國 立 交 通 大 學

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IEEE 802.11 多階隨意網路之高能源效率

媒體存取層協定

A Power Efficient MAC Protocol for IEEE 802.11

Multihop Ad Hoc Networks

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摘 要

對於攜帶式裝置，能源管理是一個重要的問題。為了減少攜帶式裝置的能源消耗，我們的基本想法是每當傳輸結束時，讓節點儘快從活動狀態轉到休眠狀態。在本篇論文中，我們提出了一個IEEE 802.11多階隨意網路之高能源效率媒體存取層協定(PEMP)。許多相關的論文著重於單階隨意網路。在PEMP中，當節點試圖傳輸資料時，它把資料相關資訊(例如: 資料大小) 附載在ATIM*及ATIM-ACK*訊框內。ATIM*及ATIM-ACK*分別表示在ATIM及ATIM-ACK上附加資料相關資訊。利用上述方法，傳輸端及接收端可以告知其相鄰節點之資料相關資訊。然後依據收集來自其它節點的資訊，每節點會分別去計算自身的傳輸優先權。基於傳輸優先權，PEMP可以排列出較佳的傳輸順序。除此之外，

類似於DPSM，PEMP也依據網路狀況動態地調整ATIM視窗。藉著減少在活動狀態的閒置時間及動態地調整ATIM視窗，PEMP相較於DPSM，其在能源消耗上可減少20%。本論文所提之高能源效率媒體存取層協定可適用於多階的隨意網路,使其兼顧到能源的消耗、產量及封包的延遲。

關鍵詞： IEEE 802.11，媒體存取層協定，多階隨意網路，能源效率。

A Power Efficient MAC Protocol for IEEE 802.11 Multihop Ad Hoc Networks

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Abstract

Power management is a critical issue for portable devices. To reduce power consumption of a portable device, our basic idea is to switch a node from active state to sleep state when its transmission finishes. In this thesis, we propose a power efficient MAC protocol (PEMP) for IEEE 802.11 *multihop* ad hoc networks. Most of related work targeted at *single hop* ad hoc networks. In PEMP, when a node intends to transmit data, it will piggyback a data profile, including *data size*, on ATIM* and ATIM-ACK*. ATIM* and ATIM-ACK* are ATIM and ATIM-ACK with a piggybacked data profile, respectively. In this way, senders and receivers can inform their neighbor nodes of the data profiles. Then, each node calculates its transmission priority according to the collected data profiles. Based on transmission priorities, PEMP can schedule a better transmission sequence. In addition, similar to DPSM [11], PEMP also adjusts the ATIM window dynamically. By decreasing the idle time in active state and adjusting the ATIM window dynamically based on network conditions, the power consumption of PEMP is 20 % less than that of DPSM. PEMP is suitable for multihop ad hoc networks and can achieve a better tradeoff between power consumption, throughput and delay.

Keywords: IEEE 802.11, MAC protocol, multihop ad hoc network, power efficient.

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Chapter 1

Introduction

Rapid development of wireless digital communication technologies makes it possible to have information accessible anywhere, at any time, and at any device. Among these wireless technologies, IEEE 802.11 [1] [2] plays an important role. The IEEE 802.11 MAC consists of two components: PCF (Point Coordination Function) and DCF (Distributed Coordination Function). PCF is a centralized MAC protocol that supports collision free and time bounded services, which an access point uses it to control all transmissions. DCF is a random access scheme, based on the *carrier sense multiple access with collision avoidance* (CSMA/CA) and thus works efficiently even without an access point. The above mentioned characteristic makes DCF popular for ad hoc networks. Ad hoc networks are dynamic, distributed and self-organizing networks. No access points are needed. So they are suitable for constructing temporary networks for special situations, such as battlefields, temporary conferences, natural resources monitoring, entertainments, and etc. However, mobile hosts have considerable usage limitations that result from limited battery capacity. To extend battery lifetime, minimization of power consumption in the network interface has become an essential issue.

1.1 Power-saving Issue in the IEEE 802.11 MAC Layer

Solutions addressing the power-saving issue in the IEEE 802.11 MAC layer can generally be classified to two major categories: *power control* and *power management*.

1.1.1 Power Control

Power control [4][5][6][7][8][9] reduces the power level of a transmission to achieve reduced power consumption while maintaining the transmission success rate and network connectivity. However, the shortcomings of power control are increased packet error rate and degraded network throughput. COMPOW [4] found the smallest common power level at which a node reaches a desired station based on the received signal strength. In [5], it relies on dynamic adjustment of the data packet transmission power and guarantees the node's connectivity to the rest of the network. CLUSTERPOW [6] was designed for non-homogeneous networks and provides dynamic and implicit clustering of nodes based on transmission power levels regardless of geographical regions.

1.1.2 Power Management

Wireless interfaces support *active*, *sleep* and completely *power-off* states. The active state contains three physical states: *transmitting*, *receiving*, and *idle*. In the MAC layer, the IEEE 802.11 standard supports two power modes: active mode and power saving mode. In active mode, a node is active and is ready to transmit or receive data at any time. In power saving mode, a node only needs to wake up periodically. In Chapter 2, we will describe detailed operations of the power saving mode.

When to switch the power mode is an interesting problem. On-demand power management [10] determines power saving mode or active mode based on traffic load. [12] focuses on wireless sensor networks, and it proposed nodes to sleep periodically, virtual and physical carrier sense to avoid collisions, and nodes to fragment long messages into small fragments to reduce the high cost of retransmitting long messages.

Considering the IEEE 802.11 power saving mode, the ATIM (Ad Hoc Traffic Indication Map) window size will affect network performance and power efficiency. [11] dynamically adjusts the ATIM window size according to observed network conditions. [13] assumed that mobility is unpredictable and no clock synchronization exists. It proposed three protocols to determine when a node will wake up to receive packets asynchronously. In single hop ad hoc networks, [14] schedules a transmission sequence based on ATIM announcements to remove contention overhead. Similarly, [15] schedules a transmission after the ATIM window and also adjust the ATIM window dynamically to adapt to the traffic status. TRACE [16] was designed for real-time voice packets in single hop broadcast networks. In TRACE, nodes predetermine the transmissions based on the receiver-based listening cluster and schedule the transmissions to improve energy efficiency.

1.2 The Challenges of Power Management in Multihop Ad Hoc Networks

Power management in *multihop* ad hoc networks is a difficult problem [13]. First, a multihop ad hoc network is a distributed network, and access points do not exist. Secondly, a node can be a data source, a destination or an intermediate node, and the node will play different roles with time. Thirdly, it is difficult to get information of nodes in entire networks compared to single-hop ad hoc networks.

1.3 Thesis Objective and Organization

In the thesis, we will assume that time is divided into beacon intervals that begin and end approximately at the same time at all nodes [15]. We focus on the power management in power saving mode in multihop ad hoc networks. We propose a power efficient MAC protocol (PEMP) that integrates the information exchange method, the QoS method and the ATIM window adjustment to achieve a better trade-off between power consumption, network throughput and delay.

The rest of the thesis is organized as follows. Chapter 2 gives an overview of the power saving mode in IEEE 802.11 wireless ad hoc networks. In Chapter 3, existing approaches of power management for wireless ad hoc networks are reviewed. The proposed design approach is described in Chapter 4. Simulation results and discussion are presented in Chapter 5. Chapter 6 gives concluding remarks and outline future work.

