On Demand Paging Using Bluetooth Radios on 802.11 Based Networks

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Abstract

The power consumption of the network interface plays a major role in determining the total operating lifetime of wireless handheld devices. On demand paging has been proposed earlier to reduce power consumption in cellular networks. In this scheme, a low power secondary radio is used to wake up the higher power radio, allowing the latter to sleep or remain off for longer periods of time. In this paper we present use of Bluetooth radios to serve as a paging channel for the 802.11 wireless LAN. We have implemented an on-demand paging scheme on a WLAN consisting of iPAQ PDAs equipped with Bluetooth radios and Cisco Aironet wireless networking cards. Our results show power saving ranging from 19% to 46% over the present 802.11b standard operating modes with negligible impact on performance.

Keywords— System Design, Experimentation with Real networks/Testbeds, On Demand Paging , Wireless LAN

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I. INTRODUCTION

Wireless handheld devices such as PDAs are increasing in usage. These devices commonly feature wireless communication using both Bluetooth (BT) and 802.11b radios, often on the same platform. These radios are used for different purposes. BT radios are used for ad hoc connections with other devices (and possibly network connections using Scatternet) whereas the 802.11b radios are used for connection to the internet or to a Local Area Network (LAN). Wireless LANs have also become popular and have advantages including connectivity, high bandwidth, roaming access. The power consumption of the network interface in these wireless handhelds plays a major role in determining the total operating lifetime of these devices.

The power consumption of the 802.11 network interface is quite significant. The problem is worse when dealing with handheld wireless devices like PDAs due to their small form factors, hence limiting their battery life. Figure 1 shows the power consumption of various components of a typical handheld. According to our experimental measurements coupled with power figures of various components of the iPAQ given in [18], the power consumption of the wireless card alone can be as much as 50% of the total power of the handheld device.

A large portion of the power consumption in the wireless interface is idle power, that is, power consumption with an idling radio and network interface. Because of the importance of conserving battery energy, the medium access control (MAC) layer specification of the IEEE 802.11b contains several provisions to reduce power consumption [5]. When idle, the wireless interface can transition to a *sleep state*. However, power consumption is generally a transmitter side issue, since there is little control on the power consumed by the receiver. In fact, the interface has to be periodically woken up to check for buffered data at the access point (AP). In case there is no buffered data the network interface can transition back to the sleep state. This periodic wakeup causes unnecessary power consumption in the case where no useful data transfer takes place. One strategy to reduce this power consumption is to wake up the clients only when there is useful data for them to receive or transmit. E.Shih *et al.* [10] propose such a scheme for a PDA-based phone like application scenario called "Wake on Wireless" using a special radio as a paging channel. Very limited range of the special purpose radio hardware requires additional strategies to maintain connection as briefly discussed in the Related Works section. In contrast, we explore use of commodity radios already available in many PDA platforms to reduce the overall power. The power consumption of BT radio, which is somewhat more than the custom radio used in [10] is still an order of magnitude less than the power consumed by a 802.11b radio. This provides incentives for seeking additional power reductions while using available platforms.

The basic idea behind on-demand paging is to switch on the 802.11b radio only when required and to keep it off at all other times thus saving idle power. A wireless client always has control over when to transmit or send data, but it has no control over reception of data. In our scheme whenever a client wants to send any data to another client it wakes up its own 802.11b interface and also "pages" the destination to wake up its 802.11b radio. Since the sender and receiver radios are otherwise asleep at all other times, the duty cycle of these radios can be reduced significantly.

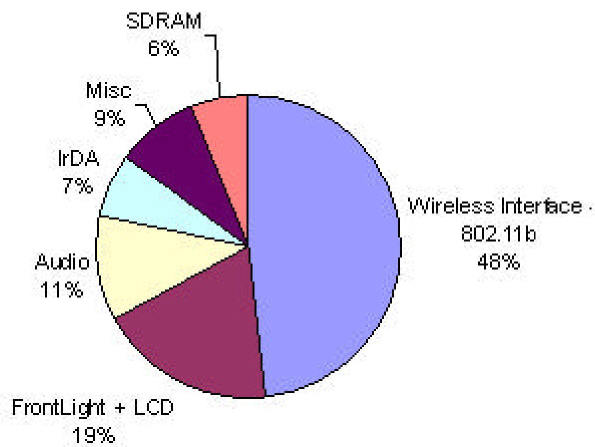

Figure 1. Power Consumption of various components in an iPAQ handheld [18]

The rest of the paper is organized as follows. Section II presents previous work in this area. Section III explains in detail the power management in the present IEEE 802.11 standard. Section IV and V explains On-Demand Paging and details of our implementation respectively. Section VI discusses results while Section VII suggests future work.

