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# SOME ASPECTS OF QUALITY OF SERVICE IN WIRELESS LAN[1]

**Summary**. IEEE 802.11 MAC protocol is the de facto standard for wireless local area networks (WLANs). In today's Internet, the emerging widespread use of real-time voice, audio, and video applications makes QoS (Quality of Service) a key problem. This article tries to show that implementation of some mechanisms of traffic shaping causes some improvement of the level of QoS in WLANs.

**Keywords**: 802.11, QoS, TBF

# WYBRANE ZAGADNIENIA JAKOŚCI USŁUG W SIECIACH BEZPRZEWODOWYCH

**Streszczenie**. Protokół dostępu do łącza 802.11 jest standardem dla lokalnych sieci bezprzewodowych (WLAN). Aktualnie w Internecie szeroko wykorzystuje się aplikacje audio i wideo wymagające zapewnienia jakości usług. Ten artykuł jest próbą wykazania, że niektóre mechanizmy kształtowania ruchu powodują polepszenie poziomu jakości usług dla sieci WLAN.

**Słowa kluczowe**: 802.11, QoS, TBF

## 1. Introduction

Current market trends show that wireless communication is the most developing transmission technology, becoming the base for many audio and video applications. Evolution of

[1] This research was financed by Polish Ministry of Science and Higher Education project no. N517 025 31/2997 and supported by European Network of Excellence EuroFGI (Future Generation Internet).

this technology is a two-way process, dealing with mobile telephony and wireless local area networks (WLANs) [1].

First, the speed of data transfer rate in cellular networks is gradually growing. Nowadays second generation (2G) of mobile telephony systems is not suitable for efficient digital data transfer thus 2G-systems were extended by 2.5G technology containing packed-switched capabilities: data transmission mechanism High-Speed Circuit-Switched Data (HSCSD), packed switched technologies General Packet Radio Service (GPRS) and Enhanced Data rates for GSM Evolution (EDGE). Another step is third generation (3G)Universal Mobile Telecommunications System (UMTS) and mobile telephony communications protocol High-Speed Downlink Packet Access (HSDPA).

Second, there is greater and greater employment of the mobile wireless local area networks (WLANs). Achieved bitrates (above 1 Mbit/s) are considerably higher than that in mobile telephony standards GPRS and EDGE. The cost of local installations is relatively low so this technology has gained tremendous attention in recent years. WLANs are mostly implemented as Wi-Fi (IEEE 802.11), Bluetooth (IEEE 802.15.1) or WiMAX (IEEE 802.16).

At present the most popular standard of wireless networks is IEEE 802.11 [2]. The 802.11 standard family was developed by the Institute of Electrical and Electronics Engineers (IEEE) [3], in order to deal with the modern wireless connectivity needs. The IEEE 802.11 standard includes detailed specifications for both the medium access control (MAC) and the physical layer (PHY). The original 802.11 MAC protocol includes two modes of operation characterized by coordination functions:

- DCF – compulsory distributed co-ordination function – is an asynchronous data transmission function, which best suits delay intensive data (e.g. email, ftp),
- PCF – optional point co-ordination function – the pooling-based function is utilized in delay sensitive data transmission (e.g. real time audio or video).
- DCF defines two access mechanism to employ packet transmission:
- the default scheme is called the basic access mechanism, in which station transmit data packet after deffering the medium is busy,
- an optional way of transmitting data packets, namely, the request to send/clear to send RTS/CTS reservation scheme. This scheme uses small RTS/CTS packets to reserve the medium before large packets are transmitted in order to reduce the du-ration of a collision.

The second of the above mentioned mechanism is at the moment the most spread in wireless networks. Unfortunately it has been observed that the packet delay increased dramatically when the number of active stations increased. The wireless network infrastructure will not be adjusted to the Quality of Service (QoS) requirements. The authors of this paper want to show that it is possible to achieve demanded parameters of transmission in the wireless network based on the CSMA/CA mechanism.

