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Current standardization activities for wireless local area networks (WLAN) have focused the effort on providing high throughput and supporting applications with QoS requirements. In order to achieve such goals, the MAC mechanisms of legacy IEEE 802.11 and .11e protocols need to be improved. Multipolling mechanisms are often employed to improve the protocol efficiency, however, current available multipolling mechanisms suffer from hidden terminal and/or inefficient channel usage problems. In this paper, we propose a multi-polling mechanism that utilizes novel metric for channel access and thus is capable to utilize channel resource effeciently and overcme the hidden terminal problem. Analysis shows that the proposed mechanism improve the throughput from 5% to 40% compared to legacy 802.11e.

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On the Performance Enhancement of Wireless LAN — A Multi-polling Mechanism with Hidden Terminal Solution

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***Abstract*— Current standardization activities for wireless local area networks (WLAN) have focused the effort on providing high throughput and supporting applications with QoS requirements. In order to achieve such goals, the MAC mechanisms of legacy IEEE 802.11 and .11e protocols need to be improved. Multipolling mechanisms are often employed to improve the protocol efficiency, however, current available multipolling mechanisms suffer from hidden terminal and/or inefficient channel usage problems. In this paper, we propose a multi-polling mechanism that utilizes novel metric for channel access and thus is capable to utilize channel resource efficiently and overcome the hidden terminal problem. Analysis shows that the proposed mechanism improve the throughput from 5% to 40% compared to legacy 802.11e.**

***Index Terms*— WLAN, Multipoll, hidden terminal, performance enhancement,**

I. Introduction

Recent Advances in areas of wireless communications, smart antennas, digital signal processing and VLSI technologies make it feasible to provide very high capacity wireless channel at *physical* (PHY) layer. These emerging technologies offer at least an-order-of-magnitude larger bandwidth than the standards of current generation. The IEEE 801.11n [4] task group, for example, is standardizing *medium access control* MAC and PHY specifications that offer up to 100Mbps throughput at MAC layer. However, to truly deliver 100 Mbps or above throughput at the MAC *service access point* (SAP), the efficiency and overhead of current MAC layer protocol must undergo necessary amendments before it can be applied in the high throughput wireless LAN/PAN.

Multipoll mechanism is often employed in order to improve efficiency and reduce overhead, however, current available multipoll schemes often suffer from inefficient channel utilization or hidden terminal problems. Hidden terminal problem refers to the situation that a STA that is not in the transmission range of the transmitter senses the channel at the receiver side to be idle (this STA is said to be hidden from the transmitter) and transmits to the receiver, thus introduces collision. Hidden terminal problem is very common in multihop wireless LAN, however current solutions that address the hidden terminal problems can not provide efficient channel utilization due to the reasons that either polling information are transmitted multiple times or the access point is not able to re-utilize the *transmission opportunity* (TXOP) that assigned to a station (STA) when the STA finishes transmission before scheduled time. Therefore, in order to improve the network performance, new solutions for these problems are needed.

In this paper, we present a novel multipoll mechanism that maintains the high efficiency of multipolling while overcomes the hidden terminal problem. In this mechanism, as most multipoll mechanisms, overall polling information is sent only once at the beginning of *contention free period* (CFP) and each STA retrieves its corresponding polling information. Moreover, each STA only transmits when it receives a number of simple-poll messages (piggybacked with acknowledgment when necessary) that are specified in the multipoll message, the multipoll mechanism maintains the order of STAs' channel access through the number of simple-poll messages a STA should observe before transmission. Since each STA will only access channel after receiving simple-poll message, therefore, the proposed mechanism maintains the advantage of simplex-polling because the AP always has the comprehensive information of the network and channel access is controlled in a centralized fashion, thus hidden terminal problems are avoided. Performance analysis shows that under certain configurations, the throughput of proposed mechanism is 5% to 40% better than legacy 802.11e.

The rest of this paper is organized as follows: In section-II, background related to IEEE 802.11/.11e and multipoll mechanisms are provided. In section-III the multipoll mechanism with hidden terminal solution is presented and implementation of the proposed mechanism is discussed. Section-IV presents the performance comparison of proposed multipoll mechanism of legacy 802.11e HCCA and one of the current multipoll algorithms. Finally section-V concludes the paper and discusses the future work.

II. Background

In this section related background are provided. Subsection-II-A summarizes major features of IEEE 802.11/.11e that are related to the context of this paper; Subsection-II-B reviews several multipoll mechanisms and discusses the advantage and limitations of each mechanism. The multipolling mechanism that solves those limitations are presented in Section-III.

