A Performance Investigation of the Modified PCF under Hidden Station Problem

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Abstract: A modified version of the *point coordination function* (PCF) in the IEEE 802.11 standard called the *Modified PCF* has been introduced to improve the channel utilization over the standard PCF. The Modified PCF is a hybrid scheme incorporating polling and channel sensing. Therefore, a collision might occur in the channel if some stations cannot sense the change of channel status in case there is a station transmitting a packet, the so-called *hidden station problem*.

In this paper, we present an investigation of the effect of the hidden station problem on the performance of the Modified PCF and propose a new collision resolution technique, which presumes a hidden station and then drops the station into a list of hidden stations. The simulation results show that the hidden station problem increase the overall delay of the system in the uplink. However, using the proposed collision resolution technique, the delay can be effectively reduced.

Keywords: Collision Detection, Hidden Station, PCF, Wireless LAN, 802.11.

I. Introduction

The IEEE 802.11 wireless local area network (WLAN) standard [1] has been the most successful among current WLAN technologies. With the widespread usage of these networks has followed a demand for support of new applications including multimedia applications such as voice and video. One of the keys to proper support for these multimedia applications behavior lies in the *medium access control* (MAC) sublayer defined in the 802.11 standard.

The fundamental access mechanism in the standard 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) scheme to control the transmission of data traffic. In order to support any real-time traffic such as voice and video, the *point coordination function* (PCF) has been proposed as an option in the standard. The PCF is based on a centralized polling protocol where a *point coordinator* (PC) located in an *access point* (AP) provides contention-free services to the wireless stations ordered in a polling list.

Since the bandwidth of the wireless channel is limited, channel utilization becomes of primary concern. However, it was noted before the release of the standard that the PCF performs badly due to polling overheads including the use of null packet resulting in a low number of possible voice conversations [2]. To overcome this problem, we have proposed a modification of the PCF called the *Modified PCF* which improves the utilization of the medium. In the Modified PCF, stations have to monitor the channel before they start their transmissions. Therefore, the efficiency of the protocol is mostly dependent on the so-called *hidden station problem*. It has been shown that the utilization can be drastically improved using the Modified PCF in case there is no hidden station problem through a simulation study [3] and a mathematical analysis [4].

In this paper, we propose an investigation of the effect of the hidden station problem on the performance of the Modified PCF through a simulation. We also propose a collision resolution technique which presumes a hidden station and drops it into a list of hidden stations. The simulation results show that the hidden station problem leads to an increment in the *end-to-end* (ETE) delay of the system. However, the results show that the ETE delay can be reduced if the proposed collision resolution technique is applied with the Modified PCF.

II. Related Work

Superpoll [5], a protocol and chaining mechanism was introduced to increase the reliability of receiving polling packets in the PCF. However, the proposal suffers from overheads since a Superpoll message is appended to every sent packet. Also, this scheme can only operate efficiently with CBR traffic where the packet size is constant because each station in the list has to set a pre-calculated timeout.

A contention-based multipolling mechanism called *Contention Period Multipoll* (CP-Multipoll) was proposed in [6]. Since the protocol uses the *request-to-send* (RTS) and *clear-to-send* (CTS) messages to avoid collision between contending stations, performance is comparable to standard PCF with polling overheads and consequently low link utilization.

III. An Indirect Collision Detection (ICD) in IEEE 802.11 MAC Sublayer

A. Introduction

Collision detection is necessary for the retransmission process and the collision resolution technique proposed in this paper. However, our technique is based on the IEEE 802.11 standard which does not implement a collision detection mechanism. We therefore introduce a novel way of detecting collisions in our modified PCF.

Unlike the collision detection used in IEEE 802.3, a transmitting wireless station cannot detect a collision during its transmission because of the half-duplex transmission. Nevertheless, other stations, which are monitoring the shared wireless channel, may detect the collision. The collision detection in an IEEE 802.11 wireless network can therefore be performed using the advantage of the *clear channel assessment* (CCA) function and a peer-to-peer service primitive called *PHY-RXSTART.indicate*. In this paper, we refer to this as an *indirect collision detection* (ICD).

In the following section, we describe the way we use the CCA and the primitive to detect a collision. Since the *direct sequence spread spectrum* (DSSS) is the most commonly used transmission technology in the *physical layer* (PHY) of most WLAN products, we have focused on the implementation of indirect collision detection using the DSSS technology.

