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Performance Evaluation of a Helper Initiated Distributed Cooperative Medium Access Control Protocol for Wireless Networks

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***Abstract*—Cross layer cooperative protocol which exploits the benefits of physical layer cooperative communication, is one of the widely recognized MAC layer protocol design strategies for future wireless networks. This paper presents performance analysis of a cooperative mac and these performance parameters are compared those of the legacy IEEE 802.11 DCF MAC. Appropriate relay station selection is the main hurdle in designing efficient cooperative MAC protocol for wireless networks. This cooperative mac demonstrated that intermediate relay nodes themselves can initiate cooperation for relaying data frame to the receiver on behalf of the sender. This procedure makes the selection process of a "helper node" more distributed in nature as well as it contributes to increase throughput of a wireless network by reducing the overheads that are usually incurred in the helper selection process. It has been shown by thorough analytical analysis that the proposed cooperative MAC protocol offers higher throughput and lower frame transmission delay in both ideal and error prone wireless environment. These performance metrics are also evaluated while the wireless nodes are mobile as well.**

***Keywords*—RTS, CTS, Cooperative Networking, IEEE 802.11 DCF MAC, BEB**

I. INTRODUCTION

MULTI-RATE capabilities of different IEEE 802.11 wireless LANs' standards have encouraged the researchers to divert the cooperative communication from physical layer to MAC layer and upper layers of OSI reference model. Physical layer cooperative communication schemes have facilitated the surrounding wireless stations of both source and destination to process and relay the overheard signal on behalf of the source. A well-defined cooperative MAC protocol is one that enables nodes in wireless LANs to help each other in transmitting data. Cooperative MAC protocol facilitates lower data rate stations to get more benefits in transmitting frames as they are assisted by other high rate wireless stations. Medium access in IEEE 802.11 DCF MAC protocol is performed using carrier sense multiple access with collision avoidance (CSMA/CA). In this scheme each wireless station gets fair access to the medium during the saturation period. If the lower data rate stations get assistance from higher rate stations to speed up their transmissions, access time to the medium by other stations fairly increases. There are a number of physical layer specifications of IEEE 802.11 i.e. IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, IEEE 802.11n etc. All of these physical layer implementations support multiple data rates. Now-a-days, the size of wireless terminal and hand-held devices have been decreased. Architectures of those wireless devices may not be congruent with the minimum physical layer requirements of MIMO. Implementation of cooperative transmission techniques in MAC layer of OSI reference model achieves spatial diversity without equipping individual nodes with multiple antennas. If there is severe fading in the link or the distance of the source destination pair is high, the effective direct data transmission rate is decreased considerably. In Cooperative MAC, a transmitter sends its data to a helper and the helper forwards the data packet to the receiver. Thus, the data frame is sent to the receiver by two hops instead of single hop. This cooperative communication exploits the broadcast nature of the wireless transmission medium.

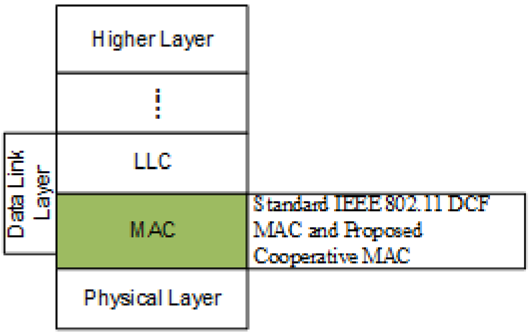

Fig. 1. OSI reference model and Implementation area of cooperative mac

The cooperative mac may be standardized with Legacy IEEE 802.11 DCF MAC as shown in fig.1. The proposed protocol does not change the frame structure of IEEE 802.11 DCF MAC. Therefore, proposed cooperative MAC is backward compatible with legacy IEEE 802.11 MAC. In cooperative MAC design, the significant issue is the selection of an effective helper station and the appropriate coordination with the source destination pair. An appropriate helper selection strategy can reduce the overhead in cooperative communication significantly. A bad helper selection strategy in worst case may abruptly reduce throughput performance of the communication system. Initiating a cooperative mode of communication in MAC layer should be selective. Sometimes a sender station may not need cooperation from the relay station. This paper is focused on the

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analysis of different performance metrics of a helper station initiated distributed cooperative mac. In this cooperative technique, it is shown how relay stations themselves determine whether initiating cooperation for a particular data transmission session is beneficial.

Unlike other works [4], in this paper it has been shown how a relay station could be an initiator of the cooperative communication. The rest of the paper is organized as follows: Section 2 overviews the related works of cooperative MAC design, Section 3 briefly describes the legacy IEEE 802.11 DCF MAC. In Section 4 we briefly present helper initiated distributed cooperative MAC, and section 5 depicts throughput and delay analysis as well as numerical results in mobile wireless environment. Section 6 concludes this paper with proposal of future amendments.

