An Analysis of the Influence of the Threshold Parameter on the IEEE 802.11 Network Performance

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Abstract-**This paper presents a simulation analysis of the influence of the RTS_Threshold parameter on the IEEE 802.11 network performance. The throughput and the mean frame delay as functions of offered load for different RTS_Threshold values and number of stations transmitting frames of a random size are studied. The optimal value of the RTS_Threshold as a function of the number of contending stations is determined. This allows us to design an IEEE 802.11 network in such a way that can substantially improve its performance.**

I. INTRODUCTION

Wireless LANs (Local Area Networks) are one of the most dynamically developing fields of telecommunications. In addition to the mobility that becomes possible with wireless LANs, these systems can also be used in environments where the cable installation is expensive or impossible. They play a very important role in the network architecture as a provider of easy and unconstrained access to the wired infrastructure.

Currently, there are two standards that describe WLANs, namely IEEE 802.11 [6] and HIPERLAN [5]. One expects that IEEE 802.11 will play a very similar role to that of Ethernet in wired networks. In this paper we focus our attention on IEEE 802.11 networks. The medium access protocol (MAC) for IEEE 802.11 wireless networks incorporates two access methods. The first method is mandatory and based on the CSMA/CA (Carrier Sense Multiple Access / Collision Avoidance) protocol. It is called the Distributed Coordination Function (DCF). The second one, PCF (Point Coordination Function), is optional and only used in the infrastructure mode to provide time-bounded services.

The CSMA/CA protocol has been enhanced by the exchange of short frames called RTS/CTS (Request_To_Send / Clear_To_Send). This handshaking is realized between the transmitter and the receiver before the data exchange. It allows the protocol efficiency to arise in two ways mentioned below.

1. If the collision occurs (that is two ore more stations select the same slot from the Contention Window) then the RTS/CTS frames are lost. The efficiency will be higher because the stations can fast recognize the collisions.
2. The two-way handshaking allows to decrease the unprofitable influence of hidden stations on the network performance [10]. The hidden stations appear when one or more stations cannot hear each other. This very unpredictable situation is caused by the nature of medium. RTS/CTS frames contain the information about the length of data frames. Two-way handshaking enables reservation of the medium in the area of the transmitter/receiver operation.

The IEEE 802.11 standard permits to set the threshold of RTS/CTS exchange usage. All transmitted data frames exceeding the assumed threshold are preceded by the RTS/CTS exchange. This parameter is called the RTS_Threshold. The usage of RTS/CTS exchange in the case of short data frames (for example 53-bytes ATM cells) can bring the performance degradation because the overhead is relative large compared to the payload [9].

An analysis of the RTS/CTS mechanism with RTS_Threshold usage has been presented in the literature. The dependence between the maximum throughput and the RTS_Threshold parameter for different mean lengths of frames was studied in [3]. A brief analysis of the RTS_Threshold parameter as a function of the physical layer preamble was presented in [9].

This paper presents the realized throughput and the mean frame delay as a function of offered load for different RTS_Threshold parameters, number of stations and the RTS/CTS mechanism enabled or disabled. The throughput and the mean frame delay as a function of the data frame length for RTS/CTS are also considered. The obtained results are the basis to determine the optimal value of RTS_Threshold as a function of the number of contending stations.

II. DCF FUNCTION

The IEEE 802.11 standard supports two access methods: the Distributed Coordination Function (DCF) method (mandatory) which is available in both ad hoc and infrastructure configurations, and the Point-Coordinated Function (PCF) which is optional and available in certain infrastructure environments. PCF enable us to provide time-bounded services.

DCF is the fundamental access method used to support asynchronous data transfer on the best effort basis. All the stations must support DCF. DCF employs the carrier sensing (CS) mechanism that check whether the signal energy in the occupied band does not exceed a given threshold to determine whether the medium is free and available for transmission. In order to minimize the probability of collisions a random backoff mechanism is used to randomize moments at which medium is tried to be accessed [4], [6], [8].

