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High throughput MAC protocol using sequential collision resolution and outband signalling

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Abstract

Since the release of the IEEE 802.11 standard, several efforts have been made to improve its performance. By using collision resolution together with collision detection in wireless networks, the time spent on collision can be reduced, thus improving system throughput. In this paper, collision detection is initiated by the receiver and a Sequential Collision Resolution mechanism is proposed where preferential access is given to all the colliding packets. Extensive simulations are carried out to evaluate the performance of this collision resolution protocol and a higher system throughput and lower delay is obtained.

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*Keywords:*HT MAC; collision detection; collision resolution; receiver initiated; outband signalling.

1. Introduction

With the number of devices on the network increasing day by day, Wireless Local Area Network (WLAN) is

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becoming very much popular; mobile phones and cameras are already part of this network. IEEE 802.11 is the widely used WLAN standard, which provides different channel access mechanisms such as Point Coordination Function (PCF) and Distributed Coordination Function (DCF). Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)[1] provides the basis for the random access protocol DCF. Though DCF is able to accommodate varying traffic loads, it has several draw backs such as low throughput / efficiency. This is mainly due to the inability of detecting collisions while transmitting and the Binary Exponential Backoff (BEB) scheme employed[2]. The performance degrades as the number of devices increases because of the increased rate of collisions, resulting in low efficiency.

One method to increase the throughput is to introduce collision detection in wireless networks. Collision detection was considered impractical in wireless networks because of two main limitations. One of the reasons is that a wireless transmitter cannot transmit and listen simultaneously on the same channel since the signal strength of self-signal is too strong to detect a collision by the transmitter. The other reason is that as the channel conditions in wireless networks are different, they may vary at the transmitter and the receiver resulting in false indication of collision i.e a collision detected by the transmitter may not indicate a collision at the receiver.

Extensive research work is carried out to reduce the time spent on collisions and to improve system efficiency, by applying collision detection technique to wireless environments[3,4,5]. The CSMA with time split collision detection (CSMA-TCD), a paper published in 1984, suggests stopping an on-going transmission and executing carrier sensing for a period after transmitting the preamble with a fixed length[3]. Simultaneously transmitting stations can detect the other preamble signals because of the radio propagation delay and can recognize the collision before data transmission. This protocol is specialized for a radio communication scenario with a long propagation delay.

In fully connected single hop networks, fixed numbers of slots are introduced to provide collision detection in WCSMA/CD[5]. This is achieved by randomly providing a CD slot (CDS) within a fixed collision detection period after starting data transmission. Transmission is stopped and channel is sensed during CDS. If an energy level higher than threshold is sensed during CDS, transmission is aborted and stations take random back off. Otherwise, transmission continues. The disadvantage is that collisions may increase since all the colliding stations take random backoff and contend again. This is overcome in CSMA/CR[6].

In CSMA/CR protocol, the first collision-detecting station transmits a jam signal and the other transmitting stations recognizing the jam signal immediately stop their on-going transmissions. The station which transmits the jam signal has a priority to access the channel for its retransmission and resumes data transmission after CDP without the back off time. This ensures a successful transmission of one of the collided packets in the same time slot after a collision.

Taking into account the capture effect, receiver is the only one which can predict whether the current transmission is a collision or not. In the event of a collision between two frames at a receiver, the hardware is capable of detecting and decoding the packet with stronger signal strength. This is beneficial and has been exploited by many MAC and networking protocols to prevent packet collisions, increase network throughput and decrease delay[7]. So the receiver initiated collision detection protocols perform better as compared with the transmitter detecting protocols.

CSMA with Collision Notification (CSMA/CN) uses, Soft-PHY, collision detection scheme at the receiver with explicit feed back to the transmitter to abort an unsuccessful transmission[8]. But the techniques used such as signal correlation and architecture modification make it complicated. Efficient collision detection through transmitter parameter optimisation is done using power sensing and time domain signal processing[9].

Another approach is out of band signalling scheme[10]. Here two different physical channels; a signalling channel operating at a low bit rate and a data channel at a high bit rate are used.