II. RELATED WORKS

A number of physical layer cooperative communication studies are present in literature. Amplify and forward and decode and forward are the two well-known methods [1]-[2]. Only a few research studies have focused on cooperative MAC protocol design. rDCF [3] (Relay Enable DCF) has exploited the multi rate nature of IEEE 802.11b network. In this protocol a helper station is selected in a proactive manner for a cooperative transmission session. It does not consider the dynamic nature of wireless network topology. A helper station may not remain as a suitable candidate because of the dynamism of wireless topology. To provide fairness among relay nodes, a protocol FC-MAC [4] is proposed which considers the role of relay nodes which could get less access time due to their cooperation. In that protocol a source node distributes the transmitted packets among a set of relay nodes. In this way the protocol ensures uniform power management among relay nodes. This strategy increases the network lifetime. rPCF protocol [5] enables multi hoping in IEEE 802.11PCF mode which assures contention service during medium access. However, PCF mode supports limited range of applications. Pei Liu had proposed a cooperative MAC [6]. In this work, a helper is chosen by the sender node in a predefined manner. Cooperative MAC [15] differs from CoopMac[6] specifically that a station declares itself as a helper. A cooperative MAC protocol for vehicular networks is proposed in [7]. Helper selection in this protocol incurs overheads which degrades the system throughput. Hangguan Shan and others have proposed a cross layer cooperative MAC protocol [8]. A helper is selected from a cooperative region and collision probabilities among candidate helpers are very high. In [9], Xin has proposed a receiver-initiated helper selection process and data transmission from the helper is prone to collision. S. Bharati [10] has proposed a cooperative ad hoc MAC for vehicular networks. TDMA approached is used for cooperative data transmission and also has modified the legacy IEEE 802.11 DCF Mac frame format. This scheme is not backward compatible with the legacy IEEE 802.11 DCF MAC. Other cooperative MAC protocols have also been proposed in [11].

III. IEEE 802.11 DCF

DCF (Distributed coordination function) is based on carrier sense multiple access with collision avoidance (CSMA/CA) protocol. It is a widely used multiple access mechanism for wireless local area networks. There are two access mechanisms in IEEE 802.11 DCF MAC. Its frames structures are shown in Fig. 2.

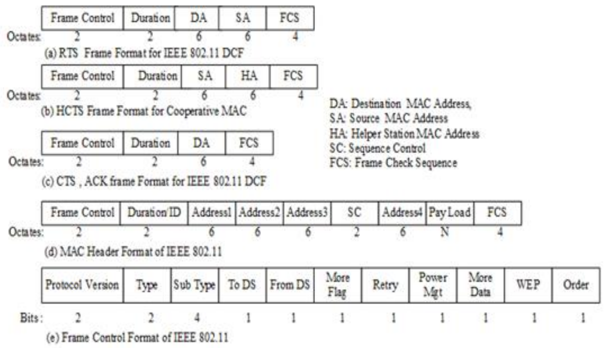


Fig.2. Frame structure of IEEE802.11 DCF mac and cooperative mac

A. Basic Access Mechanism

Each station follows random binary exponential back off algorithm (BEB) to avoid collision. Particularly, access time is slotted. Every station is allowed to transmit at the beginning of a time slot. A station cannot transmit until its back off counter is decremented to zero. The back off counter (BC) of a station is decremented while the medium is sensed idle and BC is frozen while the medium is sensed busy due to transmission of a frame from any other station.

In order to track BC, every station maintains a contention window (CW). Each station has a maximum retry count which indicates the number of times a frame can be retransmitted due to its transmission failure. The value of CW is chosen between $(0, CW-1)$. Value of CW depends on the number of failure of a frame transmission. At the first time, CW is set to its minimum value CW_{min}. If a collision occurs during a frame transmission, CW value is doubled. CW has a maximum value which is $CW_{max} = 2^k CW_{min}$, where k is the maximum number of retry limit. If the CW reaches to its maximum, it will remain in its maximum until the CW is reset to CW_{min} . CW is set to its minimum in case of a successful frame transmission or if the maximum retry limit for a frame is reached. If the frame transmission for a station is not successful until the maximum retry limit is reached, a station quits and discards the frame. Basic access process is shown in Fig. 3.

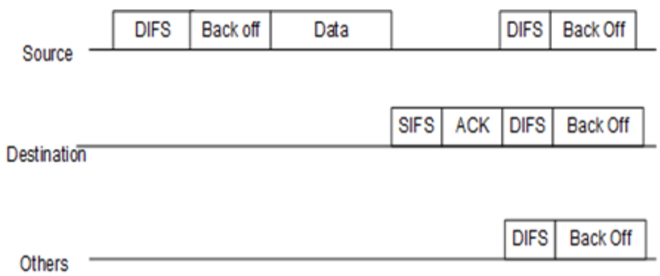


Fig. 3. Basic access mechanism in IEEE802.11 dcf mac

If a station has a frame to send, it senses the medium for DIFS (Distributed Inter frame Space) time. If it finds the medium idle during that time and its back off counter is zero, it simply sends the frame. After the frame is received correctly in the receiver, destination station sends an acknowledgement (ACK) of the receipt frame to the sender after SIFS (Short Intra frame

Space).The length of SIFS is shorter than that of DIFS. If there are more frames queued at the sending stations it must follow the same procedure each time it tries to send a frame. The whole frame may be collided with other frames.

