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Analysis of Frequency Channel Division Strategy for CSMA/CA with RTS/CTS Mechanism

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***Abstract*—In this work we study the collision probability, saturation throughput and statistical delay for the carrier sense multiple access collision avoidance (CSMA/CA) protocol with request to send and clear to send (RTS/CTS) mechanism in the case of frequency channel division. We propose in this paper a modified version of CSMA/CA-RTS/CTS to be compatible with the channel repartition technique and we prove that an important gain is introduced in terms of system performance especially for loaded networks. Simulations highlight that dividing the channel into independent sub-channels reduces drastically the RTS collision probability. Moreover, a gain in terms of saturation throughput and delay is shown especially in dense networks.**

***Index Terms*—Carrier senses multiple access/collision avoidance (CSMA/CA), Frequency channel division, RTS/CTS, MAC protocol.**

I. INTRODUCTION

Nowadays, WLANs are deployed by many companies for indoor and outdoor services and are shared by many users. Wireless local area networks (WLAN) using the IEEE 802.11 standard [1] are becoming omnipresent. WLAN's employs a robust medium access control (MAC) based on random-access, called carrier-sense multiple access/collision avoidance (CSMA/CA) [2] [3]. The CSMA/CA could be adopted for many reasons: it allows to operate in an environment with an unknown number of devices with the entire available bandwidth [4], operates in distributed manner [5] and leads to a cheaper deployment since it doesn't require much planning, interoperability and management complexity [6]. When CSMA/CA is used in WLAN/WSN topologies a very huge degradation in terms of system performance is noticed especially in loaded networks [7] [8]. To avoid wasting the limited radio resources, many researchers proposed to split, in frequency, the single shared channel to multiple sub-channels [9] [10].

A multichannel CSMA MAC protocol for multihop wireless networks is proposed in [11]. The authors describe a new CSMA protocol for multihop wireless networks. The protocol divides the available bandwidth into several channels and selects an idle channel randomly for packet transmission. They show via simulations that this multichannel CSMA protocol provides a higher throughput compared to its single channel counterpart by reducing the packet loss due to collisions.

All the cited works apply the basic version of CSMA/CA for each channel part in order to improve the throughput performance and to reduce the packet collision probability between users. In fact, they obtained simultaneous transmission on different sub-channels. However since packets duration will be multiplied by the number of sub-channels, the system performance will be penalized in terms of transmission delay. Also results are illustrated only for advantaged scenario where network is very charged (225 nodes in [11]). On the other hand, they didn't explain in which limit there is interest to use this kind of strategy. Actually the RTS/CTS mechanism for CSMA/CA protocol was adopted in the IEEE 802.11 to reduce the collision probability caused by hidden nodes terminals [12]. So applying the CSMA/CA - RTS/CTS to each channel part should improve the performance in terms of throughput and collision probability.

We propose to assess a better tradeoff by using the frequency channel division strategy only for RTS messages, while keeping the whole channel for the CTS, DATA and ACK transmissions. Also, we prove by simulations that the performance of the proposed protocol is better than the classical one. The paper is outlined as follows. We explain and describe in section II the proposed protocol and we give the system model. In section III we present the simulation results and the protocol analysis. Finally, section IV is reserved for conclusion.

II. SYSTEM MODEL

In this Section, we consider a scenario where many users would transmit packets to a base station (uplink communication mode). Actually the system performance is closely related to the collision between simultaneous transmitted packets [13]. Considering a symmetrical and ideal channel with RTS/CTS mechanism, collisions may occur only during RTSs transmissions. Sending RTS on sub-channels may help to reduce drastically this collision probability.

