A Novel Solution to the Hidden Terminal Problem in Contention-based Multipolling Mechanism --- the ACK/Restart Counting Scheme

Yue Fang, Daqing Gu, Jinyun Zhang
Mitsubishi Electric Research Laboratories
Cambridge, MA 02139, USA
Email: {yfang, dgu, jzhang}@merl.com

1. Novelty

The upcoming IEEE 802.11n standard requires that throughput of 100 megabits per second (Mbps) or higher to be achieved at the medium access control (MAC) layer service access point (SAP). Various mechanisms in the current IEEE 802.11 [1] and IEEE 802.11e [2] MAC protocols entail immense overhead and eventually result in serious throughput performance degradation. Due to the low protocol efficiency, direct application of the legacy MAC protocol to the IEEE 802.11n standard is not plausible. In order to improve the throughput and efficiency, several mechanisms [7] [6] aimed at overhead and contention reduction are proposed for wireless communication. Among them, in the MERL's recent patent, [6] proposed the sequential coordinated channel access (SCCA) mechanism that employed a contention-based multipolling mechanism to reduce polling and handshaking overhead therefore improve the efficiency of polling from the legacy 802.11e HCCA significantly. However, the proposed mechanism suffers from hidden terminal problem where internal collisions among polled STAs may happen if two polled STAs cannot listen the transmission each other in the BSS, the network performance will be degraded. We hereby propose a novel deferring mechanism under which special frames are counted instead of time slot or time unit used in current multipolling systems, this mechanism solves the hidden terminal problem and at the same time maintain the high channel utilization of multi-polling system. The proposed mechanism has good backward compatibility and the low implementation complexity. In fact, the STA will behave same as current multipolling system (e.g. SCCA) when no hidden terminal is present.

2. Technical Disclose

2.1 Background

Recent advances in the areas of wireless communications, smart antennas, digital signal processing, and VLSI make it feasible to provide very high-capacity wireless channel at the physical (PHY) layer. These emerging technologies offer at least an-order-of-magnitude larger bandwidth than the standards of current generation. IEEE 802.11n [3], for example, is standardizing MAC and physical layer specifications that offer up to 100Mbps throughput at MAC layer. IEEE 802.15.3a [4], the upcoming IEEE standard for high-capacity wireless "personal" area networks, aims at data rates of 110 Mbps or higher based on ultra-wideband (UWB) communications. However, to truly deliver 100Mbps or above throughput at the MAC SAP, a pure PHY layer solution is not sufficient, due to the significant protocol overhead caused by the legacy MAC layer protocol. Therefore, current MAC layer protocol must undergo necessary amendments before it can be applied in the high throughput wireless LAN.

Proposed in [6], contention-based multipolling mechanism SCCA is one of the important amendments for IEEE 802.11n to achieve the goal of providing throughput up to 100Mbps or higher. However, the contention-based nature of channel access makes SCCA be affected by hidden terminal problem that will degrade the network performance significantly under certain circumstance, hence to overcome the hidden terminal problem becomes the underlying motivation of the proposal of ACK/Restart counting scheme. Consequently, for the ACK/Restart counting scheme, we focus on SCCA mechanism, which operating at the infrastructure mode, where polling is used for the AP to schedule transmissions among all STAs associated to it.

2.1.1 IEEE 802.11 PCF/IEEE 802.11e HCCA Polling

In the current IEEE 802.11/11e wireless local area networks (WLANs) 6, polling mechanism are used to allow the AP to schedule the transmission in contention free period, each STA can only transmit when it is polled thus there is no hidden terminal or collision exist in the network. Figure 1 and Figure 2 illustrate the IEEE 802.11 PCF and IEEE 802.11e HCCA polling scheme, respectively.

