BusySiMOn - a New Protocol for IEEE 802.11 EDCA-Based Ad-Hoc Networks with Hidden Nodes

Katarzyna Kosek-Szott, *Student Member, IEEE,* Marek Natkaniec, *Member, IEEE,* Andrzej R. Pach, *Member, IEEE*

***Abstract*—This article presents a new MAC layer protocol for IEEE 802.11 EDCA-based ad-hoc networks with hidden nodes. The key idea of the proposed solution is based on an intelligent two-step reservation procedure which is combined with the advantages of EDCA service differentiation. The new protocol achieves significant performance improvement for high priority traffic (e.g., Voice) in terms of fairness, throughput and average frame delay. It is also compatible with the IEEE 802.11 standard. The obtained results emphasize the advantages of the new protocol over the currently used four-way handshake mechanism.**

***Index Terms*—EDCA, Hidden Nodes, MAC Protocol, QoS**

I. INTRODUCTION

The IEEE 802.11 standard is currently one of the most popular wireless access technologies. It allows for quick and simple configuration of local broadband networks and greatly facilitates Internet access. With the growth of the popularity of IEEE 802.11, the number of available services also increased and the need for Quality of Service (QoS) provisioning became apparent. As a remedy to this problem, the Enhanced Distributed Channel Access (EDCA) function of the IEEE 802.11 standard was proposed [1].

Unfortunately, the IEEE 802.11 standard has a serious disadvantage. Due to the half-duplex nature of the wireless devices hidden nodes may appear within a wireless system. As a result, in a network with hidden nodes not only the overall throughput value may greatly decrease but also EDCA service differentiation and fairness among the nodes may be strongly deteriorated [5].

A number of MAC layer protocols trying to address the problem of hidden nodes have been proposed in the literature. Exemplary solutions are presented in Table I. As can be noticed, the majority of protocols rely on RTS/CTS-based or similar frame exchanges during the channel reservation process. All presented solutions can be divided into five major protocol types: contention-based, multi-channel, busy tone-based, energy-efficient and directional antenna-based. The most important advantages and disadvantages of each protocol type are presented in Table II. Among all available solutions, only the legacy four-way handshake mechanism has become broadly used and implemented in wireless devices. Currently it is the only mechanism recommended by the IEEE 802.11 standard to minimize the negative effects caused by hidden nodes. Unfortunately, as it was shown in [5], its effectiveness is insufficient to provide appropriate service differentiation in EDCA-based ad-hoc networks.

K. Kosek-Szott, M. Natkaniec and A. R. Pach are with the Department of Telecommunications, AGH University of Science and Technology, Krakow, Poland.
E-mail: {kosek, natkaniec, pach}@kt.agh.edu.pl

In this article we propose Busy Signal-based Mechanism turned On (BusySiMOn) — a new MAC layer protocol which combines smart reservation of the wireless channel with the advantages of EDCA service differentiation. The proposed approach remarkably improves QoS provisioning in IEEE 802.11 ad-hoc networks with hidden nodes in terms of throughput, average frame delay and fairness among the nodes. It also assures compatibility with the IEEE 802.11 standard.

The outline of this article is the following. Firstly, we describe EDCA and BusySiMOn. Then, we provide the simulation scenario which evaluates the performance of the proposed protocol and shows its advantages over the four-way handshake mechanism. Finally, we devote a section to our conclusions.

II. IEEE 802.11 EDCA

In networks with heterogeneous traffic the QoS requirements of each service should be carefully taken into account. In particular, in the case of simultaneous transmissions of voice and data traffic the delay constraints of the voice service should be primarily met. To achieve this goal voice traffic should have certain priority over data traffic. Within wireless ad-hoc networks it is the EDCA function of the IEEE 802.11 standard which was designed to satisfy this requirement.

