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Impact of Capture Effect on Receiver Initiated Collision Detection with Sequential Resolution in WLAN

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***Abstract*—*All existing protocols in wireless networks are mainly based on Carrier Sense Multiple Access with Collision Avoidance. By applying collision detection in wireless networks, the time spent on collision can be reduced and thus improves system throughput. However in a real WLAN scenario due to the use of nonlinear modulation techniques only receiver can decide whether a packet loss takes place, even there are multiple transmissions. In this proposed method, the receiver or Access Point detects the collision when multiple data packets are transmitted from different wireless stations. Whenever the receiver detects collision, it sends a jamming signal to all the transmitting stations so that they can immediately stop their on-going transmissions. We also provide preferential access to all collided packet to reduce unfairness and to increase system throughput by reducing contention. However this preferential access will not block the channel for long time. Here, an in band transmission is considered in which both the data frames and control frames are transmitted in the same channel. We also provide a simple mathematical model for the proposed protocol and give the simulation result of WLAN scenario under various capture thresholds.*

***Keywords*—802.11, WLAN, capture effect, collision detection, collision resolution, receiver initiated**

I. Introduction

THE Wireless Local Area Network (WLAN) has been widely deployed in homes, offices, public hotspots, and universities, because of its mobility, cost savings, ease of installation and operation compared to traditional wired LANs. IEEE 802.1 WLAN standard uses, DCF, a random access protocol based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) [1]. Even though due to its distributed nature, this random access protocol is able to accommodate varying traffic load, it has several drawbacks such as low throughput/efficiency due to inability of detecting collisions while transmitting and unfairness due to exponential back off [2]. To address this issue, this paper proposes a receiver initiated collision detection and resolution mechanism, capable of detecting collision in WLAN, namely RFSR (Receiver initiated Fast Sequential collision Resolution) considering Capture Effect, which outperforms the existing IEEE 802.11 DCF scheme.

In the earlier research works on the throughput of WLAN (DCF), it is assumed that the wireless channel is noise free; all packets arrive at the receiver with the same power level & at the same instant. In all these works the basic assumption is that whenever two or more packets reach at the receiver simultaneously, they collide and all packets involved are lost. However several recent research work [12,13,14] and experiments shows that the data under collision will not be totally lost and the receiver can receive a collided packet if its power is greater than the other interfering powers by a certain amount.

In the existing IEEE 802.11 DCF, the transmitter must complete the entire packet transmission process and then deduce a collision from the absence of an ACK from the intended receiver. This leads to low throughput since the failed packets will have to be retransmitted later. To increase the throughput, it is desirable to introduce collision detection in wireless networks. However collision detection was considered as infeasible in wireless networks due two main constraints. First, a wireless transceiver is half duplex, i.e. cannot transmit and listen on the same channel simultaneously. It due the fact that the signal strength of its own transmission (self-signal) would be too high to detect a collision (other nodes transmission). Second, the wireless channel conditions are dissimilar at the transmitter and the receiver and a collision noticed by the transmitter may not be a collision at the receiver (capture effect).

There are several efforts to increase system efficiency by reducing the time spent on collisions [3, 4, 5]. The CSMA with time split collision detection (CSMA-TCD), a paper published in 1984[3], suggests to discontinue an on-going transmission and carry out carrier sensing for a period after transmitting the preamble with a fixed length. Simultaneously transmitting stations can sense the other preamble signals because of the radio propagation delay and can distinguish the collision before

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data transmission. This protocol is particular for a radio communication scenario with a long propagation delay.

