Study and Analysis of Performance of IEEE 802.11 Power Saving Mode

A THESIS
SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR DEGREE OF

BACHELOR OF TECHNOLOGY

IN THE DEPARTMENT OF
COMPUTER SCIENCE AND ENGINEERING

by

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May 2011

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Certificate

This is to certify that the work in this thesis Report entitled ***"Study and Analysis of Performance of IEEE 802.11 Power Saving Mode"*** submitted by ***Shrimoy Tripathy(107CS049)*** has been carried out under my supervision in partial fulfillment of the requirements for the degree of Bachelor of Technology in Computer Science during session 2010-2011 in the department of Computer Science and Engineering, National Institute of Technology, Rourkela, and this work has not been submitted for any degree or academic award elsewhere.

Place: NIT, Rourkela
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ACKNOWLEDGEMENT

First of all I would like to express our deep sense of respect and gratitude towards our Project Guide **Prof. Ashok Kumar Turuk**, *Professor, Department of Computer Science and Engineering*, for his guidance, support, motivation and encouragement throughout the period for which this work was carried out. His readiness for consultation at all times, his educative comments, his concern, criticism and assistance even with practical things have been invaluable and pivotal.

I would also like to convey my sincerest gratitude and indebtedness to my entire faculty members and staff of the Department of Computer Science and Engineering, NIT Rourkela, who imparted their efforts and guidance at appropriate times without which it would have been very difficult on my part to finish the project work. A vote of thanks to my fellow students for their friendly co-operation and suggestions.

Shrimoy Tripathy(107CS049)

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Abstract

The nodes need to be turned into low-power states when they are not in use to conserve energy and power for battery-powered wireless devices. One of the most important techniques in wireless LAN and multi-hop wireless networks is the IEEE 802.11 power saving mode which is used to coordinate the power states of communication devices [1]. Energy performance and bandwidth resource limitations are the backbone of any ad hoc network design. Multi-rate adaptation architectures had been proposed to increase bandwidth utilization efficiency and to reduce the control overhead [4]. Simulations were performed in order to see how specific parameters influence the performance of the power saving mechanism for the wireless Local Area Networks IEEE 802.11. Simulations were made for an adhoc- network with 25 stations. The throughput were obtained for specific window size and beacon interval and then an optimal ratio between ATIM window interval and beacon interval is recommended. It is found that the ratio between ATIM window interval and beacon interval should be between 30 to 40 percent.

Chapter 1

INTRODUCTION

1.1 Overview

In networking, Wireless Local Area Networks (WLANs) are a fast growing area . The main reason is due to the upcoming of movable devices like mobile phones and notebooks. A key feature of these devices is that the finite battery energy, which limits their time in action. So there is a need for power saving mechanisms, which prolong the life time of the batteries [2]. Limited battery capacity and finite bandwidth resources are the most important constraints in ad hoc networks design. Therefore, most of the research on ad hoc networks has focused on algorithms which reduce control overhead and increase the efficiency of bandwidth usage [4]. There are two different operational modes defined in IEEE 802.11: the infrastructure networks in which a specific central entity manages the communication between nodes, and the ad hoc networks where mobile nodes communicate with each other over multiple wireless hops [3]. In ad hoc networks, nodes are mobile and they rely entirely on their finite battery energy. Therefore, energy conservation techniques are needed which increase the lifetime of the nodes and the network as a whole [3]. IEEE 802.11 defined a Power Saving Mechanism (PSM) for both infrastructure networks, namely, Basic Service Set(BSS) and ad hoc networks (Independent Basic Service Set(IBSS)) [6]. In IEEE 802.11, Power Saving Mechanism (PSM) is based on powering down nodes wireless interfaces whenever there is no traffic activity. For Ad-Hoc networks, PSM divides time into specific periods called Beacon intervals. At each beacon intervals beginning, a starting sub-period called the ATIM window is reserved during which all the stations must be active to exchange frames (called beacons) for synchronization and announce buffered data frames (called ATIM messages). Data frames are temporally buffered by each station which are to be relayed to a neighbouring station whose transceiver is powered down. In the ATIM window of the following beacon interval, these data frames will be announced. If any node had sent or received announcements, then it must remain active during the entire beacon interval. Newly generated data frames are transmitted by the generating station during the current beacon interval only if this station has announced buffered data frames to the destined stations, otherwise the traffic should be delayed to be first announced in the next ATIM window. A station must announce all its buffered traffic to all the destined neighbours irrespective of whether they intend or not to remain active in the beyond ATIM window. Also, forwarding of traffic to a neighbouring station during the current beacon interval is only possible if the station has announced buffered data frames to the destined stations, otherwise the traffic would be delayed to be first announced in the next ATIM window. This behaviour inherent to IEEE 802.11 PSM results not only in wastage of energy, but also in an increase in the time of data frames and reduction in network throughput [3].

1.2 Motivation For Thesis

Major hurdles for any adhoc-network design are energy performance and bandwidth resource limitations. Moreover, the best way to conserve energy for wireless nodes would be to switch them off. But if we do this, the nodes will lose the capability to communicate in both directions, i.e. a node in this type of a power saving mode would not know if any packets are arriving for it during this time [2]. So, there is a need for power saving mechanisms, by which nodes can sleep during the time in which they dont perform any transmission and reception, and can remain active when they transmit or receive any signals.

