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Delay and Energy Behaviour for Power Management Scheme in Communication Devices

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Abstract— **The vast advancements of upcoming new computing, communication and entertainment applications on wireless handsets, power demands are increasing rapidly day by day. Power consumption is the limiting factor for the functionality offered by portable devices that operate on batteries hence Power Saving Management (PSM) has been widely used in WiFi devices for power saving .But this energy efficiency varies greatly under different patterns of traffic. Our proposal is to use a ZigBee assisted PSM (ZPSM) for WiFi devices which use a wake up strategy adapted to both packet arrival rate and delay requirements.**

Each of this access points and clients has ZigBee (802.15.4) and a WiFi (802.11) interface by which regular and on demand wakeups are scheduled to minimize overall energy consumption. For energy beacon interval (BI) the wifi and ZigBee energy consumption is analyzed and the time delay is observed also the variations in energy are observed with respect to battery level. The overall performance of ZPSM like link quality, per packet energy consumption, for the clients can be studied by implementing a ZPSM system. On average our proposed ZPSM can save 83.9% more energy than SPSM.

Index Terms— **Wifi, Zigbee, Wakeup Strategy, Traffic Pattern, Energy Efficiency, Time Delay**

I. INTRODUCTION

Communication devices are intensely equipped with multiple network interfaces [1], [2], [3]. It has been common for a mobile device (e.g., smart phones, PDA, laptops and palmtops) to have both WiFi and Bluetooth interfaces. As ZigBee technology invades into communication field, embedded ZigBee interfaces have emerged leading to miniature sizes. In future years it will not be surprising to see the interfacing of ZigBee into our mobile devices. [4]- [6]

This ZigBee interface allows mobile devices to communicate with various electrical and electronic appliances to realize smart home entertainment, control, mobile services, home awareness, smart industrial plants, commercial building [7]. Motivated by this trend, we design a power saving management with ZigBee (ZPSM) for WiFi devices, aiming to deliver energy efficiency along with bounded delay.

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The proposal is to use a low-power ZigBee radio to dynamically wake up asleep high-power WiFi radio for packet transmission between the AP and setup clients. ZPSM system presents a wakeup strategy which is adapted to both packet arrival rate and delay requirements for the purpose of maximizing energy efficiency. Moreover, ZPSM is built on top of the standard PSM, and thus requires no change to the WiFi standard. In the following, Section II presents methodology, followed by theoretical study in Section III. Section IV elaborates the implementation of ZPSM followed by results and analysis in Section V and concluding with conclusion of proposed system in Section VI

II. METHODOLOGY

Power Management for WiFi Devices usually supports two power modes. They are the power saving mode (PSM) in which the radio wakes up to receive the data packets periodically so as to reduce the duration for idle listening and also the energy consumption. The other mode is the constantly awake mode (CAM) in which data packets can be received but at the cost of high power consumption. In the simple PSM, the AP will broadcast beacon frames every beacon interval (BI); each client wakes up for every certain number of BIs, which is called listening interval (LI), to check whether it has any data packets buffered at the AP. This AP shows the presence of buffered packets by setting the Traffic Indication Map (TIM) fields in the beacon frame. If a client finds the corresponding TIM field is set, it sends a Power Save Polling (PS-POLL) frame to retrieve the buffered packets from the AP. Besides, the AP uses more bits in the data packet if any to indicate if more packets are buffered, thus helping the client to decide when to go to sleep. Parameter LI is configurable, and its setting directly influences the performance. While the WiFi interface is for data transmission the ZigBee interface is for power management. Both the WiFi and ZigBee interfaces of the AP are always awake, while the WiFi and ZigBee interfaces of clients are awaked sporadically for energy conservation. In addition to that, each client runs in either the standard PSM (SPSM) or the ZigBee-assisted PSM (ZPSM). Particularly, when a client is out of the ZigBee range (but still in the WiFi range) of the AP, it switches back by default to SPSM. The percentage of packets received with a delay below than the desired delay bound di among all incoming packets must be δi (called delay-meet ratio), where $0 < \delta i < 1$. This is the delay requirements. Here, the delay is defined as the time elapsed from the arrival of a packet at the AP to the receipt of the