II. RELATED WORK

In order to bridge the gap between circuit technology and power supply technology various techniques for reducing system power consumption at various levels have been proposed in the recent years. Usually known as dynamic power management (DPM), these techniques range from application level to the micro-architectural level [20].

Other techniques such as use of the application specific information to reduce power usage have been proposed [3]. There has also been work done in modification of existing protocols to make them power aware [14][15]. The authors in [2] propose protocol optimizations for the various layers of the communication protocol stack geared towards low power embedded systems.

Regarding power consumption by the wireless interface, Stemm *et al.* [13] have quantified the effect on power consumption by techniques that increase radio sleep time through extensive simulations and application-based power optimizations.

The use of a secondary radio for paging has been proposed in [10]. The authors describe their *Wake-on-wireless* scheme and implementation of their prototype. They use a specially designed radio to function as their paging channel. Their strategy focuses on a PDA based cell-phone application. Their framework has various components like location servers, presence servers and proxies which are needed for cell phone type applications to track clients. They show 17% to 40% increase in lifetimes for their PDA based phone. However these given energy saving estimates are based on cell phone based application and usage patterns with very large idle times. The handheld device in their strategy was on only during the call and switched off completely all other times. The authors have not measured the added latency in communication of their strategy but mention that it could be of the order of 5 – 10 seconds.

In [12], Chiasserini *et al.* suggest similar approach to use a secondary mechanism to wake up nodes by means of small range ID tags to wake up a group of nodes.

III. POWER MODES IN IEEE 802.11B

Since we are using the IEEE 802.11b as the baseline case for our comparisons, we present an overview of the power management capabilities provided by it. According to the standard there is some medium access layer (MAC) power management specified. It allows mobile stations in either ad-hoc or infrastructure mode to conserve power by switching to low power modes. The standard specifies the power modes but does not specify the implementation details. In case of infrastructure mode the power management is centralized in the Access Point. The radio can be in an *awake, sleep* or *off* state. In the *awake* state the card consumes most power and is used for data transmission and reception. The *sleep* state does not allow data reception or transmission and is a low power state. The *off* state is when the radio is switched off.

Using these states there are two modes of operation as specified in the 802.11b standard, Awake Mode (AM) or Power Saving (PS) mode. In case of awake mode the radio is continuously ON and listening for packets. This is a high power mode as the radio consumes power equivalent to the awake state, which is shown to be an order of magnitude higher than the sleep state. The power in this state also varies depending on whether the card is idle, receiving or transmitting. The power consumption is maximum during transmission, less during reception and the least when the card is idle.

The power consumption for typical 802.11 cards in the different states is shown in Table I.

Vendor	Average Power (Watts)		
	Idle	***Transmission (Tx)***	***Reception (Rx)***
Cisco PCM 350	1.43	1.80	1.52
Orinoco Gold	1.02	1.50	1.22
Linksys	1.1	1.48	1.28

TABLE I. TYPICAL POWER CONSUMPTION FOR WLAN CARDS

Take for example an infrastructure based wireless network comprising of various Access Points (AP) and client adapters (802.11b clients). In addition to other functions, the APs buffer incoming messages for various clients associated with them. When a client goes into PS mode it informs the AP about it. The AP then buffers the messages for this client and at the beginning of a pre-determined interval called Beacon Period the AP sends out a Traffic Indication Map (TIM) to signal the various clients whether they have data for them buffered at the AP. Any client in PS mode wakes up at the beginning of every Listen Interval which is a multiple of Beacon Period. It receives the TIM transmitted by the AP. In case the client determines that the AP has data ready for it, it can send a PS-POLL packet to the AP. The AP then sends each buffered packet. If there is no buffered data the client can go back to sleep. Since the 802.11b specification does not specify the implementation details of power saving mode, different manufacturers implement it differently. In case of our experimental setup we used a Cisco Aironet PCM-350 card which has two modes of operation Constant Awake Mode (CAM) and Power Saving Polling (PSP) mode.