The concept of CSMA-TCD is extended to WCSMA/CD [5] to provide collision detection by introducing a fixed number of slots (slot concept) in fully connected single-hop networks. In the WCSMA/CD protocol, each station allocates a short collision detection slot (CDS) randomly within a fixed collision detection period (CDP) after starting data transmission. It stops its transmission and senses the channel during the selected CDS. If a station perceives a higher energy level than the threshold during the CDS, a collision is detected and it aborts its transmission and tries again after a random back off time. Otherwise, the station continues data transmission and successfully completes it. The deficiency of this protocol is that all the stations take random back off and contend again which may lead to further collisions. This is overcome in [6], by proposing Collision Resolution (CR). In CSMA/CR protocol, the first collision-detecting station sends a jam signal and the other transmitting nodes recognizing the jam signal instantaneously 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 the capture effect into account, only receiver can decide whether the present transmission is a collision or not. When a collision between two frames at a receiver, the node is capable of detecting and decoding the packet with stronger signal strength due to capture phenomena in an FM radio. This is beneficial for the system and has been exploited by many MACs and networking protocols to stop packet collisions, rise network throughput and reduction of packet delay [14]. So the receiver initiated collision detection protocols perform better as compared with the transmitter detecting protocols. CSMA with Collision Notification (CSMA/CN) [7] uses, Soft-PHY, collision detection system at the receiver with explicit feed back to the transmitter to stop an unsuccessful transmission. But the techniques used such as signal correlation and architecture alteration make it difficult.

Fast Collision Resolution (FCR), a distributed contention-based MAC algorithm to resolve collisions and reduce idle slots, is proposed in [8]. FCR algorithm resolves the collisions quickly by increasing the contention window sizes of both the colliding stations and the deferring stations in the contention resolution. Therefore, all stations having packets to transmit (including those which are deferred) will change their contention window sizes at each contention period in the FCR .To decrease the number of idle slots, the FCR algorithm uses a small idle back off period for each station with successful packet transmission. When a station finds a number of consecutive idle slots, it will start to decrease the back off timer exponentially, compared to the linear reduction in back off timer in the IEEE 802.11 MAC.

In all 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 or one level of contention it is unfair to force them go through a general contention once again. By analysis and through simulation we have shown that the average number of stations undergoing collision in a transmission slot is between 2 to 3 (Appendix 1). So an efficient collision resolution algorithm that provides resolution for all the collided stations, without receiving the medium for a longtime for sending the entire collided packets, within the framework of IEEE 802.11 standard is needed. Based on the above observations, a novel scheme, Receiver Initiated Collision Resolution (RFSR), is proposed in this paper. This algorithm attempts early detection of the collision by the receiver considering capture effect. 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 RFSR protocol.

II. RECEIVER INITIATED FAST SEQUENTIAL COLLISION RESOLUTION (RFSR)

The proposed protocol RFSR 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.

A. Basic Packet Transmission in RFSR

All the stations compete for the channel as in IEEE802.11 and those, with minimum back off, transmit data header and preamble followed by a silent period known as Collision Detection Slot (CDS). If a collision occurs at receiver and the receiving station sends a jam signal during the CD slot. When a station is an active sender, it senses the CD slot. If the CD slot is idle it continues the data transmission. Otherwise the transmitting stations involved in collision recognize the jam signal 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.

In Fig.1, station 1 wins the channel and transmits the packet. The receiver acknowledges the successful reception with ACK signal after a short SIFS period.

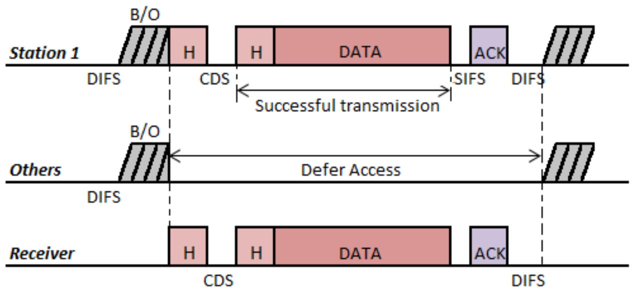

Fig.1. RFSR Protocol when there is no collision

In Fig.2, stations 1 and 2 win the channel simultaneously. A collision occurs and the receiving station sends a jam signal during the CD slot to all the transmitting stations. When the stations sense the jam signal in CDS, they immediately stop transmissions and go for the contention resolution (Fig.2) for transmitting the packets.

