Paper

New Metric for World Wide Web Service Quality

Tadeus Uhl[1], Janusz Klink[2], and Paweł Bardowski[2]

[1] *Maritime University of Szczecin, Szczecin, Poland*
[2] *Wrocław University of Technology, Wrocław, Poland*

Abstract—The main topic of this paper is the quality of the WWW service evaluation. The authors present well-known measurement methods, and present the new "Power" metric for quality, advocating it as a method of assessing the quality of such service. This metric is based on the most important network parameters that affect any assessment of the WWW service, i.e. Web page opening time and download data transfer rate. The new method is easy to implement, fast in operation, and provides stable and repeatable results.

Keywords—Apdex, G.1030, QoE, QoS, quality metrics, service quality assessment, WWW service quality.

1. Introduction

The vigorous development of the Internet has meant that the worldwide web has become the most widely and frequently used communication platform of all, offering a steadily increasing range of applications and services. The volume of data transfer is increasing rapidly as well. According to the latest estimates from Cisco [1], the volume of data that is transferred over the Web will reach the zetabyte (10^{21}) mark in the course of 2015.

Because the Web works on the packet switching principle without resource reservation, it can very quickly come to deterioration in quality of service (QoS) – one of the chief issues in this paper [2]–[4]. Even the European Parliament has become very concerned with the issue in recent years. In 2009, for instance, European Union Directives were published that directly affect neutrality and transparency within the telecommunications market [5], [6]. With the publication of these documents all EU member states became compelled to put the Directives into practice. In November 2012 the Polish national regulator, UKE, issued the so-called "Memorandum on QoS" with the aim of formulating regulations on QoS in networks designed to transport electronic services [7]. The German regulator, BNetzA, undertook similar initiatives in April 2013, establishing a so-called "Discussion Forum" which was to pursue goals similar to those mentioned above [8] and be generally accessible over the Web. Workgroups of both regulators are endeavouring to complete their deliberations and publish their reports before the end of 2013. It will then become clear whether a policy of self-regulation or a corpus of regulation laws will govern the telecommunications market.

Internet services can be divided into two groups: real-time and non-real-time services. The first group contains such services as VoIP, VToIP, IPTV, and video-conferencing. These services are extremely susceptible to the network parameters as: network delays, jitter and packet losses. The second group contains such services as FTP, TFTP, mail, video on demand, and WWW. The most important factor here is the reliability of transfer. That is why the reliable protocol TCP is used for these services.

The WWW service is one of the non-real-time services. Network delay is an insignificant impairment parameter. Whilst efficiency of data transfer is the most decisive attribute, the time factor cannot be ignored entirely. From the end user's point of view it is important that Web pages should be loaded within an acceptable time span. Obviously, the web page opening time, which is sum of different delays in the server, network and user equipment, impacts on the WWW service quality perceived by the user. It should be underlined that the point of measurement, i.e., the specific operator's network or Internet access, can influence the quality evaluation results. Therefore, it is extremely important, for the objective quality evaluation, to fulfil by the network operators all the EU requirements mentioned above, concerning net neutrality. So the question here is how can the quality of the WWW service can be described, and which metrics should be used to quantify it?

Having analysed existing documentation from the ITU-T [9], [10] and ETSI [11]–[15], the authors propose a new, objective metric for determining QoS in the WWW service, based on the well-known Mean Opinion Score (MOS) scale [16]. The new metric takes into account measurement circumstances, i.e. network delay, therefore allows to achieve more objective results of the service quality offered by the service provider. Such an approach hasn't been presented in the literature by now.

2. The Well-Known QoS Techniques for Evaluating the WWW Service

Many approaches to evaluating IP-based services and methods to evaluate the quality of the WWW service are described in the relevant literature. In all these methods, the time period between the user's issuing a request and the page loading time is used as a criterion of quality.

A good example of such approach to quality assessment is the Application Performance Index (Apdex) method [17]. It is an open standard, that allows measurable parameters of the network, the services or the application's performance to be converted into one commonly understood factor. The magnitude of this factor can be described as a value on a scale of user satisfaction. The evaluation result, which can have values between 0 and 1, can be calculated from:

$$A_T = \frac{Lz + \frac{Lt}{2}}{Lw}, \tag{1}$$

where: A_T – evaluation score according to Apdex, T – maximum time of service "realization" (e.g. WWW page opening time) which permits a service classification, in the user's opinion, as very good, Lz – number of users who are satisfied with the service quality, Lt – number of users who tolerate the service quality, Lw – total number of users in the test.

The final result that is obtained using Eq. (1) depends heavily on the threshold time T. It is the value of the delay which, in the user's opinion, represents only a negligible reduction of service quality (Fig. 1). Thus, it can be assumed that a Web page loading time of no longer than T guarantees high user satisfaction of WWW service operation.

