A Modified Point Coordination Function in IEEE 802.11 Wireless LAN

Apichan Kanjanavapastit
School of Electrical Engineering and Telecommunications
The University of New South Wales
Sydney, Australia
Email: apichan@ee.unsw.edu.au

Department of Telecommunication Engineering
Mahanakorn University of Technology
Bangkok, Thailand
Email: apichan@mut.ac.th

Bjorn Landfeldt
School of Information Technologies and School of Electrical and Information Engineering
The University of Sydney
Sydney, Australia
Email: bjornl@staff.usyd.edu.au

Abstract- **With recent advances in wireless technologies, wireless LANs are becoming increasingly widespread as an alternative to fixed access technologies. The IEEE 802.11 standard has gained the most popularity among the different standards and is currently being deployed both within enterprises as well as being used for public access.**

One of the weaknesses of the basic medium access in the 802.11 standard is its relatively poor support for real-time traffic. In order to provide this support, the MAC layer implements a Point Coordination Function (PCF). However, since the PCF is based on a centralized polling protocol, some bandwidth is wasted due to the polling overheads and null packets in case the polled stations do not have any data to transmit. In order to reduce the waste and increase the channel utilization this paper presents a modified version of the standard PCF.

The modified PCF uses a distributed polling protocol (DPP) as an access mechanism for the uplink transmission. The transmission period in the modified PCF consists of a distributed polling protocol period (DPPP) which is controlled by the DPP and the real-time traffic downlink period (RTDP). The paper further introduces a technique for dealing with the hidden station problem for use together with the proposed modification. This problem occurs when one or more stations misinterpret the status of the medium leading to unforeseen collisions.

Using simulation we compare the performance of the modified PCF with the standard PCF when they are used to support voice transmissions. The results show that the modified PCF significantly improves the channel utilization since it can support a higher number of stations than the standard PCF.

I. Introduction

As wireless networks become increasingly popular it is becoming evident that they have quite different properties than their wired counterparts. Even so, they are largely used for the same purposes as wired networks and the end users expect the behavior of applications to be similar to a wired networking environment. One of the keys to applications behaving well lies in the medium access control (MAC) layer of the protocol stack.

The major functions of a MAC protocol are to provide a delivery mechanism for user data, fairly control access to the shared medium and to protect the delivered data. Therefore, the MAC protocol is a very crucial part in the data communication protocol stack. In addition, Quality of Service (QoS) is largely dependent on the efficiency of the MAC protocol. Moreover, since the demand for the transmission of real-time traffic (i.e. voice and video) has been growing significantly in recent years, a MAC protocol which can provide good QoS is required. However, it is not trivial to design a good MAC protocol given that real-time traffic uses large amounts of bandwidth and also requires strict boundaries in terms of delay, jitter etc. Since wireless is such a noisy and unreliable medium, it makes the task of designing a good MAC protocol even more challenging.

The IEEE 802.11 Working Group (WG) proposed the IEEE 802.11 WLAN standard in 1997 and a revised version appeared in 1999 [1]. The standard defines a MAC sublayer, MAC management protocols and services, in addition to physical (PHY) layers. The fundamental access mechanism in the IEEE 802.11 MAC sublayer is the distributed coordination function (DCF). The DCF is a contention-based protocol, which uses the carrier sense multiple access with collision avoidance (CSMA/CA) protocol which was especially designed to support the transmission of traffic in wireless networks. Since wireless stations must contend to access the wireless medium in the DCF, the medium access delay for each station cannot be bounded during high load conditions. Thus, the DCF can support only the asynchronous data transmission on a best-effort basis.

In order to support real-time traffic such as voice and video, the point coordination function (PCF) is proposed as an option. The PCF is based on a centralized polling protocol where a point coordinator (PC) residing in an access point (AP) provides contention-free services to the stations associated with a polling list.

Recently, some work have investigated the performance of the PCF when used to support real-time traffic [2-5]. In [2] it was shown that the large overhead introduced by the PCF resulted in a low number of possible voice conversations. Since the PCF is based on a centralized polling protocol, some bandwidth is wasted due to polling overheads and also due to subsequent null packets if a station does not have any data to respond as stated in [1]. In addition, the MAC layer retransmissions of lost or corrupted data can be unnecessary or even harmful for real-time traffic with hard delay and jitter constraints since it introduces extra delay. Furthermore, there are several methods for reducing the effect of packet loss on real-time traffic such as error-resilient encoding and error concealment.