The idle power consumption for the Cisco PCM-350 card in various modes of operation is shown in Table II. The idle power consumption in PSP mode is 52% less that CAM mode.

OPERATING MODE	Average Idle Power (Watts)
CAM	1.43
PSP	0.68

TABLE II. PCM-350 Idle Power Consumption For Various Power Modes

As seen from the figures above, operating the Cisco 802.11b adapter in PSP mode provides the longest operating time. Operating the 802.11 cards in PS mode has a penalty associated with it in terms of latency and throughput. The throughput figures for a FTP session to a dedicated server using the Cisco PCM-350 card are given in Table III.

OPERATING MODE	Average Throughput Reception (kbps)
CAM	760
PSP	410

TABLE III. Average Throughput For An FTP Session For Cisco PCM-350

IV. ON DEMAND PAGING USING BLUETOOTH AS A PAGING MECHANISM

In this paper we present an implementation of a low power scheme using Bluetooth (BT) as a paging mechanism to wake up the higher powered 802.11b radio as and when required. The advantage of this dual radio based paging scheme is that is saves more power than the best power saving modes of Wi-Fi 802.11b protocol without affecting throughput. As shown in Section III the idle power in 802.11b radios is quite substantial, even in power saving mode. The basic idea behind the scheme is to shut off the 802.11b radio whenever no data transmission or reception is taking place. This saves on the idle power and the switching power consumption. Our paging scheme ensures complete connectivity and on demand wakeup of the handheld device.

Our paging scheme works as illustrated in Figure 2. Assume a scenario with numerous wireless clients in an 802.11 based infrastructure network. All clients have their 802.11 radios switched off when there is no data transfer. Each client monitors the BT paging channel continuously to sense paging signals. As soon as any client wants to communicate it switches its radio on (Step 1). It also sends a paging signal to the destination client via its low power Bluetooth radio to wake up (Step 2). The destination client on receiving this paging signal switches its 802.11b radio on (Step 3). As soon as the sender finishes it switches off its 802.11b radio (Step 4) and sends another paging signal (Step 5) to the destination to do the same, i.e. shut off its radio (Step 6) . The 802.11b radio is switched on only when needed and hence saves power by remaining off during idle periods.

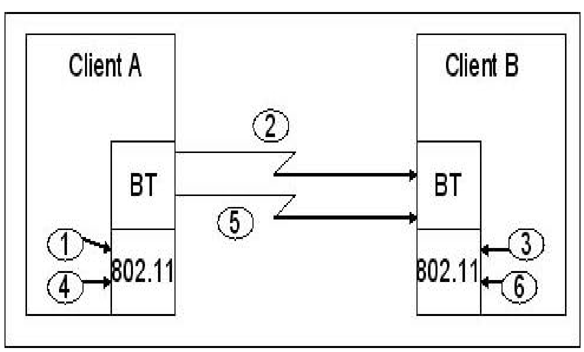

Figure 2. On-Demand-Paging Scheme

One advantage in our scheme is that it is completely application independent. A simpler case would be to tailor each application to be power aware of the underlying paging architecture. This however would be severely limiting the capability of our framework. Our scheme detects any TCP/IP requests and wakes up the transmitter radio. Any application that uses TCP/IP can use this underlying paging mechanism without any changes in its source code.

In our scheme participating clients are those clients that use the paging architecture while non-participating clients do not use it. Another advantage in our scheme is that it allows participating clients to communicate with non participating clients. If a certain client would like to make sure of minimum communication latency it could switch off the paging algorithms and operate in a normal mode.

The next section explains the implementation details of our scheme.

V. IMPLEMENTATION

In order to make the scheme transparent it was necessary to detect whenever any application wanted to communicate over the network. In order to achieve this we modified the Linux kernel to raise a signal whenever an application initiated a connection. This was done at the kernel level to ensure minimum latency. All other implementation was done at user space level. Our power management scheme comprises of separate communicating modules that can be activated and deactivated as and when desired. Power management at the user level can have a disadvantage that it could increase latency than if done at the kernel level. However in our experimentation we found that the additional latency introduced was negligible and the advantage of the scheme being transparent made is more attractive than doing the power management in the kernel. Moving it to kernel however is a relatively simple task if so desired.

