Enhancing PSM Efficiencies in Infrastructure 802.11 Networks

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Abstract: *Power conservation techniques are of utmost importance in Wirreless LANs to prolong the life of mobile stations relying on portable limited enrgy batteries. A power conservation mechanism should provide the maximum energy saving at light traffic loads, yet thrives to deliver data as much as possible in high traffic conditions. In this paper, we investigate the inherent functional properties of the infrastructure mode IEEE 802.11 Power Saving Mechanism (PSM). We show through extensive simulations that PSM stands very short and does not level up to its design objectives. PSM blocks the network traffic flow, yet it does not adequately save energy as supposed to be. We show that at high traffic loads, PSM exhibits a very poor throughput and excessive power consumption per delivered data frame. We therefore investigate the inherent properties that made PSM inefficient and propose two different enhancements called State Aware PSM (SA-PSM) and Once Poll PSM (OP-PSM). We show through extensive simulations that tangible improvements are attained. These enhancements save power as much as PSM for light traffic loads and deliver as much a throughput as when no power saving mechanism is deployed. Virtually at all traffic loads, OP-PSM and SA-PSM nicely outperform PSM and provide a much less average time spent by a data frame from its generation at the source station until its delivery to the destination station.*

1. Introduction

In the last few years, the cost of 802.11 wireless network cards and Access Points (AP) dropped down significantly, making WLANs and Wi-Fi hotspots very attractive for public wireless Internet Access. 802.11 WLANs support various usage scenarios. They are often deployed in area such as enterprises, convention centers, conference locations, public hotspots, shopping malls, parking lots, airplanes, trains and campuses [1, 2, 3, 4, 5, 6, 7, 8].

Wireless stations are often powered by batteries which provide only a limited amount of energy that should be wisely managed. Energy management has been a central issue to prolong the lifetime of a mobile station. Indeed, networking activities account for up to 50% of the total energy spent by a mobile station [9, 10]. It is therefore essential to design efficient power saving approaches. To this end, IEEE

802.11 standard defined a Power Saving Mode (PSM) allowing to save energy by powering down the station wireless interface to a much lower power state (the doze state) when deemed reasonable [11]. To the best of our knowledge, very little efforts have been conducted to evaluate the performance of PSM for IEEE802.11 infrastructure architectures. This paper focuses on the inherent properties of the PSM IEEE 802.11 MAC energy conservation. We evaluate the performance of the PSM for infrastructure mode IEEE 802.11 and propose two simple enhancements which provide much better efficiency.

A power saving protocol should provide the maximum energy saving at light traffic loads, yet thrives to deliver data as much as possible in high traffic conditions. A power saving mechanism should not save energy by throttling the traffic flow. Indeed, when the network traffic load is light, stations are able to power down their transceivers. But at high

workload, stations are obliged to keep receiving and/or sending their traffic, and consequently could not power down their transceivers virtually all the time.

A station can be in awake state, doze state or off state [11]. In the off state, the station wireless interface is completely powered off. In the doze (sleep) state, the station is unable to receive or transmit and has no knowledge of activities taken place on the wireless medium and hence uses very little power. In this state, the transceiver is powered off but the station wireless interface still consumes very little power. Since only the transceiver (the radio) is powered off, the wireless interface (the card) can switch the radio on and off very quickly. The transition from the doze state (radio off) to the awake state (radio on) is reported to take form hundreds microseconds [12] to few tens milliseconds [20, 30]. This transition results also in some additional power consumption [13]. In the awake state, a station can be in three different modes: transmit, receive or idle, and consumes power at different rates. In the idle mode, the station transceiver is not currently transmitting or receiving its own data frames, but it is powered on to keep participating to the basic MAC protocol activities. In the transmit mode, the station transceiver is currently sending a data frame. In the receive mode, the station transceiver is currently receiving a data frame. Power consumption measurements for commonly available 802.11 interfaces [10, 14, 15, 16] indicate that the energy consumption, while in transmit or receive mode, is not much more than the energy consumption while in the idle mode, however the doze state power consumption is much less significant. Authors in [10, 14, 15, 16, 17], indicate that the idle state consumes only around 36% less energy then continuously transmitting. The doze state however, consumes more than 95% less power than continuously transmitting, and the receive mode consumes about 80% of the transmit mode power consumption.

IEEE 802.11 defined two operation modes: PCF and DCF [11]. PCF (Point Coordination Function) is a centralized medium access control scheme based on polling, whereas DCF (Distributed Coordination Function) is a fully distributed protocol. While IEEE 802.11 specifies PSM for both PCF and DCF, we only focus in this paper on power saving schemes for DCF. In [18], the authors presented a novel method to arrange wakeup schedules for stations in the doze state. The wakening up is performed in such a manner that keeps wakeup stations balanced in each beacon interval, an interval of usually 100 milliseconds that it is periodically announced by the Access Point (AP) as will be explained later on. Their method tries to reduce the probability of collisions

and hence stations would save more energy. In [19], they presented measurements which show that when TCP is run over IEEE 802.11 PSM, performance suffers because round trip times are rounded to the beacon interval length. They proposed adaptation mechanisms in which the mobile station dynamically adapts its sleeping time. Hence, if traffic load is light, the mobile station can enter the doze state for a longer period. In [20], they presented a power aware and a QoS- aware model where mobile stations use proxies to save data frames so that stations can sleep for a longer period of time. To accomplish power aware communications while satisfying QoS requirements, a scheduling scheme is proposed to decide instants at which different flows are to be served. In [21, 22], the authors proposed that stations synchronize their wakeup schedules with each other such that a station can deliver buffered frames at right times. In [27], they proposed an approach allowing stations to power down their wireless interfaces if they do not expect to receive, originate or relay any traffic. Their approach predicts traffic patterns at each station by monitoring incoming and outgoing traffic through stations interfaces. Here, we should point out that power saving policies based on schedules might on the contrary loose energy due to frequent transitions between doze and awake states. We recall that these transitions take time, yet consume battery energy. In [23], they proposed a distributed power control algorithm which adaptively adjusts the transmit power of the station transceiver to achieve power saving in IEEE 802.11 infrastructure mode. In [19, 24], they investigated the behaviour of PSM by means of simulations and experiments. They focused on web applications and showed that non negligible delays are introduced in delivering frames to mobile stations. In [25, 26], authors provide an analytical model for PSM. They reported that PSM, in a standard TCP/IP set up, scales quite well with respect to the number of users inside the hotspot.