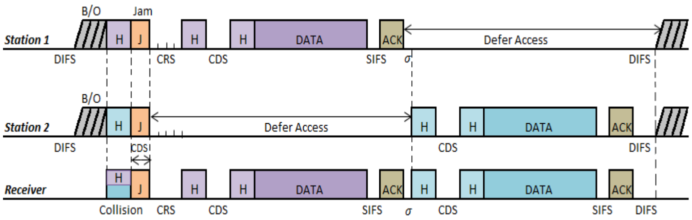

Fig.2. RFSR-Protocol when receiver detects a collision.

In the second stage of contention resolution which uses Busy Tone Contention Protocol (BTCP) [9], there are 4 time slots each having duration of τ. We select the value of τ as 6 µs which depends on the hardware feature of the wireless node [16].

Since τ=6µs, total time duration of the second collision resolution is 24 µs 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. For the completeness of this paper we briefly explain BTCP protocol. 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 differs from further contention [9]. 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 SIFS, 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 successfully transmit their data.

The capture effect in WLAN is shown in Fig.3. With capture effect, the instantaneous powers received at the AP for different terminals will generally not be the same. Therefore, even if there are more than two wireless terminals transmitting their packets at the same time, one of them may be successfully received at the AP. Though stations 1 and 2 are transmitting at the same time, receiver gets captured by the station having high signal power (station1). No collision is detected at the receiver and normal transmission occurs between receiver and station1. Since there is no jam signal, both the stations 1 and 2 continue with their data transmission resulting in a packet error at station 2. As shown in Fig.3 station 2 becomes aware of the non-reception of its packet only when the expected acknowledgement is not received. In this scenario we adopt an exponential back off scheme as used in IEEE 802.11. After each unsuccessful transmission, 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

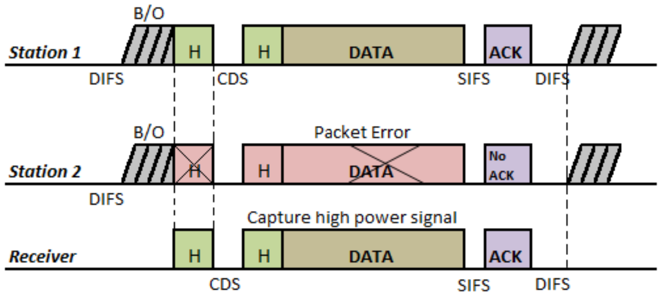

Fig.3. Effect of capture phenomenon at the receiver

III. THROUGHPUT ANALYSIS

In this section we describe a mathematical model for the proposed protocol while considering the capture effect in to the consideration. Here we modify the famous Bianchi model of DCF to include the contention resolution and capture effect. In RFSR, (Fig 4) the system goes through a virtual state called CR, which is a definite transition, and finally return to the same state of Bianchi model. Because CR is a definite/not having memory, effectively there is no modification in the finite state machine diagram of DCF. The term *pc* in the Markov chain model (Fig 5) corresponds to the success probability due to capture effect. The next we briefly explain the modification required in the saturation throughput of Bianchi model.

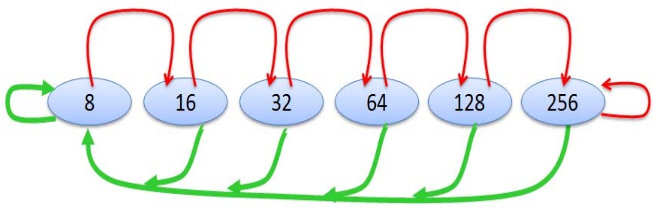

Fig 4.a Simplified Bianchi model. *After a collision station increases its back off stage by one (red arrow).*

