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Efficient collision resolution protocol for highly populated wireless networks

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Efficient Collision Resolution Protocol for

Highly Populated Wireless Networks

by

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Abstract

An efficient Medium access control (MAC) protocol is an important part of every wireless system. It prevents multiple devices from accessing the channel at the same time by defining rules for orderly access. Due to the fact that wireless networks have received enormous popularity in the last 10 – 15 years, number of users in these networks increased dramatically. Thus, support of large user population for modern MAC protocol is not an option anymore but a necessity, especially for dense Wireless Sensor Networks (WSNs). This work proposes a novel random MAC protocol for wireless networks named BCSMA/CA that can provide high channel throughput for very large number of users. The main idea of the protocol is based on the absence of backoff intervals where the channel is idle and using this time for active collision resolving. By presented analytical model and means of simulation, performance of the proposed protocol itself as well as in the framework of 802.11 Distributed Coordination Function (DCF) is explored. Corresponding comparison shows that 802.11 under BCSMA/CA is more suitable for applications where number of users is large compared to the traditional DCF approach.

Glossary

ACK	Acknowledgement
BCSMA/CA	Backoffless CSMA/CA
BEB	Binary Exponential Backoff
CD	Collision Detection
CDF	Cumulative Distribution Function
CDP	Collision Detection Slot
CR	Collision Resolution
CRP	Collision Resolution Period
CSMA	Carrier Sense Multiple Access
CSMA/CA	CSMA with Collision Avoidance
CSMA/CD	CSMA with Collision Detection
CTS	Clear to Send
CW	Contention Window
DCF	Distributed Coordination Function
DIFS	Distributed Interframe Space
DSSS	Direct Sequence Spread Spectrum
IEEE	Institute of Electrical and Electronics Engineers
LAN	Local Area Network
MAC	Medium Access Control
MAC_{hdr}	MAC header
PHY_{hdr}	Physical header
PMF	Probability Mass Function
QoS	Quality of Service
RTS	Request to send
RV	Random Variable
SIFS	Short Interframe Space
WCSMA/CD	Wireless CSMA/CD
WSN	Wireless Sensor Network

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Summary of Contribution

- Proposed algorithm for random channel access
- Theoretical analysis of saturation throughput of the channel
- Comparison with traditional 802.11 DCF Basic access method
- Comparison with traditional 802.11 DCF RTS/CTS access method
- Significant improvement of channel throughput for large number of users

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1. Introduction

Number of applications that employ wireless networks is constantly growing. In comparison with traditional wired networks they give various benefits as less cost of deployment, much easier installation and management. Besides, wireless networks can be set up in areas where wires are impossible to place. However, wireless environment brings some peculiarities which affect the development of such networks. The most important of them is the broadcast nature of wireless communications that leads to inability of devices to transmit and receive information at the same time. This fact hampers the use of random Medium Access Control (MAC) protocols proposed for wireline communications.

The First random MAC protocol for wireless communication was Aloha [1]. Pure Aloha allows users to start transmission as soon as it is needed regardless of channel condition. Collisions and data corruption are unavoidable and if collision has been detected, then users involved immediately retransmit the frame with probability p or wait with probability of 1 – p to retransmit a frame. Slotted Aloha is a modification of pure Aloha and assumes that time is divided into time slots and all devices are synchronized to start their transmission at the beginning of a time-slot, therefore reducing collision vulnerable period and making utilization of the channel twice larger. Appearance of carrier sensing technique significantly improved channel access in wireless environment and originated a huge class of MAC protocols. The most popular of them is the Carrier Sense Multiple Access with Collision Detection (CSMA/CD) [2]. Exceptional performance and simplicity made this protocol an integral part of the IEEE 802.3 standard for wired Local Area Networks (LANs) other known as Ethernet. However, being designed for wired networks, CSMA/CD has very low efficiency in wireless communications due to the reasons mentioned above. In general, the idea of collision detection either in wired or wireless environment is based on preventing entire frame transmission if collision has occurred, therefore reducing the amount of time spent by the system in useless transmission. References [3], [4], [5] are devoted to the collision detection problem in wireless LANs. In [3] Rom describes a slotted medium where each station shortly after beginning its transmission stops in a randomly chosen time slot called Collision Detection (CD) slot and evaluates channel conditions for a presence of other transmissions. If foreign activity has been detected then participants abort their transmissions at the end of time period called Collision Detection Period (CDP) and then backoff. Paper [4] gives a CSMA/CD cross-layer design for multipacket-reception capable physical layers while [5] employs data channel and out of band control channel for exploring channel conditions.

Collision detection is not the only way to improve network performance. IEEE 802.11 Distributed Coordination Function (DCF) [6] utilizes different channel access method called CSMA with Collision Avoidance (CSMA/CA) that tries to avoid collisions as opposed to detect them. Each station in CSMA/CA generates a random backoff interval in time slots according to Binary Exponential Backoff (BEB) scheme. The corresponding counter is decremented each time the medium is found idle during the slot duration or freezes if it is busy. Station is allowed to transmit only after the counter reaches zero. Thus, collision avoiding practically implies the way of minimizing the probability for a frame to collide. Study of different backoff strategies has received popularity in this domain and authors of [7], [8] showed that BEB with its default parameters provided by 802.11 DCF is not always optimal. Other methods are proposed in [9] and [10]. [9] describes a method where collisions are avoided by disjointly maintained set of time slots for transmission whereas researches in [10] suggest including the backoff duration into the MAC header in order to exchange this information among users and therefore eliminate collisions.

This thesis proposes a novel MAC protocol for wireless networks named Backoffless CSMA/CA (BCSMA/CA). BCSMA/CA has some similarity to the protocol described in [3] but with some important modifications. If a user senses any other transmissions during the CD slot it immediately stops its own transmission. This change leads to the fact that BCSMA/CA employs collision resolving instead of collision detection. In addition, the proposed protocol does not require any additional information exchange for the purpose of synchronization between transmitter and receiver but requires starting transmission with a preamble. Another important feature of BCSMA/CA is that it assumes 1-persistence together with no backing off channel access strategy.

The rest of the thesis is organized as follows. Chapter 2 describes the proposed protocol in details. Chapter 3 gives a theoretical analysis of saturation throughput of the channel using classical probability theory. Next section shows the most important results of the analytical model, gives some recommendations on choosing the system parameters and presents the result for BCSMA/CA implemented in 802.11 DCF. Finally, chapter 5 concludes the thesis.

2. Protocol description

All notations in this work follow the reasoning in [11] where possible. [11] presents throughput analysis of WCSMA/CD protocol that is described by Rom in [3]. In BCSMA/CA, if user, who has packet to send, finds the channel to be idle during the time period with duration "*a*" (Figure 1) , then location of Collision Resolution (CR) slot is randomly chosen from the closed interval [1, CRP] according to some distribution specified in the analysis section. CRP stands for collision resolution period and is a system design parameter since it has to be equal for all stations in the network. CRP affects channel throughput and there is always an optimal value of CRP for specific set of system parameters. If the channel is busy then user senses the channel until it is free for an "*a*". Transmission always begins with a preamble (not useful data) that has a variable length depending on CR slot location. Preamble is transmitted until the CR slot where user stops and evaluates channel conditions (listens to channel). If foreign transmissions have been detected then user refrains from further participation in order to release the channel for others and expects it to be idle again for a duration of "*a*". User is allowed to start data transmission if no channel activity has been found during the CR slot. For the system to be functional duration of CR slot denoted in Figure 1 as "*w*" has to be less than the time needed to decide whether the channel is free before originating a new transmission stage (*a*). If this condition is not met, then user that is about to join the channel and performs initial carrier sensing will not be able to detect the user that is currently on a CR stage channel listening, thereby causing a collision. The same consideration was made in [3].