The present solutions of VoIP or VOD applications show that it is possible to guarantee some level of QoS in the networks based on the random access to link. On the other hand the specificity of Internet makes easier to apply algorithms which do not require too many changes in the network infrastructure (it is the reason why the Diffserv model is more popular than the Intserv).

Currently there are many publications describing models of 802.11 networks such as [14] and [15]. They examine the issue of wireless connections of remote stations to the access point. According to the best knowledge of the authors there is the lack of research works that treat the access point not only as an repeater in the wireless connection, but also as a bridge between wireless and the wired part of the network.

The authors of this paper noticed (based on the analysis of the traffic in the campus network) that the traffic between wireless and wired network is the most part of the traffic transmitted by access point. Modifying the rules of the access point behavior by adding active queue management functionality can significantly improve the parameters of transmission. It is certainly important to realize that it is impossible to obtain full QoS. However, the implementation of some techniques, well-known and implemented in the wired networks (for example advanced methods of scheduling packets in queues [16]) allows to achieve the satisfying level of QoS.

Many empirical and theoretical researches on Ethernet [5], Wide Area Network [6, 7], WWW traffic [9] and VBR video traffic [8] have shown the self-similar characteristic of the network traffic. These results cannot be directly applied to the wireless LANs due to the difference in their MAC protocol implementation. As a part of this work the wireless traffic was analyzed. Our studies confirmed the occurrence of the self-similarity feature in the analyzed traffic, which is confirmed by research described in [17, 18]. Section 2. presents the results of the wireless traffic analysis. This section gives also some definition of self-similarity.

This chapter investigates the impact of TBF-mechanisms implemented in WLAN stations on some aspects of QoS in Wireless LAN. The authors also try to show that the implementation of AQM-mechanisms in Access Point has also the great impact on the level of QoS in WLAN. Section 3. describes the simulation model of the 802.11 with above mentioned extensions and presents the obtained results.

The summary and conclusions drawn from the research conducted in this work are included in the section 4.

## 2. Characteristics of the traffic in Wireless LAN

This section describes research concerning EDGE and UMTS data file transmission and streaming audio/video transmission. The tests were conducted separately for EDGE and UMTS technology. In order to achieve the same propagation conditions, one mobile network operator and one location were used. The following data trans-mission parameters were observed:

- download time,
- upload time,
- mean, minimum and maximum bit rate of EGDE and UMTS link,
- delay of packet transmission through EDGE and UMTS network,
- streaming audio/video transmission,
- number of retransmissions,
- traffic intensity through the scales of time.

The results obtained during the file transmission in UMTS Network are presented in the table 1. The streaming audio file transmission was measured while the device was connected to UMTS network. File was downloaded using RTP. The received results are presented in the table 2.

Table 1

Downloading file in UMTS network

| File transmission in UMTS network | Result |
|---|---|
| Download time | 20.452s |
| Exact file size | 536557 bytes |
| Minimum bit rate | 175432 b/s |
| Mean bit rate | 1865b/s |
| Maximum bit rate | 413987 b/s |
| Mean transmission time of IP packet | 53 ms |
| Packet retransmissions | 8 |

Table 2

Streaming audio transmission (downlink) in UMTS

| Streaming audio transmission in UMTS network | Result |
|---|---|
| Transmission time | 194.348 s |
| Minimum bit rate | 69684b/s |
| Mean bit rate | 49376b/s |
| Maximum bit rate | 94846b/s |
| Mean IP packet size | 835bytes |
| Packet retransmissions | 2 |

Finally our research shows that it is possible to transmit a streaming audio even if the network has no QoS mechanisms (low variance of bit rate). Specificity of CSMA family protocols causes the growth of variance together with the increase of network load and can make the transfer of multimedia data impossible. On the other hand research has shown that the traffic in WLAN networks reveals the self-similarity feature.

Self-similarity of a process means that the change of time scale does not influence the process: the original process and the scaled one are statistically the same. It results in long range dependence and makes possible the occurrence of very long periods of high (or low) traffic intensity. These features have a great impact on a network performance. They enlarge the mean queue lengths at buffers and increase the probability of packet losses, reducing this way the quality of services provided by a network [19].

