Throughput Analysis and Improvement of the IEEE 802.11 Network in Non-Ideal Channel Conditions

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ABSTRACT: *The electromagnetic noise in large cities is inevitable, it causes high delays and worsens the throughput due to data distortion. To reduce the impact of noise on the performances of IEEE 802.11 networks, we propose an enhancement of the IEEE 802.11 RTS/CTS scheme to recognize the reason of a transmission failure (collision or noise errors), thus the data packet is immediately retransmitted with zero-waiting backoff time if a failure happens due to distortion by noise. This retransmission continues until the data packet is successfully transmitted or dropped when the number of packet transmission attempts reaches its limit. The proposed performance evaluation and comparison have been done under our own network simulator tool. So, we have analyzed the overall throughput of the IEEE 802.11 network.*

Keywords: IEEE 802.11 Networks, RTS/CTS Scheme, Noisy Channel, Enhancement and Simulation

Received: 8 March 2013, Revised 3 April 2013, Accepted 9 April 2013

1. Introduction

In recent years, wireless data communication networks have become one of the major trends of the network industry developments. Wireless LANs can be considered as an extension of the wired networks with wireless link for connecting a large number of mobile terminals. The obvious merit of wireless LANs is the simplicity of implementation, LAN topology can be dynamically changed with connection, movement, and disconnection of mobile users without much loss of time [9]. The IEEE 802.11 is an international standard (ISO/IEC 8802-11) for Wireless Local Area Networks (WLANs). It was first released in 1999 [1] and reissued later in 2007 [2] grouping some of the subsequent amendments. The IEEE 802.11 standard includes detailed specifications for both the Medium Access Control (MAC) and the Physical Layer (PHY). In the MAC layer, the standard includes the Distributed Coordination Function (DCF) and the optional Point Coordination Function (PCF). DCF is an asynchronous data transmission function. It is available in ad hoc or infrastructure network configurations. PCF is used for real time services and it is only available in infrastructure environments.

The fact that the DCF function of the IEEE 802.11 MAC protocol is based on CSMA/CA and BEB as the contention resolution algorithm leads to some under-performance that has been deeply analyzed and improved in the literature over the past years

[3-6]. Cali et al. [7] proposed to improve both fairness and throughput by tuning the backoff algorithm at run-time and adjusting it to the load conditions of the network. Other ideas based on adding a power control mechanism to improve the performance of the 802.11 system, as [11] where, Agarwal et al. proposed to transmit the RTS/CTS handshake at maximum power while data and ACKnowledgment (ACK) are transmitted at the minimum required power, or [8] where, Jung et al. proposed that data senders transmit power spikes during data transmission in order to reduce the probability of having any potential interfering station. Some recent papers address the performance of DCF under error-prone channel, where unsuccessful transmission can be caused either by collision or noise errors. Lyakhov and Vishnevsky [9] studied packet fragmentation that allows reducing significatively the influence of noise, and proposed a backoff rule modification. Li et al. [10] developed a novel scheme called aggregation with fragment retransmission (AFR) in which multiple packets are aggregated into and transmitted as a single large frame. In this paper, we propose and study a modification of the IEEE 802.11 RTS/CTS scheme to provide the wireless station means to differentiate between collision and noise loss, and retransmit immediately with zero-waiting backoff time the data packets lost due to noise errors.

The remainder of this paper is organized as follows: an overview of the IEEE 802.11 DCF function is presented in section II. We propose an enhancement of the IEEE 802.11 RTS/CTS scheme in section III. Then, we present the performance evaluation and comparison in section IV. Section V concludes the paper.

2. IEEE 802.11 DCF Function Overview

The DCF is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). Retransmission of collided packets, is managed according to Binary Exponential Backoff (BEB) rules. DCF describes two methods for packet transmission. The essential method used in DCF is called Basic Access Method, and the optional method is called Request to Send/Clear to Send (RTS/CTS) method. A comprehensive description of DCF can be found in [2].

2.1 Basic Access Method

Access to the wireless medium is controlled by the use of the InterFrame Space (IFS) time period between the transmissions of frames. A small IFS gives a higher priority for access to the medium of a mobile station. The two major IFSs used in DCF scheme are Short IFS (SIFS) and Distributed IFS (DIFS). SIFS is the shortest IFS. After a SIFS, only acknowledgement (ACK), CTS or fragment may be sent. DIFS is used before any packet transmission. Under the basic access mechanism, any station ready to transmit a new data packet senses the channel status before transmission.

If the channel is idle for a period of time equal to a DIFS, the station transmits. Otherwise, the station differs its transmission (deferring period) and continues to sense the channel until it is idle for a DIFS. At this point, the station chooses a random number as backoff time (see Figure 1). This time is immediately decreased after the DIFS period while the channel is sensed idle, stopped if the channel is sensed busy and reactivated if the channel is idle again, for a DIFS time duration. When the backoff timer reaches zero, the data packet is transmitted.