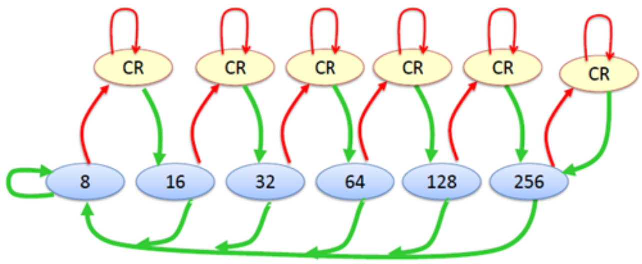

Fig 4.b RFSR model. *After a collision station goes contention resolution stage and increases the back off stage by one unit. That is CR can be considered as a virtual state.*

In RFSR protocol, a successful packet transmission can be either through DCF or by the preferential accesses in RFSR after collision. Using the steady state transition analysis of two dimensional Bianchi model of DCF [1] and the capture effect is given by [19] the conditional collision probability (the probability of a collision seen by a packet being transmitted on the channel) is given by

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

where τ is the stationary probability that a station transmits in a randomly chosen slot time and n is the number of stations in the WLAN and p_c is the capture probability. For a given number station n the value of p and τ evaluated numerically [1]. The probability of capture, when $N+1$ wireless terminal transmit packets is given in [14].

A slot in RFSR can be either ideal, successful transmission or collision. Unlike [1] the collision duration includes the time spent in CR state to transmit collided packet. Next step is to find the average amount of time required to transmit the N_c collided packets through collision resolution. The average time for transmitting first packet among N_c packets is given by

$$T_{Ncr} = \quad T_s^{cr} + \frac{P_{Ncr} \quad T_c^{cr}}{1-P_{Ncr}} \ldots.. \qquad (2)$$

where P_{Ncr} is the collision probability when Nc trying to access in the preferential channel access in RFSR and its calculation is given in [7]. The probability of Nc number of stations involving in a transmission in a slot is given by

$$P_{Nc} = \binom{n}{Nc} \tau^{Nc} (1-\tau)^{n-Nc} \qquad \ldots\ldots\ldots.. \quad (3)$$

In the above equation (2) T_s^{cr} is successful packet transmission time and T_c^{cr} is collision duration time involved when a collision happens in collision resolution again. The equation 4 gives the time for transmitting Nc packets.

$$T_{Nc} = \sum_{i=0}^{Nc-2} \; T_{(Nc-i)r} \ldots\ldots.(4)$$

Now we are in a position to find the average amount of time required to transmit collided packets on collision resolution. It is given by the ensemble average of the time required for all collision possibilities i.e. number of colliding stations from 2 to N.

$$T_{ac} = \sum_{Nc=2}^{N} T_{Nc} \, P_{Nc} \cdots (5)$$

In the next step we calculate the average slot duration. In the proposed protocol there are three categories of slots, namely idle slots, transmission slots in DCF and contention resolution slots. We can calculate the probability of each slot and its duration for a given number of stations using equations (3) to (5).

Now we are in a position to evaluate the throughput of RFSR. The throughput, S, is the normalized system throughput, which is defined as the fraction of time the channel is used to successfully transmit payload bits. The expression for S is derived as follows:

$$S = \frac{E[\text{payload information transmitted in a slot time}]}{E[\text{length of a slot time}]} \qquad (6)$$

In RFSR, as compared to DCF, the successful packet happens after collision also. Considering that, the throughput of RFCS is expressed as:

$$S_{cr} = \frac{P_{tr} P_S E[P] + \sum_{Nc=2}^{N} P_{Nc} N_c E[P]}{(1-P_{tr})\sigma + P_{tr} P_S T_S^b + P_{cc} P_{tr} (T_{ac} + T_c^b)} \qquad (7)$$

where $Ps = \frac{N\tau(1-\tau)^{N-1} + pc}{P_{tr}}$ and $p_{cc} = 1 - Ps$ is the collision in a slot. In the above equation (7) E[P] is the average packet payload size. P_{tr} P_s is the probability of a successful transmission occurs in a slot time and $P_{tr} P_S E[P]$ is the average amount of payload information successfully transmitted in a slot time. The probability of the channel idle periods is given by $1 - P_{tr}$ and σ is the duration of an empty slot. The time duration for various events are as follows: T_s^b is the average time the channel is sensed busy because of a successful transmission and T_c^b is the average time the channel is sensed busy by each station during a collision. Similarly T_s^{cr} is average time taken for a successful transmission and T_c^{cr} is the average time during a collision in the collision resolution state.