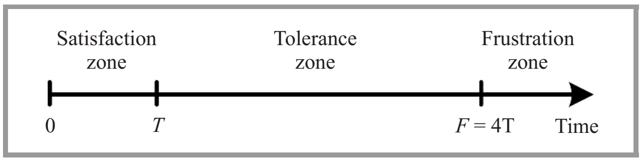


Fig. 1. Threshold values for the Apdex method.

It is assumed that $4T$ is the upper limit of delay tolerated by the user. In practice, this problem consists in fixing the maximum value of T that will guarantee, in the user's opinion, a very good quality of service. When setting the value of T for a specific service, observation of users' behavior can be very helpful. In other words, it can be assumed that for the WWW service T is the maximum time which does not distract the user's attention from the service as a result of his waiting for an application response. For delays longer than T that do not exceed $F = 4T$, users will notice a deterioration in the service quality, but they will tolerate it. Users' evaluation is expressed on the five-degree MOS scale and is inversely proportionate to the value of delay. When delays exceed $F = 4T$, users no longer accept the service quality.

In Recommendation G.1030 [10] the International Telecommunication Union proposes a methodology of service quality assessment in IP networks and presents a precise evaluation model which reveals the relationship between network performance measurement results and Web-browsing user satisfaction.

User appraisal depends on several factors connected with, among other things, the network itself, customer end-point equipment performance, the software used and the degree of user-application interaction.

A WWW service quality evaluation model, based on user opinion, was presented in an appendix to Rec. G.1030. This model takes into account relationships between measurable, i.e., objective, service operation factors such as page response time and data download time and the user's, i.e. subjective, opinion.

The authors must stress the fact that Web page response time is the dominant and objective quality factor for the WWW service. On the other hand, the user's evaluation score is very subjective, and depends on different factors, not least their experiences and expectations. Three time scales (thresholds) have been specified which are connected with the perceptual quality evaluation of the service that is provided to the user:

- first threshold (0.1 s) – describes the optimum value of interaction time between user and service. Within this time period the user has the impression that the service reacts immediately, i.e. without any delays. This is very important for real-time services (conversations, etc.);
- second threshold (1 s) – denotes the maximum service reaction time that, although noticeable by the user, does not lead to problems in service utilization. This time does not interrupt service continuity;
- third threshold (10 s) – the maximum time that allows a user to work with the application without any distractions. Longer times are considered to be unacceptable. In such cases it is recommended that the user be informed that additional delay is possible and when an ongoing operation is expected to be completed.

It has been noticed that users who have been informed about expected waiting time (e.g., for opening the web page) will accept it more readily and even award a better mark for the service operation.

An experiment was done which consisted of starting a search engine, typing a given phrase and finding and opening a suitable page (Fig. 2).

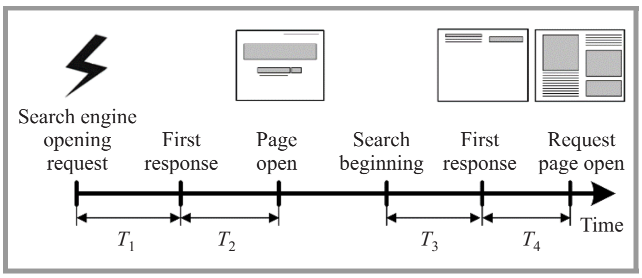


Fig. 2. Web page opening experiment times.

Users evaluating quality of the WWW service have been divided into two categories: the first consists of professionals, the second includes non-professionals, i.e., people with little computer experience.

Evaluation results presented by the two categories have similar trends though – the marks they awarded were inversely proportionate to the page opening delays. In long-period observations, however, a significant difference between these groups has been observed. Non-professionals tended to be more radical in their evaluations than professionals, who were relatively moderate. Non-professionals gave much higher marks for short opening times of the Web pages and very low marks for long delays. This WWW service evaluation was conducted in three sessions, lasting 6 s, 15 s and 60 s, respectively. It was observed that the difference between the evaluation marks of the two groups decreased as the delays became longer. For 60-second sessions the correlation between page opening times and users' subjective evaluation marks exceeded 0.95 in both groups.

In both methods mentioned above quality of service evaluation consists of determining suitable metrics. This will reveal a relationship between network performance, customer end-point equipment and applications parameters described by so-called intrinsic QoS with the quality that is experienced by the customer i.e. Quality of Experience (QoE).

In both cases the Web page opening time was the main parameter that was measured and assessed. Such metrics permit an evaluation of quality of the service which is delivered within a given time and environment. They rather describe facts (QoS/QoE) without searching for the reasons. That is why these methods are not suitable for the benchmarking of different ISP WWW services made by measurement staff located at various network destinations. Final evaluation marks are strongly influenced, among other things, by data transfer delay which depends on the throughput of the Internet access line which is used in a specific locality. Measurements performed at different destinations can therefore yield conflicting results. That is why the authors of this paper decided to introduce a new metric, called "Power", which can extract each element responsible for the delays caused by Internet user access.

