The Impact of Self-similarity on Traffic Shaping in Wireless LAN

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Abstract. IEEE 802.11 MAC protocol ist 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. At the MAC layer, 802.11e defines extensions to enhance the QoS performance of 802.11 WLAN. This MAC layer solution leaves such issues of QoS as QoS guarantee and admission control to the traffic control systems at the higher layers. This article tries to show that implementation of some mechanisms of traffic shaping causes some improvement of the level of QoS in WLANs. First we analyse the influence of the traffic shaping in WLANs stations by the mechanism of token bucket filter. Next the analysis of the behaviour of Access Point with AQM mechanism was carried out. The conducted research has shown that it is possible to achieve certain level of QoS thanks to the implementation of traffic shaping mechanisms. We make our experiments comparatively for the traffic sources with self-similarity and without it. Our results confirm the necessity of taking into account the self-similar character of wireless traffic.

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 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 Circit-Switched Data (HSCSD), packed switched technologies General Packet Radio Service (GPRS) and Enhanced Data rates for GSM Evolution

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(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]. This standard is widely available because of its low cost and relatively high capacity. Meanwhile, Quality of Service - sensitive applications such as multimedia streaming service become increasingly popular, and these applications require certain real time constraints such as bandwidth, delay, and jitter to be satisfied. In the section 2 the improving of IEEE 802.11 to manage some aspects of QoS is described. 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 [7]. This article 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 4 describes the simulation model of the 802.11 with above mentioned extensions and presents the obtained results.

Many empirical and theoretical researches on Ethernet [8], Wide Area Network [10,9], WWW traffic [11] and VBR video traffic [12] 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. Section 3 gives some definition of self-similarity and describes recent empirical studies of WLAN traffic characteristic. The conclusion of this studies causes the using in our simulation model the self-similar traffic sources (see section 4).

The summary and conclusions drawn from the research conducted in this work are included in the section 5.

2 Quality of Service in Wireless LAN

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 delailed 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 polling-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 duration of a collision.

The IEEE 802.11 standard is the most widely deployed wireless local area network infrastucture. However, it cannot provide QoS support for the increasing number of multimedia applications. Thus, a lot of research works have been carried out to enhance the QoS support in 802.11 networks [13]. So far, most research works for the QoS support in IEEE 802.11 have focused on controlling the priority to access the wireless medium by modifying the MAC protocol [5,6] The IEEE 802.11 Task Group E (802.11e) has defined enhancements to the original 802.11 MAC to provide QoS. The 802.11e standard introduces the Hybrid Coordination Function (HCF), which combines functions from DCF and PCF with enhanced QoS-specific mechanisms and frame types. HCF has two modes of operation - Enhanced Distribution Coordinate Access (EDCA) and HCF Controlled Channel Access (HCCA). EDCA and HCCA are contention-based and polling-based mechanisms for channel access. EDCA contention access is an extention to DCF and provides prioritized access to the wireless medium. HCCA uses a Hybrid Coordinator to centrally manage the wireless medium access to provide parameterized QoS. Like PCF, HCCA uses a polled-based mechanism to access the medium. This MAC layer solution, IEEE 802.11e, 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 [7].

This article try to show that it is possible to achieve certain level of QoS thanks to the implementation of traffic shaping mechanisms.

3 Characteristics of the Traffic in Wireless LAN

Clasically, the traffic intensity, seen as a stochastic process, was represented in queueing models by short term dependencies [14]. However, the analysis of measurements shows that the traffic has also long-terms dependencies and has self-similar character. It is observed on various protocol layers and in different network structures [8,9,10,11,12].