Therefore, we propose a modified version of the PCF which uses a distributed polling protocol (DPP) to transmit any real-time traffic in the uplink period. The scheme can increase the channel utilization and diminish the negative effects of polling overheads and null packets. Moreover, the scheme avoids the retransmission process in the MAC-level and also avoids acknowledgments from receiving stations.

Since the DPP is based on a carrier sense protocol, which is sensitive to the hidden station problem, the performance of the DPP may decrease due to unforeseen collisions. Hence we also propose a technique for collision resolution and for reduction of the probability of the hidden station problem.

We have done a simulation study to compare the performance of the standard PCF and proposed modified PCF. The results show that the modified PCF utilizes the channel more efficiently and can support a higher number of wireless stations than the standard PCF for voice traffic.

The remainder of this paper is organized as follows. Section II briefly covers related work. The operation and drawback of the PCF are explained in Section III. Section IV details the modified PCF and the operation of the DPP. The details of the simulations are given in Section V. Section VI describes the simulation results of the modified PCF compared to the standard PCF and an evaluation of the simulation results is presented in VII. Finally, we conclude and describe our future work in Section VIII.

II. Related Work

Some previous research papers have proposed modifications to the PCF in IEEE 802.11. The work in [6] proposed a modified version of the PCF called M-PCF for implementing QoS. Although M-PCF and the modified PCF proposed in this paper have similarities, in M-PCF the AP still sends the polling packet in case a station does not have any data to transmit. Moreover, M-PCF does not provide a collision resolution technique to resolve the hidden station problem. A protocol called Superpoll was proposed in [7]. It contains a message that includes list of stations that will be polled during a current CFP. In addition, it proposes a chaining mechanism to improve the reliability of the protocol by attaching the Superpoll message in every sent packet. However, in the Superpoll protocol, if a station has noting to send, it sends a null packet, which still causes bandwidth to be wasted. Moreover, the Superpoll message, which is appended in the header of every sent packet, decreases the channel utilization. In addition, this scheme can only operate with traffic in which the packet size is constant since a station in the list has to set a pre-calculated timeout.

III. The Point Coordination Function (PCF)

The PCF provides contention-free services to wireless stations that have real-time traffic to transmit by arranging them in a polling list. A PC located in the AP provides support for real-time traffic using a centralized polling protocol in the PCF. The PCF is built on top of the DCF and the two operate concurrently. The protocol operates as follows.

The PC begins a period of operation called contention-free period (CFP) in which the PCF is operating. The CFP occurs periodically in accordance with a preset CFP repetition interval. The CFP also alternates with a contention period (CP) where the DCF is applied. The operation periods of the DCF and PCF create the superframe structure as shown in Fig. 1.

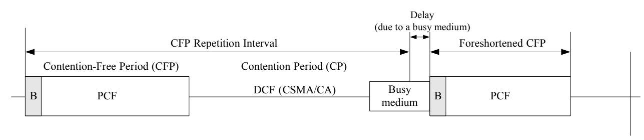

Fig. 1. Superframe structure.

The PC begins the CFP repetition interval by transmitting a beacon packet. Since the PC must contend with other stations for the medium, the beginning of the CFP may be delayed from its ideal start time resulting in a foreshortened period called a stretching period. After sending the beacon packet, the PC polls those stations that have requested contention-free service. During a CFP, if the PC does not have any packet to deliver, it just sends a polling packet to a station. However, the PC and stations can make use of a piggybacking technique whereby a data packet is sent together with the poll or a subsequent acknowledgement. If a polled station does not have any data to respond, it has to transmit a null packet back to the PC as stated in [1]. In this case, some of the bandwidth will be used only for polling and transmission of null packets and consequently wasted.

To clearly illustrate the drawback of the PCF operation, Fig. 2 shows an example period. After the PC has sent the initial beacon packet, it sends a data packet with the poll to station 1 within the short inter frame space (SIFS). Since station 1 has data to send, it then piggybacks the packet with the acknowledgment for the received packet from the PC. The operation continues until the polling sequence has arrived at stations 3 and 4. Since the PC does not have any packet to deliver to these stations and they in turn have no data to respond, the PC transmits only the polling packets and stations 3 and 4 respond with null packets. During this period the channel is un-utilized.