The EDCA function defines several QoS enhancements to the legacy IEEE 802.11 DCF which are based on the idea of Access Categories (ACs). Four ACs (priorities) are defined: Voice, Video, Best Effort, and Background. To provide traffic differentiation each AC has a different set of the following medium access parameters: the contention window minimum (CW_{min}) and maximum (CW_{max}) size, the arbitration inter-frame space number ($AIFSN$), and the transmission opportunity limit ($TXOP_{Limit}$). The functions of the access parameters are as follows. $CW_{min}[AC]$ and $CW_{max}[AC]$ determine the number of *Backoff* slots:

$$Backoff[AC] =$$
$$= \text{random}\left[0, \min\left(2^k(CW_{min}[AC]+1)-1, CW_{max}[AC]\right)\right]$$

where k is the number of collisions occurred to the currently transmitted frame. $AIFSN[AC]$ determines the minimum time interval before a frame transmission may begin:

$$AIFS[AC] = AIFSN[AC] \times T_e + SIFS$$

TABLE I
COMPARISON OF DIFFERENT MAC PROTOCOLS FOR NETWORKS WITH HIDDEN NODES

Protocol Name	Required IEEE 802.11 Change	Modification	Channel Reservation Method	Hardware	Signaling Overhead	Channel Reservation	QoS Support	Designed for (Network Type)	Year
IEEE 802.11 Four-way Handshake [1]	None	—	Based on RTS/CTS	Standard	Large	Slow	Yes (EDCA, HCCA)	Infrastructure and ad-hoc	2007
Slotted MACA-BI [9]	Large	RTS and CTS replaced by the Ready-To-Receive frame, slotted channel (slotted ALOHA-based).	Based on RTR frame	Standard	Medium	Medium	No	Ad-hoc	2009
DBTMA [6]	Large	Out-of-band signaling, busy tones, omitted ACK frame.	Based on RTS/CTS	Complex (two transceivers)	Large	Slow	No	Ad-hoc	2002
DRCE [7]	Large	Additional signaling frames, transmission power control, two separate channels.	Based on RTS/CTS	Complex (with two transceivers and power control)	Large	Slow	Yes	Ad-hoc	2005
EDCA/RR [8]	Medium	Extended RTS/CTS frames.	Similar to RTS/CTS	Standard	Large	Slow	Yes	Ad-hoc	2006
SSPC [10]	Medium	Power control of Data, RTS and CTS frames. Changed format of RTS and CTS frames.	Based on RTS/CTS	Complex (with power control)	Large	Slow	No	Ad-hoc	2009
SAM-MAC [11]	Large	Balances traffic over multiple channels, two half-duplex transceivers for each node, additional signaling.	Based on RTS/CTS	Complex (with two half-duplex transceivers)	Large	Slow	No	Ad-hoc	2008
RDMAC [12]	Large	Smart usage of directional and omni-directional antennas, additional signaling.	Based on RTS/CTS	Complex (with support of directional and omni-directional transmission)	Large	Slow	No	Ad-hoc	2009
PUMA [13]	Medium	Additional JAM signal for isochronous traffic. Modified control frames. Double Increment Double Decrement (DIDD) backoff mechanism.	Based on JAM, RTS and CTS	Standard	Large	Slow	Yes	Ad-hoc	2002
MARS [14]	Large	Additional signaling (Ready-to-Receive-and-Transmit frame), changed RTS frame format, smart antennas.	Based on RTRT/RTS/CTS frames	Complex (with smart antennas)	Very large	Slow	No	Ad-hoc	2009
CDR-MAC [15]	Large	Circular directional transmission of RTS. Directional antennas with predefined number of beams. Multiple RTS transmissions. Each node maintains location table.	Based on RTS/CTS	Complex (with support of directional transmission)	Very large	Slow	No	Ad-hoc	2007
DMAC-PCDR [16]	Large	Each node equipped with GPS. Smart usage of omni-directional and directional antennas. Rotation of receiving antenna beams.	Based on RTS/CTS	Complex (with support of directional and omni-directional transmission)	Large	Slow	No	Ad-hoc	2008
CCM-MAC [17]	Medium	Additional control frames: decide-channel-to-send (DCTS), information-to-in-form (ITI), confirm (CFM).	Based on RTS/CTS/DCTS/IFI/CFM	Standard	Very large	Slow	No	Ad-hoc	2009
BAS-DTR [18]	Large	Directional antennas for transmission and reception, narrow beamwidth.	N/A	Complex (with support of directional transmission)	Small	N/A	No	Ad-hoc	2008
BusySiMOn (described in this paper)	**Small**	**Two additional busy tones.**	**Based on busy tones**	**Standard**	**Large**	**Fast (preliminary reservation)**	**Yes**	**Ad-hoc**	**2010**