In this paper, we propose two traffic aware power saving mechanisms that adapt and improve IEEE 802.11 Power Saving Mode (PSM) for infrastructure WLANs. These two enhancing protocols are called State Aware Power saving Mechanism (SA-PSM) and Once-Poll Power Saving Mechanism (OP-PSM). SA-PSM introduces two new management frames to allow the Access Point to maintain the power saving state of associated stations. The AP relays data frames to destinations whenever they are awake and buffers them momentarily if stations are sleeping. OP-PSM does not add any management frame to IEEE 802.11 PSM, but instead uses just one PS-Poll frame to get all buffered data frames. In both SA-PSM and OP-PSM, the AP is not only capable of

chaining the relay of buffered data frames but also directly forwards newly arrived data frames to awake destinations. Extensive simulations are conducted to prove the efficiency of these mechanisms as compared to the poor performance of PSM. Performance measures studied include the total energy consumption, the consumed power per delivered data frame and the average delay spent in the network. In SA-PSM, we propose that a station may momentarily refrain, for a time called the Watch Time, to request to go to sleep and conserve power. This allows a station to transmit or receive a new data frame immediately. Evaluation of this Watch Time is also presented.

The rest of the paper is organized as follows. In section (2), we present an overview of the IEEE 802.11 power saving mechanism (PSM) for infrastructure networks. We also present some critics to the inherent functioning of PSM. In section (3), we present our first enhancement: the OP-PSM protocol. In section (4), we present our second enhancement: the SA-PSM protocol. Section (5) presents the simulation model used and performance evaluations and comparisons. Section (6) presents the conclusion and some further future work.

2. Power Saving Mode (PSM) in an infrastructure WLAN

In infrastructure mode IEEE 802.11, a mobile station can use the power saving (PS) mode and therefore can power down its transceiver to conserve energy. The basic approach is for the Access Point (AP) to keep all stations timers synchronized. This approach is known under the name of TSF (Timing Synchronization Function) [11]. The AP periodically transmits a frame called a beacon comprising among other things a timestamp to which all stations must synchronize. The transmission period of beacons is called beacon interval and defines Target beacon Transmission Times (TBTTs). At the next TBTT instant, a station expects to receive the next beacon. However, the AP may delay the beacon transmission if the channel is sensed busy, as show on figure 1 below.

Figure 1. Beacon transmission and TBTT

IEEE 802.11 [11] defines two power management modes:

- The Active Mode (AM) in which a station transceiver is always kept awake, and hence cannot be powered down to conserve its energy.
- The Power Save mode (PS mode) in which a station is allowed to power down its transceiver to conserve energy.

In the PS mode, a station can be either in the awake state in which it can send and receive frames, or in the doze state in which its transceiver is powered down and hence cannot send or receive frames.

Each station communicates its power management mode to its AP. Thus the AP knows the power management mode of every station associated to it. The AP must directly deliver unicast frames destined to stations in AM mode and temporally buffer unicast frames destined to stations in PS mode. To inform the stations having buffered unicast frames, the AP includes in each beacon a Traffic Indication Map (TIM), a virtual bit map indicating which stations have buffered unicast frames. A station requests its buffered frame by sending a PS-Poll (Power-Save Poll) management frame to the AP. For broadcast frames delivery, the AP directly delivers a broadcast frame if all member stations are in the Active mode, otherwise it buffers the frame. Buffered multicast frames are periodically forwarded. This period is called the DTIM (Delivery Traffic Indication Message) period.

The IEEE 802.11 defines two medium access protocols: the PCF (Point Coordination Function) protocol in which the AP determines which station has the right to transmit and the DCF (Distributed Coordination Function) protocol in which all stations share the medium in a completely distributed fashion. Accordingly, the beacon interval is divided in two periods: CFP (Contention Free Period) for which the medium access protocol is PCF and CP (Contention Period) for which the medium access protocol is DCF. In this paper, we study the PSM for DCF only.

The following two paragraphs define the detailed functional step to implement the Power Saving Mode mechanism for both the AP and the stations working in PS mode. We note that the same infrastructure mode WLAN can accommodate at the same time stations in PS mode and stations in the AM mode.

2.1 AP operation during the Contention Period

AP maintains the power management mode for each station associated to it. AP operates as follows:

- Buffers unicast frames destined to a station in PS mode.
- Transmits unicast frames destined to a station in Active mode.
- Informs the stations having buffered frames by sending TIM in every beacon at every beacon period.

- Buffers broadcast frames if any member station is in the PS mode.
- Transmits buffered broadcast frames every DTIM.
- Forwards a buffered unicast frame upon receiving a PS-Poll management frame from the destination station.
- Deletes frames buffered for more than a specific period.
- Sends buffered frames without waiting a PS-Poll management frame if the destination station changes to the Active mode.