Receiver Initiated Busy Tone Multiple Access (RI-BTMA) is proposed for better performance and throughput[11]. In RI-BTMA, the communication channel is divided into a data channel and a control channel. A packet preamble is sent to the intended receiver by the transmitter. Once the preamble is received correctly, the receiver sets up an out-of-band busy tone and waits for the data packet. The transmitter, upon sensing the busy tone, sends the data packet to the destination. The drawback is that RI-BTMA does not have any resolution mechanism to give preferential access. Besides, multiple frequency tones will require additional channel resources.

A contention-tone protocol[12] avoids transmission collisions and shows better performance under heavy traffic. It uses the contention tone, transmitted on a separate narrowband signalling channel, to resolve the station contention concurrently during an ongoing frame transmission. Since the contention resolution occurs concurrently with the data transmission period, this allows the protocol to operate at near maximum throughput.

Fast Collision Resolution (FCR), an efficient distributed contention-based MAC algorithm is used to resolve collisions and reduce idle slots[13]. FCR algorithm attempts to resolve the collisions quickly by increasing the contention window sizes of both the colliding stations and the deferring stations in the contention resolution. When a station detects a number of consecutive idle slots, it will start to reduce the back off timer exponentially fast, compared to the linear decrease in back off timer in the IEEE 802.11 MAC.

In existing contention resolution protocols, only one of the data packet gets the resolution advantage and gets transmitted, which creates unfairness. Remaining data packets have no priority in transmission and have to take a back off. Since these stations have already completed one contention resolution process it is unfair to force them to go through a general contention once again. The average number of stations undergoing collision in a transmission slot is between 2 to 3 (Appendix 1). An efficient collision resolution algorithm to provide resolution for all the collided stations along with collision detection within the framework of IEEE 802.11 standard is the need of the hour. Based on the above observations, a novel scheme, High Throughput MAC using Sequential Collision Resolution and Outband Signalling (HT MAC), is proposed. This algorithm attempts early detection of the collision by the receiver. A notification about collision to the transmitters is provided so that they can stop their ongoing transmission. Through collision resolution, priority access is given to all the collided stations, which leads to increased throughput and reduced packet delay in HT MAC protocol.

2. High throughput MAC protocol using sequential collision resolution and outband signalling(HT MAC)

The proposed protocol HT MAC for WLAN is illustrated in this section. The distinguishing feature of this protocol is the Collision Resolution, in which all the collided stations are given priority. It is presumed that all the nodes in the network are within the carrier sense range and can hear each other, even though transmitted packets cannot be decoded properly.

2.1 Basic Packet Transmission in HT MAC:

All the stations contend for the channel as in IEEE 802.11 and those, with minimum back off, start data transmission. If there are multiple signals at the receiver, collision is sensed and the receiving station sends a collision notification through the control channel. Every station monitors the control channel during the transmission through the data channel. If the control channel is idle, it continues the data transmission. Otherwise the transmitting stations involved in collision recognize the collision notification and they immediately stop their on-going transmissions. These stations are taken to an intermediate state called Collision Resolution State (CRS) and transmitted from that state.

