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

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ABSTRACT

WiFi interface is one of the prominent factors of high power consumptions for the smart devices. However, smart devices use a smart power management policy for the WiFi interface in order to maintain the Power Saving Mode (PSM). Despite the intelligent power management policy for WiFi, we have showed that utilizing the audio interface(mic/speaker) in regards of power management of the WiFi could increase the expected battery lifetime. In this paper, we propose A2PSM: an audio channel assisted power saving mechanism for WiFi. A2PSM leverages the lower power consumption of the audio interface to minimize the energy consumption of the Wi-Fi interface during PSM. The advantages of A2PSM scheme are the following: (1) It does not require any changes in the 802.11 protocol, and (2) The scheme works without requiring any changes in the application. In this paper, we develop small scale prototype testbed of the proposed scheme in real environment to evaluate the A2PSM scheme.

1. INTRODUCTION

WiFi is becoming the common network interface for data communication in smart devices (e.g., smartphones) because of its low/free cost, high throughput, and relatively large range. 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 the data communication performance over the Wi-Fi network by integrating the mic/speaker of the smart devices as a parallel communication channel. We envision a novel communication framework utilizing the audio channel (i.e., mic/speaker) to develop more efficient WiFi network communication. The availability of mic/speaker most of the smart devices the non-interferential nature with WiFi network are main advantages of using audio communication channel for this purpose. In audio communication, we exploit the frequency band beyond the human ear's perception. Nowadays, most, if not all, of the 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 WiFi power saving mechanism for the 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 network.

2. MOTIVATION AND CONTRIBUTION

WiFi power management has an important impact on the battery endurability of smart devices. As a part of the Audio-WiFi project, this paper proposes Audio Assisted WiFi Power Saving Mechanism (A2PSM). Although A2PSM mechanism could be applied to any WiFI network mode, we focus in this paper on the WiFi infrastructure mode networks. A2PSM exploits both the audio interface hardware (mic/speaker) and the existing WiFi power saving mechanism of the smart devices. Most smart devices have mainly two power management modes for WiFi network; Constant Awake Mode (CAM) and Power Saving Mode(PSM). In CAM mode, WiFi interface remains awake all the time while the WIFi interface in PSM mode remains sleep for a certain number of beacon interval before waking up.

Because of the importance of power management, several PSM mechanisms with different features have been proposed. For example, some smart devices have Extreme Low Power(ELP) mode that puts the WiFi interface in a deep sleep for longer duration compared to normal PSM. In ELP mode, WiFi consumes less energy then any other mode with the price of high traffic latency. The most common used PSM mechanism in smart devices is Static PSM (SPSM). In SPSM, the sleeping duration is set at the association process between the device (STA) and the access point (AP). Considering the optimal sit-

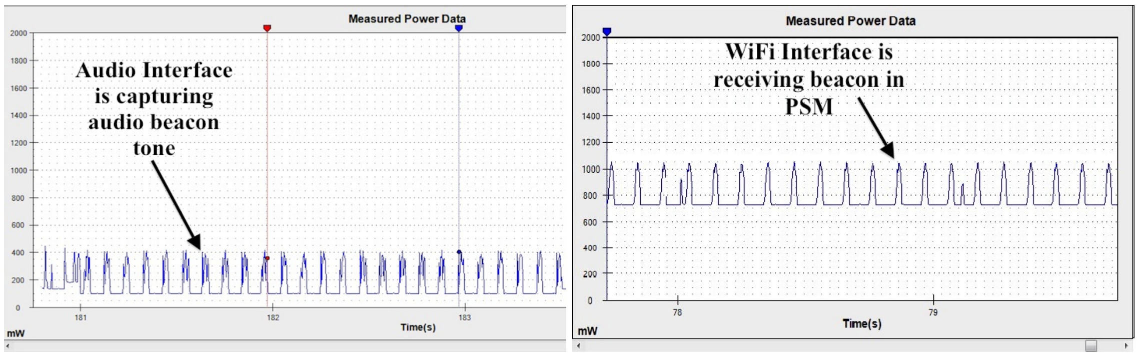


Figure 1: (a) Monsoon Power monitoring while audio interface is receiving audio beacon tone. (b) Monsoon Power monitoring while wifi interface is receiving beacon during CAM.

uation, the STA's WiFi interface should sleep as long as their is no data to exchange between AP and STA. Such optimal situation is impossible to achieve in SPSM because of the pre-determined static communicated to the device by the AP at the association time. In our proposed A2PSM, we try to mimic the optimal situation using the audio interface as a parallel channel to the WiFi interface in order to allow the device to have extended sleeping periods and consequently save more power.