$$T_s^b = 2H + CDS + E[P] + SIFS + ACK + DIFS \quad (8)$$

$$T_c^b = H + DIFS + CDS \quad (9)$$

$$T_s^{cr} = 2H + CDS + E[P] + SIFS + ACK + SIFS + CRs$$

$$T_c^{cr} = H + CDS + SIFS + CRs \quad (10)$$

Where CDs is the collision detection slot duration *(6 micro sec)* and CRs is the collision resolution slot duration (four slots, 24 microsec) and H is the packet header given by

$$H = PHY_{hdr} + MAC_{hdr} \qquad (11)$$

The values $E[P]$, T_s^b, T_c^{b}, T_s^{cr}, T_c^{cr} and σ are of the same unit.

TABLE 1

PHY mode	OFDM
Channel bit rate	6 Mbps
ACK length	120 bits
RxTx Turnaround time	2 μs
TxRx Turnaround time	2 μs
Slot time	9 μs

SIFS	16 µs
PHY Header	20
CDS length	6 µs
Minimum CW size	7
Maximum CW size	255
Payload size	600 bytes

IV. RESULT AND DISCUSSION

In this section, we evaluate the performance of RFSR and compare it with 802.11 DCF. For this, an infrastructure WLAN, with AP at the center and stations distributed within a radius of 100m, is considered. The table I summarizes the important parameters used for simulation. It is presumed that all stations in the network can hear each other and a saturated condition is considered i.e. each station always has a packet available for transmission in its transmission queue. We use a discrete event simulator developed using Matlab to simulate DCF and RFSR protocol.

For simulating the capture effect, we use power capture model [14], where a packet will be successfully received if the power of the concerned packet exceeds the joint power of the other interfering packets by at least a capture ratio z. That is

$$w_0 > z\{\sum_{i=1}^{N} w_i + \eta\} \qquad (12)$$

where w_0 is the power of concerned packet, w_i (i = 1, 2, ..,N) is the power of interfering packet i, and η is the power of additive white Gaussian noise[14]. The relationship between the received signal power and the distance of the stations from access point is given by

$$P(r) = \frac{1}{r^4} \qquad (13)$$

where r is the distance between the station and the access point[15].

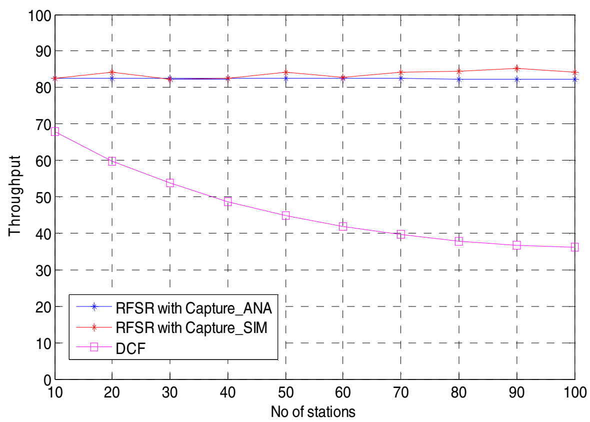

Fig 6 Throughput versus number of stations.

Fig 6 shows that the proposed RFSR protocol outperforms DCF. The throughput of basic DCF protocol sharply decreases with an increase in the number of stations because of the repeated collision and back off. The throughput of RFSR is high as compared to DCF and is almost independent of the number of stations in the network.

Fig 7 shows the throughput of IEEE 802.11 DCF with and without considering capture effect. With capture the throughput is slightly higher due to the reduced number of effective collision.

