A COMPARATIVE STUDY OF IEEE 802.11 MAC ACCESS MECHANISMS FOR DIFFERENT TRAFFIC TYPES

Mohammad Saraireh, Reza Saatchi, Samir Al-khayatt, Rebecca Strachan
Sheffield Hallam University, Pond Street,Sheffield, UK

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Abstract: The fast growth and development of wireless computer networks and multimedia applications make the Quality of Service (QoS) provided to their transmission an important issue. This paper aims to investigate the impact of varying the number of active stations on the network performance. This was carried out using different data rates. The investigations also considered both MAC protocol access mechanisms, i.e. the basic access and the Request To Send / Clear To Send (RTS/CTS). The effect of traffic type i.e. Constant Bit Rate (CBR) and Variable Bit Rate (VBR) traffics was also examined. The findings revealed that in large networks (larger than 15 stations), the RTS/CTS access mechanism outperformed the basic access mechanism since the performance of the latter was more sensitive to the increase and decrease of the number of active stations. Increasing the data rate improved the network performance in term of delay and jitter but it degraded the network performance in term of channel utilisation and packet loss ratio.

1 INTRODUCTION

Wireless systems are increasingly used for transmitting different type of applications such as voice, video and data. Wireless transmission requires a controller to manage accessing the medium in a fair and suitable manner and to share the resources. Random transmission may lead to incomprehensible or unpredictable results. Therefore, a controller for accessing and sharing the resources is an essential tool for achieving a successful transmission process between the communication parties.

The Medium Access Control (MAC) protocol in wireless networks controls access to the shared medium by applying rules and procedures that permit the communication pairs to communicate with each other in an efficient and fair manner.

The IEEE 802.11 standard defines two coordination functions (IEEE, 1999). They are Distributed Coordination Function (DCF) and Point Coordination Function (PCF). The focus of this study is the DCF that is part of the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA).

Under DCF protocol, data packets are transferred using two mechanisms. The main mechanism is a two-way handshaking process which is called basic access mechanism. The optional or alternative mechanism is called RTS/CTS access mechanism that based on the exchange of RTS and CTS messages before data packets transmission.

RTS/CTS access mechanism is used to reserve the channel before data transmission. Under DCF, all stations in the same Basic Service Set (BSS) have to compete between each other to gain access to the medium. The competition between stations is controlled by different parameters of the physical layer (PHY) and the MAC sub-layer. The parameters include the Inter Frame Space (IFS) i.e. time period between the transmission of frames, Contention Window (CW), and backoff mechanism that randomises instants at which stations are attempting to access the channel.

All these parameters play important roles on the network performance through their effect on the degree of competition between the active stations within the same BSS. Consequently, an increase in the number of active stations in the BSS increases the degree of competition which in turn increases the probability of collisions. As a result of that, an increase in the number of stations has an obvious impact on the network performance.

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2 RELATED WORK

The variation of the number of active stations in IEEE 802.11 DCF protocol has been investigated in several studies by both simulation tools and mathematical models. An analytical model was proposed to analyse DCF operation and compute the saturated throughput performance through employing Markov chain models (Bianchi, 2000). This proposed model considered a finite number of stations with ideal channel conditions. The results obtained in this paper showed that the performance of the basic access mechanism depends on the MAC parameters mainly contention window minimum and number of wireless stations in the wireless networks. On the other hand, the results showed that the RTS/CTS access mechanism is marginally dependent on the system parameters. In another study the capacity of the medium was investigated by developing a mathematical model that calculates the DCF throughput and the packet virtual transmission time (Cali, 2000).

IEEE 802.11 CSMA/CA protocol over wireless channel was investigated in (Kleinrock, 1975). They provide an analysis for the channel performance during the up-time of unstable channel. They showed that CSMA theoretically exhibits behaviour similar to ALOHA. In (Haitao, 2002) a scheme named DCF+, which is compatible with DCF; to enhance the performance of reliable transport protocol over WLAN was proposed. Moreover, the impact of increasing the number of stations on the saturated throughput and delay in DCF and in the proposed scheme DCF+ was investigated. Their results revealed that increasing number of stations has an obvious impact on the network performance.