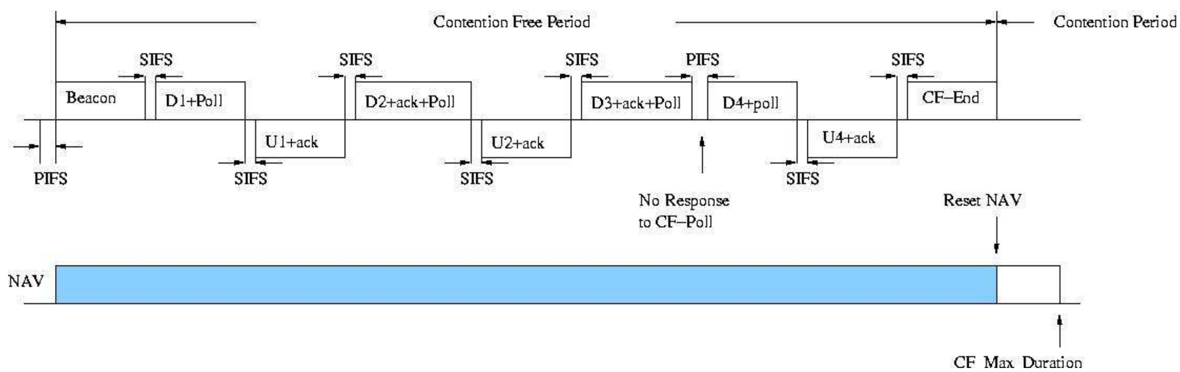

Figure 1: Example of IEEE 802.11 PCF frame transfer

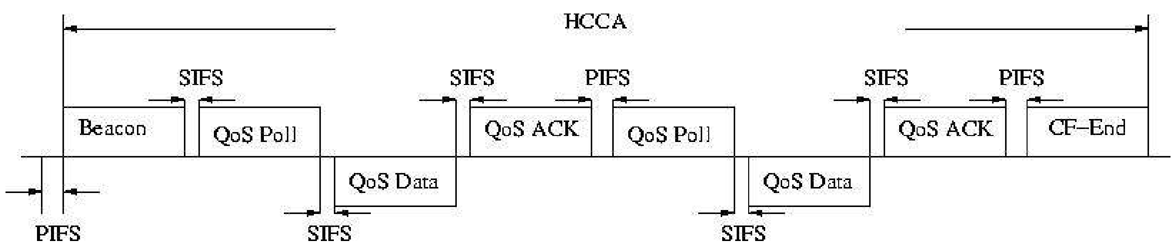

Figure 2: Example of IEEE 802.11e HCCA frame transfer

In PCF/HCCA, each time the AP will only poll one STA, there will be no hidden terminal problem in the network since each STA can only transmit when polled, moreover, since AP will monitor the STA's activity one a per poll base, if the STA does not response to AP's poll, AP will immediately poll next STA in polling list after detecting the timeout of STA's transmission therefore the waste of channel resource is negligible. On the other hand, although in IEEE 802.11 the polling message can be piggybacked within acknowledgment and data, according to the frame format of polling message of IEEE 802.11 standard, the overhead will be high. Moreover, in 802.11e, since normally QoS Poll will not be piggybacked in QoS ACK unless they are addressed to the same destination.

2.1.2 Multipolling Mechanisms

2.1.2.1 Overview of Multipolling Mechanisms

The major limitation of the polled scheme employed by IEEE 802.11/11e is the low channel throughput due to the overhead. To reduce the overhead, the concept of multipolling was proposed. The PC/HC can poll a *polling group*, which is composed of several flows from different STAs, at a time. Each flow in the same polling group will initiate its own transmission in order after receiving the multipolling frame --- a mechanism that is called *contention-free multipolling* (CF-multipolling).

In some multipolling mechanisms, [8], the polling order is specified in the time domain. That is, an individual time interval is assigned to each flow in the polling group. However, using this specification, once a polled STA fails to receive the multipolling frame or has no packet to send, the time interval allocated to this STA may be wasted. To reduce the failure in receiving the polling frames, the *SuperPoll* using replicated polling frames was proposed in [9]. In this approach, each polled STA will attach a polling frame to the current transmitted data frame and the polling frame contains the polling message of the remaining polled STAs. Clear the render order of a STA in the polling group has the greater possibility of receiving the polling message it gets. However, the redundant polling frames occupy more channel space.

2.1.2.2 Prior Multi-poll Proposal at Mitsubishi Electric Research Laboratories --- Sequential Coordinated Channel Access (SCCA)

To improve the efficiency of the wireless channel usage, a multi-polling mechanism is proposed in [6] based on the idea of contention-based multipolling --- *contention period multipoll* (CP-Multipoll). The basic idea of CP-Multipoll is to transform the polling order into the contending order which indicates the order of winning the channel contention. Different backoff time values (time slots) are assigned to the flows in the polling group and the corresponding STAs execute the backoff procedures immediately after receiving the CP-Multipoll frame without waiting for DIFS/PIFS. The contending order of these STAs is the same as the ascending order of the assigned backoff time values. CP-Multipoll avoids the channel waste caused by a STA's either failure of receiving polling message or not having enough packets to transmit. However, CP-Multipoll still suffers from hidden terminal problem.