A. IEEE 802.11/.11e

In 1997 IEEE adopted Std. 802.11-1997, the first WLAN standard. This standard defines the MAC and *physical* (PHY) layers for a LAN with wireless connectivity. Following the first standard, several amendments, 802.11a, b, e [5] [1] are proposed. According to the standard, a WLAN consists of *Basic Service Sets* (BSS), each of which is composed of wireless STAs. There are two possible configurations for WLAN — ad hoc mode (independent BSS) or infrastructure mode (composed of an *access point* (AP) and the associated STAs).

IEEE 802.11 supports two channel access mechanisms, the so called "coordination functions" — contention based *Distributed Coordination Function* (DCF) and contention-free *Point Coordination Function* (PCF). DCF performs *carrier sensing with collision avoidance* (CSMA/CA) at both PHY and MAC layer and employs exponential backoff procedure for access control. Access priority is maintained through the use of *interframe space* such as DIFS and SIFS. PCF is carried out by the *point coordinator* (PC) resides in AP. The PC determines which STA currently get the channel access by polling the STA. Once polled, the STA can only transmit one packet and should return the channel to the AP after that. DCF and PCF can coexist by alternating the *contention period* (CP) and *contention free period* (CFP). A CFP and a CP together are referred as a *Superframe*.

IEEE 802.11e provides QoS enhancement of the 802.11 MAC through prioritized and parameterized QoS data delivery. The *Enhanced DCF* (EDCF) supports prioritized data delivery by assigning each traffic flow with a different backoff time whose value decreases with traffic priority increases. While the *hybrid coordination function* (HCF) supports parameterized data delivery through QoS Polling during CFP and *contention free burst* (CFB) during CP. The polling scheme in 802.11e is different from 802.11 in that at each polling frame, a *transmission opportunity* (TXOP) associated with a *traffic identifier* (TID) is assigned to each STA, thus, instead of single packet transmission in 802.11, each STA in 802.11e is able to transmit a burst of packets before the PC polls next STA in the network.

B. Multipoll Mechanism

Some of the limitations of IEEE 802.11/.11e's polling schemes are the low efficiency due to the overhead of polling frames. To reduce the overhead of polling frames, multipoll mechanisms are proposed — The PC can poll a *polling group*, which is composed of several flows from different STAs at a time. Each flow will initiate its own transmission according to the order defined in the multipoll frame.

The polling order of the multipoll mechanism can be specified in the time domain [2] — each flow in the polling group is assigned with a time interval before the STA can access the channel. In this mechanism, the assigned time interval may be wasted if the polled STA fails to receive the polling message or it does not have enough traffic to be sent during the specific time interval. In order to solve the above problem, in [3], each polled STA will attach a polling frame that contains the polling messages for the remaining polled STAs. [3] reduces the failure in receiving the polling frames and each STA will relay the channel access to the next STA in the polling list as soon as the TXOP limit is reached or no packets are left for transmission. On the other hand, the drawback of [3] is also obvious: the redundant polling frames occupy more channel space, thus the channel is not utilized efficiently.

In [6], a contention-based multipoll mechanism is proposed. In the proposed multipoll mechanism, polling order is transformed into the contending order which indicates the order of winning the channel contention. Different backoff time values are assigned to each flow in the polling group. Upon the reception of multipoll frame, each STA retrieves its corresponding backoff time value and executes the backoff procedures. The contending order of STAs is the same as the ascending order of the assigned backoff time values. The proposed multipoll mechanism is more flexible — if a polled STA makes no response to the polling message, other STAs in the same polling group will detect the channel idle right away and advance the starting of channel contention. No explicit polling is needed thus the efficiency can be improved. However, the proposed mechanism is prone to hidden terminal problems since each STA will decrement backoff counter when it senses channel is idle, when hidden terminals exist in the network, different STAs will complete their backoff simultaneously and collision will happen.

As discussed above, current multipoll algorithms do improve the MAC efficiency under certain conditions, however, each of them has drawbacks. Hence, a multipoll algorithm that is both efficient and robust is needed. In this paper, a multipolling mechanism with high efficiency that also addresses the hidden terminal problem is proposed, Section-III provides the design detail of this mechanism.

III. Multipoll with hidden terminal solution

In this section a novel multipoll mechanism with hidden terminal solution is presented. The multipoll mechanism takes advantage of the high efficiency of multipoll mechanism as well as maintains the central control capability of the PC. Instead of using contention-based multipoll with assigned backoff-time or contention-free multipoll with assigned transmission time duration, a novel metric is proposed — the number of simple-poll frames/piggybacked with QoS CF-ACK that a STA observed. The proposed scheme retains the advantage of both simplex-poll and multipoll to overcome hidden terminal problem and, at the same time, maintains high efficiency of multipolling.