Behaviour of the described protocol can be referred to as 1-persistent type since devices are given channel access as soon as they sense it is idle for a certain amount of time. Thus, having two or more users awaiting current transmission to be over, technically leads to a collision that ideally will be resolved. Figure 1 shows successful collision resolving for three users. From the figure it follows that User 1 stops first and detects Users 2 and 3. Therefore, he terminates the transmission as well as User 2 terminates his transmission because User 3 is active. Consequently, User 3 has remained alone and senses an idle medium during the CR slot followed by data transmission. However, it is important to understand that successful collision resolving in BCSMA/CA is not always guaranteed. Scenario where collision resolving mechanism fails is depicted in Figure 2. Here User 1 successfully detects other users and aborts his transmission whereas User 2 and 3 are not able to detect each other since they have chosen the same CR slot therefore thinking that medium is free. As a result both of them start using the channel causing a collision that can now be resolved only on higher levels. Thus, in case where two or more users have chosen the same largest (among all chosen) CR slot is not resolvable.

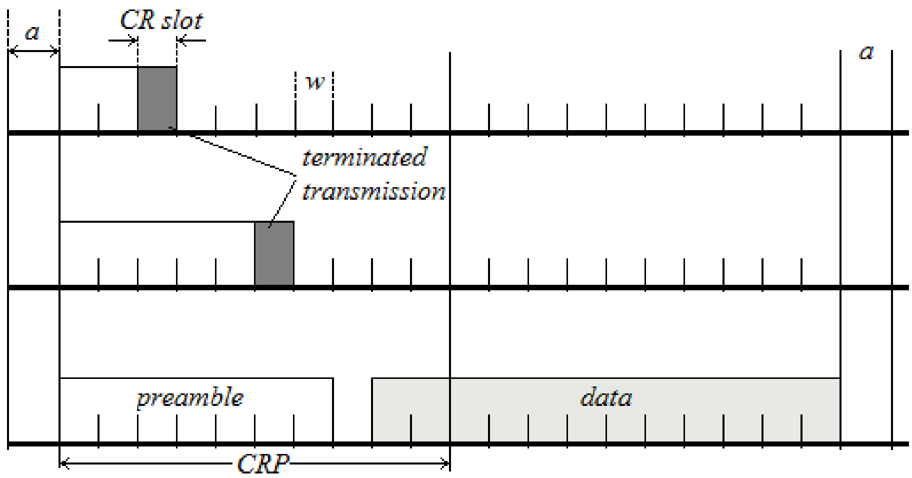

Fig. 1. Successful collision resolving

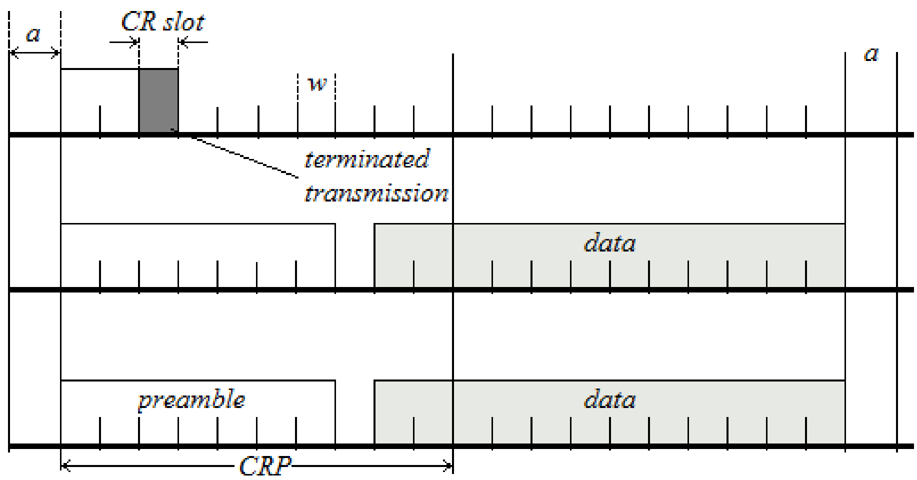

Fig. 2. Failure of collision resolving

Figure 3 summarizes this section and shows the block-diagram of simplified operation of an end device in BCSMA/CA network. Necessity of the condition whether chosen

CR slot is greater than the length of CRP is explained in the following sections and depends on the method by which the CR slot is chosen randomly.

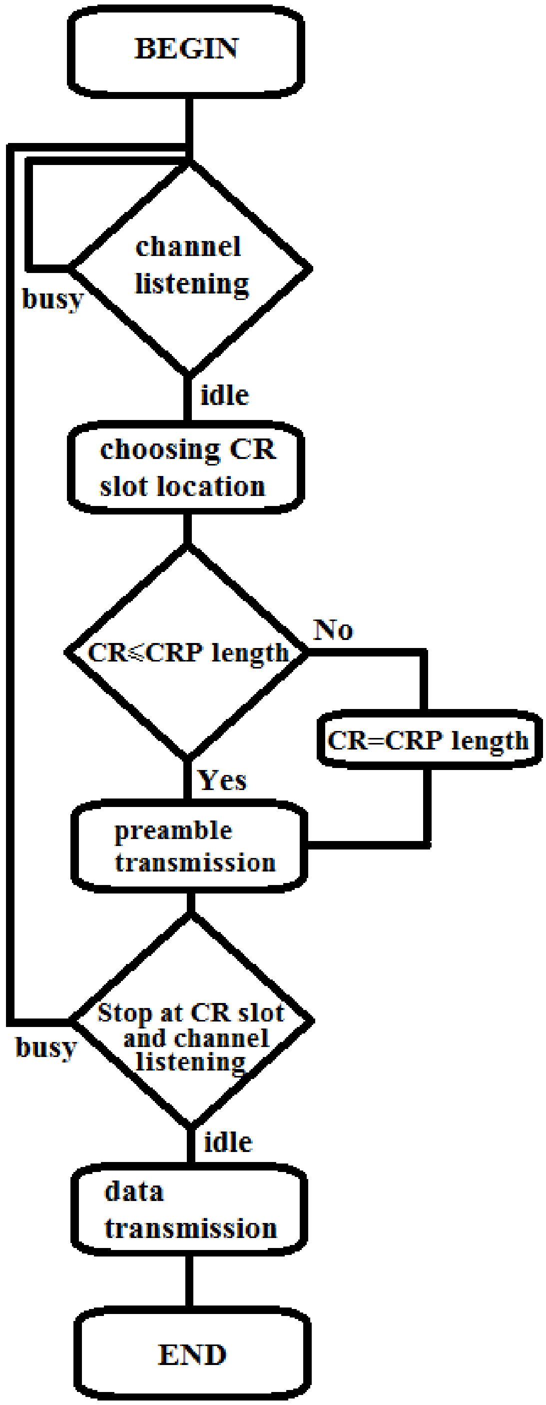

Fig. 3. Operation of an end device using BCSMA/CA

3. Throughput Analysis

Model description: In the analysis it is assumed that the medium is slotted after it has been sensed idle for time *a* and users can start their transmission only at slot boundaries – even weaker assumption of slotted medium than made in [3]. As was mentioned in the previous section *w* denotes the duration of the time slot. In this case it is easier to treat the time in terms of time slots. Thus, *R* and *L* denote the length of CRP and data packet in time slots respectively. For the purpose of simplification *L* is a fixed system parameter and channel is assumed to be idle providing error-free packet reception for *N* users with no hidden or exposed nodes. Without loss of generality *L/w* can be assumed to be an integer. The system is analysed under saturation condition meaning that each user always has a packet to send. Thus, this section provides throughput analysis for saturation mode which is defined in [12] as fundamental performance figure that shows the limit of system throughput with increasing of offered load. In other words, saturation throughput represents the maximum load the network can handle in stable conditions.