The term "*self-similar*" was introduced by Mandelbrot [15] in description of processes in the field of hydrology and geophysics. It means that a change of time scale does not influence statistical properties of the process. A stochastic process X_t is self-similar with Hurst parameter $H(0.5 \leq H \leq 1)$ if for a positive factor g the process $g^{-H} X_{gt}$ has the same distribution as the original process X_t, [16]. Mathematically, the difference between short-range dependent and long-range dependent (self-similar) processes is as follows [17]:

For a short-range dependent process:
- $\sum_{r=0}^{\infty} \mathrm{Cov}(X_t, X_{t+\tau})$ is convergent,
- spectrum at $\omega = 0$ is finite,
- for large m, $\mathrm{Var}\,(X_k^{(m)})$ is asymptotically of the form $\mathrm{Var}\,(X)/m$,
- the aggregated process $X_k^{(m)}$ tends to the second order pure noise as $m \to \infty$;

For a long-range dependent process:
- $\sum_{r=0}^{\infty} \mathrm{Cov}(X_t, X_{t+\tau})$ is divergent,
- spectrum at $\omega = 0$ is singular,
- for large m, $\mathrm{Var}\,(X_k^{(m)})$ is asymptotically of the form $\mathrm{Var}\,(X) m^{-\beta}$,
- the aggregated process $X_k^{(m)}$ does not tend to the second order pure noise as $m \to \infty$,

where the spectrum of the process is the Fourier transformation of the autocorrelation function and the aggregated process $X_k^{(m)}$ is the average of X_t on the interval m:

$$X_k^{(m)} = \frac{1}{m}(X_{km-m+1} + ... + X_{km}) \qquad k \geq 1.$$

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 process through the scales of time. The other one is the estimation of aggregated index of dispersion *IDC* or aggregated coefficient of variation *CV*. The aggregated index of dispersion is equal to the variance of the number of arrivals within the interval m divided by the average number of arrivals during the same interval:

$$IDC(m) = \frac{\mathrm{Var}\,(mX_k^{(m)})}{E(mX_k^{(m)})}$$

and *CV* is

$$CV(m) = \frac{\sqrt{\mathrm{Var}\,(mX_k^{(m)})}}{E(mX_k^{(m)})}$$

For a self-similar processes, *IDC* increases on several time scales and *CV* is much more than 1 for small time intervals. Estimation of Hurst parameter is the most frequently used method to check if a process is self-similar: for non-self-similar processes $H = 0.5$; for $0.5 < H \leq 1$ process is self-similar; the closer H is to 1, the greater the degree of persistance of long-range dependence. The parameter can be estimated by various methods, among others by the analysis of variance-time plot [16]. The variation of aggregated self-similar process is equal to:

$$\mathrm{Var}\,(X_k^{(m)}) \approx \mathrm{Var}\,(X)\,m^{-\beta}, \quad \text{or} \quad \log \mathrm{Var}\,(X_k^{(m)}) \approx \log \mathrm{Var}\,(X) - \beta \log m$$

so the log-log plot of $\mathrm{Var}\,(X_k^{(m)})$ versus m is a straight line with slope $-\beta$, $0 < \beta < 1$, and $H = 1 - \beta/2$.

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 [18]. According to Stallings [18], "Self-similarity is such an important concept that, in a way, it is surprising that only recently has it been applied to data communications traffic analysis". As mentioned above, many empirical and theoretical researches have shown the self similar characteristics of the network traffic. These results cannot be directly applied to the wireless LANs due to the difference in their MAC protocol implementation. Recent empirical study on WLANs demonstrates that the wireless traffic exhibits self-similarity on a wide range of time scales [19,20,21,22] 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.

4 The Model of the 802.11 Network - Numerical Results

In models created for the needs of this article we use the traffic source based on the MMPP (Markov modulated Poisson process) source introduced by S. Robert [23,24] 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 memoryless, geometrical source, the frame comes into system with fixed probability α. 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 behaviour on one time scale, hence