The paging scheme is implemented in two separate modules. The first module is called the paging module (PM) and basically takes care of paging the destination in order to wake them up. This paging module uses bluetooth (BT) to communicate with the other clients. For our implementation we use the BlueZ bluetooth stack which is also open source. The BT address of each client is a 6 byte hexadecimal string similar to an ethernet MAC address. In order to map which particular destination to wake up, the paging module looks up in a table to match the particular destination with its BT address. The paging is implemented via socket calls. The paging signal is a data packet which contains a bit which is set to 1 or 0 depending on whether the signal is to switch the destination radio on or off. It also contains the source IP address of the sender. There is space available in the data packet sent for future expansion in case signals other than just to wake up destination are to be sent.

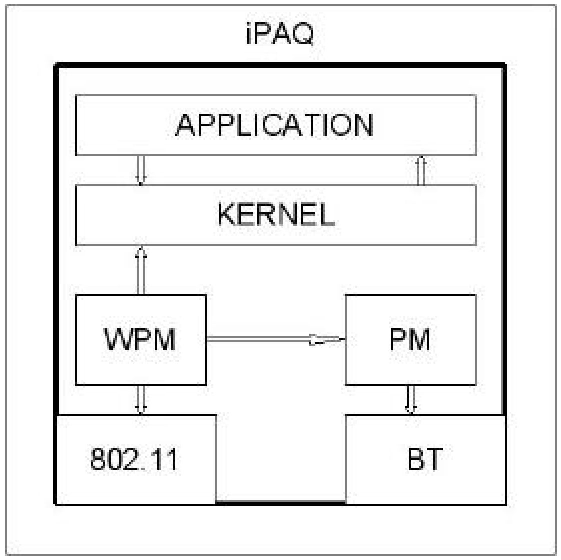

Figure 3. Various Software Components
WPM : Wireless Power Manager
PM- Paging Module

The second module is the wireless power manager module (WPM). The paging module is separate from the WPM module to ensure minimum latency of the wakeup process. The paging module communicates via software interrupts with the other module (PM). The WPM module is responsible for sensing the need for the interface to be turned on as signaled by the kernel. This is done by monitoring a structure in memory written by the Linux kernel. Whenever any application wants to use the network interface the kernel updates the data structure in memory and the WPM senses it. The WPM module performs the function of switching the transmitter 802.11b radio on and then sending a signal to the paging module to page or "wake-up" the receiver's 802.11b radio also.

There are two sleep states, SS1 & SS2 defined in our implementation. SS1 basically turns the radio off and in effect there is no transmission or reception possible. The latency to switch to this state is the order of milliseconds. The radio can be woken up from this state with maximum latency of approximately 0.5s. The power required to switch to this state is 5-7 mW. The second sleep state, SS2 is the deeper sleep state. It basically switches off the interface and hence puts the radio is a complete sleep state. The latency to switch to this state is approximately 0.5s. The latency to switch the radio back from SS2 to awake state where it can transmit and receive data, is about 1.5 seconds. The switching power consumed to switch to awake state is of the order of a few mW.

In order to explain how these modules and Sleep States SS1, SS2 tie together consider a scenario where all clients have their wireless interfaces switched off. Client-A wants to communicate with Client-B. Both clients are participating nodes in our low power framework and execute the WPM module and paging module. Client-A starts an application to communicate with Client-B. The WPM module then senses this and switches on Client-A's radio. It also signals the paging module (PM). The advantage of first switching on the 802.11b radio is that while the radio is being enabled the paging signal to the destination can be sent. This minimizes total wake-up latency to the maximum of the two latencies. The paging module on receipt of the signal identifies the particular BT paging address associated with the destination IP address and sends a paging signal to the destination. Client-B has a server running which on receiving the paging signal from Client-A switches its 802.11b interface on.