Notation	Definition
Z	the set of ZPSM clients
B	the length of a BI (the default value is 100 ms)
W	the length of a wakeup slot
m	the number of wakeup slots contained in a WI
x_i	the number of on-demand wakeups for client i within a LI
y_i	the number of BIs contained in a LI of client i
p_i	the ZigBee link quality between the AP and client i
d_i	the desired delay bound for packets targeted at client i
δ_i	The required delay meet ratio of client i
λ_i	the average arrival rate of packets for client i
θ_i	the success probability of any on-demand wakeup of client i
τ_i	the expected interval between two on-demand wakeups of client i

TABLE I

Fig. 1. Tabular figure showing notations used

same packet at the destination client. For compatibility with SPSM, ZPSM clients are allowed only to retrieve packets after receiving a beacon frame as specified in the SPSM. In SPSM, we assume all clients are in synchronization with the AP and in addition, due to the unreliable link quality of ZigBee channel, ZigBee transmission can fail; and the ZigBee interface at a client might be used for many other purposes, packets transmitted by the ZigBee interface at the AP may also fail to reach the client occasionally. We use the link quality pi to represent the probability that a packet is sent by the AP from its ZigBee interface arrives at client i successfully. Noting that the value of pi might vary over time the AP is stationary while the clients mobile with relative mobility. Through minimizing unnecessary wakeups and idle listening, our design should significantly decrease the overall power

- Bounded Delay: Our system should satisfy the delay requirements for each client.
- Compatibility: Our proposed system should not be against the IEEE 802.11 standards. The system must be built atop the standard PSM and further must be synchronized to the standard PSM.

III. THEORITICAL STUDY

In this section we develop an optimization problem step by step to formulate the design in our proposed system. The problem to be solved in our system is how to schedule the regular and on demand wakeups for each client so as to minimize the overall energy consumption of all clients while satisfying their delay requirements. We make the following assumptions

- Uplink data traffic (i.e., data traffic from clients to the AP) and the data traffic to/from CAM clients are not taken into consideration.
- Downlink data packets for each client arrive at the AP following the Poisson process [3], [10], [11].
- Ideal WiFi channel conditions indicating no packet loss are assumed.
- The size of all data packets is identical.

Consider the packet transmission between the AP and a ZPSM client i during a LI the period is assumed to be from time instant 0 to yiB. Let λi denote the average arrival rate of packets aimed at client i then, the number of packets whose delay bound can be guaranteed through regular wakeup is (di − B) λi, because all packets arriving between time yiB − (di −B) and yiB can be transmitted during the BI followed by the next regular wakeup (i.e., between time yiB and yiB + B) with a delay less than di. Thus, the number of packets that need on-demand wakeup during a BI *is yiBλi − (di − B) λi = (yiB − di + B) λi.*

To deal with ZigBee transmissions fails we assume that, once the AP sets the corresponding bit in wakeup frame, it sets the bit until the AP receives a PS-POLL (indicating the client wakes up and retrieves packets) from that client, which can be modeled as Geometric distribution. Then, for a client I with link quality pi, the success probability of any on-demand wakeup, denoted by θi, can be computed as

$\theta i = 1 - (1 - pi)^{\, di - B/mW}$ (1)

This is because any packet arriving di −B time before an on demand wakeup can be transmitted during the BI following that wakeup with a delay less than di. Therefore, the delay requirements of client I can be defined as

$\delta i \le (yiB - di + B)\theta i + (di - B)/\, yiB \le 1$ (2)

From Eq. (2),

We can solve yi and get $yi \ge di - B/\, B$ (3)

And $(\delta i - \theta i)\, yi \le (1 - \theta i)\, (di - B)/\, B$ (4)

For Eq. (4), there exist the following two cases.

