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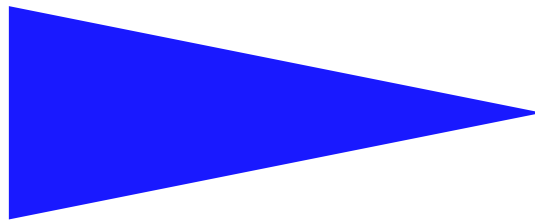
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MODELING AND ANALYSING AN IMPROVED 802.11 MAC  
LAYER UNDER NOISY CHANNEL

ADLEN KSENTINI, MARC IBRAHIM



## Modeling and analysing an improved 802.11 MAC layer under noisy channel

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**Abstract:** The ISM free-licence band is highly used by wireless technologies such IEEE 802.11, Bluetooth as well as additional private wireless schemes. This huge utilization increases dramatically the interferences (high Bit Error Rate) leading to lowering the reliability of such networks. Among these wireless-based technology, IEEE 802.11 suffers particularly from these high interferences since the wireless sender is confused by loss' origins (noise or collision). In fact, the contention resolution mechanism (known as Backoff Exponential Binary) used by 802.11 assumes that each loss in the network is caused only by collision and hence acts to overcome this situation by delaying the retransmission of the packet lost. However, this mechanism is not efficient when the wireless channel is deployed in noisy environments, where collisions are mixed with high BER-caused errors. In this paper, we adapt the RTS/CTS handshake mechanism to the noisy channel through two possible mechanisms. After that, we model the proposed mechanisms by a two-dimension Markov model and validate these models by NS2 -based simulations.

**Key-words:** IEEE 802.11, RTS/CTS, Contention Window, Noisy channel

*(Résumé : tsvp)*

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## Modélisation et analyse d'un nouveau mécanisme MAC 802.11 dans un environnement

**Résumé :** La bande de fréquence Industrial, Scientific and Medical (ISM) utilisée par les réseaux IEEE 802.11 est complètement saturée. En effet, beaucoup d'autres technologies sans fil utilisent cette bande de fréquence, causant ainsi une augmentation des interférences dont la conséquence est l'augmentation du nombre de paquets erronés dans le réseau 802.11. Dans ce contexte, le réseau 802.11 affiche des performances beaucoup plus faibles et donc loignées des performances optimales. L'une des sources de cette dégradation de performance est le comportement de l'algorithme BEB lorsque les collisions sont mixées avec les erreurs du Bit Error Rate (BER). En effet, dans ce cas, l'algorithme BEB considère toutes pertes de paquets comme le résultat de collisions et augmente la fenêtre de contention ou Contention Window (CW) afin d'absorber l'augmentation de la congestion dans le réseau. Ce comportement est inapproprié la situation, tant donné que le paquet a été perdu cause du canal et donc il n'y a pas besoin d'augmenter le CW. Dans cet article, nous proposerons d'adapter l'échange de paquets RTS/CTS en utilisant deux différentes méthodes, et ceci afin d'améliorer les performances du réseau 802.11 dans les environnements bruyants. Par la suite, nous allons modéliser nos deux propositions par le biais d'une chaîne de Markov deux dimensions, et nous validerons ces modèles par des simulations avec NS2.

**Mots clés :** IEEE 802.11, RTS/CTS, Fenêtre de contention, Bruit

## 1 Introduction

Wireless communication is becoming an essential part of modern life, allowing users to maintain network access without being tied to a particular location by a wire. Since bandwidth and throughput of wireless technologies have increased, it has become possible to support true multimedia applications, including, voice, and video traffic. However, the IEEE 802.11 [1] physical modulations operate in the Industrial Scientific and Medical (ISM) frequency band, 2.4 GHz, which involves high interferences with other products using this unlicensed frequency. By interferences we mean that the channel operates with high Bit Error Rate (BER) degrading thus the wireless link reliability by corrupting the transmitted packets. For instance, consider the simulation results obtained in [2], where the authors show such a situation: a Bluetooth (using FHSS) slave operating close to a Wireless LAN Access Point (AP) (using IEEE 802.11, DSSS), causes a very high frame drop rate, up to 46 and high access delays on the WLAN side.

