QOS Analysis of IEEE 802.11 Wireless LAN

Toni Janevski[1] Vasil Maljanovski[2]

***Abstract* - In this paper we present a new approach for performance analysis of IEEE 802.11 Wireless Local Area Network (WLAN). Our analysis is targeted to the Quality of Service experienced by the user. Main QoS parameters in these analyses are throughput and packet delay, which are evaluated using simulation methodology.**

***Keywords* – QoS, 802.11 WLAN, Throughput, Delay**

I. INTRODUCTION

Wireless Local Area Networks (WLAN) are gaining momentum today, either as corporate wireless networks or public hot-spots that provide higher data rates than current cellular networks. To provide an efficient and robust network in a wireless environment, the IEEE has chosen the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol as the basic standard protocol at Medium Access Control (MAC) layer for 802.11 WLAN. There has been significant research on the evaluation of its performance. However, performance evaluation of the IEEE 802.11 WLAN under realistic traffic conditions has been considered difficult. Therefore, many analyses have assumed simpler traffic conditions such as Poisson sources with fixed size data frames [1].

In telecommunication networks like WLAN is very important to obtain the behavior of the system with varying number of users and at different transmitting bit rates. If we want to maintain defined Quality of Service (QoS) level, we need to keep the number of users that simultaneously communicate, their throughput and packet delay in acceptable limits [2]. If we suppose that characteristics of wireless link do not vary in time and space and if we do not consider mobility of users, which are main sources of appearance of transmission errors, then we should focus out attention to analysis of throughput and packet delay in a given service area.

In this paper we consider the 802.11 standard that is world wide deployed today, that is 802.11b [3]. This WLAN standard is created to provide users with maximum of 1; 2; 5.5 or 11 Mbps, which is dependent upon the physical layer (i.e. multiple access and modulation scheme). To be complete, we should mention the other two existing WLAN standards today, 802.11a and 802.11g, which are using different physical layer than 802.11b with aim to achieve higher data rates up to maximum of 54 Mbps. Also, there is ongoing work to develop other 802.11 standards, such as 802.11e for QoS support, 802.11i for better security etc.

[1]Dr. Toni Janevski is an Ass. Professor at the Faculty of Electrical Engineering, Karpos 2 bb, 1000 Skopje, Macedonia, E-mail: tonij@cerera.etf.ukim.edu.mk

[2]Vasil Maljanovski is a graduate student at the Faculty of Electrical Engineering, Karpos 2 bb, 1000 Skopje, Macedonia, E-mail: maljanovski@hotmail.com

The paper is organized as follows. In Section 2 we present WLAN model used in the analysis. Section 3 we show and discuss the results from the simulations. Finally, Section 4 concludes the paper.

II. MODEL OF IEEE 802.11 NETWOKS

In the IEEE 802.11 standard there are defined two access methods: Distributed Coordination Function (DCF), which provides basic method for contended access based on CSMA/CA; and Point Coordination Function (PCF), which provides uncontended access by allocating part of the bandwidth to some users. We are interested to analyze the most commonly available access method, and that is CSMA/CA. In this paper we refer in our analysis to this basic access method, which is shown in Fig. 1.

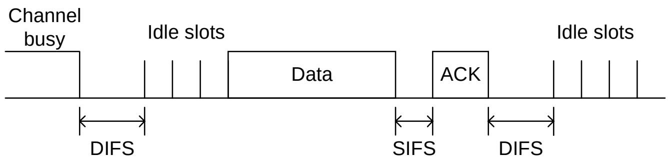

Fig. 1. IEEE 802.11 basic access method

The period that is observed here is Contention Period (CP) that is the period when MUs content for an access to the wireless channel. Mobile users transmit and receive packets using one access point (AP) that first buffers packets and then transmits them. In our analysis we observe only the upstream case, which is more sensitive to collisions. Also, we use finite size buffers in the simulations, so we may have losses due to a packet arrival in a full buffer. Packets are generated from users randomly. Inter-arrival time between two packets is modeled as a stochastic variable following the exponential distribution:

$$P_\lambda(t) = \lambda e^{-\lambda t} \quad (1)$$

where $P_\lambda(t)$ is the probability distribution function (pdf), and λ is the average packet arrival rate. Then, mean value of the inter-arrival time equals to $t_{ia}=1/\lambda$. For example, if a user transmits with bit rate of R=1Mbps and packet length is 1500 bytes, then he would generate packets with rate of λ=1048576bps/(1500*8 bits/packet)=87.38 packets/s. In this example average time between two successive packets would be 1/87.38=11.44 ms (Eq.2). This means that on average every 11.44 ms comes one packet. If the user's bit rate or/and packet length are different then this value is also changed.