B. Clear Channel Assessment

The function of the CCA is to determine the status of the medium whether the wireless medium is busy or idle and then report the status to the MAC sublayer. In the DSSS PHY of the IEEE 802.11, the CCA can be performed using three methods.

The CCA mode 1 and mode 2 are not suitable in the implementation of the indirect collision detection. This is because in mode 1 the busy medium can be reported to the MAC with any signal whose energy is above the *energy detection* (ED) threshold. Thus, it can be misunderstood that the medium is busy if a station is near a strong signal generator, such as microwave oven. For mode 2, although the busy medium is reported upon the detection of a DSSS signal with any signal strength, the state can also be misinterpreted if a strong signal generator is in another *basic service set* (BSS). For these reasons, CCA mode 3 is the most suitable in the implementation of the indirect collision detection since it detects a DSSS signal whose energy is above the ED.

C. Implementation of an ICD

Normally, data transmission in the PHY is initiated by firstly transmitting the preamble of the PHY and then data from the MAC sublayer. The preamble consists of a *synchronization* (SYNC) field, a *start frame delimiter* (SFD) field, a signal field, a service field, a length field, and a *cyclic redundancy code* (CRC) field.

Upon receiving a transmitted signal, the status of the busy medium shall be reported to the MAC according to the selected CCA mode. Then the PHY entity shall search for the SFD field. Once the SFD field is detected, the subsequent fields such as signal, service, and length are received simultaneously with the initiation of the CRC processing. If the verification of the received information using the CRC is successful, a *PHY-RXSTART.indicate* which is a peer-to-peer service primitive shall be issued to the MAC entity. On the other hand, if the verification fails, the service primitive is not sent to the MAC.

In general, if there is a collision, the result will be unintelligible. This means a collision will lead to the failure of the CRC verification and then the *PHY-RXSTART.indicate* will not be issued to the MAC. Consequently, if a *PHY-RXSTART.indicate* is not issued to the MAC after the busy state of the medium has been reported (within 192 us), this implies that there is a collision between transmissions of a station which gets the right to transmit and a hidden station. The time stems from the total number of bits in the preamble of the PHY (192 bits) transmitted at a basic rate of 1 Mbps as stated in the 802.11 standard.

Although the collision detection can be implemented in this indirect method, there might be an inaccuracy in the determination of collisions due to channel errors. In other words, the errors in the wireless channel can also result in the failure of CRC verification. However, this problem is unlikely to occur since the modulation technique used to transmit the preamble of PHY at 1 Mbps is DBPSK, which is more resilient to errors than the other modulations used in high data rate transmissions. Another problem in the implementation of the indirect collision detection is that a collision can be detected only in the 192 us interval. This problem limits the number of wireless stations as described in Section IV-C.

IV. The Modified PCF

A. Introduction

The Modified PCF was first introduced in [3]. Its main feature is that it can improve the utilization of the wireless medium by reducing the overheads (i.e., polling packet, null packets, and MAC-level acknowledgments) as used in the standard PCF. The channel transmission time of the Modified PCF is illustrated in Fig.1. As seen in the figure, during the *contention-free period* (CFP) the channel transmission time is divided into two transmission periods: a *distributed polling protocol period* (DPPP) and a *real-time traffic downlink period* (RTDP).

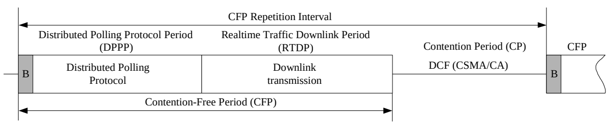

Fig.1 Channel transmission time in the Modified PCF

Any wireless station already associated in a polling list sends its real-time traffic to the PC during the DPPP. On the other hand, the PC sends real-time traffic destined to wireless stations during the RTDP. A *distributed polling protocol* (DPP) is the mechanism used to control the accesses of stations to the medium during the DPPP. The DPP allows stations to send their real-time data without a polling packet issued by the PC. In order to achieve this, the stations have to monitor the status of the wireless medium before transmitting. Thus, the transmission order for each station can be recognized by sensing the status of the medium. However, because of the hidden station problem, a station can misinterpret the status of the medium and start its transmission while another station is already transmitting. Therefore, a collision between the two transmissions would occur.

