Iwona Dolińska
Akademia Finansów i Biznesu Vistula – Warszawa

The EDCA Implementation in NS-3 Network Simulator

Summary

Wireless networks built in the IEEE 802.11 standard are very popular in every environment now. Their widespread use causes many problems with throughput, transmission QoS and even with radio channel access. IEEE 802.11 standard is still improved, increasing network throughput and coverage, transmission security, mesh networks, wireless access for the vehicular environment, improvements related to hotspots, wireless network management etc. IEEE 802.11e is an important amendment, because it introduced the possibility of QoS (Quality of Service) providing in wireless network. Because of high communication demands and, on the other hand, because the wireless communication is very complex process, the network simulators are very useful tools. They give the possibility of making communication efficiency analyses and different scenario testing. In this article, the implementation of EDCA method in NS-3 is analyzed. It turned out, that nowadays the implementation is missing of one important feature. So, the EDCA implementation in NS-3 should be improved.

Key words. EDCA, QoS in WLAN, network simulator, NS-3.

JEL codes: L86

Introduction

Wi-Fi networks, known also as WLAN (Wireless LAN), are important or even basic part of every kind of LAN computer networks. From its beginning IEEE 802.11 standard has still been evolved up today. The rapid proliferation of wireless devices at homes and work places has given rise to huge demands for higher wireless speeds and wider coverage areas. The ever-increasing need for mobile connectivity and high throughput requirements of present-day wireless devices and applications drive the need for deploying wireless technology with significant enhancements in terms of speed, reliability and Quality of Service (QoS) (Siddiqui et al. 2015).

The network throughput and coverage were increased by every successive standard amendment, starting from IEEE 802.11b through IEEE 802.11a and IEEE 802.11g until to IEEE 802.11n, IEEE 802.11ac, IEEE 802.11ad (IEEE 802.11 2012, IEEE 2013). The IEEE 802.11n version is the most popular nowadays. This version introduced some revolutionary changes into the WLAN networks. MIMO (Multiple Input Multiple Output) communication, channel bonding, short guard interval was added in PHY level and frame aggregation in MAC level. IEEE 802.11n network can achieve even 600 Mbit/s throughput using four antennas. IEEE 802.11ac improves and extends IEEE 802.11n functionality (Dolińska

2016), i.e. it has more channel bonding, denser constellation (higher modulation levels) and more spatial streams. The aggregated frame can be up to 1,048,575 octets. The new features, introduced in IEEE 802.11ac are: multi-user MIMO and standard-based beamforming. This standard has theoretical throughput of 1 Gb/s. The next standard, IEEE 802.11ad is not compatible with the rest of the family, because it operates in band of 60 Hz (Masiukiewicz 2013). This frequency band has significantly different propagation characteristics than the 2.4 GHz and 5 GHz bands where Wi-Fi networks operate. The frequency of 60 GHz band is not suitable for long range transmissions because of very high attenuation due to frequency value itself as well as influence of some factors which are not critical for lower frequencies. The IEEE 802.11ad offers up to 7 Gbit/s.

IEEE 802.11 standard development it is not only network throughput and coverage. It also covers a lot of changes, like transmission security, mesh networks, wireless access for the vehicular environment, improvements related to hotspots, wireless network management. IEEE 802.11e is an important amendment, because it introduced the possibility of QoS (Quality of Service) providing in wireless network. The significance of this improvement is even more important nowadays, when all the WLAN users need the very high throughput, because video on demand and Internet radio and TV started to be very popular (Dolińska and Masiukiewicz 2012). Moreover, social services with a lot of pictures and videos are widely used also. Nobody likes delays, when watching movie or listen to the music from Internet. DCF (Distributed Coordination Function), which has been the basic method of medium access from the beginning the standard, don't support QoS, because this method treats all frames in the same way. There is no possibility to differentiate more important and less important network traffic. IEEE 802.11e introduced priorities, which can be assigned to packet or packet streams. With EDCA (Enhanced Distributed Channel Access), high-priority traffic has a higher chance of being sent than low-priority traffic: a station with high priority traffic waits a little less before it sends its packet, on average, than a station with low priority traffic. The major benefits offered by the 802.11e standard are reducing the latency through prioritizing different types of traffic packets, enabling access points (APs) to allocate resources based on data rate and latency requirements from each individual station and improving wireless bandwidth efficiency and reducing packet overheads (Gao 2005). In the newest standards, like IEEE 802.11ac and like IEEE 802.11ad, it is basic media access method, instead of DCF (Bellalta et al. 2016).