Actually, the IEEE 802.11 MAC layer uses the Carrier Sensing Multiple Access/Collision Avoidance (CSMA/CA) protocol to share the wireless medium among the stations. Before sending a packet, a wireless station first senses the medium for the duration of Distributed Inter-Frame Space (DIFS). If the medium is free for the duration, the wireless station starts sending the packet immediately. Otherwise, if the wireless station detects the medium was busy for the duration, the wireless station backs off for a multiple of time slots (Slot-Time). The multiple is randomly chosen between  $[0, 2^m CW_{min}] (i = 0, 1, 2, \dots, m)$ . Note that,  $CW_{min}$  is called minimum Contention Window (CW) size, and it is set to the same value for all wireless stations. On the other hand, if the wireless station transmitted a packet and received ACK frame correctly, then  $i$  is set to 0. If the wireless station failed to receive ACK frame,  $i$  is incremented by 1. Here,  $i$  can be up to  $m$ , so the maximum CW size is  $2^m CW_{min}$ . In 802.11-based wireless networks, a packet error means transmission failures between a pair of wireless stations due to: (i) collision with other packets; (ii) BER-corrupted packet. When detecting such packet, receiver station must automatically reject this packet. That is, no ACK is transmitted for this packet. Accordingly, the sender station assumes that packet loss is an effect of collision and takes measures to avoid further collision in the network by delays the retransmission of the packet loss (i.e. increase its Contention Window). This is obviously sub-optimally in case of BER-corrupted packets: Contention Window (CW) should not be increased to avoid collisions when loss is due to noise, so it is important for the sender to differentiate between the origins of the lost packet. To tackle this issue we introduced Enhanced RTS/CTS (Request and Clear to Send) mechanism that allows the wireless station means to differentiate between collision and BER-loss through adapting the RTS/CTS handshake mechanism to noisy channel environments. The main idea was to response to a packet loss following an RTS/CTS exchange by invoking the retransmission routine; however instead of increasing the CW, it was useful to maintain the current value.

Our main concern in this paper is to extend the work developed in [3] by modeling the proposed mechanism through a two-dimension Markov model. We go further in the analysis by comparing the performance the Enhanced RTS/CTS after losing a packet rising from

noises, when: (i) the CW value is maintained to the current value; (ii) the CW is initialized to the  $CW_{min}$ .

This paper is organized as follows: section II shows the impact of packet errors on IEEE 802.11 performances. In section III, we give details of our proposition. We present performance evaluation in section IV, and conclude the paper in Section V.

## 2 IEEE 802.11 AND RELATED WORK

The IEEE 802.11 MAC defines two transmission modes for data packets: the Distributed Coordination Function (DCF) and the Point Coordination Function (PCF). The DCF provides contention-based access to the medium. The PCF is a polling scheme, allowing an access point to control all transmissions in order to provide contention-free access. 802.11 defines a repetition interval called a "superframe," which is subdivided into contention-free (PCF) and contention (DCF) periods, as well as a beacon or management frame. Although the PCF was designed to support real time traffic, it has several drawbacks. It requires considerable control overhead, and has difficulty scaling to support large numbers of nodes. Additionally, due to its reliance on a central node for coordination, it does not adapt well to ad hoc configuration scenarios. As a result, the PCF is considered optional, and is rarely implemented in 802.11-based devices. Besides, packets errors usually occur due to non ide-

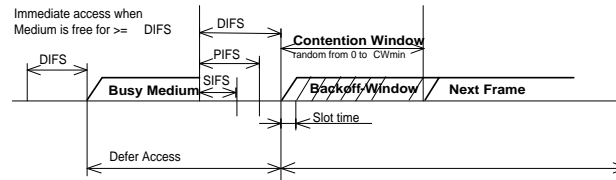


Figure 1: DCF access mechanism

al channel condition. Partition loss in the building and multipath fading combined with ambient noise, decrease SNR (Signal-to-Noise Ratio), and therefore cause packets errors. Co-channel and adjacent channel interferences also cause packet errors. Further, wireless device variability is another source of packet errors. Different devices have different output power, receive sensitivity and firmware, which may incur packet error. The packet errors cause packet retransmissions at the sender station which is not the effect of collision, resulting in highly increased packet delays.

Previous works have improved the well-known Bianchi Markov-based model [?] aiming at analytically analysis the IEEE 802.11's behavior under noisy channel. Among these works, [6] draws the saturation throughput in respect to the Packet Error Rate (PER) values. From the results obtained, the authors show clearly the weakness of DCF and particularly the CSMA/CA confusion when a transmitted packet is lost. For the best of our knowledge

there is no works that tried to enhance the behavior of DCF access under noisy channel. To tackle this issue and improve the CSMA/CA performances under noisy environment, we proposed in [5] to enhance the RTS/CTS mechanism. This mechanism is adapting the RTS/CTS to the noisy channel.