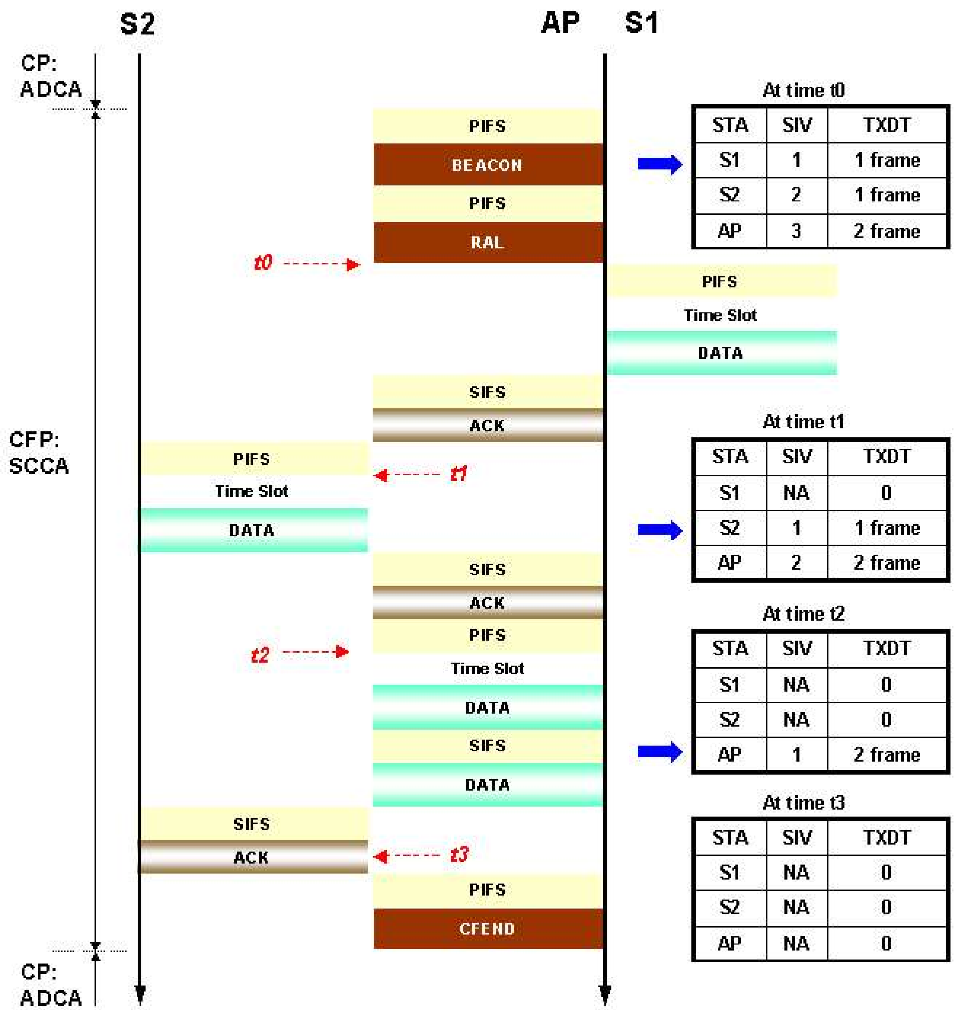

Figure 3: An example of sequential coordinated channel access (SCCA)

In MERL's patent [6], the complete scheduling information is broadcasted by the HC at the beginning of the CFP through resource allocation message (RAL), which is in fact the aggregation of all polling message for each associated STA in HCCA. Each STA retrieves its own TXOP information and the order of transmission from RAL and accesses the channel in a CSMA-alike collision free manner. A SIFS time after the successful reception of RAL message, the polled STAs will start backoff, with the initial backoff counter value set to the retrieved sequence index value (SIV) in time slots. The station consistently senses the channel and decrements its backoff counter if the channel is found idle for a time slot. Once the backoff counter reaches zero, the station begins transmission. If the channel is busy, the station then freezes its backoff counter and waits the channel to be idle again. After winning the channel access right, each data stream can transmit up to TXOP duration that is also set in RAL. Figure 3 gives an example of how SCCA works.