Chapter 2

Overview of the Power Saving Mode and MAC protocol in IEEE 802.11

In this chapter, the power saving mode and MAC protocol of the IEEE 802.11 are reviewed.

2.1 Power Saving Mode in IEEE 802.11 Ad Hoc Networks

IEEE 802.11 WLANs support two power modes: *active* and *power-saving* modes. The protocols for infrastructure networks and ad hoc networks are different. We briefly review the main operation of the power saving mode in an IEEE 802.11 ad hoc network. In the power saving mode, all nodes are connected synchronously by waking up periodically to listen beacon messages. The length of a beacon interval and the size of an ATIM window are known by all nodes. The ATIM window that nodes wake up during is a small interval at the beginning of the beacon interval. If a node acquires the medium, it will send an ATIM frame to the desired-destination node based on the CSMA/CA access scheme. The ATIM frame is announced inside the ATIM window. If the desired-destination node receives the ATIM frame, it will reply with an ATIM-ACK frame and stay active to receive data in the rest of the beacon interval. However, the ATIM frames need not be acknowledged for buffered broadcast data. After the ATIM window, the buffered data should be sent based on the CSMA/CA access scheme. If a node fails to send its ATIM frame in the current ATIM window, it should retransmit the ATIM frame in the next ATIM window. If a node does not send or receive any ATIM frame during the ATIM window, it will switch to sleep mode to decrease power consumption until the next beacon interval begins.

Fig.1 shows an example. Initially, all nodes wake up at the beginning of the beacon interval. Since all nodes did not send or receive any ATIM frames in the first beacon interval, all nodes will switch to sleep state. In the ATIM window of the next beacon interval, node A has a packet destined for node B and similarly node C has a packet destined for node D. Therefore, nodes A and C, respectively, sent ATIM frames to nodes B and D based on the CSMA/CA access scheme and both successfully received the ATIM-ACKs. After the ATIM window finishes, nodes A and C tried to transmit buffered data to nodes B and D, respectively, based on the CSMA/CA access scheme.

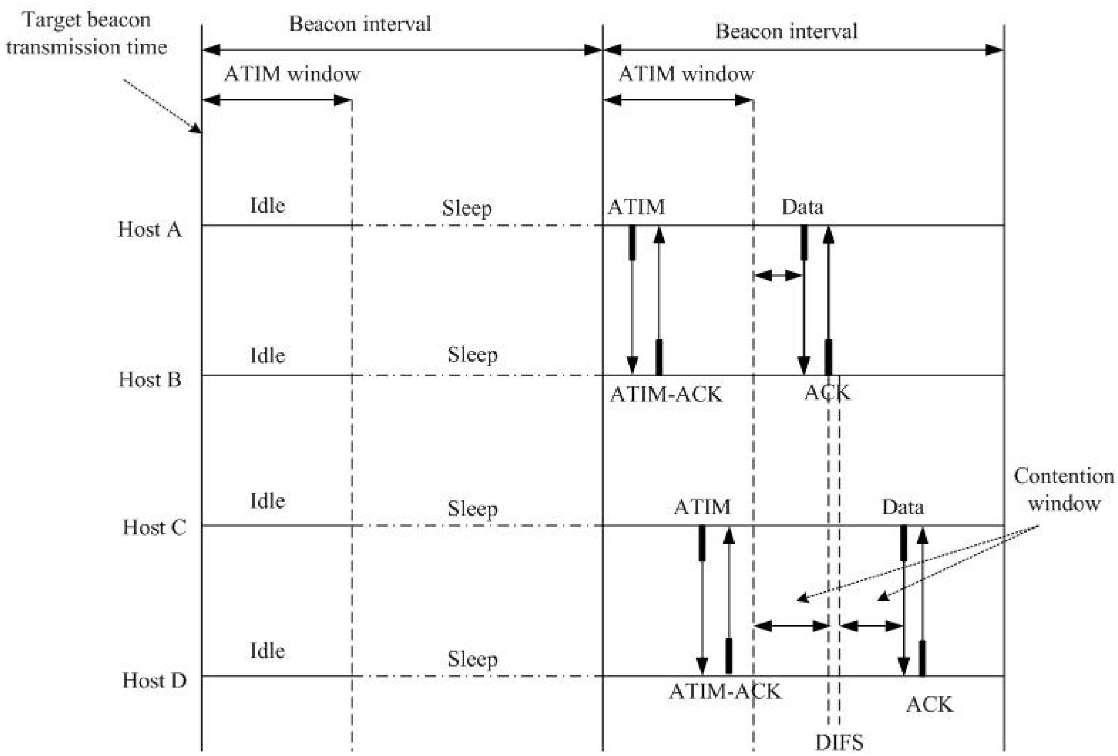

Fig. 1: Power saving mechanism for DCF in IEEE 802.11 [1][2].

2.2 Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)

The CSMA/CA protocol works as follows. When a node desires to transmit, it may encounter two kinds of situations. First, if the medium has been idle longer than the DIFS (DCF Inter Frame Space) such that potential collisions with other nodes can be avoided, transmission can begin immediately. Secondly, if the medium is busy, the node defers its transmission until the medium become idle. If the medium stays idle during the DIFS period, then the backoff procedure is invoked by selecting a *backoff counter* (BC) from zero to the contention window value. If the medium is idle, the BC will decrement. If the medium is busy, the BC will be frozen. When the BC reaches zero and the medium is still idle, transmission can begin immediately.

Chapter 3

Existing Approaches

In the chapter, we review existing power management protocols for IEEE 802.11 ad hoc networks and compare them qualitatively.

3.1 On-demand Power Management (ODPM) [10]

The goal of on-demand power management (ODPM) [10] is to maintain a good balance between energy conservation and communication efficiency. As mentioned in Section 1.1, the IEEE 802.11 standard supports active mode and power saving mode. The key idea of ODPM is that transitions from power saving mode to active mode are triggered by communication events, such as routing control messages or data packets. Transitions from active mode to power saving mode are determined by a *soft-state timer*. The soft-state timer is refreshed by the same communication events. The state transitions of ODPM is shown in Fig. 2.

