consumption of the smartphone under two different power saving schemes: A2PSM and SPSM. During the power consumption measurement, we turn off all the other radio interfaces as well as the display screen of the smartphone. Moreover, we use the same settings of the smartphones under both power saving schemes.

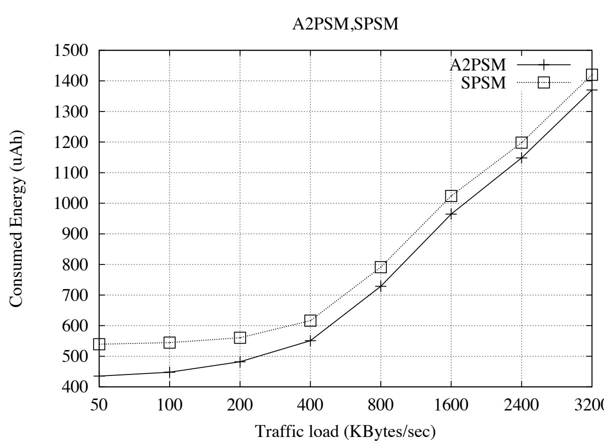

Figure 8: Power consumption comparison between A2PSM and SPSM schemes under different traffic loads.

Figure 8 shows the power consumption for both SPSM and A2PSM schemes under different traffic loads. Each point in the figure is the measured power consumption of the STA averaged over 10 experiment runs for the same traffic load. As shown, our implemented A2PSM prototype could save up to more than 25% more power than the existing SPSM scheme. We observe that A2PSM saves more energy at lower traffic loads. For example, A2PSM saves almost 25% more power under a traffic load of 100 KBytes/sec, while it saves only 5% more power under 3200 KBytes/sec load. Figure 9 shows the expected battery life time of the smartphone for both power saving schemes under different traffic loads.

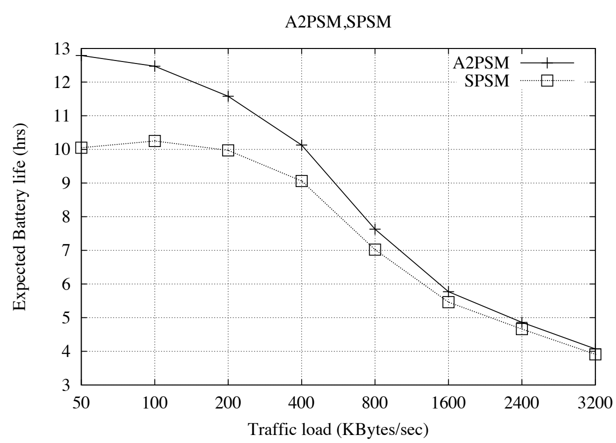

Figure 9: Expected battery life time comparison between A2PSM and SPSM under different traffic loads.

In order to evaluate whether A2PSM scheme has any effect on the network performance, we conduct similar experiment to measure the network throughput. After repeating the experiment several times under different traffic loads, we found out that there is no significant difference in network throughput under both A2PSM and SPSM schemes. Such result validates that our A2PSM scheme has no effect on the network performance.

8. RELATED WORK

Number of prior solutions have been proposed to reduce the energy consumption of the wireless network in smart devices. In this section, we focus on only those that are related to multiple radio interfaces. Using multiple radio interfaces is a popular idea in optimizing or enhancing the overall performance of the wireless communication [12, 4].

Recently, large focus has been given to improving the power consumption of wireless communication in smart devices. Several proposed solutions focused on utilizing the Bluetooth interface for improvising the performance of the Wi-Fi [11, 4]. For example, CoolSpots [11] enables automatic switching mechanism between multiple wireless interfaces (i.e., WiFi and Bluetooth) of the mobile device in order to extend the battery lifetime. The Blue-Fi system [4] utilizes the nearby bluetooth contact-patterns and cell-tower information to predict the availability of the Wi-Fi connection. Thus, it allows the device to turn off the Wi-Fi interface and minimize the number of idle state periods and and the number of neighbor discovery scans. However, one of the major challenges to be addressed in using Bluetooth with Wi-Fi is the co-existence [7].

Researchers have proposed to use other wireless network interface such as ZigBee as a parallel communication to enhance the energy efficiency of the Wi-Fi network, such as Wi-Zi Cloud [9]. Typically, current smart devices do not support ZigBee interface. Authors in [13] propose to switch and use a separate low-power control channel in addition to the main high-power data channel. When the device is inactive, it turns off the high-power channel and uses the low-power control channel to send control messages (i.e., wakeup message). In this scheme, authors use special hardware as a separate low-power interface in addition to the typical Wi-Fi interface. To the best of our knowledge, A2PSM is the first of its kind that utilizes the audio interface to reduce the power consumption of Wi-Fi interface in smart devices.

9. CHALLENGES AND FUTURE WORK

Broadcast Frame: In case of receiving unicast transmissions, data are polled by STAs from the AP. On contrary, data are pushed by the AP for the broadcast transmissions. This scenario imposes additional challenges in designing A2PSM for broadcast transmissions. Since different STAs using A2PSM scheme will receive the audio beacon at different times as discussed in section 5.2, the AP in broadcast transmissions needs to wait until the farthest STA receives the audio beacon before sending the broadcast data. As a result, STAs that are nearer to the AP will have to wait longer time before receiving the broadcast data. As a consequence, a STA closer to the AP consumes more power in receiving a broadcast data. In future, we plan to address the broadcast transmissions challenge within A2PSM.

Multiple STAs: In this paper we have just implemented a small scale prototype testbed of our A2PSM scheme for one AP and one STA. In future work, we plan to develop a complete A2PSM scheme that supports multiple STAs.

In conclusion, this paper proposes a novel power saving scheme that utilizes both the audio and the Wi-Fi interfaces in smart devices. In the paper, we designed, implemented and evaluated a preliminary version of A2PSM scheme on real testbed. Results are promising and motivate us to continue developing the complete A2PSM scheme for smart devices.

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