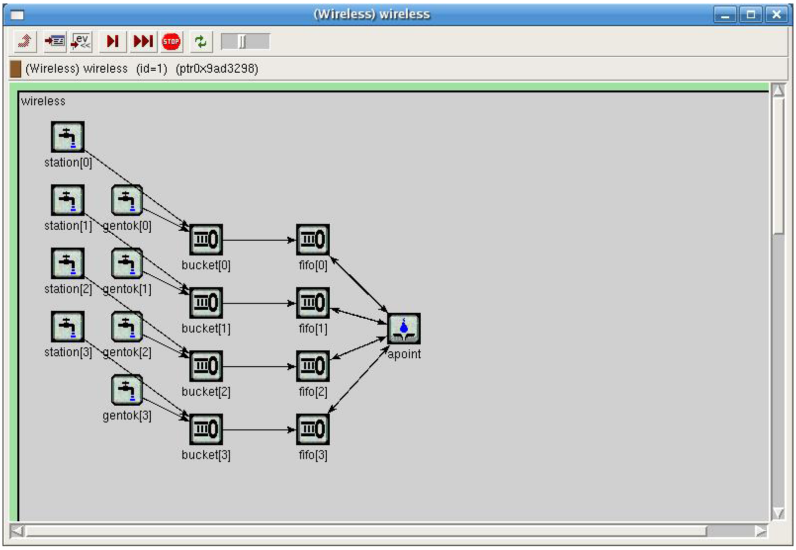

Fig. 1. 802.11 model, traffic controlled by TBF alghoritm - OMNET++

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).

This section contains the analysis of the 802.11 MAC network with several workstations and one Access Point (AP). We also analyse 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 [25]. 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 1.

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 [26].

Table 1. Simulation results for self-similar sources $\alpha = 0.081$ $\mu = 0,05$, 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 transmissions	665076	663818	692600	716392
Transmission length	13321347	13247352	13827542	14317817

Table 2. Simulation results for Geometrical sources $\alpha = 0.081$, $\mu = 0,05$, Empty slots: 9593991, All slots: 72000000, All transmissions: 2627087

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

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 1 and 2 show the influence of input traffic characteristics for the number of RTS, the number of collisions and the number of transmissions for all workstations.

In figures 2 and 4 the RTS distribution with low load conditions is presented. Figures 3 and 5 present the RTS distribution for self-similar and geometrical traffic in the case when network is heavily loaded. When the network is oveloaded the number of collision are greater than the number of successfully sended reservation frames. Because of that in the next model the traffic generated in the workstations is shaped by the Token bucket filter mechanism (fig. 1).

Figures 6 and 7 show the impact of TBF (Token Bucket Filter) mechanism for the RTS distribution.

Table 3 presents more detailed results.

Table 3. Comparison of transmission for geometrical and selfsimilar sources with TBF

Model	factor of network utylization	factor of network collisions
geo $\alpha = 0,5$	0,327996486	1,114468403
geo $\alpha = 0,081$	0,729666653	0,02495586
self $\alpha = 0,5$	0,690259625	0,486739722
self $\alpha = 0,081$	0,759917472	0,0215725
geo with TBF $\alpha = 0,5$	0,452072075	1,108089167
self with TBF $\alpha = 0,5$	0,728667884	0,399881278