B. *IEEE 802.11 RTS-CTS access Mechanism*

Broadcast signal in wireless medium access contributes two problems in basic access mechanism i.e. hidden station problem and exposed station problem. To deal with former problem, IEEE 802.11 DCF has employed RTS and CTS control frames. These two frames minimize extra time consumed due to more frequent collisions in heavily loaded wireless transmission system. Frame transmission timeline of RTS-CTS access mechanism are shown in Fig.4.

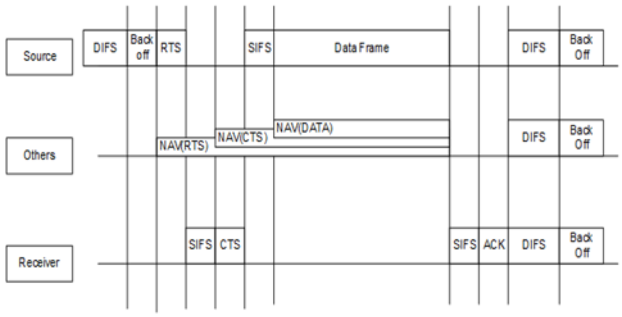


Fig. 4. RTS-CTS access mechanism of IEEE802.11 dcf mac

While a station finds the medium idle for DIFS time, it sends a RTS frame. If the RTS frame is received by the destination correctly, it replies to the source station with a CTS frame after a SIFS time interval. The source after upon receiving a CTS frame from the receiver, it sends the frame spending a SIFS time interval. After the data frame is received at the receiver correctly, an ACK is sent to source after SIFS time. Therefore, the collision time is kept minimized for a long data frame which was imminent in IEEE 802.11 DCF basic access mechanism.

IV. HELPER STATION INITIATED COOPERATIVE MAC PROTOCOL [15]

A. *Problem Statement*

Each station within a single collision region get equal medium access time at the saturation condition. By exploiting these phenomena researchers are trying to initiate cooperation in the MAC sub layer of the data link layer. Usually stations that reside in the maximum transmission distance from an access point (AP) in wireless LAN transmits data frame using 1 Mbps rate in IEEE 802.11b. Due to those low transmitting stations, high transmitting station gets much lower time to access the medium. Hence, the transmission efficiencies of those high transmitting stations are wasted. If low transmitting nodes gets help from other high rate stations in relaying data frames on behalf of those low transmitting stations to the destination, system's throughput is increased. On average this facilitates all other stations to get more access time to the medium.

Adaptation of multiple rates by each wireless node plays significant role in designing cooperative MAC shown in Fig 5. More importantly, to make cooperative MAC protocol a standard for OSI reference model, an efficient and effective helper station selection algorithm must be devised with low overheads.

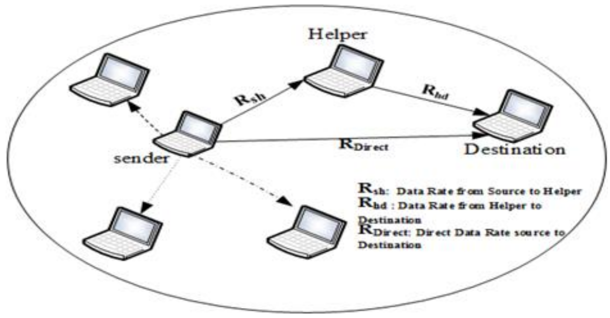


Fig. 5. Cooperation among nodes

B. *Cooperation Initiation*

In addition to its usual activity, each station performs the role of relay for other stations. In 802.11 MAC, if a frame is received by a station, it first examines the destination address field (DA) of the received frame. If the frame is not intended for the station, the station drops the frame by updating its own NAV (Network Allocation Vector) to the value accordingly. Stations that hear both RTS and CTS control frames from sender and receiver respectively may act as the potential helper stations. Each potential helper station estimates the maximum direct data rate between source and destination pair by overhearing the Physical Layer Convergence Protocol Header (PCLP). Intermediate nodes that have sender- helper (R_{sh}), helper-receiver (R_{hd}) and sender-receiver ($R_{sd)}$ link data rate information declares itself as a potential helper node for a particular frame transmission session.

C. *Relay Station Selection and CoopTable Maintenance*

Each wireless station maintains a *CoopTable*. In IEEE 802.11, control frames and headers are always modulated at the base rate.i.e. 6Mbps for IEEE 802.11a and 1 Mbps for IEEE 802.11b wireless networks [3]. Unlike [5] a *CoopTable*in our proposed protocol follows the format like in Table I. Each row of the table keeps track of the updated transmission rate information of sender-helper and helper-receiver links. Each wireless node calculates the overheard RTS and CTS signal strength (RSS) within its proximity. Station which receives RTS and CTS control frame from both sender and receiver respectively assumes itself as a potential relay station for the ensuing data transmission session. Each relay station calculates maximum direct data rate between relay-sender and relay–receiver links through measuring the signal strength of RTS and CTS respectively [11]. In either case, if maximum transmission rate is greater or equal than a threshold (5.5 Mbps for IEEE 802.11 b); it adds the source MAC address of RTS/CTS and *timestamp* of the last received RTS/CTS frames into its *CoopTable*. If a relay station already has an entry of a neighbor station in its *CoopTable* from which it has just received an RTS/CTS and supported direct transmission rate is below a threshold, it discards that neighbor from its *CoopTable*.