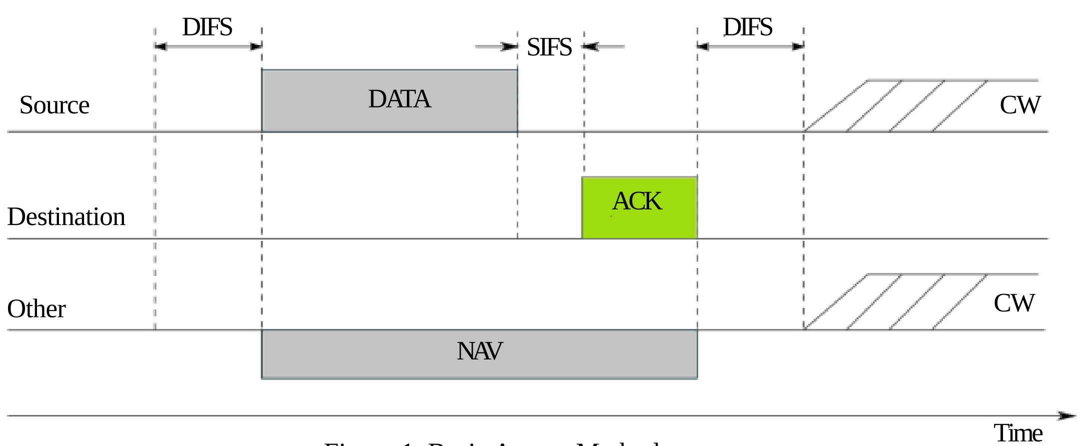

Figure 1. Basic Access Method

2.2 Binary Exponential Backoff

The choice of the backoff time value is based on the BEB algorithm, where a station chooses any of numbers randomly in an interval of time, called Contention Window (CW), between 0 and CW-1. CW is set to be CWmin for every new data packet transmission. CW is doubled each time when the transmission is unsuccessful, until it reaches CWmax, and then it remains at CWmin (see Figure 2). If the data packet transmission is successful, a positive acknowledgement (ACK) is transmitted by the destination station to the source after a SIFS period. If the source station does not receive an ACK, the data packet is assumed to have been lost, and a retransmission is required. If the number of retransmission attempts exceeds its maximum, the data packet is dropped and CW is set to CWmin.

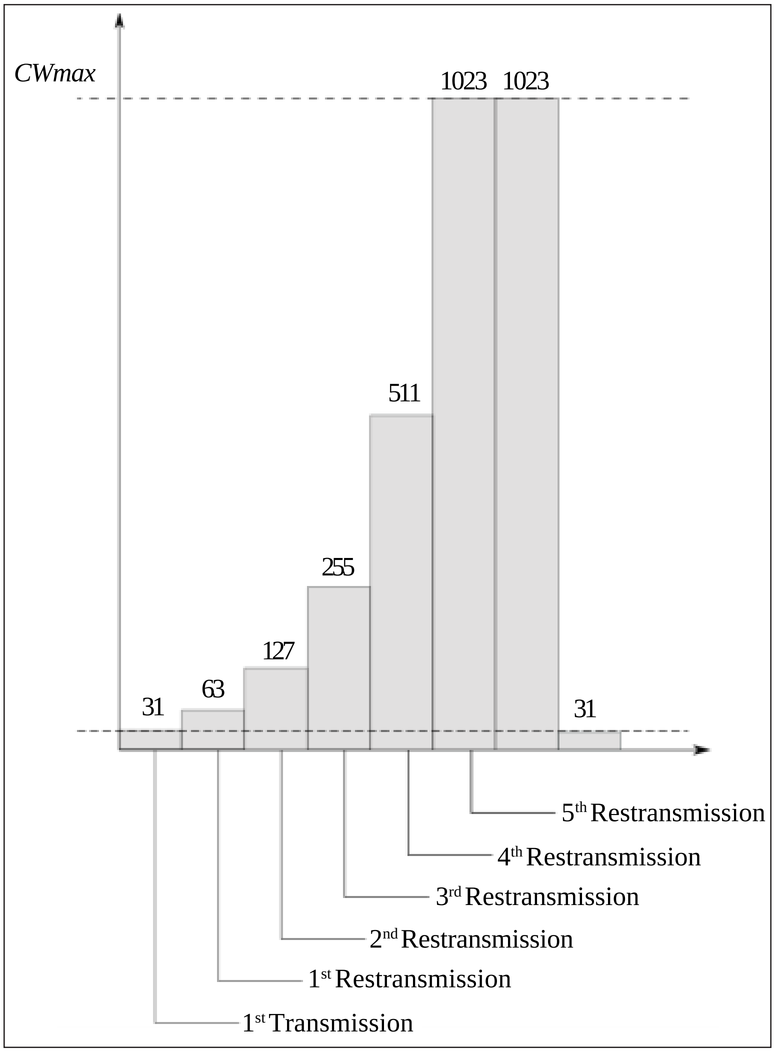

Figure 2. Binary Exponential Backoff

2.3 RTS/CTS Access Method

RTS/CTS is an optional access method initially conceived to resolve the hidden nodes problem, and to protect data packets against collisions. It introduces an additional operation on the top of the basic access mechanism, before a data packet transmission is taken place (see Figure 3). When the backoff timer reaches zero, instead of transmitting a data packet, the source station transmits an RTS frame to request for a transmission right, and the destination station replies with a CTS frame after a SIFS period. Once the RTS/CTS is exchanged successfully, the source station then, transmits its data packet after a SIFS period. If the RTS/CTS transmission is unsuccessful or the ACK is absent, the RTS/CTS operation must be resumed. To enhance the RTS/CTS access method, an additional mechanism Network Allocation Vector (NAV), is introduced. RTS and CTS frames include time fields, indicating to other stations the duration of the current transmission. All neighbor stations that receive the RTS or CTS frames update their NAV field to the value of the duration field in these frames and they don’t access to the medium until the NAV reaches 0.