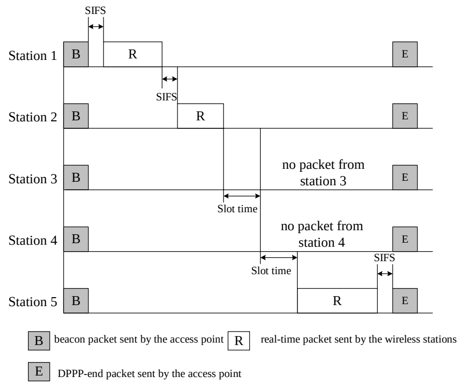

Fig.2 Access procedure of the DPP

B. A Distributed Polling Protocol (DPP)

In order to transmit real-time information in the DPPP, a wireless station has to be in a polling list. After the station has been added to the polling list, the PC returns the 16-bit *polling identification* (polling ID) number assigned to that station. 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 BSS. Since the polling sequence of stations is added in the beacon packet, the transmission order of a station can be identified among the wireless stations. The stations that cannot receive the sent beacon packet are not allowed to transmit in the current period. On the other hand, if the sent beacon packet can be received, the first station, which gets the first transmission order, is allowed to transmit a packet after the *short inter-frame space* (SIFS) has elapsed. The following stations in the polling sequence should sense into the medium to check whether the medium is in idle or busy state. Since each station maintains a counter used to count the number of status in the medium, a station can identify its turn to transmit a packet when the counter equals its transmission order. The sensing time of the idle period is dependent on the underlying physical layer. In case of DSSS, which is considered in this paper, the stations shall determine an idle period by waiting to hear a transmission during a slot time of size 20 us. If no transmission has been detected, the counter is incremented by one and the next station takes turn to transmit as illustrated in Fig.2.

It is possible that a number of stations in the sequence are unable to transmit their data during a DPPP since the end of the DPPP is reached before their turn to transmit. Therefore, to achieve fairness among stations in the polling list, each station would circularly shift its transmission order by one position in the next DPPP.

C. Operation in the DPPP with the ICD

As mentioned in Section III-C, a collision can be detected only during 192 us after the busy state has been reported. However, the Modified PCF uses the 20 us slot-time to determine if a station is accessing the channel. For this reason, the number of stations in a polling list cannot exceed 9 stations (192 us divided by 20 us) if the indirect collision detection is applied. To support a larger number of stations, we therefore divide a number of stations into small groups of the limited number of 9 stations.

As depicted in Fig.3, the channel transmission time during the DPPP is divided into a number of transmission periods corresponding to the number of groups in the system. Note that the polling sequence for each group is announced in the polling packet transmitted for each group. To give transmission fairness among the groups, the group order will be circularly shifted in-between rounds, e.g., in a current round, the group order is 1, 2, 3, 4 and in the next round the group order will be 4, 1, 2, 3. Note that the transmission order within a group would be circularly shifted by one in the next round as well.

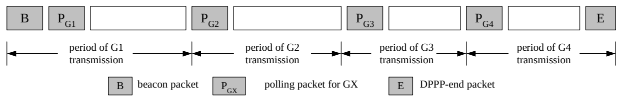

Fig.3 Channel transmission time in the DPPP if the indirect collision detection is applied