TABLE II
ADVANTAGES AND DISADVANTAGES OF DIFFERENT MAC PROTOCOL TYPES FOR NETWORKS WITH HIDDEN NODES

Protocol Type	Advantages	Disadvantages
Contention-based (Four-way handshake, Slotted MACA-BI, EDCA/RR)	Standard hardware. If the standard RTS and CTS frames are used interoperability with existing standards (IEEE 802.11) becomes possible.	Medium/large signaling overhead. Slow/very slow channel reservation procedure.
Multi-channel (DBTMA, SAM-MAC, CCM-MAC)	Use of multiple channels to separate data and control traffic and minimize the probability of collisions. Possibility of load balancing and use of busy tones. Simultaneous transmissions in the same region without interference. Higher network efficiency than for legacy IEEE 802.11.	Separate channels must be assigned to different nodes in real time. Nodes must be sometimes synchronized which is not suitable for multi-hop networks. Additional hardware complexity is introduced because of additional channels and transceivers. Channel gain of data and control channels may not be the same. Interoperability with existing standards (IEEE 802.11) is difficult. Large signaling overhead. Slow channel reservation procedure. Current solutions do not support QoS.
Single-channel busy tone-based (PUMA, BusySiMOn)	Standard hardware. Busy tones can be recognized more easily than MAC frames. Partial of full interoperability with existing standards (IEEE 802.11). QoS support. Quick channel reservation is possible.	Increased signaling overhead.
Energy-efficient (DRCE, SSPC)	Decreased energy consumption. Power-aware mechanisms can be combined with busy tones or can take advantage from using multiple channels.	Signal fading may degrade performance. Reducing power for ACK transmission may lead to increased number of collisions due to decreased carrier sensing range. Additional hardware complexity. Large signaling overhead. Slow channel reservation procedure.
Directional antenna-based (RDMAC, MARS, CDR-MAC, DMAC-PCDR, BAS-DTR)	Simultaneous data transmission and reception. Minimized probability of collisions. Higher network efficiency than for legacy IEEE 802.11.	New kinds of hidden terminals, higher directional interference and deafness. Performance is decreased with node mobility. Additional hardware complexity. In most cases large signaling overhead and slow channel reservation procedure. Performance is strongly dependent on network topology. Current solutions do not support QoS.

where T_e is the duration of a single slot time. $TXOP_{Limit}[AC]$ allows for the consecutive transmissions of several frames after gaining channel access, known as contention free bursting. This parameter is optional.

In the literature there are a number of articles which describe the advantages of EDCA traffic differentiation. Most of the studies, however, consider systems without hidden nodes. In [4] it has been proven for the first time that EDCA tends to cease to function in environments with hidden nodes. In particular, it has been shown that:

- Unhidden nodes are generally favored over hidden nodes in the channel access, regardless of their access category. This may lead to situations in which low priority traffic (e.g., Background) transmitted by an unhidden node receives better service than high priority traffic (e.g, Voice) generated by a hidden node.
- The four-way handshake mechanism may sometimes improve the throughput values achieved by the hidden nodes, however, it does not completely eliminate the unfairness in granting medium access.
- The higher the priority of traffic transmitted by hidden nodes the more collisions occur, even if the four-way handshake is used.