### 3 ENHANCED RTS/CTS MECHANISM

#### 3.1 The proposed scheme

Usually, the RTS/CTS mechanism is used to solve the hidden terminal problem. When this mechanism is applied, the contention winner does not transmit the data immediately, instead, it sends an RTS frame to which the receiver answers with a CTS frame. This guarantees that all terminals in the range of either the sender or the receiver know that a packet will be transmitted. In this case, terminals remain silent during the entire transmission by initiating the NAV variable with the duration of the ongoing transmission, so only the sender is allowed to transmit frames. Consequently it is obvious that the RTS/CTS packets are the only packets that collide in the networks, meanwhile the data packets are apart of collision loss.

$$PER = 1 - (1 - BER)^L \quad (1)$$

where L is the packet length in bits

On the other hand, if we consider Figure 2 that represents the PER of both RTS/CTS and Data packets in respect to equation (2), we notice that the probability that either RTS or CTS packets are erroneous is very negligible by report to Data packets, whatever the BER value. This in fact, means that Data packets are highly affected by network error in contrast of RTS/CTS packets. Therefore, we assume that in case of noisy channel, the RTS/CTS packets are lost due to collision with others RTS/CTS packets while DATA packets are dropped due to errors introduced by the channel.

Based on these two important observations we can improve the RTS/CTS mechanism by differentiating between BER-corrupted packet and collision. After RTS/CTS exchange, if no ACK is received for a data packet (which indicate that packet loss is raised from a network noise), we propose as response that the sender station reacts by invoking the retransmission routine. However, instead of increasing the current CW value, the sender station can uses the same CW's value [3] or reset the CW to the initial value. Later in this paper we will show through the analytical model the best option between resetting or maintaining the CW value.

However in case where no CTS packet is received after sending RTS packet (loss due to collision, second observation), the sender calls the RTS retransmission routine as described in the 802.11 standard, i.e increase the CW and retransmit the lost packet.

By avoiding the confusion between network-increased load (collision) and bad wireless channel (high BER), the adaptation of RTS/CTS mechanism is an interesting alternative that permits to increase the CW only for the relevant reason.



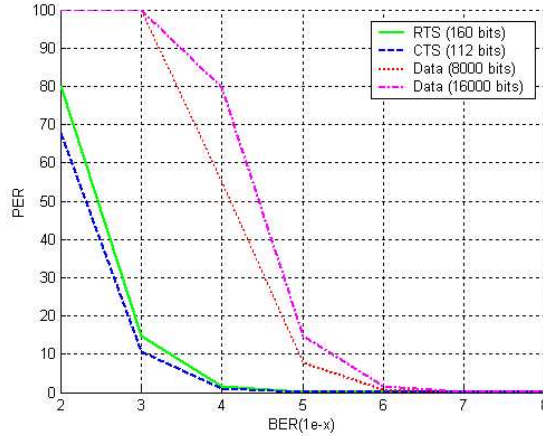


Figure 2: PER versus BER and Packet length

In the following, we draw an analytical model of the Enhanced RTS/CTS mechanism by developing a Markov-based chain model. We describe the model and then derive an analytical solution of the saturation throughput in the following section.

### 3.2 The analytical model

Since the Enhanced RTS/CTS is used with two solutions, either initiating or maintaining the CW when losing a packet due BER, we derive three analytical models: *(i)* The classical RTS/CTSv1 mechanism (model1); *(ii)* The enhanced RTS/CTSv2 when keeping the same backoff stage when a data packet is lost (model2); *(iii)* The enhanced RTS/CTS when initiating the backoff stage after a data packet lost (model 3).

At this point, we use the term model *i* to indicate either the model itself or the correspondent scenario *i*. These models utilize the discrete bi-dimensional Markov chain introduced by [5] and suitably modified to take into account the channel errors as well as the proposed solutions. Original model is the reference model representing the normal DCF. Since some modifications, it follows the model investigated in [5].