The wireless communication is a very complicated and complex process. That's why WiFi networks simulators are widely used to learn, explore, and make research on such networks. The NS-3 network simulator is one of the best known and most widely used in scientific research. The NS-3 simulator allows to simulate wired and wireless networks of different standards. In this article, the implementation of EDCA media access method in NS-3 will be described. A simple example of network using such communication method will be presented also.

The rest of the article is organized as follows. The next section contains the short description of the basic media access method in IEEE 802.11, i.e. DCF, given to remind some details to show the differences between DCF and EDCA. EDCA details are presented in the third section. The next section contains NS-3 presentation and introduction to EDCA implementation. The last section concludes the article and gives some remarks about future works.

Basic media access methods in IEEE 802.11

DCF method was introduced in the first version of IEEE 802.11 and has been used until today, because it is a basic media access method in subsequent standard amendments, like IEEE 802.11a, IEEE 802.11b, IEEE 802.11g and IEEE 802.11n (IEEE 802.11 2012). It is a method of distributed coordination of competing network stations. DCF works as a "listen-before-talk" scheme based on CSMA/CA where stations listen to the medium to determine when it is free. The simple example of communication and competition for media based on DCF in the network containing AP and two stations is presented on Figure 1. If a station, that has packets to send, senses the medium is busy, it will defer its transmission and initiate a backoff counter. The backoff counter is a uniformly distributed random number between 0 and contention window (CW). Once the station detects that the medium has been free for a duration of DCF Interframe Space (DIFS), it starts a backoff procedure, i.e., decrementing its back-off counter as long as the channel is idle. If the backoff counter has reduced to zero and the medium is still

Figure 1

The example of DCF method in simple wireless network
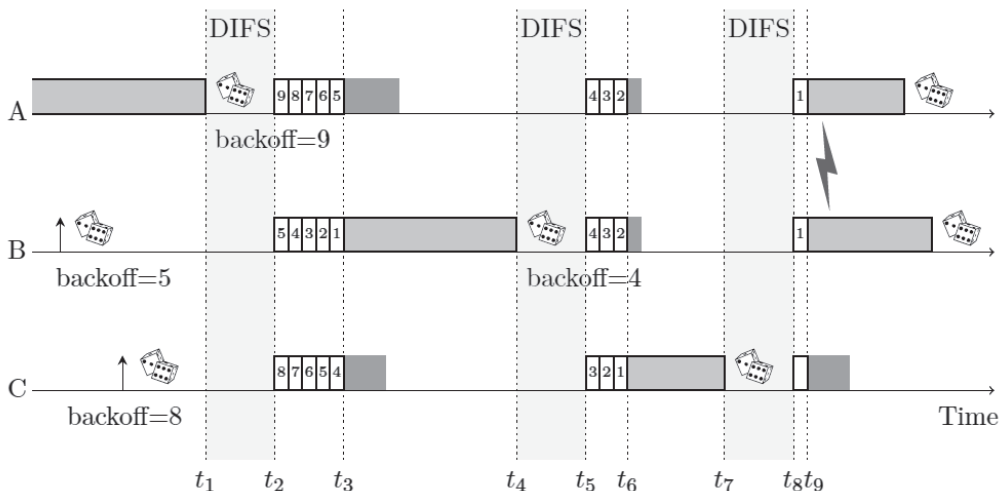
Source: Bingmann (2009).

free, the station begins to transmit (see Figure 1). If the medium becomes busy in the middle of the decrement, the station freezes its backoff counter, and resumes the countdown after deferring for a period of time, which is indicated by the so-called network allocation vector (NAV) stored in the winning station's packet header (Gao et al. 2005).