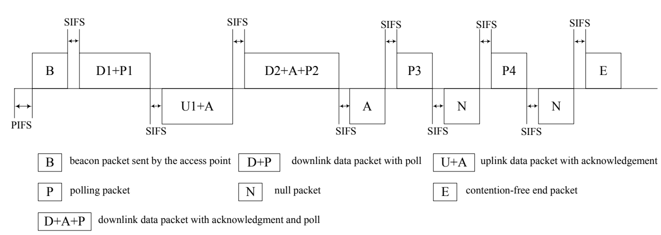

Fig. 2. Operation in the PCF.

The problem with the standard PCF can become severe when the centralized polling protocol is used to control voice traffic. If a voice activity detector (VAD) is applied, voice traffic consists of ON periods and OFF periods. Since the

OFF period is longer than the ON period [8], the probability of the PC polling a station during an OFF period is high which in turn leads to poor utilization of the link.

IV. The Modified Point Coordination Function

In order to overcome the under-utilization problem, we propose a modified PCF which uses a distributed polling protocol (DPP) for supporting real-time traffic instead of the centralized polling scheme as used in the standard PCF.

As illustrated in Fig. 3, during the CFP in the modified PCF the channel transmission time comprises two transmission periods: the distributed polling protocol period (DPPP) and the real-time traffic downlink period (RTDP). The length of the DPPP and RTDP in the modified PCF is equal to the length of the CFP in the standard PCF. Since the CFP interval provided in the standard has to be shared between the DPPP and RTDP, their length should be equal. However, if the DPPP does not fully use its allocated time, the remainder can be lent to the RTDP.

The wireless stations send real-time traffic during the DPPP as described in the next section. In contrast, the PC sends real-time traffic during the RTDP. This traffic includes downlink traffic and real-time traffic that is relayed from one wireless station to another.

Generally, real-time traffic should be transferred to the destination within a bounded delay period and therefore retransmission of real-time traffic as is done in the standard PCF is not a good solution. This also implies that the acknowledgment from the receiver to the transmitter at the MAC-level is not required. Instead, in our scheme it is left to the higher layer protocols to manage errors either by retransmissions or by redundant coding techniques. Since the acknowledgment is not used in the modified PCF, we cannot benefit from the piggybacking technique, which also explains why the modified PCF uses the RTDP.

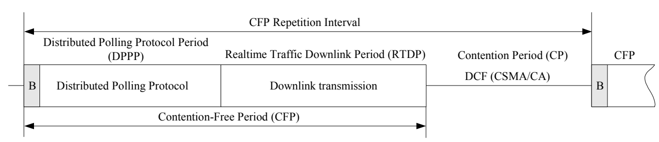

Fig. 3. Channel transmission periods in the modified PCF.

A. *A Distributed Polling Protocol (DPP)*

The DPP allows wireless stations to send their real-time traffic without a polling packet being issued by the PC. In order to achieve this, the stations must monitor the status of the medium before transmitting. Therefore, the transmission order for each station can be recognized by sensing the status of the medium whether it is in idle or busy state.

1) *Access Procedure*: Since the transmission of real-time traffic has to commence in the DPPP, which is supported by the DPP, a wireless station has to be in the polling list only if it has real-time data to transmit. To enter the polling list, the station sends an association request to the AP during the CP. To confirm that the station has been added to the polling list, the PC returns the polling identification (pollingID) and transmission order assignment. Stations that are already in the polling list update with the new transmission order after receiving a successful association. After the association stage, the station then waits to transmit its traffic in the DPPP. Any change to the transmission order in the polling list is announced during the RTDP. The reason for a change can be a station leaving the polling list or the PC rescheduling the order to minimize the hidden station problem as discussed later in the next subsection.

Fig. 4 shows the access procedure of the DPP. To initiate a DPPP, after the priority inter-frame space (PIFS) has elapsed, the PC broadcasts a beacon packet to every wireless station in a basic service set (BSS). Like the standard PCF in IEEE 802.11, the beacon packet contains important information used in the CFP such as the maximum CFP duration and the CFP repetition interval. After receiving the beacon packet, the first station, which gets the first order of transmission accesses the medium by transmitting a packet after the SIFS has elapsed. The following stations in the polling list should sense the medium to check whether it is idle or busy.