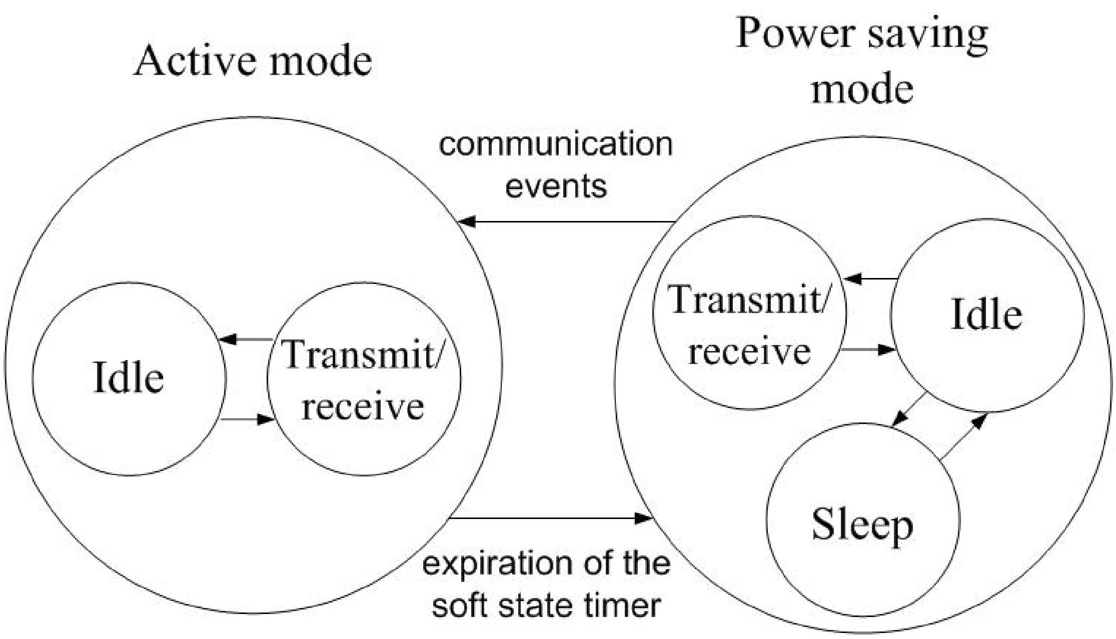

Fig. 2: State transition of ODPM [10].

3.2 Dynamic Power Saving Mechanism (DPSM) [11]

In DPSM [11], each node independently chooses an ATIM window size based on observed network conditions. This might result in each node using a different ATIM window size. To adjust the ATIM window size, five rules needed to be followed. First, a node checks its buffer data to see if the ATIM window is big enough to announce ATIM frames. Otherwise, the node increases the ATIM window size. Secondly, if ATIM-ACK has not been received after exceeding the retry limit, the transmitted packet is "marked" and will be tried to transmit in the next beacon interval. When a node receives a marked packet, the node will increase its ATIM window size to the next higher level. Thirdly, each node piggybacks its own ATIM window size on all transmitted packets. A node will increases its ATIM window size if it overhears the ATIM window size that is much larger than the ATIM window size itself. Fourthly, as long as a node is active, it will accept the ATIM message not only during the ATIM window but also in the rest of beacon interval. Finally, a node will decrease the ATIM window size slowly. By adjusting the ATIM window dynamically according to network load, a node can decrease unnecessary power consumption and improve network throughput. The size of an ATIM window in IEEE 802.11 significantly affects the throughput and the amount of energy saving. Thus, a fixed ATIM window cannot perform well all the time. A Node can dynamically adapt its ATIM window size according to observed network conditions to achieve a better trade-off between power consumption and network throughput.

3.3 Enhanced Power Saving Scheduling (EPSS) [14]

EPSS [14] incorporates a contention-free scheduling function for data transmission within the beacon interval. But all stations are required to be able to hear from each other directly. Nodes that overhear ATIM frames will generate a contention-free schedule for data transmission in the rest of the beacon interval, rather than let those nodes that have succeeded to announce in the ATIM window to contend again for the data transmission. With all the information received at each station during the ATIM window, a deterministic scheduling can be generated. This not only eliminates extra contention in the data transmission but also increases the efficiency of power saving.

3.4 An Energy Efficient MAC Protocol (EEMP) [15]

In EEMP [15], nodes schedule those to-be-transmitted data frames after ATIM window. According to a buffered data frame's duration, nodes determine the transmission order. Data transmission takes place to avoid unnecessary frame collision and backoff time. Besides, nodes adjust the ATIM window dynamically to adapt to the traffic status.

3.5 Comparison of Existing Approaches

We highlight the major differences among these existing approaches in Table 1. DDPM [10] , DPSM [11] and proposed PEMP are suitable for multihop ad hoc networks. EPSS [14] and EEMP [15] are only suitable for single hop ad hoc networks. ODPM emphasizes the transition between power saving mode and active mode. DPSM adjusts the ATIM window to decrease power consumption and increase throughput. EPSS and EEMP schedule the transmissions to avoid contention window overhead and data collision, In PEMP, nodes decease the idle time in active state by information exchange and QoS methods. In Chapter 4, we will describe PEMP in detail.

Table 1: Comparison of existing approaches.

Scheme	Power mode	Network	Approach	Advantage
ODPM [10]	Active mode/power saving mode	Multihop	Transit between power saving mode and active mode	Adapt to the traffic load
DPSM [11]	Power saving mode	Multihop	Adjust the ATIM window size	Choose a suitable ATIM window size
EPSS [14]	Power saving mode	Single hop	Generate a contention-free schedule for data transmission	Avoid extra contention
EEMP [15]	Power saving mode	Single hop	Schedule data transmission according to a buffered data frame's duration	Avoid contention and choose a suitable ATIM
PEMP (proposed)	Power saving mode	Multihop	By information exchange and QoS methods, a node calculates its transmission priority	Decrease the idle time in active state

Chapter 4

Design Approach: A Power Efficient MAC Protocol (PEMP)

4.1 Basic Idea

We propose a power efficient MAC protocol (PEMP) for IEEE 802.11 multihop ad hoc network. In the power saving mode of IEEE 802.11, nodes that announce ATIM frames successfully stay active during the whole beacon interval. But it is not necessary to let nodes that finish transmissions to continue to stay active. After a node finishes transmission, PEMP switches the node from active state to sleep state to decrease power consumption. The key idea of PEMP is how to decrease the idle time in active state.

We use an example to illustrate PEMP. Assume nodes A, B and C are within each other's transmission range. All nodes want to transmit packet after the ATIM window finishes. Assume node A wants to transmit a very big size of data, and nodes B and C both transmit smaller sizes of data. Because IEEE 802.11 DCF is based on the *Carrier Sense Multiple Access with Collision Avoidance* (CSMA/CA) to support asynchronous data traffic, nodes A, B and C have to contend for the channel to transmit packets. If A succeeds to contend for the channel, B and C will have to wait for a long time and possibly remain idle until the beacon interval end. If we let B and C transmit data before A, then B and C can switch to sleep state early and decrease their power consumption.

In single hop ad hoc networks, each node can communicates with each other directly. Each node can receive transmission announcements, such as ATIM and

ATIM-ACK, from other nodes. Each node can schedule a better transmission sequence easily by listening to network traffic. Considering multihop ad hoc networks, it is difficult to schedule a better transmission sequence because a node can not hear the transmissions of those nodes that are not within its transmission range. In multihop ad hoc networks, we can schedule a better transmission sequence by information exchange and QoS methods. These two methods will be described in section 4.2 and section 4.3, respectively..

4.2 Information Exchange Method

For information exchange, we modify the operation flow of ATIM announcement in the original IEEE 802.11 power saving mode. In PEMP, the information exchange can be divided into two steps. In the first step, when node A has a packet destined for node B in the IEEE 802.11 power saving mode, node A broadcasts an ATIM* to neighbor nodes, including B , C and E. ATIM* is an ATIM with a piggybacked data profile, including a data size. In the second step, B will retrieve a data profile from ATIM* if B succeeds to receive the ATIM*. B piggybacks its data profile on the ATIM-ACK* and broadcasts the ATIM-ACK* to its single hop neighbor nodes, including A, C and D. ATIM-ACK* is an ATIM-ACK with a piggybacked data profile. By broadcasting the ATIM* and ATIM-ACK* to neighbor nodes, nodes that are within single hop distance from the sender or the receiver may obtain the data profile. The reason why nodes don't flood the entire network with ATIM* and ATIM-ACK* is that flooding will consume too much energy and bandwidth. Fig. 3 shows the exchanges of ATIM* and ATIM-ACK* between nodes A and B.