All these observations were also confirmed in [5]. Therefore, it became obvious that a new MAC protocol is required to meet the severe demands of high priority traffic (Voice and

Video) and to improve the fairness among nodes.

III. BusySiMOn

The key idea of the proposed MAC protocol is to minimize the probability of collisions of the signaling data within wireless systems with hidden nodes. To achieve this goal we propose a new channel reservation procedure consisting of the following two steps which are depicted in Figure 1:

1) Preliminary reservation of the wireless channel using two busy tone signals (Busy 1 and Busy 2). Both signals are very short — Busy 1 has the length of one slot time period (STP) and Busy 2 has the length of three STPs. Therefore, the preliminary channel reservation can be done very quickly. The lengths of the busy tone signals are distinguished in order to avoid the problem of mistaking Busy 1 for Busy 2 and vice versa.
2) Distributing information about the transmission duration as well as the source and destination node addresses with the use of the legacy RTS and CTS frames.

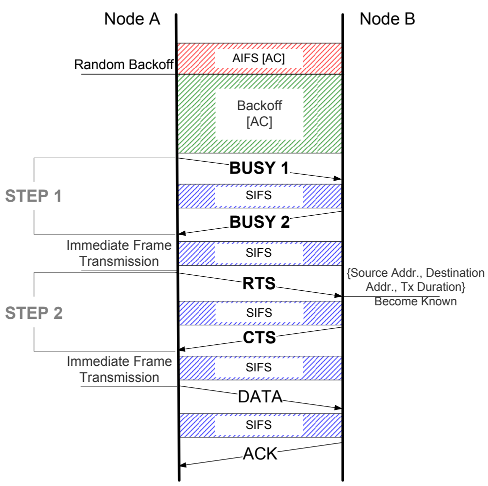

Fig. 1. BusySiMOn operation

The proposed intelligent reservation of the wireless channel allows to minimize the probability of collisions of signaling data which happen when the four-way handshake mechanism is used.

The length of Busy 2 is set to three STPs in order to minimize the risk of mistaking consecutive transmissions of Busy 1 tones for Busy 2. An exemplary scenario in which three Busy 1 tones transmitted by hidden nodes are mistaken for one Busy 2 is presented in Figure 2. For this scenario we can assume saturation conditions and that the *Backoff* is chosen from the range [0, 7]. Then, with the use of simple probability analysis, we can calculate the probability of misleading the unhidden node. It is equal to 0.38 and 0.05 for a Busy 2 length of two and three STPs, respectively. This relation is preserved in scenarios with a different number of hidden nodes and in the case of other *Backoff* ranges. Therefore, it is better to set the length of Busy 2 to three STPs. The gain of using longer Busy 2 tones is negligible.

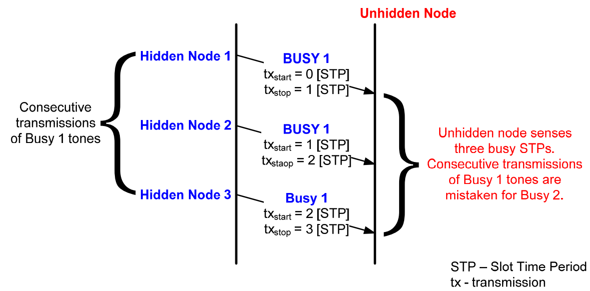

Fig. 2. Overlapping of busy tones

The problem of traffic prioritisation is resolved in BusySiMOn by the combination of the proposed reservation mechanism with the unchanged EDCA access parameters (c.f., Figure 1).