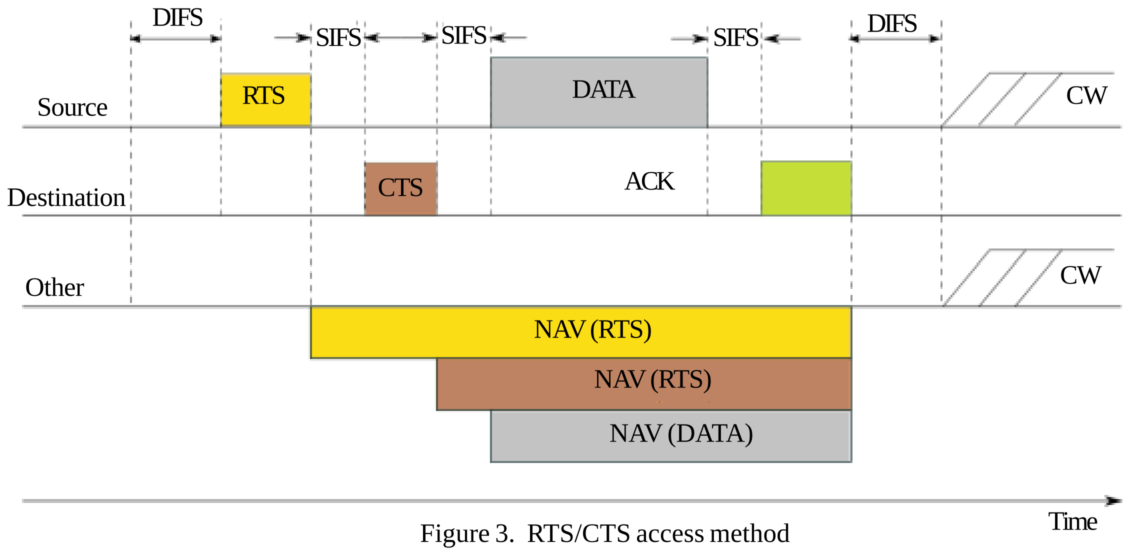

Figure 3. RTS/CTS access method

3. Enhancement of the IEEE 802.11 RTS/CTS Scheme

The enhanced IEEE 802.11 RTS/CTS scheme is presented in this section as an adaptation and extension of the standard IEEE 802.11 RTS/CTS scheme. All the parameters used in his section are mentioned in Table 1.

Parameter	***Description***
m	Maximum number of packet transmission retries.
m'	Minimum number of packet transmission retries.
i	i^{th} transmission retry.
CW	Contention window.
CW_0	Minimum contention window.
CW_i	Contention window at the at the i^{th} transmission retry.
P	Data packet payload length.
DIFS	Time interval of DIFS (Distributed InterFrame Space).
SIFS	Time interval of SIFS (Shortest InterFrame Space).
BOF	Number of backoff time slots chosen randomly in the CW.

Table 1. Parameters

To improve the performance of the IEEE 802.11 MAC protocol in an error-prone channel, we propose to enhance the RTS/CTS mechanism. RTS/CTS is a collision avoidance (CA) mechanism, it can be established between source and destination before the actual transmission of data. This CA mechanism guarantees that all stations in the range of either the sender and the receiver know that a data packet will be transmitted. So, stations initiate their NAV variables to the duration of the ongoing transmission, and remain silent during the entire transmission. Consequently, it is evident that the RTS/CTS control packets are the only packets which collide and the data packets are spared of collision related losses.

Otherwise, in the Figure 4, where we study the PER (Packet Error Rate) of both RTS/CTS control packets and data packets according to the BER values by using the equation (1), we note that the error probability of RTS or CTS control packet is very negligible compared to the error probability of data packets, whatever the BER value. Therefore, we can affirm that when the channel disturbed, the RTS/CTS control packets can be lost due to collision with others RTS/CTS control packets while the data packets can be lost due to noise errors introduced by the channel.