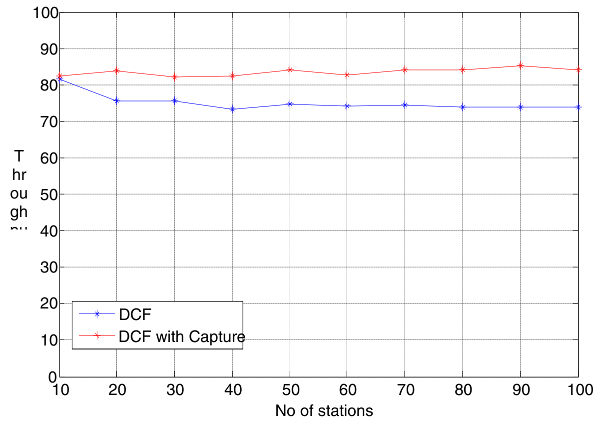

Fig 7 Throughput of DCF with and without capture effect (Simulation result)

Figure 8 and 9 shows the delay characteristics of RFSR and DCF. From these, it can be seen that the proposed RFSR protocol having less average packet delay in all scenarios. From the CDF of the packet delay it can be seen that maximum delay is small for RFSR (approx. only ten percentage of DCF). This is because of the preferential access given to the collided station in RFSR and there by the removal of unfairness of DCF to the collided stations.

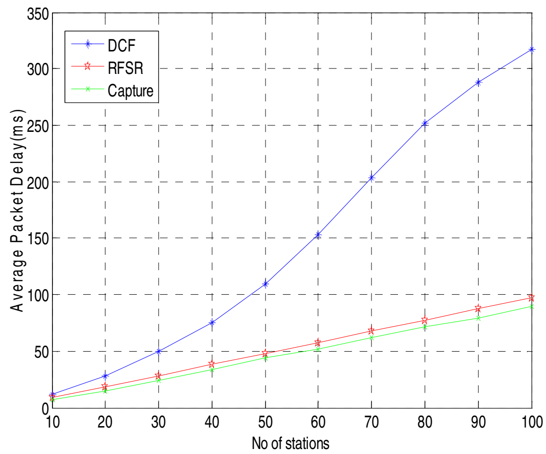

Fig 8: Average packet delay of DCF, RFSR& Capture Effect

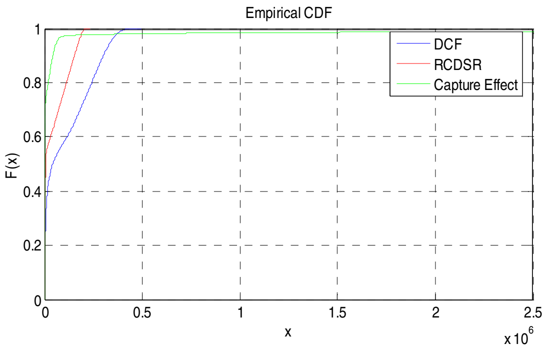

Fig 9: CDF of packet delay

V. CONCLUSION

We propose a new protocol; Receiver initiated Fast Sequential collision Resolution (RFSR), to increase the system throughput of IEEE 802.11. The simulation results show that the proposed RFSR protocol consistently has the best throughput and less delay irrespective of the number of stations. In view of its practicality and performance improvement, the RFSR protocol will prove to be the best possible choice for future WLAN systems, where an exponential increase in the number of wireless devices is expected.

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Appendix I

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.

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

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.

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

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

$$P_3 = \binom{n}{3}\tau^3(1-\tau)^{n-3}$$

$$P_N = \binom{n}{N}\tau^N(1-\tau)^{n-N}$$

Average number of stations collide in a collision slot is given by

$\frac{\sum_{N=2}^{n} N\, P_N}{\sum_{N=2}^{n} P_N}$. By using this the average number of station undergoing

collisiion is between 2 to three even the number of station increased

to 100