It is possible that two or more stations begin to transmit at the same time. In such a case, a collision occurs, what is presented on Fig. 1, at t_9 time. Collisions are inferred by no acknowledgement (ACK) from the receiver. After a collision occurs, all the involved stations double their CWs (up to a maximum value, CWmax) and compete to gain control of the medium next time. If a station succeeds in channel access (inferred by the reception of an ACK), the station resets its contention window CW to CWmin. (Gao et al. 2005)

Before data frame sending, a station can optionally send RTS (Request-to-send) to a receiver. If the receiver can receive frame, sends CTS (Clear-to-send) to the sender. RTS/CTS frames exchange allow to reserve virtually the channel. Other station must defer transmission. Detailed description of DCF algorithm is given in (Dolińska and Rządkowski 2014) and (Bingmann 2009).

Point Coordination Function (PCF) defines contention-free type of communication in Wi-Fi network. This method allows AP to be also a point coordinator (PC) and organize centralized communication. PC can initiate contention-free periods (CFP) alternating with contention periods. During every CFP coordination point can poll stations for sending data and only polled station can send data frame to AP. CFP parameters are broadcasted in beacon frame (Bingmann 2009). PCF functionality seems to be implemented very rarely, so is only mentioned in this article.

## EDCA method of media access

The stations have to compete for media access in wireless networks. This competition is defined and ordered by DCF, which is simple and easy to implement. As it was mentioned above, DCF method doesn't provide QoS of wireless transmission, what is its important defect. To solve this problem, IEEE 802.11e standard was approved in 2005. It introduced enhanced media access method, named hybrid coordination function (HCF), that defines QoS guarantees. HCF manages both contention-free and contention-based access to the wireless medium. It defines two medium access mechanisms: enhanced distributed channel access (EDCA) and HCF controlled channel access (HCCA). EDCA is only used in the CP while HCCA can be used in both phases (Bingmann 2009; Gao et al. 2005). EDCA is a simple and easy to implement method. Four types of traffic are distinguished: voice, video, best effort, and background.

The IEEE 802.11e standard introduces some new concepts, like TXOP and access categories (Bingmann 2009). Transmission opportunity (TXOP) is allotment of access time to

the medium, which can be used to transmit a single frame or multiple frames in a sequence. It is defined by start time and duration. The station sending on a TXOP must complete its frame transmission including acknowledgements within the defined time interval, it must not utilize the medium for longer than the allocated duration. If a frame is too large to be transmitted in a single TXOP, it should be fragmented into smaller frames. A TXOP time interval of 0 means it is limited to a single MAC service data unit (MSDU) or MAC management protocol data unit (MMPDU). The access category defines the level of priority of the frame. The QoS support is realized through introducing multiple access categories (ACs) in each QoS station (QSTA).

EDCA defines four ACs, and different ACs have different priorities, servicing different types of traffic. The four AC are labeled *AC_VO* for "voice" class traffic, *AC_*VI for "video" class traffic, *AC_BE* for best effort traffic and *AC_BK* for background traffic. Every AC is an extended version of DCF, what is presented in Fig. 2. With EDCA, packets with different traffic types on the same node compete for the medium as if they are on separate nodes. The ACs are internal queues, that contend for TXOP, using specified channel access parameters. These parameters contain: minimal CW value for a given AC (CWmin[AC]), maximal CW

Figure 2

EDCA queues on one station
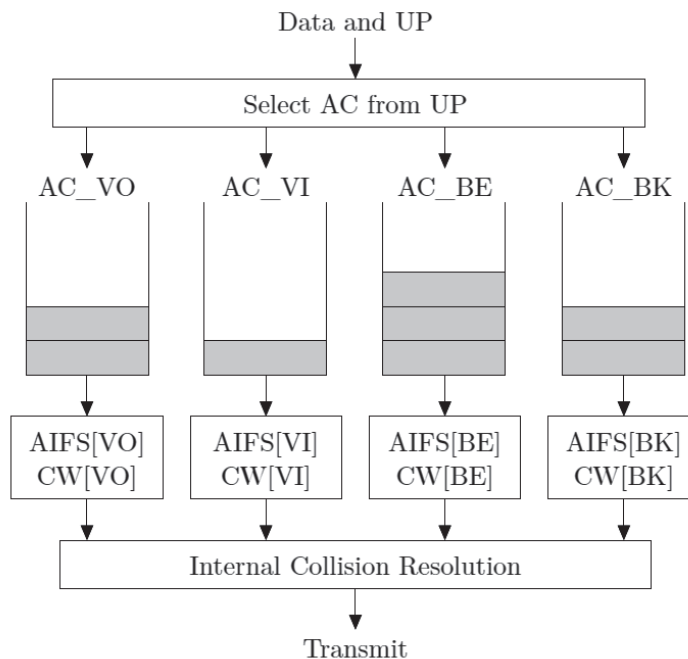
Source: as in Figure 1.