IV. Effectiveness of Channel Reservation

In the case of the legacy RTS/CTS-based channel reservation three types of collisions may happen — collisions of RTS with either another RTS, CTS or DATA. They are common even for the simplest line topology depicted in Figure 3. In the first scenario two RTS frames sent by the hidden nodes collide with each other. After the collision is detected they have to be re-transmitted after a random *Backoff* time. The number of possible retransmissions is limited to the *Short Retry Limit* defined by the IEEE 802.11 standard. It is worth noting that due to the low sending rate of RTS frames (1 Mb/s for HR/DSSS) hidden nodes do not have to simultaneously start their RTS transmissions to cause a collision. In the second scenario, node N1 positively reserves the wireless channel with the use of the RTS/CTS exchange. At the same time, however, the RTS frame sent by N3 collides with the CTS frame sent by N2. Obviously, after a random *Backoff* time, N3 will try to resend its RTS frame. If the *Backoff* value will be small enough, the resent RTS frame will collide with the DATA frame currently being transmitted by N1. As a result, N1 will have to resend its DATA frame.

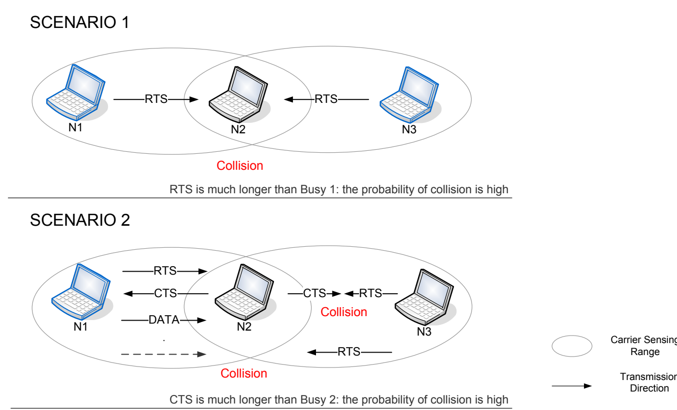

Fig. 3. Types of signaling data collisions for the four-way handshake mechanism

For a given *Backoff* stage, with the use of simple probability analysis, we can compute the lower bound of the probability

TABLE III
LOWER BOUND OF THE PROBABILITY OF SUCCESSFUL TRANSMISSION BY EITHER OF THE HIDDEN NODES IN THE FIRST SCENARIO FOR DIFFERENT PHYS

PHY	PLCP Header and Preamble [μs]	Slot time [μs]	Lowest TX rate [Mb/s]	$\max[CW]$ [STP]	T_{RTS} [STP]	$p_s^{H,RTS}$	T_{Busy1} [STP]	$p_s^{H,Busy1}$
DSSS	192	20	1	7 15 31 1023	17.60	0.00 0.00 0.09 0.48	1,00	0.33 0.41 0.45 0.50
OFDM	20 or 40 or 80	9 or 13 or 21	6	7 15 31 1023	5.19 or 5.13 or 5.08	0.04 0.21 0.34 0.49	1,00	0.33 0.41 0.45 0.50

of a successful channel reservation by either of the two hidden nodes (p_s^H) in the first scenario:

$$p_s^{H,RTS} = \\ = \max\left[0; \frac{(\max[CW] - T_{RTS})(\max[CW] - T_{RTS} + 1)}{2(\max[CW] + 1)^2}\right]$$

where $\max[CW]$ is the maximum possible size of the current contention window and T_{RTS} is the time required to send the RTS frame (together with its PLCP header and preamble). Both values are given in STPs.

If BusySiMOn was used to reserve the wireless channel the probability p_s^H would be the following:

$$p_s^{H,Busy1} = \\ = \max\left[0; \frac{(\max[CW] - T_{Busy1})(\max[CW] - T_{Busy1} + 1)}{2(\max[CW] + 1)^2}\right]$$

where T_{Busy1} is the number of STPs required to send the Busy 1 signal, which is equal to one.

The comparison of $p_s^{H,RTS}$ with $p_s^{H,Busy1}$ for different PHYs and different $\max[CW]$ values is given in Table III. The probability $p_s^{H,Busy1}$ is always greater than $p_s^{H,RTS}$. This is because the new protocol maximizes the probability of successful reservations of the wireless channel for hidden nodes by minimizing the probability of collisions of signaling data. The probability of collisions is minimized because the time spent on the preliminary channel reservation is noticeably reduced in comparison to the time spent on the traditional RTS/CTS exchange.

