Proceedings of the 5th WSEAS International Conference on Applied Computer Science, Hangzhou, China, April 16-18, 2006 (pp445-450)

Enhanced Point Coordinator Function in IEEE 802.11 MAC Protocol for Infrastructure Basic Service Set

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Abstract: Infrastructure based wireless LAN technology has been widely used in today's personal communication environment. Power efficiency and battery management have been the center of attention in the design of hand-held devices with wireless LAN capability. In this paper, a hybrid protocol named enhanced PCF operation is proposed which intelligently chooses the Access Point (AP) assisted DCF (Distributed Coordinator Function) and enhanced PCF (Point Coordinator Function) transmission mechanism of IEEE 802.11 protocol in an infrastructure based wireless LAN environment. Received Signal Strength Indicator (RSSI) is used to determine the trade-off between direct mobile-to-mobile transmission and transmission routed by AP. Based on the estimation, mobile stations can efficiently communicate directly instead of being routed through AP if they are within the vicinity of each other. Simulation results show that using the proposed protocol energy consumption of mobile devices can be reduced at the cost of slightly longer end-to-end packet delay compared to traditional IEEE 802.11 PCF protocol. However, in a non-time critical environment, this option can significantly prolong the operation time of mobile devices.

Key–Words: Ad Hoc Network, IEEE 802.11 MAC protocol, Power-efficient, Point Coordinator Function, Hybrid Protocol

1 Introduction

IEEE 802.11 [1] based wireless LAN devices are being used more and more by portable computers and handheld devices as standard configuration. These devices are often powered by batteries or depletable sources of energy to achieve mobility and flexibility. Due to constraint of weight and volume, batteries can provide only a finite amount of energy. Transmitting and receiving data through the wireless radio transceiver is costly in terms of energy consumption, especially when a random-access wireless radio channel is shared among many users. Efficient use of battery power is now a significant consideration in designing mobile devices.

In this paper, modifications to the PCF operation of IEEE 802.11 protocol are proposed that reduces the energy consumption and increases the throughput. The proposed protocol improves the mobile-to-mobile traffic in the infrastructure network using DCF transmission mechanism assisted by the AP. The protocol behavior and performance of traditional IEEE 802.11 PCF is analyzed first especially in an environment where traffic is mostly mobile to mobile. The improved PCF operation is introduced which adaptively selects between PCF and AP assisted DCF transmission mechanism based on RSSI information of mobile stations for different traffic types. A two-phase polling mechanism is proposed. The first polling phase is utilized for traffic information collection and downlink traffic. The second polling phase is utilized for uplink traffic and traffic routed by AP. The contention-free period ends when AP sends the control frame of subtype CF-end, which piggybacks the explicit transmission scheduling information for DCF transmission [2] of the packets that have been announced in the first polling phase and have not been transmitted during the two polling phases. An AP assisted retransmission mechanism is also proposed in this paper. Mobile stations can pass their unsuccessfully transmitted packets in direct transmission phase to AP during next polling phase and AP can help to retransmit packets to the destination mobile stations. Our proposed protocol operates in a hybrid mode by taking advantage of the capability of AP and the flexibility of AP assisted DCF operation that is capable of providing service with reduced power consumption and increased throughput.

The rest of the paper is organized as follows. Section 2 presents the proposed enhancements to IEEE 802.11 PCF protocol to achieve energy efficiency and throughput improvement. Section 3 describes the simulation model and results which show the advantage

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of the proposed algorithm. Section 4 concludes the paper.

2 Enhanced PCF Operation of Access Point

In this section, detailed description as to how the traditional IEEE 802.11 PCF protocol can be modified to achieve a better performance is given. The original IEEE 802.11 is analyzed to show that PCF is not suitable for the environment where most traffic is between mobile stations in an infrastructure BSS. Then our improved PCF operation is introduced which is a hybrid protocol using AP assisted DCF operation for mobile-to-mobile traffic in an infrastructure based wireless LAN environment.

2.1 Problem Analysis of IEEE 802.11 PCF

IEEE 802.11 PCF mode is a centralized polling scheme, which uses AP as a coordinator for all communications within its coverage. The benefit of using the AP is obvious: it will guarantee a contention-free transmission period through the centralized polling. However, it also has the following drawbacks in an infrastructure BSS:

1. During each CFP, the AP shall issue polls to a subset of the stations on the polling list in ascending order of Association Identifier (AID) value. During the CFP, if all CF frames have been delivered and all STAs on the polling list have been polled, the AP may generate one or more CF-Polls to any station on the polling list. However, this is often not possible when number of mobile stations is large and the traffic intensity is high. If it is assumed that mobile stations can only be polled once during each beacon interval, the average delay between two consecutive transmissions of a mobile station is the length of the super-frame. Although it aims to maintain fairness for all stations, the mobile stations are expected to experience long packet end-to-end delay if the number of stations is very large.