A. Case I:

If $\delta i \le \theta i$, the inequality always holds true. This indicates that the delay requirements can be satisfied through only on-demand wakeup. Since the IEEE 802.11 standard only specifies 2 bytes to represent the LI parameter, $yi \le Ymax\ 2^{16} - 1$, where Ymax denotes the maximum LI. Relating it with Eq. (3),

We have $di - B/B \le yi \le Ymax$ (5)

B. Case II:

If $\delta i > \theta i$,

then $di - B\, /B \le yi \le (1 - \theta i)\, (di - B)\, /B\, (\delta i - \theta i)$, (6)

which indicates that on-demand wakeup alone cannot satisfy the delay requirements without using regular wakeup. Besides, the expected time interval between two on demand wakeups of client i, denoted by τi, consists of two parts. One is the expected time of the first packet arrival after one on-demand wakeup, which is 1/λi . If the client is woken up before the deadline (with the probability of θi), the client has to wait for at most di before its wakeup; otherwise (with the probability of 1 − θi), based on the memory less property of Geometric distribution, the waiting time can be computed as di + mW/pi , where 1/pi is the expected number of attempts to wake up the client after deadline. Hence,

$\tau i = 1/\lambda i + [\theta i di + (1 - \theta i)(di + mW/pi)]$ (7)

For any LI, it holds that $yiB - (di - B) \le \tau ixi \le yiB - B$ (8)

For this above analysis we have to design a prototype hardware model so that we can schedule the regular and on demand wakeups of the overall system.

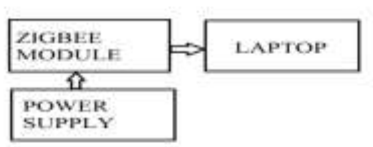

Fig.2. (a) Figure showing the Receiver Block diagram

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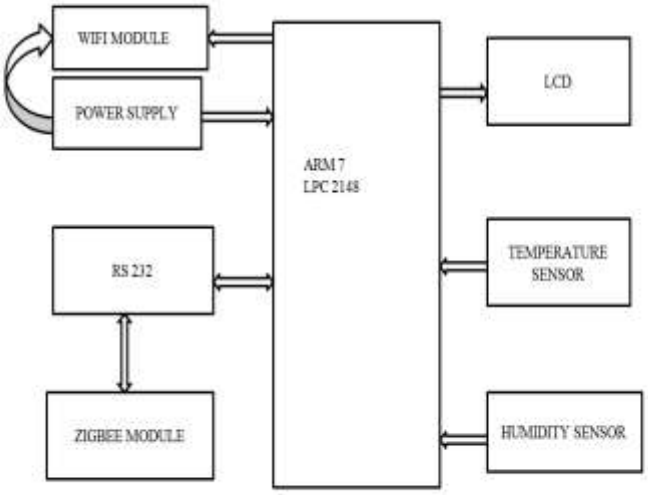

Fig.2. (b) Figure showing the Transmitter block diagram.
Fig. 2. Transmitter and Receiver Block diagram

This architecture of the above system has three main components which are the framework configurator component which periodically configures LI and WI for each client and also the AP (called wakeup framework), respectively. Under the configured wakeup framework, the delay requirements can be satisfied by adopting our proposed wakeup strategies. Based on this framework, the wakeup scheduler component steadily and dynamically schedules on-demand wakeup (called wakeup dynamics) for minimizing energy consumption, if a client cannot meet the delay bound of receiving data packets through regular wakeup. Finally, the ZigBee controller component, implemented on both AP (Access points) and client sides, is responsible for exchanging control messages and waking up client at scheduled BIs.

IV. IMPLEMENTATION

We implement a prototype of this proposed system using a communication device like multiple laptops where one of it is the access point while the others are the client units.
Microcontroller is programmed using Embedded C program, the programming is done using Keil software version 4.The hex code is dumped in an application called Flash Magic. Data can be monitored from mobile through wifi and can also be seen in Hyper terminal application for zigbee.
The baud rate setting is 9600bps and LPC 2148 is the micro controller used. The oscillation frequency is 12MHz.
The hardware description consists primarily of a microcontroller, sensors for obtaining values of temperature and humidity. The sensor values are continuously sent to microcontroller thereby sent to receiver through the ZigBee interface. This is done spontaneously by ideal and on demand wakeup. To ascertain the proposed system, we conduct extensive simulation based on ns2. The clients are connected to the WiFi module. Zigbee module is used at both at transmitter and receiver to control the wifi status.
A number of clients can be connected to the WiFi which is limited to 4 in this project.The wifi used is ESP8266 module.