The DCF protocol is enhanced further by provision of a virtual CS indication called Net Allocation Vector (NAV), which is based on duration of information to be transferred. This is done in the exchange special RTS/CTS frames before the data exchange. It allows stations to avoid transmission in time intervals in which the medium is surely busy.

When using DCF, a station, before initiating a transmission, senses the channel to determine whether another station is transmitting. The station proceeds with its transmission if the medium is determined to be idle for an interval that exceeds the Distributed Inter Frame Space (DIFS) (see Figure 1). In the case when the medium is busy, the transmission is deferred until the end of ongoing transmission. A random interval (backoff interval) is then selected and used to initialize the backoff timer. The backoff timer is decremented only when the medium is idle. It is frozen when the medium is busy. After a busy period the decrementing of the backoff timer resumes only after the medium has been free longer then DIFS. A station initiates a transmission when the backoff timer reaches zero. To reduce the probability of collision, after each unsuccessful transmission attempt the expected value of the random backoff interval is increased exponentially up to the predetermined maximum.
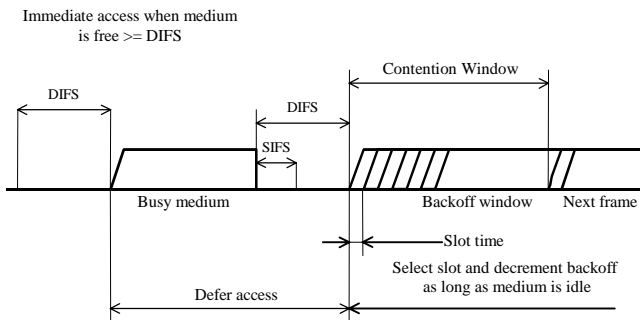

Fig. 1. Basic access method

Immediate positive acknowledgements are employed to determine the successful reception of each data frame. The receiver initiates the transmission of an acknowledgement frame after a time interval called Short Inter Frame Space (SIFS). This time is less then DIFS. In the case when an acknowledgment is not received, the data frame is presumed lost and the transmitter schedules a retransmission.

III. RTS/CTS MECHANISM

Since a source station in a Basic Service Set (BSS) cannot hear its own transmission when the collision occurs, the source continues transmitting the complete data frame. If data frame is large (e.g., 1500 octets), a significant amount of the channel bandwidth is wasted due to a frame corruption. RTS and CTS control frames can be used by station to reserve the channel bandwidth prior to the transmission of data frame and to minimize the amount of bandwidth wasted when collision occurs. The rules for the transmission of an RTS frame are the same as those for a data frame under basic

access. The transmitter sends an RTS frame after the channel has been idle for a time interval exceeding DIFS. On reception of a RTS frame the receiver responds with a CTS frame, which can be transmitted after the channel has been idle for a time interval exceeding SIFS. After the successful exchange of RTS and CTS frames the transmitter can send the data frame after SIFS. In the case when a CTS frame is not received within the predetermined time interval, the RTS is retransmitted following the backoff rules as specified in basic access.

The RTS and CTS frames contain the duration field that indicates the period for which the channel is to be reserved for the transmission of the actual data frame. Stations that can hear either the transmitter and/or the receiver use this information to update their Net Allocation Vector (NAV). The NAV timer is always decreasing if its value is non-zero. A station is not allowed to initiate a transmission if its NAV is non-zero. The use of NAV to determine the busy/idle status of the channel is referred to as the Virtual Carrier sense mechanism. Since stations that can hear either the transmitter or the receiver resist from transmitting during the transmission of the data frame under consideration the probability of its success is increased. However, an increase of the probability of successful delivery is achieved at the expense of the increased overhead involved with the exchange of RTS and CTS frames, which can be significant for short data frames. An example of the typical frame exchange with RTS/CTS mechanism enabled is shown in Figure 2.
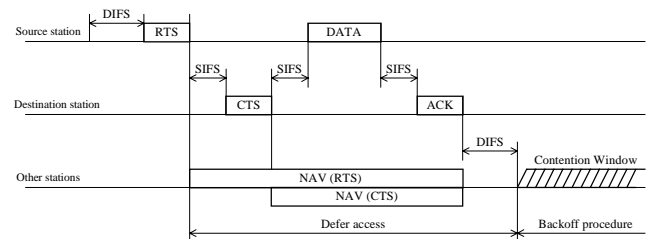