To understand the power consumption of both the audio and WiFi interfaces, we conducted a simple experiment with the use of Monsoon power monitoring tool[1]. In the experiment, the audio interface and the WiFi interface receive an audio beacon tone and a WiFi beacon respectively in a periodic pattern. Clearly, Figure 1 shows that the WiFi interface consumes energy 3 times more than the audio interface. Such observation motivated us to consider new mechanisms to utilize the audio interface in enhancing the current PSM mechanisms of the smart devices to optimize the power consumption of the device.

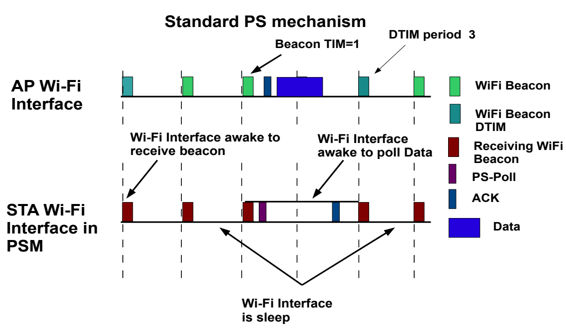


Figure 2: Standard PS mechanism for Infrastructure wireless network

In summary, the contributions of this paper are as follows:

1. *Introduce the idea of using the audio communication channel to assist the WiFi PSM mechanism.* A2PSM is an initial attempt to use audio as an additional interface for the wireless communication WiFi. This paper takes the first step to explore the feasibility and the future direction of building Audio-WiFi interface.

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

3. *Implement the A2PSM schema in a smart device.* We Implement our prototype of A2PSM on Nokia N900 phones.

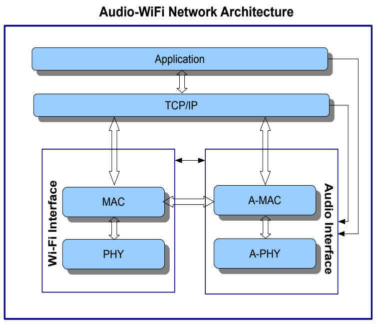
4. *Evaluate the A2PSM scheme in real environment.* We evaluate the power efficiency of our implemented prototype using Monsoon power monitoring tool. We also identify several steps for future research.

3. BACKGROUND: PSM OVERVIEW

In standard PS mechanism the STA's Wi-Fi interface awake periodically to receive beacon from the AP. A beacon message from the AP with TIM bit set indicates AP has some buffered data for the STA. As a result STA's Wi-Fi interface transit from PSM to CAM and poll the data from AP. In case of broadcast frame AP transmit a special kind of beacon message,DTIM periodically in certain beacon interval. Figure 2 gives an overview of the Standard PS mechanism. On the other hand, In A2PSM schema, we keep the STA's WiFi interface in deep sleep until STA needs to transits from PSM to CAM. While STA's Wi-Fi interface in deep sleep, the communication between AP and STA happens thru audio interface. In our schema, we assume both AP and STA have an audio interface (mic/speaker). In section 5 we describe details of our A2PSM schema.

4. AUDIO-WIFI ARCHITECTURE

The preliminary architecture of the Audio- WiFi network includes WiFi interface and Audio interface (Figure 3). The Audio interface has two layers: 1) A-PHY



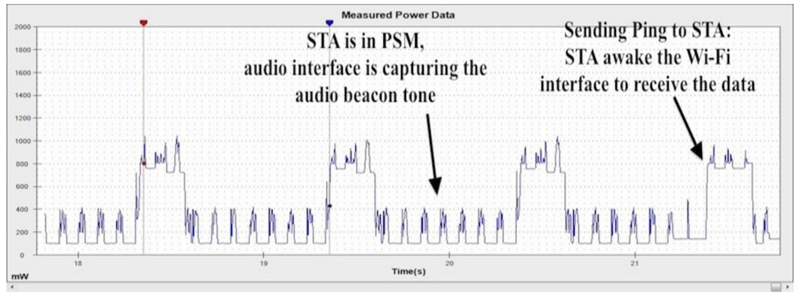


Figure 3: (a) Preliminary Audio-WiFi Framework Architecture. The single line arrow represents control path and the double lined arrow represents data path. (b) Monsoon Power Monitoring observation of A2PSM schema while STA is receiving ping message during PSM.