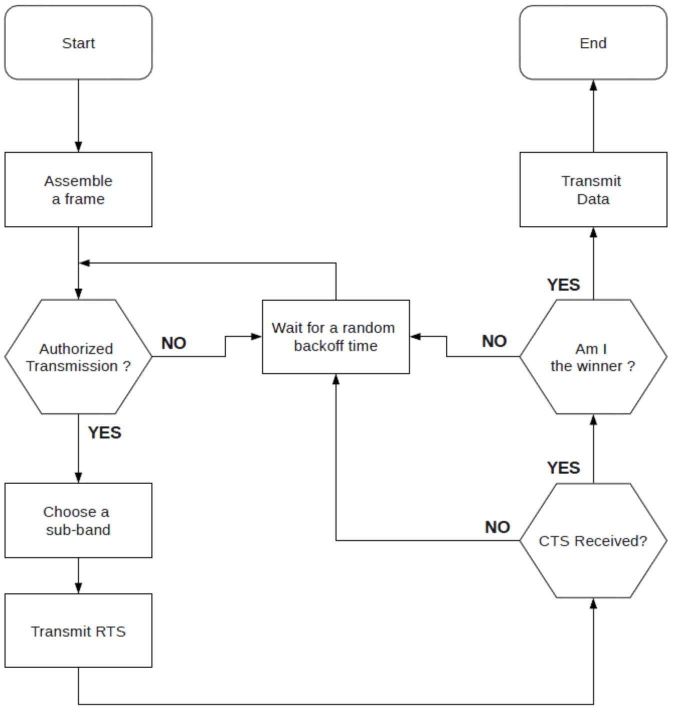


Fig. 1. Flow chart of the proposed protocol.

In this paper, orthogonal frequency multiplexing for these RTS is considered. Hence a single channel is divided into N sub-channels during RTS transmission. Due to RTS channel decomposition the duration to transmit the new RTS message (T^{new}) will be equal to the time needed for original RTS (T) multiplied by the number of sub-channels (N). Hence, $T^{new} = N \times T$. We assume that both transmitter (TX) and receiver (RX) have the knowledge of the sub-channels size and central positions. The proposed protocol is based on a CSMA/CA protocol with RTS/CTS techniques. The proposed scheme is used to avoid collisions between multiple users (source nodes) which are willing to access at the same time to a common access point (destination node). A state machine of the proposed protocol is depicted in Figure 1. According to this protocol, a source node wishing to transmit data should first listen to the communication channel. Note that the receiver listens to all sub-channels simultaneously.

If a signal is detected on at least one sub-channel, the channel is declared busy. Then, a period (expressed in number of time slots) of a waiting counter (known as ”backoff counter”) is chosen randomly in the interval [0, CW-1], where CW is a contention window. The backoff counter is decremented by one each time the channel is detected to be available for a DIFS duration (”Distributed Inter-Frame Space”). The wait counter freezes when the channel is busy, and resumes when the channel is available again for at least DIFS time.

When the backoff counter attempts zero, the source randomly chooses one sub-channel over the N available sub-channels to send a request permission message (RTS ”Request To Send”) to the destination node. It waits for receiving an authorization message (CTS ”Clear To Send”) from the destination node (access point) before transmitting data. The access point (AP) listens simultaneously to sub-channels. If one or more RTS is detected, the AP broadcasts CTS over all the sub-channels indicating the authorized station to communicate. How the AP selects the authorized station (STA) in case of decoding several RTS messages depends on the scheduler and on some priorities that can be easily implemented. This question is kept out of the scope of this paper. The chosen STA sends its data and waits for Acknowledge (ACK) from the AP. Both data and ACK messages are sent over all the sub-channels. Upon receipt of all transmitted data (successful transmission), and immediately, after a SIFS duration (”Short Inter-Frame Space”), the destination node sends an ACK (for ”Acknowledgment”). Contention window (CW) is an integer between CWmin and CWmax. The CW is initially set to the minimum value; CW=CWmin. Whenever a source node is involved in a RTS collision, it increases the waiting time of transmission by doubling the CW, up to the maximum value CWmax=2^m. Where m is the number of backoff stages. Conversely, in case of a successful RTS transmission, the source node reduces the CW to CWmin.

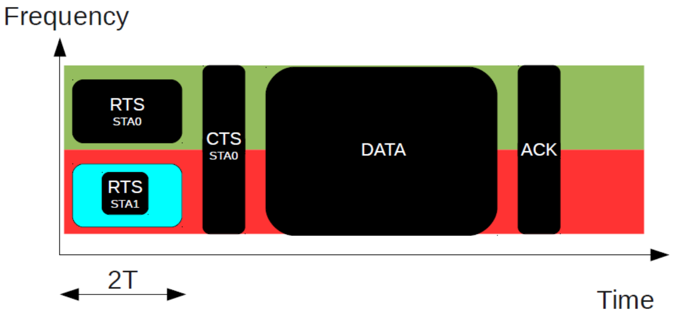
We illustrate in Figure 2 both standard and proposed protocols for the case of CSMA/CA with RTS/CTS scenario. The RTS duration is doubled respect to the standard when two sub-channels are considered ($T^{new} = 2 \times T$). In the proposed protocol, we consider that two stations are ready to transmit (Backoff=0) with one AP. STA0 (resp. STA1) chooses randomly sub-channel 1 (resp. 2). At the receiver side, the AP detects both RTS from STA0 and STA1. The AP chooses randomly the STA0 and sends CTS over all present sub-channels indicating that STA0 has gained the channel access. All the STAs receive and decode the CTS and only STA0 tries to send its packets during a defined amount of time (many time slots). Successful communication takes place when the AP responds with ACK over all the sub-channels. The case of many RTS transmission was considered as a collision in the classical CSMA/CA-RTS/CTS (see Figure 3). The proposed scheme provides the collision avoidance aspect in the shared medium context.

