A Review towards HoWiEs: Zigbee Assisting WiFi for Reducing Energy

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Abstract: ***This paper is a step towards HoWiEs, a system that saves Energy, consumed by WiFi interfaces in mobile devices with the assistance of Zigbee radios in mobile devices. The WiFi radio power consumptions is significant nowadays in mobile devices and other . Existing measurements showed that the power consumptions of WiFi scanning and PSM standby in a Samsung Galaxy S2 smartphone accounted for 65% and 11% of the entire system power consumption respectively, and recent works showed that the wakeup contentions could cause up to four times more power consumption. There are three scenarios where a WiFi radio has to stay active without performing any real communications. First, a WiFi radio must be continuously active to scan for networks in the scanning state. The power consumption is low for network scanning when WiFi coverage may not be available. Second, during PSM (Power Save Mode) standby, a WiFi radio needs continuously active to receive wireless access point (AP) beacons, and check if the AP has buffered its packets. Long WiFi leads in power reduction even during PSM standby. Third, when waken up from PSM standby, a WiFi radio has to active while waiting period for its turn to communicate with the AP if there are multiple devices contending for the channel. Study ,related to WiFi power reduction and related work shows effective results. Related work optimizing concepts ZiFi, Wake On Wireless, ipoint, E-MiLi etc.***

Keywords: Zigbee, WiFi, EMiLi, Ipoint, Work on wireless, ZiFi

1. Introduction

Energy saving in mobile devices must be taken into consideration recently [1]–[6]. The WiFi radio power consumptions are significant: our measurements showed that the power consumptions of WiFi scanning and PSM standby in a Samsung Galaxy S2 smart phone accounted for 65% and 11% of the entire system power consumption respectively, and recent works [7], [8] showed that the wakeup contentions could cause up to four times more power consumption. To reduce WiFi power consumption in the these scenarios, we propose to delegate those WiFi operations to a low power ZigBee radio. In this case, WiFi radio will be turned off when there is no packet to transmit and receive, and the ZigBee radio is responsible for discovering the presence of WiFi networks and detecting if the AP intends for the device to communicate. This way, the significant power consumptions on WiFi radio in those scenarios can be reduced to reasonably low power consumptions of ZigBee radio. ZigBee radio (i.e., IEEE 802.15.4 [9] compliant radio)is designed for low power communication working on 2.4GHz ISM band, which coincides with most of theWiFi standards. Recently, an increasing amount of attempts have been made by both industry and academia to integrate ZigBee radios with smartphones for smart home applications [10] and energy savings [11], [12]. Indeed, as we did in our system implementation, a ZigBee radio can be directly connected to a mobile device via USB interface. With the unveiling of the first Android phone with ZigBee capability [13], and due to its usefulness in many areas, we believe that ZigBee will become a standard interface in mobile devices in the near future. In this work, we design and implement HoWiES, a system that utilizes ZigBee radio to perform WiFi scanning and periodic AP beacon checking for the WiFi interface in the same device. The scenario is that a mobile device keeps its WiFi interface offline, while using its ZigBee radio to discover WiFi networks (during WiFi scanning) and to check if the associating AP has buffered the device's packets (during WiFi PSM standby). Given that it is not possible for ZigBee to decode WiFi packets directly, it is necessary to build a channel, through which a WiFi AP can convey information to ZigBee radio in mobile devices. Since the AP does not need feedbacks from the mobile device in the intended scenarios, a unidirectional channel from WiFi AP to ZigBee radio is sufficient. Fortunately, the same frequency band occupied by both WiFi and ZigBee allows ZigBee radio to sample background energy of WiFi transmission, which enables WiFi AP to convey information to ZigBee radio by using different WiFi transmission patterns. We demonstrate that, by using a simple coding scheme, our system can create a unidirectional communication channel in which an AP can deliver thousands of messages to ZigBee radios. When ZigBee decodes the information transmitted through the side channel, it either ignores the message background energy of WiFi transmission, which enables WiFi AP to convey information to ZigBee radio by using different WiFi transmission patterns. We demonstrate that, by using a simple coding scheme, our system can create a unidirectional communication channel in which an AP can deliver thousands of messages to ZigBee radios.When ZigBee decodes the information transmitted through the side channel, it either ignores the message if it is not for the device, or wakes up the WiFi radio for communication.