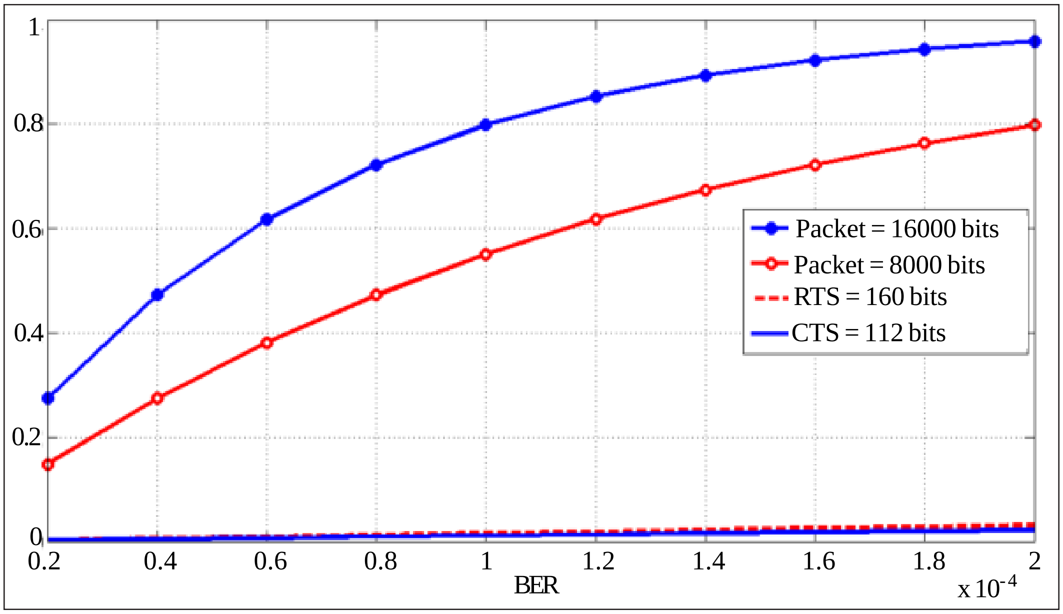

Figure 4. PER versus BER and Packet length

$$PER = 1 - (1 - BER)^{P} \qquad (1)$$

Based on these two observations, we can propose an enhancement of the IEEE 802.11 RTS/CTS scheme to recognize a reason of a transmission failure (collision or noise errors). So, if no CTS control packet is received after sending RTS control packet, the RTS loss is due to collision. In this situation, the sender calls the RTS retransmission routine and increases the CW value (the CW value is increased only when collision occurs). However, after RTS/CTS exchange sequence, if no ACK is received for a data packet (which indicates that a data packet is lost due to noise errors), instead of increasing the current CW value (see Figure 5), we propose that the sender retransmit its data packet immediately with zero-waiting backoff time (see Figure 6), and this retransmission shall continue until the data packet is successfully transmitted or is dropped when the number of packet transmission retries i attains its limit m.

To guarantee that all stations in the range of receiver remain silent during the next retransmission of data packet, the receiver must send a particular acknowledgment that we call Negative-ACKnowledgment (N-ACK). This N-ACK contains the time duration of the next entire retransmission of data packet, and it is sent by the receiver only if the data packet is distorted by noise errors and it is always possible that it will be retransmitted ($i < m$). A detailed example of the enhanced RTS/CTS between two senders is given Figures 7 and 8.

4. Results and Comparison

The parameters used to obtain simulation results are summarized in Table 2.

We have implemented the standard version and the enhanced version of the IEEE 802.11 RTS/CTS rules in a custom-made simulator. Our simulator is an event-driven simulation program, written in C++ programming language under Linux operating system, that closely follows all the IEEE 802.11 MAC protocol details for each independently transmitting station. The simulator works in procedural-oriented basis and the source code of each station runs in parallel using multi-threads programming. Each station in the network constitutes different threads that execute the code that would be implemented in a real platform. The main motivations for implementing the standard version and the enhanced version of the IEEE 802.11 Fragmentation mechanism in a custom-made C++ simulator rather than in any other well-known simulators (such as ns-2, for example) are the possibility of isolating the IEEE 802.11 MAC protocol performance from the rest of the network and the faster execution of the simulations.

Figure 9 represents the overall throughput variation according to BER values in cases of the standard and Enhanced version of the IEEE 802.11 RTS/CTS scheme. In this figure, we note that, the overall throughput of the IEEE 802.11 network is highly