2.2 PS mode station operation during the Contention Period:

A station in PS mode shall operate as follows:

- Wakes up early enough to receive the beacon frame (just before TBTT).
- Sends a PS-Poll frame when receiving a beacon with a TIM indicating that it has buffered unicast frame.
- Remains in the awake state until receiving a buffered frame or receiving another beacon indicating that the AP has no more buffered frame destined to this station.
- Sends another PS-Poll frame when receiving a frame whose More Data field indicates that further frames are buffered (More Data bit set).
- Wakes up every DTIM period to receive broadcast buffered frames.
- Enters in the doze sate if it has no more data to receive from the AP and no more data to send to the AP.

2.3 PSM critics

From the above discussion of the AP operation, we note that the AP buffers data frames destined to serviced stations activating the PS mode regardless of their actual power management states, that is even if these stations are in the awake state. This means that these data frames will unnecessarily undergo additional transmission delays which may have negative consequences on the QoS for real time applications, yet no power saving is gained. On the contrary, these stations being awake consume indeed some of their batteries energy.

We also note that the TIM within the announced beacon merely indicates the existence of buffered unicast frames and not their number. According to IEEE 802.11 standard [11], a station has to send a PS-Poll management frame to get a single data frame. Thus as many PS-Poll frames should be sent as there are data frames buffered for such a station at its AP. Authors in [31] proposed to further indicate in the

announcements the number of currently buffered frames. In the following section, we propose enhancements of the PSM protocols that take into account both of theses two remarks.

3. OP-PSM: Once Poll Power Saving Mode

Our first enhancement of the PSM protocol is to limit the number of PS-Poll needed to acquire the data frames buffered at the AP. We propose here to use the more data field within the IEEE 802.11 MAC frame. Upon receiving a beacon with a TIM indicating some buffered data frames, a station transmits a single PS-Poll. A received frame with a More Data field set indicates that the station should remain in the awake state to be able to receive further buffered data frames. The AP should keep forwarding the rest of the data frames. Upon receiving a data frame with the More Data bit unset, the station goes into the doze state. In this way, not only the frames buffered at the time of the beacon transmission will be forwarded upon the reception of the single PS-Poll, but further data frames arriving to the AP during the rest of the beacon interval are also forwarded given that the destination station is still in the awake state receiving its buffered data. The station new behavior is characterized as follows:

- Upon reception of a beacon with a TIM indicating buffered data frames, the station sends a PS-Poll management frame.
- Upon reception of a data frame having the More Data bit set, the station remains in the awake state but does not send another PS-Poll as in IEEE 802.11 PSM.
- Upon reception of a data frame having the More Data bit unset, and if it has no more data to send to the AP, the station enters in the doze state.

The AP new behaviour is characterized as follows:

- AP periodically, each beacon interval, transmits a beacon with a TIM indicating the stations having buffered data frames.
- Upon reception of a PS-Poll management frame from destination d, the AP delivers one data frame for d and adds station d to a list called Poll-List if more frames are buffered for this destination. This Poll-List records the identities of the stations having sent a PS-Poll during the current beacon interval and still having further stored data frames. The AP initialized its Poll-List to empty at the start of each beacon interval and before sending its beacon. The data frame is sent with a More Data bit set if more frames are stored at the AP, unset otherwise.

• AP stores incoming data frames in a FCFS (first come first served) queue. During the current beacon interval, the AP keeps forwarding stored data frames to stations registered in the Poll-List. The forwarding is done according to the FCFS policy of the queue. The data frame that is closest to the head of the queue and destined to a station already recorded in the Poll-List will be forwarded first. Here, we limit our study to the FCFS policy, but we should note that other treatments are possible if we want to differentiate between different flows and provide different QoS to different flows.

• Upon forwarding the last buffered data frame for destination d, the AP unset the More Data bit of the frame and delete d from the Poll-List.

4. SA_PSM: State Aware Power Saving Mode

In both regular PSM and OP-PSM, the AP knows only the power saving mode of each station either the Active mode or the PS mode. Incoming data frames are automatically stored by the AP regardless the power state of the destination station to which the frame is destined. While the AP in the regular PSM must store incoming data frames destined to stations in PS mode until they are announced in the TIM on the next beacon and forwarded, in OP-PSM newly arriving data frames could be forwarded during the current beacon interval. This favourable fact can be generalized for all stations in PS mode but in the awake state.

In SA-PSM, each station in the PS mode indicates to the AP its power management state. As in OP-PSM, a station gets awake just enough before the theoretical beacon arrival time (TBTT). But unlike OP-PSM, if the received beacon's TIM does not indicate a buffered data frame, and if the station does not have a data frame to send, the station does not enter directly into the doze state. Instead, the station sends a sleep request (a Sleep-Request management frame) to the AP to enter the doze state. If and only if the AP responds positively (by a positive Sleep-Confirm management frame) then the station goes into doze. Therefore, the AP maintains information on which stations are in the awake state and whish stations are in the Doze states. In SA-PSM, the AP directly forwards incoming data frames destined to stations currently in the awake state and stores only data frames destined to stations currently in the Doze state. We recall here that the AP relays data frames always according to our fixed FCFS policy.

Moreover, in SA-PSM, a station desiring to enter the Doze state, that is just before sending the Sleep-Request management frame, should refrain to do so for a period of time called the Watch Time. This Watch Time is a parameter to set probably by higher layers according to the needs of the application and its traffic pattern. This time might be necessary, for example, to an application layer to force the MAC layer to transmit newly generated data frames and to receive a forwarded frame without any extra delay.