Let a process $X_k$ represent the traffic intensity measured in fixed time intervals and let the aggregated process $X_k^{(m)}$ be the average of the basic process over a group of *m* consecutive samples: $X_k^{(m)} = (X_{km-m+1} + ... + X_{km})/m$, where $k \geq 1$. There are several methods used to check if a process is self-similar. The easiest one is a visual test: one can observe the behaviour of the basic process $X_t$ and the aggregated process $X_k^{(m)}$. If these processes have the same character – the increase of *m* does not smooth the process, the process is self-similar. More formally, the difference between short-range dependent and long-range dependent (self-similar) process is as follows [5]: for the first process the sum of covariance $\sum_{k=0}^{k=\infty} Cov(k)$ is convergent, the spectrum of the process $S(\omega) = \sum_{k=-\infty}^{k=\infty} R(k)e^{-j\omega k}$, where $R(k)$ is the autocorrelation function of the process, is finite at $\omega = 0$ end the variance $var(X_k^{(m)})$ tends asymptotically for large *m* to the function $var(X)/m$. In the case of long-range dependent process, the sum of covariance $\sum_{k=0}^{k=\infty} Cov(k)$ is divergent, $S(0)$ is singular, and $var(X_k^{(m)})$ tends asymptotically to $var(X)/m^{\beta}$ where $0<\beta<1$. The parameter $\beta$ is related to the Hurst parameter $H$ (often used to characterise the self-similarity of a process): $H = 1 - \beta/2$ [5]. For $0.5 < H \leq 1$ process is self-similar; the closer $H$ is to 1, the greater is the degree of persistence of long-range dependence.

Figure 1 present the traffic intensity in UMTS network on different time scales. It is clearly seen that changing the time scale does not cause the change in the character of the process representing the traffic intensity.

The Hurst parameter for analysed traffic, determined by the variance-time plot method [22], has shown the value variance through the time scale ranging from 0.76 to 0.83. That confirms the occurrence of self-similarity in the wireless network traffic. As a consequence of this fact there is a need of the proper selection of traffic sources when modelling behaviour of this type of networks.

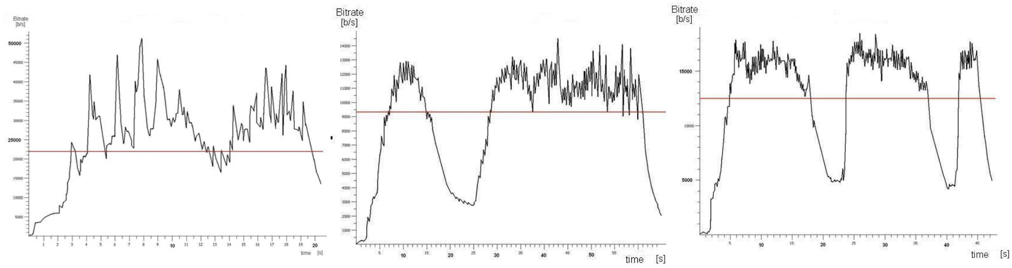


Fig. 1. Bit rate during downloading file in UMTS network
Rys. 1. Prędkość transmisji podczas pobierania pliku w sieci UMTS

In models created for the needs of this chapter we use the traffic source based on the MMPP (Markov modulated Poisson process) source introduced by S. Robert [20, 21] to represent the self-similar traffic. The time of the model is discrete and divided into unit length slots. Only one frame can arrive during each time-slot. In the case of memory less, geometrical source, the frame comes into system with fixed probability $\alpha_1$. In the case of self-similar traffic, packet arrivals are determined by a $n$-state discrete time Markov chain called modulator. It was assumed that modulator has $n = 5$ states ($i = 0, 1, \ldots, 4$) and packets arrive only when the modulator is in state $i = 0$. The elements of the modulator transition probability matrix depend only on two parameters: $q$ and $a$ – therefore only two parameters should be fitted to match the mean value and Hurst parameter of the process. If $p_{ij}$ denotes the modulator transition probability from state $i$ to state $j$, then it was assumed that $p_{0j} = 1/a^j$, $p_{j0} = q/a^j$, $p_{jj} = 1 - (q/a)^j$ where $j = 1, \ldots, 4$, $p_{00} = 1 - 1/a - \ldots - 1/a^4$, and remaining probabilities are equal to zero. The passages from the state 0 to one of other states determine the process behavior on one time scale, hence the number of these states corresponds to the number of time-scales where the process may by considered as self-similar.