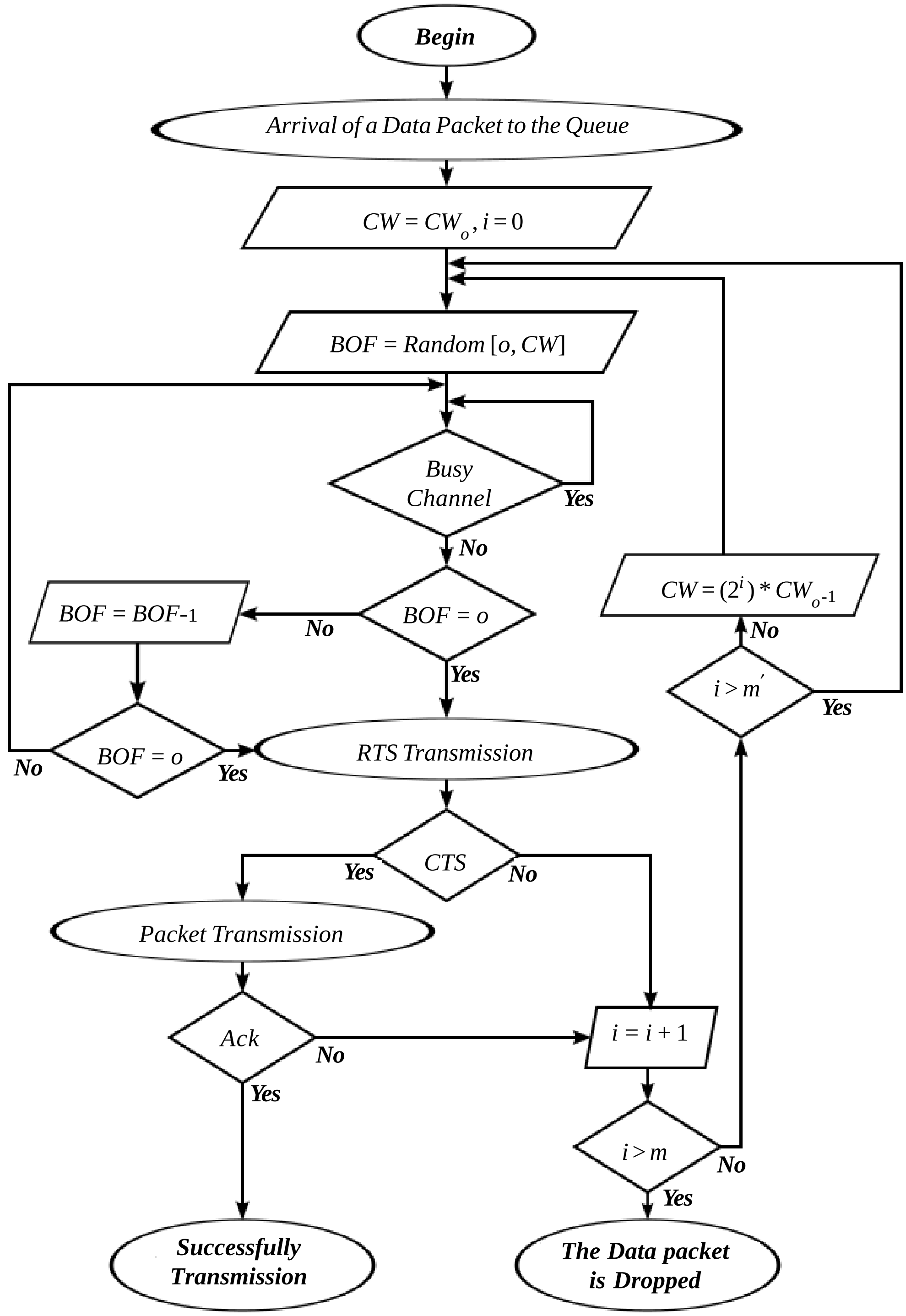

Figure 5. Flowchart of the standard IEEE 802.11 RTS/CTS scheme

affected by the Bit Error Rate, the more the BER value increases the more the overall throughput decreases, because the Packet Error Rate is in linear relationship with the BER, so it increases with the increase of the BER. We note on this figure that, the enhanced version of the IEEE 802.11 RTS/CTS scheme improves the overall throughput of the IEEE 802.11 network, because in our proposal when a data packet is lost due to noise, it is immediately retransmitted with zero-waiting backoff time.

Figure 10 represents the overall throughput variation according to data packet length in cases of the standard and enhanced