Every station in the polling list maintains a counter, which is used to count the number of transmissions or the number of idle periods in the medium. A station will identify its turn to transmit a packet when the counter equals its transmission order as determined by the PC. Thus, the initial counter value is one and it is increased by one with every sensed transmission or idle period in the medium. This process should be continued until the last station has finished its transmission. However, any station that has outstanding real-time packets to transmit can alert the PC by setting a “more data” bit in the header of the transmitted packets. As the PC knows that there is more real-time data to transmit, it will not issue the “contention free end” packet to stop the DPPP if there is still time remaining in the CFP. Thus, the first station in the transmission sequence continues transmitting after the last station has finished and then the second etc.

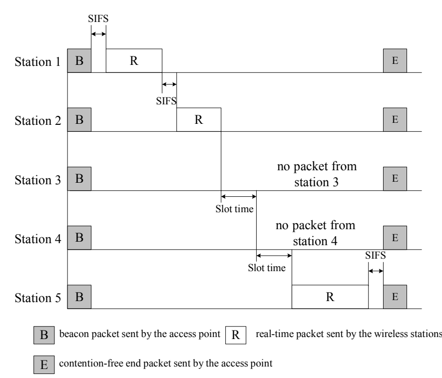

Fig. 4. The access procedure of the distributed polling protocol.

Note that the sensing time of idle period is dependent on the underlying physical layer. In case of the direct sequence spread spectrum (DSSS) physical layer, which is considered in this paper, the stations will determine an idle period by waiting to hear a transmission during a slot time. If no transmission has been detected, the counter is increased by one and the next station takes turn transmitting after a slot time has elapsed. This is illustrated in Fig. 4 where stations 3 and 4 have no data to transmit. Station 5 waits for one slot time and determines that station 3 has no data to transmit. It then waits for another slot time and determines that also station 4 had no data to transmit. Again increasing the counter it identifies its turn and transmits a packet when two slot times have elapsed. This waiting period also consumes bandwidth. However, it is significantly lower than the polling and null packet overhead used in the standard PCF.

Note that there are two cases in which the PC transmits a "contention-free end" packet to stop the DPPP (and also to start the RTDP). Firstly, if there is no time remaining in the DPPP and secondly if time in the DPPP still remains but no station in the polling list has any packet to transmit. In the second case, the remaining time will be added to the coming RTDP as mentioned earlier.

It is possible that some stations in the polling list are not able to transmit during the DPPP because the maximum DPPP period is reached before their turn. Therefore, each station in the polling list has to circularly shift its transmission order after it has received the contention-free end packet. This method can improve the fairness amongst stations in the polling list and can also be used to reduce the probability of the hidden station as discussed next.

2) *Collision Resolution*: As mentioned earlier, the hidden station problem occurs frequently in wireless networks. It is an advantage if the DPP implements a collision resolution mechanism that minimizes the problem because if such a mechanism is not present, the wireless stations that encounter the problem will only be able to transmit intermittently. In order to describe the collision resolution mechanism, assume that station 3 cannot sense the transmission commenced by station 2 as shown in Fig. 5. Hence station 3 will start its transmission after a slot time, which is measured from the end of the last transmission and therefore a collision will occur. After the transmission has finished, the PC and the other stations in the list will detect the collision since they cannot receive any packet after the medium is changed to idle state. The stations will then wait for the collision resolution process from the PC to take place.

Since the PC has identified that station 2 started its transmission within SIFS but the transmission was not successful, the cause of the unsuccessful transmission may come from a transmission of a following station in the polling sequence. Although the PC cannot identify exactly which station is the cause of the collision, the PC knows that station 3 is the following station that will get the right to transmit. Therefore, the collision resolution should involve stations 2 and 3 only.

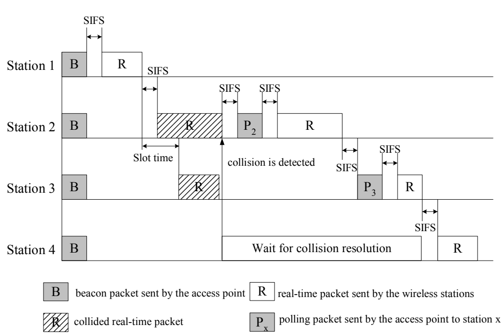

Fig. 5. The collision resolution of the distributed polling protocol.