layer: responsible for all signal processing, modulation/demodulation and transmitting/receiving signal using speaker/mic hardware. 2) A-MAC layer: responsible for sending/receiving audio signals or data frames over acoustic media. The MAC and TCP/IP layers could took the benefit of using acoustic media to send control data frames or signals using the A-MAC layer in Audio interface. In a similar way, A-MAC could receive control/acknowledgment packets or signal over the acoustic media and send it to TCP/IP and MAC layer. In order to manage these control/data flows, we need to define the cross-layer interaction between the Application, TCP/IP, MAC layers and the Audio interface. In the implementation section we describe, how we use this architecture to implement our prototype of the proposed A2PSM scheme.

5. A2PSM DESIGN

The scope of this paper is to design and implement the A2PSM scheme for unicast frame transmission in PSM. The broadcast frame transmission scheme will be discussed in Section 9 later. In designing A2PSM scheme, we need to fulfill the following requirements: (1) The PSM using audio interface should cost less energy then the traditional WiFi interface. (2) The audio interface needs to generate and receive the audio beacon tone within the same time limit as the WiFi beacon, in order not to increase the latency time of data transmission. 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 WiFi beacon frame, AP needs to generate an audio beacon tone synchronized with the WiFi beacon. This additional audio interface activity might increase the power consumption of the AP. Since AP is supplied by constant power, hence AP's power consumption is not an issue. On the other hand, STA's power consumption is our main concern in this paper. In our scheme, when the AP has a data to transmit to the STA, the AP transmits an audio beacon tone with imposing certain frequency along with the Wi-Fi beacon(figure 3b). The audio beacon tone mimics the Wi-Fi beacon with TIM bit set. According to 802.11 standards, during the association process, the AP assign an Association Id (AID) to the STA, which is unique within this WiFi infrastructure network. In A2PSM, similar to AID, each STA has a unique audio frequency that is inferred from the AID. In this case, a STA can infer its audio frequency from the assigned AID and check whether its audio frequency is in any audio beacon transmitted later. When a STA receives an audio beacon with its audio frequency, it put the audio interface to sleep and then awake the WiFi interface to poll its buffered data from the AP. In A2PSM, while STA is in PSM, the audio interface awakes periodically to capture the audio beacon tone. In order to make sure that audio interface is consuming less energy in comparison to WiFi interface, the audio interface awakes for short period to capture the audio beacon. In our implementation, we set this period to 20ms, which is the average duration of WiFi interface being awake to receive the beacon frame. Figure 3b shows the overall power saving mechanism of the A2PSM.

5.2 Relative position

In figure 3b, we can observe the time difference between the generation of the audio beacon by the AP and the reception of it by the STA. This time difference is due to the slow propagation of the audio channel. The observed time difference depends on the relative distance of the STA with respect to the AP. To measure the relative distance between the STA and the AP, several existing ranging schemes could be utilized such as Beep-Beep scheme [4]. Knowing the relative distance from the AP, STA can calculate when it should awake its audio interface just before the reception of the audio beacon transmitted by the AP. As a result, STAs with different