2. The AP serves as a bridge between the mobile stations and the wired network (internet etc.). Extra buffering and processing delay are expected at the AP side for the mobile to mobile traffic which is routed through the AP.

3. In an infrastructure BSS all the packets will go through the AP. This is not efficient for mobile to mobile communication.

Each data packet is required to be transmitted twice: mobile→AP then AP→mobile. This increases the collision probability and also increases channel utilization time.

As wireless transmission is subjected to higher Bit Error Rate (BER), two-hop transmission will encounter a higher overall error rate than that for a single-hop transmission.

The AP will buffer packets from the source station until the time the destination station is polled. So data packets are expected to have longer end-to-end delay. This delay can be as long as the whole length of a super-frame if AP polls the destination station earlier than the source station.

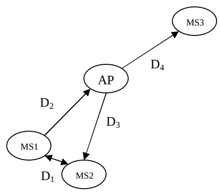

Figure 1: Choose the transmission method based on position information

The two-hop transmission may consume more energy than a direct single-hop transmission as illustrated in Figure 1. It is assumed that the receiver uses constant power for receiving a packet. A scheme that has been used in our proposed protocol to dynamically adjust transmission power of mobile stations is described in the latter section, in which the overheard RSSI information of control frames is used to estimate the minimal required power for packet transmission to other mobile stations. The AP is at a fixed known position and always transmits with fixed power. The transmission power required for mobile stations to maintain an acceptable Signal to Noise Ratio (SNR) at AP can also be estimated based on the RSSI information of polling message from AP, which can be used by mobile stations to dynamically adjust their transmission power to AP. According to the basic theory of radio communication, the received signal strength is inversely proportional to some power of distance between the sender and receiver. To guarantee a fixed SNR at the receiver side, transmitted power should be adjusted proportional to D^{λ} ($2 \leq \lambda \leq 4$ for outdoor transmission), where D is the distance between sender and receiver.

It is assumed the power required at mobile station 1 for direct transmission is $P_{1 \rightarrow 2}$ and for the transmission routed by AP is $P_{1\rightarrow AP}$. So $P_{1\rightarrow AP}$ is much larger than $P_{1\rightarrow 2}$ as shown in Eq. 1, if $D_2 > D_1$ given that $2\leq\lambda\leq 4$. As in this particular example, a direct transmission (MS1→MS2) is more power efficient than the transmission routed by AP (MS1→AP→MS2).

$$\frac{P_{1\rightarrow AP}}{P_{1\rightarrow 2}} = (\frac{D_2}{D_1})^{\lambda} \quad (1)$$

The transmission MS1→AP→MS2 will occupy the shared wireless channel almost twice longer than a direct transmission MS1→MS2. Both sender and receiver have to wait longer time in an idle state, which is considered as a waste of energy.

4. Under PCF mode, there exists an option for mobile stations to reply the contention-free poll from AP by sending a frame to other mobile stations. In the forthcoming IEEE 802.11e protocol [3], a Direct Link Protocol (DLP) is also proposed, which refers to the ability to exchange data directly between two stations in the network, without being routed through the AP. However, due to the lack of the position information and operating state (in PS state) of destination, such transmission is not guaranteed and sometimes not even possible. So it is not actually implemented in most of the wireless LAN devices under an infrastructure BSS setup. As shown in figure 1, MS3 is either out of the transmission range of MS1, or requires much more energy than using AP as router to forward traffic.

2.2 Proposed Improved PCF Operation

Based on the above analysis, modifications to the PCF are necessary to achieve higher performance. In traditional PCF protocol of IEEE 802.11, right after the beacon transmission AP will poll the registered stations within the service set one by one in a round robin fashion. Upon reception of the polling message (without payload if there is no downlink data for the specific station), the station will return its uplink packets if there is any or to return a packet without payload which indicates that it has no uplink packet. The modified version operates in two phases:

1. AP will poll all stations at least once. During the first polling phase, AP follows the traditional PCF operation, while stations will return the following information of their pending traffic instead of actual data packets.

   - Number of pending packets for AP.
   - Number of pending packets for other mobile stations.
   - The destination address of mobile stations.
   - The location information (calculated based on the RSSI information of the poll from AP).