Throughput analysis: According to the definition, normalized throughput is a fraction of time the channel is used for useful transmission (data being transmitted) and therefore can be expressed as:

$$\eta = \frac{L(1-P_{mr})}{T_s(1-P_{mr})+T_cP_{mr}} \tag{1}$$

where P_{mr} is a probability that collision will not be resolved. T_s denotes time that passes in case of successful transmission whereas T_c is time that the channel wastes when collision occurs. The complementary probability of P_{mr} is the probability that the collision would be resolved. This happens when all users choose CR slots which are less than k except one user that picks the k-th slot. Thus, for given R and N this complementary probability is

$$1 - P_{mr} = \sum_{k=1}^{R} Np(k)\,\mathrm{P}^{N-1}(k-1) \tag{2}$$

where $p(i)$ is a Probability Mass Function (PMF) and $P(i)$ is a Cumulative Distribution Function (CDF) of random variable (RV) k that means selected by the user slot number. Expressions for T_s and T_c are system dependent and always functions of RV r_{max} which represents the largest chosen slot number. Probability of the i-th slot to be the largest or, in other words, PMF of r_{max} is:

$$p_{r_{\max}}(i) = \Pr(r_{\max} = i) = \sum_{j=1}^{N} C_j^N p^j(i) P^{N-j}(i-1),\ i \in [1, R] \tag{3}$$

where C_j^N is the number of combination of N taken j at a time. The fact that (1) now is also a function of r_{max} leads to an expression for averaged saturation throughput of BCSMA/CA:

$$\overline{\eta} = E[\eta(r_{\max})] = \sum_{i=1}^{R} \eta(i)\, p_{r_{\max}}(i) \tag{4}$$

that can be determined for the given R, L, N, T_s, T_c and an arbitrarily chosen distribution of k. The rest of the section specifies two different distributions – uniform and exponential and gives all required derivations in order to obtain the saturation throughput using expression (4).

A) Uniform distribution

For uniform distribution, the probability of choosing any time slot within the CRP is the same and equal to 1/R. Thus, the PMF and CDF of uniformly distributed RV k are given by:

$$p(i) = \begin{cases} 1/R, & i \in [1, R] \\ 0, & otherwise \end{cases} \tag{5}$$

$$P(i)=\begin{cases}0, & i\le 0\\ i/R, & 0<i\le R\\ 1, & i>R\end{cases} \qquad (6)$$

Substituting (5) and (6) into (2) and solving for P_{mr} using standard algebra gives:

$$P_{mr}=1-\frac{N}{R^N}\sum_{i=1}^{R}(i-1)^{N-1} \qquad (7)$$

Substituting (5) and (6) into (3) results in:

$$p_{r_{\max}}(i)=\sum_{j=1}^{N}C_j^N\left(\frac{1}{R}\right)^j\left(\frac{i-1}{R}\right)^{N-j},\ i\in[1,R] \qquad (8)$$

Thus, using equations (1), (7), (8) and (4) a closed-form expression for saturation throughput given R and N can be found.

$$\bar{\eta}=\sum_{\xi=1}^{R}\frac{LNS}{T_sNS+T_c(R^N-NS)}\sum_{j=1}^{N}C_j^N\left(\frac{1}{R}\right)^j\left(\frac{\xi-1}{R}\right)^{N-j} \qquad (9)$$

Here $S=\frac{N}{R^N}\sum_{i=1}^{R}(i-1)^{N-1}$ and both $T_s = T_s(\xi)$, $T_c = T_c(\xi)$.

B) Exponential distribution

Due to continuous nature of exponential distribution it is impossible to implement it directly. For this purpose we use a quantization technique where each number if it is smaller than *R-1* is assigned to the nearest larger integer or to the *R* otherwise. Thus, PMF is given by:

$$p(i)=\Pr(k=i)=\int_{i-1}^{i}\lambda e^{-\lambda x}dx,\ i\in[1,R-1] \qquad (10)$$

or (if the number exceeds *R-1*)

$$p(R)=\Pr(k=R)=\int_{R-1}^{\infty}\lambda e^{-\lambda x}dx=1-p_{R-1} \qquad (11)$$

Consequently the CDF is:

$$P(i) = \Pr(k \le i) = \sum_{\gamma \le i} \Pr(k = \gamma) = \sum_{k \le i} p_k, i \in [1, R] \qquad (12)$$

Here λ is the parameter of exponential distribution (λ^{-1} is the mean value) and has to be defined along with other parameters as R, L, N, T_s, T_c. We notice again that T_s and T_c are functions of RV r_{max} and therefore not constants. Thus, substituting (10), (11), (12) into (2) and (3) and then using (4) together with (1), saturation throughput of BCSMA/CA in case of exponential distribution can be calculated.

4. Results and Discussion

This section is divided into several parts. Part A gives a comparison of BCSMA/CA protocol for uniform and exponential distribution and demonstrates the superiority of the latter. In Part B the effect of different parameter combinations on system performance are investigated. Next section shows the saturation throughput of BCSMA/CA and WCSMA/CD for the same set of parameters. Finally, part D describes the state-of-the-art 802.11 distributed coordination function (DCF) and a method for embedding BCSMA/CA in it.

A) Comparison of uniform and exponential distribution.

In order to compare the two proposed distributions we show the most important results of analytical model. Figures 4 and 5 depict probability of unsuccessful transmission and saturation throughput versus number of users respectively. It is important to say that propagation delay is negligible here since it is assumed to be much smaller than slot duration therefore giving values of T_s and T_c as:

$$T_s = T_c = a + wr_{max} + L, \qquad (12)$$

Since BCSMA/CA does not distinguish whether transmission is successful or not, time the channel is spent in collision and successful transmission are equal. The values of all other parameters that have been used to obtain numerical results are detailed in Table I.

L	200
R	45
w	1
a	2
λ	10/R

Table 1. Parameters used to compare uniform and exponential distribution

From Figure 4 it follows that probability for the packet to collide in case of uniform distribution grows rapidly and is over 0.7 for a hundred users whereas the same probability for exponential distribution grows extremely slowly so that it is even difficult to notice. This fact can be explained by nature of exponential distribution where choosing small values is most likely. Thus, any new user does not affect the system performance significantly since the slot number he chooses is also small and probably not the largest. For the uniform distribution it is not true. Users here choose any slot with equal probability and therefore the chosen slot number has much higher probability to be selected by anybody else and be the largest at the same time. Thus, it is not a surprise that saturation throughput shown in Figure 5 is so much different for proposed distributions. The blue dashed line representing the exponential distribution decays less than 5% over a span of 100 users with approximate throughput of 80%. In addition, exponential distribution is more flexibility and adaptive due to its parameter λ that can be adjusted according to environment and needs. For example, by changing λ for a certain group of users or applications Quality of Service (QoS) can be provided. Since the superiority of the exponential distribution is obvious, in the rest of the thesis by BCSMA/CA we imply BCSMA/CA with exponential distribution