In (Sweet, 1999), throughput performance measures for varying number of stations in CSMA/CA were presented. They showed that the RTS/CTS access mechanism achieved higher throughput for CBR traffic when the number of stations increased above 10 stations. Their results also showed that higher transmission speeds yielded lower average throughput results.

Changing the number of active stations has an obvious impact on achieving QoS over wireless ad-hoc networks. This is due to the increase of collision probability over the medium. Also varying the data rate has a considerable impact on the average end-to-end delay and jitter. These parameters have critical impact on the transmission of multimedia applications.

An aim of this study is to investigate the impact of increasing the number of active stations and data rate on the network parameters. In particular, on the QoS parameters, throughput, end-to-end delay, jitter, and data packets drop. The performance of MAC protocol access mechanisms for CBR and VBR traffics was analysed.

This paper is organised into five sections. In the next section, the basics of the IEEE 802.11 MAC protocol are introduced. The experimental procedure is introduced in section 4. The findings and discussions are presented in section 5. The conclusion and future work is presented in section 6.

3 IEEE 802.11 MAC PROTOCOL

The IEEE 802.11 standard (IEEE, 1997) specifies a CSMA/CA protocol. In CSMA/CA, when a station has a packet to send, it first listens to the medium to ensure no other transmission is currently taking place. If the channel is idle, it then transmits the packet. Otherwise, it picks a random "backoff interval" which determines the period of time the station has to wait until it is allowed to transmit its packet. The selection of the random number of the backoff time is based on a binary exponential backoff algorithm. The competing stations select a random number between 0 and CW-1 with equal probability. If the data packet is successfully transmitted, the backoff counter of the transmitted station will reset and then the station starts to compete with the other stations for accessing the medium. During the idle period of the channel, the transmitting station decrements its backoff counter. When the backoff counter reaches zero, the station transmits the packet as shown in Figure 1. During the busy period the station suspends its backoff counter. After successful receiving a packet, the receiving station replies with a positive acknowledgement (ACK) after waiting for a Short Inter Frame Space (SIFS) period. If an ACK is not detected within a SIFS period after the packet transmission, the transmission is assumed to be unsuccessful, and a retransmission is scheduled according to the specified backoff rules. The unsuccessful transmission is due to collision over the link. If a collision occurs CW will be doubled until reaching the maximum value $CW_{max} = 2^m(CW_{min} + 1) - 1$, where m is the number of retransmission attempts.

The RTS/CTS access mechanism is mainly used to minimize the amount of time spent when a collision occurs since collision occurs in these short messages.

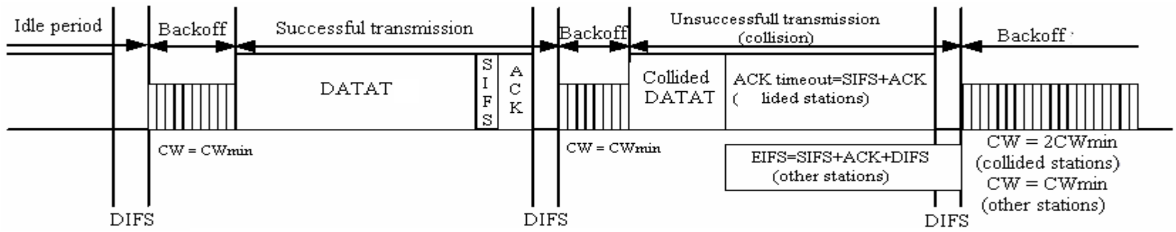


Figure 1: Timeline of Basic access mechanism in DCF.

Before commencing the transmission of a data packet, the source station sends a short control frame, called RTS, declaring the duration of the forthcoming transmission. When the destination station receives the RTS frame, it replies with a CTS frame after SIFS interval, with the duration of the future transmission. Upon hearing RTS and CTS, all other stations in the vicinity of the sender and the receiver update their Network Allocation Vectors (NAV). This process reserves the medium for the sending station. Thus, all stations in the neighbourhood of the sender and receiver defer their transmissions and receptions to avoid collisions. After the successful RTS/CTS exchange, the source station transmits the data packet then the receiver responds with an ACK frame. Figure 2 depicts the time line of the RTS/CTS access mechanism.