To start the collision resolution, the PC sends a polling packet to the station that has received its turn to transmit within SIFS after the state of the medium is changed from busy to idle (i.e. station 2 in the example). Note that all stations including those that cannot sense the transmission from stations 2 or 3 should receive the polling packet and then wait until the collision resolution process has finished. Like a general centralized polling protocol, the polled station responds to the polling packet by retransmitting the lost packet to the PC within SIFS. After the PC received the packet sent by station 2, it waits for the SIFS to elapse before sending another polling packet to station 3. Since the following stations in the polling sequence know that the collision resolution always involve just two stations, they can resume normal operation after identifying the packet sent by station 3. As seen in Fig. 5, station 4 can commence its transmission within SIFS after the transmission from station 3 has finished. Note that the following stations set their counter according to the transmission order of the last polled station when they return to the normal operation.

Although the collision resolution technique can solve the hidden station problem, some bandwidth will be used up transmitting the polling packets. Therefore, we should have a technique to reduce the frequency of the collision resolution process. To achieve this goal, the probability for the hidden station should be minimized. Since the problem depends on the location of the wireless stations, rearranging the transmission order for the stations in the polling list will achieve this. Consequently, the PC should rearrange the transmission order when the PC identifies that a collision occurred in the medium. Then the new order is announced in the RTDP as described earlier.

V. Simulation Study

We evaluated the performance of the modified PCF by comparing it to the standard PCF in a simulation study using OPNET [9]. Because we concentrated on the performance of the proposed protocol in CFP, transmissions in the CP using the DCF mode were neglected and consequently the stretching period did not occur in the simulations. Since voice is of highest priority for the wireless industry, we investigated the performance of the standard and modified PCF when carrying voice traffic only. The simulation scenario was set to be the same in both systems consisting of a number of wire line stations communicating with a corresponding number of wireless stations via an AP. Each station in the system generated voice traffic using the G.729 codec. VAD was applied to the voice traffic and digitized voice packets were generated only during ON periods. The duration of the simulation was set to 5 minutes which is the acceptable average call holding time according to [10]. The voice traffic parameters used in the simulation are shown in Table I and the IEEE 802.11 parameters are shown in Table II.

TABLE I
Voice Traffic Parameters

Voice Traffic Parameters	Values
Packet inter-arrival time during ON state	25 ms
Mean interval in ON state	1 s
Mean interval in OFF state	1.35 s
Voice packet payload	20 bytes
RTP layer overhead	12 bytes
UDP layer overhead	8 bytes
IP layer overhead	20 bytes

TABLE II
IEEE 802.11 Parameters

IEEE 802.11 Parameters	Values
Data rates for data packet	11 Mbps
Data rates for control packet and PHY overhead	1 Mbps

MAC layer overhead	28 bytes
PHY layer header	24 bytes
Beacon body size	35 bytes
SIFS interval	10 us
Slot time interval	20 us
CFP interval	10 ms
CFP repetition interval	20 ms

The following assumptions were made for the simulations:

- Since we were interested only in the performance of the modified PCF which is in the wireless part, the wire line stations were connected to the AP by a point to point link with negligible link delay.
- The wireless medium was error free; the capture effect and the fading effect were ignored. In addition, there was no hidden station in the system so collisions did not occur in the medium.
- Each wireless station was allowed to transmit voice packets only in CFP.
- The buffer size in each station including the AP was unlimited; there was no buffer overflow.
- The transmission order of voice packets sent by the wire line stations in the RTDP was based on first-come-first-serve (FCFS).
- A beacon packet was assumed to be sent only once in the beginning of a CFP per superframe.
- At the beginning of the simulation, the starting of voice packet generation in each station was a uniform distribution between 0 and 0.01 sec.
- The location of each wireless station was fixed.

In addition, we defined the polling list management used in the simulation for the standard PCF as follows.

- The PC polled the stations in the polling list according to a simple round robin method.
- If the PC could not finish polling every station in the polling list within one CFP, the polling sequence for the next CFP would start with the next station in the polling list.
- According to the previous issue, if the polling sequence did not start with the first station in the polling list and the end of the polling list was reached before the end of a CFP, the PC would poll continuously the polling sequence with the first station.
- The polled stations could set the "more data" bit to notify the PC that they still had more packets to transmit. Therefore, if time still remained in the CFP after every station had been polled during one CFP, the PC could continuously poll the stations which had set this bit.
- The PC could terminate the current CFP if every station had been polled and no more packets were waiting in the buffers of either the stations or the PC.