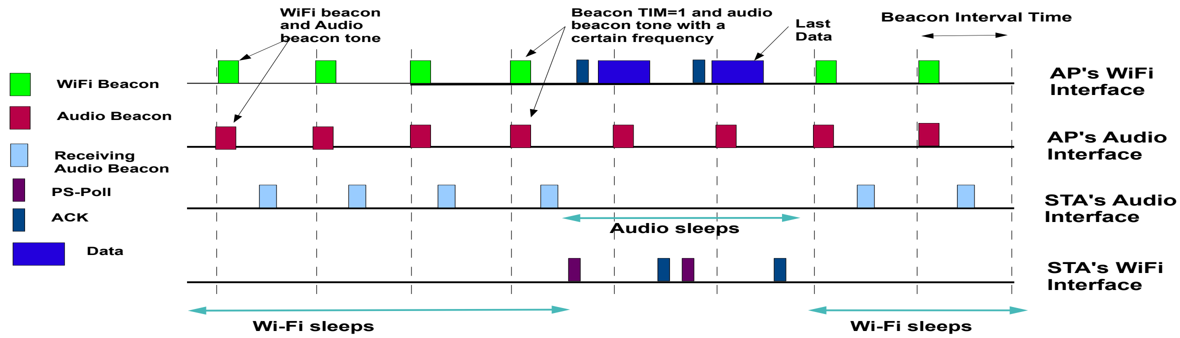


Figure 4: Overview of unicast frame transmission from AP to STA in A2PSM schema.

distance from the AP will turn on the audio interface at different time (Figure 5). For example, in figure 5, while STA2 has not received the audio beacon yet, STA1 started to receive the audio beacon from the AP. This scenario leads us to the challenge of the second design requirement.

According to the second requirement, even the farthest STA of the AP needs to receive the audio beacon before the beacon interval time. Such requirement is necessary to reduce the latency of the data traffic. The wireless network AP at home environment typically has a range of 20-25 meter. Considering the speed of sound in air, for 20-25 meters range, farthest STA would hear the beginning of the audio beacon tone transmitted by the AP within 60ms time limit. Given the default beacon interval of an AP is 100ms, the farthest STA would be still able to capture the audio beacon before the end of the typical beacon interval time. On the other hand, receiving the audio beacon corresponding to broadcast frame is more challenging. We describe this challenge in further details in Section 9.

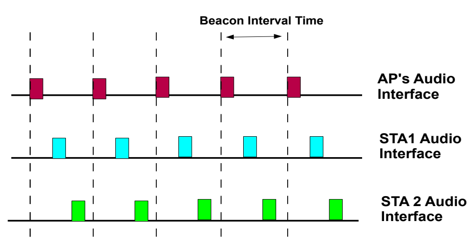


Figure 5: Audio beacon communication between two STAs and AP. In the scenario, STA2 is further away from the AP compare to STA1.

6. IMPLEMENTATION

We have implemented our prototype of A2PSM on two Nokia N900 phones. We use one phone as an AP and other as a STA. We connect the STA with Monsoon power monitoring device in order to evaluate the operation of the proposed A2PSM scheme. The power monitoring observation in figure 3 b validates the feasibility of the propose A2PSM scheme. In the implementation, we did the followings: (1) implemented the audio interface for both the STA and AP. (2) Implemented the interaction control between WiFi Interface and Audio Interface.

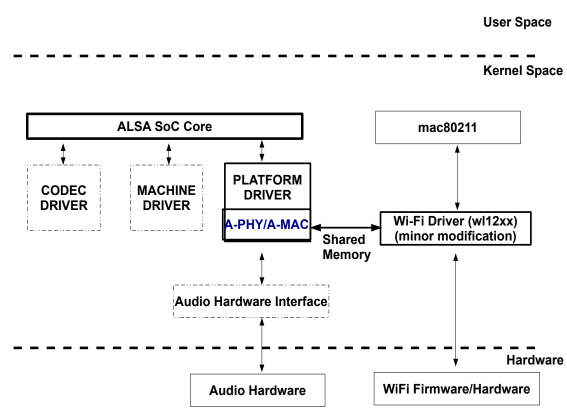


Figure 6: Implementation architecture of Audio-WiFi system for A2PSM schema.

6.1 Audio Interface:

In audio interface, we implemented a simple prototype of A-PHY layer. The implemented A-PHY layer is responsible of the transmission and reception of the audio beacon tone. In addition we implemented a simple hight pass FIR with 10 co-efficient in A-PHY layer. We use one Nokia N900 phone as an AP and the other N900 as a STA. In our implementation the A-PHY of the AP only generates the audio beacon tone synchronized with the WiFi beacon. The A-PHY in STA receives the audio beacon tone and applies a high pass filter to detect a certain frequency component. Figure 6 shows the detail architecture of both ALSA SoC(ASoC) Driver and WiFi driver(wl12xx) where we did our implementation. We implemented the A-PHY layer in the platform driver (omap-pcm) of the ASoC driver. Platform driver contains the audio DMA engine, which uses the audio interface driver (I2S) to transfer the raw audio frame to the actual audio hardware. In our implementation, we had to use Fixed-point math in order to do all the required floating-point operation.