4 EXPERIMENTAL PROCEDURE

To analyse the impact of varying the number of active stations and data rate on the network performance for both the MAC protocol access mechanisms and the two different traffic types a number of simulation studies were carried out using the network simulator package (ns2) version 2.27 (ns2). The studies were carried out under different scenarios and they were based on the QoS parameters; throughput, delay, delay variation, and packet loss.

The performance of the IEEE 802.11 MAC protocol was investigated when the number of active stations in the same BSS was increased. Two different channel data rates were chosen for data packet transmission; low data rate equal to 2Mbps and high data rate equal to 11Mbps. While the control frames were transmitted at data rate equal to 1Mbps. IEEE 802.11b standard was used since it offers multi data rates. The protocol parameter settings were as shown in Table 1. A random topology with 20 stations was adopted when all stations were located in the same BSS. The network was offered by 100% of offered load every time the simulation run. Each connection was specified as a source - destination pair in which the number of connections was varied each time the network simulation was run. The simulation was carried out for CBR and VBR traffic at both MAC protocol access mechanisms. The CBR traffic had fixed packet size (1280-byte) while the VBR traffic had variable packet size and variable interval (mean packet size 3993 bytes and 2541 bytes standard deviation).

All nodes were arranged in a random topology with area of 200x200 metre with the help of random way point model, and the same model was used for all the simulations. Throughout the simulations, all nodes were within range of each other and there were no hidden terminals occurrences. Each scenario was run for 10 times. The results were the mean value for simulations. Each simulation was run for duration of 100 seconds using Ad-hoc On-demand Distance Vector (AODV) as the routing protocol since it has proven to be efficient as opposed to proactive protocol in Mobile Ad-hoc Networks (MANET) (Broch, 1998).

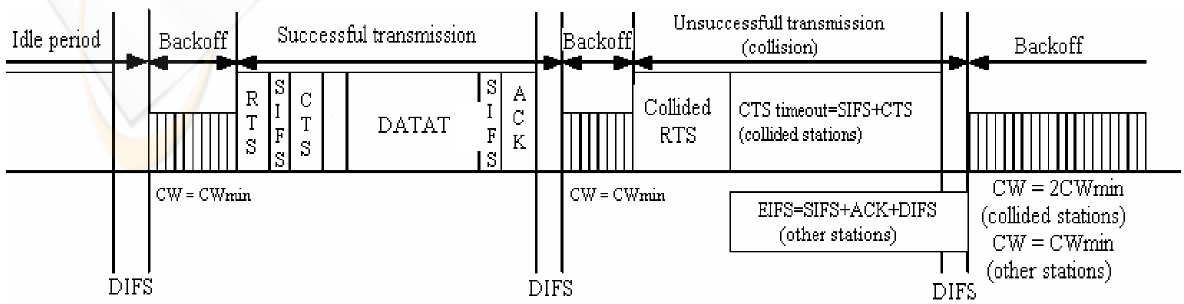


Figure 2: Timeline of RTS/CTS access mechanism in DCF.

Table 1: IEEE 802.11b Parameter (ORiNOCO) settings.

Parameter	**Value**
Data Rate	2, 5.5, 11 Mbps
Basic Rate for broadcast	1 Mbps
DIFS	50 μsecs
SIFS	10 μsecs
CWmin	31
CW max	1023
Slot time	20 μsec
Short Retry Limit	7
Long Retry Limit	4

5 RESULTS AND DISCUSSIONS

This section outlines performance evaluation of the Distributed Coordination Function (DCF) that is a part of the IEEE 802.11 standard. It demonstrates through simulations the performance of the IEEE 802.11 MAC protocol when the number of stations is varied. Further, the impact of this variation on the QoS parameters is analysed. A comparison of the access methods provided by the IEEE 802.11 MAC protocol is carried out and comments are made as to when each should be employed.