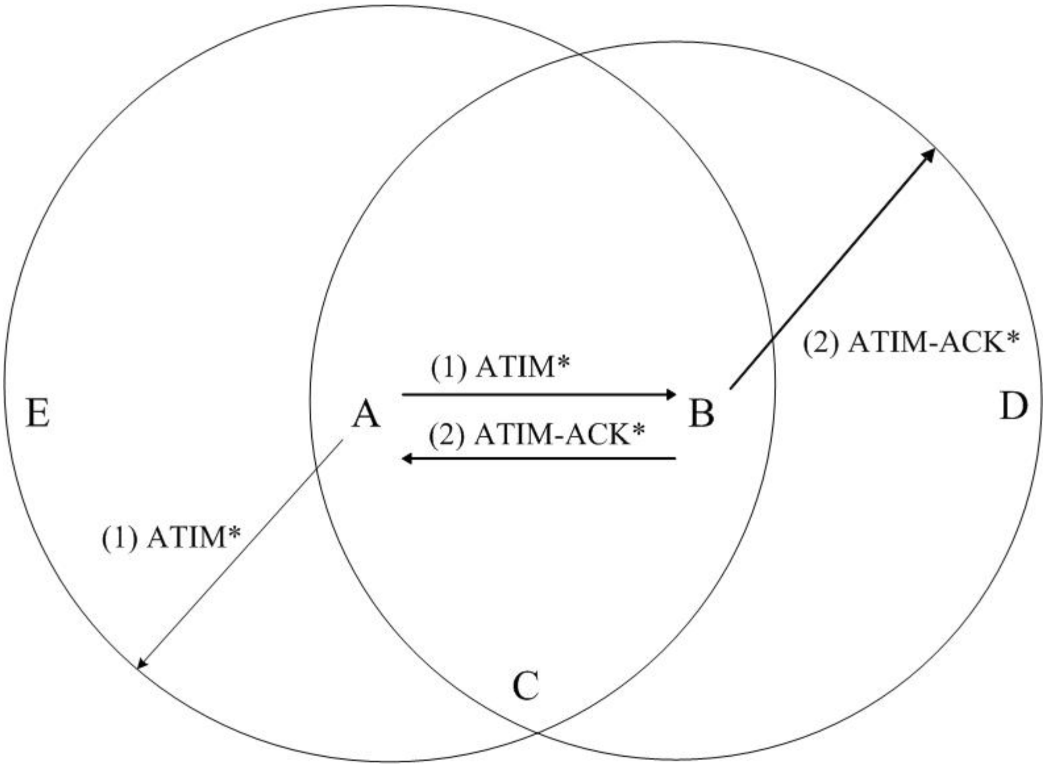

Fig. 3: The exchange of ATIM* and ATIM-ACK* between nodes A and B.

4.3 QoS Method

In PEMP, each node employs prioritized contention based Enhanced Distributed Channel Access (EDCA), as defined in the 802.11e [3]. Each transmission queue has a different interframe space (AIFS) and a different contention window limit. After the ATIM window, nodes that want to transmit data or want to receive data will awake. Each node that intends to transmit data will calculate its priority according to the collected data profiles. Nodes will adjust the contention window size and AIFS time. It can be expected that the smaller AIFS a node has, the higher priority it can have. Similar arguments apply to the contention window size. Fig. 4 illustrates the time diagram of EDCA [3]. 802.11e suggests the use of different AIFS and different contention window limits according to different ACs. Table 2 shows the parameters for the maximum contention window (CW_{max}), the minimum contention window (CW_{min}) and AIFS for each AC.

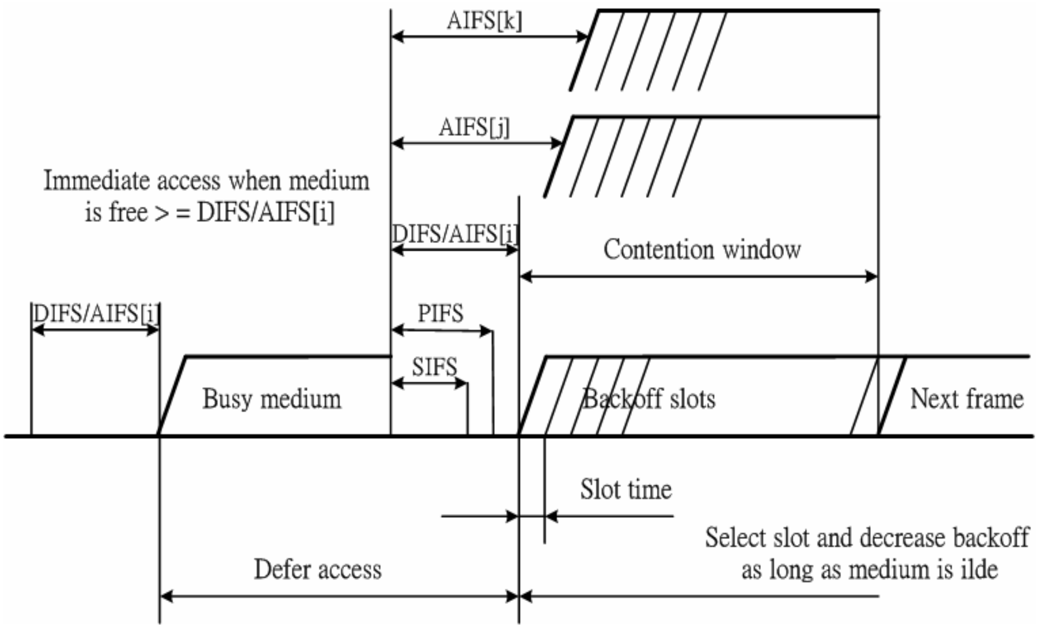

Fig. 4: The timing diagram of 802.11e EDCA [3].

Table 2: The default EDCA parameters [3].

AC	CW_{min}	CW_{max}	AIFSN
AC_BK	aCW_{min}	aCW_{max}	7
AC_BE	aCW_{min}	aCW_{max}	3
AC_VI	$\frac{aCW_{\min}+1}{2}-1$	aCW_{min}	2
AC_VO	$\frac{aCW_{\min}+1}{2}-1$	$\frac{aCW_{\min}+1}{2}-1$	2

The value of AIFS is determined by the following equation (1) [3]:

$$AIFS = AIFSN \times aSlotTime + SIFS \tag{1}$$

where the value of AIFS Number (AIFSN) is an integer greater than zero and is dependent on each AC.