5. Performance Evaluation

The purpose of any power saving mechanism in 802.11 WLANs is to save as much energy as possible, yet not degrading the throughput as it can be when no power saving mechanism is deployed. Any energy saving mechanism should be more effective at light traffic then in heavy traffic conditions. Indeed, when the network load is light the majority of mobile nodes are able to enter the doze state. Whenever load is high, mobile nodes are obliged instead to handle such traffic and hardly find time to go dozing. In other words, an adequate power saving approach should achieve a maximum energy saving at light network loads and should rather not throttle traffic from entering or leaving the network. We recall here that our objective is to conserve battery energy as much as possible, yet to flow traffic with virtually no throttling. Therefore the essential performance measures are:

• the power consumption representing the quantity of energy consumed by network stations,

• the total number of delivered data frames from sources to destinations,

• the power consumed per frame which is the power consumption divided by the total numbers of delivered frames, and

• the mean sojourn time which represents the average time a data frame spent in the network from its generation at the source to its delivery at the destination.

Our objective is to minimize the total power consumption, the power consumption per data frame and the mean sojourn time and to maximize the total number of delivered data frames. Special attentions are given to the power consumption per delivered data frame.

5.1 Simulation model

For our simulation, we used basically the J-Sim simulator [28]. While J-Sim implements only the mesh (ad hoc) version of 802.11, our choice stems from the fact that the TSF function is implemented very adequately. We recall that most researches use instead NS2 which, in our opinion and based on many tests that we conducted, does not implement 802.11 appropriately [29]. To perform our performance evaluation, we have integrated into J-Sim implementations of the 802.11 infrastructure mode hereafter denoted by NO-PSM, the regular PSM, the OP-PSM and the SA-PSM protocols. Extensive experiments are conducted to test and validate our implementations [29].

Recall that a station can be either in the Active mode or PS mode. In PS mode, a station can be either in the awake state or in the doze state. Being in the awake state or the Active mode, the station can be transmitting a frame (data, control or management), receiving a frame (data, control or management) or idle that is neither transmitting nor receiving its destined frames. Hence, it makes sense hereafter to consider that a station can be in one of four states: transmit, receive, idle or sleep (doze). The table below gives the energy consumed by a station per second at each one of these states.

Station state	Power consumption per second
transmit	660 mWatt
receive	395 mWatt
idle	$\alpha * 395$ mWatt
doze or sleep	0 mWatt

Note that α is a parameter between 0 and 1 which we will evaluate its influence on the total power consumption.

Each simulation is performed for a duration of 500 seconds using a beacon interval equals 0.1 seconds, a 2 Mbps wireless medium capacity, a Constant Bit Rate traffic model with a data frame length of 128 bytes and a source station, a destination station and an access point all mutually in Line of Sight (LoS). Both the source and the destination stations are in PS mode.

5.2 Investigation of the Watch Time

Recall that the Watch Time is the period of time during which a station waits for an incoming or an outgoing traffic before it requests from the AP to enter the doze state. Here, we adopt $\alpha=0.25$ and a traffic load equals to 100 Kpbs generated by the source station. That is a data frame each 0.01 second. Figure (2) portrays the energy consumption as a function of the Watch Time. We observe that for a Watch Time up to 0.01 (i.e.; the data frame inter-arrival time), the energy consumption increases rather linearly. This is purely the energy consumption according to the idle state. Beyond such a value of the Watch Time, and according to the CBR used, the energy consumption is collectively due to transmitting, receiving and idle states and thus we see that the energy consumption becomes less dependent on the Watch Time as the later attains larger values.

Figure (3) below provides the total number of delivered data frames as a function of the Watch
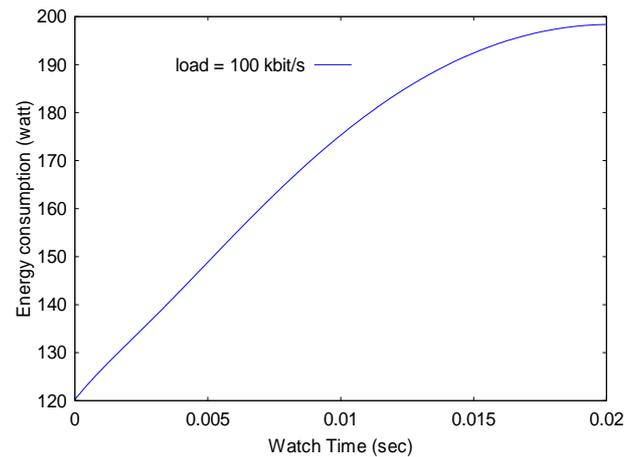
Figure 2. Energy consumption versus Watch Time

Time. We observe that it is rather insensitive to the Watch Time. For such a traffic load, all data frames get chance to be delivered. A data frame is delivered either during the current or the next beacon interval. This fact has rather an implication on the mean sojourn time given on figure (4) below.
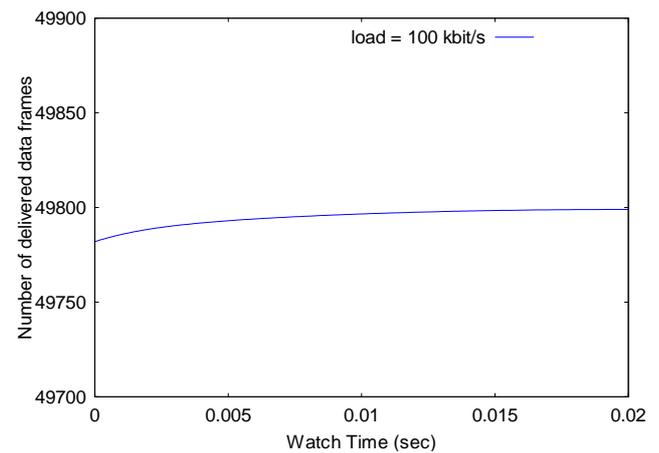