2. Background and Related Work

2.1 Background

WiFi power management The power management mode of WiFi stations can be

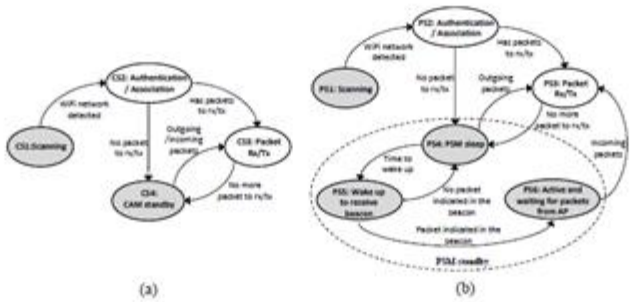

Figure 1: Operating state diagrams of (a) CAM and (b) PSM stations

Shaded states have room for energy savings either CAM (Constantly Awake Mode) or PSM (Power Save Mode). CAM stations keep their WiFi radios active all the time. Figure 1 (a) shows the operating states of a CAM station. After detecting and associating with a WiFi AP, the CAM station switches its working state between "Receiving/Transmitting" ("Rx/Tx" for short) and "standby" (i.e., transitions between CS3 and CS4 in Figure 1 (a)). Since WiFi radio is active all the time, batteries in a CAM station drain at a rapid speed. To save energy wasted in the CAM standby state, 802.11 Power Save Mode (PSM) has been introduced [15]. Figure 1 (b) depicts the operating states of PSM stations. Similar to CAM stations, PSM stations also switch their working states between "Rx/Tx" and "standby" during operations. The difference is that PSM stations do not always keep their WiFi radios active in the standby state. Instead, PSM stations put their WiFi radios into sleep (i.e., state PS4 in Figure 1 (b)) most of the time during standby. In the sleep state, WiFi radios consumes very low power but is not able to receive or transmit. PSM stations in sleep state switch to "Rx/Tx" state whenever they have outgoing packets (i.e., transition PS4 to PS3). To receive incoming packets, a sleeping PSM station needs to periodically switch its WiFi radio to active (i.e., transition PS4 to PS5) to receive its AP's beacons, through which the AP advertises buffered packetsfor its sleeping clients. If there is no packet indicated in the beacon for the PSM station, the station simply goes back to the PSM sleep state (i.e., transition PS5 to PS4). Otherwise, the station stays active and waits for its incoming packets from the AP (i.e., transition PS5 to PS6). Then the station further switches to the "Rx/Tx"state on receiving the first incoming packet from its AP (i.e., transition PS6 to PS3). Upon the completion of the receptions/transmissions, depending on detailed implementation, the station goes back to the sleep state either immediately or after a fixed amount of time without incoming or outgoing packets (i.e., transition PS3 to PS4).

2.2 Related work

Energy saving in WiFi scanning. A common way for WiFi scanning energy savings is to perform Wi Fi availability prediction. For example, several works have considered, without turning on WiFi radios, predicting WiFi networks availability by using different context information [16], tracking and learning user movements [17], or collecting information about bluetooth devices and cell towers [18]. Though these solutions are shown to have reasonably good performance regarding WiFi availability prediction, they rely on certain information that may not always be available to perform prediction, and the prediction cannot achieve near-100% accuracy. To address these issues, ZiFi [11] proposes to detect WiFi networks with the assistance of ZigBee radios. The idea of ZiFi is to use ZigBee to detect WiFi beacon patterns, which indicate the existence of WiFi networks. Mobile devices in WiFi scanning state keep their WiFi interfaces offline, and turn them on when WiFi beacon patterns are detected by ZigBee radios. Similar to ZiFi, our solution also utilizes ZigBee radios in detecting WiFi availability.However, we take a different approach: we enable APs to advertise themselves by broadcasting messages that are understandable by ZigBee radios. Thus, an advantage of our solution over ZiFi is that with HoWiES, WiFi radios can be selectively waken up when suitable APs are encountered, which allows for further energy savings during scanning. For example, APs can encode WiFi network SSIDs, capabilities (e.g., with Internet connection or not), and association requirements (e.g., open or password verification needed) using our WiFi-ZigBee message delivery scheme. Consequently, a ZigBee radio is able to wake up the WiFi interface in the same device only when encountering suitable WiFi networks. Furthermore, the approach suggested by ZiFi cannot be used to save energy in the states of WiFi standby and WiFi wakeup.