This model enables us to represent, with the use of few parameters, a network traffic which is self-similar over several time-scales. For such a source model, one must fit only two parameters: expectation and the Hurst parameter (plus the number of states in Markov chain $n$; it defines the number of time scales on which the process has self-similar character).

## 3. Model of 802.11 (DCF – RTS/CTS) network – numerical results

This section contains the analysis of the 802.11 MAC network with several workstations and one Access Point (AP). We also analyze the 802.11 network with modifications like AQM implemented in AP and TBF packet scheduling algorithms implemented in workstations. Our analysis were carried out in the OMNeT++ simulation environment [12].

OMNeT++ is a public-source, component-based, modular and open-architecture simulation environment. OMNeT++ is free for academic and non-profit use; commercial users must obtain a license. The example screenshot of our model graphical representation in OMNeT++ is presented on figure 2.

To emphasize the importance of using self-similar traffic sources the comparative research has been carried out for the self-similar and Poisson (non self-similar) source. Input traffic intensity was chosen as $\alpha = 0.5$ or $\alpha = 0.081$, and due to the modulator characteristics, the Hurst parameter of self-similar traffic was fixed to $H = 0.8$. For both considered in comparisons cases, i.e. for geometric interarrival time distribution (which corresponds to Poisson traffic in case of continuous time models) and self-similar traffic, the considered traffic intensities are the same. A detailed discussion of the choice of the source parameters is presented in [23].

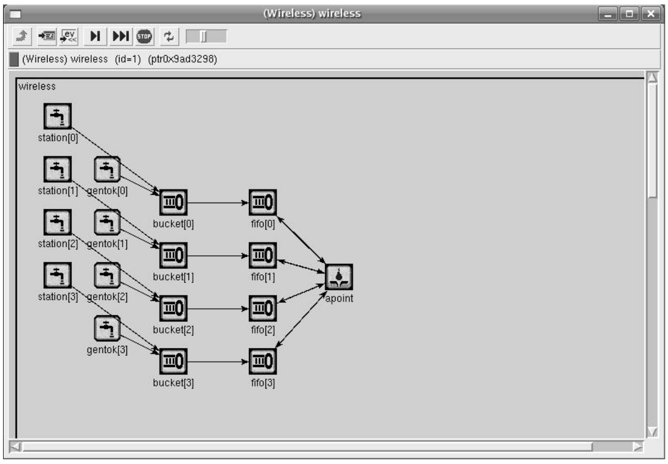


Fig. 2. 802.11 model, traffic controlled by TBF algorithm – OMNET++
Rys. 2. Model sieci 802.11, ruch sieciowy kontrolowany przez mechanizm TBF – OMNET++

Our model of 802.11 network uses compulsory distributed co-ordination function (DCF) with RTS/CTS reservation scheme. The model assumes that Access Point is also a Medium Access Controller. Our first goal is to capture the aspect of collision distribution on the level of RTS/CTS signals and the usage of the transmission channel for this mechanism and to compare the results for self-similar and Poisson traffic. Tables 3 and 4 show the influence of input traffic characteristics for the number of RTS, the number of collisions and the number of transmissions for all workstations.