Figure 3. Number of delivered data frames versus Watch Time
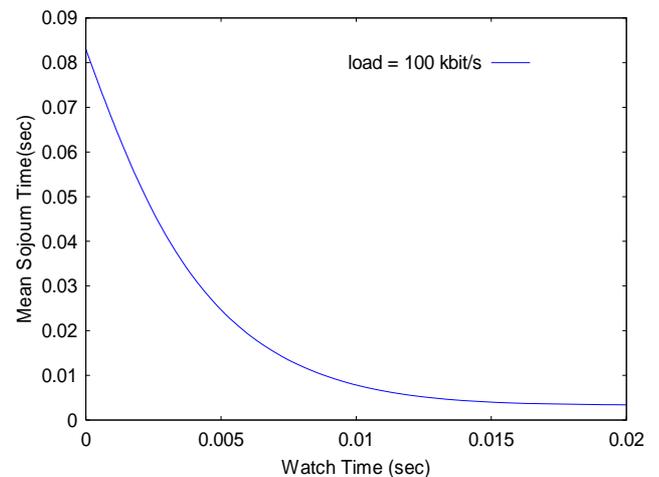
Figure 4. Mean Sojourn Time versus Watch Time

We clearly note that for a Watch Time smaller than 0.01 seconds, which is the inter arrival time of the considered CBR, the mean sojourn time is relatively high. Indeed, for a null Watch Time, any later arrived

data frame is only transmitted in the next beacon interval. Here, we should note that the mean sojourn time decreases rapidly as the Watch Time increases. Beyond the value of 0.01 seconds, the mean sojourn time stabilizes. Therefore, we are dealing with real-time applications, care should be taken to fix an appropriate value for the Watch Time. Since our objective is rather to minimize the energy consumption while maximizing the number of delivered data frames, we plot the energy consumed per delivered data frame in figure (5) below for a traffic load of 100 Kbps and 200 Kbps.
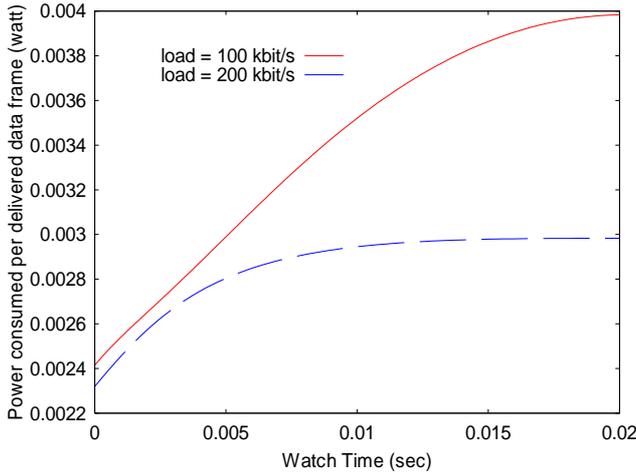

Figure 5. Power consumed per delivered data frame

We clearly observe that a Watch Time equal to zero minimizes the energy consumed per delivered data frame. The curve for a traffic load 200 Kbps is lower than the one corresponding to a traffic load of 100 Kbps since much more data frames are delivered, and therefore the influence of the idle state power consumption gets lower. For the rest of the paper, we shall consider only a null Watch Time value.

## 5.3 Performance of the proposed power conservation protocols

We recall that our primary objective is to save the maximum energy at light traffic conditions and to flow the maximum traffic at high load conditions. For our purpose, a good power saving protocol should try to deliver data frames as much as the NO-PSM, yet give the best savings in energy. Figure (6) below portrays the number of delivered data frames as a function of the traffic load submitted to the network. This figure shows the inefficiency of the PSM protocol. Such a protocol, in the quest of saving the maximum of energy, throttles the network traffic. For PSM, the number of delivered data frames degrades rapidly even at moderate traffic loads. This is due to the need of sending a separate PS-Poll management frame to get a single buffered data frame. Moreover, These PS-Poll frames contend for the medium with the transmission of data frames.
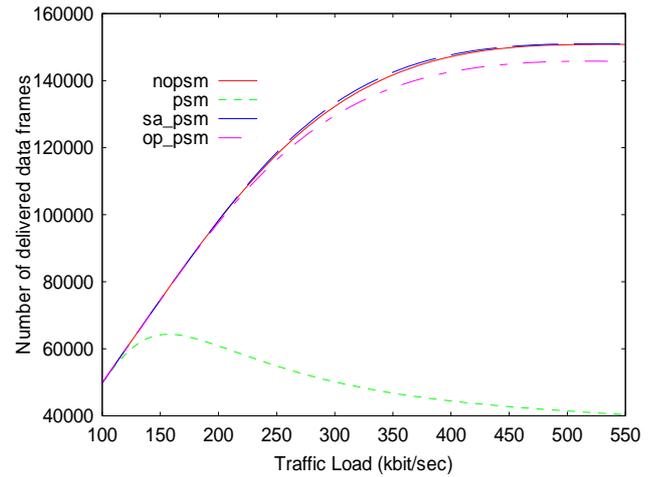
Figure 6. Number of delivered data frames versus the

traffic load

This contention gets stronger as traffic load increases. Both OP-PSM and SA-PSM exhibit good performance and level up nicely with NO-PSM. It is also interesting to note that SA-PSM stands up superbly in that it delivers as much data frames as NO-PSM.