Energy saving in WiFi standby. Two different approaches have been proposed to save energy in WiFi standby (i.e., when WiFi radio is idle). The first approach proposes to turn off WiFi radios when they are idle (i.e., state PS4 in Figure 1 (b)), and wake them up through a low-power non-WiFi channel when there are incoming WiFi activities. For example, Wake-on-wireless [19] establishes the low-power channel by attaching an additional device to both APs and WiFi clients. Wake on- WLAN [20] uses ZigBee radio at the receiving end to detect incoming WiFi signal so as to wake up the WiFi radio. Though the idea of using Zig Bee radio to sense WiFi energy is similar to ours, Wake-on-WLAN is designed to work in long distance point-to-point connection scenario, where the presence WiFi signal indicates the receiving end is intended for communication. Therefore, the Zig-Bee radio simply needs to wakeup WiFi radio whenever energy is sensed. Whereas we target normal WiFi networks where WiFi activities present all the time. As a result, we need to, by using ZigBee radio, identify which client is intended to be waken up by the AP. Cell2Notify [21] uses cellular channel to wakeup WiFi radios for VOIP calls. The other approach to save WiFi standby energy is suggested by E-MiLi [22], which proposes to reduce power consumption in WiFi idle listening state (i.e., state PS6 in Figure 1 (b)) by reducing clock-rates of WiFi chips. Since the two approaches target different portions of WiFi standby, they are complementing each other in saving WiFi standby energy. In this work, we adopt the first approach: we establishes a low-power channel between APs and devices'ZigBee radios, through which APs can wake up standby devices selectively. The fundamental difference between our work and the existing works is our interference resistant WiFi-ZigBee message delivery scheme, which enables WiFi senders to actively transmit a large amount of information to ZigBee radios in receivers without adding new hardwares. Whereas Wake-on-wireless [19] needs new devices at both sender and receiver side, and c [20] and Cell2Notify [21] only enable receivers to detect the existence of the low-power channels. Therefore, our approach can be applied to wider application scenarios with less deployment overheads.

Energy saving in WiFi wakeup. Recent works have shown and addressed the energy waste problems caused by wakeup contentions between WiFi clients that belong to the same AP [7] or multiple interfering APs [8]. In HoWiES, our solution naturally solves the problem of wakeup contentions between clients associated with the same AP by waking up WiFi clients one at a time. To alleviate wakeup contention between clients associated with different APs, we coordinate APs such that there are not two interfering APs wake up their client at the same time (more details in x4.2.3).

Information encoding utilizing WiFi packet length.
iPoint [23] designs a passive information kiosk system, where cell phones send their requests to the kiosk device by broadcasting WiFi packets with different lengths, and the kiosk device transmits information back to cell phones via an optical channel. In the application scenario of iPoint, there is no background WiFi traffic. Moreover, iPoint is equipped with a specially designed rectifier that can accurately detect the lengths of WiFi packets. On the contrary, our system has to deal with background WiFi traffic with off-the-shelf ZigBee radio, which imposes more significant challenges on accurate information encoding/decoding. Esense [14] is another work utilizing WiFi packet length in information delivery. We have introduced Esense and elaborated the differences between Esense and our work in x1.

3. Motivation

3.1 WiFi energy saving opportunities

We observe the following three significant energy saving opportunities for WiFi stations.