2.1.3 Limitations of SCCA/Similar Multipolling Approach

As discussed in the previous subsection, SCCA improve the efficiency of HCCA through the introduction of multi-polling mechanism. For example, for a network with 1 AP and N STAs, the efficiency will improve from 2% to 16% when N increases from 5 to 50. However, SCCA has a serious problem that will limit its application --- the hidden terminal problem. We all know that the PCF/HCCA polling overcome hidden terminal problem by one-to-one polling, STA which is not polled shall never transmit, whereas in SCCA, since multipolling mechanism is employed, all the STAs are polled at the same time --- at the beginning of CFP, and start their backoff, so when one STA, say STA A is out of the transmission range of another STA, STA B, it will not be able to sense the transmission hence the backoff counter will not be frozen as it should be, and collision will happen.

CF-Multipoll use time unit instead of time slot for sequence index value, each STA will wait for a specific amount of time before it start transmitting. This method will solve the hidden terminal problem but introduce another problem. Since the STA will not able to transmit even the channel is idle if the specified time has not been reached. The channel waste will be very serious if the previous STA doesn't use all the TXOP that HC scheduled for it or some problems make it unable to transmit at the scheduled time. So a new solution that is capable to solve both hidden terminal and channel waste problem is desired.

2.2 Solution

Instead of currently used time slots or time units, we propose a novel metric for STAs to count before transmission --- the number of ACK/Restart frames it received sent by PC/HC. The proposed scheme retains the advantage of both one-to-one polling and multi-polling to overcome hidden terminal problem and at the same time, maintains a highly efficient information dissemination.

The underlying idea is that the HC/PC is the one (and sometimes only one) that have complete information of the BSS, thus instead of relying on own-view of the network, all the STAs should trust the view of PC/HC on the BSS and use the information given by the PC/HC to conduct any action. ACK/Restart frames reflect the PC/HC's view of network about whether channel is idle, while both time slots and time units decrement are based on STA's own view of the BSS. Moreover, the specific subtype of ACK/Restart frames make them be differentiated by STAs from normal ACK frames easily.

3 Description and Explanation

3.1 Overview

We focus on the ACK/Restart counting scheme that is backward compatible with the IEEE 802.11/802.11e protocols. The proposed solution works for data transmission during contention free period, more specifically, in a CP-Multipoll scenario.

The ACK/Restart counting scheme depends on the PC/HC's capability to recognize the last packet transmitted from STAs, which in turn depends on the STA's capability to flag the last packet they transmit. Hence, it will be desirable for the STA to be able to set corresponding flag to indicate the last packet of transmission whenever it is able to detect it, however this is not a mandatory requirement, without this capability, the scheme still work with the price of channel usage efficiency.

Three new types of control frame are introduced for the ACK/Restart counting scheme. The previously reserved subtype values are used for the identification of ACK/Restart frames. Moreover, the "more data" bit in MAC header's frame control field are redefined to enable the STA to indicate the last packet of current transmission.

3.2 Detailed ACK/Restart Counting Design

3.2.1 Definition of ACK/Restart Frames

Figure 4 and Figure 5 depict the MAC frame format and the frame control field of MAC header for IEEE 802.11e, respectively. The MAC frame format comprises a set of fields that occur in a fixed order in all frames, while the frame control field consists several subfields along with the type and subtype that we will modify.

Octets: 2	2	6	6	6	2	6	2	n	4
Frame Control	Duration/ID	Address 1	Address 2	Address 3	Sequence Control	Address 4	QoS Control	Frame Body	FCS

Figure 4: MAC frame format

B0 B1	B2 B3	B4 B7	B8	B9	B10	B11	B12	B13	B14	B15
Protocol Version	Type	Subtype	To DS	From DS	More Frag	Retry	Pwr Mgt	More Data	WEP	Order

Figure 5: Frame control field

Three new control frames are introduced for the ACK/Restart counting scheme, namely, the ACK/Restart, the BlockACK/Restart and the Restart frame. Among these 3 frames, ACK/Restart or BlockACK/Restart are used by the PC/HC to acknowledge the packet that a STA sends to it as well as polling the next STA in the polling list, depends on the STA's requirement of ACK or BlockACK, when the STA indicates that this is the last packet from it for that TXOP. While Restart is to merely poll the next STA in turn. The subtype values of those frames are listed in Table 1. Table 1 is part of the valid type and subtype combinations of IEEE 802.11e, in which we made our modifications.