The power consumption as a function of traffic load is portrayed on figure (7) below.
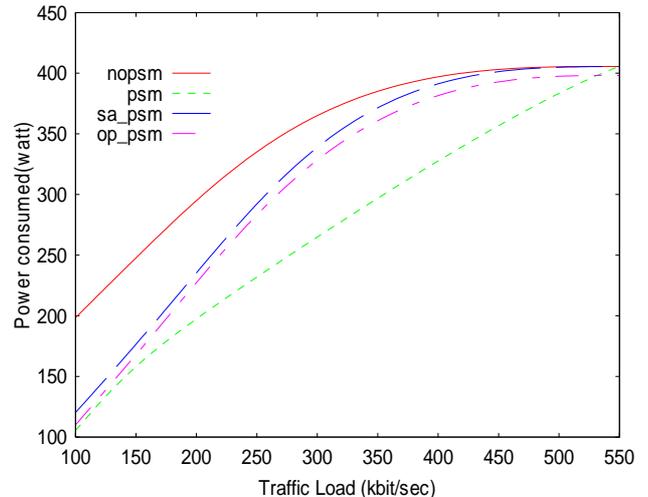
Figure 7. Power consumed versus traffic load

We observe that NO-PSM uses more energy since stations do not use any power saving mechanism and therefore stay in the awake state all the time. We also observe that PSM conserves more energy than all the other protocols due to its very conservative strategy. SA-PSM conserves slightly less power than OP-PSM since stations are obliged to wait for the reception of a positive Sleep-Response before going into the doze state. We recall here that we are using a null value for the Watch Time. We may also note that although Figure (7) portrays a substantial difference in power consumption between NO-PSM and the others, such difference could be accentuated if we consider more stations in the network and use a larger value for α. We also note that all curves goes to a limiting value

as the load become very high since at such a high load all stations become awake all the time.

Now it is interesting to see the efficiency of these protocols in terms of the energy consumed per delivered data frame. This is exhibited in figure (8) below.
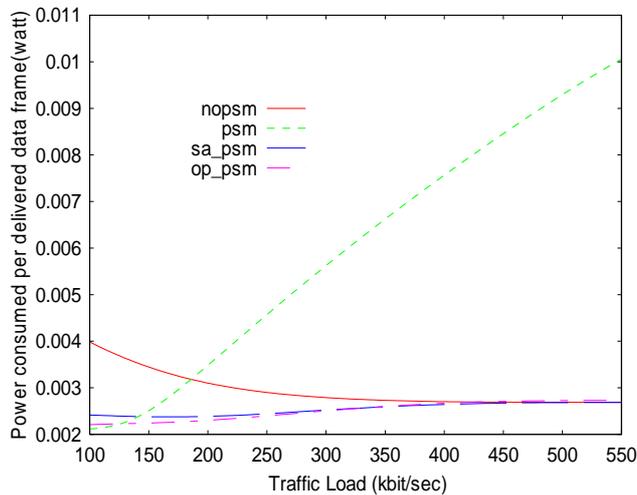

Figure 8. Power consumed per delivered data frame

We interestingly note that PSM not only throttles the network traffic as shown on figure (6), yet it does not adequately save energy as supposed to be. Virtually at all traffic loads, OP-PSM and SA-PSM nicely outperform PSM. OP-PSM and SA-PSM portray a great energy saving per delivered data frame. These two protocols exhibit a noticeable nice behavior: at low traffic loads, OP-PSM and SA-PSM save a large amount of energy per delivered data frame, and at high traffic loads they flow as much traffic as NO-PSM.

We notice also that while OP-PSM stands slightly better at light traffic loads, SA-PSM become slightly better at moderate to high traffic loads. We recall here from figure (6) that SA-PSM delivers more data frames than OP-PSM. This fact becomes clearer at high traffic loads.

Now we turn to the mean sojourn time. Figure (9) below portrays the mean sojourn time of a data frame as a function of the data frame traffic load. We observe that PSM requires a large average delay to deliver a data frame. This is mainly due to the traffic throttling performed by PSM. We note that the other three protocols exhibit a much better mean sojourn time. While SA-PSM slightly outperforms NO-PSM, it equals NO-PSM (the curves for SA-PSM and NO-PSM are superimposed). This is to say that SA-PSM induces no tangible penalty on the mean sojourn time in performing its task to save energy. For interactive real time applications such as VoIP, the mean sojourn time is a vital parameter and should be smaller than 100 milliseconds [20]. We should recall here that we are using a null value for the Watch Time. Larger

values will certainly decrease SA-PSM induced mean sojourn time and consequently give preference to this protocol.
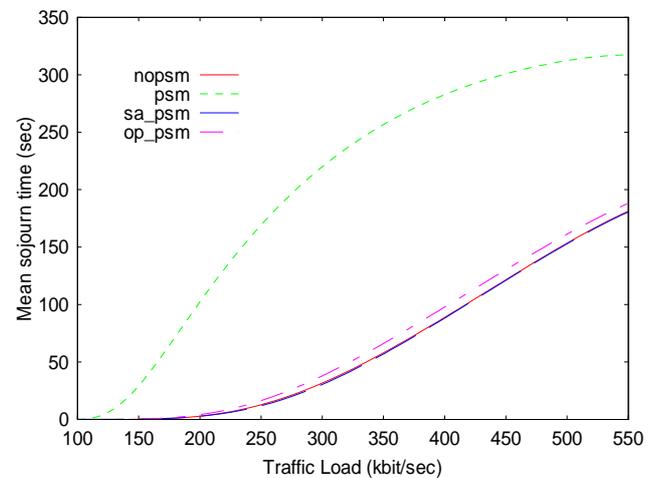
Figure 9. Mean sojourn time versus traffic load

Consequently, we observe from figure (9) that PSM could only be adequate for such applications when traffic load is under say 200 Kbps that is below 200 data frames per seconds. We recall that we are using a data frame length of 128 bytes (around 1 Kbits) and a network capacity of 2 Mbps. The other protocols and in particular SA-PSM allows more than double the traffic load.