5.1 Average Throughput

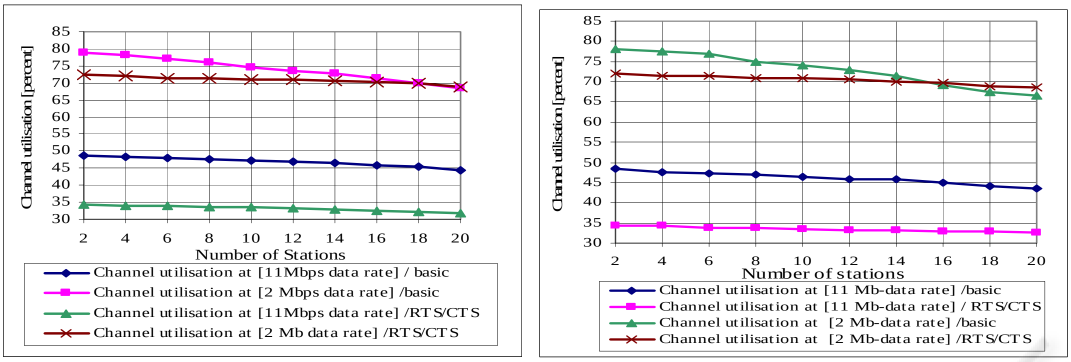
An increase in the number of contending stations in the same BSS causes more collisions and as a result more channel bandwidth is wasted. This wastage of bandwidth causes a reduction in the achieved throughput for both MAC protocol access mechanisms.

Figures 3a and 3b show the relationship between the active stations and the channel utilisation (channel utilisation is the ratio of the received bits to the channel data rate). When the number of active stations was increased, the channel utilisation slightly declined when the RTS/CTS access mechanism was used compared to the basic access mechanism. In RTS/CTS mechanism, collisions only involve control frames which are relatively small in size compared to data packet sizes, hence the bandwidth wasted in collisions is less than the basic access mechanism. This explains the slight rate of decrease in the channel utilisation curve when the RTS/CTS access mechanism was used.

If there are few stations in the network, (i.e. less than 10 stations), the RTS/CTS access mechanism provided a lower channel utilisation and lower average throughput. This was due to the overhead introduced by the control frames RTS and CTS. The impact of this overhead on the average throughput became very small when data packet sizes was very large (above 2000 bytes) as shown Figure 4. At small packet sizes, the basic access mechanism outperformed the RTS/CTS access mechanism due to the impact of the overhead, while at large packet sizes, the RTS/CTS access mechanism outperformed the basic access mechanism since the size of RTS and CTS is very small compared to data packet sizes.

With regard to channel data rate, low data rate (2Mbps) achieved better channel utilisation than high data rate (11 Mbps). This is because in low data rate the data packets were sent at 2 Mbps while the headers and control frames were sent at basic rate (1 Mbps). The two data rates (low data rate and basic rate) are relatively close to each other which resulted in better channel utilisation. At high data rate, the data packets were sent at 11 Mbps while the headers and control frames were sent at 1 Mbps, the difference here was relatively high compared to low data rate which resulted in a high rate of reduction in the channel utilisation. In this case, the transmission of headers and control frames caused a bottleneck when data packets were sent at high data rate.

The channel utilisation was degraded for CBR and VBR traffics. For CBR traffic, the reduction over an increase from 1 to 20 stations was 4.3% at 11 Mbps and 10.5% at 2 Mbps when the basic access mechanism was used. When the RTS/CTS access mechanism was used the reduction was slightly smaller, it was 2.4% at 11 Mbps and 3.5% at 2 Mbps. For VBR traffic, the channel utilisation degraded by 4.8% at 11 Mbps data rate and by 11.5% at 2 Mbps data rate when the basic access mechanism was used. When the RTS/CTS access mechanism was used the reduction in the channel utilisation was 1.8% at 11 Mbps and 3.5% at 2 Mbps. The results obtained indicate that the channel utilisation was degraded for CBR and VBR traffic in both; the RTS/CTS and the basic access mechanisms, but the RTS/CTS access mechanism provided a smaller rate of decrease in the channel utilisation when the number of stations was increased. Also high data rate (11 Mbps) provided a slight decrease in the channel utilisation compared to the low data rate (2 Mbps).