To judge the effectiveness of the four-way handshake we compare the standard values of CW_{min} and CW_{max} of different ACs (Table IV) with different $\max[CW]$ (Table III). By analyzing $p_s^{H,RTS}$ it can be deduced that especially for hidden nodes with Voice priority flows the probability of successful channel reservation is very low for each PHY when the four-way handshake is used. For BusySiMOn the probability $p_s^{H,Busy1}$ for Voice priority flows is much higher.

V. COMPATIBILITY WITH EDCA

BusySiMOn is compatible with EDCA because it does not change the values of the channel access parameters defined by the IEEE 802.11 standard. Furthermore, because the RTS/CTS/DATA/ACK exchange is part of the proposed protocol, each node implementing BusySiMOn is able to respond to legacy IEEE 802.11 nodes. Additionally, if a BusySiMOn node wants to communicate with a legacy node it must have at least one other BusySiMOn neighbor. In Figure 4 Nodes A and B implement BusySiMOn and Node C is a legacy node. After Node B broadcasts Busy 1 to all nodes within its range, Node A sends Busy 2 in response. This allows Node B to communicate with Node C with the use of the traditional RTS/CTS/DATA/ACK exchange.

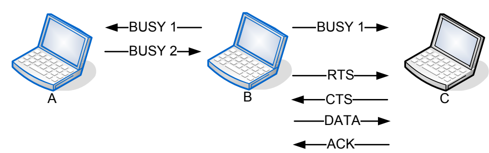

Fig. 4. Compatibility with legacy nodes

A problem occurs if a BusySiMOn node does not have any BusySiMOn neighbors. To overcome this obstacle and assure full compatibility with the IEEE 802.11 standard, the BusySiMOn protocol can easily be extended in the following way. If a node implementing BusySiMOn does not receive a reply to n Busy 1 tones it assumes that all other nodes use the legacy IEEE 802.11. Then it reverts to the traditional RTS/CTS/DATA/ACK exchange.

VI. SIMULATION STUDY

Simulation results were gathered from the ns-2 simulator patched with a considerably improved version of the TKN EDCA extension [2]. The wireless channel introduced no errors. Table IV contains the major parameters selected for the simulations. As can be noticed, HR/DSSS (commonly known as IEEE 802.11b) was chosen as the PHY layer, although BusySiMOn can be applied to any other 802.11 PHY. The general conclusions presented in this section remain the same regardless of the chosen PHY. The EDCA parameters were set as defined by the IEEE 802.11 standard [1]. $TXOP_{Limit}$ was set to zero to avoid contention free bursting.

The performance of the new protocol has been evaluated in an exemplary wireless ad-hoc network presented in Figure 5, in which N0 is the only unhidden node. Nodes N1, N2 and N3 are hidden from N4, N5 and N6 and vice versa.

The evaluation has been done in terms of throughput, average frame delay and fairness obtained within a single collision domain for different values of per flow offered load.

TABLE IV
SIMULATION PARAMETERS

IEEE 802.11 PHY Parameters			
Basic Rate	1 Mb/s	Data rate	11 Mb/s
Propagation delay	2 μs	Slot time	20 μs
PHY overhead	192 bit	MAC header	32 Bytes
SIFS interval	10 μs	EIFS	318 μs
ACK/CTS frame	112 bit	RTS frame	160 bit
Data frame	1000 Bytes	Traffic model	CBR
Distance between N0 and other nodes	200-210 m	Carrier sensing range	262 m
802.11 EDCA Parameters			
Access Category	$AIFSN$	CW_{min}	CW_{max}
Voice	2	7	15
Video	2	15	31
Best Effort	3	31	1023
Background	7	31	1023