This filtering ensures that only the effective data transmission would take place through this helper keeping the size of the *CoopTable* minimum. Apparently, a station considers itself as an effective relay for a particular data transmission session if it finds that.

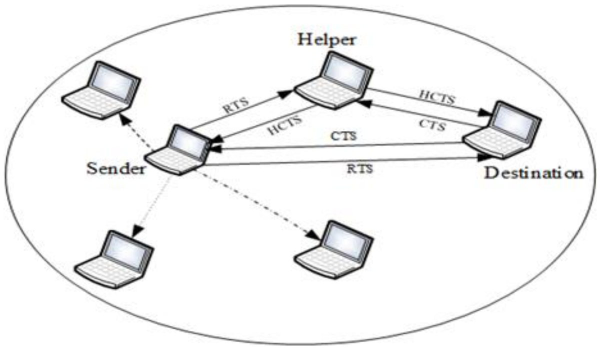


Fig. 6. Frame handshaking in cooperative mac

Where R_{sh} and R_{hd} are data rate for two hop transmission from source to relay and relay to destination respectively. R_{sd} is the direct supported data rate from source to destination. Every intermediate station which hears both RTS and CTS gets the value of R_{sh} and R_{hd} from its *CoopTable*. A helper station is selected in a distributed manner. If more than one intermediate station satisfies (1), to eradicate collision, potential helper stations start their back off counter. Station, whose back off counter reaches to zero, senses the medium before sending HCTS if it finds medium idle for DIFS time. All other intermediate stations that intended to be a helper finds the medium busy or their back off counter may not reach to zero.

$$\left(\frac{1}{R_{sh}} + \frac{1}{R_{hd}}\right)^{-1} > R_{sd} \qquad (1)$$

D. Data Transmission using a Relay

Frame handshaking in cooperative mac is depicted in Fig 6. Sender sends RTS, neighboring stations overhear it. If the RTS-CTS mechanism is not enabled during control frame handshaking, our cooperative MAC is disabled. This decision is made using RTS threshold. In basic access method, cooperative MAC mechanism is not initiated. In non-cooperative mode source sends its frame directly to the destination. After RTS is sent, the sender waits for the CTS and HCTS (Helper Clear to Send) times.

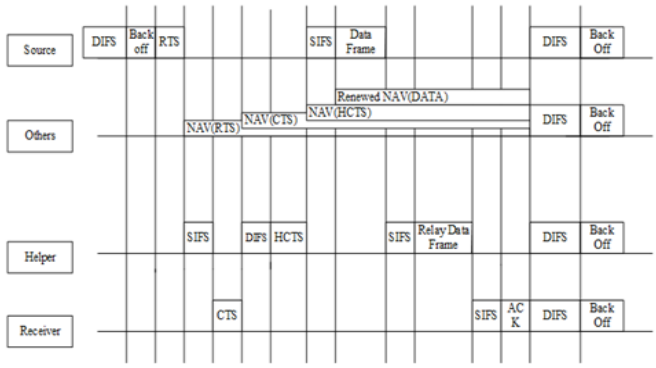
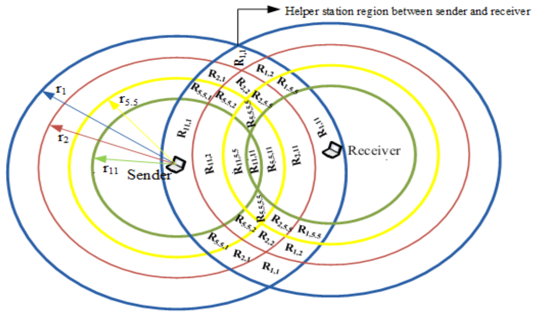


Fig. 7. Time line of control and data frames transmission in cooperative mac

Fig.7. describes timeline of control frames and data frame transmission in the proposed cooperative MAC. Potential helper stations also overhear the CTS. If the direct data rate between the source and destination is 1 or 2 Mbps (IEEE 802.11b), it sends an HCTS frame after DIFS time interval. While the source receives an HCTS from any of the helper node, it sends frame to that helper using rate R_{sh}. The relay forwards the frame to destination with rate R_{hd}. A cooperation region and the supported data rate of a potential helper node are shown in figure 8 for IEEE802.11b.



$R_{X,Y}$ indicates regions of supported X Mbps data rate from sender to helper station and Y Mbps data rate from helper station to receiver. $r_1, r_2, r_{5.5}, r_{11}$ denotes IEEE 802.11b maximum transmission regions for data rate of 1,2,5.5 and 11 Mbps respectively.