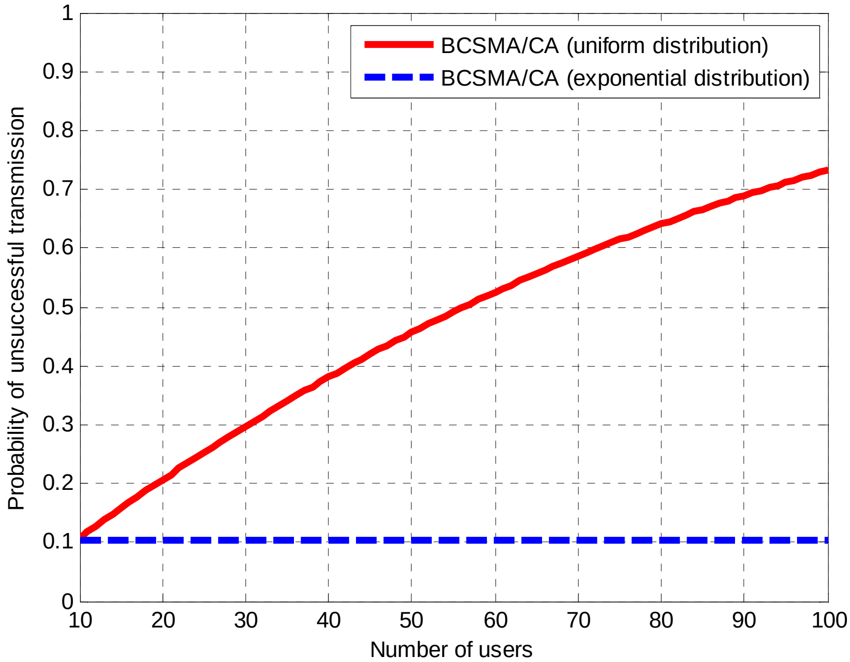

Fig. 4. Probability of unsuccessful transmission for uniform and exponential distribution

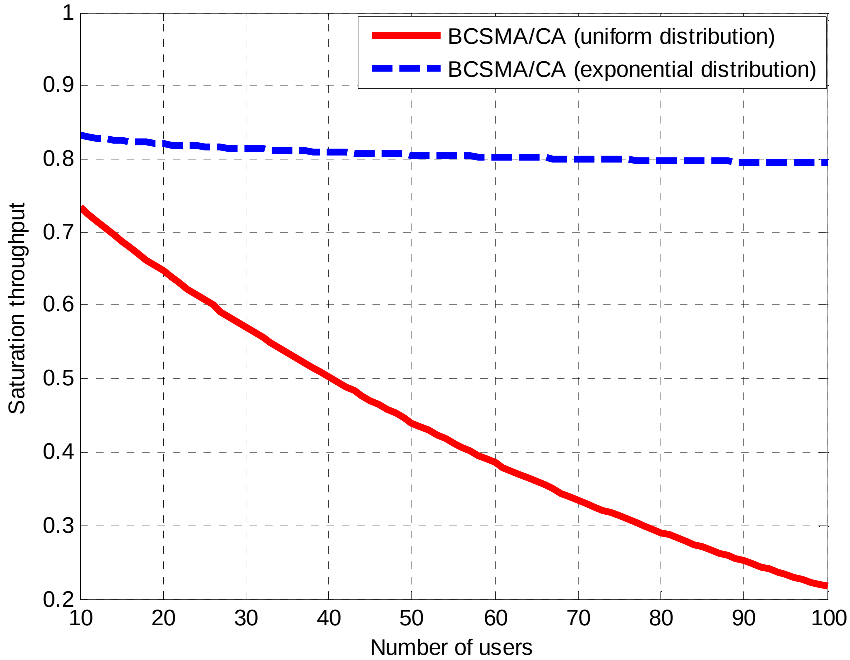

Fig. 5. Saturation throughput for uniform and exponential distribution

B) Effect of different parameters on system performance

As described in chapter 2, BCSMA/CA introduces variable overhead by using preamble along with CR slot. Thus, even if collision is resolved successfully the time of (a + wr_{max}) is wasted. This means that protocol performs better for large packets.

Such behaviour is confirmed by numerical results and depicted in Figure 6. Moreover, advantage of large packet size is also provided by ideal channel conditions since with error-prone reception probability that a single bit is corrupted and therefore probability that packet is retransmitted increases with the size of the packet. As in former section parameter values are summarized in Table 2.

L	800, 500, 200
R	50
w	1
a	2
λ	10/R

Table 2. Parameters used to evaluate the effect packet size

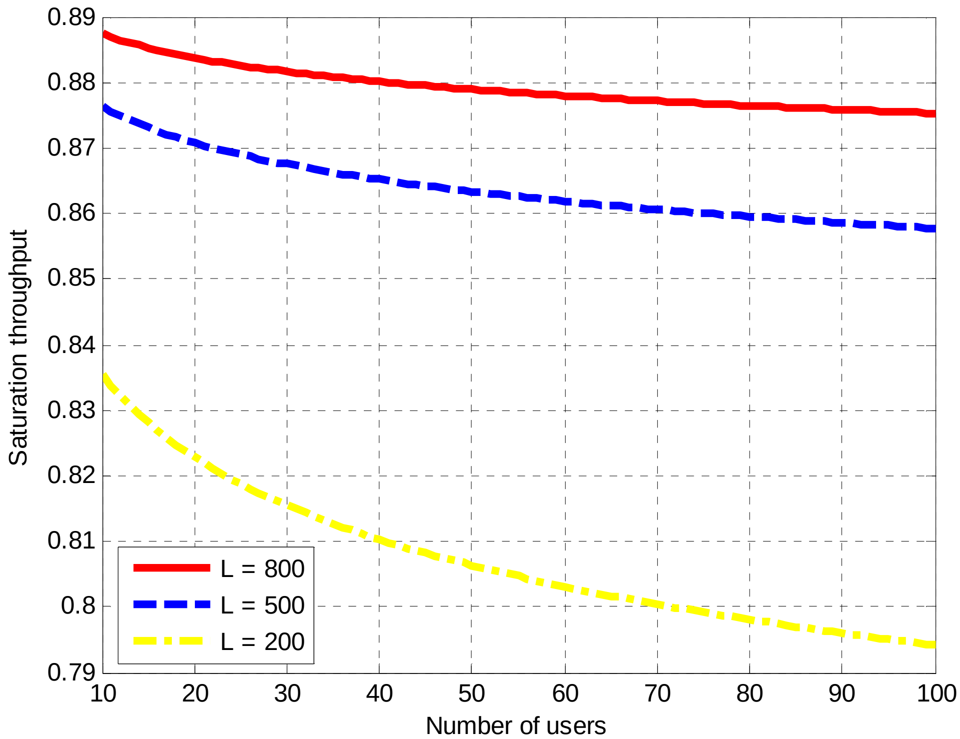

Fig. 6. Saturation throughput for different packet sizes

Another critical parameter which affects the system performance is the length of CRP. On the one hand, a small value of *R* reduces the overhead introduced by the protocol which increases the throughput. On the other hand, insufficient CRP length leads to a higher probability of unresolved collisions. As a consequence, optimal value of *R* for given number of users is expected. Figure 7 proves this fact and shows optimal duration of CRP for different number of users.