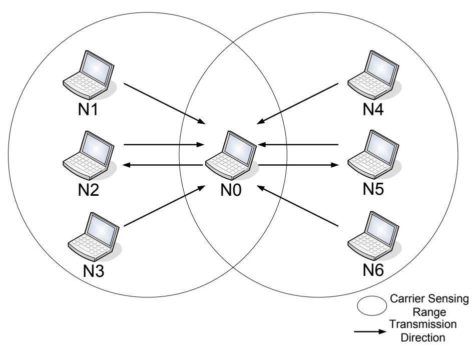

Fig. 5. Simulation scenario

A collision domain is defined as a single carrier sensing range. In Figure 5 there are four flows in each of the two collision domains. The per flow offered load is the total number of bits generated by a single node for a single flow per time unit (second). Throughput is defined as the ratio of the number of correctly received bits per time unit. In the results presented in this section both the average per node throughput and the overall (per collision) throughput are considered. The average frame delay is the average time of a successful transmission, measured from the frame generation at the source node until its successful reception at the destination node. This is computed separately for each simulated AC. The fairness is defined as the Jain's fairness index which is given by the following equation [3]

$$Fairness = \frac{(\sum x_i)^2}{n \sum x_i^2}$$

where x_i is the average throughput of the i-th flow and n is the number of flows with the same AC.

From the list of available MAC protocols for networks with hidden nodes (Table I) we have chosen only the four-way handshake in our comparison. This is because, as it was already mentioned, the RTS/CTS exchange is the only solution implemented in wireless drivers which is recommended by IEEE 802.11 to be used in environments with hidden nodes.

Two different scenarios were considered. In the first scenario, the efficiency of three different medium access methods (EDCA without RTS/CTS, EDCA with RTS/CTS and BusySiMOn) was compared under saturation. Each hidden node generated a load of 2.5 Mb/s. The unhidden node generated a load of 5 Mb/s (2.5 Mb/s in each collision domain). In the second scenario, the maximum values of possible network load were found under which the wireless network was not yet saturated. This was done separately for BusySiMOn and EDCA with RTS/CTS. Then, the two protocols were compared with regard to the overall throughput and the average frame delay obtained for the found values of the network load. Additionally, in order to determine whether the ad-hoc nodes transmitting traffic with the same AC receive a fair share of the wireless channel resources, the Jain's fairness index was computed for both scenarios.

A. Saturated Network Conditions

The results obtained for the first scenario are presented in the upper half of Table V. The table contains the comparison of the efficiency of three different MAC protocols in four different configurations.

In the first two configurations, all nodes transmitted flows with the same AC — Voice and Background, respectively. For Voice traffic the highest overall throughput and the best fairness is achieved for BusySiMOn. For Background traffic the overall throughput achieved with the use of the new protocol is slightly worse in comparison with EDCA. On the other hand, the fairness of the new protocol is almost two times better.

In the next two configurations the traffic flows of the hidden nodes were assigned ACs opposite to that of the unhidden node. When the hidden nodes transmitted Voice, the performance of BusySiMOn was four times better than the performance of the four-way handshake mechanism and over 12,000 times better than the performance of pure EDCA. When the hidden nodes transmitted Background traffic, the performance of the new protocol was practically the same as the performance of EDCA with RTS/CTS.

In summary, BusySiMOn assures fairness among all ad-hoc nodes under saturation. Therefore, it eliminates the problem of prioritizing unhidden nodes over hidden nodes described in [5].

B. Unsaturated Network Conditions

So far, it has been shown that BusySiMOn outperforms the four-way handshake with respect to the fairness among the nodes and improves the throughput of the hidden nodes. However, for delay-sensitive traffic it is the average frame delay which is the most important constraint. The Voice service can tolerate a maximum frame delay of 150 ms, Video — 300 ms. For both services, frames with greater delay are dropped.