$$t_{ia} = \frac{packet\ length}{R} \quad (2)$$

If two or more users are sending packets at the same time then a collision occurs. To avoid collisions mobile users in IEEE 802.11 WLAN utilize the CSMA/CA method. The CSMA/CA protocol is a random access protocol that is targeted to prevent or minimize collisions. In the case of a collision, each mobile station executes so-called Binary Exponential Backoff retransmission algorithm to resolve the collision and maintain the stability of the wireless channel.

At first MU senses the wireless channel. If it is busy, MU waits until it gets free. After that moment MU waits additional interval called DIFS (DCF-IFS Distributed Coordination Function - Inter Frame Space). The value of DIFS is taken to be 30 µs. Critical moment is at the end of this interval. After that every user that has packets to transmit will send and a collision will occur. However, to avoid such situation, which is undesired due to scarce wireless medium, 802.11 WLAN uses Backoff Algorithm. According to it, MU waits supplementary time that is a product of randomly generated number and a given time interval called time slot (TS). Randomly generated number can belong to the interval [0, CW-1], where CW stands for “Contention Window” and it has an integer value from interval [CWmin, CWmax]. Typical values for CWmin and CWmax are CWmin=8 and CWmax=1024. TS is defined as time that is needed for a station to detect a transmission of another station, and its standardized value is TS=20 µs.

After DIFS interval ends, every MU backs off a time period that can be from one time slot to 7 time slots. For example, if exist 3 users and they generate extra time of 2 TSs, 4 TSs and 4 TSs correspondingly then first user can use the channel and other will have to wait until first user finishes with transmission. But if the order is: 2 TSs, 2 TSs and 5 TSs then first and second MU will collide. The program code for this simulation is written so that collision is registered and after that, mobile users that collide (in this example 2 of them, 1st and 2nd) will generate random number from 0 to 15. So, probability of colliding after this action is diminished. If once again this happens then randomly generated number would have values from 0 to 31 and so on. In the simulation random number for the backoff algorithm are generated by uniform probability distribution function.

After successful packet reception in the buffer, AP waits time interval called SIFS (Short Inter Frame Space) and then transmits message called ACK to let the user know that its packet is received [4]. SIFS represents time interval during which MU is changing its regime from a transmitter to a receiver. In the simulation SIFS=10 µs and ACK transmission time is 210 µs [3].

In our analysis we refer to several different QoS parameters, such as: packet delay, throughput per user, number of collisions, number of rejected packets and number of passed packets, using different traffic conditions (i.e. bit rate) and different number of users served buy a single AP. The packet length is 1500 bytes.

Packet delay is defined as time interval between the instant when the packet enters into the buffer (which, in fact, is the same moment when it is generated by the user because air propagation time is ignored) and instant when the same packet leaves the AP. Packet delay is a sum of its waiting time in the buffer and serving time. For packet length of 1500 bytes and link speed of 11 Mbps the serving time is calculated as:

$$t_{\mu} = \frac{1500 * 8bits}{11534336bits/s} \approx 1.04ms \qquad (3)$$

Throughput for one user presents number of his packets that left AP multiplied by packet length (expressed in bits) divided with time interval that is difference between moment when last packet of the same user left AP and moment when first packet of the same user left AP.

Number of rejected packets is the number of those packets who tried to enter into the buffer while it was full. It depends upon the buffer size (how many packets the buffer can accept), packet length, number of users, and bit rate.

Number of occurred collisions is the number of events when two or more users at the same time tried to send packets. Of course this depends on number of users.

III. SIMULATION RESULTS

We have performed several simulation experiments with aim to obtain QoS behavior of 802.11 WLAN. In first set of simulations we are changing the bit rate per user for the case with single user, and for the second case with two users served by one AP (in the latter case both users are transmitting at the same rate). In the second set of simulations we change number of users served by a single AP.