4.4 Calculating Transmission Priority

In this section, we describe how a node obtains its transmission priority. After the ATIM window, a node calculates the *data_sum* (data sum), *Mean* and *Var* (variance) according to the following formulas:

$$data\_sum_{host} = \sum_{i=1}^{n} data_{\mathrm{i}} \qquad (2)$$

$$Mean = \frac{1}{host\_count} \sum_{i=1}^{host\_count} data\_sum_i \qquad (3)$$

$$Var = \frac{1}{host\_count} \sum_{i=1}^{host\_count} (data\_sum_i - Mean)^2 \qquad (4)$$

where $data\_sum_{host}$ is the total data size of the node. *host_count* is the number of neighboring nodes with buffered data. *Mean* is the average of all data sums received. *Var* is the variance of all data sums received. The results of calculation will be related to an AC, as follows:

AC can be AC_BK (background), AC_BE (best effort), AC_VI (video) or AC_VO (voice) [3].

$$\text{AC\_BK} = \{data\_sum_{host} \geqq Mean \text{ and } (data\_sum_{host} - Mean)^2 \geqq Var\}$$

$$\text{AC\_BE} = \{data\_sum_{host} \geqq Mean \text{ and } (data\_sum_{host} - Mean)^2 < Var\}$$

$$\text{AC\_VI} = \{data\_sum_{host} < Mean \text{ and } (data\_sum_{host} - Mean)^2 < Var\}$$

$$\text{AC\_VO} = \{data\_sum_{host} < Mean \text{ and } (data\_sum_{host} - Mean)^2 \geqq Var\}$$

At the end of the ATIM window, nodes will contend for the medium for transmission. By employing the QoS method, the priorities of nodes that have smaller data destined for other nodes will be increased. In this way, higher priority nodes need less waiting time to transmit data.

We use an example to illustrate the operation of PEMP, as shown in Fig. 5. Fig. 5 is based on the topology of Fig. 3. Assume node A has a packet destined for node B and node C has a packet destined for node B. Node A broadcasts an ATIM* frame to its single-hop neighbors, like B and C. When B succeeds to receive ATIM* frame, B replies an ATIM-ACK* frame to its single-hop neighbors, like A, C and D. By the above steps, A and B complete the information exchange and announcement. For the transmission of C to B, similar steps are followed. After the ATIM window, all nodes calculate their priorities according to the received data profiles and then determine AIFS and contention window limits. Assume A succeeds to contend for the channel according to its transmission priority. After its transmission finishes, node A switches to sleep state to decrease power consumption.

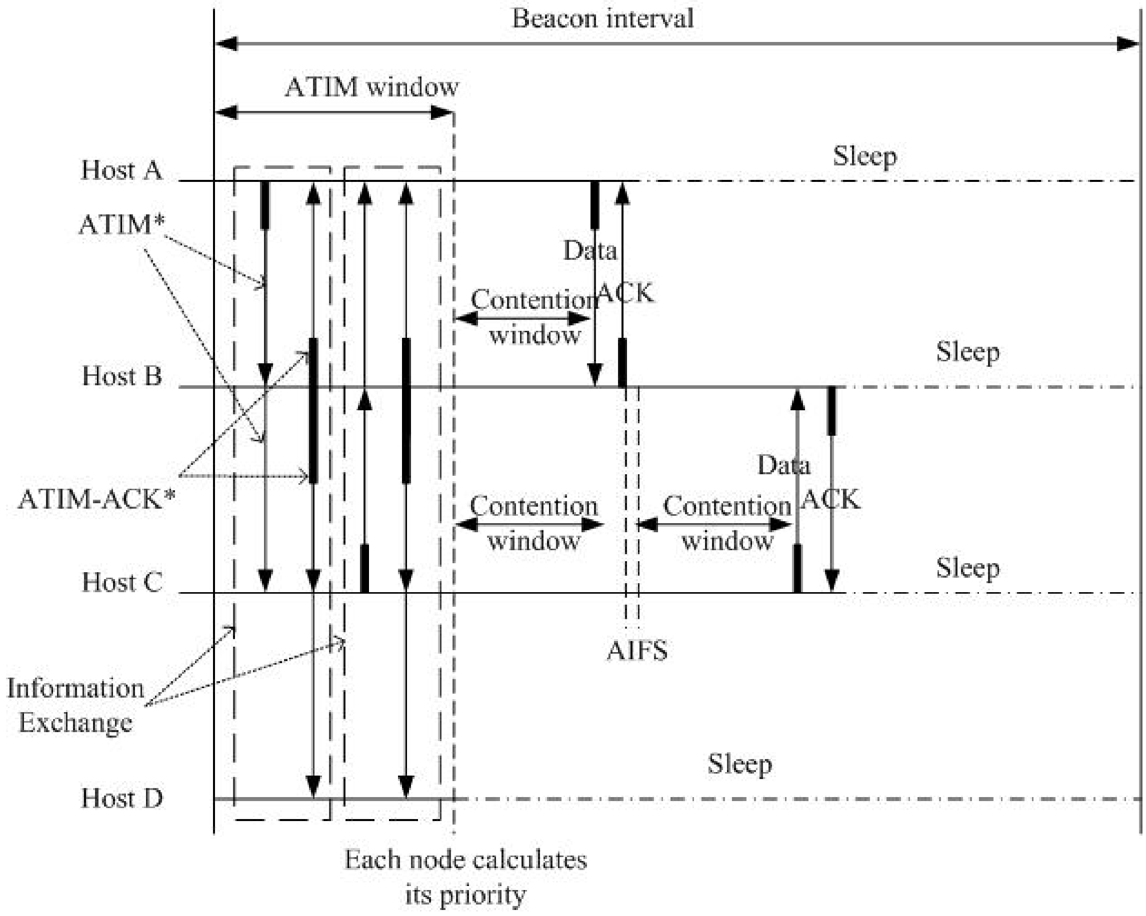

Fig. 5: Activities in the beacon interval of PEMP.

4.5 Avoiding Starvation

If nodes that have succeeded to transfer ATIM frames do not finish sending the entire data in the beacon interval, they will retransmit ATIM frames in the next beacon interval. In PEMP, it is possible that a low priority node may fail to transmit the entire data after several beacon intervals and result in high delay. With buffered data increasing, it may be hard for a low priority node to succeed to contend for the medium. In other words, it may cause starvation for low priority nodes. To avoid starvation, each node records its buffer delay. The buffer delay is expressed in terms of number of beacon intervals passed. The *bc* maintains the count of beacon intervals passed for the buffered data. After completing a beacon interval, each node increases its *bc* of buffered data by one. We set an *up-bc* as the upper limit of the number of beacon intervals passed. If a node has buffered data with *bc* higher than *up-bc*, the node will be switch AC to AC_VO until *bc* is smaller than *up-bc*. By increasing the priority for those nodes with long buffer delays, starvation can be avoided.

The detail of the PEMP operation is shown in Fig. 6. The ATIM window that nodes wake up during is a small interval at the beginning of the beacon interval. If a node acquires the medium, it will transmit an ATIM* frame to neighbor nodes, including desired-destination node. If the desired-destination node receives an ATIM* frame, it will reply an ATIM-ACK* frame to neighbor nodes, including the transmitter. At the end of the ATIM window, each nodes calculates its transmission priority and checks if *bc* is larger than *up-bc*. After the ATIM window finishes, the sender-receiver pairs will transmit data according to their transmission priorities.