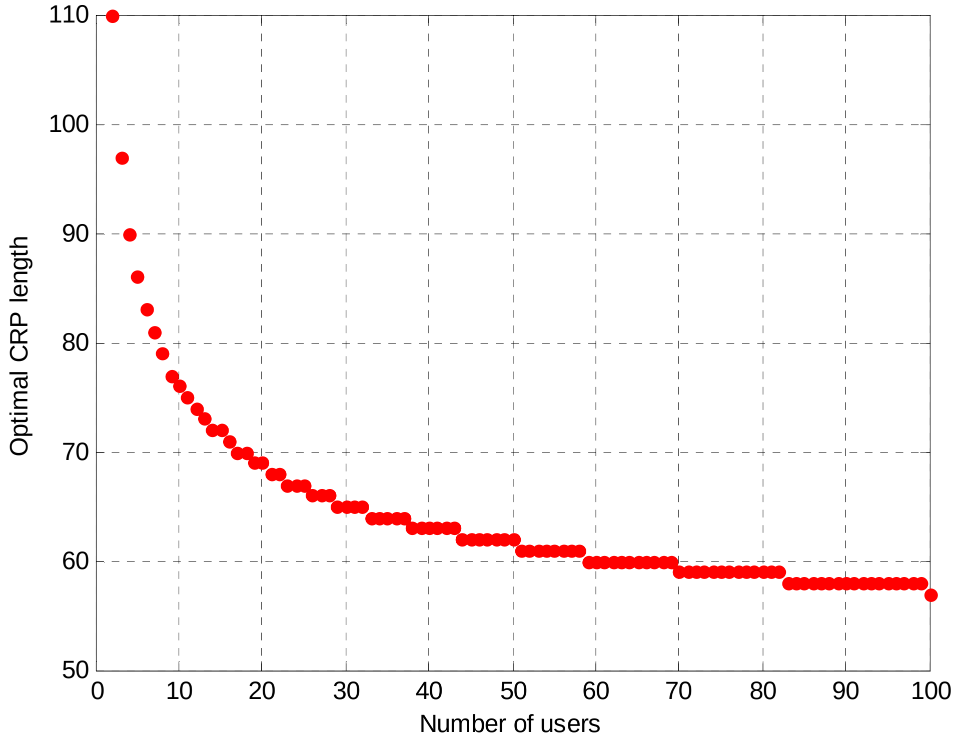

Fig. 7. Optimal CRP length for different number of users

However, using optimal CRP value is not practical. This information must be somehow distributed among the users in the network which is not an easy goal to achieve since the number of users in the network frequently changes. For that reason Figure 8 gives the channel throughput for optimal and fixed length of CRP. Relying on the previous figure, *R* value has been chosen to be close to the optimal value for large *N*. This choice explains the fact that sub-optimal curve is below the optimal one only when number of users is relatively small and matches it otherwise. Thus, using fixed CRP length does not affect the system throughput significantly, especially for large number of users.

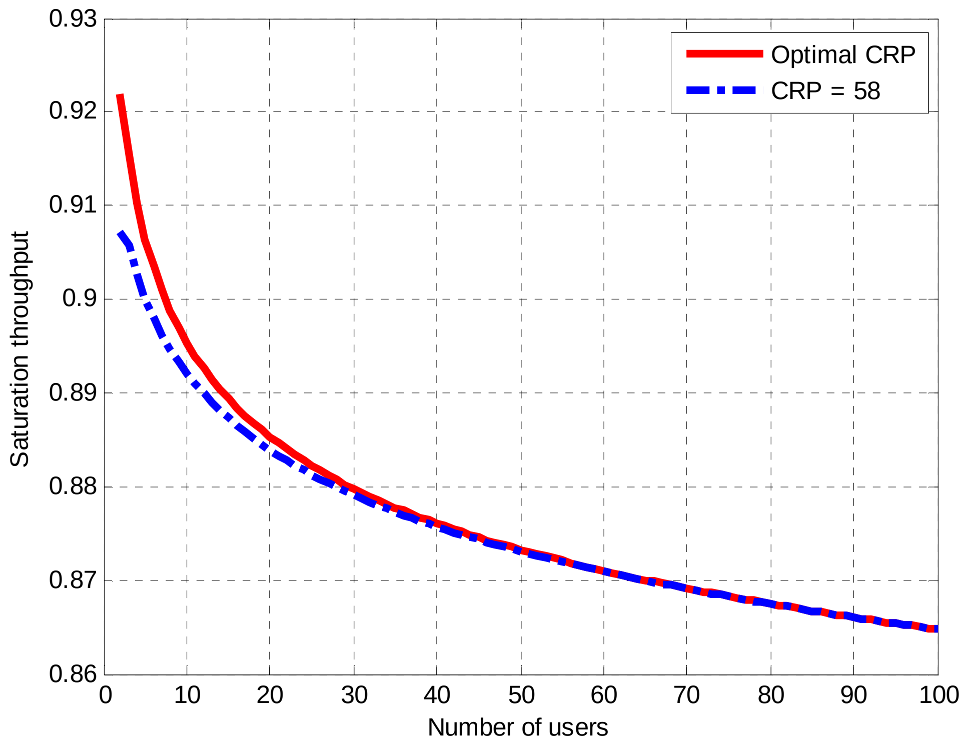

Fig. 8. Saturation throughput for optimal and sub-optimal CRP values

Parameters used to obtain two previous figures are given in Table 3.

L	500
R	Optimal or 58
w	1
a	2
λ	$8/R$

Table 3. Parameters used to evaluate the effect of CRP length

Parameter of exponential distribution λ also has an effect on saturation throughput. For simplicity, we assume that it is a function of CRP length (i.e. $\lambda = \lambda(R)$). Since in real system design CRP does not change Figure 9 investigates how λ influence the system performance in terms of throughput for a fixed sub-optimal value of R taken from Table 3. All other parameters also remained their values. Note that in figure 9, horizontal axis scale is different from that in figure 8.

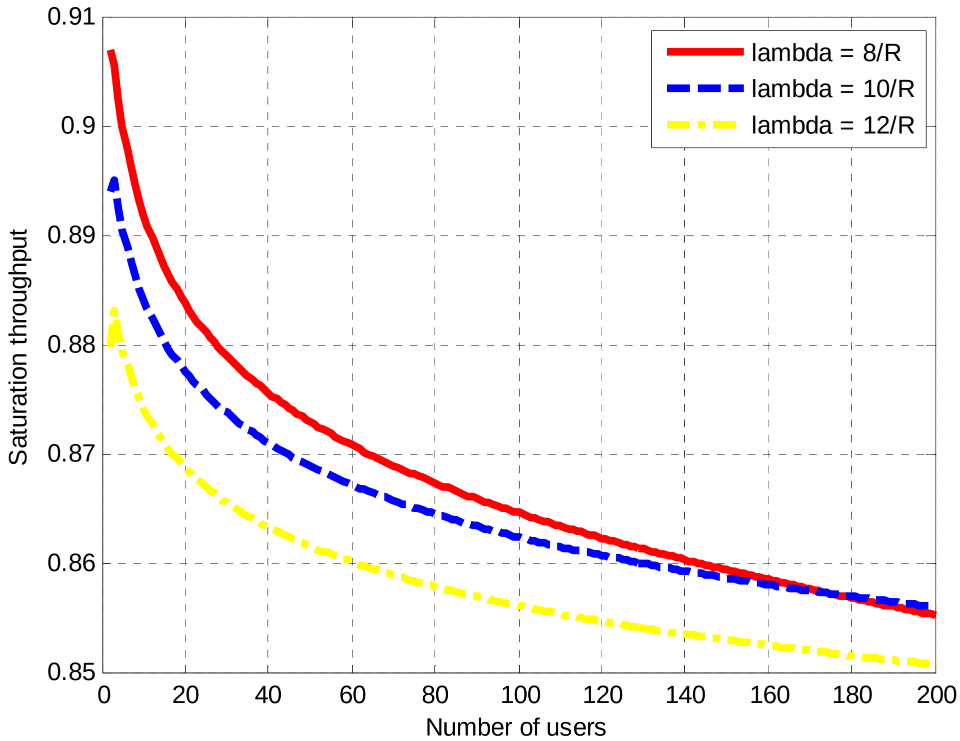

Fig. 9. Saturation throughput for different values of lambda

From the figure it follows that choice of λ can vary depending on the number of users expected. For example, if N lies in the range of 1 and 170 then it is better to use $\lambda = 8/R$. In the case when N is larger than 180 utilizing $\lambda = 10/R$ appears to be more preferable.