VI. Simulation Results

To compare the performance of the modified PCF and the standard PCF, we investigated some metrics from the simulations that indicate the number of stations the two systems could support. Since the traffic comprised only voice communications, the medium access delay of the voice traffic was chosen to be the factor that determined the number of supportable stations. The acceptable one-way delay of voice communication for user applications recommended by ITU is at most 150 ms [11]. In accordance with [4] we considered that any delay within the wireless part should be less than 50 ms with the residual time of around 100 ms to be used for passing the wide area network (e.g. the Internet). Therefore, the access delay should be less than 25 ms since the packetization delay of the voice traffic generated by G.729 is around 25 ms.

A. *Standard PCF*

As seen in Fig. 6, the average medium access delay of the standard PCF varies with the number of wireless stations, N. The figure shows that the average medium access delay changes significantly from around 15 ms to around 35 ms when the number of wireless stations is greater than 22. This means that the number of wireless stations which the standard PCF can support is 22 under the provided simulation parameters. Fig. 7 shows the average uplink throughput of the standard PCF versus time for different numbers of wireless stations. As shown in the figure, the average throughput is around 180 kbps when the number of stations is 22.

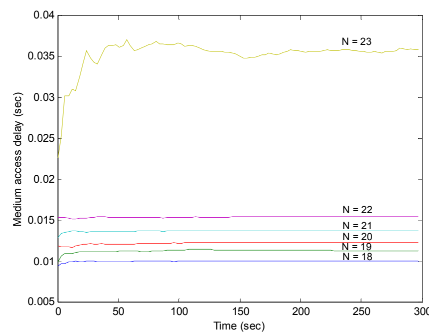

Fig. 6. Average medium access delay of the standard PCF.

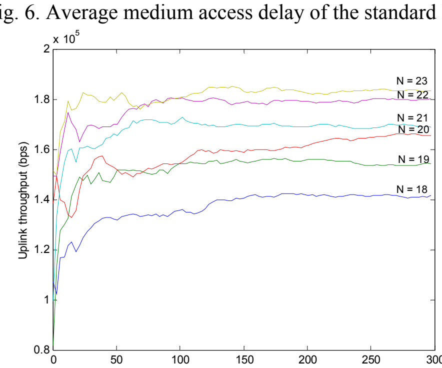

Fig. 7. Average uplink throughput of the standard PCF.

B. *Modified PCF*

Fig. 8 illustrates the average medium access delay of the modified PCF. Although the average delay is fluctuated in the range of around 150 seconds, the modified PCF can support 33 stations since the average medium access delay is under

25 ms. The average uplink throughput of the modified PCF, which is shown in Fig. 9, is around 265 kbps with 33 stations.

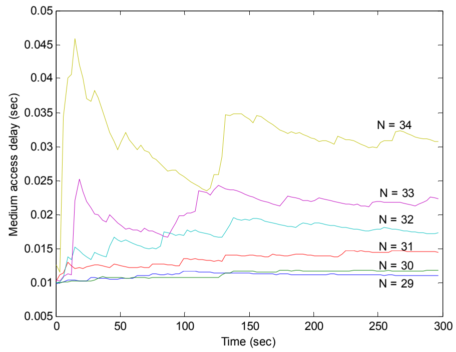

Fig. 8. Average medium access delay of the modified PCF.

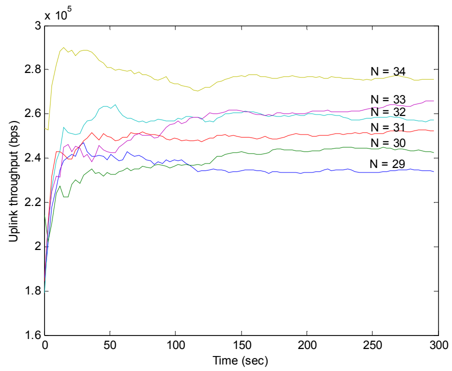

Fig. 9. Average uplink throughput of the modified PCF.

VII. Evaluation of the Results

As the results show, the modified PCF which uses the distributed polling protocol in the DPPP can support a significantly higher number of wireless stations than that of the standard PCF. In this simulation, we can add 11 more wireless stations carrying G.729 voice traffic in the system.