1.3 Organization Of Thesis

This thesis is divided into 4 chapters. The chapter 1 gives some introduction and motivation for study of performance of IEEE 802.11 Power Saving Mechanism (PSM). The chapter 2 deals with the literature study of IEEE 802.11 Power Saving Mechanism (PSM). Chapter 3 discusses the related works in this field like the multirate power save protocols, neighbourhood aware power saving mechanism (NA-PSM), neighbourhood and traffic aware power saving mechanism (NTA-PSM), and improving IEEE 802.11 Power Saving Mechanism (IPSM) etc. Chapter 4 briefs the simulation environment that has been used to simulate the power saving mechanism for an adhoc- network with 25 stations. The throughput were obtained for specific window size and beacon interval and then an optimal ratio between ATIM window interval and beacon interval is recommended . Chapter 5 concludes the thesis.

Chapter 2

IEEE 802.11 POWER SAVING MECHANISM (PSM)

2.1 Introduction

In IEEE 802.11 Power Saving Mechanism, all nodes in PS mode need to be synchronized to wake up at the same time. At this time there starts a window in which the sending node announces buffered frames for the receiving node. A node that received such an announcement frame stays awake until the frame was delivered. Therefore, in IEEE 802.11, Power saving consists of a Timing Synchronization Function (TSF) and an actual power saving mechanism. For an infrastructure network (the Point Coordination Function - PCF), the Timing Synchronization Function can be seen in Figure 2.1. The access point (AP) which is responsible for generating beacons, also contains a valid time stamp and other information. Nodes within the Basic Service Set (BSS) adjust their local timers to that time stamp. If the channel is in use after the beacon interval then, the AP has to wait for the channel to be free again [2].

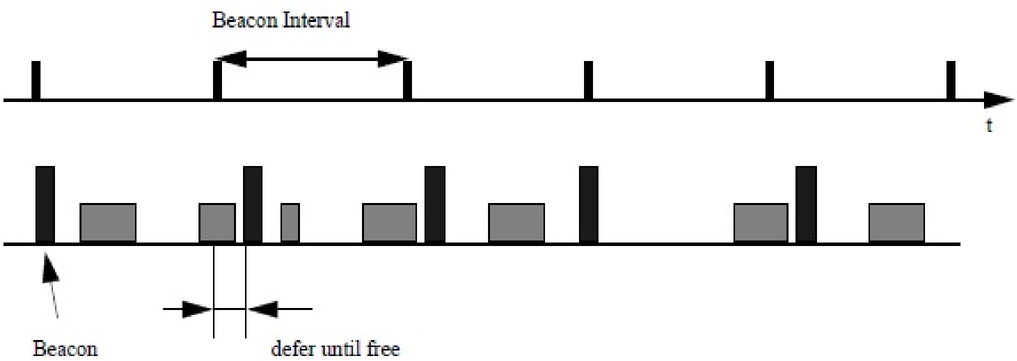

Figure 2.1: TSF for infrastructure networks in 802.11 [2]

For an ad-hoc network (the Distributed Coordination Function - DCF, see Figure 2.2), the situation is more complicated. Here, the timers adjust in a distributed way. Every node is responsible for generating a beacon. All nodes compete for transmission of the beacon after the beacon interval using the standard backoff algorithm. The node which wins the competition, transmits the beacon and all the other nodes cancel their beacon transmission and adjust their local timers to the time stamp of the transmitted beacon [2].

The power management in the Point Coordination Function is simple due to the existence of the access point which serves as the central buffer for all packets to the nodes in doze(sleep) mode. The AP transmits together a beacon and a Traffic Indication Map (TIM). For the nodes in sleep mode, all the unicast packets are announced in the TIM. Afterwards, the mobile nodes poll the AP for the packets. If broadcast or multicast frames need to be transmitted, they are announced by a Delivery TIM (DTIM) and are sent immediately afterwards. The nodes in power save mode wake up just before the end of the beacon interval and they stay awake till the end of beacon transmission [2]. For an ad-hoc network (the Distributed Coordination Function DCF), the timers adjust in a distributed manner. For a node in doze state, the packets are buffered by the sender till the beacon interval ends. They are announced using Ad-hoc Traffic Indication Maps (ATIMs). These are transmitted in a special interval

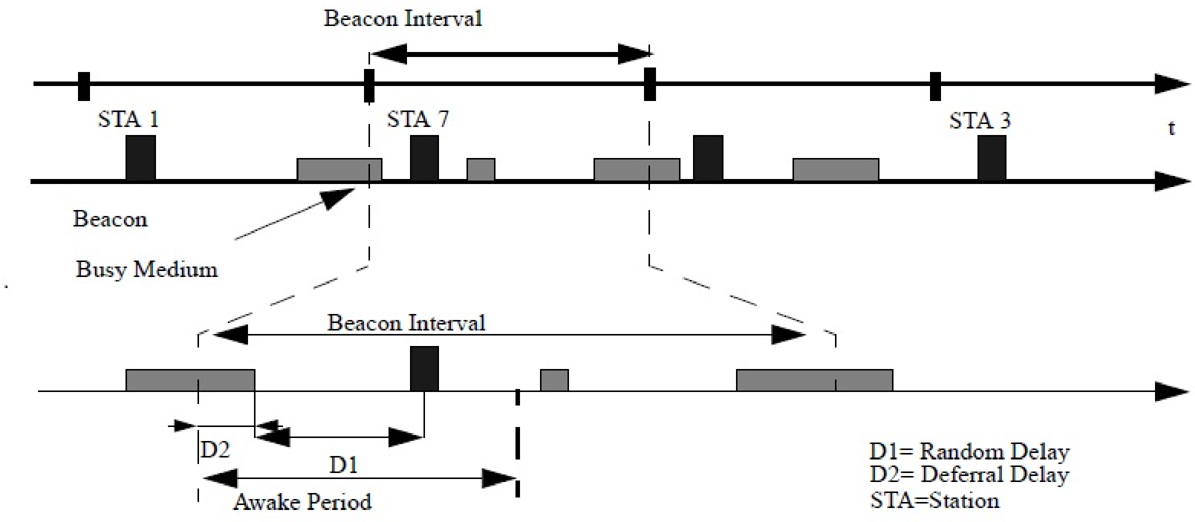

Figure 2.2: TSF for ad-hoc networks in 802.11 [2]