In order to implement this protocol we assume that we possess a physical layer able to encapsulate our proposed MAC. The physical layer should be able to decode each sub-channel independently.

III. SIMULATION RESULTS

In this Section, we study the collision probability, saturation throughput and statistical delay for the proposed protocol. The scenario of one AP and many mobile stations is considered

(a) Classical CSMA/CA - RTS/CTS Scenario



(b) Proposed CSMA/CA - RTS/CTS Scenario

Fig. 2. Illustration of CSMA/CA - RTS/CTS for standard and proposed protocols.

for simulation. It should be noticed that due to the nature of the protocol, this scenario is equivalent to a plurality of AP. Home-made event-driven simulator was used to model the protocol behavior. The protocol and channel parameters adopted are those specified in Table I which correspond to 802.11n standard. The minimal contention window (CWmin) has been chosen constant and equal to 16. It should be mentioned that in order to study the proposed protocol we consider a MAC layer integrating this protocol and an ideal physical layer (no path loss, no fading, no shadowing, ...).

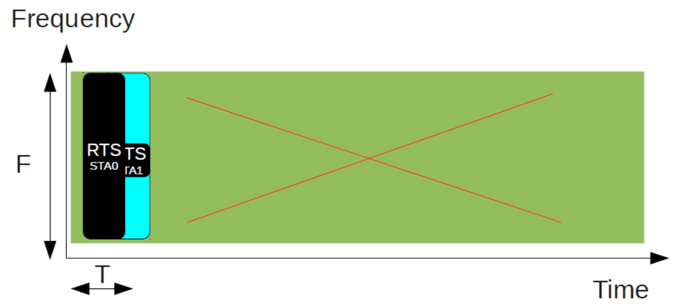
TABLE I

PHY LAYER PARAMETERS FOR 802.11N

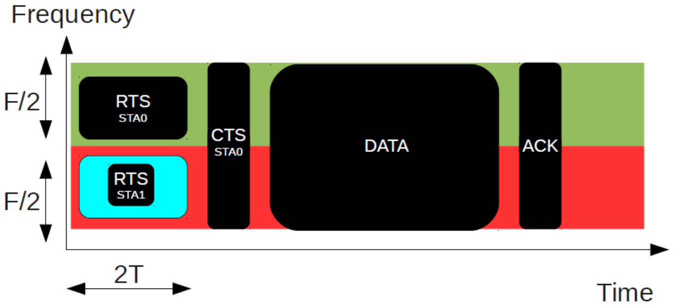
Packet payload	8184 bits
MAC header	272 bits
PHY header	128 bits
ACK length	112 bits + PHY header
RTS length	160 bits + PHY header
CTS length	112 bits + PHY header
Channel Bit Rate	72.2 Mbit/s
Propagation Delay	1 μs
SIFS	10 μs
Slot Time	9 μs
DIFS	28 μs

A. *Collision Probability*

Since the throughput and the delay are related to RTS collision probability, it will be interesting to analyze the impact of the proposed protocol on this factor. This study will be the object of this sub-Section. We assume a plurality of source nodes (stations) trying to access a destination node (AP). Figure 4 depicts the collision probability between RTS messages in function of the number of mobile stations present in the network for various RTS bands number.



(a) Standard Scenario with two RTS transmissions where collision occurs.



(b) Proposed Scenario with two RTS transmissions where sucessfull transmission takes place.

Fig. 3. Illustration of CSMA/CA - RTS/CTS for standard and proposed protocols in the case of two RTS messages.