   So after this polling phase, all the downlink packets will have been transmitted.

2. AP will send a broadcast message to all mobile stations after the first polling, which enables those mobile stations with no pending packets to or from AP and other mobile stations to switch to the power saving state until next beacon period.

3. Then AP will poll the stations that are still in the active state again.

   It will first poll the stations that only have pending packets for AP based on the traffic announcements received in last polling phase. The packet transmission procedure will be according to the original PCF mode. Upon reception of the polling message, stations will acknowledge the polling by returning their uplink packets. After the transmission, stations without any pending packets for other mobile stations can switch to the power saving state until next beacon period.

   If the location information of mobile stations can be obtained from a location service [4], mobile stations can utilize the distance information between each other to dynamically adjust their transmission power. In case such location service is not available, mobile stations can use RSSI measurements [1, 5, 6] based on the overheard control frames to estimate the minimal necessary power for desired destination mobile stations. In our proposed protocol, as shown in Figure 1, MS1 has data packets for MS2. During the first polling phase, if MS1 is polled first, MS1 will announce its pending data packets as a reply to the poll. MS2 can then overhear the announcement which has MS2's AID as the destination address and calculate the RSSI from MS1. The RSSI value between MS1 and MS2 is transmitted to AP as piggyback information when MS2 is polled. If MS2 is polled first, MS2 will reply a frame without payload to AP since it does not have pending packets. MS1 can actively overhear the transmission and transmit the RSSI value between MS1 and MS2 to AP when it is polled.

   The signal strengths between AP and mobile stations are monitored by AP constantly, while the signal strength information between different mobile stations is collected by mobile stations and reported to AP when polled. The mean of the most recent 20 signal strength values is then used in our proposed algorithm. Based on the RSSI information between different mobile stations and the traffic condition (mobile to mobile), AP will calculate the power required for routed transmission (mobile to AP to mobile) and direct transmission (mobile to mobile) as described previously. It will choose the transmission method based on the comparison. Stations that can only use AP to forward their mobile-to-mobile traffic (either because the source and destination are out of transmission range, or the direct transmission is not power efficient, eg. MS1 to MS3) will be polled by AP for their pending packet subsequently. After the transmission, stations without any pending packets for mobile stations can switch to the power saving state until next beacon period.

After all the stations that satisfy the above mentioned criteria have been polled, AP will signal the end of the contention free period by transmitting a control frame of subtype CF-End. If there is any mobile-to-mobile traffic pending, AP will piggyback the transmission order information [2] to schedule the AP assisted DCF transmission period to reduce any possible collision. The transmission order information includes the source and destination address of mobile stations, the number of pending packets and the scheduled transmission time. Stations operating in the contention period must follow the explicitly announced transmission order by AP, which can minimize the contention when multiple stations with pending packets try to access the channel simultaneously.

4. During the direct transmission, if a specific packet has not been correctly acknowledged by the destination, the source mobile station will transmit the packet to AP during its next polling round as its uplink packet. AP will then retransmit the packets to the destination. It operates in the following manner. Suppose that A has a series of packets to be directly transmitted to B with sequence number 1, 2, 3, 4 and after the transmission of packet 2 to B, A has not received ACK from B within the ACK timeout. In this case, the transmission error is probably caused by random noise. In our proposal, A will try to retransmit packet 2 only once. If the retransmission is successful, then remaining packets will be transmitted as usual. If the retransmission is not acknowledged either, A will stop the direct transmission and pass all the remaining packets to AP during the next polling. (In this case, the destination maybe in deep fading, out of range, or subject to interference).

3 Simulation and Analysis

In order to verify our proposed algorithm as it is incorporated into existing IEEE 802.11 protocol and provide comparison results, we used the well-known network simulator NS-2 version 2.1b8 [7] with contributed PCF model provided by Anders Lindgren [8], which has a detailed simulation of the MAC/PHY layer characteristics and infrastructure based operation of IEEE 802.11. We have implemented our proposed modifications on-top of the existing model to support the improved AP operation. In the simulation, we setup a wireless LAN environment with AP and mobile stations. The physical layer is modeled as the 2Mbps wireless medium as widely used in most of the IEEE 802.11 compatible devices. The physical data rate dose not significantly affect the results, since the MAC level protocol operate basically in the same way for different data rates and we only make modifications on MAC level. The simulation area is a flat square ($500{\times}500m^2$), and the AP is a special node with infinite energy and fixed position which is located in the center (250,250) of the simulation area. The total number of mobile stations in the simulation area is 20. Mobile stations randomly move within the area constantly with maximum speed of 5 meters/second. We use the constant bit rate traffic with fixed length packet size of 1024 bytes. The beacon interval is set to be 1 second and the max duration of the CFP is 0.8 second for PCF mode. The default energy consumption model is described in table 1. We assume that mobile stations use fixed energy level for receiving, idle and power-saving state. The transmission power is adjustable and we only apply the transmission power adjustment for data packets. As a result, mobile stations use maximum transmission power ($P_{transmitting}$) for communication during the first polling phase and control packets. Based on the estimated distance (D_{est}) between sender and receiver, we use equation 2 to obtain the minimal required energy (P) for the transmission.