called the ATIM window, directly after the beacon. ATIMs are unicast frames which must be acknowledged by the receiver. After the acknowledgment is sent, the receiver stays awake and it waits for the announced packet (see Figure 2.3).Standard back off algorithm is used for the transmission of both ATIMs and the data packets [2].

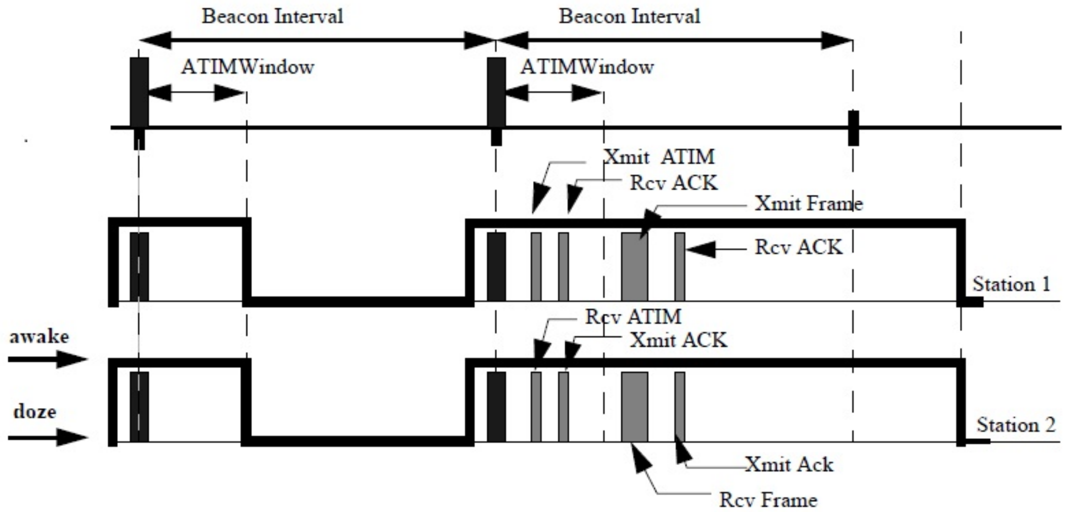

Figure 2.3: Power Management in the DCF of 802.11 [2]

2.2 Synchronization In An Ad-hoc Network

In an Ad-Hoc network, synchronization is based on a distributed Timing Synchronization Function (TSF) that keeps the timers synchronized for all nodes of the IBSS. Each of the nodes maintains a local TSF timer. Every node expects to receive beacons at every Beacon interval. A node sending a beacon synchronizes its own local TSF time with the Beacons timestamp. The node that initiated the IBSS, establishes the beacon interval of the IBSS. A series of Theoretical Beacon Transmission Times (TBTTs) are defined which are exactly one beacon interval time units apart. According to the following criteria, a node will transmit a beacon:

- A node awakes just before the end of the TBTT so that it is able to receive beacons.
- A random delay is calculated upon which it transmits a beacon.
- The random delay is decremented according to the back off algorithm.
- If no beacon was received and the random delay has expired, then then it sends its own beacon.
- If a beacon was received before the random delay has expired, then the decrementing of the random delay is suspended [3].

2.3 Power States In Power Save Mode (PSM)

Two different power states are defined in PSM. They are:

- Awake: In the awake state, the nodes wireless interface is powered on and is able to transmit and receive. A node can be transmitting, receiving or just in idle state.
- Sleep (or Doze): In the doze state, the nodes wireless interface is powered down. So it is not capable of transmission or reception [3].

PSM defines two management modes:

- Active Mode (AM): the node is in the awake state.
- Power Saving (PS): the node can either be in the awake state or in the sleep (or doze) state [3].

Each node must stay awake during a fixed time period, called the Adhoc traffic Indication Message (ATIM) window, at the start of each beacon interval. Data frames which are destined to other nodes in the doze state are temporally buffered by the node. During the ATIM window, these buffered data frames are announced using unicast ATIM frames. On receiving an ATIM frame, the node replies immediately after a Short Inter Frame Spacing (SIFS) by sending an ATIM acknowledgement and stays awake for the entire beacon interval waiting to receive the announced frames. If a node hasnt sent any ATIM frame nor received any ATIM-ACK frame, it enters the Sleep state at the end of the ATIM window. The announced frames are transmitted using the normal CSMA/CA back off algorithm, after the completion of ATIM window. If a node has sent at least one ATIM frame, it must stay awake during the entire current beacon interval [3].