V. RESULTS AND ANALYSIS

A. Experimental results for delay and energy behaviour

The below Fig (a) shows that the time delay increases gradually as the distance increases. This is because, as the delay bound increases gradually, clients wake up less frequently, this reduces the wakeup overheads for turning on/off WiFi, receiving beacon and sending or listening in idle state. Thus in the below graph we can see that as the delay bound increases there is fall in per-packet energy.

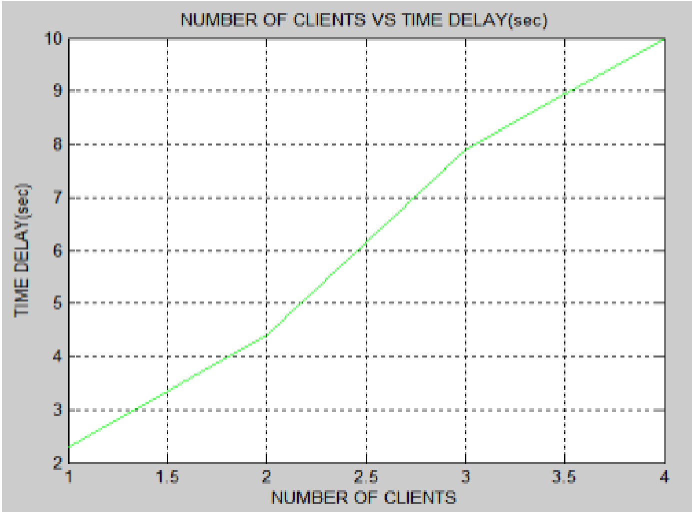

Fig. 3. Number of clients vs time delay

Time elapsed	Transmitted packets	Received packets
16sec	1531	1840
42sec	2821	3605
1m 02sec	2861	3670
1m18sec	2890	3695
1hour 20 sec	41807	46189

TABLE II
Fig.4 . Tabular figure showing notations used

Fig 4 is the graphical representation of the data packets transferred of a client 1. Always the received packets are more compared to sent packets of data. The above was collected from the application psiphon which shows the total statistics of data transfer for a time session.

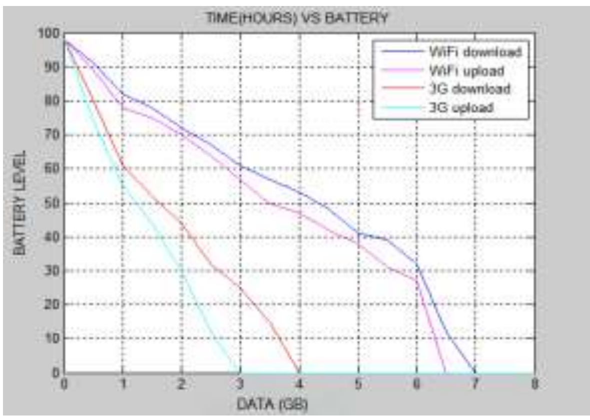

Fig.5 . Energy consumption compared to the elapsed time

Above graph shows the WiFi upload and download with accordance to battery level. Using Wifi maximum of 7GB can be downloaded for a total battery level of 100% and

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6.5GB can be uploaded. This is compared with the 3G data transfer.

Data transfer of 50 KB when using 3G needs 12.5 J, while when using WiFi the same data transfer consumes 7.6 J of energy indicating that WiFi communication technology is 39.2% more energy efficient than 3G communication technology.

B. Experimental results under various cases of p and d.

The below Fig (a) shows that the energy consumption decreases gradually as the required delay bound increases. This is because, as the delay bound increases gradually, clients wake up less frequently, this reduces the wakeup overheads for turning on/off WiFi, receiving beacon and sending or listening in idle state. Thus in the below graph we can see that as the delay bound increases there is fall in per-packet energy.