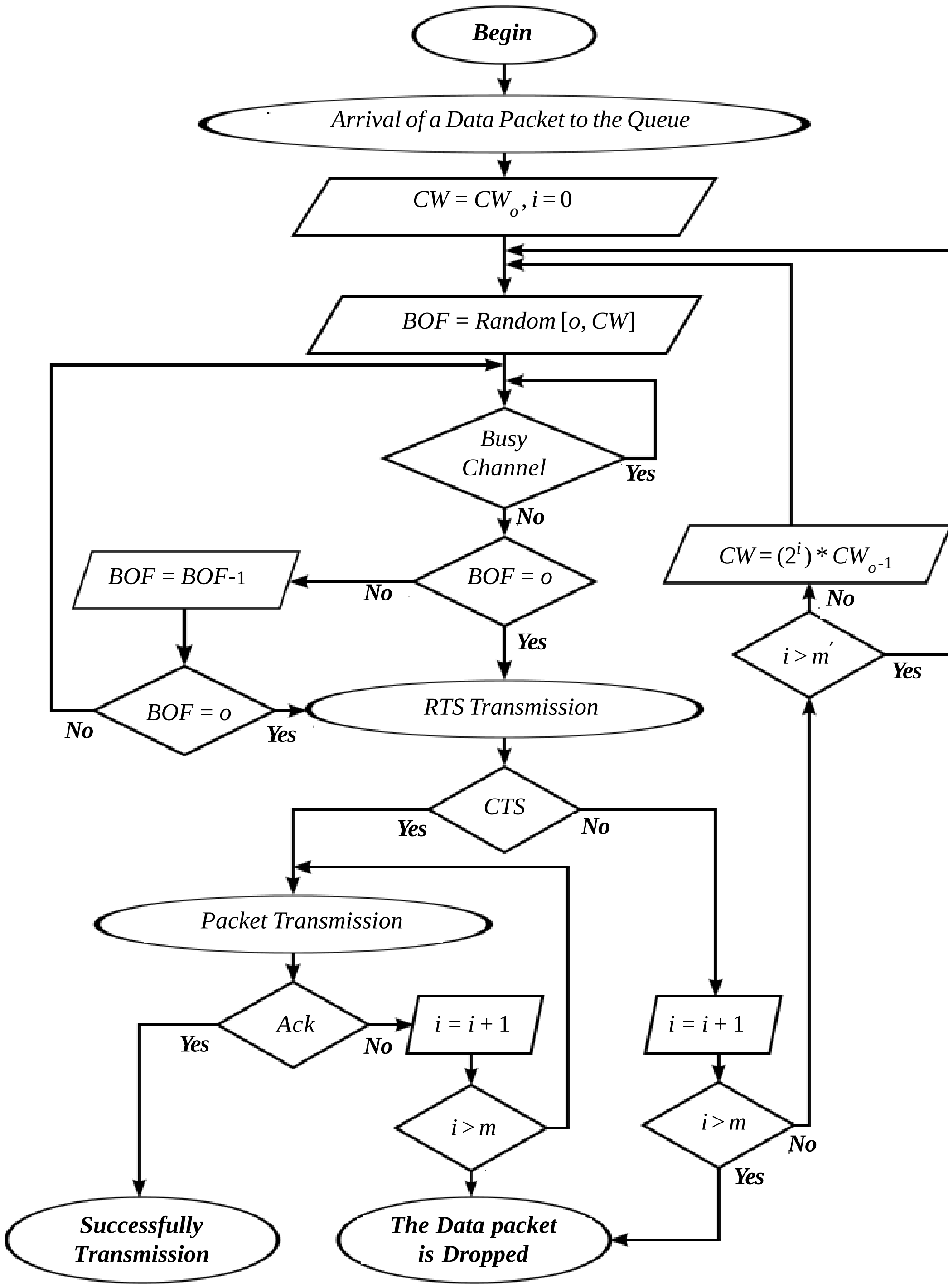

Figure 6. Flowchart of the enhanced IEEE 802.11 RTS/CTS scheme

version of the IEEE 802.11 RTS/CTS scheme. We note on the this figure that, the overall throughput is also highly affected with the increase of the data packet length, because the PER is in exponential relationship with the data packet length. We also note on this figure that, the proposed version of the IEEE 802.11 RTS/CTS scheme allows to improve the performance of the IEEE 802.11 network, especially when the length of data packet becomes great, because the PER increases quickly. So, with our version of the IEEE 802.11 RTS/CTS scheme, the data packets lost due to noise errors are retransmitted with zero-waiting backoff time.