value for a given AC (CWmin[AC]), Arbitration Interframe Space (AIFS[AC]), maximal TXOP value (TXOPlimit[AC]). The higher is the data priority, the lower are the parameter values to give the data higher probability to be send as first (Obaidat et al. 2016). Table 1 contains parameter values for IEEE 802.11a and 802.11n standards.

Communication using a wireless medium is significantly less reliable than wired communication. But with EDCA method, defining in IEEE 802.11e standard the transmission conditions are better, than with DCF.

Table 1

Default EDCA parameters for each AC

AC name	AC description	CWmin	CWmax	AIFNS	Max TXOP	Priority
AC_BK	Background	15	1023	7	0	lowest
AC_BE	Best Effort	15	1023	3	0	
AC_VI	Video	7	15	2	3.008ms	
AC_VO	Voice	3	7	2	1.504ms	highest
DCF	Legacy stations	15	1023	2	0	

Source: own preparation.

IEEE 802.11ac amendment enhances EDCA method by adding TXOP Sharing possibility. In the case of the legacy TXOP, only frames belonging to the same Access Category (AC) are transmitted and multiple frames belonging to different ACs cannot be simultaneously transmitted. TXOP sharing, also referred to as the Multi-User Transmit Opportunity (MU-TXOP) mechanism, extends the legacy 802.11 TXOP concept to support Down-Link (DL) MU-MIMO, what is presented in Figure 3. TXOP Sharing defines two types of Access Categories (primary and secondary), and two types of destinations (primary and secondary). A Primary AC is the AC that wins the TXOP for channel access after both external and internal competitions. There is only one primary AC at any time. A Secondary AC is an AC that does not win a TXOP but wants to share the TXOP obtained by the primary AC for simultaneous transmissions. There could be multiple secondary ACs at any time. Primary destinations are those targeted by the frames belonging to the primary AC. There could be one or more Primary destinations at any time. Secondary destinations are those targeted by the frames belonging to secondary ACs. There could be one or more Secondary destinations at any time. For each AC, an enhanced version of the DCF, called Enhanced Distributed Channel Access function (EDCAF), contends for TXOPs using a set of EDCA parameters. Once an EDCAF wins a TXOP it becomes the owner of the TXOP. Its corresponding AC becomes the Primary AC, and its corresponding destination(s) become Primary destination(s). The Primary AC can share the TXOP with other ACs that did not win the medium access

the TXOP becomes the MU-TXOP. These other ACs become Secondary ACs and their corresponding destinations become Secondary destinations. The AP then groups the Secondary destinations together with the Primary destination(s) for simultaneous transmission (e.g. using GroupID). When the primary AC allows secondary ACs to share the TXOP for simultaneous transmissions, it results in Multi-User TXOP (MU-TXOP) (Siddiqui et al. 2015).