5.4 Influence of the energy consumed by the idle state

The energy consumed by a station at the idle state varies from a transceiver brand to another [10, 14, 15, 16, 17]. To analyze the influence of this energy consumption on the performance of the different protocols, we have fixed it as a fraction of the energy consumed during a frame reception. This fraction denoted by α is so far maintained at 0.25. Many transceivers actually use larger values [17].

Figure (10) shows the amount of energy consumed by the four protocols as a function of the value of α and for traffic load equals to 100 Kbps. At such a light traffic load, PSM, OP-PSM and SA-PSM do not have intense traffic to handle and thus spent most of the time in the doze state. On the contrary, NO-PSM rather remains in the idle state which consumes energy proportionally to the value α. For a value of α equals to 0.8, which is normally the practical used value [10, 14, 15, 16, 17], we notice the large energy saving performed by the other protocols.

Figure (11) portrays also the power consumption as a function of α but instead for a traffic load of 400 Kbps. For this high traffic load, the curves corresponding to NO-PSM and SA-PSM are superimposed meaning that both protocols are in

awake state all the time to be able to flow the traffic. OP-PSM curve has the same behavior though attains a better energy conservation at the expense of less traffic delivery as it has been shown on figure (6).
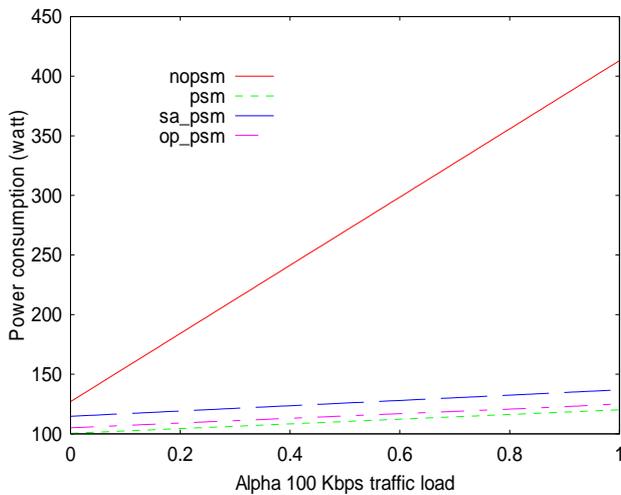
Figure 10. Power consumption versus α

100 Kbps traffic load
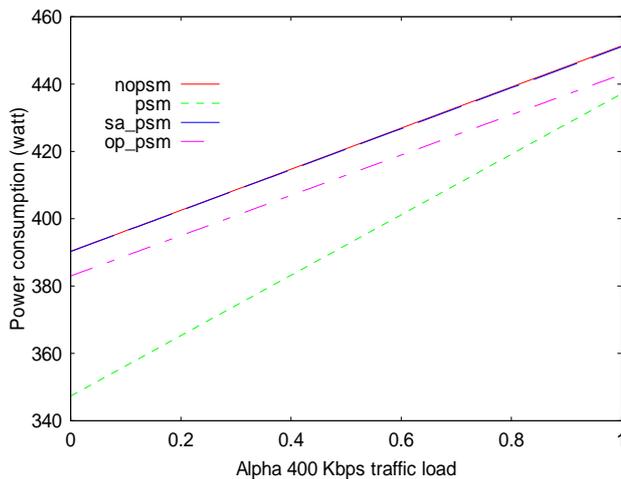
Figure 11. Power consumption versus α

400 Kbps traffic load

PSM, on the other hand shows a lesser power consumption since it throttles the traffic flow, however more sensitive to the value of α since it needs to send many PS-Poll management frames which get in contention with data frames and therefore the throughput goes down as shown in figure (6) and stations spend more time in back off periods consuming energy at the rate of the idle state.

6. Conclusion

This paper investigates the adequacy of the well known power saving mechanism, the IEEE 802.11 PSM for infrastructure mode. PSM stands very short and does not level up to its design objectives. Extensive simulations are conducted to show that

PSM conserves energy at the expenses of throttling the network traffic flow. At high traffic loads, PSM exhibits a very poor throughput and excessive power consumption per delivered data frame. We investigated the inherent properties that made PSM inefficient and proposed two different enhancements. We showed through extensive simulations that tangible improvements are attained. These enhancements, State Aware PSM and Once Poll PSM, save power as much as PSM for light traffic load, yet deliver as much throughput as when no power saving mechanism is deployed.

Both SA-PSM and OP-PSM provide a much less average time spent by a data frame from its generation at the source station until its delivery to the destination station. At nominal workload conditions, both protocols could exhibit adequate average sojourn time, under few tens milliseconds. Further investigations are still needed to evaluate the performance of these protocols when used for interactive real time applications such as VoIP.

References

[1]   P. Bahl, W. Russel, Y.M. Wang, A. Balachandranand, G. M. Voelker and A. Miu, "PAWNs: satisfying the need for ubiquitous secure connectivity and location services", IEEE Wireless Communications, Vol. 9, No. 1, 2002.

[2]   C. Bormann and N. Pollem, "Wbone: WLAN roaming based on deep security", TERENA Networking Conference (TNC), May, 2003.

[3]   D. Schwab and R. Bunt, "Characterising the use of a campus wireless network", IEEE INFOCOM'04, Hong Kong, March 7-11, 2004.

[4]   K.D. Lin and J.F. Chang, "Communications and entertainment onboard a high-speed public transport system", IEEE Wireless Communications, Vol. 9, No. 1, February 2002.