Opportunity 1 - scanning state: WiFi stations in scanning state constantly iterate through all the channels to search for available WiFi networks. We have measured the system power of two mobile platforms, a Samsung Galaxy S2 smart phone and a Lenovo T400 laptop, in the WiFi radio scanning state. From the measurement results (Table 1), we can see that about 65% and 12% of the system power consumption are spent in WiFi scanning for the smart phone and the laptop respectively. Therefore, we are motivated to find an energy efficient way for mobile devices to perform WiFi scanning.

Opportunity 2 - standby state: As introduced in x2.1, in standby state, a CAM (Constantly Awake Mode) station keeps its WiFi radio on all the time, and a PSM (Power Save Mode) station puts its WiFi radio in a low-power state most of the time when there is no traffic, and periodically wakes up the radio to receive and check AP beacons for buffered packets. Table 2 presents the measurement results of the standby state power consumption of a Galaxy S2 smart phone and a T400 laptop, which are by default configured as PSM and CAM stations respectively by their device drivers. The smart phone consumes 33 mW more power, which accounts for about 11% of the overall system power, in the WiFi standby state than when the WiFi radio is turned off. This power overhead mainly comes from periodic wakeup to check beacons, because when we prolonged the smart phone's wakeup interval, the power overhead decreased accordingly. The laptop also consumes about 10 percent of its system power in the standby state. We have performed an experimental study to investigate how much time stations stay in the standby state during WiFi sessions. In this experiment, we developed and deployed a WiFi activity recorder in our office percentages in the corresponding WiFi sessions. building and in our university's library, both of which are with heave WiFi usage. The recorder sniffed WiFi packets and recorded their MAC

Table 1: System power consumption in WiFi scanning state

	with WiFi scanning	with WiFi off	scanning/overall pert.
Galaxy S2	766 mW	265 mW	65.4%
T400	14498 mW	12732 mW	12.2%

addresses, packet types (e.g., data, management or control), packet sizes, data rates, received signal strength (RSS) and the packet reception times. To process the data, we first identified WiFi stations based on MAC addresses and packet types, and filtered out those stations whose packets have low RSS values, as the recorder may miss some of their packets because of low SNR. Then we analyzed the WiFi packets of the remaining stations to study how much time they were idle during WiFi sessions. Based on the 15 hours of WiFi activity data collected in 5 days, we identified 151 unique stations in 218 WiFi sessions. For each interval between two consecutive packets of the same WiFi session, if the interval (calculated by comparing at the two packet reception times) is longer than 5 seconds, we marked the interval as aWiFi standby period. Figure 2 (a) plots the CDF of WiFi session lengths, and (b) plots the CDF of standby percentages in the corresponding WiFi sessions. The results suggest that over 70% of stations spent more than 60% of their time in standby during their WiFi sessions. During these idle periods, WiFi radios stay in the standby state because of the absence of WiFi radio interface activity, which is caused by either long user think time (e.g., time spent on reading web page), or user behaviors of leaving their smart phones unused for most of the time [24], [25]. The significant standby power overhead (about 10%) and the large proportion of WiFi standby time over the entire WiFi session motivate us to design an energy efficient way for WiFi standby. Ideally, WiFi radios should sleep without periodic wakeup or be completely off as long as there is no WiFi activities. Meanwhile, it must be still possible to wake up the WiFi radios if there are incoming packets for the WiFi radios.

Opportunity 3 - energy waste due to wakeup contention:
When multiple PSM stations working at the same channel and associated either with the same AP TABLE 2: System power consumption in WiFi standby state

	with WiFi standby	with WiFi off	standby/overall pert.
Galaxy S2	298 mW	265 mW	11.1%
T400	14078 mW	12732 mW	9.6%

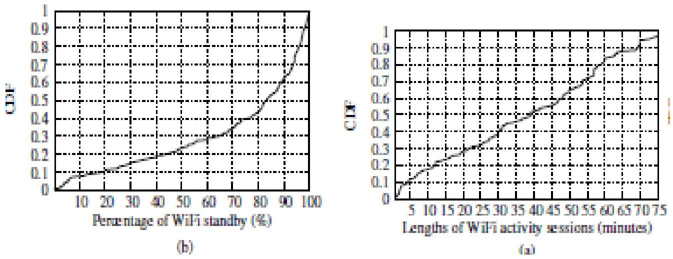

Figure 2: The experiment on WiFi standby time: (a) is the CDF of WiFi session lengths. (b) is the CDF of the WiFi standby percentages in the corresponding WiFi sessions.