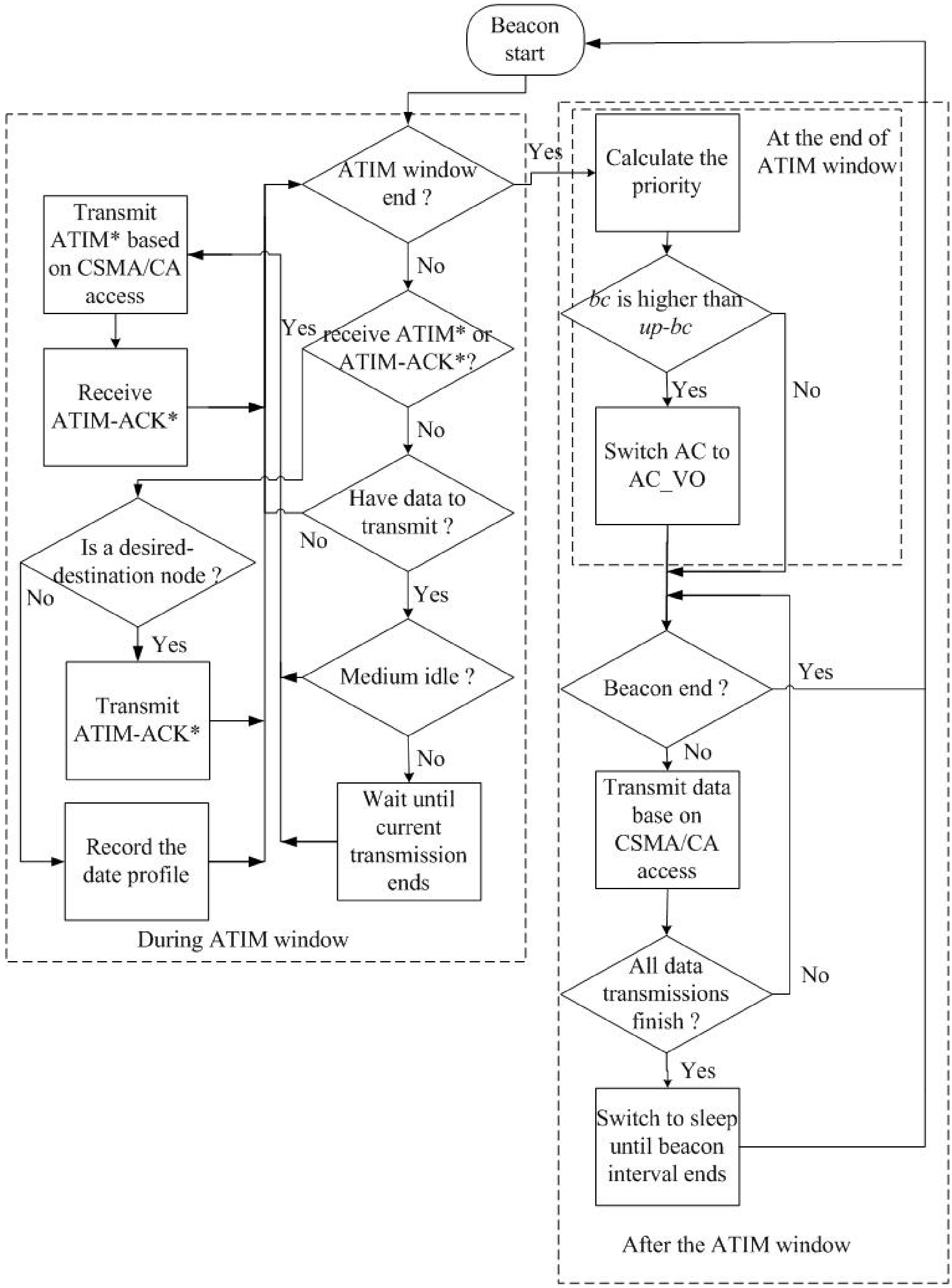

Fig. 6: PEMP operation flow.

4.6 Adjusting ATIM Window Size Dynamically

According to [11], the ATIM window has a great effect on energy efficiency and performance. If the ATIM window is too large, nodes will not get chance to transmit data and increase power consumption. On the contrary, if the ATIM window is too small, only a few nodes can send ATIMs successfully. In PEMP, the ATIM window size is also adjusted dynamically based on network conditions [11].

Chapter 5

Simulation and Discussion

5.1 Simulation Model

For evaluation, we used *ns-2* with the CMU wireless extension [19]. Simulation parameters are showed in Table 3 [15][20][22]. Nodes are randomly placed in an area of 1000 square meters. The transmission rate of each node is 2 *Mbits/sec*. The transmission range is 250 meters. The routing protocol is DSR (Dynamic Source Routing) [21]. The length of a beacon interval is 100 *ms*. The number of flow is a half of the number of nodes [20]. We set the upper limit of the number of beacon interval passed *(up-bc)* as three. Each node generated variable-rate traffic according to the exponential on-off traffic model. The packet size is randomly selected between 256 and 1024 bytes. We use the same energy model as in [15][22]. The power consumption for switching between active and sleep is negligible and not considered here. Nodes do not run out of energy during the simulation. We have three performance metrics: *power consumption* (*J/sec/node*), *aggregate throughput* (*Kbytes/sec*) and *average end to end delay* (*msec*). We study the performance when the network has 20 or 40 nodes. We simulated PEMP, DPSM and PSM. We define PSM(*T*) as power saving mode, and *T* represents the size of an ATIM window. In PSM simulations, we changed the size of an ATIM window size between 5 *ms* and 30 *ms*. Note that nodes in PSM continue to stay active after finishing transmissions. But for fair comparison in our experiments PSM will allow a node to switch to sleep state after finishing its transmissions.

Table 3: Simulation parameters.

Simulation configuration	Area	1000 m × 1000 m
	Bandwidth	2 *Mbps*
	Range	250 *m*
	Routing protocol	DSR
	Beacon interval	100 *ms*
	Number of nodes	20, 40
	Up-bc	3
Traffic configuration	Traffic rate	Exponential
	Packet size	256 ~ 1024 bytes
Energy model	Transmit	420 + 1.9 × frame size(μ J)
	Receive	330 + 0.42 × frame size(μ J)
	Idle	808 *mw*
	Sleep	27 *mw*

5.2 Simulation Results and Discussion

Fig. 7 and Fig. 8 show the power consumption (*J/sec/node*) under 20 and 40 nodes, respectively. When the number of nodes increases, the power consumption becomes large. Power consumption in PSM is approximately linear increasing with *T* (ATIM window size) increasing from 5 *ms* to 30 *ms*. That is, if the ATIM is longer in PSM, nodes will consume more power consumption according to Fig. 7 and Fig. 8. Comparing to PSM and DPSM, PEMP can decrease unnecessary idle time in active state by information exchange and QoS methods. The power consumption of PEMP is 20 % less than DPSM by decreasing the idle time in active state.