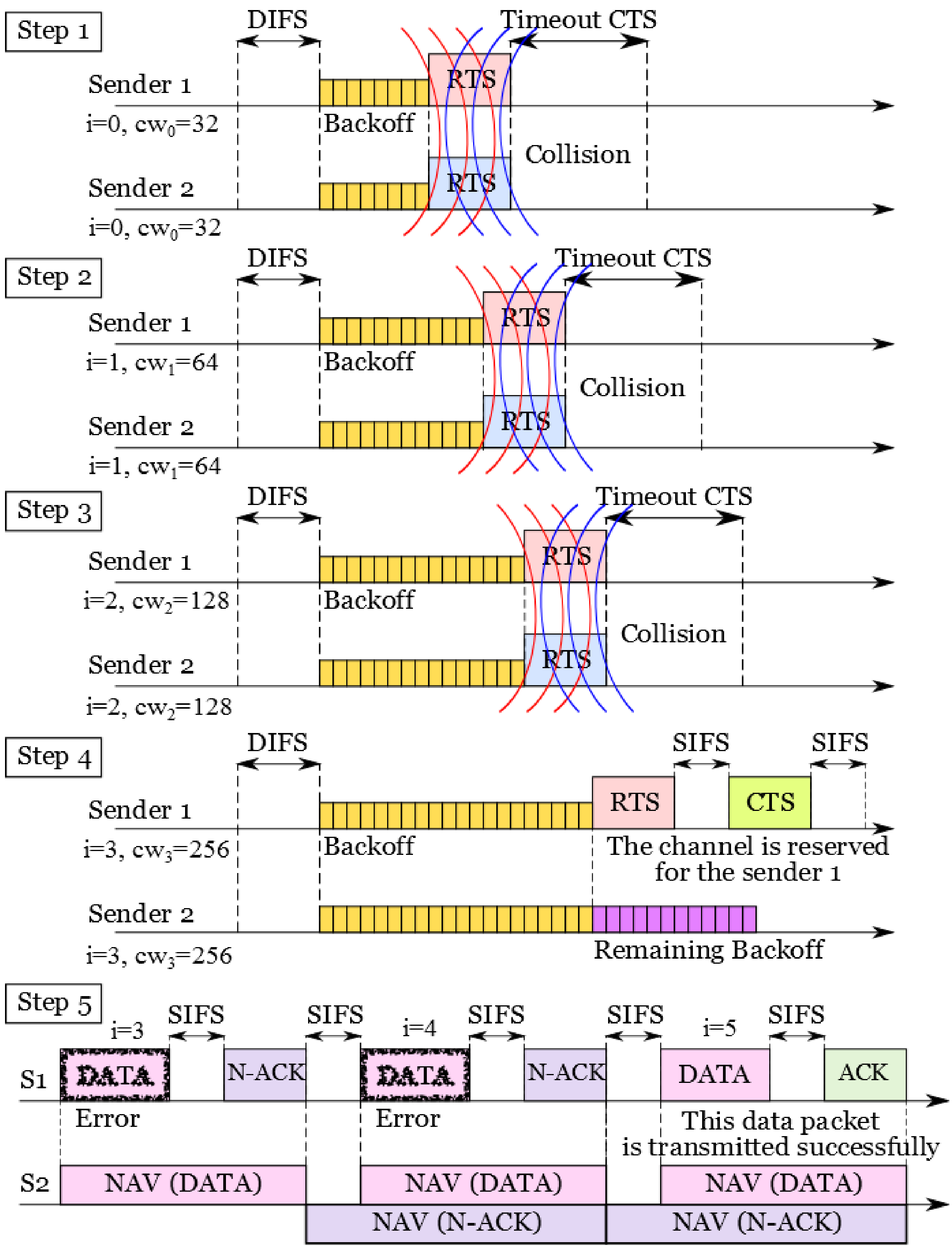

Figure 7. Enhanced IEEE 802.11 RTS/CTS scheme (Example: part 1)

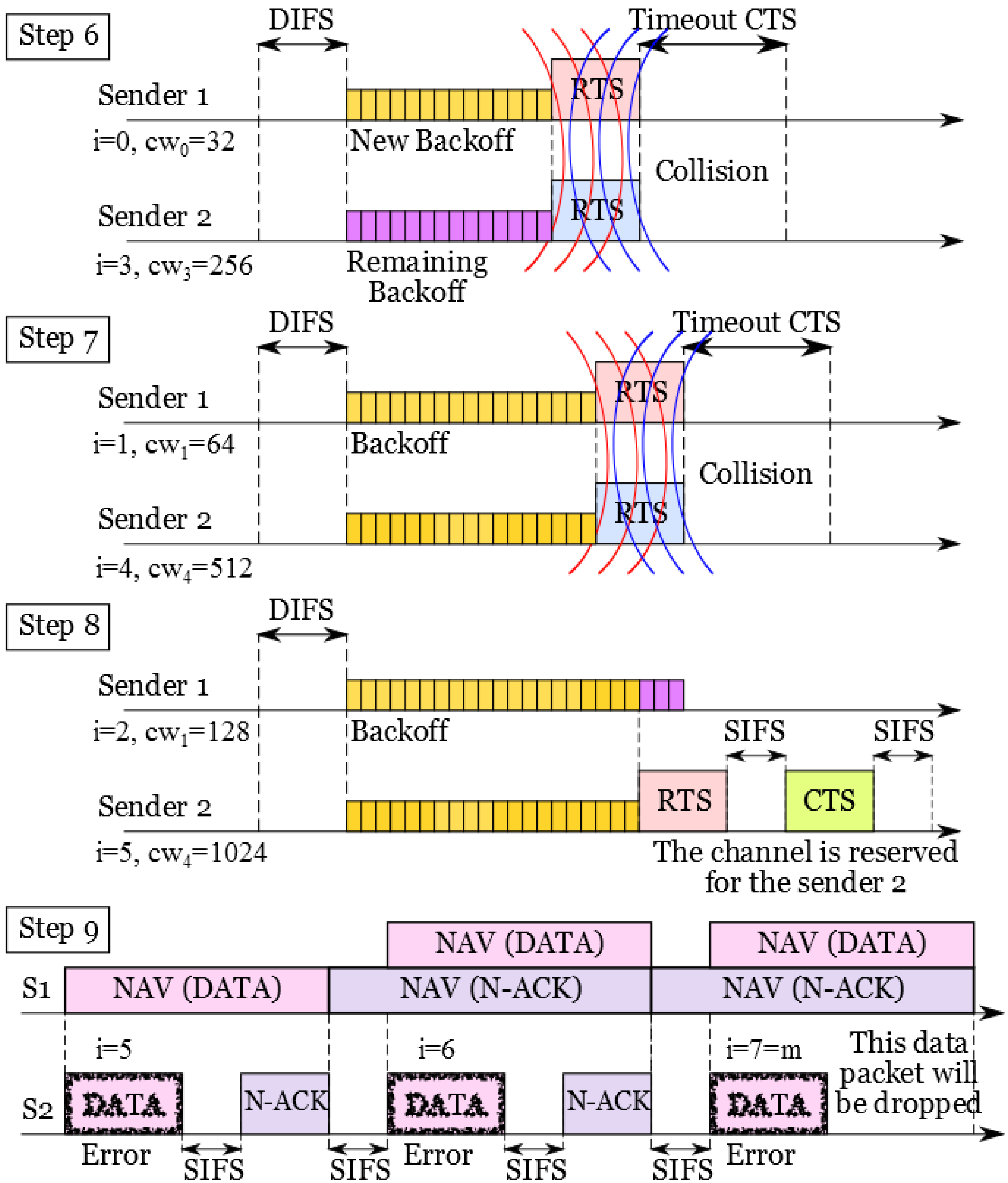

Figure 8. Enhanced IEEE 802.11 RTS/CTS scheme (Example: part 2)