The underlying idea is that the PC is the one (and sometimes the only one) entity that has complete information of the BSS, thus instead of relying on self-view (for example, back-off algorithm) of the network, all STAs should trust the PC and use the information provided by the PC to conduct any action. Simple-poll frames reflect the PC's view of BSS about whether the channel is idle, while both back-off time [6] and time interval [2] decrement are based on STA's self view of the BSS, therefore, hidden terminal problems are eliminated. On the other hand, it reduces the overhead of 802.11e because piggyback polling is appropriate now since STAs know their position in polling list hence explicit polling is not necessary anymore.

A. Basic Idea

In this subsection the basic idea of hidden terminal free multipolling is summarized, and subsection-III-B provides details of the design.

At the beginning of each CFP a resource allocation frame (RAL) that contains polling information for all the STAs are broadcasted in terms of *transmission sequence index value* (SIV) defined by the number of simple polling message/piggybacked with QoS CF-ACK a STA should observe before transmission as well as the corresponding TID and TXOP. Each STA retrieves its SIV and assigned TXOP from RAL and sets defer counter to the value of SIV, therefore the polling order is disseminated to each STA. The PC (in 802.11e, *hybrid coordinator* (HC)) is responsible to detect the completion of transmission of current STA either from TXOP limit or from the QoS-Null frame sent by STA and polls the next STA in the polling list. When piggybacked with the QoS acknowledgement, the simple-poll is addressed to the STA that being acknowledged hence the polling is implicit. Upon the reception of the simple-poll (piggybacked with QoS acknowledgement), each STA decreases its defer counter, a STA will access the channel only when the defer counter reaches zero — it has observed the enough simple polling messages.

B. Design Details

In legacy 802.11/.11e, three new frames are introduced in the mechanism, it is preferred to define those new frames as type data, however, since in IEEE 802.11e all the possible subtypes have been used up, to maintain backward compatibility, the reserved type in 802.11/.11e are redefined as Multipoll to define the RAL and simple-poll frame. Table-I illustrates the type and subtype combination of the new frames. Figure-1 and 2 depict the format of RAL and simple-poll frame respectively.

A RAL frame contains MAC header (frame control and duration), a receiver address field, a BSSID field, a frame check sequence (FCS) field, a length field and several multi-schedule element fields. Length field and multi-schedule element fields are related to multipoll. The length field indicates the number of multi-schedule element the RAL frame contains. Each multi-schedule element contains the SIV that determines the polling order as well as the TID and TXOP in units of $32\mu s$.

Type b3 b2	Type Description	Subtype b7 b6 b5 b4	Subtype Description
1 1	Multipoll	0 0 0 0-1 1 0 0	Reserved
1 1	Multipoll	1 1 0 1	RAL
1 1	Multipoll	1 1 1 0	Simple-poll
1 1	Multipoll	1 1 1 1	Simple-poll piggybacked with QoS ACK

TABLE I
DEFINITION OF RAL AND SIMPLE-POLL

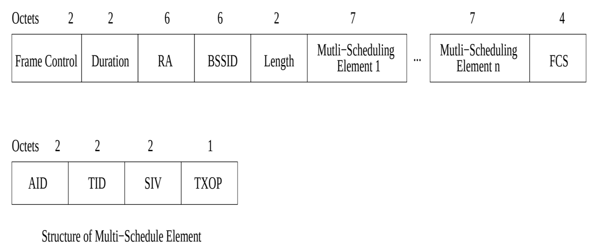

Fig. 1. Frame Format of RAL

A simple-poll frame consists the MAC header (frame control and duration), an address field and a FCS field. For simple-poll frame, the address field contains the address of the STA being polled; for simple-poll frame piggybacked with QoS acknowledgement, the address field contains the address of the STA being acknowledged, in this case, the next STA in the poll list is polled implicitly. The STA will start transmission when the SIV counter reaches zero.

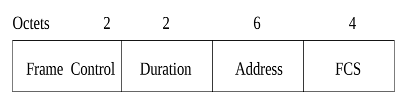

Fig. 2. Frame Format of simple-poll

C. Implementation Issue

In subsection-III-B the necessary modifications of IEEE 802.11/.11e in order to incorporate the proposed multi-polling scheme are provided. This subsection discusses the implementation of the multipoll scheme. Figure-3 illustrates the flowchart for the proposed multipolling scheme.