Figure 3

Multi-User Transmit Opportunity (MU-TXOP) Sharing
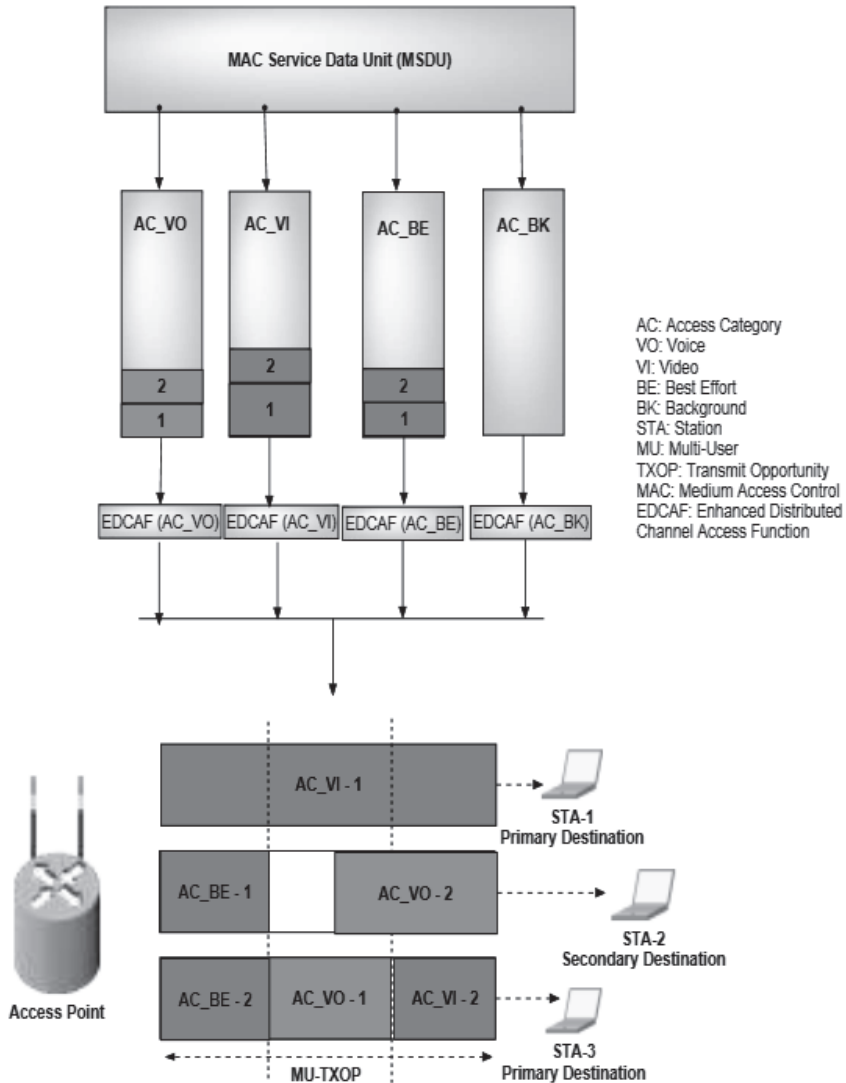
Source: Siddiqui et al. (2015).
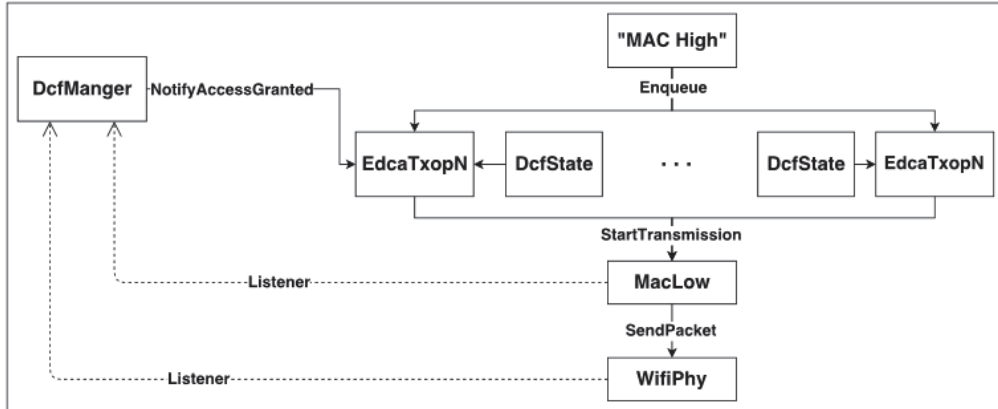
EDCA implementation in NS-3

The ns (from network simulator) is a name for a series of discrete event network simulators, specifically NS-1, NS-2 and NS-3. All of them are discrete-event computer network simulators, primarily used in research and teaching. The NS-3 is free software, publicly available under the GNU GPLv2 license for research, development, and use. The NS-3 has been developed to provide an open, extensible network simulation platform, for networking research and education. In brief, NS-3 provides models of how packet data networks work and perform, and provides a simulation engine for users to conduct simulation experiments (NS-3 Tutorial 2017). The goal of the NS-3 project is to create an open simulation environment for computer networking research that will be preferred inside the research community. Since the process of creation of a network simulator that contains a sufficient number of high-quality validated, tested and maintained models requires a lot of work, NS-3 project spreads this workload over a large community of users and developers.