Fig.8 Potential helper stations geographical position and their supported two hop data rates (IEEE 802.11b)

In Fig.8, the geographical position of a helper station between a sender-receiver pair is shown with corresponding date rates. It also shows the supported maximum data rate of the two-hop links relative to the geographical position of a helper station. A missing HCTS during DIFS time means no cooperation mac is required. Access mechanisms follows IEEE 802.11 dcf mac i,e, direct frame transmission. In cooperative mac an intermediate node considers itself as a potential helper if it satisfies the following condition. The sender node re-calculates the value of the duration field of the transmitting frame. This duration value is much less than the value of the filed while no-cooperation is used. Correspondingly, NAV values of waiting nodes are set to this updated lesser value.

$$\frac{8L}{R_{hs}} + \frac{8L}{R_{hd}} + 2T_{PLCP} + T_{HCTS} + 2T_{SIFS} + T_{DIFS} < \frac{8L}{R_{sd}} \qquad (2)$$

Where, L is the length of the data frame in bits.
The waiting time of other nodes decreases and gets more access time to the channel. Duration fields of control frames in IEEE 802.11 DCF MAC along with the cooperative MAC are shown in Table II.

TABLE I
COOPTABLE FOMAT

MAC Address	Data Rate	Time Stamp	RSSI (dBm)	Neighbors Mac addresses	Maximum Rate	Received time of RTS/CTS	RSS Value RTS/CTS

V. ANALYTICAL MODELING AND RESULT DISCUSSIONS

A. Throughput Analysis without Mobility

We assume that there are n number of stations equally distributed over a region with equal expected transmission probability τ in randomly selected time slot. Let, P_{trans} denotes the probability that there is at least one transmission in randomly selected slot time

$$P_{trans} = 1 - (1 - \tau)^n \qquad (3)$$

TABLE II
DURATION FIELD OF CONTROL AND DATA FRAMES

Frame Type	Duration Value
RTS	$3T_{SIFS} + T_{CTS} + T_{ACK} + T_{DATA}$
CTS	$2T_{SIFS} + T_{ACK} + T_{DATA}$
$HCTS$	$3T_{SIFS} + T_{ACK} + \frac{8L}{R_{hs}} + \frac{8L}{R_{hd}} + 2T_{PLCP}$
$DataFrame$	$2T_{SIFS} + T_{ACK} + \frac{8L}{R_{hs}} + \frac{8L}{R_{hd}} + 2T_{PLCP}$

Let, p denotes the probability that a collision occurs during a randomly selected slot time. Therefore, the value of τ and p can be found by solving the following nonlinear systems given in [13].

$$\tau = \frac{2(1-2p)(1-p^{m+1})}{(CW_{min}+1)(1-(2p)^{m+1})(1-p)+(1-2p)(1-p^{m+1})} \qquad (4)$$

$$p = 1 - (1-\tau)^{n-1} \qquad (5)$$

Where, CW_{min} is minimum contention window size, m denotes the maximum number of retry.
Let, P_s be the probability that a successful transmission happens that is the probability that a station transmits and other $n-1$ refrain from transmission in a slot time.

$$P_s = \frac{n\tau(1-\tau)^{n-1}}{P_{trans}} \qquad (6)$$

Therefore, P_s is a conditional probability conditioned on P_{trans}. Throughput S can be derived using the following equation:

$$S = \frac{E[Payload\ bits\ transmitted\ in\ a\ slot\ time]}{E[Duration\ of\ a\ slot\ time]}$$

$$S = \frac{P_b p_S E[L]}{(1-P_b)\pi + P_b p_S T_S + P_b(1-p_S)T_C} \qquad (7)$$

Here, $\pi, T_c, and\ T_s$ is duration of an empty time slot, average time spent in collision and medium is sensed busy due to a successful transmission of a frame in a time slot respectively.

For RTS/ CTS access method, T_s and T_c for IEEE 802.11 DCF MAC andour proposed Cooperative MAC can be written as follows:

$$T_s^{WithoutCoOperation} = DIFS + T_{RTS} + T_H + 3SIFS + T_{ACK} + T_{CTS} + T_{E[P]}$$

$$T_C^{WithoutCoOperation} = DIFS + T_{RTS} \qquad (8)$$

$$T_s^{WithCoOperation} = 2DIFS + T_{RTS} + 2T_H + 4SIFS + T_{ACK} + T_{CTS} + T_{HCTS} + \frac{T_{E[P]}}{R_{hs}} + \frac{T_{E[P]}}{R_{hd}} T_C^{WithCoOperation} = DIFS + T_{RTS} + T_{HCTS}$$

Where, T_{RTS}, T_{ACK} ,T_{CTS}, T_{HCTS}, $T_{E[P]}$ and T_H are the required transmission time for sending RTS, ACK, CTS, HCTS, Data Frame and Frame Header respectively from sender to receiver.