The next parameter examined in this section is the slot duration w. It is important to remember that slot duration and time required for sensing the channel idle before initiating a new transmission are related to each other. Thus, figure 10 shows the channel throughput for different combinations of w and a while keeping the same values of other parameters (Table 3). Presented results are intuitive since increasing values of w and a results in increased overhead and therefore lower values of saturation throughput. Note that slot duration is not a characteristic of the MAC layer. It is defined by physical layer and comprised of RX-to-TX and TX-to-RX turnaround times and energy detect time required for carrier sensing.

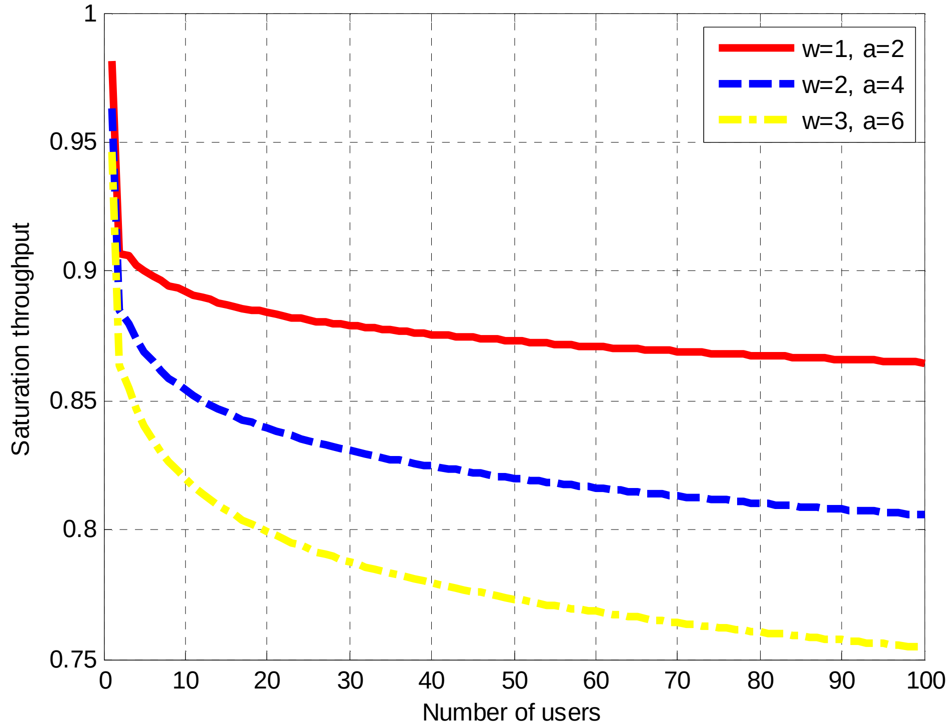

Fig. 10. Saturation throughput for different combinations of *w* and *a*

It is also interesting to investigate the effect of the number of users on the system. From figure 4 it follows that probability for a single packet to collide is constant within the specified range. Consequently, the question why does the channel throughput go down arises. Figure 11 clarifies that and shows the distribution of RV r_{max} given by (3). It can be seen from the figure that for larger N distribution moves to the right meaning that greater value of CR slot is most likely to be the largest among all chosen. This fact increases the average time of preamble and therefore explains throughput degradation. Table 4 reports the parameters used to obtain the results for this part.

L	500
R	60
w	1
a	2
λ	$12/R$

Table 4. Parameters used to evaluate the effect of the number of users

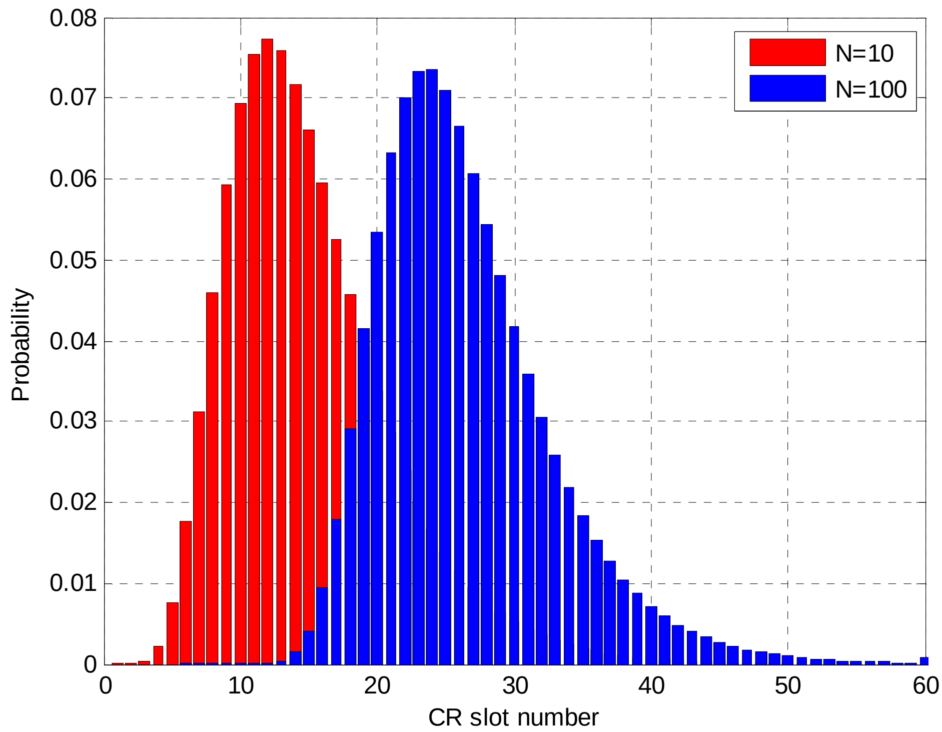

Fig. 11. Probability for the specific CR slot to be the largest for different number of users

C) Comparison of BCSMA/CA and WCSMA/CD

Some additional assumptions and changes have been made in BCSMA/CA in order to accurately compare it with WCSMA/CD. Medium now is synchronised in terms of time slots *a* and values of *L/a* and *a/w* are assumed to be integers. As in section A propagation delay is neglected and values of T_s and T_c are given by the same expression (12). Saturation throughput of both protocols is shown in figure 12 for the same set of parameters as in [11]. Figure 12 also presents curves for optimal and suboptimal CRP values in case of BCSMA/CA, whereas similar parameter named CDP in WCSMA/CD is always optimal. It can be noticed that for the given parameters extra time of *w* is wasted in every packet transmission when the largest CR slot is not even. However, in order to make the comparison with [11] fair, neither analysis nor simulation reflect this fact since [11] includes *w* into the packet length which is not correct. Although BCSMA/CA performs worse at the beginning, its superiority grows rapidly when the number of users increases. As it follows from the figure this statement is valid for the curve with optimal as well as suboptimal fixed CRP value since they are very close to each other.