To enable easy integration of new models into NS-3, its networking architecture is based on real world hardware and software. The interfaces in this architecture closely resemble those found in real operating systems and hardware. The packets passed around in the simulation are required to be exactly like real network packets, down to the last bit (Bingmann 2009). The NS-3 is built as a system of software libraries that work together (NS-3 Tutorial 2017, Lertpratchya 2014). Programming code is divided into modules, like core functionality, internet, csma (Ethernet network simulator) and many others. The wireless IEEE 802.11 network is described as wi-fi module, which is one of the biggest. In short, a *WifiNetDevice* is defined with resembles a wireless card. Different 802.11 MAC and PHY layers can be used to simulate the properties of wireless communication protocol and hardware. The *WifiNetDevice* is built up of a number of classes coordinating packet transmission and reception.

The implementation of 802.11 was ported to NS-3 from yans (Yet Another Network Simulator), which was a prototype project (Bingmann 2009). Processing of DCF access is based on "signals" from the PHY and lower MAC layer. From the PHY, physical carrier sense events as packet reception, transmission and CCA_BUSY indications must be signaled for correct DCF management. Likewise, the lower MAC layer must pass NAV durations from each received packet to the DCF manager (Wifi Models 2017, Lertpratchya 2014). EDCA functionality is the extension of DCF and is implemented on top of DCF in NS-3, what is presented in Fig. 4. Instead of one DCF queue, multiple EDCA queues exist (four queues to represent the four Access categories). Each queue has its own DCFState object that holds its own values of CW_{min}, CW_{max}, and AIFS. Those four queues perform access to the medium separately as if they are four different DCF nodes (Obaidat et al. 2016). The NS-3 implementation of EDCA, described in (Obaidat et al. 2016), only sends one packet when gaining a channel access and then releases the medium. So, this article's authors added TXOP setting

implementation, making simulation conditions and results more realistic. TXOP time limit has great impact on the network performance (Obaidat et al. 2016).

Figure 4

EDCA MAC and Physical Implementation in NS-3

Source: Obaidat et al. (2016).

The EDCA implementation in NS-3 has been developed and improved, but according to the author's knowledge, there are no researches in the literature that present TXOP sharing implementation. As it was mentioned above, TXOP sharing was introduced with IEEE 802.11ac amendment. This method allows more efficient transmission duringTXOP time, allowing for transmission not only by winning AC queue. With TXOP sharing method more different types of packet can be send in one TXOP, improving the network throughput.

Conclusions

Wireless networks built in the IEEE 802.11 standard are very popular in every environment now. Their widespread use causes many problems with throughput, transmission QoS and even with radio channel access. On the other hand, users want to watch movies online, share data, use social services and listen to the internet radio. So, the wireless standard must be still improved. EDCA was chosen as a basic wireless media access method in IEEE 802.11ac and 802.11ax, giving some QoS basic features to wireless transmission.

Because of wireless network popularity, it is very important to have a possibility of testing the efficiency of new features and different communication scenarios. The NS-3 simulator is very popular for science researches. In this article, the implementation of EDCA

method in NS-3 was analyzed. It turned out, that the EDCA implementation is not complete. It lacks the new feature, added in IEEE 802.11ac specification – TXOP Sharing possibility. The next step should be this feature implementation in NS-3 code to have possibility of simulation full IEEE 802.11ac standard network.

Bibliography

Bellalta B., Bononi L., Brunoc R., Kassler A. (2015), *Next generation IEEE 802.11 Wireless Local Area Networks: Current status, future directions and open challenges*, "Computer Communications", Vol. 75, http://www.sciencedirect.com/science/article/pii/S0140366415003874 [access: 09.08.2017].

Bingmann T. (2009), *Accuracy Enhancements of the 802.11 Model and EDCA QoS Extensions in NS-3*, Diploma Thesis, Faculty of Computer Science, University of Karlsruhe (TH), Karlsruhe.