3. The Real Environment

Figure 3 shows the real environment used in the analysis of QoS in WWW services. This environment consists of two end systems that are capable of establishing connections either to the WWW test server or to other WWW servers in the Internet and then measuring delays that occur in the course of the communication using the protocol analyser Wireshark. The used in this analysis environment is capable of emulating impairment parameters such as network delay, jitter, and packet losses. So it is quite easy to pick out each parameter and analyse its effect on QoS and QoE. The WWW test server is supplied with several, statically composed pages that contain different types of information. The time that elapses between the initiation of the call-up and the actual appearance of the pages on the screen is measured discretely. These time lapses are then used to determine objectively the quality of the WWW service. End users will appraise quality subjectively as QoE.

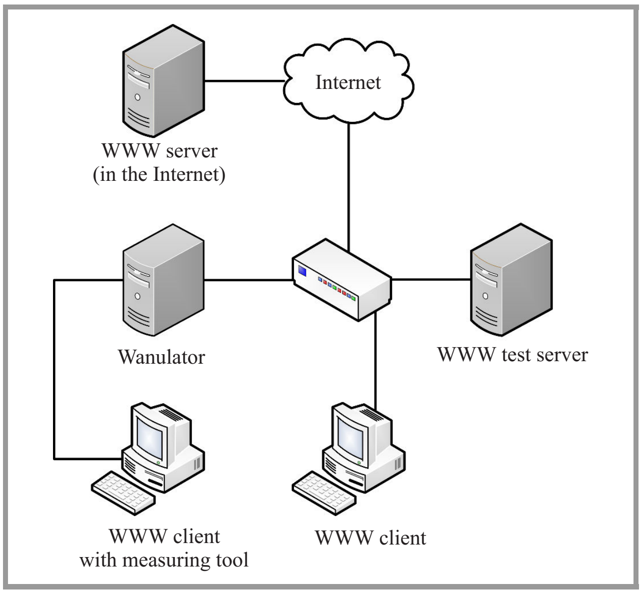


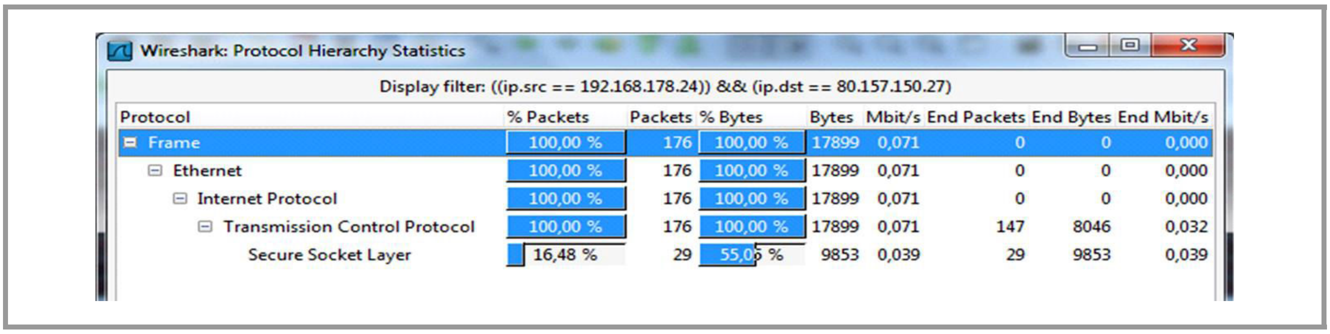
Fig. 3. The real environment.

The first measurements were designed to shed light on processes in operation during communication using the WWW service. To that end the cache of the client's Internet browser was erased and then the Web page www.facebook.com was called up. The packets, logged by the protocol analyser Wireshark, were then analysed. In the recorded sessions there were two distinct phases: (1) connection establishment and (2) data transfer. The time span in phase 1 contains, among other things, the additional delay which the server itself causes. It can be defined as the difference between the point in time at which the Web page was called and the point in time at which the first data packet called from the server actually arrives at the client. The second time span corresponds to the transfer time for all data needed for the display of the Web page. It is called "data delay" and can be defined as the difference between the point in time at which the first data packet arrives and the point in time at which the Web page is completely built up.

It can be seen from Fig. 4 that in phase 1 of communication to the server 176 frames with a total volume of 17,899 bytes were transferred. This phase lasted about 2 seconds. So the transmission rate must have been around 71 kb/s, as confirmed by the information in Fig. 4.

Figure 5 shows that in phase 2 of the communication 283 frames with a total volume of 369,504 bytes were received from the server. This phase lasted about 1.8 s. So the transmission rate here must have been around 1.69 Mb/s, which is also confirmed by the information contained in Fig. 5.