#### 3.2.1 General context

The network consists of  $N$  contending wireless terminals using the RTS/CTS mechanism. The saturation conditions are assumed if the transmission queues of all stations (STAs) are always non-empty. The STAs are divided into  $C$  logical clusters, where each cluster  $n$

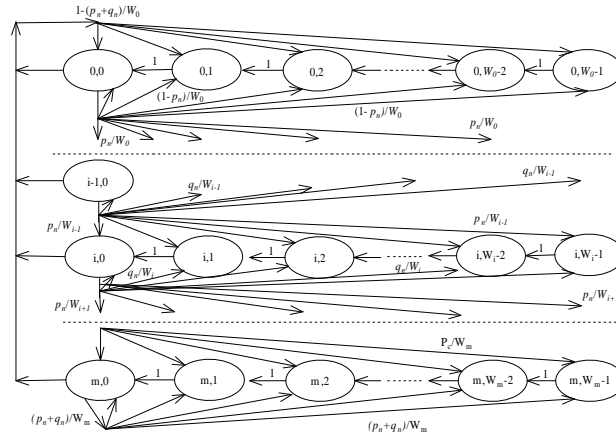


Figure 3: Markov chain

contains  $N_n$  STAs suffering from the same Bit Error Rate (BER $_n$ ). The contention window CW has a minimal value of  $W = W_0 = CW_{min}$ . We make two key approximations in the model: firstly, the loss of data packets is exclusively caused by channel errors, which is justified by the use of RTS/CTS that limits the collision possibility to the RTS/CTS exchange. Secondly, the probability that an RTS/CTS handshake fails when the station transmits is constant and independent of any event in the past.

### 3.2.2 Generic model

Based on the same symbols and notations used in [4], we derive a discrete bi-dimensional process  $s_n(t), b_n(t)$  for each cluster  $n$ . Here,  $s_n(t)$  and  $b_n(t)$  represent respectively the backoff stage and the value of the backoff time counter at time  $t$  for a random STA in the cluster  $n$ . The difference between the three models will be in how the STA behaves after a transmission failure. Therefore, a generic model with general parameters can be drawn, as it is shown in figure 3.

$$\left\{ \begin{array}{ll} P\{i, k|k+1\} = 1 & k \in (0, W_i - 2) \quad i \in (0, m) \\ P\{0, k|i, 0\} = \frac{1-p_n-q_n}{W_0} & k \in (0, W_0 - 1) \quad i \in (1, m) \\ P\{0, k|0, 0\} = \frac{1-p_n}{W_0} & k \in (0, W_0 - 1) \\ P\{i, k|i-1, 0\} = \frac{p_n}{W_i} & k \in (0, W_i - 1) \quad i \in (1, m) \\ P\{i, k|i, 0\} = \frac{q_n}{W_i} & k \in (0, W_i - 1) \quad i \in (1, m) \\ P\{0, k|i, 0\} = \frac{p_n+q_n}{W_m} & k \in (0, W_i - 1) \\ 0 & otherwise \end{array} \right. \quad (2)$$

Where  $P\{i, j|k, l\} = P\{s_n(t+1) = i, b_n(t+1) = j|s_n(t) = k, b_n(t) = l\}$

Note that the discrete time step, which is equal to 1, is the time separating two consecutive backoff time counter decrements. This is a variable quantity that depends on the state of the medium. Hence, if the channel is idle, the timer decrements each physical time slot, otherwise, the STA must wait until the medium is sensed idle for DIFS to resume its countdown. Finally, the generic model does not take into account the retransmission limits.

### 3.2.3 Stationary distribution of the chain-transmission probability

Denote by  $b_{n,i,k} = \lim_{t \rightarrow \infty} P\{s_n(t) = i, b_n(t) = k\}$ ,  $0 \leq i \leq m$ ,  $0 \leq k \leq W_i - 1$  the stationary distribution of the generic chain for cluster  $n$ , ( $0 \leq n \leq C$ ). By setting  $p_n^* = \frac{p_n}{1-q_n}$ , common calculations yield the following equalities :

$$\begin{cases} b_{n,i,0} = (p_n^*)^i b_{n,0,0} & 0 \leq i \leq m-1 \\ b_{n,i,0} = \frac{(p_n^*)^m}{1-p_n^*} b_{n,0,0} \\ b_{n,i,0} = \frac{W_i - k}{W_i} b_{n,i,0} & 0 \leq i \leq m-1, 0 \leq k \leq W_i - 1 \end{cases} \quad (3)$$

The equations in (3) are formally similar to the ones in [4]. Hence we obtain

$$b_{n,0,0} = \frac{2(1-p_n^*)(1-2p_n^*)}{(1-2p_n^*)(W+1) + p_n^*W(1-(p_n^*)^m)} \quad (4)$$