B. Throughput Analysis with Mobility

According to McDonald and Znabi [15], link availability is defined as the probability that there is an active link between two nodes at time $t+T$ provided that there is an active link between them at time t. During T_s duration the connection between sender-relay-receiver must be continuous. If the relay station is mobile and if it leaves sender-receiver vicinity a disconnection follows. If a connection is established for particular data transmission session among Sender(S), Relay(R) and Receiver (D) at time, probability that the link will be continuously available for time T_s can be defined as the following:

$$The\ Probability\ that\ link\ lasts\ for\ time\ T_s$$
$$Pr(T_s) = Pr\ (t + T_s)|the\ link\ is\ available\ at\ time\ t$$

Let, wireless stations' mobility patterns are independent of each other and the random duration during which their speed and direction remain unchanged is exponentially distributed with mean $\frac{1}{\lambda}$. We assume that wireless stations are moving with constant speed and as the exponential distribution is 'memory less'. Therefore,

$$Pr(T_s) = [1 - E(T_s)]^2 = e^{-2T_s\lambda} \qquad (9)$$

Throughput for mobile environment can be calculated using throughput result found in (7) for 1Mbps and 2Mbps transmission stations.

C. Average Frame Delay Analysis

The duration between time when the frame is available at the head of the Line (HOL) of the transmitting station for transmission and the time at which its acknowledgement is received is considered the frame transmission delay. This analysis assumes that all stations have packets queued in its HOL.
Let $E[X]$ denotes the average number of time slots required for a station to transmit a frame successfully.

$$E[X] = \sum_{i=0}^{m-1} p^i . \frac{CW_i + 1}{2} + \frac{p^m(CW_m + 1)}{1-p}$$

Simplified form of the above equation is

$$E[X] = \frac{(CW_{min}+1)(1-2p)+pCW_{min}(1-(2p)^m)}{2(1-2p)(1-p)} \qquad (10)$$

Let, T_{coe} is the average duration while the observed station itself occupies the channel during each unsuccessful retransmission attempt. As an unsuccessful retransmission occurs due to collision only, so we can write $T_{coe} = T_C$.
Average time occupied by the observed station due to unsuccessful retransmissions can be calculated as,

$$E[T|collisionTime] = \sum_{i=0}^{m-1} p^i . T_{coe} = \frac{1-p^m}{1-p} . T_{coe} \qquad (11)$$

Therefore, Average Frame Delay $E[Delay]$ can be calculated as the following without considering frame dropped probability,

$$E[Delay] = E[X].E[slot] + E[T|collisionTime] \qquad (12)$$

D. Throughput analysis over Error Prone Channel considering Rayleigh Fading channel

We assume that mobile wireless channel is flat fading Rayleigh channel. In particular time duration, the channel remains in fading states or in inter fading state. Two statesare determined by the receiver by evaluating a certain threshold value of the received signal power level. A transmitted frame is successfully received if and only if the whole frame is transmitted during inter-fading states. If any part of the frame falls into the fading state, the frame is received with error. In Rayleigh fading margin is is defined as $\rho = \frac{R_{thresold}}{R_{rms}}$ where $R_{thresold}$ is the required received power level and R_{rms} is the root mean square signal level. Fading duration and inter fading duration is exponentially distribute for $\rho = 10dB$.
Let T_{frame} is the time required to transmit a whole frame to the destination. The frame error rate in flat fading Rayleigh channel is given in [14]

$$FER = 1 - \frac{T_i}{T_i + T_f} P\left(t_i > T_{frame}\right) \qquad (13)$$

Here,t_i and t_f inter-fading and fading duration respectively of the channel. T_i and T_f denotes average inter-fading and fading duration respectively. Since $t_i$and $t_f$are exponentially distributed. Therefore,

$$P\left(t_i > T_{frame}\right) = e^{\frac{-T_{frame}}{T_i}} \qquad (14)$$

For Rayleigh fading channel, average fading duration is given by

$$T_f = \frac{e^{\rho^2} - 1}{\rho f_d \sqrt{2\pi}} \qquad (15)$$

Where f_d is the maximum Doppler frequency and it is calculated from $\frac{v}{\lambda}$. and v is the velocity of the mobile devices and λ is the wave length. In Rayleigh fading channel, $T_i + T_f$ is equal to the inverse of the level crossing rate(LCR).

$LCR = \sqrt{2\pi} f_d \rho e^{-\rho^2}$. From the above discussion it is shown that Frame Error Rate (FER) is dependent on fading margin, maximum Doppler frequency and frame transmission duration. Since fading margin and Doppler frequency are not dynamically controllable. Only controllable parameter is the frame transmission duration. Therefore, Frame Error Rate (FER) is dependent on frame transmission duration.

If FER is considered, the probability that a transmitted frame is successful can be rewritten as

$$P_s = \frac{n\tau(1-\tau)^{n-1}}{P_{trans}}(1 - FER) \qquad (16)$$

Therefore, Throughput S of (7) can be re written as

$$S = \frac{P_b p_S E[L]}{(1-P_b)\pi + P_b p_S T_S + P_b(1-p_S)T_C + P_{trans}.FER.T_{ErrorFrame}} \qquad (17)$$

Here $T_{ErrorFrame}$ is the time consumed by an erroneous frame.