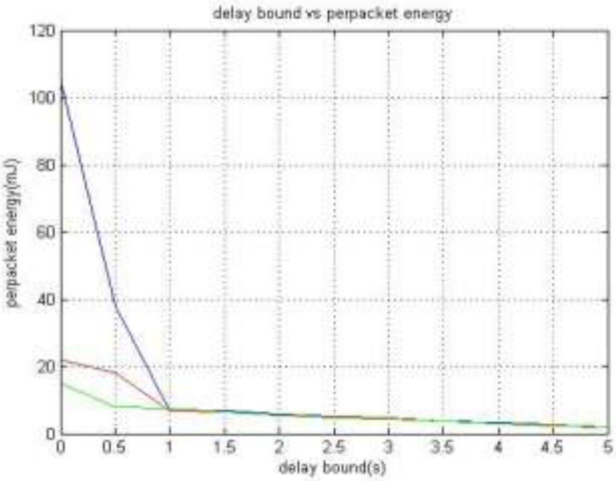

Fig. 6. (a)graph for condition P=0.7 and δ=0.9

Here we consider the average arrival rate of packets for each delay bound as indicated by blue, green and red for λ=1pk/s,5pk/s and 10pk/s.

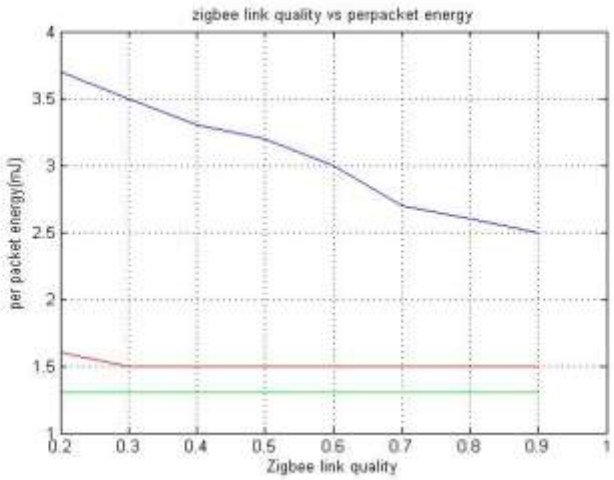

Fig.6. (b) Graph for condition d=2s and δ=0.9

The above Fig (b) shows that the energy consumption decreases as ZigBee link quality increases. This is because, as link quality increases, clients can have more chances to avail the on-demand wakeup to decrease the wakeup frequency of the WiFi interface and balance transmission workload, which can result in higher energy efficiency.

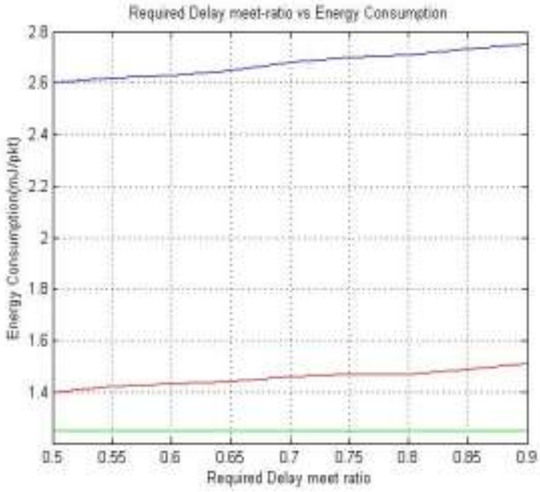

Fig. 6. (c)Graph for condition d=2s and p=0.7

The above Fig(c) shows that as the required delay meet ratio keeps increasing the energy consumption gradually increases and we can see that as the required delay-meet ratio increases the LI becomes less in order to ensure delay requirements. As a result, wakeup overheads get larger thereby leading to higher energy consumption.

Fig. 6. (d)Graph for condition d=2s and p=0.7

Fig. 6. Expected graphs in different scenarios

In this above figure we can observe that as the required delay meet ratio increases further the actual delay meet ratio rises dramatically. Thus we can make an analysis the performance of PSM under Different Scenarios

VI. CONCLUSION

Various works have been conducted to improve WiFi energy efficiency in mobile devices. Research is also done to investigate the collocated interfaces to aid wifi transmission. In this paper we propose a ZigBee assisted PSM system to leverage the energy efficiency of wifi transmission. We compare our proposed ZPSM against SPSM, optimal solution (OPT) as well as a simplified ZPSM (S-ZPSM), which uses the same wakeup framework as ZPSM except that each client is always scheduled to wake up at the latest BI. On average, our proposed AZPSM can save 81.9% and 37.5% more energy than SPSM and S-ZPSM, respectively. Results of prototype and experiment have shown significant improvement on energy consumption when compared to standard power saving management system and also the energy and delay behavior is studied.

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