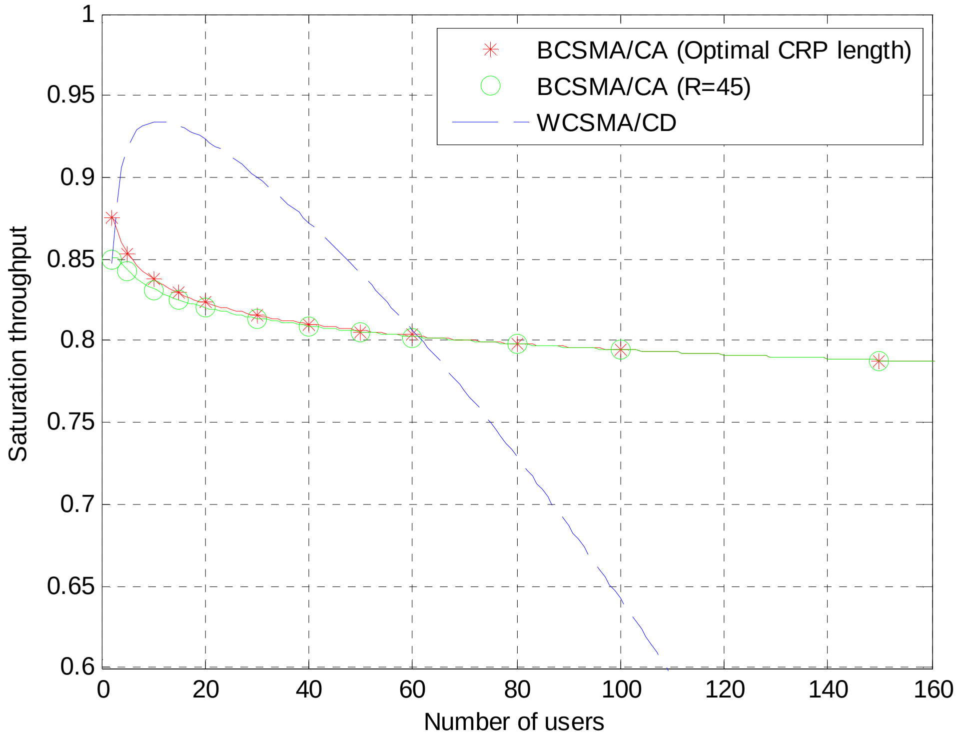

Fig. 12. Comparison of saturation throughput for BCSMA/CA and WCSMA/CD (a = 2, w = 1, L = 200, $\lambda = 10/R$, p = 0.03)

D) Performance of 802.11 DCF under BCSMA/CA

We begin by briefly describing the 802.11 DCF [6] and then discuss how it can benefit from the proposed protocol. Every station starts evaluating the channel immediately after it gets a new packet from higher levels. If the channel is sensed idle for a period of time called distributed interframe space (DIFS), the station is allowed to transmit. Otherwise, it keeps sensing until medium is free for the DIFS and after that generates an additional backoff interval according to BEB in order to minimize the probability of collision. It is important that after the DIFS station treats the channel in terms of time slots and therefore can transmit only at slot boundaries. BEB implies that backoff interval (which is now discrete) is uniformly distributed in the range of 0 and CW-1. CW is called contention window and varies depending on how many times the transmission of this packet failed. After the certain number of unsuccessful retransmissions called retransmission limit packet is discarded. The station decrements backoff time counter for each idle time slot and transmits only when it reaches zero. 802.11 DCF assumes that transmission is successful if sender receives and acknowledgement (ACK) that is transmitted by the receiver as soon as the packet is received correctly. The time between the RX packet reception and start of ACK transmission is called short interframe space (SIFS).

Along with the described technique named Basic access method, DCF also defines an optional mechanism known as RTS/CTS access method. This method follows the same rules above with an exception that station instead of data packet transmits special frame called request to send (RTS). Right after receiving the RTS and SIFS time recipient responds with a clear to send (CTS) frame. Requesting station is allowed to transmit only when it correctly receives the CTS message. RTS/CTS technique is used to deal with a hidden nodes problem as well as large number of users in the network. Operation of both Basic and RTS/CTS access method are depicted in figures 13 and 14 respectively.

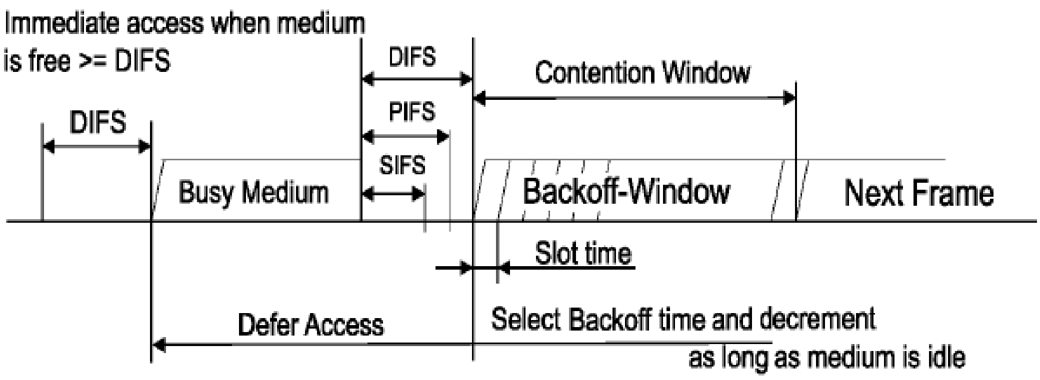

Fig. 13. Operation of 802.11 DCF (Basic access method) [6]

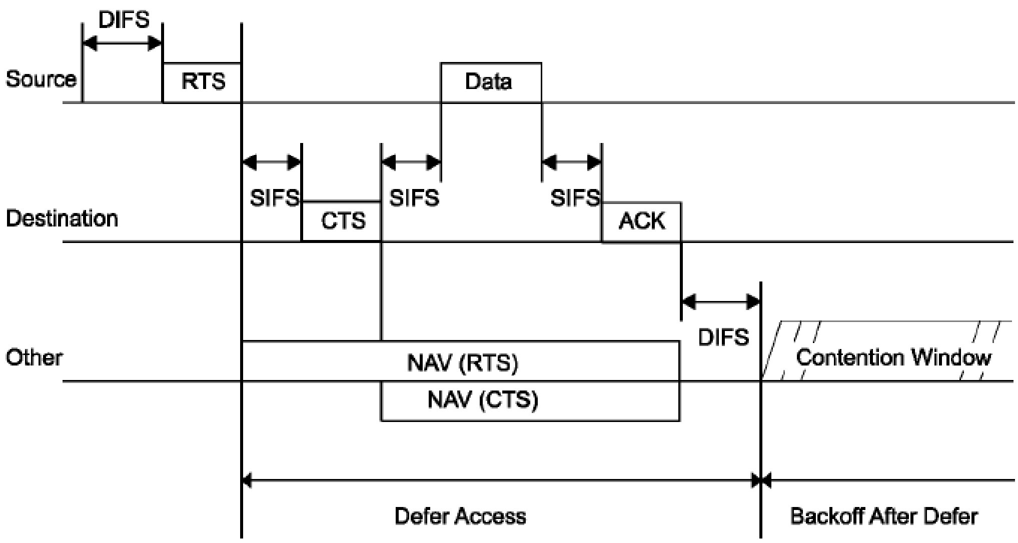

Fig. 14. Operation of 802.11 DCF (RTS/CTS access method) [6]