[5]   S. Byers and D. Kormann, "802.11b Access Point mapping", Communications of the ACM, Vol. 46, No. 5, 2003.

[6]   J.P. Singh N. bambos, B. Srinivasan and D. Clawin, "Wireless LAN performance under varied stress conditions in vehicular traffic scenarios", IEEE Vehicular Technology Conference, Vol. 2, Fall 2002.

[7] J. Ott and D. Kutscher, "Drive-thru Internet: IEEE 802.11B for automobile users", IEEE INFOCOM 2004.

[8] D. Kotz and K. Essien, "Characterizing usage of a campus wide wireless network", Proceedings of the 8th Annual Conference on Mobile Computing and Networking, pp. 107-118, September 2002.

[9] T. Starnar, "Powerful change Part 1: Batteries and possible alternatives for the mobile market", IEEE Pervasive Computing, Vol. 2, No. 4, pp. 86-88, October-December, 2003.

[10] L. Feeney and M. Nilson, "Investigating the energy consumption of a wireless network interface in an ad hoc networking environment", IEEE INFOCOM 2001, Vol. 3, pp. 1548-1557, 2001.

[11] ANSI/IEEE Standard 802.11, "Wireless LAN Medium, Access Control (MAC) and Physical, Layer (PHY) Specifications", 1999.

[12] A. Kamerman and L. Monteban, "WaveLan II: a high performance wireless LAN for the unlicenced band", Bell Labs Technical Journal, Vol. 2, No. 3, summer 1997.

[13] P.J.M. Havingaand G.J.M. Smit, "Energy efficient TDMA medium access control protocol scheduling", Proceedings of the Asian International Mobile Computing Conference (AMOC200), November, 2000.

[14] B. Awerbuch, D. Holmer and H. Rubens, "The pulse protocol: energy efficient infrastructure access", IEEE INFOCOM'04, Hong Kong, March 7-11, 2004.

[15] IEEE 802.11 WaveLAN Wireless Network Card, User's Guide, p.A-1, Lucent Technologies.

[16] M. Stemm and R.H. Katz, "Measuring and reducing energy consumption of network interfaces in hand held devices", IEICE Transactions on Communications, Special Issue on Mobile Computing, Vol. E80-B, No. 8, pp. 1125-1131, 1997.

[17] C.E. Jones, K. Sivalingam, p; Agrawal and J Chen, "A survey of energy efficient network protocols for wireless networks", ACM Journal Wireless Networks 7 (4), pp. 343-358, 2001.

[18] H. P. Lin, S.C. Huang and R.H. Jan, "A power saving scheduling for infrastructure mode 802.11 wireless LANs", in press in Computer Communications, Elsevier 2006.

[19] R. Krashinsky and H. Balakrishnan, "Minimizing energy for wireless web access with bounded slowdown", Proceedings of the 8th Annual ACME/IEEE International Conference on Mobile Computing and Networking (MobiCom 2002), Atlanta, Georgia, USA, pp. 119-130, September 23-28, 2002.

[20] H. Zhu and G. Cao, "A power aware and QoS-aware service model on wireless networks" IEEE INFOCOM'04, Hong Kong, March 7-11, 2004.

[21] J.R. Jiang, Y.C. Tseng C.S. Hsu and T.H. Lai, "Quorum-based asynchronous power-saving protocols for 802.11 ad hoc networks", Proceedings of the International Conference on Parallel Processing, Nice, France, pp. 812-817, April 22-26, 2003.

[22] J.R. Jiang, Y.C. Tseng C.S. Hsu and T.H. Lai, "Quorum-based asynchronous power-saving protocols for 802.11 ad hoc networks", ACM mobile networking and applications (MONET), special issue on algorithmic solutions for wireless, mobile, ad hoc and sensor networks, vol. 10, No. ½, pp. 169-181, 2005.

[23] A. Sheth and R. Han, "Adaptive power control and selective radio activation for low-power infrastructure-mode 802.11 LANs", Proceedings of 23rd International Conference on Distributed Computing Systems (ICDCSW'03), Providence, Rode Island, USA, pp. 812-817, May 19-22, 2003.

[24] M. Anand, E. Nightingale and J. Flinn, "Self tuning wireless network power management", Proceedings of the 9th ACM Annual International Conference on Mobile Computing and Networking (MobiCom 2003), San Diego, California, USA, September 14-19, 2003.

[25] G. Anastasi, M. Conti, E. Gregori and A Passarella, "Saving energy in Wi-Fi hotspots through 802.11 PSM: An analytical model", WIOPT, 2004.

[26] G. Anastasi, M. Conti, E. Gregori and A Passarella, "Performance Comparison of power saving strategies for mobile web access",

Performance Evaluation, Vol. 53, No. 3-4, pp. 273-294, August 2003.

[27] T. Zhang, P. Gurung, E. Van Den Berg, S. Madhani and A. Muttreja, "Silent networking for energy constrained nodes", in press in Computer Communications, Elsevier 2006.

[28] J-Sim simulator: on-line at www.j-sim.org, last visited in 23-04-2006.

[29] Wafa Akkari, Abdelfatteh Belghith and Hanen Idoudi, « Evaluation de l'implémentation de PSM (Power Saving Mode) sous le simulateur J-Sim », GEI'06, Hammamet, Tunisia, March 23-26, 2006.

[30] T. Simunic and S. Boyd, "Managing power consumption in networks on ships", ACM DATE, 2002.

[31] E.S. Jung and N.H. Vaidya, "An energy efficient MAC protocol for wireless LANs", INFOCOM 2002, New York , USA, June 23-27 2002.

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