Type Value b3 b2	***Type description***	***Subtype value*** b7 b6 b5 b4	***Subtype description***
0 1	Control	0 0 0 0 – 0 1 0 0	Reserved
0 1	Control	0 1 0 1	ACK/Restart
0 1	Control	0 1 1 0	BlockACK/Restart
0 1	Control	0 1 1 1	Restart

Table1: The type and subtype combinations for 3 frames introduced by ACK/Restart counting mechanism

The purpose of using ACK/Restart and BlockACK/Restart frames is to differentiate those frames from normal ACK or BlockACK frames PC/HC sends out. In other words, during a schedule TXOP for a specific STA, the STA may request acknowledgment from AP in the form of either ACK or BlockACK. The PC/HC will reply with normal ACK or BlockACK for all the packets it received, however, once the PC/HC knows that it has received the last packet sent by the STA for the current TXOP, it will send ACK/Restart or BlockACK/Restart to poll the next STA in the polling list.

If the STA cannot tell whether or not it is the last packet sent by it, the PC/HC must be able to send the Restart frame to poll the next STA in the polling list. PC/HC detects this event by observing the channel be idle for PIFS when a STA is supposed to transmit within SIFS and therefore sends out the Restart packet immediately. The next STA in the polling list shall start transmit upon receiving either (Block)ACK/Restart or Restart packet.

The frame format of ACK/Restart and Restart frames are depicted in Figure 6, where only the subtype subfield is different for these two frames. Figure 7 shows the frame format of BlockACK/Restart frame.

2	2	6	4
Frame Control	Duration	RA	FCS

Figure 6: Frame format of ACK/Restart or Restart frame

The objective of using BlockACK is to piggyback the Restart frame. Hence the BlockACK request sent by the STA to PC/HC shall be the same as in the legacy 802.11e or any proposed modifications (e.g. MERL's aggregated BlockACK mechanism), whichever is applicable. The only change made to the blockACK frame is to the subtype subfield of frame control field.

2	2	6	6	2	m	n	4
Frame Control	Duration	RA	TA	BA Control	BlockACK element	BlockACK Bitmap	FCS

Figure 7: Frame format of BlockACK/Restart frame

The BlockACK element consists BlockACK starting sequence control field, as well as the BlockACK bitmap field, which are different according implementation, since those two fields are of different length in different implementations, two variables m and n are used to represent their lengths. Moreover, although from Figure 7 it shows no difference of BA control field as it is in IEEE 802.11e standard, it actually may be different depending on different implementation, however, these issues have no effect and are out of the scope of the current proposal.

3.2.2 ACK/Restart Counting Scheme

The ACK/Restart counting scheme is proposed on top of MERL's sequential coordinated channel access (SCCA) scheme, so in the context the ACK/Restart counting scheme is discussed based on SCCA, although there is no technical obstacle for this mechanism to be implemented on top of any other multi-polling systems.