On the sending end, when the application finishes sending data Client-A times out and switches the radio to SS1. It also send a paging signal to the destination, Client-B in this case to switch to SS1. If all connections are closed Client-A switches to deeper sleep state SS2 and sends another paging signal to Client-B to do the same and switch to SS2.

A. PLATFORM & TEST SETUP

In order to demonstrate and test our scheme we chose a Compaq iPAQ 3870. This model had an integrated Bluetooth chipset. It also comes with an expansion pack that can be a single sleeve or a dual sleeve containing 1 or 2 PCMCIA slots respectively. The iPAQ has a Intel StrongARM processor, 64 MB of RAM and 32 MB of ROM. The complete specifications are given in [16]. The operating system installed on the handheld was Familiar Linux [4]. We chose Linux over the preinstalled Windows-CE for our experimental test bed due to the inherent advantages of it being open source and all the kernel sources being readily available. The wireless card used for our experimentation was a Cisco Aironet PCM350 card which is inserted in the sleeve. We chose the Aironet card for our test purposes as the drivers for Linux were readily available. Monitoring parameters and changing operating modes like switching the radio on/off, changing transmission rate and transmission power level control were achieved relatively easily for this card.

Figure 4. iPAQ fitted with the KAITEK PCMCIA Extender card for Power Measurements

In order to make accurate power measurements we used a data acquisition system PCI-6110E from National Instruments. We chose sampling rates of 0.5 Megasamples per second as sampling rates greater than that did not increase accuracy. Before any power measurements were done the internal battery of the iPAQ and the external sleeve had to be physically unplugged as the unpredictable charging cycles of the two batteries gave erroneous readings. The total power for the entire PDA including the 802.11b card were measured by sensing the current to the iPAQ by using a series resistor and measuring the voltage drop across it. This coupled with the measured supply voltage gave us an accurate power consumption profile. In cases where the power consumption of the 802.11b card specifically was required a KAITEK PCMCIA extender card was used to access the supply pins for the 802.11b card. We were thus able to quantify to a very high degree of accuracy the power consumption of our scheme.

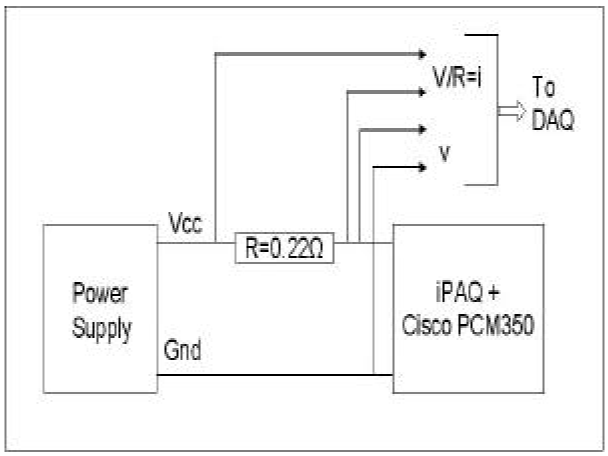

Figure 5. Test Setup for Power Measurements

VI. RESULTS

In order to quantify the benefits of our scheme we compare the power consumption of our scheme to the power saving modes of the IEEE 802.11b protocol. The CAM mode of the 802.11b protocol is a power expensive mode of operation since the radio is continuously on. The justification of this mode of operation is when minimum latency is required. This mode also gives maximum throughput. The PS mode of 802.11b is designed with power saving with mind and tries to save on power by switching off the radio periodically and then waking it up at pre-determined intervals to check for messages. The throughput of this mode is less than that of CAM as the radio periodically goes to sleep in order to save more power. This is done even if there is a sustained stream of incoming data. Since the AP buffer incoming messages the clients can go to sleep in order to save power without any loss in data. According to our measurements the throughput of PSP mode was approximately 45% less than that of CAM for an FTP session as enlisted earlier in Table III.

For test purposes we setup a separate wireless network with a separate SSID. Earlier experimentation had yielded somewhat varying results for the same operating conditions due to variations in traffic on the common wireless network. Establishment of a dedicated test wireless network in a separate room ensured consistency of results in various conditions and different test parameters. In cases where throughput measurements were to be taken a separate FTP and a SSH server was used to ensure a high degree of consistency of results. In most cases the tests were done at late night time as traffic on the wired LAN network was considerably low at those times.