(a) (b)

Figure 3: Channel utilisation for CBR and VBR traffic at two different data rates and at two MAC protocol access mechanisms. (a) Channel utilisation for CBR. (b) Channel utilisation for VBR.

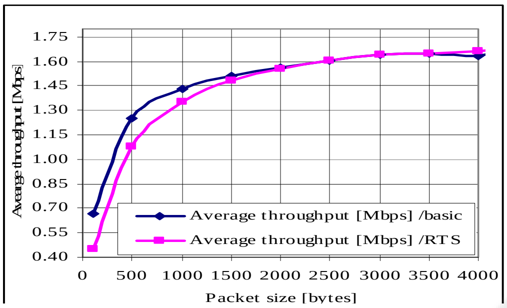


Figure 4: Average throughput at Basic and RTS/CTS access mechanisms when the packet size increased.

5.2 Average Delay

The packet delay from and end-to-end should not exceed 400 ms for time sensitive applications in order to achieve the required QoS (Coverdate, 2000). As shown in Figures 5a, 5b, 5c and 5d, low data rate (2Mbps) in both MAC access mechanisms does not meet this QoS requirement if the number of active station was increased to more than 4 stations. A high data rate (11 Mbps) achieved better performance (small values of average delay). The average delay was slightly increased which met the QoS requirements up to 10 stations and then started to exceed the limit as the number of active stations was increased.

Because of the strict delay and jitter requirements for multimedia applications (CBR and VBR traffics), the time interval between the packet transmissions has to be within a given period. This can be obtained by assigning small values of CW_{min} and CW_{max} for these applications. In this study The IEEE 802.11 and IEEE 802.11b protocols were used, and their CW_{min} and CW_{max} were kept at the default values (31 and 1023 respectively) for the pairs of communication, therefore, their delay and jitter values were increased at low data rates and slightly increased at high data rates.

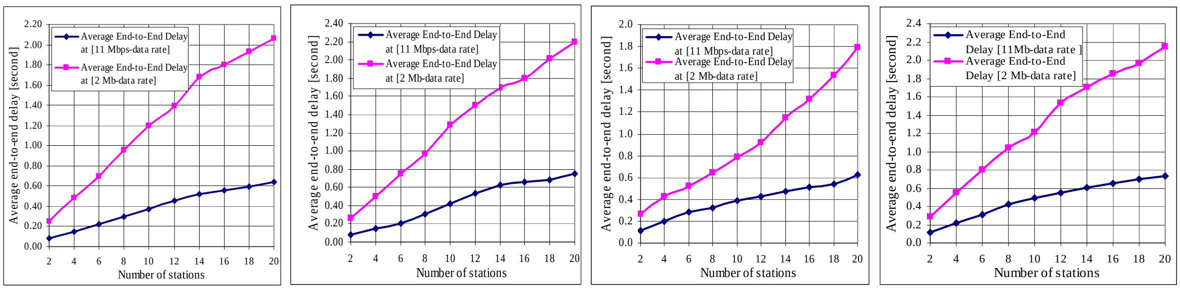
At high data rate (11 Mbps) with the basic access mechanism, the average delay was reduced by 69% and 66% compared with low data rate for CBR and VBR traffics, respectively. When the RTS/CTS access mechanism was used, the average delay at high data rate was also reduced by 58% and 63% for CBR and VBR traffics respectively.

The values of average delay in both MAC access mechanisms were located outside the desired range of QoS (150 ms for high QoS and 400 ms the minimum limit) when low data rate (2 Mbps) was used (Coverdate, 2000). Conversely, high data rate (11 Mbps) can provide acceptable QoS requirements in term of average delay.

5.3 Average Jitter

One of the major roles of QoS is to keep delay, jitter and packet loss for the transmitted applications within the acceptable range (Coverdate, 2000). For instance, to achieve high QoS for multimedia applications, the average jitter should not exceed 20 ms.