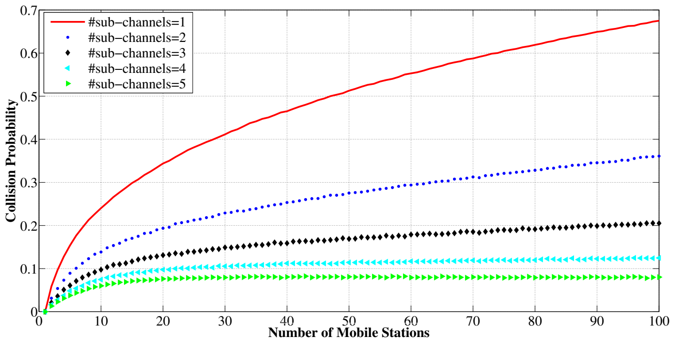
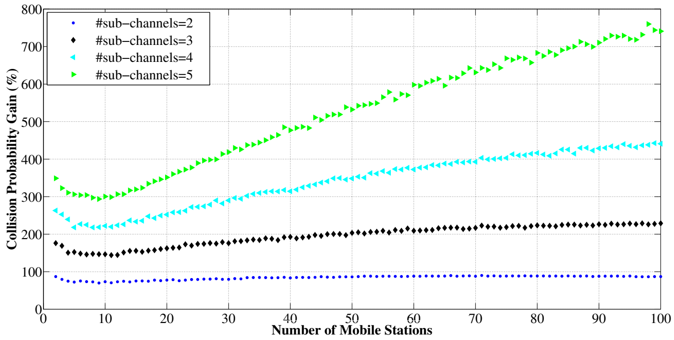


Fig. 4. Collision probability vs. number of mobile stations for various RTS bands number.

It shows that the collision probability increases proportionally with user's and the number of RTS sub-channels. For a single channel CSMA/CA with 50 users, the probability of collision is around 52%. In the case of two sub-channels



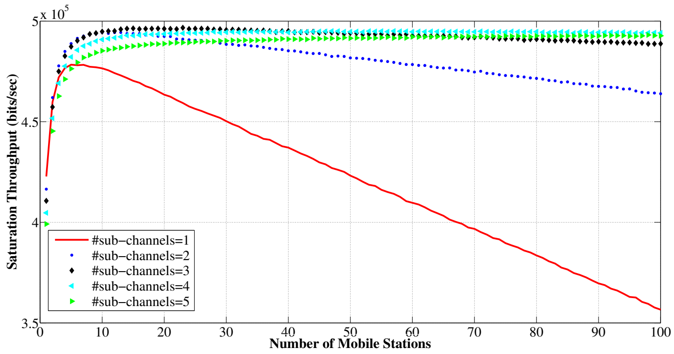


Fig. 5. Saturation throughput vs. number of mobile stations for various RTS bands number.

protocol the probability of collision is reduced to 28%. When 5 sub-channels are considered the probability of collision is less than 10%. As we discussed before, the proposed protocol reduces drastically the RTS collision probability. As collisions happen only during RTS transmissions (considering perfect channel conditions), the proposed MAC should improve the global system performance.

Figure III-A depicts the collision probability gain respect to the single channel (802.11n standard) in function of the number of users presents in the network for various number of RTS sub-channels. We can notice that the gain is proportional to the number of users and RTS sub-channels. For two bands protocol, the achieved gain in terms of RTS collision probability is close to 100%. When 5 RTS sub-channels are considered, the gain becomes much higher and can achieve 700% in dense networks. As this protocol reduces drastically the collision probability, it will be very interesting to show the effect of this factor on the throughput and delay. A full study will be the object of the following sub-Sections.

B. *Saturation Throughput*

In this Section we study the throughput in saturation mode, so we consider that the stations have always something to transmit (there is always at least one packet in the buffer of each node).

Figure 5 depicts the saturation throughput in function of the number of mobile stations present in the network for the proposed protocol with various number of RTS sub-channels.

TABLE II

SATURATION THROUGHPUT GAIN VS. NUMBER OF MOBILE STATIONS FOR TWO RTS BANDS.