Let  $\tau_n$  be the probability that a STA of the cluster  $n$  transmits at a random slot time in the steady state. Then, for ( $0 \leq n \leq C$ )  $\tau_n$  must be determined in order to proceed with the throughput calculation. Equation (5) represents a set of  $C$  equations with  $2C$  unknown variables ( $\tau_n$ ) ( $0 \leq n \leq C$ ) and ( $p_n^*$ ) ( $0 \leq n \leq C$ ). In order to compute ( $\tau_n$ ) ( $0 \leq n \leq C$ ) we derive for each model another set of  $C$  equations.

$$\tau_n = \sum_{i=0}^m b_{n,i,0} = \frac{2(1-p_n^*)(1-2p_n^*)}{(1-2p_n^*)(W+1) + p_n^*W(1-(p_n^*)^m)} \quad (5)$$

Consider now the three events that may occur when a packet is being transmitted by a STA of the cluster  $n$ .

$$\begin{cases} E1_n & \text{Collision} \\ E2_n & \text{RTS/CTS fails due either to a collision or to channel errors} \\ E3_n & \text{Data packets are lost to channel errors} \end{cases} \quad (6)$$

Knowing the independence between the transmission errors and collisions, it is then easy to verify that

$$\begin{cases} P(E1_n) = 1 - \frac{\prod_{i=1}^C (1-\tau_i)^N}{(1-\tau_n)} \\ P(E2_n) = P(E1_n) + (1 - P(E1_n))RER_n \\ P(E3_n) = (1 - P(E2_n))PER_n \end{cases} \quad (7)$$

Where  $RER_n$  and  $PER_n$  are respectively the RTS/CTS packet error rate and the data packet error rate in the cluster  $n$ .

It is useful to recall that  $RER_n = 1 - (1 - BER_n)^{RTS-size+CTS-size}$  and  $PER_n = 1 - (1 - BER_n)^{data-size}$ . Note that, the events  $E2_n, E3_n$  are disjoint.

For each of the three models,  $p_n$  and  $q_n$  can be directly written as functions of the three events  $E1_n, E2_n$  and  $E3_n$ . In fact, in model 1 ( $q_n = 0, p_n = P(E2_n) + P(E3_n)$ ), in model 2 ( $q_n = P(E3_n), p_n = P(E2_n)$ ), and in model 3 ( $q_n = 0, p_n = P(E2_n)$ ). Using (7), we obtain Model 1:

$$\begin{cases} q_n = 0 \\ p_n = 1 - \left( \frac{\prod_{i=1}^{\delta} (1-\tau_i)^N}{(1-\tau_n)} \right) (1 - RER_n) (1 - PER_n) \end{cases} \quad (8)$$

Model 2:

$$\begin{cases} q_n = \left( \frac{\prod_{i=1}^{\delta} (1-\tau_i)^N}{(1-\tau_n)} \right) (1 - RER_n) PER_n \\ p_n = 1 - \left( \frac{\prod_{i=1}^{\delta} (1-\tau_i)^N}{(1-\tau_n)} \right) (1 - RER_n) \end{cases} \quad (9)$$

Model3:

$$\begin{cases} q_n = 0 \\ p_n = 1 - \left( \frac{\prod_{i=1}^{\delta} (1-\tau_i)^N}{(1-\tau_n)} \right) (1 - RER_n) \end{cases} \quad (10)$$

Combining (5) with (8), (9), or (10) yields a non-linear system in  $(\tau_n)(0 \leq n \leq C)$  and  $(p_n^*)(0 \leq n \leq C)$ . This system has a unique solution  $(\tau_n)(0 \leq n \leq C) \in [0, 1]^{\overline{C}}$ .

### 3.2.4 Global and individual Saturation Throughput

The global saturation throughput is the maximum data rate being conveyed by the network. The individual saturation throughput is the maximum data rate that a STA can transmit. It is obvious that the global throughput is the sum of all individual throughput in the network. We use the throughput formula as defined in [1]:

$$S = \frac{E[\text{Payload} - \text{transmitted} - \text{in} - \text{time} - \text{slot}]}{E[\text{length} - \text{of} - \text{a} - \text{slot} - \text{time}]} \quad (11)$$