The average jitter increased as the number of active stations was increased. In other words, as the number of stations was increased; the probability of collisions increased due to a high degree of competition between stations. This in turn forced the MAC protocol to retransmit the collided packets. If the collided packets were successfully received at the destinations, they experienced delay variation, and this variation depended on the number of packet retransmissions.



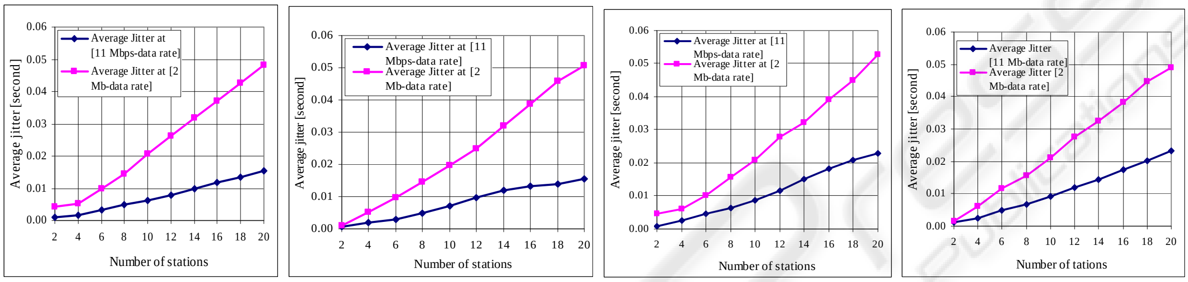
(a): Average end-to-end delay for CBR / basic.

(b): Average end-to-end delay for VBR / basic.

(c): Average end-to-end delay for CBR / RTS.

(d): Average end-to-end delay for VBR / RTS.

Figure 5: Average end-to-end delay vs. number of stations.



(a): Average jitter for CBR / basic.

(b): Average jitter for VBR / basic.

(c): Average jitter for CBR / RTS.

(d): Average jitter for VBR / RTS.

Figure 6: Average jitter vs. number of stations.

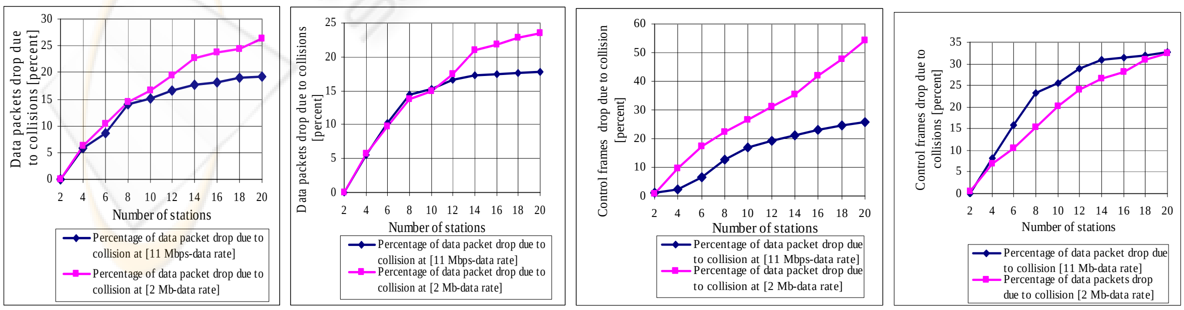
As shown in Figures 6a, 6b, 6c and 6d, the transmission of data packets with high data rate (11Mbps) had a noticeable positive impact on the achieved value of average jitter. High data rate resulted in small values of average jitter. This was because the transmission time of data packets at high data rate was smaller.

The results obtained at 11 Mbps indicated that the values of average jitter for CBR and VBR traffic in both MAC access mechanisms were kept within the acceptable range of QoS (less than 20 ms), where as low data rate resulted in large values of average jitter (more than 20 ms).

5.4 Packet Loss

In this study the packet loss was due to collisions, especially when the MAC retry limit exceeded and buffer overflow. Figures 7 and 8 show that the performance was downgraded with the increase in the number of stations in the same BSS.