#Stations	Proposed ($*10^5$)	Standard ($*10^5$)	Gain (%)
10	4.77	4.94	3.73
20	4.63	4.92	6.25
30	4.50	4.88	8.48
40	4.37	4.85	11.01
50	4.23	4.82	13.84
60	4.10	4.78	16.78
70	3.97	4.75	19.64
80	3.84	4.72	22.95
90	3.70	4.68	26.50
100	3.57	4.64	30.11

The saturation throughput for single channel degrades rapidly when the number of mobile stations increases. This protocol which is adopted by the 802.11 standard presents weak performance when the network is loaded. However, the saturation throughput is improved using the proposed protocol. We can remark from Table II that we have interest to shrink the RTS channel into 2 when the number of users is greater than 10. In fact, this amelioration is due to the reduction of the RTS collision probability which becomes significant when the number of users becomes high. Based on Figure 5, we could remark that it is more interesting to enhance the RTS channel division when the networks become denser. For instance, 2 RTS bands may considered if the number of nodes is less than 25 stations. When the network becomes more loaded, it is more advantageous to split the RTS channel into 3 or more sub-channels.

What will be the effect of this division on the delay? This question will be investigated in the next sub-Section.

TABLE III

DELAY GAIN (%) VS. NUMBER OF MOBILE STATIONS FOR TWO RTS BANDS.

#Stations	Standard (ms)	Proposed (ms)	Gain (%)
10	0.79	0.86	-9.04
20	1.02	1.07	-4.76
30	1.20	1.26	-4.68
40	1.29	1.31	-1.30
50	1.50	1.51	-0.60
60	1.72	1.62	5.60
70	1.90	1.77	7.47
80	2.15	1.92	11.91
90	2.44	2.13	14.70
100	2.75	2.29	20.43

C. *Statistical Delay Study*

In this section we study the gain/loss in terms of delay between the proposed and the single band protocols. The delay is defined as the time needed to transmit a packet. In order to compare the delay between the two strategies, we extract from simulation the cumulative density function (CDF) of the delay for one network scenario and for many

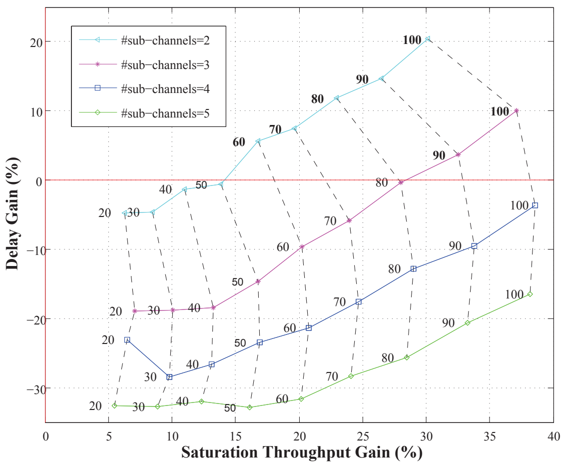


Fig. 6. Delay Gain (%) vs. Saturation Throughput Gain (%) for various number of stations and RTS sub-channels.

number of users. We reported the results for a CDF=99% in Table III for two RTS sub-channels. Table III shows that despite the doubled time needed to transmit the RTS message, improvement in terms of delay is achieved especially for loaded networks by considering the proposed protocol. For instance, the gain in terms of delay can achieve 20.43% for 100 users present in the network for only 2 RTS bands. Even the RTS transmission duration is doubled, the delay is improved in dense networks due to the important reduction of collision probability. So referring to the proposed protocol we can guarantee an important gain in terms of throughput and delay for loaded networks.

Figure 6 depicts the delay gain (%) in function of the saturation throughput gain (%) for various number of stations and RTS sub-channels. It is noticed that the gain in terms of saturation throughput and delay becomes much more important in the case of loaded networks. Increasing the number of RTS sub-channels, improves the saturation throughput (as the collision probability is reduced) but causes more delay to serve the packets (as the RTS duration is multiplied by the number of sub-channels). Moreover, this protocol is very useful for non delay sensitive applications.

IV. CONCLUSION

In this work, we proposed a novel strategy based on CSMA/CA - RTS/CTS which is characterized by shrinking a channel into a plurality of sub-channels of known size. We prove that the proposed technique will be very interesting in WLAN and WSN topologies and especially for dense networks. Dividing the channel into many parts reduces significantly the RTS collision probability which leads to improvement in terms of saturation throughput and statistical delay. For instance, when 100 users are considered with 2 RTS sub-channels, the collision probability is reduced by 87%, the saturation throughput is improved by 30% and the statistical delay by 20.43%.

To conclude, increasing the number of sub-channels, improves the saturation throughput and causes more delay to serve the packets. For delay sensitive application, the number of sub-channels should be at most equal to 3 while in the case of non sensitive delay application, the number of sub-channels may be greater.

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