It is already clear that the relationship between the time spans in phases 1 and 2 will have a decisive influence on

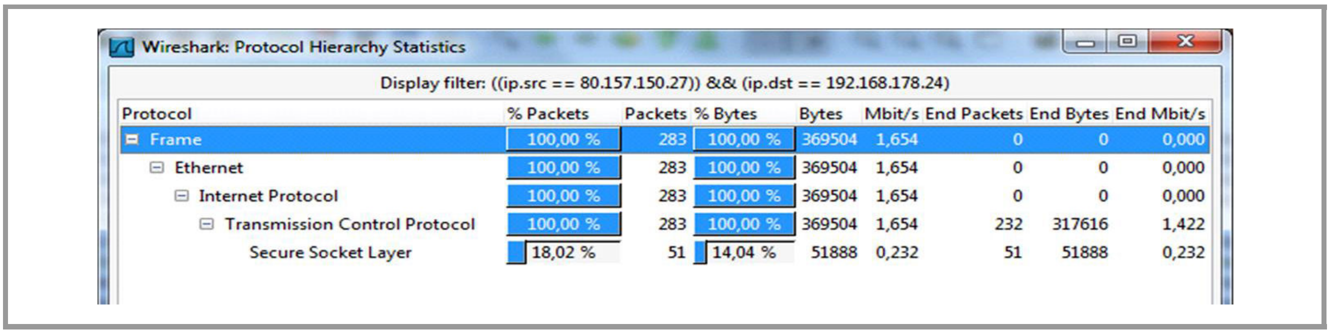


Wireshark: Protocol Hierarchy Statistics

Display filter: ((ip.src == 192.168.178.24)) && (ip.dst == 80.157.150.27)

Protocol	% Packets	Packets	% Bytes	Bytes	Mbit/s	End Packets	End Bytes	End Mbit/s
Frame	100,00 %	176	100,00 %	17899	0,071	0	0	0,000
Ethernet	100,00 %	176	100,00 %	17899	0,071	0	0	0,000
Internet Protocol	100,00 %	176	100,00 %	17899	0,071	0	0	0,000
Transmission Control Protocol	100,00 %	176	100,00 %	17899	0,071	147	8046	0,032
Secure Socket Layer	16,48 %	29	55,05 %	9853	0,039	29	9853	0,039

Fig. 4. Statistics from phase 1 during a WWW session.



Wireshark: Protocol Hierarchy Statistics

Display filter: ((ip.src == 80.157.150.27)) && (ip.dst == 192.168.178.24)

Protocol	% Packets	Packets	% Bytes	Bytes	Mbit/s	End Packets	End Bytes	End Mbit/s
Frame	100,00 %	283	100,00 %	369504	1,654	0	0	0,000
Ethernet	100,00 %	283	100,00 %	369504	1,654	0	0	0,000
Internet Protocol	100,00 %	283	100,00 %	369504	1,654	0	0	0,000
Transmission Control Protocol	100,00 %	283	100,00 %	369504	1,654	232	317616	1,422
Secure Socket Layer	18,02 %	51	14,04 %	51888	0,232	51	51888	0,232

Fig. 5. The real environment.

QoS values for the WWW service. It is to be expected that increases in additional delay and data delay will lead to a deterioration of QoS and QoE values. For this reason any new model for measuring QoS in the WWW service must take these times into consideration at all costs. One approach will be described in the following chapter.

4. Power – a New Metric for QoS in the WWW Service

In Section 3 it was shown that delay and throughput are two of the most significant impairment parameters in a network. Consequently, any new metric must take them into consideration. With that in mind, the new metric, called Power, that is defined in terms of Eq. (2), was created.

$$P = \frac{1}{1+\dfrac{\alpha}{ddr}} \cdot 100\%\,, \qquad (2)$$

where: α – delay coefficient defined by

$$\alpha = \begin{cases} 0 & \text{for} \quad t_d \leq t_h \\ t_d - t_h & \text{for} \quad t_d > t_h \end{cases},$$

ddr – download data rate [Mb/s], t_d – total delay [s], t_h – threshold of delay [s].

It is obvious that both the download data rate and the total delay, defined by the time lapse between the point in time at which the session begins and the point in time at which the Web page is completely built up, depend on the throughput of the transmission channel used. But they also depend on the locality of the WWW server, its level of activity, on the content of the Web pages being accessed, and whether that content is static or dynamic. Total delay can therefore vary within a considerable range. The new metric Power takes that into account.

In order to use the values defined in Eq. (2) in practice, it is necessary to measure each of those values properly. "Threshold" is a subjective value dependent on the judgment of the end user. It represents the time span which he considers acceptable for the building up of the Web page. Analyses have shown that this value is a matter of seconds in practice. The first calculations demonstrate clearly how the new metric works. Figures 6–9 present the results.