2.4 Issue of PSM for Ad Hoc Networks

During the ATIM window, each node, having data frames for transmission, must announce its traffic by sending unicast ATIM frames to the destination node. An ATIM frame contains both the source and the destination nodes addresses. The destination node, upon reception of the ATIM frames, replies by sending unicast ATIM-ACKs. As an ATIM-ACK contains only the ATIM-ACK receiving nodes address that is the address of the node that had sent the ATIM-ACK. So, during the ATIM window, there will be ATIM and ATIM-ACK frames sent as many as there are nodes which have traffic to send or forward. Therefore, in a dense network with many nodes having traffic to send, a large period of announcements (ATIM window) are required for nodes for sending their ATIM frames and receiving the corresponding ATIM-ACK frames. But, for a fixed size of the beacon interval, increasing the ATIM window results in the reduction of the beyond ATIM window and so the time window reserved for the transmission of data is reduced. This affects the network throughput [3].

Chapter 3

RELATED WORKS

3.1 Introduction

The devices need to be changed to low-power states when they are idle is an important technique to conserve power for battery-powered wireless devices. One of the most popular techniques in wireless LAN and multi-hop wireless networks is the IEEE 802.11 power saving mode which coordinates the power states of communication devices [1]. Many power saving mechanisms are proposed till date. This thesis presents study of some of the popular power saving mechanisms which include the neighbourhood aware-power saving mechanism (NA-PSM), neighbourhood and traffic aware-power saving mechanism (NTA-PSM), multilevel power save protocols, etc.

3.2 The Neighbourhood Aware-Power Saving Mechanism: NA-PSM

In NA-PSM [3], each of the nodes in the network maintains a data structure, referred as the Active Neighbour Table (ANT), which contains the identities of the neighbouring nodes which remain active beyond the current ATIM window (during the current beacon interval). At the beginning of each beacon interval, this table needs to be initialized to empty. The Active Neighbour Table (ANT) is updated by the following procedure:

- When a node hears an ATIM frame transmission not destined to it and addressed to a node which is not already in its ANT, it inserts the source address of this ATIM frame into its ANT. The address of the destination node of the ATIM frame is temporally saved.
- After a SIFS, this node either hears the corresponding ATIM acknowledgement (just after a Short Inter Frame Spacing (SIFS) [6]) and then the saved address is inserted in its ANT, or it does not hear the corresponding ATIM-ACK and then the saved address is discarded.

When a source node has some traffic which is to be delivered to a destined neighbouring node and before an ATIM frame is sent, the source node consults its ANT to check whether the destined node is already awake. If it is awake (that is the destined node is present in its ANT), the source node does not send an ATIM-ACK but it waits for the completion of the ATIM window for the transmission of its data frames according to the CSMA/CA algorithm. However, if the destined node is not present in the ANT of the source node, then source node sends its own ATIM frame to announce the traffic. A state diagram which governs the operation of the NA-PSM for each station in the network is provided in figure 3.1.

- When the frame reception starts (state1)
- When the frame reception ends (state2)
- When the frame transmission ends(state3)

- When the frame transmission starts(state4)
- just before the theoretical beacon transmission times (TBTT) ends (upon the beginning of the next Beacon interval) (state5)
- When the ATIM window ends, if the node has neither sent an ATIM frame nor an ATIM-ACK frame and has no traffic which is to be delivered to an already awake node (by inspecting its ANT without sending an ATIM frame) (state6) [3].

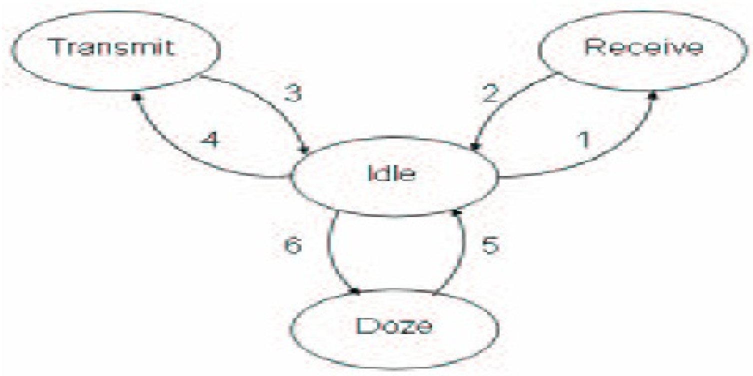

Figure 3.1: State Diagram showing the possible states and transitions for NA-PSM [3]

Since the number of announcement packets (ATIM and ATIM-ACK) which are exchanged are reduced, a smaller ATIM window can be used. This is considered as an important advantage. So, when a smaller ATIM window is used, the time period reserved for transmission of data can be increased and this will result in increased network aggregate throughput. As a result of the increased throughput, the delay of the received packets is considerably reduced.

3.3 The Neighbourhood And Traffic Aware-Power Saving Mechanism: NTA-PSM

In [6], PSM explains that if a node had sent or received an announcement or had sent a beacon then it must stay awake for the entire current beacon interval. In [7], it was shown that this may result in wasting energy especially when the traffic loads are light, where nodes should save the most. An enhancement called the Traffic Aware Power Saving Mechanism (TA-PSM) is proposed to solve this problem by allowing nodes to enter the sleep (or doze) mode when they are not involved in data transmission even if they had already sent a beacon, an ATIM or an ATIM-ACK. By TA-PSM, the energy consumption can be reduced by making PSM more sensitive to the present traffic load. First, a one bit MoreData field (one bit) is added into the frame header which indicates to the receiving node that further pending data frames are buffered. When the MoreData bit is set in the received frame, both transmitting and receiving nodes stay awake; otherwise, they can enter the doze state. So, the sending node can transmit further data frames which arrive within the same beacon interval and are destined for the same receiving node. Also, a node sending a Beacon within the ATIM window enters the doze mode if it hadnt sent or received ATIM frames during the present ATIM window. So, TA-PSM results in less power consumption per delivered data frame than PSM.