TABLE III
PERCENTAGE OF AVAILABLE TIME IN CFP AFTER USED

Modified PCF		Standard PCF	
No. wireless stations	% available time in CFP	No. wireless stations	% available time in CFP
29	34.017	18	1.441
30	31.999	19	0.043
31	30.270	20	0
32	28.334	21	0
33	27.134	22	0
34	24.763	23	0

These results highlight the inefficiency of the standard PCF due to the polling packet, null packets, and acknowledgment packet and show that a dramatic increase in efficiency can be obtained using the modified scheme.

This is further highlighted in Table III, which shows the percentage of average available time in the CFP using both the modified PCF and the standard PCF. As illustrated in the table, the available time in CFP with 22 hosts after the standard PCF has been used is zero. On the other hand, the percentage of available time after the modified PCF has been used is around 27 percent when the number of stations is 33.

This shows that the modified PCF spent less bandwidth than the standard PCF and in addition that we can add more wireless stations to the modified PCF system by lowering the voice quality at the destination through higher delay.

VIII. Conclusion and Future Work

The paper proposes a modified point coordination function (PCF) for the IEEE 802.11 MAC protocol. The intention of the proposal is to increase the channel utilization by removing the polling overheads, null packets, and MAC-level acknowledgment used by the standard PCF when transmitting real-time traffic. Since the DPP is based on a carrier sense protocol, the performance of the system may be drastically reduced if the hidden station problem occurs. Therefore, we also propose a collision resolution technique and a technique to reduce the probability of the hidden station.

A simulation scenario was setup to determine the performance of the modified PCF by carrying voice traffic generated by the G.729 codec. The simulation scenario consisted of a varied number of wire line stations communicating with a corresponding number of wireless stations. The results show that the modified PCF can support a significantly higher number of wireless stations than the standard PCF with maintained voice quality under provided simulation parameters and constrained medium access delay of the voice traffic. Since the simulation results further show that the channel utilization is higher using the modified PCF, we can add more wireless stations carrying a less delay sensitive real-time traffic type such as video in the system compared to using the standard PCF.

In future work, we will investigate the performance of the modified PCF under channel errors. We will also investigate the performance of the collision resolution technique for coping with the hidden station problem. Also, we will investigate the behavior when carrying video traffic.

References

[1] ISO/IEC and IEEE Draft International Standard, “Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications”, ISO/IEC 8802-11, IEEE P802.11/D10, Jan. 1999.

[2] M. Visser and M. El Zarki, “Voice and data transmission over an 802.11 wireless network”, Proc. IEEE PIMRC’95, 1995, pp.648-652.

[3] N. C. Coutras and S. Gupta, “Scheduling of real-time traffic in IEEE 802.11 wireless LANs”, Wireless Networks, 2000, pp.457-466.

[4] A. Kopsel and A. Wolisz, “Voice transmission in an IEEE 802.11 WLAN based access network”, Proc. 4th ACM Int. Works. Wireless Mobile Multimedia, 2001, pp.23-32.

[5] M. Veeraraghavan, N. Cocker, and T. Moors, “Support of voice services in IEEE 802.11 wireless LANs”, Proc. IEEE INFOCOM, 2001, pp.488-497.

[6] L. Zhao and C. Fan, “M-PCF modified IEEE 802.11 PCF protocol implementing QoS”, Electronic Letters, Nov. 2002, pp.1611-1613.

[7] A. Ganz, A. Phonphoem, and Z. Ganz, “Robust superpoll with chaining protocol for IEEE 802.11 wireless LANs in support of multimedia Applications”, Wireless Networks, 2001, pp.65-73.

[8] D. J. Goodman and S. X. Wei, “Efficiency of packet reservation multiple access”, IEEE Trans. Veh. Tech., Feb 1991, pp.170-176.

[9] OPNET Technologies, Inc., “OPNET Modeler: accelerating network R&D”, Available from the OPNET Web site: http://www.opnet.com/products/modeler/opnet_modeler.pdf

[10] V. A. Bolotin, “Modeling call holding time distributions for CCS network design and performance analysis”, IEEE JSAC, Vol. 12 No. 3, April 1994, pp.433-438.

[11] One-Way Transmission Time, ITU-T Recommendation G.114, Feb. 1996.