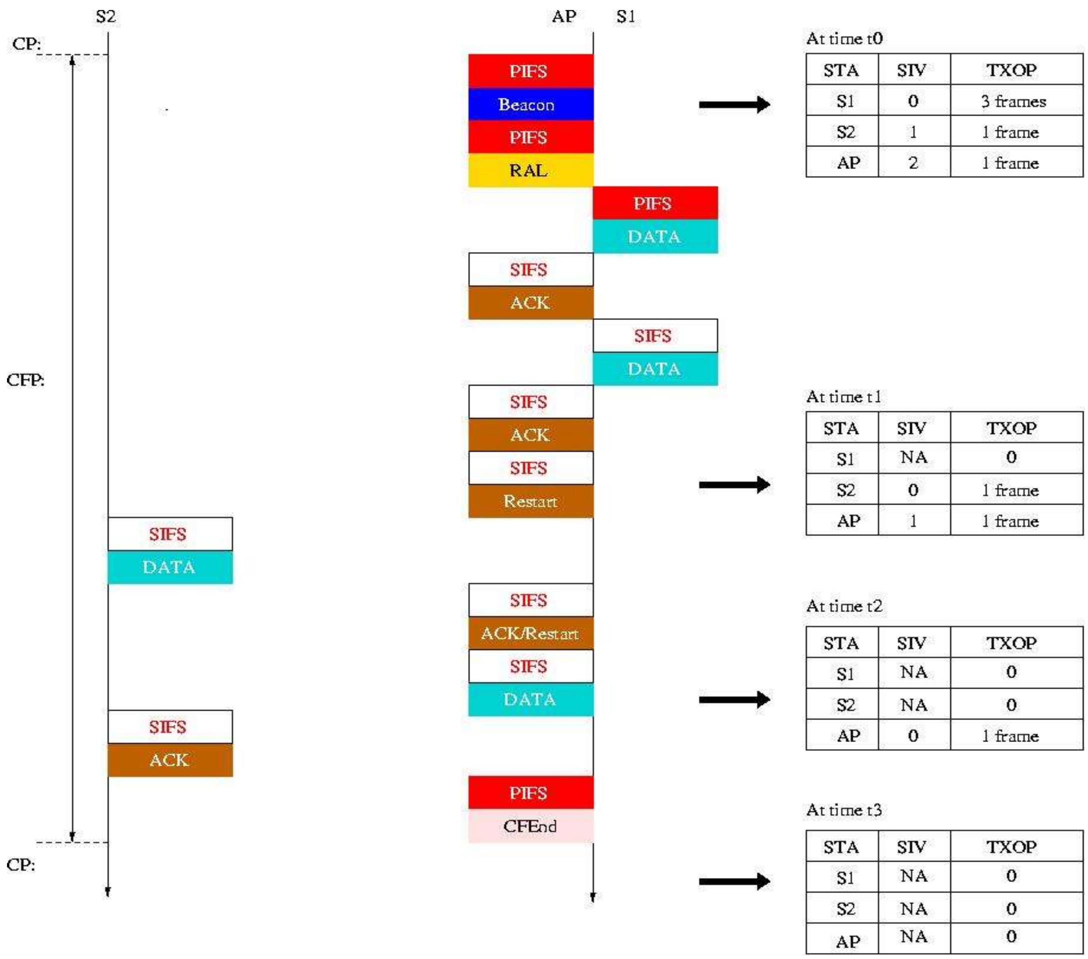

Figure 8: An example of SCCA with ACK/Restart counting

Figure 8 depicts an example of how ACK/Restart counting scheme works. Notice that since the resource reservation, allocation renegotiation and relinquishment phases are same as SCCA, and the data transmission phase is where the proposed ACK/Restart counting mechanism is going to take place, only the data transmission phase of SCCA is shown here. Moreover, instead of number of time slots, number of ACK/Restart packets is set in the SIV field, which means that the STAs will decrement the backoff counter every time they receive an ACK/Restart or Restart control frame with the 3 specific subtypes listed in Table 1. Only the HC is able to send out ACK/Restart frames, since all the STAs in the BSS should be able to hear HC, this scheme will efficiently overcome the hidden terminal problem.

In figure 8, at the beginning of the contention free period --- time t0, HC broadcast its RAL; each STA retrieves the corresponding SIV and TXOP and sets the backoff counter according to SIV. The SIV is the number of ACK/Restart OR Restart packet (for the sake of briefty, in the context, we use ACK/Restart to represent all the 3 newly introduced control frames ---Restart, ACK/Restart and BlockACK/Restart) the STA should receive or the HC should send before starting its own transmission. For example, stream 1 (S1) and stream 2 (S2) have SIV value of 0 and 1, respectively, and HC itself is assigned with a SIV of 2. Hence, the S1 do not need to wait any ACK/Restart, so it will start transmitting after SIFS.