5. Conclusion

In this paper, we are interested to simulate and enhance the IEEE 802.11 RTS/CTS scheme in error-prone channel. Since IEEE 802.11 MAC protocol can not distinguish between the collision related losses and the noise induced losses, the CW value is as result increased at every failure transmission due either to collision or noise errors. Based on this observation, we have

Parameter	Numerical value
Signal propagation delay	1 µs
DIFS	50 µs
SIFS	10 µs
Slot time	20 µs
Physical basic rate (PHY header)	1 Mbits/s
Physical basic rate (MAC header)	2 Mbits/s
Physical data rate	11 Mbits/s
Minimum contention window	32
Maximum contention window	1024
PHY header length	192 bits
MAC header length	34 bytes
ACK length	14 bytes
RTS frame length	20 bytes
CTS frame length	14 bytes
Maximum length of MAC frame	2312 bytes

Table 2. 802.11b PHY and MAC Parameters

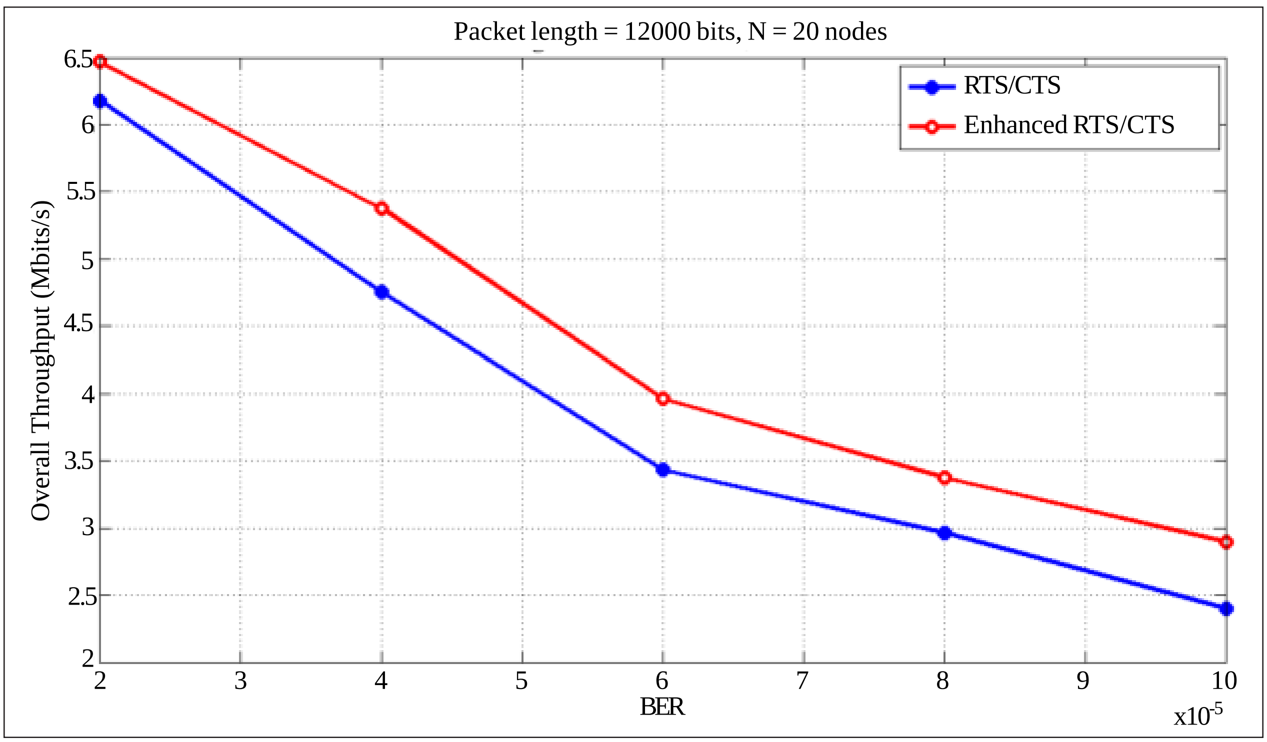

Figure 9. Overall Throughput versus BER

proposed an enhanced version of the IEEE 802.11 RTS/CTS scheme to recognize the reason of failure transmission. So, in the proposed version of the RTS/CTS scheme, when a data packet is lost due to noise errors, instead of increasing the CW value, the data packet is retransmitted immediately with zero-waiting backoff time. The performance evaluation of the enhanced IEEE 802.11 RTS/CTS scheme in error-prone channel proves the efficiency of this new version compared to the standard version.

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