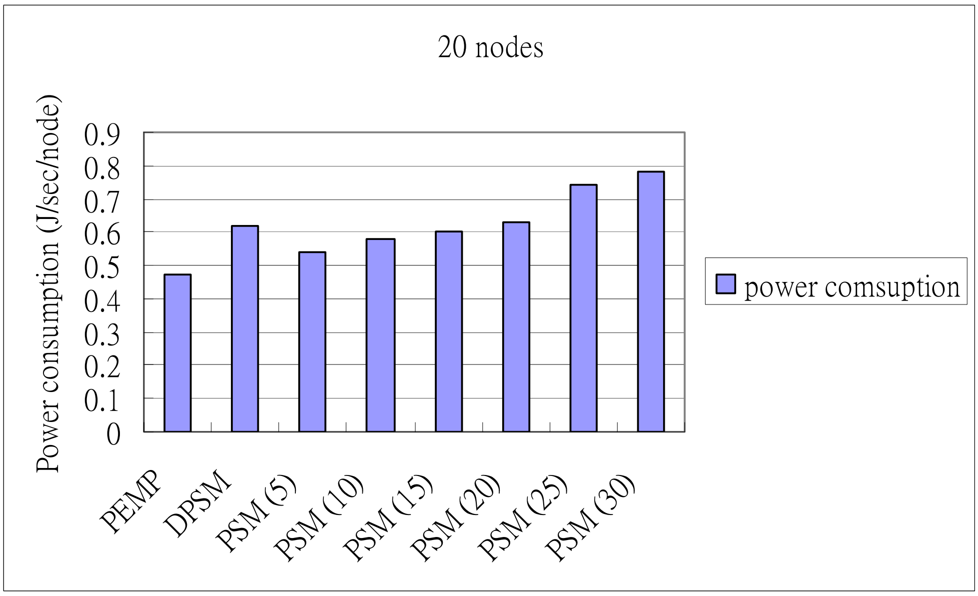

Fig. 7: Power consumption comparison under in 20 nodes.

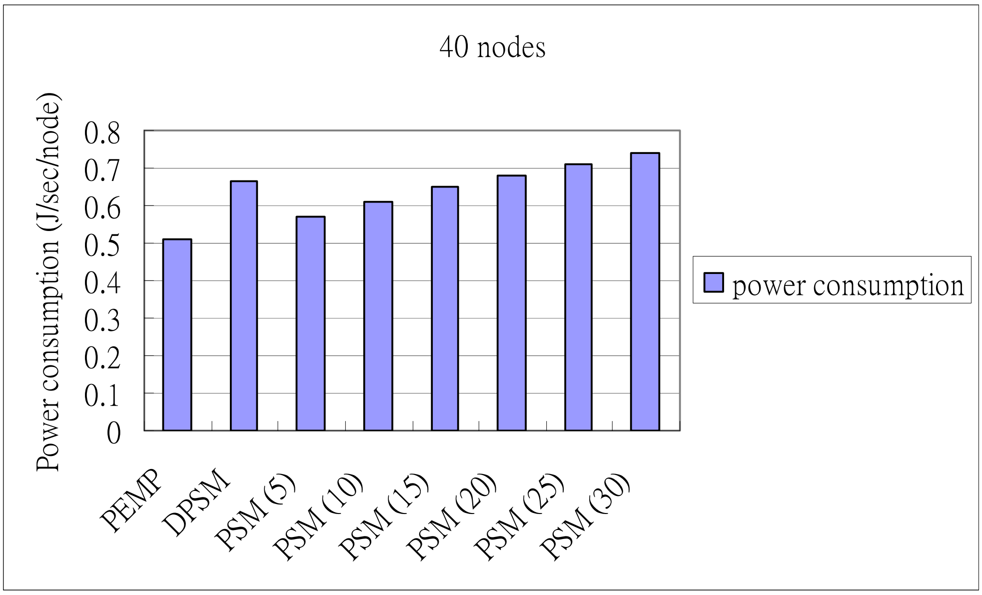

Fig. 8: Power consumption comparison under 40 nodes.

Fig. 9 and Fig. 10 illustrate the aggregate throughput (Kbytes/sec) among PEMP, DPSM and PSM under 20 and 40 nodes, respectively. If the ATIM is too small in PSM, time is inadequate to announce ATIM. In our simulation result, the aggregate throughput degrades with the ATIM window size decreasing. PSM with ATIM window size of 5 *ms* may suffer severe degradation in throughput. In Fig. 9 and Fig. 10, we observe that for PSM the ATIM window of about 20 *ms* achieve the best throughput. DPSM can achieve higher throughput by choosing a suitable ATIM window. We observe the aggregate throughput of PEMP is 0.5 % less than that of DPSM.

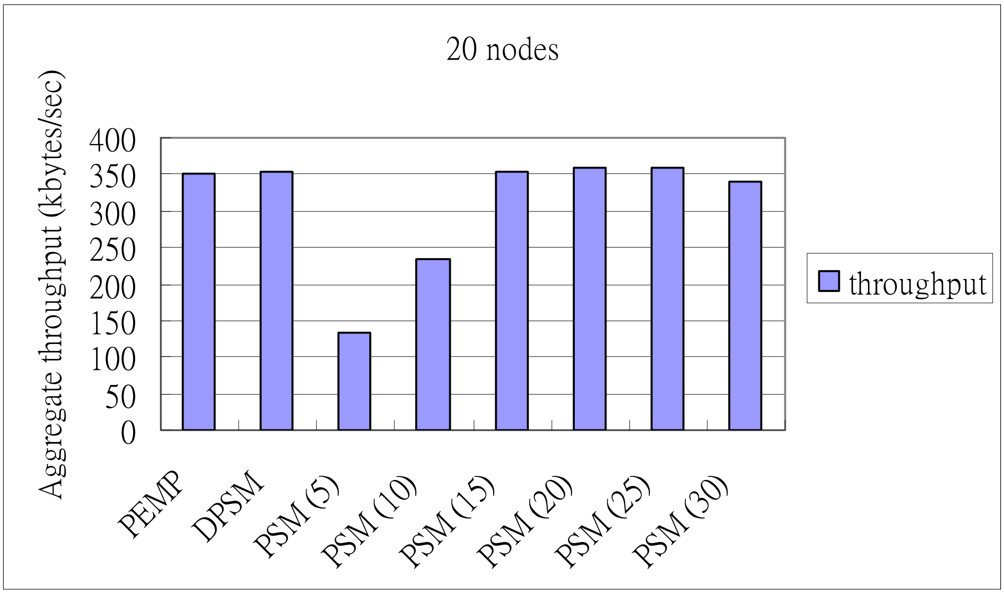

Fig. 9: Aggregate throughput comparison under 20 nodes.