Table 3
Simulation results for self-similar sources α=0.081 μ= 0.05, Empty slots: 8209875, All slots: 72000000, All transmissions: 2737886

| | St. 0 | St. 1 | St. 2 | St. 3 |
|---|---|---|---|---|
| RTS | 1076582 | 1058753 | 1092284 | 1135808 |
| Collisions | 393013 | 377450 | 382086 | 400671 |
| Nb of transm. | 665076 | 663818 | 692600 | 716392 |
| Transm. length | 13321347 | 13247352 | 13827542 | 14317817 |

Table 4
Simulation results for geometrical sources α=0.081 μ= 0.05, Empty slots: 8209875, All slots: 72000000, All transmissions: 2737886

| | St. 0 | St. 1 | St. 2 | St. 3 |
|---|---|---|---|---|
| RTS | 1295812 | 1296189 | 1294961 | 1294563 |
| Collisions | 449356 | 449647 | 449083 | 448736 |
| Nb of transm. | 657223 | 657314 | 656959 | 655591 |
| Transm. length | 13114073 | 13133069 | 13137195 | 13151662 |

In figures 3 and 5 the RTS distribution with low load conditions is presented. Figures 4 and 6 present the RTS distribution for self-similar and geometrical traffic in the case when network is heavily loaded. When the network is overloaded the number of collision are greater than the number of successfully sended reservation frames. Be-cause of that in the next model the traffic generated in the workstations is shaped by the Token bucket filter mechanism (fig. 2).

Figures 7 and 8 show the impact of TBF (Token Bucket Filter) mechanism for the RTS distribution.

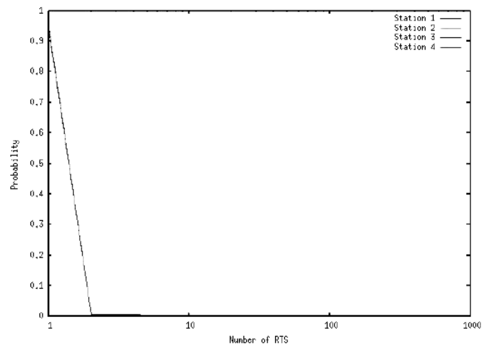


Fig. 3. RTS distribution (Self-similar sources) α = 0.081; μ = 0.05
Rys. 3. Rozkład RTS (źródła samopodobne) α = 0.081; μ = 0.05

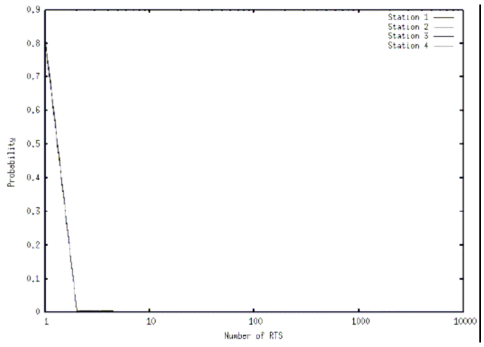


Fig. 4. RTS distribution (Self-similar sources) $\alpha = 0.5$; $\mu = 0.05$
Rys. 4. Rozkład RTS (źródła samopodobne) $\alpha = 0.5$; $\mu = 0.05$

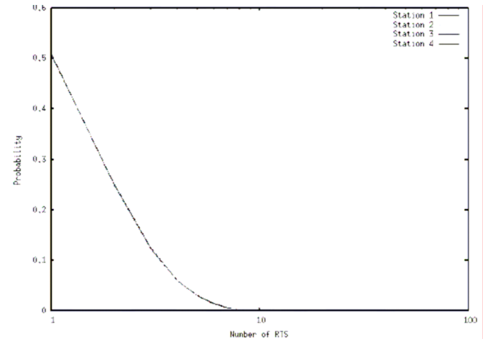


Fig. 5. RTS distribution (Geometrical sources) $\alpha = 0.081$; $\mu = 0.05$
Rys. 5. Rozkład RTS (źródła geometryczne) $\alpha = 0.081$; $\mu = 0.05$