As mentioned earlier in order to make accurate power measurements with a high degree of fidelity a high sample rate data acquisition board from National Instruments was used. The internal batteries of the iPAQ were removed in order to remove any effect of power measurements due to their erratic charging and discharging cycles.

We first took power measurements for the various components of the system when they were turned on. Power measurements were taken with the screen backlight switched off and we waited for a while for the touch screen LCD of the iPAQ to also turn off. The iPAQs were left idle for some time to make sure that the system stabilized before the power measurements were taken. The various configurations for which power measurements were taken are given in Table IV. Unless mentioned specifically all these measurements are for the total power consumed by the iPAQ. We felt that the total power consumed by the IPAQ is the ideal quantity to measure to take into account power consumed by all components of the system. The iPAQ was inserted in the PCMCIA jacket / sleeve for all measurements. All the power figures given below are Idle power figures, with no transmission or reception taking place.

	Configuration
1	iPAQ only (backlight and LCD off)
2	iPAQ with 802.11b card (CAM Mode)
3	iPAQ with 802.11b card (PSP Mode)
4	iPAQ + no 802.11b card + Bluetooth ON
5	iPAQ + no 802.11b card + BT on + Power Management Scheme (WPM + PM)
6	iPAQ + 802.11b card in SS1 + BT on + Power Management Scheme (WPM + PM)

TABLE IV. Various Power Configurations

As seen from above the base case for comparison is case 3. This is the lowest power consuming mode of operation in the present power modes of the 802.11b protocol. Our paging scheme power consumptions are given as cases 5 and 6. In case 5 the 802.11b card is inserted in the sleeve. It is in power saving state SS1 , the Bluetooth paging channel is switched on and the power management algorithms are also active. For any scheme to be better than the present PS mode of 802.11 it has to consume less power than PS mode of 802.11b. As shown above the total power consumption of the IPAQ in SS1 is 7% better than that of PSP while 39% better than CAM. Furthermore when the card is put to deeper sleep mode SS2 the power gains increase to 19% over PSP and 47% over CAM. The power consumption for the wireless card alone is also shown as the second column in Figure 6 and Figure 7.

In order to quantify the energy savings in case of actual active wireless networks we performed energy measurements for synthetic workloads. Scripts were generated to depict a typical FTP session. The FTP server chosen was a dedicated server with no other connections. The FTP script was generated such that the client logged on to this server, downloaded and uploaded a few files of varying sizes. It did various such download and upload combinations. There was also period of inactivity of varying lengths inserted between these various sessions in order to depict actual traffic and periods of no activity. These scripts were then executed for the various power modes and energy consumption was measured. The energy consumption figures for one such script - ftp1 are shown in Figure 8. This was a small script that executed for about 5 minutes. The energy consumption for our scheme in SS1 is 21% less than CAM and 4.5% less than PSP. The energy consumption in case of SS2 is 29% less than CAM and 14.4% less than PSP. As expected, longer periods of inactivity will lead to greater energy savings. Unfortunately due to time constraints we were not able to run other application scripts such as SSH or Telnet scripts. It is our belief however that the power savings will be almost similar to the ones in case of FTP sessions. Browsing web pages will give even more savings due to the nature of web browsing. Users generally open a web page and then take some time to read it leading to large periods of inactivity and hence scope for large amount of power savings.