The results of the first set of experiments regarding the behavior of throughput per user, packet delay, number of rejected packets, number of occurred collisions and number of passed packets versus transmitting bit rate of users, are shown in Figures 2-6, respectively. In the simulations the link speed is set to 11 Mbps (802.11b standard), packet length is 1500 bytes and buffer length expressed in number of packets that can be received is 5 times greater than number of users.

In the first case there exists only one user that varies his transmission bit rate from 1 Mbps to 11 Mbps. We observed that his throughput at source bit rate equal to the wireless link capacity (i.e. 11 Mbps) and assuming error-free wireless environment, is not 11 Mbps, but it is approximately 8 Mbps (Fig. 2). However, this result can be shown via analytical approach as well. For instance, the time for the transmission of a single packet is equal to [5]:

$$T_{single} = t_{pr} + t_{tr} + SIFS + ACK + DIFS \qquad (4)$$

where t_{pr} is the preamble time (144 µs), t_{tr} is the frame transmission time (packet length/transmitting bit rate), SIFS=10 µs, DIFS=30 µs, ACK is the ACK transmission time (210 µs). If user’s transmitting bit rate is 11 Mbps it means that t_{tr}=1500*8/11534336=1.04 ms. So, the proportion r of useful bandwidth is 0.725, which is calculated using the following relation:

$$r = \frac{t_{tr}}{T_{single}} \qquad (5)$$

Then, the throughput of the user is 0.725*11=7.975 Mbps, which is exactly the same as the results from the simulation analysis.

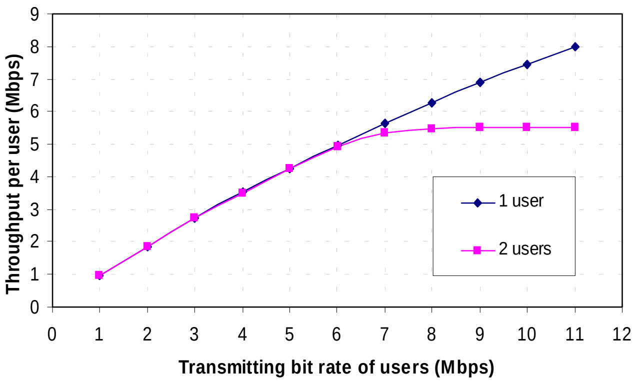

Fig. 2: Throughput per user for different values of transmitting bit rate

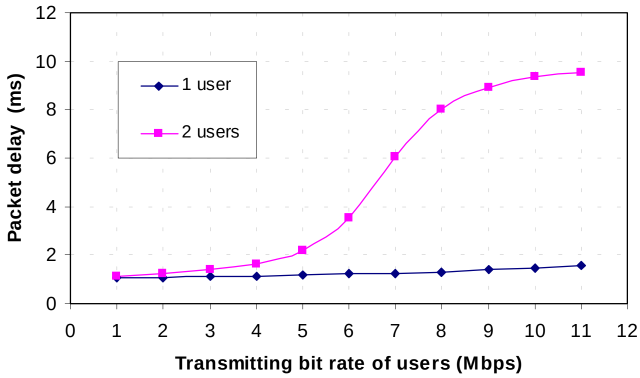

Fig. 3: Packet delay for different values of transmitting bit rate

For example, if user transmits at bit rate of 2 Mbps, then t_{tr}=12000bits/2097152bps=5.72 ms, r=5.72ms/6.114ms=0.936 and his throughput would be 0.936*2 Mbps=1.872 Mbps (refer to Fig. 2).

In the second case there exist two users that transmit simultaneously and with equal bit rates. One can notice from the results shown in Fig. 2 that when transmitting rate reaches 7 Mbps throughput per user, then the average throughput per user stabilizes around 5.5 Mbps. So, we get that we have higher utilization of the wireless link in the case of multiple users compared to the case with a single user.

In this simulation experiment number of rejected packets is relatively small. But, if the buffer size is less than the one used in this simulations, then the number of rejected packets would increase and the throughput of the user would decrease.