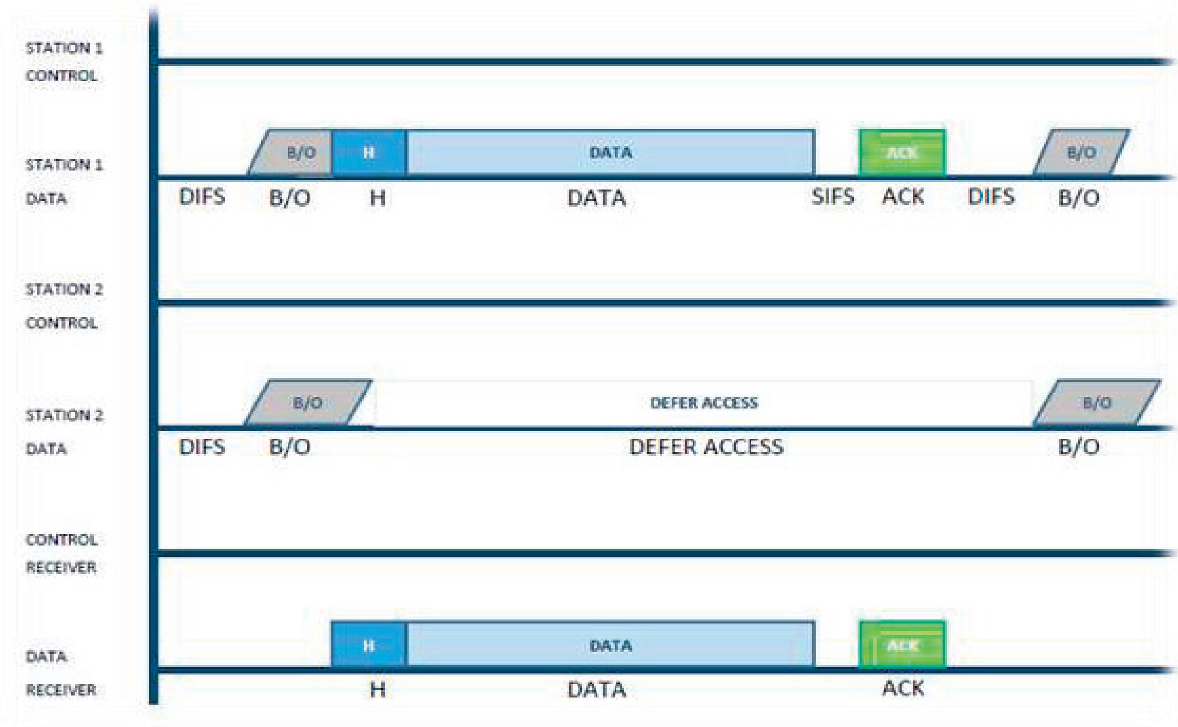

Fig.1. HT MAC-Protocol when there is no collision

Here we adopt an exponential back off scheme as used in IEEE 802.11. After each unsuccessful transmission, Contention Window CW, is doubled, up to a maximum value CW_{max}. Here CW_{min} is taken as 8 and CW_{max} is 256. When there is no collision, stations, after successfully transmitting their data packets, are allowed to contend within $(0, CW_{min})$. But in the case of collision, the collided stations are taken to a resolution state. Since the stations in the resolution state get preferential access, after each contention resolution, for the next packet transmission the contention window is doubled in order to prevent unfairness to other stations.

Stations 1 and 2 contend for the channel. Station 1 has a lower backoff value and wins the channel. It starts data transmission and successfully completes it. The receiver acknowledges the successful reception with ACK signal after a short SIFS period.

When there is collision the collided stations are accorded preferential access. In Fig.2. Stations 1, 2 and 3 are contending for the channel and stations 1 and 2 win the channel simultaneously since they are having the same backoff value. A collision occurs and the receiving station sends a collision notification through the control channel to all the transmitting stations. When the transmitting stations receive the collision notification, they immediately stop transmissions and go into the contention resolution state.