If legacy RTS/CTS mechanism is employed, $T_{ErrorFrame}$ is

$$T_{ErrFrame} = DIFS + T_{RTS} + T_H + 3SIFS + T_{ACK} + T_{CTS} + T_{E[P]}$$

In the proposed Cooperative MAC, time consumed by an erroneous frame can be derived as

$$T_{ErrFrame} = 2DIFS + T_{RTS} + 2T_H + 4SIFS + T_{ACK} + T_{CTS} + T_{HCTS} + \frac{T_{E[P]}}{R_{hs}} + \frac{T_{E[P]}}{R_{hd}}$$

A. Result Discussion

We used system parameters of IEEE 802.11b DSSS in Table III for the analysis of the proposed Cooperative MAC.

TABLE III
SYSTEM PARAMETERS OF MAC AND PHYSICAL LAYERS

Packet Payload	**8224 bits**
MAC Header	224 bits
PHY Header	192 bits
ACK	112 bits +PHY Header
HCTS	112 bits +PHY Header
RTS	160 bits +PHY Header
CTS	112 bits + PHY Header
Channel Basic Data Rate	1 Mbps
Slot Time	20 µs
SIFS	10 µs
DIFS	50 µs

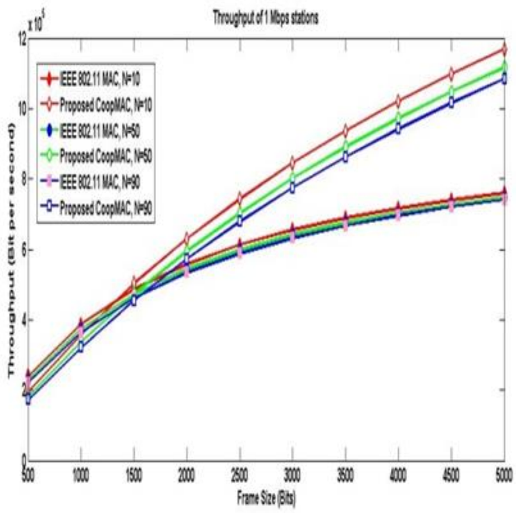


Fig. 9. Throughput versus Frame Size for 1 Mbps

In Fig. 9, throughput of 1 Mbps stations are shown with increase in frame sizes. Fig.10 depicts that 2 Mbps stations achieve more throughput than IEEE 802.11 DCF MAC with higher frame size threshold.

In both cases, slower stations are highly benefited if the proposed cooperative MAC is applied.

In Fig. 11. Variations in throughput achievement for different data rate stations are shown with the increase in number of wireless stations for a fixed frame size of 8224 bits. It reveals that cooperative MAC is not beneficial for stations with data rates 5.5 Mbps and 11 Mbps.

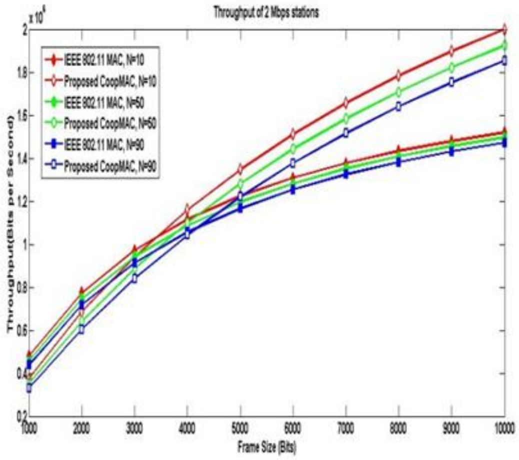


Fig. 10. Throughput versus Frame Size for 2 Mbps stations

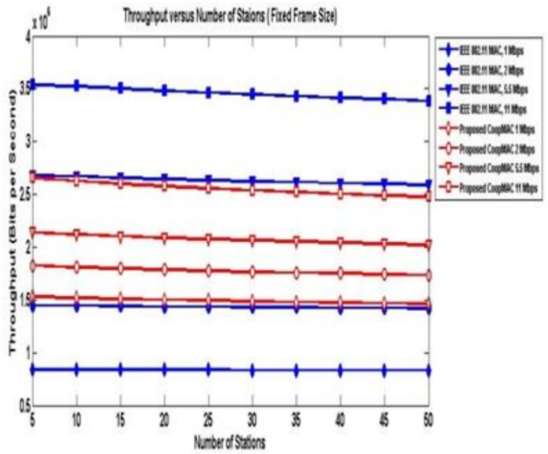


Fig. 11. Throughput of IEEE 802.11 b Station

Fig. 12 shows average frame both in legacy MAC and our MAC. Fig.13 and Fig.14 describes throughput of 1 Mbps and 2 Mbps wireless stations respectively with mobility of nodes. Finally throughput comparisons of 1 Mbps and 2 Mbps stations in flat Rayleigh fading channel are shown in Fig. 15 and Fig.16 respectively.