Fig. 2. RTS/CTS/DATA/ACK procedure and NAV sets

The handshaking allows increasing the network performance. The collision of short information frames and reduction of the unprofitable hidden stations influence increase the throughput. The RTS_Threshold parameter was introduced in the standard because the data field can change from 0 to 2312 bytes. It allows, for example, turn the RTS/CTS mechanism off when all stations can hear each other and/or they transmit very short frames. The standard assumes RTS/CTS/DATA transmission but it is used rather rarely. The time to recognize by the higher layers that the transmission is erroneous is relatively long compared to the same operation in the MAC layer. This mode of transmission is recommended only when the bit error rate in radio channel is very low.

IV. SIMULATION RESULTS AND DISCUSSION

In order to investigate these phenomena intensive simulations were performed. The obtained simulations allowed to determine the realized throughput and the mean

frames delay as a function of offered load while transmitting frames of different size (chosen randomly from 50 to 2312 bytes) for 5 different RTS_Threshold parameters (100, 500, 1000, 1500, 2000 bytes). The RTS/CTS mechanism was enabled or disabled for 5, 25 and 100 stations. The realized throughput and the mean frame delay as a function of the data frame lengths were investigated further. The obtained results allow us to determine the optimal value of the RTS_Threshold in dependence on the number of contending stations. Offered load was kept on the level of 5 Mbps, i.e. the network was saturated. The frame arrivals were realized according to the Poisson distribution. Several assumptions were made to reduce the complexity of the simulation model:

- The effects of propagation delay were neglected. This is a very realistic assumption if the transmission distances between stations are of tens meters.
- The channel was error-free, that is each frame that was transmitted by the sender was successfully and correctly received by the receiver.
- There were no stations operating in the power-saving mode. All stations should be "awake" all the time and then transmitted frames can be received immediately by the destination station.
- The stations were able to hear each other. The hidden station scenario was not considered.
- There was no interference from nearby BSSs.

The DATA + ACK mode of transmission was used. The network was configured to 2 Mbps medium capacity. Almost all parameters were taken from the standard and were adequate to the FHSS (*Frequency Hopping Spread Spectrum*) physical layer specification. The parameters used throughout all simulations are displayed in Table 1

TABLE I
PARAMETERS USED THROUGHT ALL SIMULATIONS

Parameter	Value
SIFS	28 μs
DIFS	130 μs
Length of RTS	20 bytes
Length of CTS	14 bytes
Length of ACK	14 bytes
DATA header	32 bytes
Physical layer preamble	18 bytes
Minimum number of slots – CWmin	31 slots
Maximum number of slots - CWmax	1023 slots
Slot time	50 μs
Buffer size	10 frames
Number of retransmissions of RTS frames	4
Number of retransmissions of DATA frames	4
T1 timer	300 μs
T3 timer	300 μs
Medium capacity	2 Mbps
Minimum length of DATA frame (I part of study)	50 bytes
Minimum length of DATA frame (II part of study)	20 bytes
Maximum length of DATA (I part of study)	2312 bytes
Maximum length of DATA (II part of study)	1500 bytes
Number of stations	5, 25, 100
RTS/CTS usage – RTS_Threshold (I part of study)	100, 500, 1000, 1500, 2000 bytes

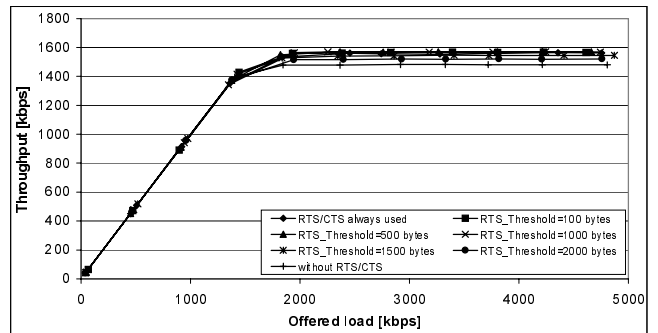The results of obtained simulations are presented in Figures 3 - 11:

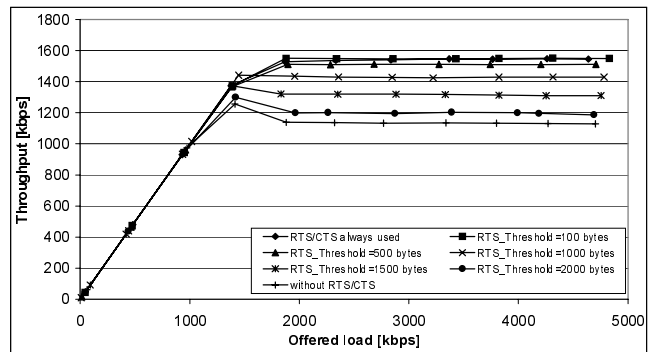Fig. 3. Throughput versus offered load for 5 stations and different values of RTS_Threshold parameter

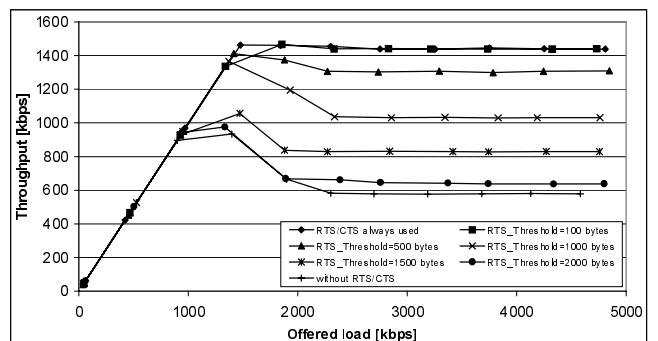Fig. 4. Throughput versus offered load for 25 stations and different values of RTS_Threshold parameter

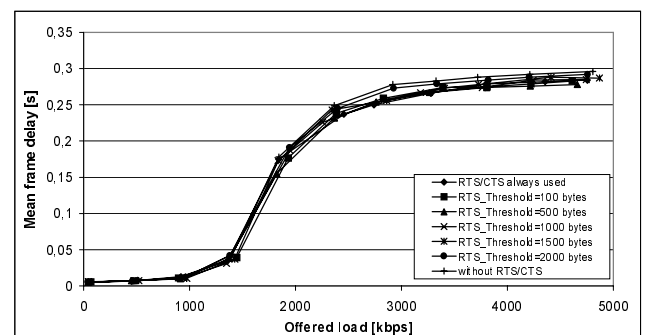Fig. 5. Throughput versus offered load for 100 stations and different values of RTS_Threshold parameter

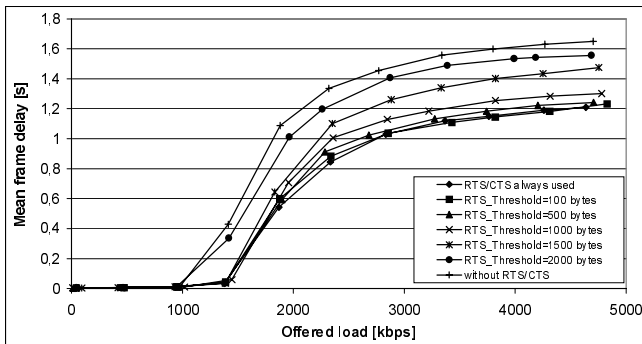Fig. 6. Mean frame delay versus offered load for 5 stations and different values of RTS_Threshold parameter

Fig. 7. Mean frame delay versus offered load for 25 stations and different values of RTS_Threshold parameter