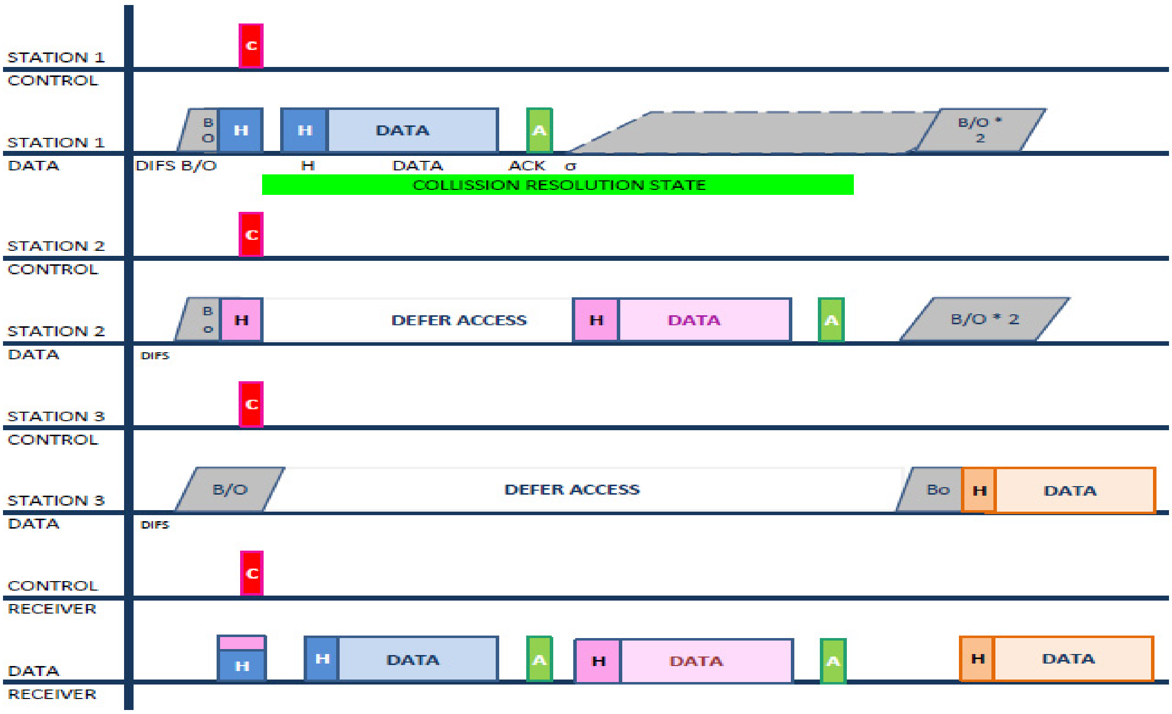

Fig.2. HT MAC-Protocol when receiver detects a collision

In the second stage of contention resolution which uses Busy Tone Contention Protocol (BTCP)[14], there are 4 time slots each having duration of τ. We select the value of τ as 6μs which depends on the hardware feature of the wireless node[15]. Since τ=6μs, total time duration of the second collision resolution is 24μs which is less than DIFS of 802.11.It ensures that in any situation none of the other stations in the network access the medium till the collision resolution is over.

The basic structure of BTCP protocol is reviewed for clarifying the modifications. In each slot a binary number ‘0’or ‘1’ is selected and depending on this, stations go for contention. If the number is ‘0’ in its slot, it transmits in that slot and if it is ‘1’ it senses the channel in that slot and defers from further contention[14]. The stations which do not sense the transmission in the contention slot win the channel and get transmitted. Based on this, station which takes the smallest 4 bit number will win the channel and get transmitted. After the transmission of first packet, by giving only a break of a slot time, the remaining collided stations contend for the transmission slot according to the contention resolution mentioned above. This continues until all the collided stations in the resolution state have successfully transmitted their data.

In the collision resolution state, station 1 gets the access first and it transmits the data packet. After the successful data transmission it doubles its existing contention window size in order to prevent unfairness to other transmitting stations. Followed by this, station 2 completes its data transmission and doubles its contention window size.

When the stations present in the resolution state (stations 1 and 2) complete their transmissions, channel becomes free. After the medium is determined to be idle for DIFS period, the back off procedure is resumed and all the transmitting stations contend for the channel, by decrementing their back off timers. Since stations 1 and 2 double their contention window, there is a high chance that station 3 gets the channel access and starts transmission.

3. Simulation and Performance Evaluation

An infrastructure WLAN which has an Access Point (AP) at the centre and distributed stations within a radius of 100m is considered for simulation of throughput and average delay. It is presumed that all stations in the network can hear each other. For packet transmission, all stations use the same packet header formats and Inter Frame Space (IFS) defined in IEEE 802.11a standard (Table 1). Saturated condition is considered i.e. each station always has a packet available for transmission in its transmission queue. AP transmits the required timing and synchronisation signals.

A discrete event simulator developed using Matlab is used to simulate Throughput and Delay of IEEE 802.11 DCF and HT MAC.