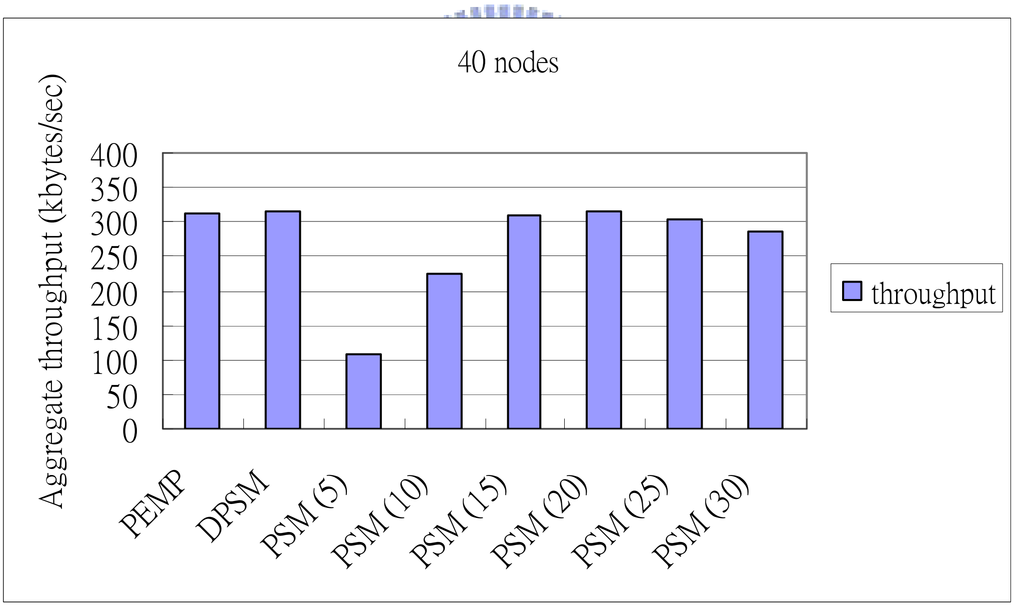

Fig. 10: Aggregate throughput comparison under 40 nodes.

The average end to end delay is shown in Fig. 11 and Fig. 12 under 20 and 40 nodes, respectively. The average end to end delay is computed by summarizing the end to end delay of all the connection flow and averaging it. We can see that smaller ATIM size cause large end to end delay. This is because using a small ATIM window size there is not sufficient time to announce the ATIM. When a node fails to send its ATIM frame in the current ATIM window, it should retransmit ATIM frames in the next ATIM window, resulting in long end to end delay. PEMP has 6% longer end to end delay than DPSM.

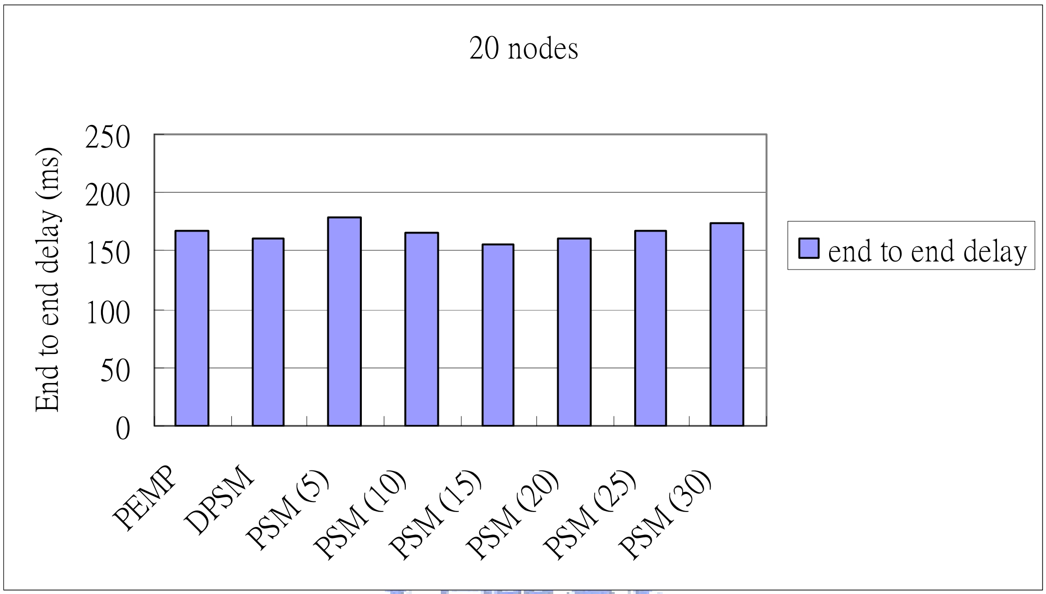

Fig. 11: End to end delay comparison under 20 nodes.

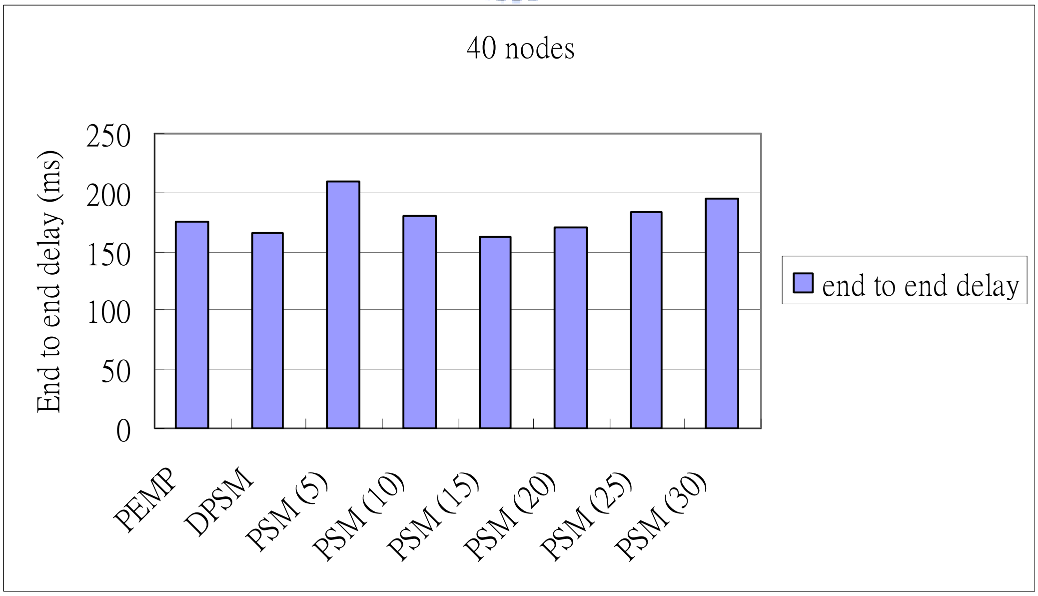

Fig. 12: End to end delay comparison under 40 nodes.

Chapter 6

Conclusions and Future Work

6.1 Concluding Remarks

We have proposed a power efficient MAC protocol (PEMP) for multihop ad hoc networks by decreasing the idle time in active state. The overall power consumption can be reduced in multihop ad hoc networks by information exchange and QoS methods. In PEMP, nodes with larger buffered data should transmit data later and nodes with smaller buffered data should transmit first. In addition, starvation avoidance is also addressed by raising a node's transmission priority if necessary. As multihop ad hoc networks are getting popular, it is important to have a power efficient MAC protocol for extending the battery life of wireless nodes. Simulation results have shown that the proposed PEMP can achieve 20% less power consumption with penalties of 6% longer end to end delay than DPSM.

6.2 Future Work

In the IEEE 802.11, a node can be in one of two power management modes, active mode and power saving mode. In active mode, a node can achieve higher network throughput but consume more energy. In power saving mode, a node can reduce power consumption but network throughput will degrade. On demand power management (ODPM) [10] addressed a design space between active mode and power saving mode for power saving. The future work is to integrate ODPM into PEMP to achieve a better tradeoff between power consumption, throughput and delay in multihop ad hoc networks.

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