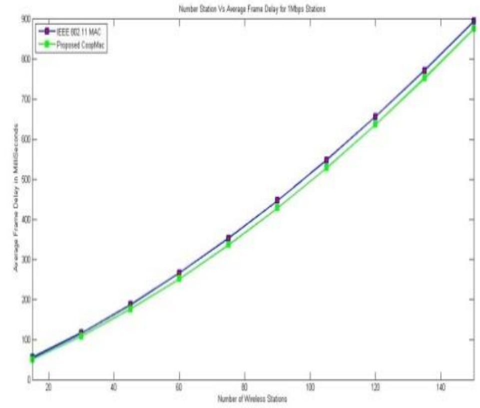


Fig. 12. Comparison of average frame delay of IEEE 802.11 DCF MAC and cooperative MAC

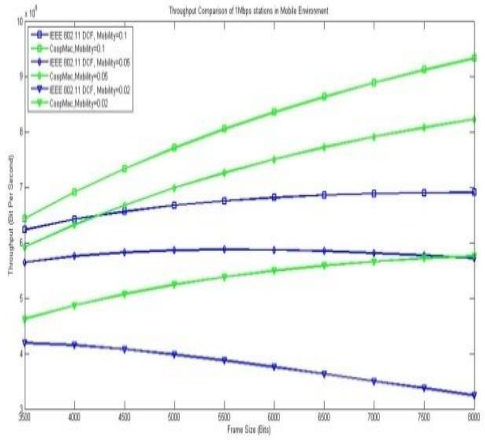


Fig.13.Throughput comparison of 1 Mbps stations with mobility

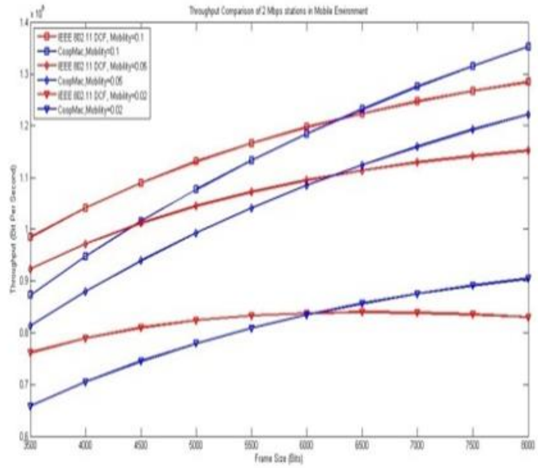


Fig. 14. Throughput comparison of 2 Mbps station with mobility

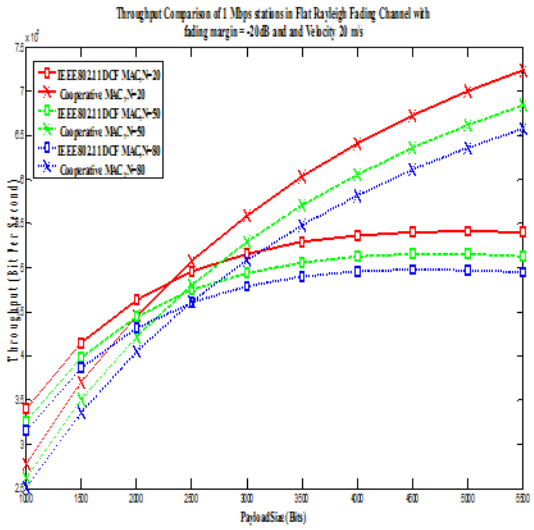


Fig. 15. Throughput with different number of stations (N) in flat Rayleigh fading channel

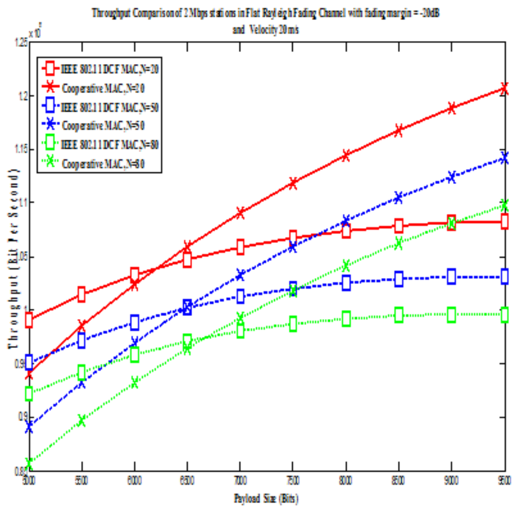


Fig. 16. Throughput with different number of stations (N) in flat Rayleigh fading channel

VI. CONCLUSION AND FUTURE WORK

In this paper IEEE 802.11 DCF MAC and a proposed cooperative MAC are studied and analyzed. Relay selection process is the corner stone in designing a cooperative MAC protocol. To facilitate the wireless stations to gain more access to wireless medium our protocol has minimized the overhead time in helper selection. The slower rate stations speed up their transmissions through cooperation from helper node. Numerical analysis shows that lower rate stations gain more throughput efficiency than the higher rate stations. For higher rate stations initiating a cooperative transmission reduces their throughput than IEEE 802.11 DCF MAC. Higher rate stations need not initiate cooperative transmission.

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