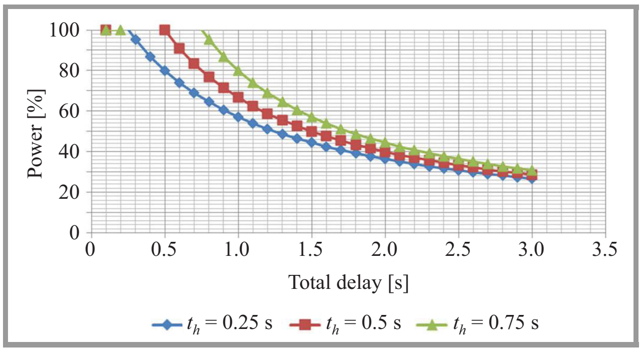


Fig. 6. Power as a function of total delay and a download data rate of 1 Mb/s.

Figures 6 and 7 show that – at a constant threshold of delay – increases in the download data rate lead to a gradual

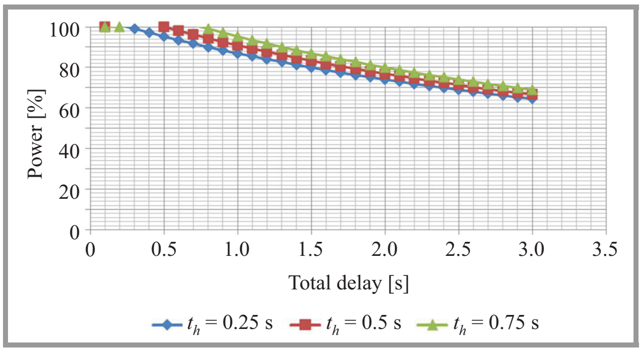


Fig. 7. Power as a function of total delay and a download data rate of 5 Mb/s.

deterioration in the values delivered by the Power metric, which is, after all, only understandable. It shows that values from the Power metric must be interpreted in tandem with download data rate values. This is because performance levels depend not only on the volume of traffic that the Internet provider is having to handle but also on the so-called last-mile bandwidth availability. This means that the new metric stands a good chance of being accepted by Internet providers and end users alike.

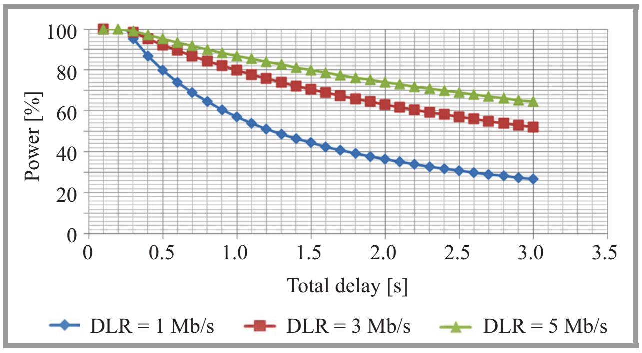


Fig. 8. Power as a function of total delay and various download data rates for a threshold of 0.25 s.

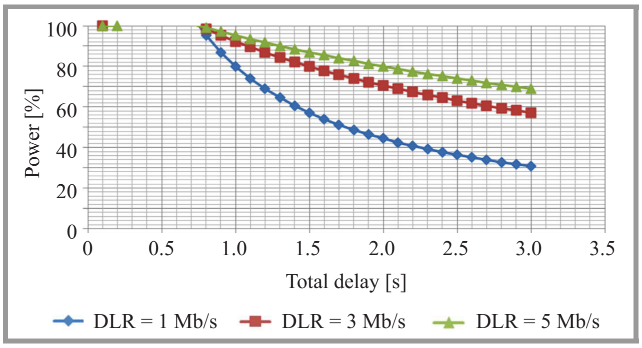


Fig. 9. Power as a function of total delay and various download data rates for a threshold of 0.75 s.

Figures 8 and 9 show that the curves progress quite similarly, the only difference being that the drop in the curves occurs later as a function of the increasing values of threshold. This fact confirms that the new metric, though a function of the subjective entity threshold, can justifiably be considered to be objective. So the practical spin-offs of the new metric can be appreciated here, too.

To demonstrate the effect of the new metric in a practical environment, Eq. (2) was integrated into a suitable measurement tool. The tool was implemented in the clients from Fig. 3. Pages from www.facebook.com were called up in this real environment. The chief impairment parameters of the network were emulated using Wanulator from Fig. 3. Examples of measurements series of the WWW service QoS are presented in Figs. 10–12.

Figures 10 and 11 show that as jitter increases, the total delay increases as well whilst the download data rate decreases. This was perhaps to be expected. The steadily increasing variations in packet arrival times are the cause. It is also evident from Fig. 12 that the metric Apdex falls

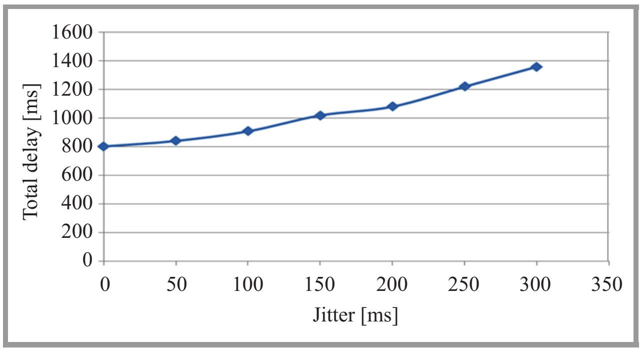


Fig. 10. Total delay as a function of jitter.