The lower half of Table V contains the comparison of the new protocol with the four-way handshake with respect to the delay constraint in four different configurations. The total offered load generated in the first and the third configuration was the maximum load under which the network was not yet saturated for BusySiMOn. The second and the fourth configuration considers the maximum load which did not cause saturation for EDCA with RTS/CTS. In each configuration

TABLE V
COMPARISON OF THE EFFICIENCY OF DIFFERENT MEDIUM ACCESS PROCEDURES

Per Flow Offered Load	Configuration	BusySiMON				EDCA with RTS/CTS				EDCA			
		N0 Throughput [KB/s] (per Collision Domain)	Other Nodes' Throughput [KB/s]	Overall Throughput [KB/s] (per Collision Domain)	Jain's Fairness Index	N0 Throughput [KB/s] (per Collision Domain)	Other Nodes' Throughput [KB/s]	Overall Throughput [KB/s] (per Collision Domain)	Jain's Fairness Index	N0 Throughput [KB/s] (per Collision Domain)	Other Nodes' Throughput [KB/s]	Overall Throughput [KB/s] (per Collision Domain)	Jain's Fairness Index
2.5 Mb/s	All: Voice	45	43	174	0.999	73	13	112	0.537	5.25	0	5.25	0.25
	All: Background	47	52	203	0.998	86	30	176	0.767	130	28	214	0.595
	N0: Background Others: Voice	0.1	61.8	185.5	1	1	15	46	1	0.015	0	0.015	1
	N0: Voice Others: Background	228	1	231	1	236	0.4	237.2	1	305	6	323	1

Per Flow Offered Load	Configuration	BusySiMON						EDCA with RTS/CTS					
		N0 Throughput [KB/s] (per Collision Domain)	Other Nodes' Throughput [KB/s]	Overall Throughput [KB/s] (per Collision Domain)	Jain's Fairness Index	Average Frame Delay for N0 [ms]	Other Nodes' Average Frame Delay [ms]	N0 Throughput [KB/s] (per Collision Domain)	Other Nodes' Throughput [KB/s]	Overall Throughput [KB/s] (per Collision Domain)	Jain's Fairness Index	Average Frame Delay for N0 [ms]	Other Nodes' Average Frame Delay [ms]
380 kb/s	All: Voice	46.3	46.5	185.8	1	< 3.46	< 3.83	46.22	14	88.22	0.714	< 11.85	> 1800
360 kb/s	All: Voice	43.9	43.9	175.6	1	< 3.2	< 3.45	43.9	15	88.9	0.759	< 10.3	< 140
510 kb/s	N0: Background Others: Voice	29	62.2	215.6	1	> 8300	< 6.27	0.92	15.3	46.82	1	> 170000	> 7500
450 kb/s	N0: Background Others: Voice	53.5	54.8	217.9	1	> 4000	< 4.3	1.5	19	58.5	1	> 12800	< 59

the new mechanism behaves better not only in terms of the average frame delay but also in terms of the offered load, fairness and the overall throughput. This means that with the use of BusySiMOn the delay-sensitive traffic is provided with much better level of QoS than with the use of the four-way handshake mechanism.

VII. CONCLUSIONS

The article presents a new method of channel reservation for IEEE 802.11 EDCA-based ad-hoc networks with hidden nodes. The simulation results have demonstrated that the currently used four-way handshake mechanism is inefficient, especially for high priority flows transmitted by hidden nodes.

The key advantage of the new protocol is the minimized risk of collisions of signaling data during the preliminary wireless channel reservation, which results in increased channel efficiency, reduced average frame delay and improved fairness among the nodes. Additionally, the combination of the preliminary reservation procedure with the RTS/CTS exchange and the unchanged values of the EDCA access parameters assures compatibility with mechanisms implemented in current wireless devices.

It is worth mentioning that BusySiMOn can be applied to more varied network configurations (involving all EDCA ACs). In each case its performance for the high priority traffic will outperform the performance of the four-way handshake mechanism.

ACKNOWLEDGMENTS

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