We define the following probabilities that describe events in a randomly chosen time slot:  $P_{tr}$  is the probability that at least one transmission occurs;  $P_s$  is the probability that a

transmission occurring in the time slot is successful;  $P_c$  is the RTS/CTS failure probability of a transmission taking place, and  $P_{err}$  the data loss probability of the transmission. The global throughput is then expressed as

$$S = \frac{P_{tr}P_sE[p]}{(1 - Ptr)\delta + P_{tr}P_sT_s + P_{tr}P_cT_c + P_{tr}P_{err}T_{err}} \quad (12)$$

$\delta$  is the length of an empty time slot,  $T_s$  is the duration of a successful transmission,  $T_c$  and  $T_{err}$  denote the average time the channel is sensed busy due to respectively a RTS/CTS failure and a data packet loss.  $E[P]$  is the average data packet size.

In our case, the different probabilities can be easily derived from their definitions:

$$\begin{cases} P_{tr} = 1 - P_{idle}, P_{idle} = \prod_{i=1}^C (1 - \tau_n)_i^N \\ p_s = \sum_{n=1}^C \frac{P_{idle}N_n\tau_n(1-PEER_n)(1-REER_n)}{P_{tr}(1-\tau_n)} \\ P_c = 1 - \sum_{n=1}^C \frac{P_{idle}N_n\tau_n(1-REER_n)}{P_{tr}(1-\tau_n)} \\ P_{err} = \sum_{n=1}^C \frac{P_{idle}N_n\tau_n(1-REER_n)PEER_n}{P_{tr}(1-\tau_n)} \end{cases} \quad (13)$$

Note that  $P_s = 1 - P_c - P_{err}$ . The individual throughput of a STA in cluster  $n$  is

$$S_n = \frac{\tau_n \frac{P_{idle}}{(1-\tau_n)} (1 - REER_n)(1 - PEER_n)E[P]}{(1 - Ptr)\delta + P_{tr}P_sT_s + P_{tr}P_cT_c + P_{tr}P_{err}T_{err}} \quad (14)$$

## 4 PERFORMANCE EVALUATION

In order to validate and study the performances of the proposed models, we constructed simulations with ns2 [7]. We follow the 802.11b specifications concerning the MAC and the Physical parameters. We review these parameter in Table1. At first we compare the results obtained by simulation with those obtained through analysis. After that we compare the original RTS/CTS with our solutions noted: (i) Enhanced RTS/CTSv1, when the CW is maintained with same value; (ii) Enhanced RTS/CTSv2, when the CW is reinitialized with  $CW_{min}$ .

Parameter	$CW_{min}$	$CW_{max}$	DIFS	SIFS	SlotTime	Phy data rate	Phy basic rate
Value	31	1023	50 $\mu$ s	10 $\mu$ s	20 $\mu$ s	11Mbps	1 Mbps

Table 1: 802.11b physical and MAC parameters

### 4.1 Model Validation

Figure 4 and Figure 5 draw the overall throughput obtained by both simulations and analysis of the two versions of Enhanced RTS/CTS. Here, the BER is set to  $10^{-5}$  and  $10^{-8}$ .

We can note clearly that results obtained by simulations match perfectly those obtained by