At the beginning of CFP, PIFS after the channel is idle, an AP is responsible for sending out the RAL frame. Upon the reception of RAL frame, STAs retrieve the corresponding SIV and TXOPs of each TID and set a defer counter (simple-poll) with the value of SIV, note that a STA may have multiple SIV and TXOP for different TIDs. The counter will be decremented every time that the STA receive the simple-poll message (indicated by the specific of type and subtype combination in MAC frame's

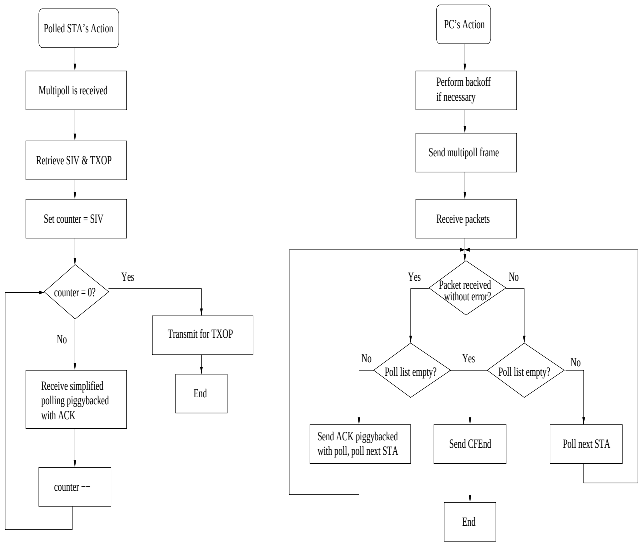

Fig. 3. Flowchart for the proposed multipolling scheme

frame control field). The STA starts transmission when the simple-poll counter reaches zero. Since each STA has different SIV value and counter is decremented according to global information — the simple-poll sent by AP, hidden terminal problems are eliminated. On the other hand, AP is capable to detect the end of the transmission from a STA either through TXOP limit or the reception of QoS-Null frame transmitted by the STA. Thus AP sends Simple polling message/piggybacked with ACK addressed to the STA that just transmits the packet(s) given that frames are received without error. Otherwise, AP will send simple polling message addressed to the next STA in the polling list. When the poll list is empty, the AP sends out CF-End frame to terminate the CFP.

IV. Performance Comparison

In this section, the performance of proposed multi-poll scheme is compared with legacy 802.11e and the contention-based multipoll scheme from [6]. Only CFP is studied in this analysis, packet size is fixed while the number of STAs in the BSS and data rate are varied to compare the performance with legacy 802.11e under different configurations. Parameters used by the analysis are summarized in Table-II.

Parameter	value	Parameter	value
Packet Size	1000 bytes	PLCP header	4 μs
Basic Data Rate	6Mb/s	MAC header +FCS	36 bytes
PIFS	25 μs	ACK/CTS	14 bytes
SIFS	6 μs	Beacon	64 bytes
CF-End	20 bytes	Simple Poll (+ACK)	36 bytes

TABLE II
System Parameters

Figure-4 depicts the throughput of a BSS *without* hidden terminal obtained from proposed multi-poll and 802.11e and the corresponding improvement for with different data rate and the number of associated STAs respectively. From those figures it is shown that the throughput improvement increases with the data rate and the number of associated STAs. The increment can be attributed to the compact frame format and efficient piggyback scheme that saves PIFS time between acknowledgement and polling frame in 802.11e. The more STAs that are associated with an AP, the more PIFSs that are saved, hence more throughput improvement; moreover, the improvement becomes more notable as the data rate become faster, since the proportion of the interframe spaces is higher compared to the time used to the transmit packets as the data rate increases.