At time t1, the TXOP assigned for S1 is 3 frames, however, only 2 frames are transmitted, and there is no more frames available for transmission, if STA 1 doesn' t indicate the end of transmission in the MAC header of the second frame transmitted, (as shown in Figure 8), after SIFS, HC detects this event and sends Restart, this will trigger the HC to decrement its backoff counter. Meanwhile, upon the receipt of Restart frame, at time t2, STA 2 decrement its backoff counter, STA 2's backoff counter reaches zero and it will transmit for the specified TXOP

(1 frame in this example). HC will acknowledge this data packet by ACK/Restart, and decrement its backoff counter again. At time t3, HC's backoff counter reaches 0, and HC will transmit packets following the rule of TXOP. Finally, after PIFS of last acknowledgment for HC, HC will send CFEnd frame to flag the completion of the CFP.

3.2.3 Detect ion and Indication of Current TXOP's Last Packet

It is desirable for the STAs have the ability to detect and indicate to the HC the last packet it sends for the current TXOP. Although this is not always possible for the STA to detect the last packet of transmission, whenever possible, this functionality can be realized by the redefinition of "more data" bit --- bit13 of the MAC header frame control field.

3.2.3.1Detection of last Packet

A STA is able to detect and mark the last packet it sends out for current TXOP when:

1. After previous transmission, there is no packet left in the buffer
2. There is no packet to send at all when the STA is polled

However, the STA is not able to detect the last packet it sends out when:

3. There is packet pending in the buffer; however, there is no TXOP left for transmission.

So for cases 1 and 2, the STA is able to indicate to HC that current packet is the last packet it will send during this TXOP using the mechanism introduced as follows and therefore HC will send ACK/Restart or BlockACK/ Restart to acknowledge as well as poll the next STA; for case 3, since the STA can not detect the last packet, HC has to wait timeout and sends Restart to poll the next STA.

3.2.3.2"More Data" bit in IEEE 802.11/11e

"More data" bit is the 13th bit of MAC header's frame control field, which is shown in Figure 5. In IEEE 802.11, this bit is used to:

1. indicate to a STA in power-save mode by the AP that more MSDUs, or MAC management PDUs (MMPDU) are buffered for that STA at the AP by setting this bit to 1.
2. indicate to a PC in contention free period by a contention free pollable STA in response to a CF-Poll to indicate that the STA has at least one additional buffered MSDU for transmission in response to a subsequent CF-Poll by setting this bit to 1
3. indicate to STAs by AP in broadcast/multicast frames when additional broadcast/multicast MSDUs or MMPDUs remain to be transmitted during current beacon interval by setting this bit to 1.

For all other cases, this bit is set to 0, for IEEE 802.11e, in addition to the above cases, this bit can also be used to:

4. indicate to a non-AP QSTA by QAP that it has a pending transmission for it.

3.2.3.3 "More Data/Last Packet" Redefinition

Based on the usage of "more data" bit in IEEE 802.11, it is straightforward to extend such usage to the multipoll environment, more specifically, the SCCA mechanism. However, the interpretation of "more data" here is different from above. Thus it is necessary to redefine the "more data" bit to the "more data/last packet" bit. In SCCA, each STA will set "more data" bit to 1 to indicate this is the last packet it sends for current TXOP, this bit should be 0 for all other frames during SCCA TXOP. Figure 9 depicts the redefined frame control field of MAC header. Note that this redefinition doesn' t affect any other functions for both contention and contention free period, hence has very good backward compatibility.

B0 B1	B2 B3	B4 B7	B8	B9	B10	B11	B12	B13	B14	B15
Protocol Version	Type	Subtype	To DS	From DS	More Frag	Retry	Pwr Mgt	More Data /Last pkt	WEP	Order

Figure 9: Frame control field after redefinition of "more data" bit

4 Backward Compatibility

The proposed frame format and flag usage do not require any modifications from current IEEE 802.11 produces. All the new frame format use the reserved value of control subtype and the redefined flag bit at frame control field will only take effect during SCCA, in all the other states, the flag is used normally. Hence the backward compatibility is always guaranteed and the implementation complexity is low.

5 Conclusion

Multipolling mechanism has been proposed to improve the throughput and reduce the overhead of wireless communication. However, the improvement is achieved at the price of the possible hidden terminal and/or unnecessary waste of channel. We propose a novel counting scheme for the STAs to count ACK/Restart frames they received before accessing the channel. The new mechanism allows STAs to overcome the hidden terminal problem as well as avoid unnecessary waste of channel resource. New types of frames are introduced and specific flag is redefined to accommodate the proposed mechanism with high backward compatibility and low implementation complexity.

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