$$P = P_{transmitting} \times (\frac{D_{est}}{D_{range}})^{\lambda} \qquad (2)$$

We use UDP traffic at each source with constant packet generation rate at 4 packets per second. The connection patterns are randomly generated. In Figure 2 to 4, the X-axis "number of stations polled by

Table 1: Energy Consumption Model

Operation mode	**Energy**
Idle	1.15 W
Power saving mode	0.045 W
Receiving	1.4 W
Transmitting ($P_{transmitting}$)	1.65 W
Transmission range (D_{range})	250 m

AP" means the number of stations that are communicating with each other using the AP as the router, in which the traffic sinks are at the destination stations (mobile stations). It should be noted that all other stations communicating with AP have their destination addresses of UDP traffic set at a remote server attached to AP. The simulation time is 200s and all UDP traffic start at 7s together. In the simulation, we compare the traditional IEEE 802.11 protocol with our proposed modifications: the improved PCF operation and smart AP protocol. In our protocols, the mobile stations take advantage of the AP assisted DCF transmission mechanism for direct transmission between each other without routing through AP if certain criteria are met. Mobile stations do not have to stay active in every beacon interval owing to the waking up time estimation and announcement of TIM through beacon transmission.

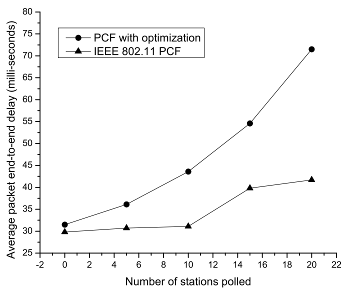

Figure 2: Average packet end-to-end delay.

In the simulation, IEEE 802.11 PCF protocol has the minimum end-to-end delay as shown in Figure 2. The average delay calculation includes stations with packets destinated for wired stations and mobile stations. Suppose a total of N packets have been received successfully, the average delay can be calculated as described in equation 3, where RCV^i_{time} represents the time i_{th} packet is successfully received, and GEN^i_{time} is the generation time of i_{th} packet.

$$average\_delay = \frac{\sum_{i=1}^{N}(RCV^i_{time} - GEN^i_{time})}{N} \quad (3)$$

There are several reasons that affect the results. In IEEE 802.11 PCF, stations will stay active for the entire beacon period. After all the stations in the polling list have been polled, AP can poll any station that has down-link data packets pending. Packets that are generated or received during the polling period can still be transmitted to mobile stations if the contention free period is not over. Furthermore, in our proposed algorithm, we use two-phase polling mechanism during which the first polling period is utilized for traffic information collection. So the average time that a station with pending data is polled is larger than that in the traditional IEEE 802.11 PCF protocol, especially when the number of stations in the polling list of AP is very large. Mobile stations are enabled to stay in the power saving state for a longer time in our proposed protocol.

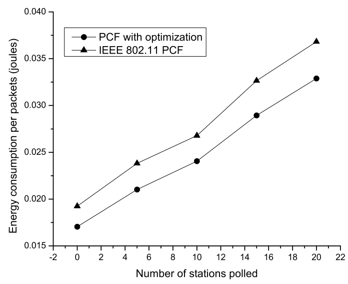

Figure 3: Energy consumption per packet.