Dolińska I. (2016), *The New Features of 802.11ac Standard Improving the Corporate Wi-Fi Networks Capabilities*, „Kwartalnik Naukowy Uczelni Vistula (Vistula Scientific Quarterly)", nr 1(47).

Dolińska I., Masiukiewicz A. (2012), *Quality of service providing in WLAN networks possibilities, challenges and perspectives*, Information systems in management, WULS Press, Warszawa.

Dolińska I., Rządkowski G. (2014), *The Method of DCF Simulation and Analysis for Small Wi-Fi Networks*, „Zeszyty Naukowe Uczelni Vistula (Vistula University Working Papers)", nr 38.

Gao D., Cai J., Ngi Ngan K. (2005), *Admission Control in IEEE 802.11e Wireless LANs*, http://www.ntu.edu.sg/home/asjfcai/IEEE_network_ID133_revision.pdf [access: 09.08.2017].

IEEE 802.11 (2012), *IEEE 802.11-2012, Part 11 (2012): Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*, IEEE Working Group for WLAN Standards, http://www.ieee802.org [access: 10.08.2017].

IEEE 802.1ac (2013), *IEEE StdP 802.11ac:Part11:Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Enhancements for Very High Throughput for Operation in Bands below 6 GHz*.

Lertpratchya D., (2014), *Wi-Fi Module in NS-3*, https://www.nsnam.org/tutorials/consortium14/ns-3-training-session-5.pdf [access: 01.09.2017].

Masiukiewicz A. (2013), *802.11ad - 60 GHz WLAN Implementation*, „Elektronika", nr 12.

NS-3 Tutorial (2017), Release NS-3.26, https://www.nsnam.org/docs/release/3.26/tutorial/ns-3-tutorial.pdf [access: 01.09.2017].

Obaidat I., Alsmirat M., Jararweh Y. (2016), *Completing IEEE 802.11e Implementation in NS-3*, 7th International Conference on Information and Communication Systems (ICICS), http://ieeexplore.ieee.org/document/7476109/ [access: 01.09.2017].

Siddiqui F., Zeadally S., Salah K. (2015), *Gigabit Wireless Networking with IEEE 802.11ac: Technical Overview and Challenges*, "Journal of Networks", Vol. 10, No. 3, https://pdfs.semanticscholar.org/a969/fe34daa19d07519b8636346cc766a19113be.pdf [access: 01.09.2017].

Wifi Models (2017), *NS-3 doxygen documentation*, https://www.nsnam.org/docs/release/3.26/doxygen/group__wifi.html [access: 01.09.2017].

Implementacja metody EDCA w symulatorze sieciowym NS-3

Streszczenie

Sieci bezprzewodowe budowane w standardzie IEEE 802.11 zyskały ogromną popularność. Ich powszechność powoduje jednak problemy z uzyskaniem odpowiedniej przepustowości, jakości transmisji, a nawet dostępu do kanału radiowego. Standard IEEE 802.11 jest stale ulepszany. Zwiększane były zasięg i przepustowość, dodano zabezpieczenia transmisji, sieci typu mesh, poprawiono mechanizmy zarządzania itd. Rozszerzenie IEEE 802.11e wprowadziło możliwość zapewnienia jakości transmisji QoS w sieciach bezprzewodowych. Z powodu wysokich wymagań użytkowych z jednej strony i złożoności procesu komunikacyjnego z drugiej, bardzo wygodnymi narzędziami do badania sieci są symulatory. Umożliwiają one analizowanie efektywności komunikacji i testowanie różnych scenariuszy połączeń. W niniejszym artykule przeprowadzono analizę implementacji metody EDCA w symulatorze sieciowym NS-3. Wykazała ona, że implementacja EDCA nie obejmuje jednej ważnej właściwości tej metody, a więc powinna być poprawiona.

Słowa kluczowe: EDCA, QoS w sieciach WLAN, symulator sieciowy.

Kody JEL: L86

Afiliacja:
dr Iwona Dolińska
Akademia Finansów i Biznesu Vistula
Wydział Inżynierski
ul. Stokłosy 3
02-787 Warszawa
e-mail: i.dolinska@vistula.edu.pl