Table 1.Parameter Setup

PHY Mode	OFM
Channel bit rate	6 Mbps
ACK length	120 bits
Propagation delay	1 μs
RxTx turnaround time	2 μs
TxRx turnaround time	2 μs
Slot time	9 μs
SIFS	16 μs
DIFS	34 μs
PHY Header	20
CDS length	6 μs
Minimum CW size	7
Maximum CW size	255
Number of stations	10-100

Table 1 summarizes the used parameters.The number of stations during the simulation is varied from 10–100. The throughput, delay and fairness are the widely used metrics to compare the performance of MAC protocols. Throughput is defined as the fraction of the channel capacity used for data transmission[16]. A MAC protocol's objective is to maximize the throughput while minimizing the access delay.

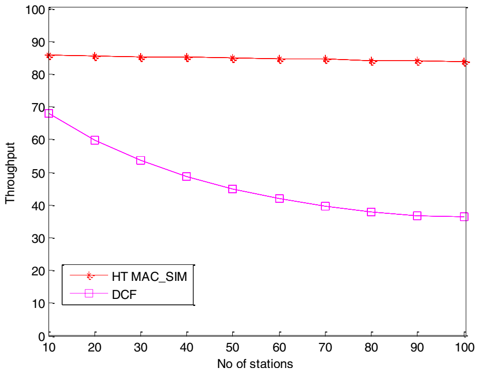

Fig.3. Throughput of DCF and HT MAC

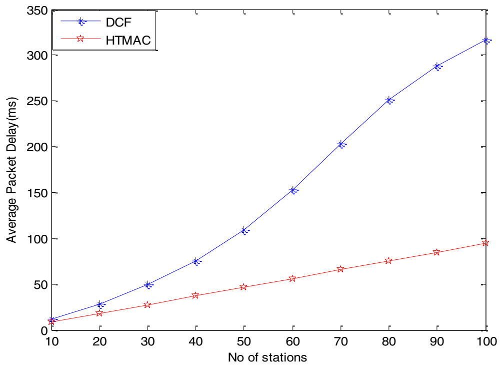

Fig.4. Average packet delay of DCF and HT MAC

Fig.3. shows the throughput of DCF and HT MAC for varying number of stations. The throughput of basic DCF protocol sharply decreases with an increase in the number of stations from 10 to 100. This is due to the repeated collision and back off. The throughput of HT MAC is high as compared to DCF and is almost consistent. The most significant factor evident from the plot is that the throughput of HT MAC is almost independent of the number of stations in the network.

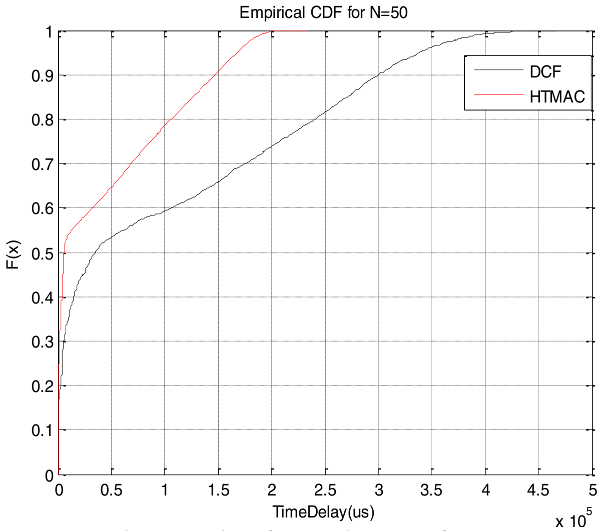

Fig.5. CDF plots of DCF and HT MAC for N=50

The delay experienced by the end user is the most significant one in wireless networks. To understand the impact of new protocol HT MAC, a parameter called average packet delay is estimated. The average packet delay is defined as the average time interval between two consecutive successful transmissions by a targeted station. This is actually the delay experienced by an end user due to the back off and time lost due to collision. Delay is a function of protocol and traffic characteristics. Fig.4. shows the average packet delay characteristics of DCF and HT MAC. For DCF, as the number of stations increase from 10 to 100, the packet delay increases almost exponentially, due to the repeated collisions and allied binary exponential back off. Corresponding delay for HT MAC shows only a linear rise from 9ms to 95ms only. Thus when the number of stations is 100, the delay experienced by the DCF user will be 3.4 times more than that of HT MAC user.