In the implementation we have faced number of questions such as (1) how long we need to keep the audio interface awake to capture the beacon tone properly? (2) How much the miss-alignment in synchronization between audio beacon and WiFi beacon beginnings? The answer to these questions depends both on our implement and the hardware limitation. In the implementation, we wanted to reduce both the duration of the audio beacon capturing event and the miss-alignment time. The duration of the audio capturing event depends on three factors; sampling period, buffer size and period size. Usually the audio hardware and the platform driver transfer raw audio data using ring buffer. The buffer size defines the size of this ring buffer. The period size defines how many raw audio data needs to be filled up in the ring buffer to start the DMA operation. According to our requirement, we select a minimum period size with sufficiently larger buffer size to avoid overrun situation. In the implementation, we were able set 10ms duration of audio beacon capturing event, which is same as the Wi-Fi interface keep awake to receive the beacon in normal PSM.

6.2 Audio-WiFi Interaction

Fast interaction between audio and WiFi interfaces guarantees lower miss alignment between audio and WiFi beacons. In the implementation, we use shared memory to facilitate the interaction between the drivers corresponding to the two interfaces. We utilize a shared memory between the WiFi driver and the Platform driver to share variables that control the operation of the two drivers. We made minor changes in the existing WiFi driver to change the shared variable that the audio platform driver uses under different conditions. Using the shared information, the WiFi driver signals the audio driver about the beacon transmission. Similarly, the WiFi drive informs the audio driver about the change in its PSM mode.

7. PERFORMANCE EVALUATION

In this section we evaluate the performance of our proposed A2PSM scheme by evaluating the following two questions: (1) How much energy saved by the A2PSM scheme compare to the standard power saving mechanism implemented in the smart devices under different traffic load? (2) Does the A2PSM has any effect over network throughput? We determine this by measuring the throughput of the network under different power saving mechanism.

In performance testing, we use iperf [2] tool and two N900 phones. We use two Nokia phones, one N900 as a STA and other as an AP. We run the iperf in STA as server mode and the iperf in AP as client mode. We send UDP data from iperf client to the iperf server under different traffic bandwidth in 20 seconds. We replicate this experiment 10 times for each traffic bandwidth settings. We fixed the distance between the the STA and the AP during the experiments to 3 meters. We also connect the STA with the Monsoon Solution Power Monitor [1] to measure the energy consumption of the smartphone. We compare the power consumption of the smartphone for two different power saving mechanism: (1) A2PSM, and (2) Standard Power Saving Mechanism (SPSM) implemented in the smart devices. While measuring the power consumption, we turned of all the radio communication as well as the screen of the phone. In measuring the power consumption for both power saving mechanisms, we maintain the same settings of the phone.

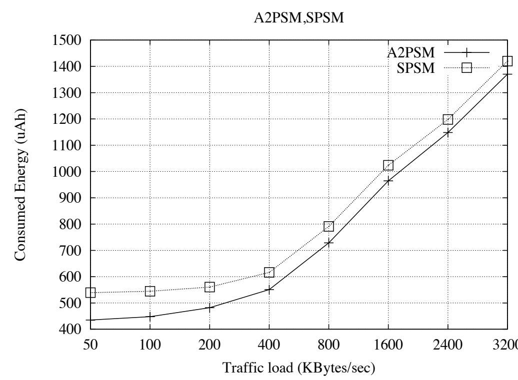


Figure 7: Power consumption comparison between A2PSM and Static PSM under different traffic load.

Figure 7 shows the comparison of power consumption between two power saving mechanism SPSM and A2PSM from our above experiment. In our implemented prototype, A2PSM saves almost 25% more power compare to the currently existing SPSM. We observe that A2PSM saves more energy at low bandwidth traffic compare to higher bandwidth traffic. For example under traffic bandwidth of 100 KBytes/sec, A2PSM saves almost 25% more compare to the SPSM. Where as in traffic bandwidth with 3200 KBytes/sec, A2PSM saves only 5% more energy compare to SPSM. Each point in Figure 7 is the average power consumption of 10 running samples in certain traffic bandwidth. Figure 8 shows the expected battery life time of the two power saving mechanism under different traffic bandwidth. In the experiment, we set the battery size to 1000mAh.