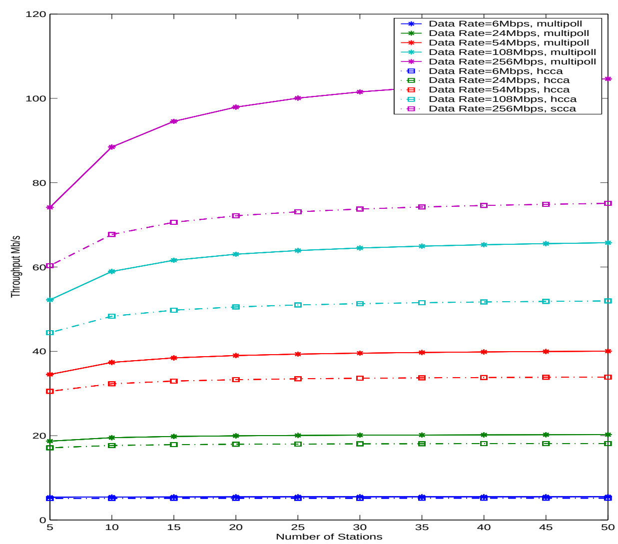

Fig. 4. Throughput Comparison of Proposed Multi-Poll over 802.11e

STA	SIV	TXOP
STA1	0	1
STA2	1	1
STA3	2	1

Next the performance comparison of proposed multipoll mechanism over contention-based multipoll [6] at different data rate when hidden terminal exists is conducted. In this case, the configuration of the BSS is shown in Figure-5, there are one AP and 3 STAs in the BSS, STA1 and STA2 are hidden from each other, while STA3 can hear all the other AP and STAs in the BSS. Above table shows the multipoll scheduling information for the system, for contention-based multipoll mechanism, the back-off time assigned to STA1 to STA3 will be 1,2 and 3 time slots respectively. STA1 is polled first and followed by STA2 and STA3. In contention-based multipoll mechanism, after backoff of 1 time slot, STA1 starts to transmit packets while STA2, hidden from STA1, will sense the channel to be still idle, and starts transmission 1 time slot later. The packets will collide at AP. STA3 is able to hear all the transmission and will only transmit when both STA1 and STA2 stop transmission plus two more backoff time slots are elapsed.

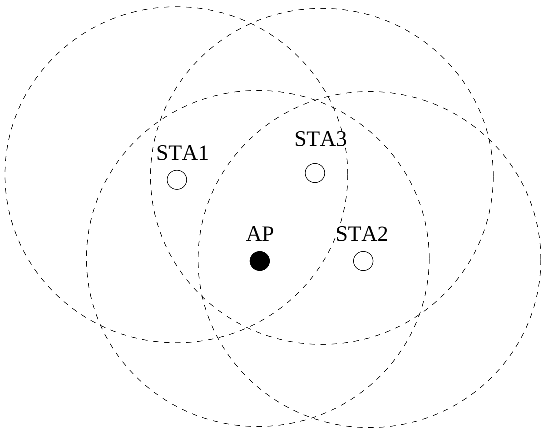

Fig. 5. Throughput Comparison of Proposed Multi-Poll over Contention-based Multipoll

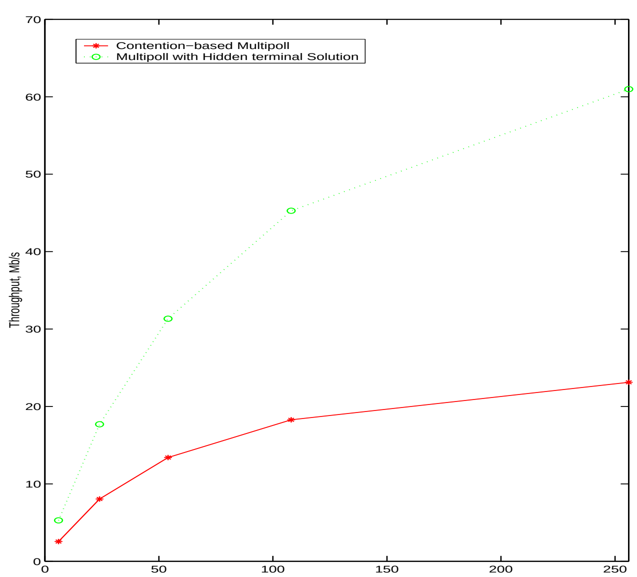

Fig. 6. Improvement of Proposed Multi-Poll over Contention-based Multipoll

While for the proposed multipoll mechanism, since hidden terminal problem is eliminated by the centralized polling of AP, the transmission from each STA will be successful. Figure-6 depicts the throughput obtained from proposed multipoll mechanism and contention-based multipoll under different data rate. As in Figure-4, the throughput improvement becomes more notable when the data rate is higher, since the channel wasted for the packet collision becomes more serious when the data rate is higher.

The comparison of proposed multipoll mechanism over 802.11e illustrates the advantage of multipolling over simplex-polling, on the other hand, the proposed multipoll has eliminated hidden terminal problems, hence it also has performance advantage over existing multipoll algorithms.

V. Conclusion

In order to provide higher throughput at MAC layer, more efficient and robust medium access control mechanisms are being investigated in the wireless communication community. Multipolling mechanism is a popular solution for throughput improvement, however, current available multipolling mechanisms suffers from low efficiency or hidden terminal problems. In this paper, a multipolling scheme that solves the hidden terminal problems is proposed to support robust and high efficiency wireless communications. The design and implementation issues are discussed in detail and the performance enhancement is summarized. Under certain configurations, the proposed mechanism can provide 5% to 40% improvement over legacy 802.11e.

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