In NA-PSM [3], buffered data frames are announced by a node using Unicast ATIM frames in the ATIM window. If a node receives a unicast ATIM frame then it responds by sending a unicast ATIM acknowledgment. Both these nodes must remain awake during the entire beacon interval. All other nodes having any traffic to deliver to the source or the destination of any ATIM frame must stay awake during the present beacon interval. If one of these nodes has just one or few frames to transmit to another node, both nodes will stay awake for the entire beacon interval. This results in more consumption of energy than needed. By NTA-PSM, energy conservation is more effective for light traffic load than in heavy traffic conditions. When the traffic load is light, most of the mobile nodes are able to enter the doze mode. Whenever, the traffic load is heavy, mobile nodes handle such traffic and they hardly doze. So, an adequate power saving mechanism should achieve maximum energy conservation at light traffic loads and should not adversely affect the traffic from entering or leaving the network.

3.4 Multi-level power save protocols

In multi-level power save protocol [4], k power levels are added to PSM which may give rise to some of the problems explained below:

- Wake up and sleep process: Here, the nodes traverse from one level to another, so, depending on transmission or not the latency of the network will increase and the network performance will decrease. If the nodes have a packet to send it will wait till the next ATIM (ad hoc traffic indication message) window which may be very far because this particular node is in level k.

- Sensitivity of the Node: As the node traverses to higher levels (level k), the sensation of the node about its environment change will reduce and this is a critical issue in ad hoc network.

- Traverse from level to level by factor of 2: At k= 1, the ratio between ATIM (ad hoc traffic indication message) window and beacon window interval is 10 percent. By moving to level k= 2, this ratio will be 5 percent and for k= 3 the ratio will be 2.5 percent and so on. The difference between the first and the second ratio is huge, which will affect the networks performance.

In multi-level power save protocols, the k levels are determined in two levels because more energy is saved than standard PSM, with reasonable performance. The nodes traverse from level to level by factor of one so that the latency of the network

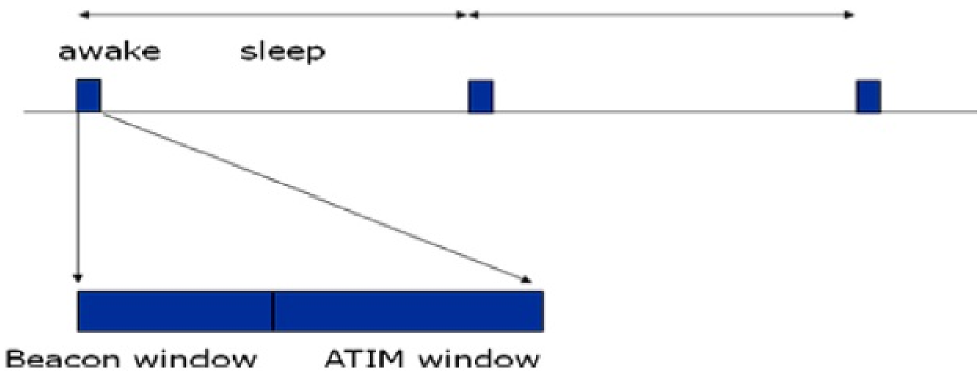

Figure 3.2: Power saving at MAC layer [4].

decreases. A node wakes up immediately if there are packets for transmission. Here, some of the nodes are at level 1 and some of them are at level 2 and so on [4]. Now, three power saving protocols are proposed. For each power save (PS) host, the time axis is divided into a number of fixed-length intervals known as the beacon intervals. For each beacon interval, a subinterval exists called the ATIM interval. During the ATIM interval, the PS host turns on its receiver for listening to any packets and take proper steps as usual, and if the node has packets for transmission, it sends its ATIM frame to its neighbouring node. If the node is in ATIM window without any activity, then it sends beacon frame from time to time to its neighbours for synchronizing the network nodes. After the ATIM interval, if a PS host has no packet to send or receive, then it may go to the doze state [4].

3.4.1 Multi-level power save protocol with k= 2 (M2)

Here, the time axis is divided into fixed-length beacon intervals, for each of the PS hosts. For each beacon interval, the lengths of ATIM window are fixed. Traversing from level 1 to level 2 is respectively depends on the fact that if there is transmission or not. A PS host in level 1 will wake up at the ATIM window of every beacon interval. But for a PS host in level 2, the wakeup process will depend on the beacon sequence number. If the beacon sequence number is divisible by the node level, the PS host wakes up else it continues sleeping [4].

3.4.2 Multi-level power save protocol with k= 3 (M3)

Here, the time axis is divided into fixed-length beacon intervals, for each of the PS hosts. For each beacon interval, the lengths of ATIM window are fixed. Traversing from level 1 to level 3 through level 2 is respectively depends on the fact that if there is transmission or not. A PS host in level 1 will wake up at the ATIM window of every beacon interval. But for a PS host in level 2 or level 3, the wakeup process will depend on the beacon sequence number. If the beacon sequence number is divisible by the node level, the PS host wakes up else it continues sleeping [4].

3.4.3 Modified multi-level power save protocol with k= 3 (MM3)

Here, the time axis is divided into fixed-length beacon intervals, for each of the PS hosts. For each beacon interval, the lengths of ATIM window are fixed. Traversing from level 1 to level 3 without going through level 2 follows a different procedure. If there transmission occurs, the PS host will traverse to level 1, else the PS host will traverse to level 3. A PS host in level 1 will wake up at the ATIM window of every beacon interval. But for a PS host in level 3, the wakeup process will depend on the beacon sequence number. If the beacon sequence number is divisible by the node level, the PS host wakes up else it continues sleeping [4].