It is well-known that high transmission rates have a lower Signal to Noise Ratio (SNR) than low data rates (Thruong, 2003). Therefore, at high data rates, the probability that a packet can not be received correctly by the destination is high.



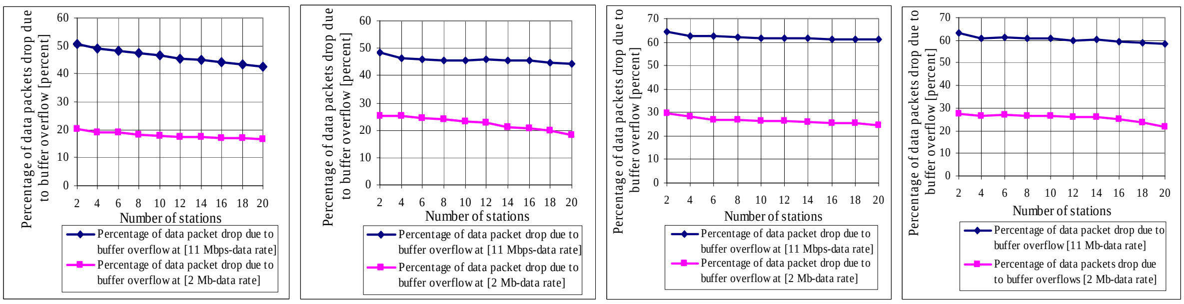
(a): Data packet drop due to collision for CBR/basic.

(b): Data packet drop due to collision for VBR/basic.

(c): Control frame drop due to collision for CBR/RTS.

(d): Control frame drop due to collision for VBR/RTS.

Figure 7: Percentage of Collision drop vs. Number of stations.



(a): Data packet drop due to buffer for CBR/basic.

(b): Data packet drop due to buffer for VBR/basic.

(c): Data packet drop due to buffer for CBR/RTS.

(d): Data packet drop due to buffer for CBR/RTS.

Figure 8: Percentage of buffer drop vs. Number of stations.

The results obtained showed that the drop due to buffer overflow is relevant in the total loss ratio only with low data rate if the number of active stations was increased, while with high data rate the main cause of packet loss was the collisions (MAC retry limit) as shown in Figures 7 and 8

As shown in Figures 8a, 8b, 8c, and 8d, at high data rates the packet loss ratio was larger by 30% and 23% than the obtained values at low data rates for CBR and VBR traffics, respectively when the basic access mechanism was used. When the RTS/CTS access mechanism was used, the packet loss ratio was larger by 36% and 35% than the obtained values at low data rates for CBR and VBR traffic, respectively.

In this scenario, the basic mechanism outperformed the RTS/CTS mechanism in term of packet loss when the number of stations was small. For large networks, the RTS/CTS access mechanism outperformed the basic access mechanism because of collisions. In RTS/CTS access mechanism, collisions occurred for control frames while in the basic access collisions occurred for data packets as well as control frames.

6 CONCLUSION

In this study extensive experiments were carried out using ns2 simulation software to investigate the performance of the IEEE 802.11 MAC protocol by varying the number of active stations and varying the channel data rate.

Both MAC protocol mechanisms, i.e. the basic access and RTS/CTS access mechanisms were employed. The effect of traffic types (i.e. CBR and VBR) on the performance of the access mechanisms was also analysed.

The study indicated that increasing the number of active stations had an impact on the average throughput when the basic access mechanism was used.

High data rates improved the average throughput, but degraded the channel utilisation. This was because the control frames were sent at low data rate (1 Mbps).

The basic access mechanism outperformed the RTS/CTS access mechanism when the number of active stations was small. For a large network size, greater than 15 stations, the RTS/CTS access mechanism outperformed the basic access mechanism.

In the future a detailed evaluation of QoS parameters for various applications such as audio, video, file transfer and data will be carried out for small and large networks. Furthermore, the network parameters will be used for predicting the QoS and other network conditions as an approach for improving the protocol performance.

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