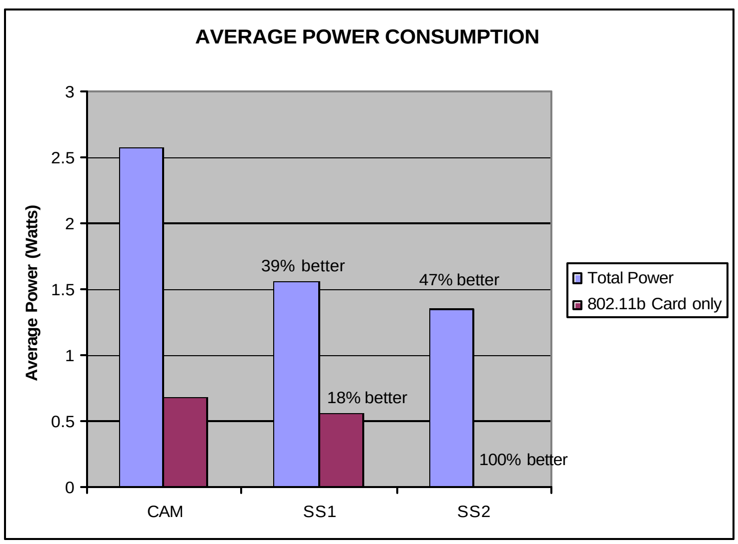

Figure 6. Total Power savings for iPAQ compared to CAM mode

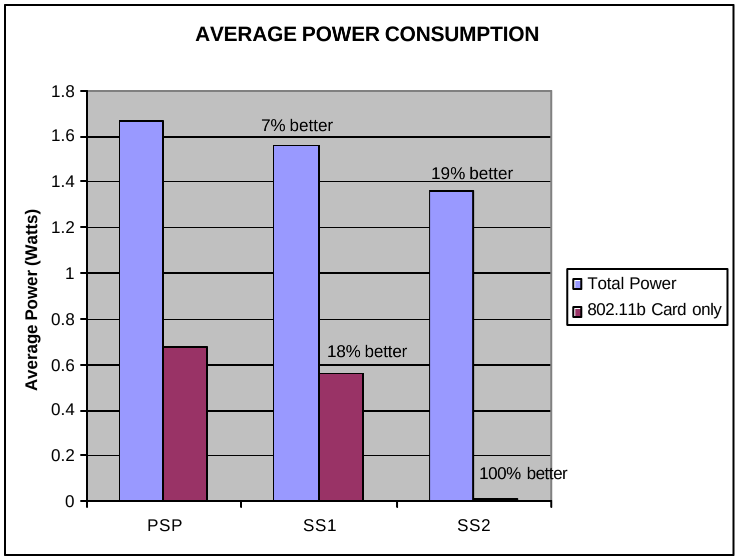

Figure 7. Total Power Savings for iPAQ Compared to PSP Mode

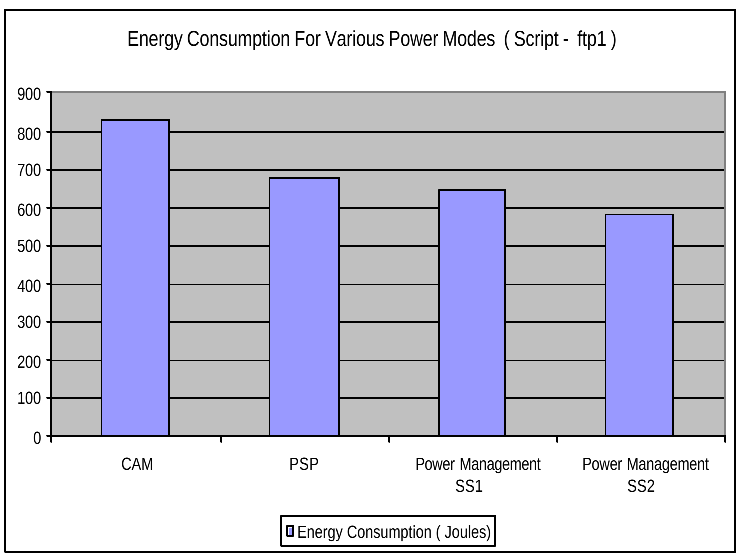

Figure 8. Total Energy Consumption for Various Power Modes (script ftp1)

A. LATENCY

An important consideration usually in any power management scheme is the tradeoff with respect to some other performance parameter. In case of network interfaces one such tradeoff is latency. Power saving can lead to higher latency. In our paging based scheme as described earlier, the two sleep states SS1 & SS2 have different latency penalties. For SS1 the latency penalty to be paid for switching back and forth to awake mode is less than 0.5 seconds. For SS2 which is a deeper sleep state resulting in more power saving the latency penalty to switch back to awake mode is higher and of the order

1.5 seconds. It is also true that the power saving associated with these low power states makes up for the latency penalties.

In cases where latency is a severe constraint it perhaps would make more sense to switch to SS1 only since the latency penalty to switch back is comparatively less. We however also believe that this latency to switch back and forth between states even though small may be further reduced.