Energy consumed per packet (E) is computed for each packet received at the destination, which accounts for the average energy consumed by each successfully received packet. It can be described as equation 4, in which $E^i_{initial}$ and E^i_{remain} are the initial energy and remaining energy of mobile station i when simulation finishes, respectively.

$$E = \frac{\sum_{i=1}^{N}(E^i_{initial} - E^i_{remain})}{total\_packet\_received} \quad (4)$$

The proposed protocols lead to less energy consumption per packet than IEEE 802.11 PCF, which may prolong the battery lifetime up to 35% in the best scenario as shown in Figure 3. Stations do not have to stay active for the entire contention free period unless it has setup schedule with AP during the first polling period, otherwise energy is wasted since stations wait in an idle state without receiving or sending any data packets. The two-hop transmission is also reduced to a single hop direct transmission if necessary for power efficiency. Stations can switch to power saving mode after receiving the first poll, if they do not have packets to transmit or receive. Stations can also switch to power saving mode after the second poll, if they have finished the packets transmission and no direct transmission (AP assisted DCF) is scheduled by AP.

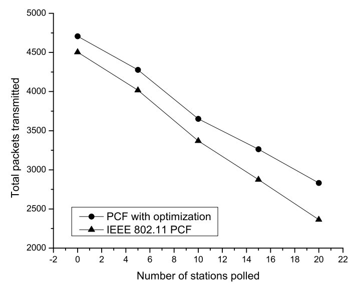

Figure 4: Total packets transmitted during the simulation time

Figure 4 shows the number of data packets that have been transmitted and successfully received by the destinations. Since all the simulations run for the same amount of time and the traffic arrival rate, more packets transmitted suggests higher bandwidth utilization. Our proposed protocol utilizes the beacon interval as long as possible for the two-phase polling if most traffic is between AP and mobile stations. When most traffic is between different mobile stations, our scheme will enable them to be directly transmitted during contention period. Furthermore, the two-hop transmission is reduced to a single hop direct transmission without contention, which reduces the channel utilization and possibility of collision. Hence there will be more time in each contention free period for stations that actually have pending data packets, which increases the throughput significantly.

4 Conclusion

In this paper, we have proposed an improved PCF operation as enhancement to the traditional IEEE 802.11 PCF protocol. Simulation results show that using the proposed protocol energy consumption of mobile devices can be reduced while the end-to-end packet delay is slight longer than traditional IEEE 802.11 PCF protocol. The throughput is increased significantly due to the reduction of channel utilization time through the direct transmission. The proposed protocol is a hybrid of AP assisted DCF and PCF operation, which is more flexible and fault-tolerant, and can be readily reverted to the traditional IEEE 802.11 protocol for compatible reason when required.

Acknowledgements: The research was supported by School of Computer Engineering, Nanyang Technological University and in the case of the first author, it was also supported by the Grant of Nanyang Technological University Research Scholarship.

References:

[1] LAN MAN Standards Committee of the IEEE Computer Society, IEEE Std 802.11-1999, Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications.

[2] M. H. Ye, C. T. Lau and A. B. Premkumar, Modified Power Saving Mode in IEEE 802.11 Distributed Coordinator Function, Performance issues of Wireless LANs, PANs and ad hoc networks, Elsevier Computer Communications, Volume 28, Issue 10, June 2005, Pages 1214-1224.

[3] IEEE 802.11 WG, Draft Supplement to STANDARD FOR Telecommunications and Information Exchange Between Systems - LAN/MAN Specific Requirements - Part 11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: Medium Access Control (MAC) Enhancements for Quality of Service (QoS), IEEE Std 802.11e/D4.0, November 2002.

[4] Seapahn Meguerdichian, Sasa Slijepcevic, Vahag Karayan, Miodrag Potkonjak. Localized Algorithms in Wireless Ad-Hoc Networks: Location Discovery and Sensor Exposure, MobiHOC 2001, pp. 106-116, October 2001.

[5] Moustafa Youssef, Ashok Agrawala, A. Udaya Shankar, WLAN Location Determination via Clustering and Probability Distributions, IEEE International Conference on Pervasive Computing and Communications (PerCom) 2003, Fort Worth, Texas, March 23-26, 2003.

[6] P. Krishnan, A.S. Krishnakumar, Wen-Hua Ju, Colin Mallows, and Sachin Ganu, A System for LEASE: Location Estimation Assisted by Stationary Emitters for Indoor RF Wireless Networks, IEEE Infocom, Hong Kong, March 2004.

[7] The CMU Monarch Project, The CMU monarch project's wireless and mobility extensions to NS, Available: http://www.monarch.cs.cmu.edu/cmuns.html.

[8] Anders Lindgren and Andreas Almquist and Olov Schelén, Quality of Service Schemes for IEEE 802.11 Wireless LANs - An Evaluation In the Special Issue of the Journal of Special Topics in Mobile Networking and Applications (MONET) on Performance Evaluation of QoS Architectures in Mobile Networks, Volume 8, Number 3, June 2003