In the case with single user average packet delay is increasing with the transmitting bit rate (Fig. 3). When transmitting bit rate reaches infinity, the buffer will be full all the time (for any finite size), and hence packet delay will be equal to the maximum waiting time in the buffer. In our case, buffer size is set to 5 packets (including the serving one), so maximum delay will be 5*1.04ms=5.2 ms. Also, in the case with single user it is trivial to say that number of occurred collisions is zero (Fig.5). In the case of two users packet delay increases, but starts with saturation (due to finite buffer size of 10 packets) near transmitting bit rate of 11 Mbps (Fig.3). This is the result of collisions between the two users.

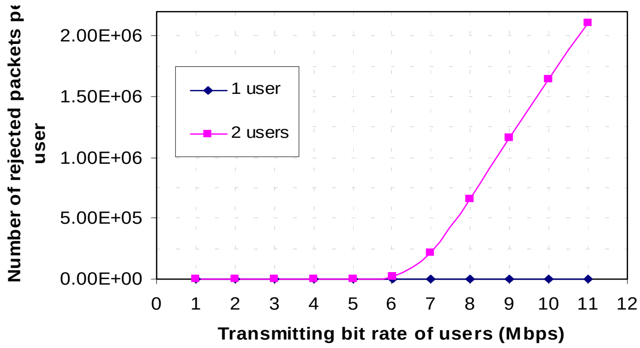

Fig. 4: Number of rejected packets per user for different values of transmitting bit rate

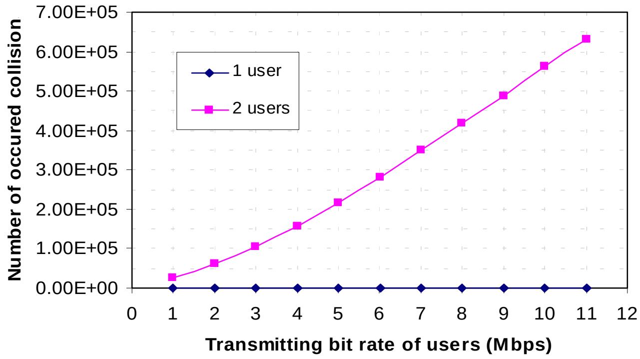

Fig. 5: Number of occurred collisions for different values of transmitting bit rate

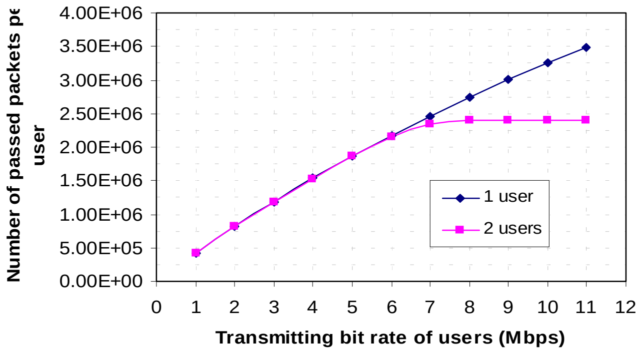

Fig. 6: Number of passed packets per user for different values of transmitting bit rate

So, packet delay would be theoretically 10*1.04ms=10.4ms. This value is asymptotical and can be reached when transmitting bit rate of users reaches infinity. Simulation was done for transmitting bit rates in range 11-20 Mbps (for transmitting bit rate of 20 Mbps packet delay is 10 ms) and the results confirms that packet delay very slowly achieves that theoretical value, which is maximum for the packet delay under previously given assumptions.

While there are no rejected packets or collisions when there is only one user, for the case with two users served by single AP number of rejected packets and collisions are increasing due to finite buffer size (Fig.4-5). Due to statistical multiplexing of traffic from multiple users, number of passed packets is increasing as well (Fig. 6). Because wireless link speed is 11 Mbps t_{μ}=1.04 ms (Eq.3). This means that for an interval of 1 second one AP can serve maximum 1/1.04 ms=961.5 packets. Simulation lasts 5000 seconds, so maximum number of passed packets can be around 4807692. This value is not achieved for the bit rate of 11 Mbps because t_{ia} is not 1.04 ms, but t_{ia}=1.04+0.394=1.434 ms. For higher user's bit rate that value can be reached.