B. THROUGHPUT

Another important performance parameter in case of networks is throughput. In case of our scheme the throughput is the same as offered in the CAM mode of operation. Since the WPM module after sensing that an application want to use the wireless interface switches the radio on and sets it to awake mode, the maximum throughput equal to awake mode is available.

C. REDUCTION IN RADIO TRAFFIC

We also observed that this on demand paging based scheme can lead to reduced radio traffic in the crowded radio spectrum. The 2.4Ghz band in which the 802.11b radios operate is a license free band and a lot of other devices like microwave ovens, cordless phones and other wireless networks utilize it. In case of 802.11b the AP continuously transmits beacon frames and Traffic Indication Maps (TIM) to the clients in order to let them know if there is any data buffered for them at the AP. Now if all the clients were using on demand paging, the AP could also switch off its transmitter and switch it on only when desired thus reducing radio traffic. It has come to our notice that some manufacturers are offering AP with both BT and 802.11b which makes this feasible. In a scenario in which these dual AP were used the AP could shut off its 802.11 radio. A client using on demand paging wanting to transmit data can send a BT paging signal to the AP and to the destination to wake up both of them.

VII. FUTURE WORK

In this work we implemented a bluetooth based paging scheme to lower the power consumption of the 802.11b wireless interface and hence prolong the battery life of handheld devices using 802.11b cards. The bluetooth radio was used as a secondary paging channel. This BT paging channel can have certain other advantages and uses other that being used to just turn on the destination radio.

The low power channel can be used for some of the functions that are presently done by the 802.11b card. Features like route setup, load balancing, congestion control can perhaps be done by the BT rather than being done by the 802.11b card. If certain nodes know that they will not need to communicate they can signal neighboring nodes.
802.11 Access Points can also be intelligent and instead of waking all the clients up at regular intervals can use the BT paging signal to wake up every particular destination when it has data queued for them. The client on the other hand can communicate their state to the AP.

A dual throughput architecture is also a possibility. For applications needing a specific amount of throughput maybe BT can serve as the primary data channel , while if the throughput requirement becomes larger than the BT channel can sustain then the 802.11 radio can take over.

In this work we have primarily focused on infrastructure based networks and power saving in them. A low power framework can also be designed such that the BT paging channel can be used to signal the clients which other clients are close to them. The client if within range can communicate with each other directly (ad-hoc) rather that going through the access point (infrastructure). This would enable the clients to be able to switch between Infrastructure and ad-hoc mode as desired and best suited.
Though this paper focuses mainly on power saving in case of infrastructure networks , the idea of paging is very applicable to ad hoc Networks also. Power consumption in case of ad hoc mode of operation is quite large as all the clients have to wake up at the beginning of every beacon and stay awake till the end of the Traffic Indication Window (ATIM). This is necessary so that stations can signal destinations when they want to communicate. This is a difference as compared to infrastructure mode in which the AP buffers the messages in case the client is asleep and hence the clients can sleep for longer intervals of time. The scope for power savings in ad-hoc mode using of BT paging is thus quite large.

VIII. CONCLUSION

Power consumption in case of handhelds devices is a major cause of concern. Their small form factor and portability requires smaller batteries. With the current battery technological advancements not being able to follow suit with the microprocessor advances the energy gap is growing, leading to innovative strategies to get more out of the limited battery life. In this paper we have proposed an implementation of a bluetooth based paging scheme to save idle power in the 802.11b wireless interface, in effect prolonging batter life.

Our implementation has advantages like application independence, high throughput and low latency. Handhelds with integrated BT and 802.11b have become popular. BT radios are also very low power, making them ideal for use in paging. Presently the range of the BT devices is comparatively smaller with respect to 802.11b, but this would not be an issue with advances in BT technology. Some manufacturers [17] are already proposing integrated AP containing both BT and 802.11b access points. BT on an AP would increase its range considerably. Our scheme leads to considerable amount of power savings which are very attractive in case of larger networks. We have shown that our implementation can benefit several common applications like web browsing, file transfer and telnet. This scheme may also be applicable to large sensor based networks. The radios in that case may not use 802.11b but the dual radio paging approach will still be applicable.

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