3.5 Improving IEEE 802.11 Power Saving Mechanism (IPSM)

There are two major differences between IPSM [5] and PSM. The first difference is that, in IPSM, a node is capable of adjusting its ATIM window size by observing its network conditions. The second difference is that, in IPSM, a node can enter the doze mode in the middle of the beacon interval if all the transmissions are completed that are explicitly announced during the ATIM window. The second one is done by piggybacking the pending packets inside data packets. In IPSM [5], only one ATIM frame is used by the node to announce the pending packets for the same destination node during the same beacon interval. When the actual data packets are transmitted, the data packets include the number of packets that are pending for the destination. This information helps the destination node to know when all the packets are received that was pending at the source node during data transmission. If the current beacon interval expires and the source node is not able to deliver all the pending packets that were announced previously to the destination node, then both the source and destination nodes remain in wake up mode for the next beacon interval. During the next beacon interval the source node sends the pending packets without any additional ATIM frames. After the transmission is over and if the nodes have no other announced pending packets to send or receive, then the nodes enter into the sleep mode [5].

Chapter 4

Results and Discussion

4.1 Simulation Setup

This Section describes the scenario in the study followed by the results and discussion.

4.1.1 Scenario

Scenarios are created using Qualnet simulator. The topology is a square area with 1500 m length and 1500 m width. The network nodes are randomly distributed. Each scenario is configured with a network consisting of 25 nodes, randomly distributed over a 1500 m- 1500 m terrain. The movement speed of a node can vary between 0 and 5 m/s. 10 nodes are randomly chosen to be constant bit rate sources, each of which generates 512 byte data packets to a randomly chosen destination node. In the simulation the tunable parameters are: beacon interval, mobility and ATIM window interval. The beacon interval is varied from 60ms to 120ms with an increment of 20ms. The ATIM window is varied from approximately 10 to 60 percent of the corresponding beacon interval.

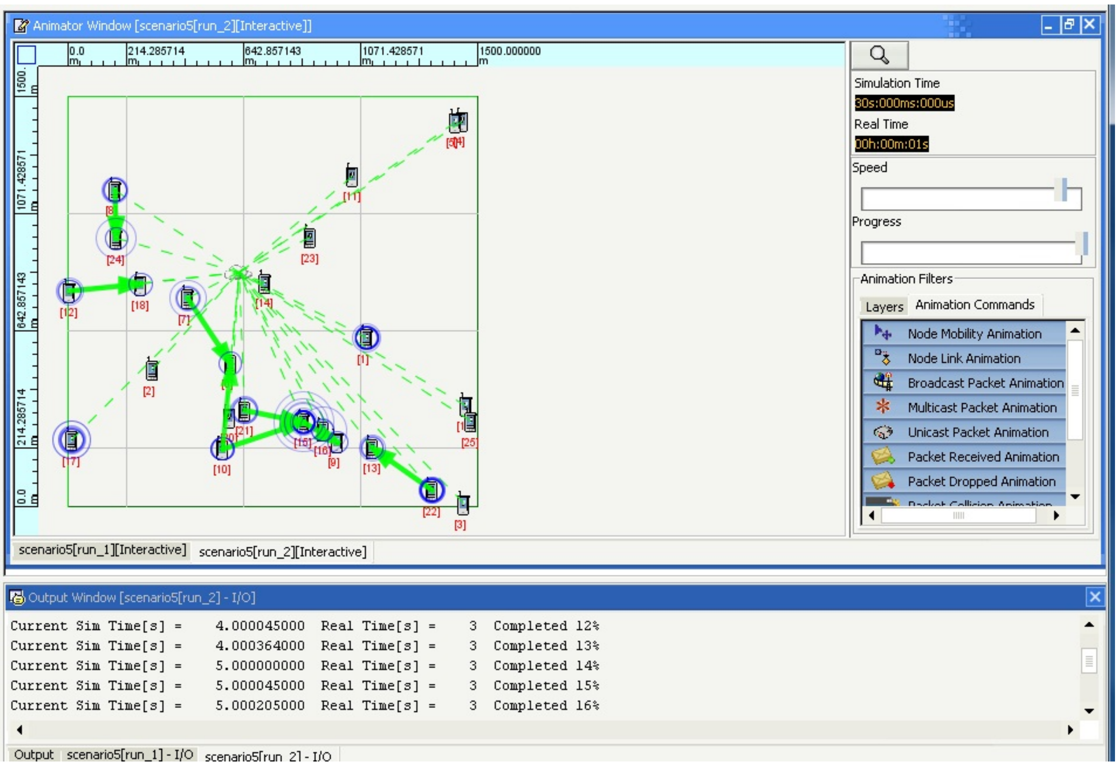

Figure 4.1: Simulation Snapshot

4.2 Simulation Results

First the dependencies of the throughput is analysed for different beacon interval sizes and different ATIM window sizes. For more number of stations in power save mode, it may result in lower throughput. Also, there is a reduction in throughput for very small and very big ATIM window sizes. If an ATIM window is too small then it will