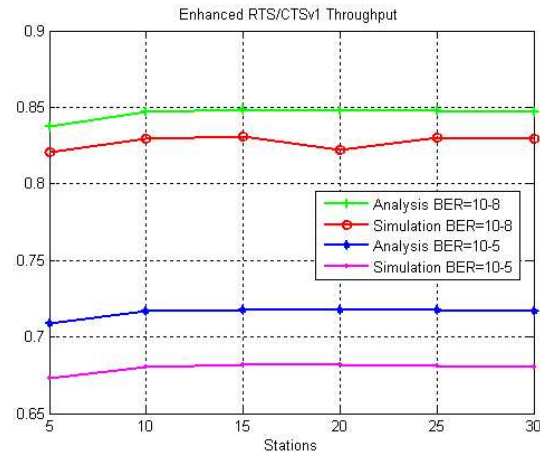


Figure 4: Enhanced RTS/CTSv1 Overall throughput: Simulation versus Analysis

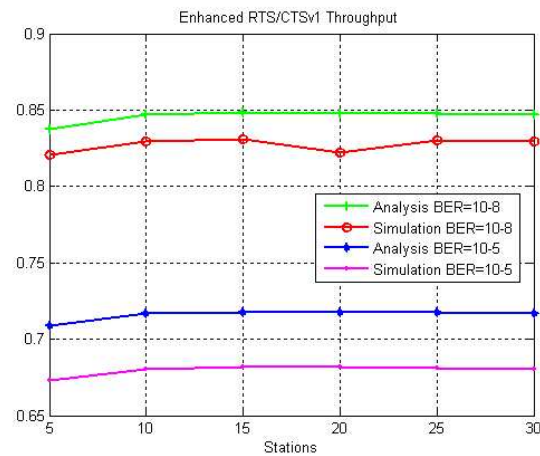


Figure 5: Enhanced RTS/CTSv2 Overall throughput: Simulation versus Analysis

analysis. The difference between them is around 5% when the ( $BER = 10^{-8}$ ) and 9% when the ( $BER = 10^{-5}$ ). We explain this difference by the fact that our models do not consider the backoff freezing procedure when another station began to transmit, which constitute an

important disparity comparing to the simulating tool.

## 4.2 Results

Now we turn our attention to the performances of the two proposed schemes compared to the original RTS/CTS, aiming at better understanding which behaviour is more appropriate to the situation when losing packets, i.e increase or maintain the CW's value. For this aim we draw Figure 6 and Figure 7 that represent the average throughput when the BER is set at ( $BER = 10^{-3}$ ) and ( $BER = 10^{-5}$ ), respectively. We depict two important information; on one hand, in case of high BER value (noisy channel), the best performances are given by the Enhanced RTS/CTSv2. We expected this result as decreasing the CW after losing a packet due to bad channel condition leads to fairly decrease the empty slot time and hence increase the channel utilization. On the other hand, when the BER is moderate (but not negligible), we distinguish two behaviours (when station's numbers is less than 20 and greater than 20). In the first case, we see that the best results are ensured by the Enhanced RTS/CTSv2, since the packets are lost principally due to bad channel conditions. However, in case of high network load meaning that high collisions are mixed with high BER-loss, the Enhanced RTS/CTSv1 takes over and gives the best results. We argue this by the fact that decreasing the CW value when losing a packet due to BER increases the probability of collision in the networks, since there are many stations contending for the channel. Globally, the two

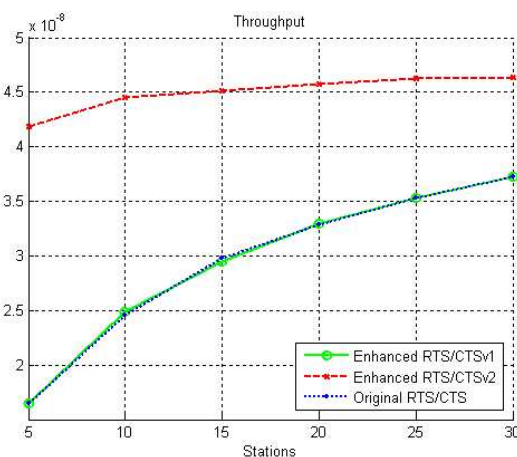


Figure 6: Overall Throughput  $BER = 10^{-3}$

enhanced RTS/CTS versions achieve better results than the original one, since these two schemes have the aptitude to differentiate between BER-loss and collision. Here, the gain

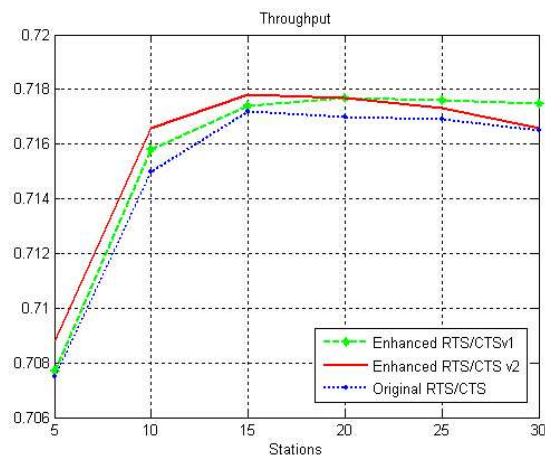


Figure 7: Overall Throughput  $BER = 10^{-5}$

is particularly important when the channel is very noisy. We observe a huge 100% of gain (Enhanced RTS/CTSv1) when the BER is set to ( $BER = 10^{-3}$ ).

Now we investigate the fairness of the proposed scheme by showing the impact of these mechanisms over: (i) a Wireless Station (WS1) suffering from bad channel conditions ( $BER = 10^{-5}$ ); (ii) a WS operating in perfect channel ( $BER = 0$ ). In fact our aim is to demonstrate that although WS1 increases its data rate, our proposed schemes can maintain good performances for the others stations, which operate in perfect channel condition.