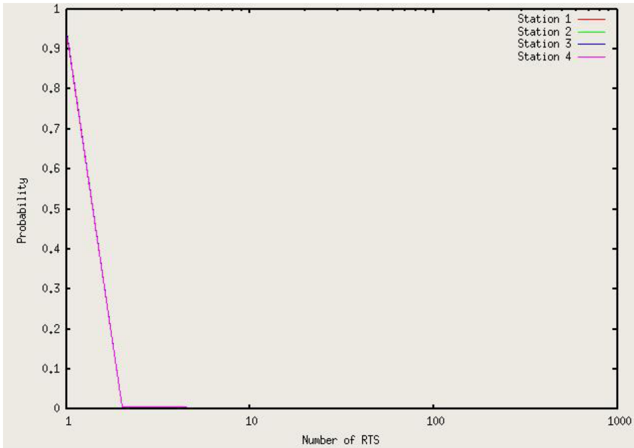

Fig. 2. RTS distribution (Self-similar sources) $\alpha = 0.081,\ \mu = 0.05$

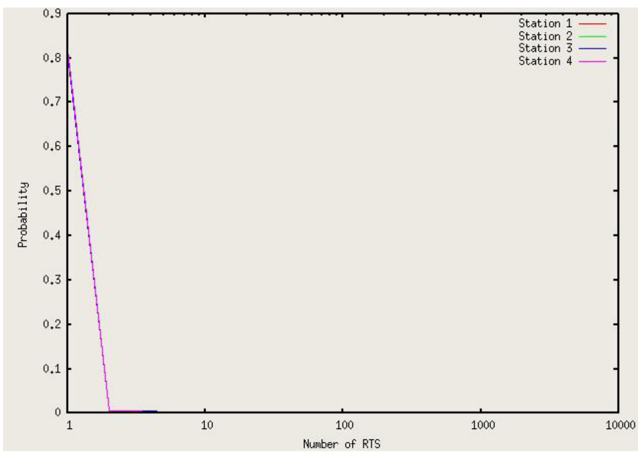

Fig. 3. RTS distribution $\alpha = 0.5$ $\mu = 0.05$ (Self-similar sources)

For $\alpha = 0,081$ both geometrical and selfsimilar sources cause low utilisation of network - 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 $\alpha = 0,5$ the usage of network falls to 32 percent for geometrical source. The usage of TBF mechanisms for the networks with the surplus of

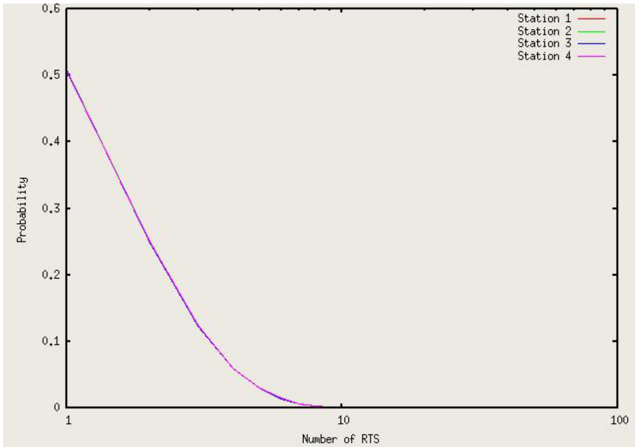

Fig. 4. RTS distribution $\alpha = 0.081, \ \mu = 0.05$ (Geometrical sources)

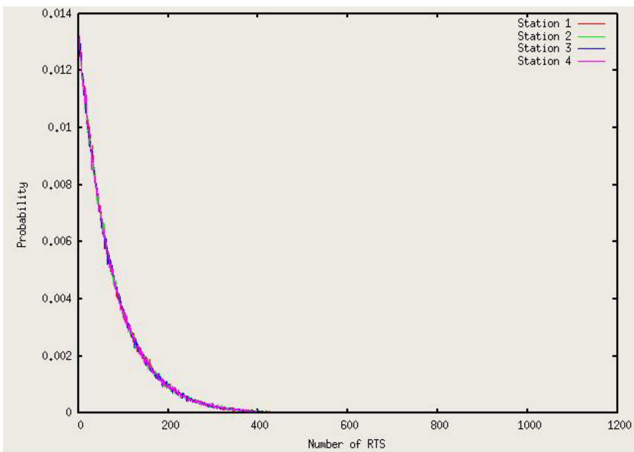

Fig. 5. RTS distribution $\alpha = 0.5, \ \mu = 0.05$ (Geometrical sources)

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.