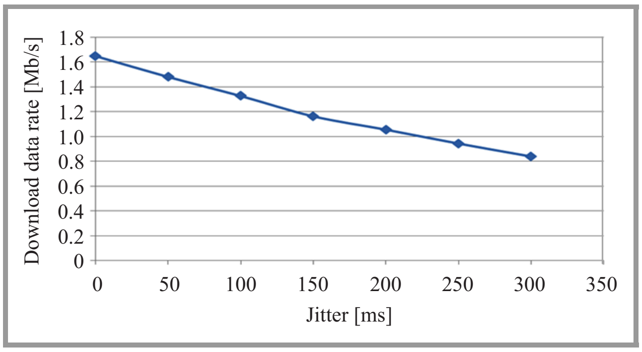


Fig. 11. Download data rate as a function of jitter.

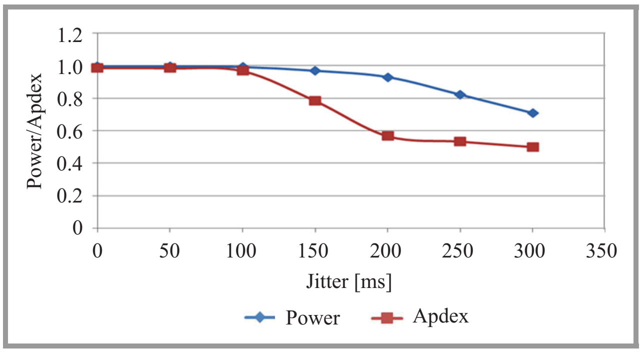


Fig. 12. Power values and Apdex values as a function of jitter for a threshold of 1 s.

abruptly as soon as the threshold is exceeded. The curve of the metric Power, on the other hand, is, if anything, exponential and therefore flatter, and reflects subjective judgments more faithfully (see too Section 5). Now this really does speak in favor of the new QoS measuring technique Power.

5. Subjective QoS Measurement in a Real Environment

After introducing the Power metric, as an objective measure of WWW service quality, a series of Web page opening time measurements was performed in order to verify the usefulness of the metric in real network situations. Measurements were conducted in the LAN shown in the configuration in Fig. 13.

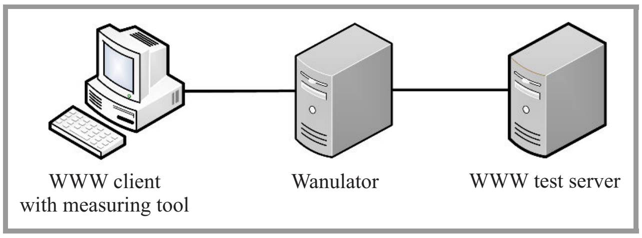


Fig. 13. Test bed for WWW service evaluation in experimental LAN.

A static Web page was launched on the test server. The content of this page was prepared according to ETSI reference page requirements [18]. The page was opened on a user PC (WWW client with special measurement tool). Additionally, Wireshark software installed on the client was used to capture IP packet streams and to register the times required by the Power metric for its calculations (Fig. 14).

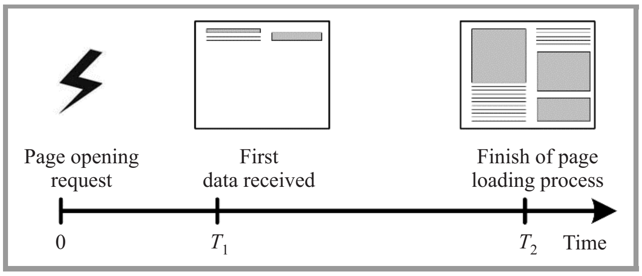


Fig. 14. Times captured during the experiment.

T_1 is the time needed by the server to respond to a request sent by the user who wishes to open the web page. T_2 denotes the time at which page opening is complete. Both times are random variables which can have quite different values for individual specific reference page opening attempts due to variations in test server activity and network load. As mentioned above, network delay was varied throughout the course of the experiment using an emulator called Wanulator.

The total Web page opening time, which is registered at the user side and denoted as T_2, plays a crucial role in the subjective evaluation of WWW service quality (QoE). It is the value t_d in the Power metric. Figure 15 shows the page opening time distribution.