Cumulative Delay distribution Function of both DCF and HT MAC are estimated when 50 stations are trying to access the channel and the plots are shown in Fig.5. When the number of stations is varied from 10 to 100, the average delay for DCF increases from 0.15 sec to 0.8 sec. But for HT MAC the range is only from 0.1 sec to 0.3 sec. Within specific period of time, more packets are transmitted in HT MAC than the basic DCF access scheme, as the packet transmission in basic access takes longer time than in HT MAC access.

4. Conclusion

We propose a new protocol, High Throughput MAC using Sequential Collision Resolution and Outband Signalling (HT MAC). This is a Receiver initiated Collision Detection and sequential resolution method using outband, to increase the system throughput and decrease the channel access delay of IEEE 802.11 DCF. The simulations show that the throughput of HT MAC is 2.4 times higher than that of DCF and the delay in accessing the channel is 3.4 times lower than DCF. The use of out-of band signalling technique achieves higher overall throughput despite the need for an additional low bit rate channel for signalling.

In the emerging scenario of almost every device having a wireless networking ability built into, HT MAC will offer a tremendous advantage to the network operators in providing high throughput and lower access times to its customers. In view of its practicality and performance improvement, the HT MAC protocol will prove to be the best possible choice for future WLAN systems.

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Appendix A

Consider a fixed number of contending stations (n). Using Bianchi model, under saturation condition, the probability τ that a station transmits in a generic slot time is given by,

$$\tau = \frac{2(1-2p)}{(W+1)(1-2p)+W(1-(2p)^m)} \qquad \text{(A1)}$$

where p is the conditional collision probability, W is the contention window size and m is the number of states considered. The transmission probability τ depends on the conditional collision probability, which is still unknown.

$$p = 1-(1-\tau)^{n-1} \qquad \text{(A2)}$$

Probability of collision is the probability of more than one station trying to access the medium simultaneously.ie,

Probability of two stations to collide is $P_2 = \binom{n}{2}\tau^2(1-\tau)^{n-2}$

Probability of three stations to collide is $P_3 = \binom{n}{3}\tau^3(1-\tau)^{n-3}$

In general, $P_N = \binom{n}{N}\tau^N(1-\tau)^{n-N}$ (A3)

Average number of stations collide in a collision slot is given by $\frac{\sum_{N=2}^{n} NP_N}{\sum_{N=2}^{n} P_N}$ (A4)

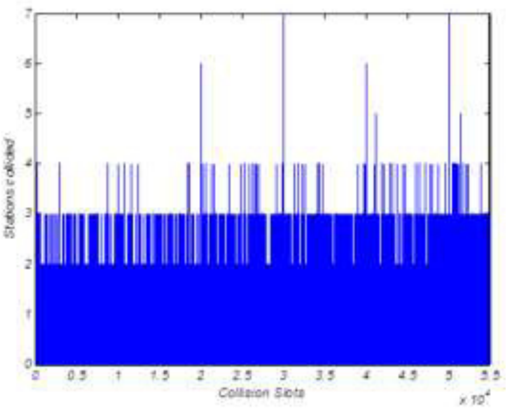

Fig.6. Average number of stations for 50000 iterations

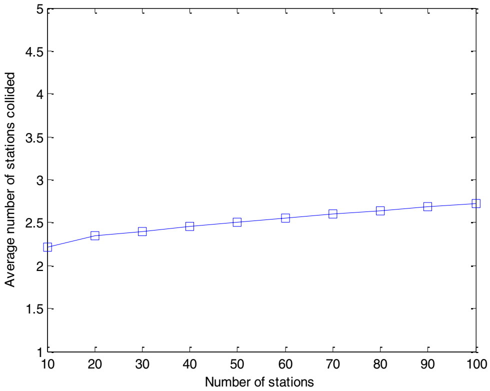

Fig.7. Average number of stations

From the above two figures it is clear that average number of stations involved in collision is only 3 as the number of contending stations vary from 10 to 100.