Figure 8 illustrates the mean data rate achieved by WS1's, when using both versions of Enhanced RTS/CTS as well as the original one. We recall here that WS1 operates in bad channel conditions ( $BER = 10^{-5}$ ). As for the overall throughput we note that the best performances are achieved by Enhanced RTS/CTSv2, which maintains a consistent delivery bit rate throughout the simulation time, despite the high BER perceived by WS1. The gain obtained is roughly 100 kbps and 50 kbps by report to the original RTS/CTS and Enhanced RTS/CTSv1, respectively.

Again, the gain achieved by Enhanced RTS/CTSv2 is mainly due to the differentiation done between BER-loss and collision as well as decreasing the CW in case of BER-corrupted packet.

Through Figure 9, we plot the data rate obtained by WS2 (operate with good channel condition). WS2's data rate is approximately the same in both Enhanced RTS/CTS versions as well as the original RTS/CTS. Although both Enhanced RTS/CTS improves the performance of stations with poor channel conditions, they also maintains fair performances for the others stations that operate with good channel conditions. Clearly, both Enhanced RTS/CTS can ensure high fairness as all stations can benefit from high performance wher-



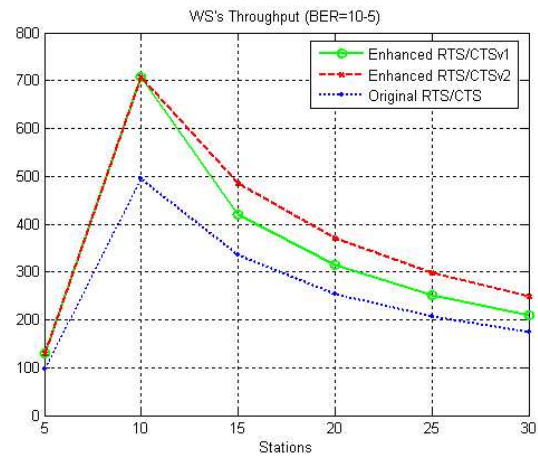


Figure 8: WS'1 throughput

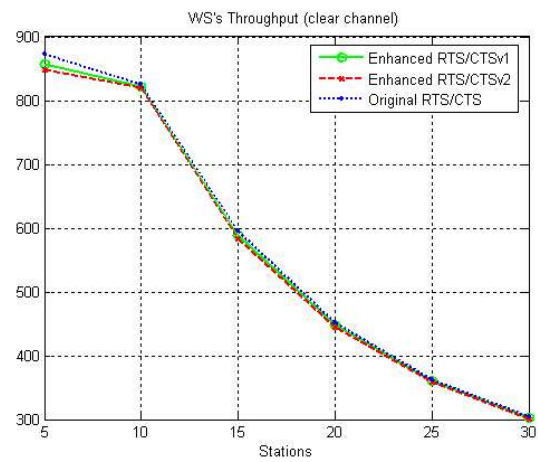


Figure 9: WS'2 throughput

ever they operate in good or bad channel conditions.

### 4.3 Discussion

From these results we can assume clearly that both versions of Enhanced RTS/CTS have achieved the original aim. That is, differentiating between BER-loss and collision. Now we have to decide which version is the best?. This question has its answer in Figure 6 and Figure 7. In fact we notice that in case of very bad channel conditions, one can consider obviously that Enhanced RTS/CTSv2 is the best choice. However, when the BER is moderate, the Enhanced RTS/CTSv1 achieves the best results. So the best compromise is to adapt the Enhanced RTS/CTS to the channel conditions. That is, when the channel operates with high BER value, the response to a BER-based loss is to reset the CW to the minimum value; and when the channel operates with either a low or a moderate BER value, the CW is maintained at the same value after a BER-based loss.

## 5 CONCLUSION

In this paper, we presented two models aiming at enhancing the DCF mechanism in noisy channel. These mechanisms noted Enhanced RTS/CTSv1 and v2 provide the sender stations the ability to differentiate between collisions and BER-loss. Thus, the enhanced RTS/CTS reduces the number of events triggering the CW increase, which therefore leads to better performances without increasing the collision rate. Our future work is to adapt the Enhanced RTS/CTS mechanism to the channel condition, in order to fully benefit from the improvement obtained through the two versions.

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