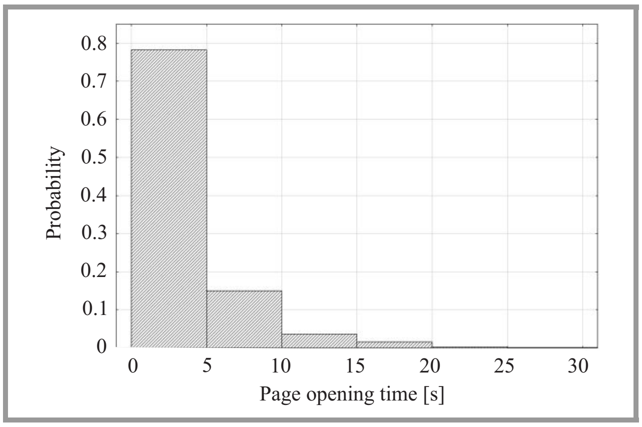


Fig. 15. WWW page opening time distribution.

Users taking part in the experiment gave their subjective mark (QoE) for the WWW service quality in the range from 1 to 5 on the MOS scale. Registered T_2 values were used to calculate objective marks (QoS) on the scale between 0 and 1. The test group consisted of over 30 persons with whom more than 1000 test measurements were conducted. In the next step the statistical analysis was performed. Figures 16 and 17 present the results obtained. As could be expected (see Fig. 16), subjective evaluation of the WWW service, as provided by the users, is inversely proportionate to Web page opening times.

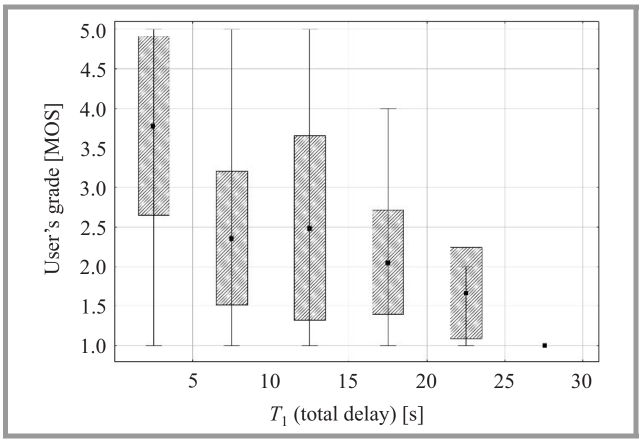


Fig. 16. Subjective evaluation of WWW page opening time in MOS scale.

Very interesting is the fact that measurement results concur with those presented in [10], where it is stated that for opening times under 2 s users are willing to award very high marks for the service (MOS = 5) whilst the lowest marks (MOS = 1) are given when opening times are 8 s and more. Obviously, it should be noted that in individual cases this evaluation mark may differ widely. It is therefore recommendable to involve large number of users and repetitions in such measurements. Careful statistical analysis of the collected data enhances the evaluation process accuracy. Figure 16 shows that people taking part in the evaluation test were quite critical with regard to the service under analysis. A rapid decrease in the quality can be observed for the Web page opening times exceeding 5 s. Confirmation of such user behavior can be found in the analysis results presented by ITU-T in Rec. G.1030 [10] mentioned above for which tests also involved non-professional users. The experiments conducted by the authors of this paper also involved test persons who can be considered to be members of the group of non-professionals. Consequently, the results that were obtained are very similar.

Analysis of the results presented in Fig. 16 leads to the conclusion that users had a considerable problem with evaluation of relatively short web page opening times, i.e., between 0 and 5 s. The average mark is approximately 3.8, but a very high degree of deviation can be observed with marks ranging from 2.6 to very nearly 5. Average evaluation marks for Web page opening times in the range of 5 to 10 s and 10 to 15 s are at comparable levels, but the high value of standard deviation is due to a big uncertainty, especially for longer opening times, i.e., above 10 s. As is known from former experiments, discussed in literature, these are the times at which many users begin to consider whether waiting for the page to open makes sense, and very many of them resign. For longer page opening times (15 to 25 s) user's marks were significantly lower and, what is interesting, standard deviation of these values was also lower. From this it can be construed that users became much more certain of their judgments. Users had the least problem making their decision when page opening times were very long, i.e., more than 25 s. Almost all of them gave the lowest mark (MOS = 1) and standard deviation of the values was very low.

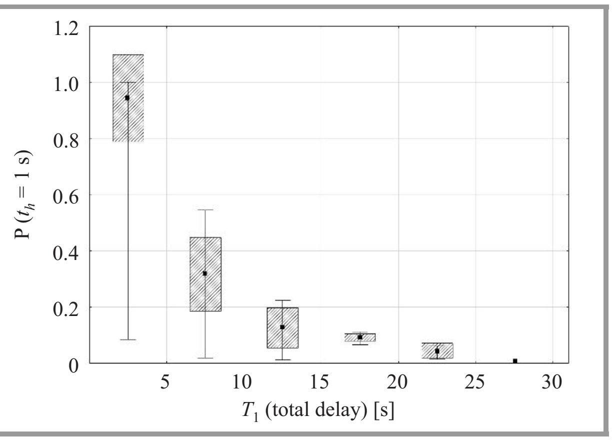


Fig. 17. Subjective evaluation of WWW page opening time in the Power metric for a threshold value of 1 s.