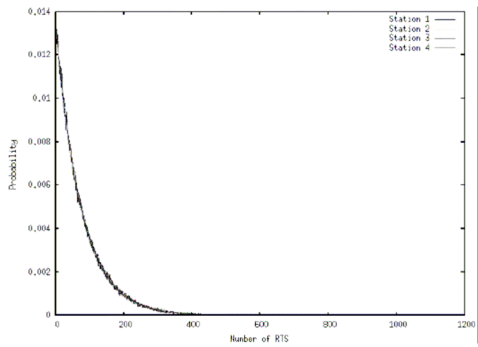


Fig. 6. RTS distribution (Geometrical sources) $\alpha = 0.05$; $\mu = 0.05$
Rys. 6. Rozkład RTS (źródła geometryczne) $\alpha = 0.05$; $\mu = 0.05$

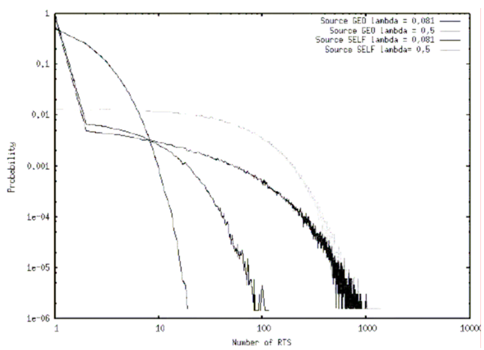


Fig. 7. RTS distribution – GEO and SELF sources
Rys. 7. Rozkład RTS– źródła GEO i SELF

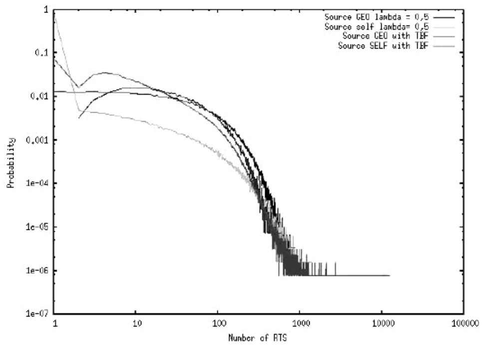


Fig. 8. RTS distribution – GEO and SELF sources with TBF
Rys. 8. Rozkład RTS– źródła GEO i SELF z TBF

Table 5 presents more detailed results. For α = 0.081 both geometrical and self-similar sources cause low utilization of net work – the factor for the channel usage reaches up to 70 percent. Also the collision factor remains low. There is no reason for shaping the outgoing traffic with the TBF mechanism for network with such a redundancy of resources. Differently, for α = 0.5 the usage of network falls to 32 percent for geometrical source. The usage of TBF mechanisms for the networks with the surplus of resources has also decreased the efficiency. For the case of overloaded network the application of TBF mechanism has improved the transmission parameters. This results confirm the sense of using traffic shaping mechanisms to achieve some level of QoS (controlled load) in 802.11 network.

Table 5

Comparison of transmission for geometrical and self-similar sources with TBF

| Model | factor of network utilization | factor of network collisions |
|---|---|---|
| geo α = 0; 5 | 0.327996486 | 1.114468403 |
| geo α = 0; 081 | 0.729666653 | 0.02495586 |
| self α = 0; 5 | 0.690259625 | 0.486739722 |
| self α = 0; 081 | 0.759917472 | 0.0215725 |
| geo with TBF α = 0; 5 | 0.452072075 | 1.108089167 |
| self with TBF α = 0; 5 | 0.728667884 | 0.399881278 |

Our last model has treated AP as a intermediary between LAN and WLAN net-works. The same transmission parameters as those above mentioned have been used. The received results were close to those obtained earlier. However it has been ob-served that high packet loss appeared in the buffer storing packets that enter the wire-less network. This problem has been solved by applying Active Queue Management. The application of the simplest RED algorithm [16] has resulted in the significant decrease of losses (fig.9).