[7] or with multiple co-located APs [8], are waken up to receive buffered packets at the same time, the contention between the stations will force them to stay active without performing any real communications. This idle waiting could further causes about up to 4 times more energy consumption. Motivated by these research results, we want our approach to wake up standby WiFi radios to avoid these energy-expensive wakeup contentions.

3.2 ZigBee radio assisted WiFi energy savings

Compared with WiFi radios, ZigBee radios are more power efficient. Table 3 lists the power consumptions we measured of ZigBee radio CC2420 and WiFi radio BCM4330 in different operating modes. Since ZigBee consumes significantly less energy than WiFi, it would provide great assistance in savingWiFi energy for mobile devices if we could make ZigBee radios communicate with WiFi radios. Fortunately, the same frequency band (i.e., the 2.4 GHz band) used by ZigBee and most WiFi standards allows ZigBee radios to sample WiFi transmission energy. We exploit this feature in designing our WiFi-ZigBee message delivery scheme (x4.1).

As we discussed in x1, Esense [14] presents the first effort in enabling unidirectional communication from WiFi to ZigBee. However, the message capacity of Esense is small (about 100), limiting its application scenarios. For example, as we will show later, when applying WiFi- ZigBee message delivery in saving WiFi standby energy, each client of an AP needs to be assigned with an ID, which corresponds to a unique WiFi-ZigBee message. Consequently, a WLAN with multiple interfering APs would needmore than 100 WiFi-ZigBee messages to assign to their clients for WiFi standby energy savings, because clients of interfering APs should be assigned with unique IDs (otherwise APs

Table 3: Power consumption of CC2420 and BCM4330

	CC2420 (ZigBee)	BCM4330 (WiFi)	ZigBee/WiFi ratio
Rx/Tx	56 mW	435 mW	0.129
Idle/Standby	1.2 mW	33 mW	0.036

would wake up clients that are not associated with them). Furthermore, even more WiFi-ZigBee messages are needed if we consider applying WiFi-ZigBee message delivery in other scenarios.

For example, when applying WiFi-ZigBee message delivery in saving WiFi scanning energy, as we discussed in x2.2, APs can use different messages to advertise their IDs and capabilities (e.g., SSIDs, with Internet connection or not, open AP or not), so that WiFi interfaces can be selectively waken up for further energy saving. In this case, the amount of WiFi-ZigBee messages needed in this scenario is proportional to the number of APs. Therefore, in order to allow the concept of WiFi-ZigBee message delivery to be applied in more scenarios, we need to design a WiFi-ZigBee message delivery scheme with large message capacity. An alternative approach to enable WiFi APs to communicate with ZigBee radios is proposed by WiZi-Cloud [12]. WiZi-Cloud enables flexible ZigBee-based bidirectional communication between two WiFi devices by integrating additional ZigBee radios with WiFi devices. As we discussed previously, to save energy in the three intended scenarios, a unidirectional channel from AP to ZigBee radio is sufficient. Our WiFi-ZigBee message delivery scheme enables this channel without changing AP hardware. Finally, we choose ZigBee over Bluetooth [26], because ZigBee has better mandatory receive sensitivity level (-85 dBm according to [9]) than WiFi (-80 dBm according to [15]), while Bluetooth's receive sensitivity level is much lower (-70 dBm according to [26]). Low receive sensitivity would cause bluetooth not to be able to sense WiFi transmissions even when the device is within WiFi AP's range.

4. Conclusion

Attention required for energy consumption and energy reduction in WiFi on mobile devices and others ,the complete study showing results of three modes in which three protocols used are Scanning, Standby and Awake. Energy reduction is possible when wiFi acts with zigbee ,HoWiEs protocol can help in this, we are going to Exploit this in next paper ,There is experimental results in which energy reduction four times with Zigbee assistance.

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