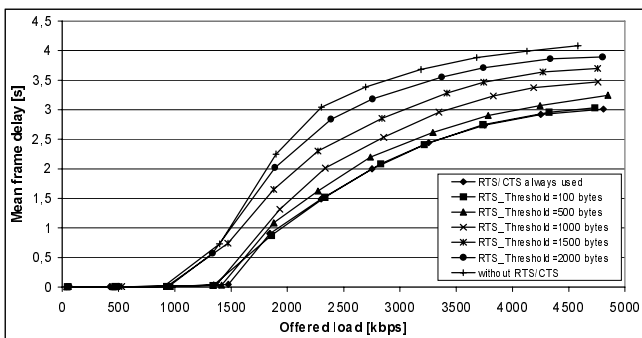
Fig. 8. Mean frame delay versus offered load for 100 stations and different values of RTS_Threshold parameter
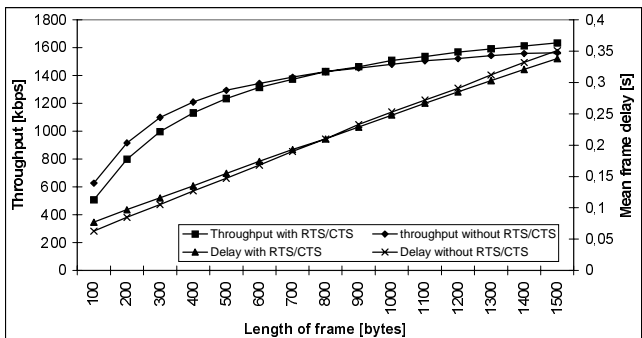

Fig. 9. Throughput and mean frame delay versus length of frame for RTS/CTS mechanism on or off for 5 stations
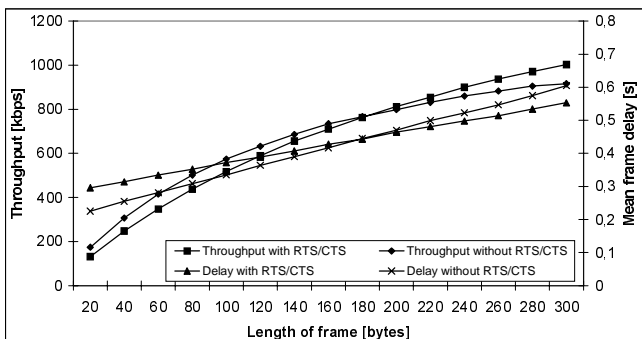

Fig. 10. Throughput and mean frame delay versus length of frame for RTS/CTS mechanism on or off for 25 stations
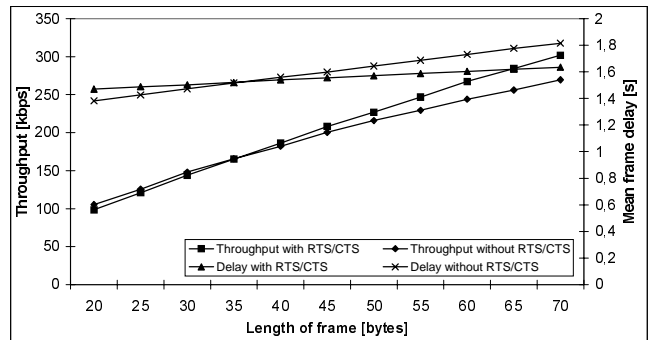

Fig. 11. Throughput and mean frame delay versus length of frame for RTS/CTS mechanism on or off for 100 stations

The plots are divided in three groups. The realized throughput as a function of offered load for different RTS_Threshold values and number of stations (Figs. 3 – 5) is the first group. The mean frame delay as a function of offered load for different RTS_Threshold parameters and number of stations (Figs. 6 – 8) is the second group. The realized throughput and the mean frame delay as a function of data frame length for the RTS/CTS mechanism enabled or disabled and different number of stations is the last group (Figs. 9 – 11).