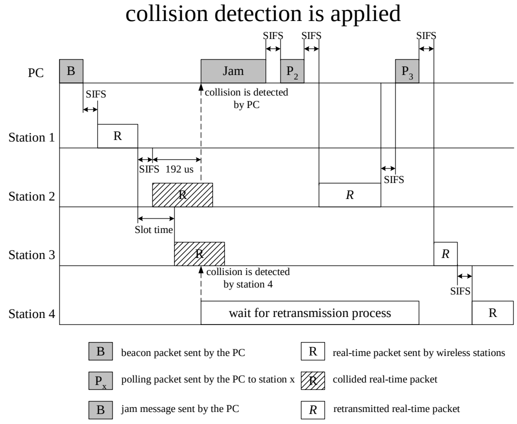

Fig.4 Retransmission process

D. Retransmission Process of Collided Packets

Since the hidden station problem will normally occur in wireless networks, it is necessary for the Modified PCF to have a retransmission process for collided packets. In order to describe the retransmission process, assume that station 3 cannot sense the transmission commenced by station 2 as shown in Fig. 4. Hence station 3 will start its transmission after a slot time, measured from the end of the last transmission and therefore a collision will occur. The PC and other stations that can hear the transmissions of both two stations will detect the collision by using the indirect method as described. Since there might be some stations that cannot detect the collision, the PC shall transmit a jamming signal by issuing a SYNC data. Note that the duration of a jamming transmission is equal to the transmission time of the preamble of the PHY plus the transmission time of the maximum packet size admitted in the system. Since the stations that cannot detect the collision by themselves and the stations involved in the collision shall receive the jamming signal for more than 192 us, they then know that a collision occurred in the channel. All stations will then wait for the retransmission process initiated by the PC to take place.

Since the PC has identified that station 2 started its transmission but the transmission was not successful, the cause of the unsuccessful transmission should 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 next station in the polling sequence that will get the right to transmit. Therefore, the retransmission process should involve stations 2 and 3 only. To start the retransmission process, the PC sends a polling packet to station 2. The polled station responds to the poll by retransmitting its packet to the PC. After the PC receives the packet, it sends a poll to station 3. After receiving the last poll, the remaining stations can resume normal operation. Note that the remaining stations set their counters according to the transmission order of the last polled station when they resume normal operation.

E. Collision Resolution Mechanism

Since collisions result in retransmission overheads it is beneficial for the Modified PCF to implement a collision resolution mechanism to minimize the number of collisions. Apart from overheads, affected stations will also experience increased medium access delay due to the retransmission process. We investigate the effects of this problem in our simulation results in section VI.

The concept of the proposed collision resolution is based on the observation that a hidden station should obtain the highest number of collisions. Since the PC can identify the station which currently has the right of transmission, it can count the number of collisions for each station. Thus, the PC presumes a hidden station by counting the number of collisions and comparing it to a collision threshold.

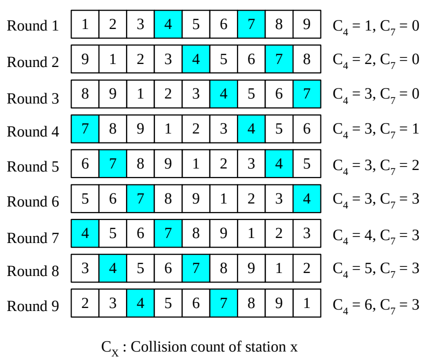

Fig.5 Operational example of presuming a hidden station

The following example illustrates the operation of presuming a hidden station. In the example, there are 9 wireless stations and each station generates only one packet per round. We assume that station 4 and station 7 are hidden from each other. As illustrated in Fig. 5, at round 9, the number of collisions in station 4 is 6, which is higher than that of station 7. If a collision threshold is set at 5, the PC can assume that station 4 is a hidden station.

After the PC identifies a station presumed to be a hidden station, it relocates the station to a special list for hidden stations. Stations in this list are polled separately using the method of the standard PCF at the end of a DPPP. However, this method is only efficient for hidden stations that are stationary. To deal with mobile stations, the dwelling time in the list of hidden stations can be set for each station. In addition, this method will also rectify wrongly identified hidden stations.

V. Simulation Study

We have performed simulations in OPNET [7] in order to investigate the effect of the hidden station problem on the performance of the Modified PCF in three cases. In the first case, there are no hidden stations in the system. In the second case, the retransmission process after a collision is applied. In the third case, the proposed collision resolution technique is applied.

In the simulation scenario, there were 9 wireless stations transmitting voice traffic through an AP. To emulate a hidden station problem, we assumed that all stations can sense their transmissions except station 4 and station 7 which cannot sense transmission of each other as described in the operational example of Section IV-E.

Since all wireless stations transmitted voice traffic, the ON-OFF model was used to generate the voice traffic. The average intervals in the ON and OFF state were 1 sec and 1.35 sec respectively according to Brady’s model [8]. A 20-byte voice packet was generated every 25 ms during ON state. The voice packet had 40 bytes of header added.