It has been proved that most subjective methods of quality assessment (QoE) are lab-intensive and time-consuming. Objective methods and metrics are therefore an interesting alternative. One such proposal is the new Power metric, discussed in the paper, which was used for QoS assessment in the test system here. Results of these experiments are shown in the Fig. 17.

It is noticeable that the relationship between Web page opening times and quality evaluation marks has an exponential character. Power value in the range between 0 and 1 (1 denotes MOS = 5) is inversely proportionate to these (measured) times. It is evident that the curve is more regular than that of the QoE results presented in Figs. 16 and 17. In other words: it shows more clearly the time-quality relationship. It is equally evident that disparity of the results is far lower, which indicates a more invariable, more dependable and – for a given environment and circumstances – repeatable WWW service quality evaluation.

6. Summary and Outlook

Determining the QoS of the WWW service has been the main topic of this paper. To begin with, the currently most commonly used methods of measuring QoS in the WWW service were presented. Following that, a new metric called Power that has been designed for this purpose was defined and explained. The metric is based on the main impairment parameters in a network, i.e. delay and throughput. It also takes account of the subjective parameter at the user's end, i.e. threshold of delay. The experiments that were conducted in the course of this work and described in this paper have confirmed that the new metric works in practice. The new QoS measuring technique is easy to implement. That is also a practical bonus. It delivers irrefutable and reproducible results in a real environment; subjective QoS measuring methods cannot. They are time-consuming and expensive to boot, and not much good in practice.

In the course of the work described in this paper the new QoS metric was used in conjunction with simple Web pages using the Hypertext Transfer Protocol (HTTP). Further measurements conducted in the real environment shown in Fig. 3 (using the Internet) have revealed that the latest Web pages often contain dynamic elements and their content is often geographically dispersed over several servers. Hypertext Transfer Protocol Secure (HTTPS) is being used more and more widely for this type of communication. The main impetus behind further work is the inclusion of all these aspects to prove the reliability of the new Power metric. Preliminary results have been very encouraging and provide ample motivation for further analyses and advances in this direction.

The paper is a modified and extended version of the paper [19] from the 29th National Telecommunications and Teleinformatics Symposium, Gdańsk, Poland, September 2013.

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Tadeus Uhl received his M.Sc. in Telecommunications from the Academy of Technology and Agriculture in Bydgoszcz, Poland, in 1975, Ph.D. from Gdańsk University of Technology, Poland, in 1982 and his D.Sc. from University at Dortmund, Germany, in 1992. Since 1992 he has worked as Professor at the Institute of Communications Technology, Flensburg University of Applied Sciences, Germany, and in addition since 2013 as Professor at the Institute of Transport Engineering, Maritime University of Szczecin, Poland. His main activities cover the following areas: traffic engineering, performance analysis of communications systems, measurement and evaluation of communication protocols, QoS and QoE by Triple Play Services, Ethernet and IP technology. He is an author or co-author of three books and some 130 papers on the subjects of LAN, WAN and NGN.

E-mail: t.uhl@am.szczecin.pl
Maritime University of Szczecin
Henryka Pobożnego st 11
70-507 Szczecin, Poland

Janusz Klink received his M.Sc. and Ph.D. in Telecommunications from Wrocław University of Technology in 1994 and 2000, respectively. Since 1994 he has worked as an Assistant and since 2000 as an Assistant Professor at the Institute of Telecommunications and Acoustics, Wrocław. In 2013 he started to work for Department of Telecommunications and Teleinformatics (since 2007 as Head of Telecommunication Networks Laboratory) at the Faculty of Electronics of the Wrocław University of Technology. His main activities concentrate on the following areas: telecommunication networks, signalling protocols, traffic engineering, quality of service and quality of experience. He is an author or co-author of 14 chapters in books, over 50 papers and about 70 reports on the subject of telecommunications networks, services and quality of service.

E-mail: janusz.klink@pwr.edu.pl
Wrocław University of Technology
Wybrzeże Wyspiańskiego st 27
50-370 Wrocław, Poland

Paweł Bardowski received his B.Eng. in Electronics and Telecommunications and M.Sc. in Computer Science from Wrocław University of Technology, in 2009 and 2011, respectively. He then began his doctoral studies in the field of telecommunications at the same university. Since 2011 he has been working for the Department of Telecommunications and Teleinformatics, Wrocław University of Technology, as an Assistant. His current research specialist areas include methods of real-time data transmission over wireless networks with multiple-hop. He is co-author of 3 papers on the subjects of quality of service in telecommunication networks.

E-mail: pawel.bardowski@pwr.edu.pl
Wrocław University of Technology
Wybrzeże Wyspiańskiego st 27
50-370 Wrocław, Poland