An analysis of the presented results allows us to draw a number of interesting conclusions. A linear growth of the realized throughput for small values of offered load can be observed. The realized throughput reaches the maximum values for the RTS/CTS mechanism always enabled and the RTS_Threshold of 100 bytes. The growth of RTS_Threshold value brings the degradation of the network performance. This degradation is highly dependent on the number of contending stations. The reduction of the maximum realized throughput with the increased number of contending stations is very characteristic. The realized throughput reaches the maximum values 1560 kbps for 5 stations, 1550 kbps for 25 stations and 1440 kbps for 100 stations. When the RTS/CTS mechanism is disabled, a significant degradation of the network performance can be observed. The realized throughput reaches: 1480 kbps for 5 stations and 1130 kbps for 25 stations. It drastically falls to 580 kbps for 100 stations. The very interesting phenomenon of the local maximum appearance for large number of stations can be observed. Greater offered load brings a large number of collisions. Too large RTS_Threshold value or its lack causes a high level of losses that arises from collisions of large data frames. The growth of offered load above the nominal capacity of the network does not brings the degradation of the realized throughput as in some others wireless networks like Aloha, Slotted Aloha or CSMA. The DCF function of the IEEE 802.11 protocol is much more stable.

The mean frame delays as a function of offered load are presented in Figs. 6 – 8. A very low increase of the mean frame delay for low offered load could be observed. It is of some tens of milliseconds. The number of stations has a little influence on the shape of the obtained characteristics but a large one on the transmission delay. The RTS/CTS mechanism does not play a significant role in the case of a

small number of stations. The growth of the mean frame delay is relatively small after a certain value of offered load. The smallest values of delays are observed when the RTS/CTS mechanism is always enabled or when the RTS_Threshold value is of 100 bytes. The biggest delays are obtained for large values of offered load and the RTS/CTS mechanism always disabled.

The optimal RTS_Threshold parameter in dependence on the number of contending stations can be determined from the last series of plots. All of three plots present four curves. Two present the realized throughput as a function of the data frame length and two show the tradeoff between the mean frame delay and the data frame length. The data were transmitted using the RTS/CTS mechanism or without any handshaking. One can observe that curves are intersected. It allows to define the optimal RTS_Threshold values. The observation of presented plots leads us to drawing some interesting conclusions. The optimal RTS_Threshold value is highly dependent on the number of contending stations. The growth of the number of stations causes a decrease of the optimal value of RTS_Threshold. The optimal value is 800 bytes for 5 stations, 180 bytes for 25 stations and 35 bytes for 100 stations. This situation is comprehensible and arises from the growth of collisions in too small Contention Window [7]. An unprofitable influence of transmission of short frames on the network efficiency can be observed. The realized throughput changes from 1600 kbps (for 1500 bytes frames) to 500 kbps (for 100 bytes frames) in the case of 5 stations. The mean frame delay grows with the data frame size, from 0,075s for 100 bytes to 0,35s for 1500 bytes in the case of 5 stations. The increased number of stations brings the growth of the mean frame delay. The dependence between the number of stations and the realized throughput is relatively small. The tradeoff between the frame size and the mean frame delay is linear. However, the tradeoff between the realized throughput and the data frame size is strongly non-linear.

IV. CONCLUSIONS

From the presented results and considerations, one can draw a number of interesting conclusions mentioned below.

1. The proper choice of the RTS_Threshold parameter in dependence on the number of contending stations is very substantial for the network performance.
2. When the number of stations increases then the RTS_Threshold should be decreased.
3. The growth of the data frame length brings the linear growth of the mean frame delay and non-linear growth of realized throughput.
4. While transmitting frames of random size it is recommended to set the RTS/CTS mechanism always on (the maximum values of realized throughput and the minimal values of delay are achieved) independently on the number of contending stations.
5. The absence of RTS/CTS mechanism brings considerable network performance degradation, especially for large values of offered load and numbers of contending stations.

The presented work gives hints how to increase the IEEE 802.11 network performance through the proper selection of the RTS_Threshold parameter. The network efficiency is, of course, dependent also on many other parameters like the number of contending stations, offered load, the physical layer preamble length, hidden station scenario etc. It is better to always use the RTS/CTS mechanism especially when we do not know what is the length of transmitted frames.

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