Our last model has treated AP as a intermediary between LAN and WLAN networks. The same transmission parameters as those above mentioned have

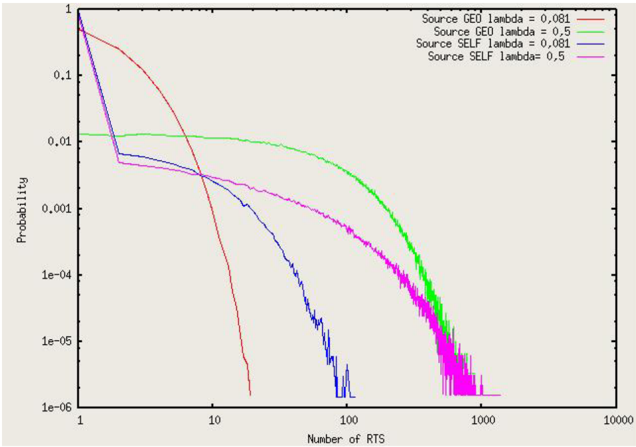

Fig. 6. RTS distribution - GEO ans SELF sources

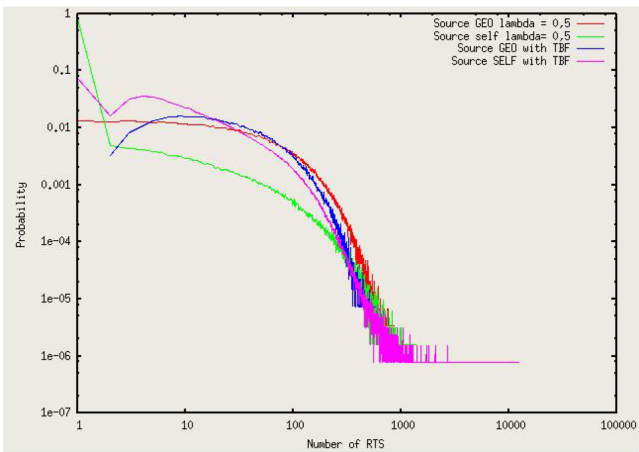

Fig. 7. RTS distribution - GEO ans SELF sources with TBF

been used. The received results were close to those obtained earlier. However it has been observed that high packet loss appeared in the buffer storing packets that enter the wireless network. This problem has been solved by applying Active Queue Management. The application of the simplest RED algorithm [28] has resulted in the significant decrease of losses (fig. 8).

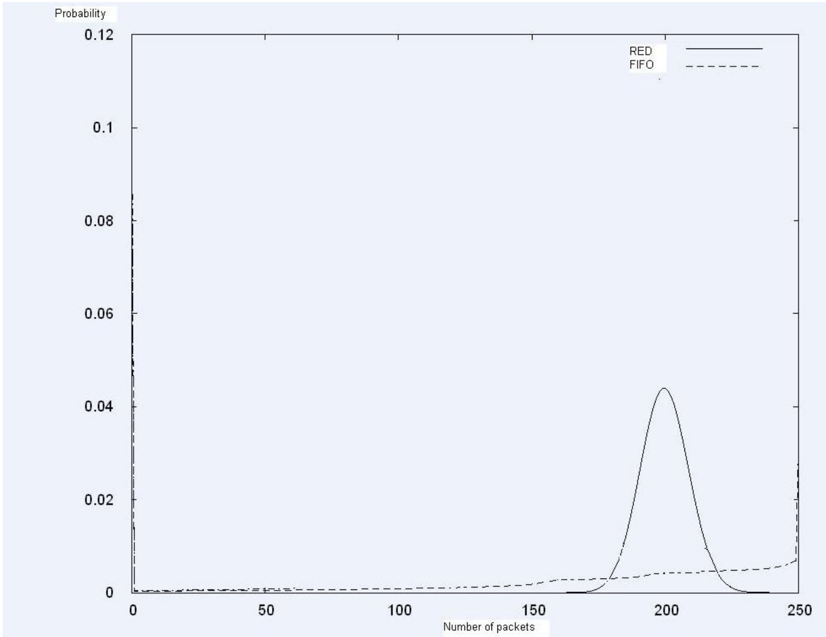

Fig. 8. Queue distributions for FIFO and RED

5 Summary

A MAC layer extension for QoS, IEEE 802.11e, has been recently ratifed 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 article 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 behaviour 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 realise 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 [28]), 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 modelling 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 modelling of WLAN.

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