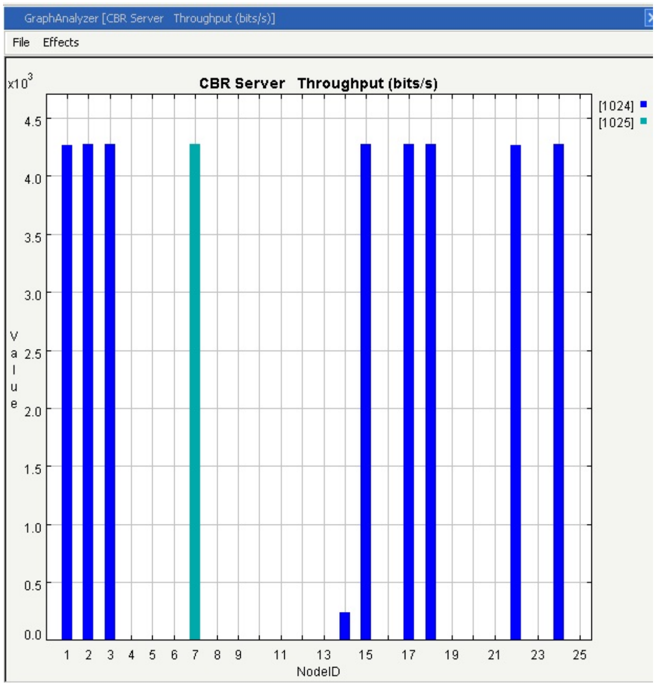

Figure 4.2: Throughput for Beacon Interval= 100ms and ATIM window= 30ms

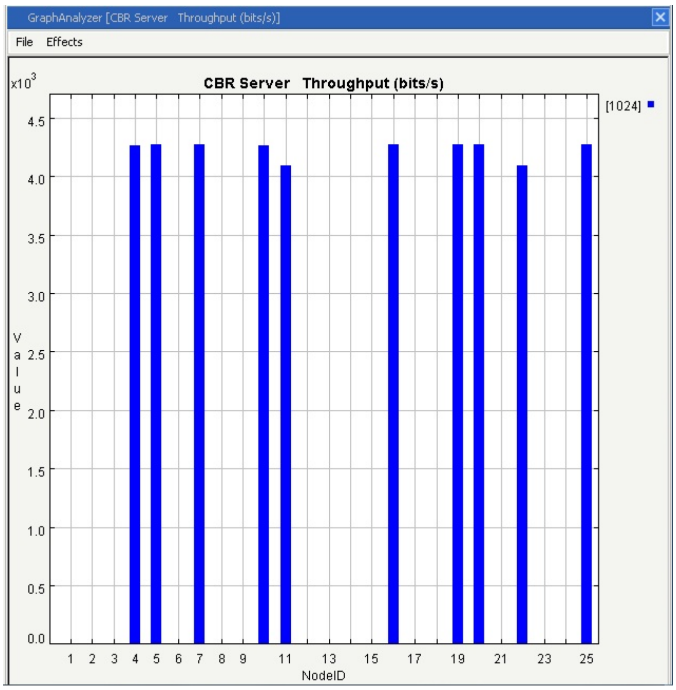

Figure 4.3: Throughput for Beacon Interval= 100ms and ATIM window= 50ms

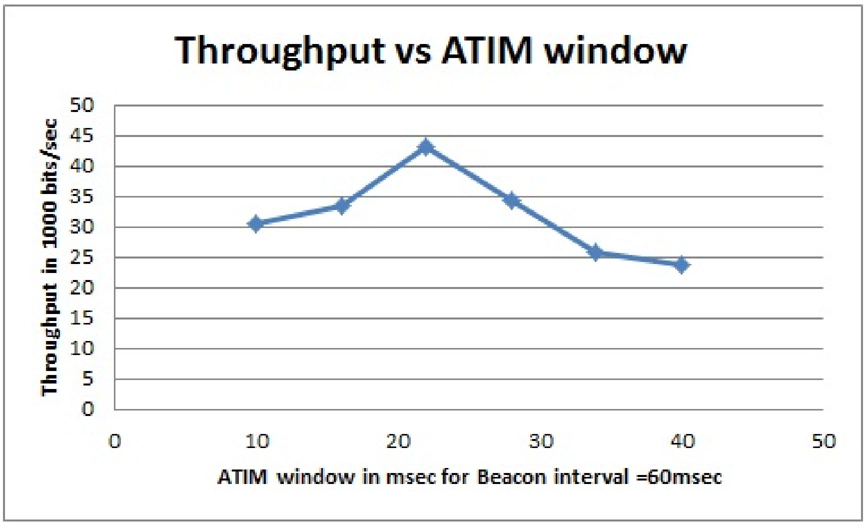

Figure 4.4: Throughput vs. ATIM window for Beacon Interval= 60ms

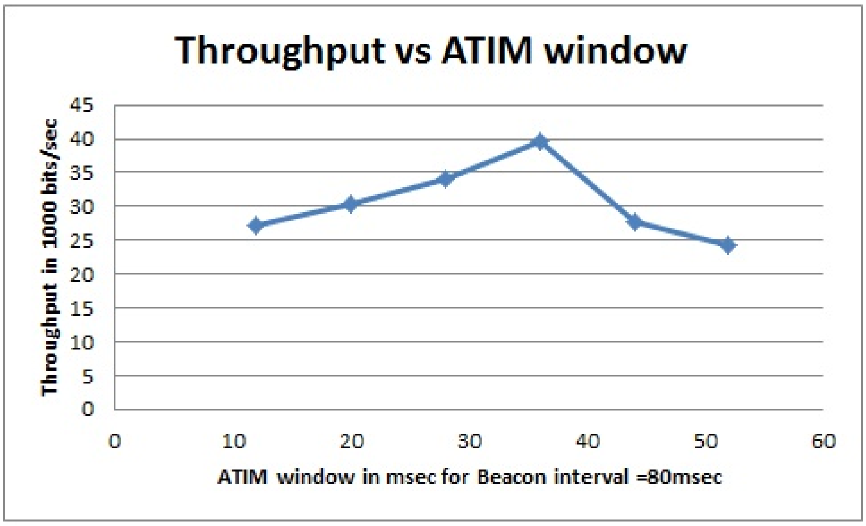

Figure 4.5: Throughput vs. ATIM window for Beacon Interval= 80ms

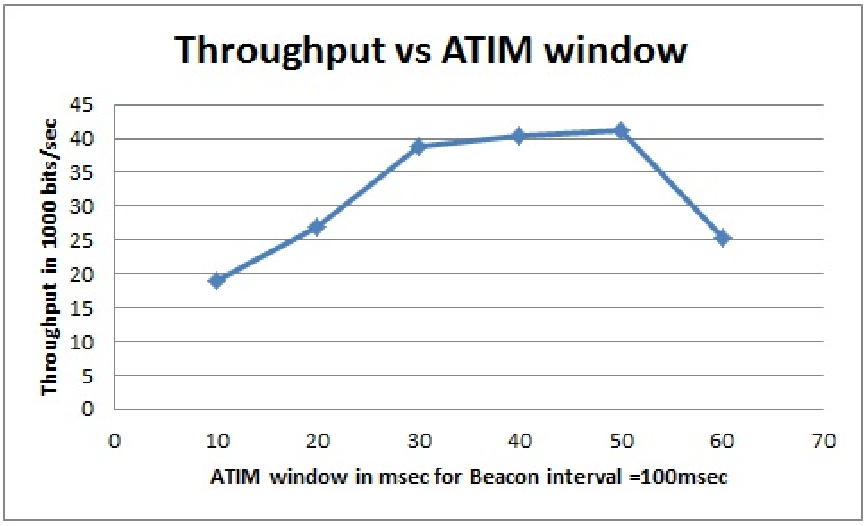

Figure 4.6: Throughput vs. ATIM window for Beacon Interval=100ms

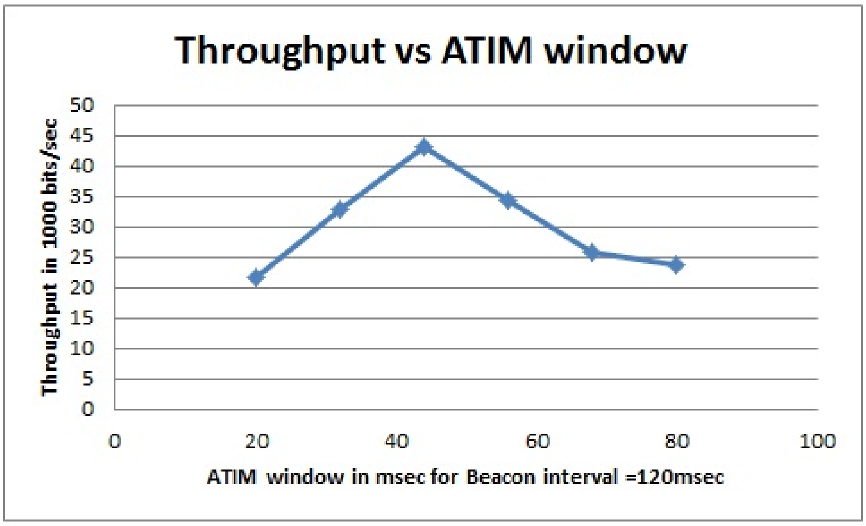

Figure 4.7: Throughput vs. ATIM window for Beacon Interval= 120ms

result in less ATIMs and this in turn results in less packets, which can be announced and transmitted. Also, for each data packet, the overhead consists of an ATIM and an ACK and two back off algorithm sequences, independent of the size of the packet which is to be transmitted. But, when the ATIM window is very big, more ATIMs are sent than there is actually time for the number of packets which could be actually sent.

The ATIM window size should be proportional to the beacon interval and that it should be approximately around 30 to 40 percent of the beacon interval. Also, bigger the beacon interval the larger is the probability that a node tries to send during that beacon interval. This means that it has to send ATIMs during every beacon interval and it has to remain awake until all the packets are sent.

Chapter 5

CONCLUSION

5.1 Conclusion

The simulations of the power saving mechanism in ad-hoc networks were presented using the IEEE 802.11 standard. The optimal ratio between ATIM window interval and beacon interval can be recommended. The ratio between ATIM window and beacon interval should be between 30 to 40 percent.For the ATIM window size with higher values for the beacon interval, it is less sensitive. The ATIM should not be too small if there are many stations in power save mode or if the traffic load is heavy, otherwise less number of packets are announced than the number of packets that could have been sent in that beacon interval. The beacon interval should be less so that the amount of time in doze mode could be longer. There has to be a trade-off between power saving and the overhead needed for it. Certain inefficiencies have also emerged from the working of PSM. When the traffic load is light, the energy that could be saved should be maximum, but in PSM, after the nodes have sent a beacon or exchanged ATIM frames, they remain in active mode irrespective of whether there are any frames to send or not. In PSM, a large number of ATIM announcement frames are sent or received in the ATIM window interval. This increases the power consumption of the network.

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