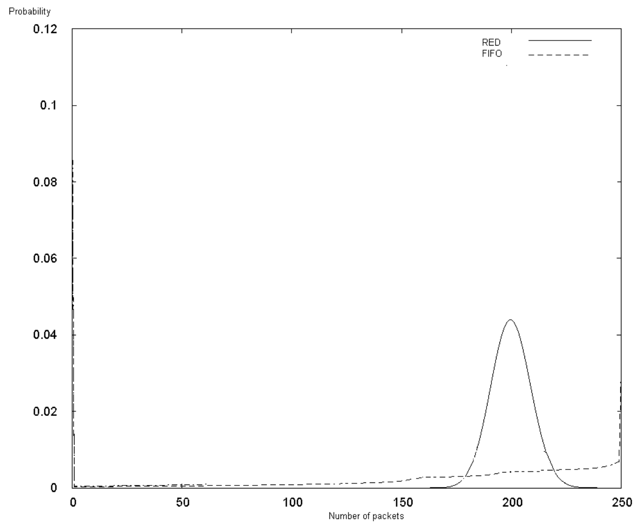


Fig. 9. Queue distributions for FIFO and RED
Rys. 9. Rozkład zajętości kolejki dla algorytmów FIFO i RED

## 4. Conclusions

A MAC layer extension for QoS, IEEE 802.11e, has been recently ratified as a standard. This MAC layer solution, however, addresses only the issue of prioritized access to the wireless medium and leaves such issue as QoS guarantee and admission control to the traffic control systems at the higher layers.

On the other hand the specificity of Internet makes it easier to apply algorithms which do not require too many changes in the network infrastructure (it is the reason why the Diffserv model is more popular than the Intserv).

This chapter tries to show that implementation of some mechanisms of traffic shaping causes some improvement of the level of QoS in WLANs. Moreover, it has been shown that the implementation of the QoS mechanisms for network with considerable redundancy did not make any sense. Modifying the rules of the access point behavior by adding active queue management functionality at the link between LAN and WLAN network can significantly improve parameters of transmission. It is certainly important to realize that in this way it is impossible to obtain full QoS. However, when applying some techniques, well-known in the wired networks and implemented in advanced routers for a long time (advanced methods of scheduling packets in queues [16]), it is possible to achieve the satisfying level of QoS. The results obtained for the overloaded network show the improvement of throughput while applying the TBF mechanism. The implementation of the AQM mechanism has allowed for the significant decrease in loss of packets in the incoming queue to the wireless network.

In the paper it has also been shown that it is necessary to take into account the self-similar feature while modeling the wireless network. Last research has shown that the traffic in WLAN networks reveals the self-similarity feature. The obtained results for the geometrical and self-similar sources have differed significantly. Therefore one should use self-similar traffic sources while modeling of WLAN.

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**Omówienie**

Protokół 802.11 jest najbardziej popularny dla bezprzewodowych sieci lokalnych (WLAN). We współczesnym Internecie kluczowym problemem stał się problem jakości usług (QoS). Standard 802.11e definiuje rozszerzenia standardu 802.11 w celu rozwiązania problemu jakości usług. Jednakże standard ten pozostawia problemy gwarantowania jakości usług oraz kontroli dostępu warstwom wyższym. W artykule wykazano, że niektóre mechanizmy kształtowania ruchu mogą poprawić poziom jakości usług w sieciach WLAN.

Przedstawiono analizę strumieni danych w rzeczywistych sieciach bezprzewodowych. Wykazała ona samopodobny charakter badanego ruchu. Ponadto, autorzy przedstawili wpływ mechanizmów kształtowania ruchu (algorytm TBF) na poprawę wydajności sieci bezprzewodowej. Przebadano również wpływ algorytmów AQM zaimplementowanych w punkcie dostępowym do sieci WLAN. Przeprowadzone badania wykazały, że dzięki implementacji mechanizmów kształtowania ruchu jest możliwe uzyskanie pewnego poziomu jakości usług

w sieci bezprzewodowej. Badania wykazały również, że przy tego typu analizach konieczne jest branie pod uwagę samopodobnego charakteru ruchu w sieciach bezprzewodowych.

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