Table 1. Simulation parameters

Simulation Parameters	Values
Data rate	11 Mbps
Data rate for control packets and PHY headers	1 Mbps
MAC overheads	28 bytes
PHY overheads	24 bytes
Beacon body size	35 bytes
SIFS	10 us
Slot time	20 us
CFP repetition interval	20 ms
CFP maximum duration	5 ms
Simulation duration	3 min

The parameters used in the simulation are shown in Table 1 and the assumptions were as follows:

- The wireless medium was error free, the capture effect and the fading effect were ignored.
- Any transmission during the *contention period* (CP) using the DCF mode was neglected; the stretching period did not occur.
- Each station transmitted its packets only in the CFP.
- The location of each station is fixed in the simulation.

VI. Simulation Results

We selected the uplink ETE delay during the wireless network as a performance metric of the Modified PCF. As illustrated in Fig. 6, which shows the overall uplink ETE delay of the system, the hidden station problem causes higher delay than the case when there are no hidden stations. This is as expected since all collisions cause retransmissions. Moreover, the retransmission process for a station involved in a collision leads to an increased delay for the following stations in the polling sequence. The latter problem can be obviously seen in Fig. 7, which shows the average uplink ETE delay of station 5. Since most of the time station 5 has to transmit a packet after station 4, which is one of the hidden stations, the retransmission processes of station 4 heavily increases the experienced delay.

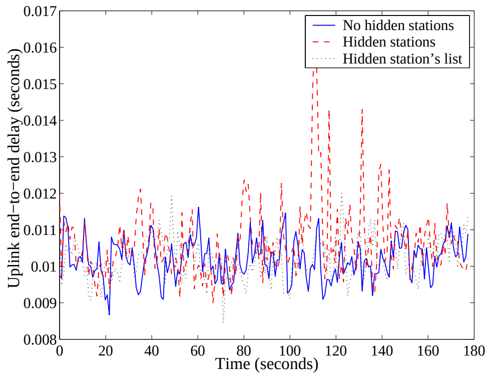

Fig.6 Uplink end-to-end delay versus time

For station 3, which precedes the hidden station the delay is only slightly affected by the retransmission processes. This is confirmed by Fig. 8, which shows that the average uplink ETE delay of station 3 is quite steady in all cases.

When the proposed collision resolution technique is applied, the uplink ETE delay of the system is significantly reduced compared to the case with hidden stations but without resolution technique as illustrated in Fig. 6. This is because one of the hidden stations, i.e., station 4, is put in the list of hidden stations. In addition, the uplink ETE delay of station 5 is noticeably reduced as seen in Fig. 7. This is because station 5 does not have to wait for the retransmission processes of station 4 after it has been removed from the normal list.

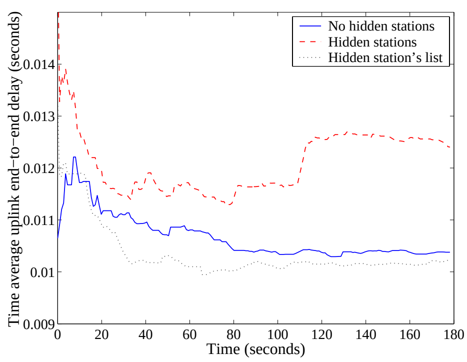

Fig.7 Average uplink end-to-end delay of station 5

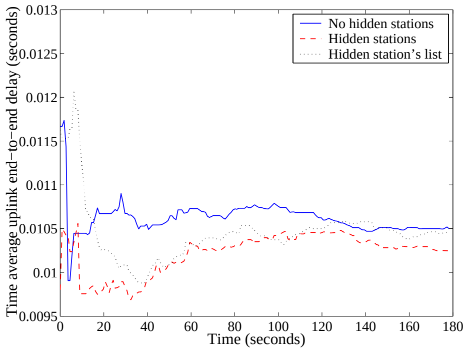

Fig.8 Average uplink end-to-end delay of station 3

VII. Conclusion and Future Work

This paper presents an investigation of the effect of the hidden station problem on the performance of the Modified PCF. A collision resolution technique is proposed to reduce the collision probability. Using the proposed collision resolution mechanism, a wireless station presumed to be a hidden station is moved into a separate polling list. The simulation results show that the hidden station problem increases the overall delay of the system and by applying the proposed mechanism; the delay can be lowered significantly.

In the future, we intend to make more thorough investigations into extended scenarios with other traffic types and station compositions. We will also incorporate investigations on jitter and overall effect on applications from both the collision resolution technique in isolation as well as the overall Modified PCF scheme.

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