In Fig. 6 number of passed packets starts to get saturated at value of 2400000 packets when transmitting bit rate reaches near 7 Mbps (it is similar to the throughput behavior, as one should expect) which is half of the previously mentioned maximum number of passed packets.

In the second simulation experiment, we vary the number of users served by single AP. In Figs. 7, 8 and 9 are shown analyses of throughput per user, packet delay and occurred collisions, using variation of number of users and total emitting bit rate (T.E.B.R.). We use three different T.E.B.R. values, and they are: 5.5, 11 and 16.5 Mbps, i.e. 50%, 100% and 150% of the wireless link speed. This means that, for example, if there are 10 users and T.E.B.R. is 16.5 Mbps then each one of them will transmit with 1.65 Mbps. From Fig. 7 can be seen that when 1 user transmits his throughput is shorten accordingly to Eq.5 and when number of users increases value of throughput per user decreases due to the increased number of collisions (Fig.9). Packet delay (Fig.8) also rises because buffer size is 5 times greater than number of users.

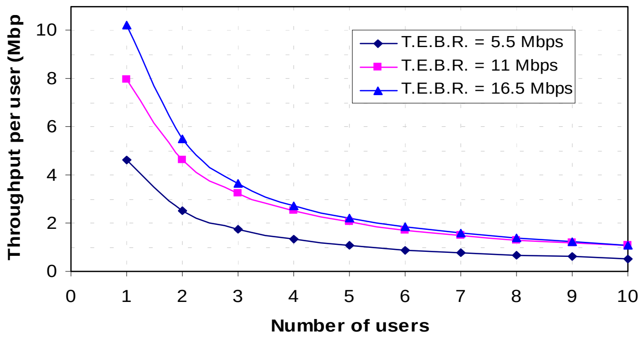

Fig. 7: Throughput per user for different number of users

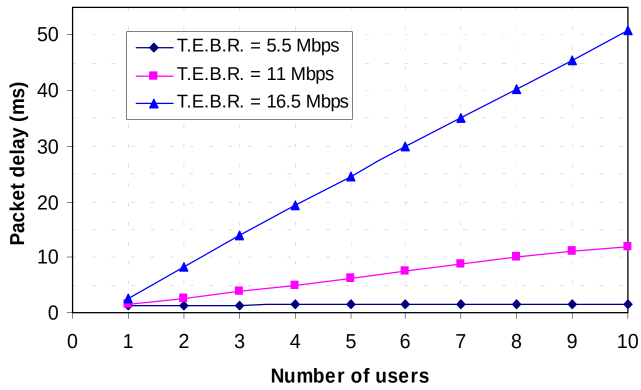

Fig. 8: Packet delay for different number of users

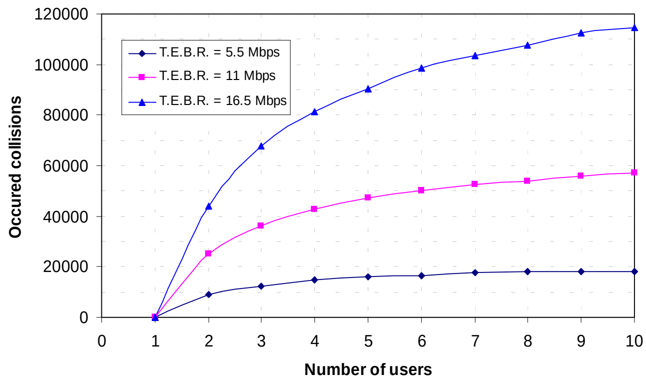

Fig. 9: Occurred collisions for different number of users

IV. CONCLUSIONS

In this paper we have performed performance analysis of IEEE 802.11 WLAN regarding mainly the MAC protocol specification. Our analysis targeted QoS parameters, such as throughput and packet delay under different traffic conditions in the network. In the analysis we have used simulation methodology.

The results showed that due to access method in 802.11 WLAN, the efficiency of utilization of wireless link capacity is around 73%. We have shown that more users increases the utilization of the bandwidth, but on the other side increases the average packet delay and number of collisions and rejected packets as well. Additionally, we have also shown that too many users will degrade the performance of the WLAN.

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