Proposed protocol can successfully replace binary exponential backoff scheme implemented in IEEE 802.11 DCF for collision avoidance. In this case *a* refers to the DIFS time, *L* refers to the payload size and *w* to the slot duration. Figure 15 shows the comparison of saturation throughput of original DCF obtained by analytical model from [13] and DCF with embedded BCSMA/CA. Due to extra time required for preamble transmission T_s and T_c are larger by wr_{max} than those in [13] and now equal to:

$$\begin{cases} T_s^{bas} = wr_{\max} + H + L + SIFS + \delta + ACK + DIFS + \delta \\ T_c^{bas} = wr_{\max} + H + L + SIFS + \delta + ACK + DIFS + \delta \end{cases} \tag{13}$$

$$\begin{cases} T_s^{rts} = wr_{\max} + RTS + SIFS + \delta + CTS + SIFS + \delta \\ \qquad + H + L + SIFS + \delta + ACK + DIFS + \delta \\ T_c^{rts} = wr_{\max} + RTS + SIFS + \delta + CTS + DIFS + \delta \end{cases} \tag{14}$$

for the Basic and RTS/CTS methods respectively. *H* here denotes a total packet header ($H = PHY_{hdr} + MAC_{hdr}$) and δ is a propagation time. To be consistent with [13] we use the same payload size and parameters therefore following IEEE 802.11 standard [6] for DSSS with an exception for retransmission limit that is assumed to be infinite. Having proved that suboptimal length of CRP is acceptable and more practical, results are given for R = 65 in case of basic method and R = 20 when RTS/CTS method is used. The values of the parameters used to obtain numerical results for analytical model as well as for simulation are detailed in Table 5. Since the curve for basic method of original DCF depicted in figure 15 lies relatively low, the difference between the rest of the curves is not apparent. For this purpose, figure 16 shows the result in expanded scale for axis y not including aforementioned curve. Observation of figure 16 shows that DCF under BCSMA/CA is significantly more efficient and preferable to use when the number of users is large. All analytical results presented in this section and section D are validated through simulation performed in Matlab. Simulation results are superimposed over the analytical curves using marker points.

Packet payload	8224 bits
MAC header	224 bits
PHY header	192 bits
ACK	112 + PHY header
RTS	160 + PHY header
CTS	112 + PHY header
Channel bit rate	1 Mbit/s
Propagation delay	1 μs
Slot time	20 μs
SIFS	10 μs
DIFS	50 μs

Table 4. 802.11 DSSS system parameters and additional parameters used to obtain numerical results for DCF(BEB) and DCF(BCSMA/CA).

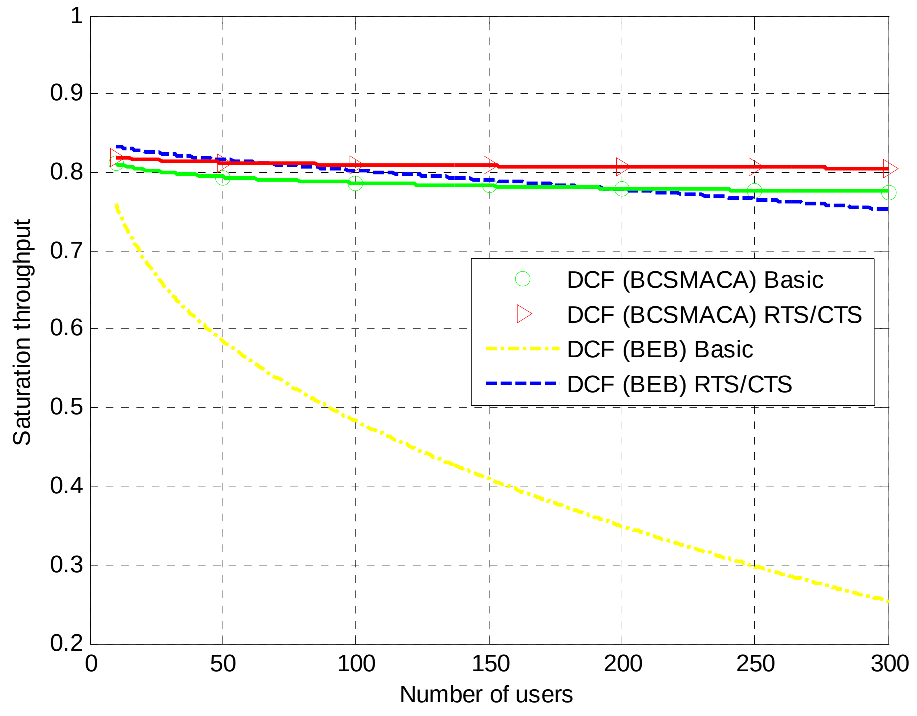

Fig. 15. Evaluation of saturation throughput for traditional and modified DCF
(CRPBasic = 65, CRPRTS/CTS = 20, λ = 10/CRP)

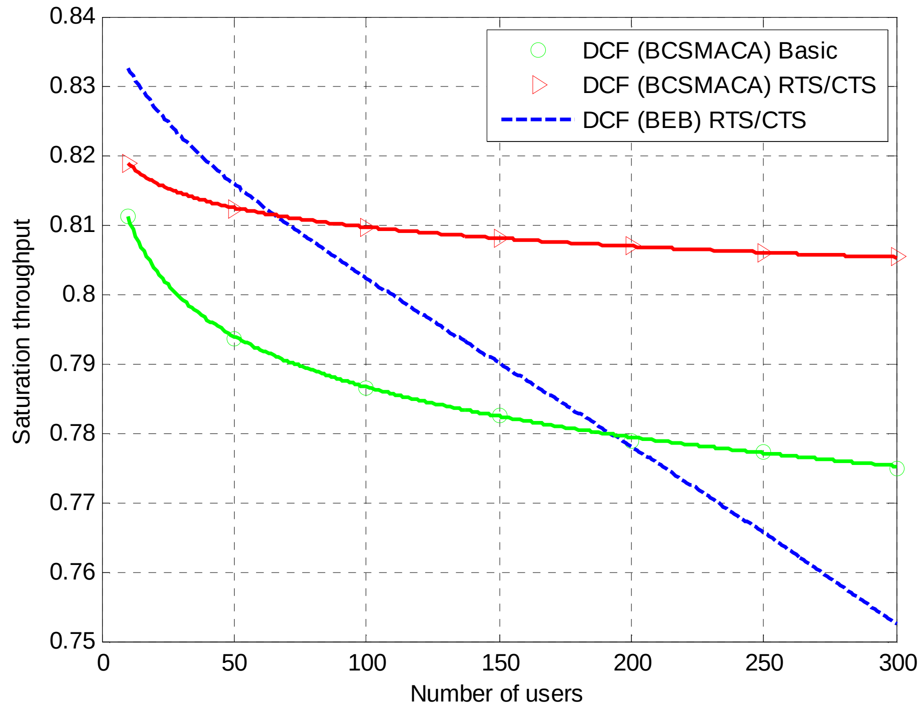

Fig. 16. Evaluation of saturation throughput for traditional and modified DCF
(expanded scale)
(CRPBasic = 65, CRPRTS/CTS = 20, λ = 10/CRP)

5. Conclusion

In this thesis we proposed a novel random channel access protocol for wireless networks named BCSMA/CA. Each user in BCSMA/CA is given the channel access right after the medium is sensed idle for a certain amount of time. However, transmission starts with preamble (instead of data) by which users can detect each other and therefore avoid collisions. With the help of analytical model that assumes ideal channel conditions, fixed packet size and finite number of users, the effect of different parameters on BCSMA/CA performance was investigated. We gave recommendations for choosing specific parameters' values and showed that using fixed suboptimal value of contention resolution period has marginal impact on saturation throughput. This work also includes the comparison of WCSMA/CD described in [11] and BCSMA/CA for the same set of parameters. Comparison showed the rapidly growing positive difference between saturation throughput of the proposed protocol and WCSMA/CD as the number of users increases. Being implemented into the IEEE 802.11 DCF instead of BEB, BCSMA/CA was also compared to the original DCF and proved to have an advantage for large number of users. Even though, proposed protocol gives promising results in highly populated wireless networks, certain parameters as λ and quantization technique might be non-optimal. Thus, optimization of these parameters as well as study of delay and fairness of BCSMA/CA will be the goal of future work.

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