In order to see whether our proposed schema A2PSM has any effect over the network performance, we conduct a separate experiment using iperf tools. We use the same settings for iperf as like the previous experiment. In the experiment we send UDP packet from the iperf client to the iperf server. We run the iperf client at the

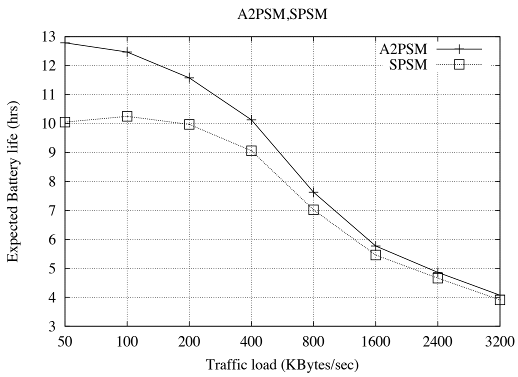


Figure 8: Expected Battery life time comparison between A2PSM and Static PSM under different traffic load.

AP and the iperf server at the STA. After running the experiment several times for different traffic bandwidth, we found no significant differences in the throughput between A2PSM and SPSM. Such result indicates that our schema has no effect on the network throughput performance.

8. RELATED WORK

A 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 those that are related to multiple radio interfaces. In the best of our knowledge, A2PSM is the first of its' kind that utilizes the audio interface in addition with the Wi-Fi to reduce the power consumption of smart devices.

Using multiple radio interface is a popular idea in optimizing or enhancing the overall performance of the wireless communication[6]. Multi-radio interface has also been applied to number of sensor network applications with small energy-constrained devices. Recently, large focus has been given in improving the power consumption of the smart devices in wireless communication. In addition with Wi-Fi interface researcher have used Bluetooth as a second channel for improvising the performance of the Wi-Fi [5]. Project like CoolSpots [5] enable automatic switching mechanism between multiple wireless interface of the mobile device, such as WiFi and Bluetooth, in order to extend the battery lifetime.

Researchers have proposed to use other existing wireless network interfaces such as ZigBee as a parallel communication for enhancing the performance of Wi-Fi network, such as Wi-Zi Cloud[3]. Although the solution of using Bluetooth and ZigBee in parallel with WiFi improves the performance, it creates severe interference with Wi-Fi for communicating in the same frequency band (2.4GHz). In addition some wireless interface are not very common with the smart devices, such as ZigBee. Although Bluetooth interface is very popular and common in all smart devices, high restricted access to the Bluetooth protocol settings makes it harder for the researcher to utilize the Bluetooth interface.

9. CHALLENGES AND FUTURE STEPS

Broadcast Frame: In case of receiving unicast transmission, the data are polled by the STA from AP. However in case of broadcast, frames are distributed by the AP. Such scenario imposes a challenge in designing A2PSM for broadcast frame. For example considering the situation in 5, assume AP wants to send a broadcast frame. In that case AP will send a special audio beacon tone, which mimic the scenario of special beacon frame DTIM, to let the STAs know about broadcast transmission. Unlike the WiFi interface, during PSM the STA's audio interface will hear the special audio beacon tone at different time. In such scenario AP needs to wait until the farthest STA receive the special audio beacon tone before sending the broadcast frame. As a result the STAs that are nearer to the AP will have to wait longer period of time to receive the broadcast frame. As a consequence, STA closer to AP consumes more power in case of receiving broadcast frame. In future work we like to address the scenario of broadcasting frames in A2PSM.

Multiple STAs: In this paper we have just implemented a small-scale prototype testbed of the A2PSM scheme for one AP and one STA. In future work, we plan to develop a complete A2PSM scheme that supports multiple STA. In addition to that, we like to explore more on the challenges of implementing the scheme for multiple STAs.

In conclusion, this paper proposes a novel power saving mechanism that utilizes two interfaces of the smart device; audio and WiFi. In the paper, we show the feasibility and the preliminary evaluation of our power saving scheme in real environment. Nevertheless, we believe that our proposed schema present a preliminary promising first steps toward developing a new efficient wireless technology for future smart devices.

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