Selected Issues of Internet Access Service Quality Assessment

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***Abstract*— This paper presents selected issues related to Internet Access Service (IAS) quality assessment. Nowadays, it is not only the price, but quality, that influences the decisions of users regarding the choice of Internet Service Provider (ISP). According to European documents, users have a right to be informed of IT services offered by different providers. However, there is a problem: what, where and how to measure the service quality? The second issue is: how service quality is perceived by users and, finally, how to correlate these two different points of view. We discuss selected objective measures of the Internet Access Service and present measurement scenarios. The users' point of view and the subjective measure of quality is also presented. In the second part of the paper, we show how the users perceive Internet Access by the services they use. An example of building the Quality of Experience model for the WWW service is also presented.**

Keywords-Internet access; quality assessment; QoS; QoE; WWW quality model.

I. INTRODUCTION

In March 2010, the European Commission has launched a strategy entitled "Europe 2020", which sets the objectives for smart, sustainable and inclusive growth of the European Union by 2020 [1]. The Digital Agenda [2] forms one of the seven pillars of the strategy and defines the key enabling role that the use of Information and Communication Technologies (ICT) will have to play in Europe in future years. It is supposed to support a better quality of life, e.g., through better health care, safer and more efficient transport, a cleaner environment, new media opportunities and easier access to public services and cultural content. The Internet will be used as a vital medium for conducting business, as well as aiding work, play and communication between users. I will also be the center of the future economy, which will be based on network-based knowledge. It is assumed that by 2020 all Europeans will have access to Internet speeds of above 30 Mbps and at least 50% of the households will subscribe to Internet connections above 100 Mbps.

According to the European Commission, the digital sector grows seven times faster than other parts of industry. Thus, in September 2016, new Commission strategy documents on Connectivity for a European Gigabit Society were adopted [3]. They set a vision of Europe where "availability and take-up of very high capacity networks enable the widespread use of products, services and applications in the Single Digital Market". A vision of "Broadband Europe" assumes the building of the Gigabit Society by 2025 and relies on three main strategic objectives:

- Gigabit connectivity for all main of socio-economic drivers,
- uninterrupted 5G coverage for all urban areas and major terrestrial transport paths,
- access to connectivity offering at least 100 Mbps for all European households.

Consumer research has revealed that price is still the most important attribute taken into account when choosing an Internet access service for 20% of users [4]. The second decision-making factor is the data cap, i.e., the monthly limit on the amount of data a user can use with an Internet connection. Moreover, what happens when a user hits their limit is a very important issue. ISPs then engage in different actions such as slowing down data speeds, charging extra fees, or preventing further usage.

The next important factors, which may influence user attitude to an ISP offer, are service differentiation and traffic management such as prioritization, blocking or throttling. These practices aim to preserve the appropriate conditions for providing high-quality services. Nonetheless, in recent years these activities have raised questions about network neutrality, which assumes that all content and applications should receive equal treatment. Moreover, neutrality also means that providers neither impose nor discriminate in favor of using a particular type of technology [5][6].

Consumer awareness of network neutrality and traffic management is rather low. On one hand, most people have very little knowledge about these terms and, on the other hand, they do not see the influence of these issues on their Internet usage. As is shown in [7], consumers care very little for all the technicalities connected with data transport and the role of ISPs. Users are not interested in net neutrality or traffic management practices and instead are tied to their experience of traffic management effects.

Germany's "Wissenschaftliches Institut für Infrastruktur und Kommunikationsdienste" (WIK-Consult) study, which concentrates on contract-based consulting services for public and private institutions, asked a series of questions about the way consumers would respond to specific changes in the traffic management policies operated by their ISP, e.g., the

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introduction of throttling on video traffic, or of data caps. A significant majority of respondents said that they would even change the provider in response to some significant changes in the traffic management policies of their ISP [4].

The issues mentioned above show a much higher interest of users in their ISP traffic engineering operations when these activities touch the concrete services and influence the users' experience. Nowadays, users not only trust the service level agreements of their providers, but also want to be able to check them.

The rest of this paper is organized as follows. In Section II, we present a general overview of IAS structure from the technical perspective as well as the users' point of view. Next, in Section III, the main parameters that may influence quality are discussed and the quality measurements of IAS, according to the present standards, are presented. Section IV describes the service quality issues as perceived by users. We underline the difference between objective quality measures and the subjective users' perception of different services used by them. We validate the need to build quality models for the most popular services and mention WWW browsing as one of them. In Section V, the Quality of Experience (QoE) model for the WWW service is discussed. We present the laboratory test-bed, measurement results and method of the model derivation. The paper ends with a conclusion and the plans for future work.

II. Internet Access Service

One of the major factors influencing the decision of users when choosing an ISP is the Internet Access connection throughput offered by the provider. However, there are many misunderstandings regarding this term. Physically, it is a combination of different connections and services that are needed to establish a functioning Internet access. Each of them can be treated as a separate service. Most users, however, treat Internet access as an access to the end-to-end services available on the Internet. A purely physical access to the Internet has no practical meaning to them. Thus, Internet access is generally understood as a platform that provides access to Internet services, such as e-mail and Web browsing, etc. From a technical point of view, however, the primary meaning of the term Internet access should be understood as a physical and logical access to the core of the network, including all functionalities needed to enable the user to establish a connection to further entities in the Internet and to run advanced services [8].

Providers often advertise the maximum values of the throughput, which is rarely accessible, due to it being strongly connected strongly connected with the variable traffic load and the still increasing demand for data transmission bandwidth in recent years. Many users often expect such throughputs for most of the day, irrespective of the time and network conditions.

Unfortunately, according to the CISCO forecast, presented in Visual Networking Index [9], global IP traffic will increase nearly threefold over the next 5 years and by 2020 will reach 2.3 ZB per year.

Moreover, traffic load varies significantly during the day. Busy-hour (the busiest 60-minute period in a day) Internet

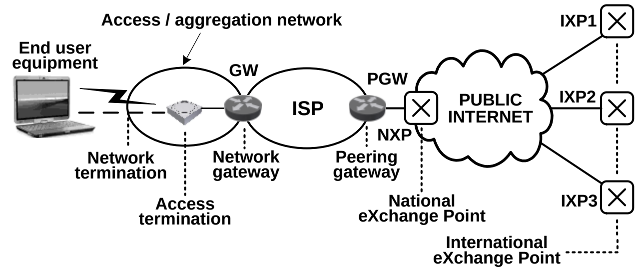

Figure 1. General overview of elements and network sections of IAS.

traffic is growing more rapidly than average Internet traffic. It increased by 51 percent in 2015, compared with a 29-percent growth in average traffic. It means that service providers will face even higher network load fluctuations and more serious traffic engineering problems than up to now.

Users can be connected to the various ISPs via the access networks, using wired or wireless connections. Communication over the Internet requires data interchange over different National and International eXchange Points (NXPs and IXPs). Figure 1 presents a generic overview of the elements, network sections and interfaces of the IAS according to [10].

A very important issue is the proper definition of the Internet Access Service (IAS). The answer to this question is not only crucial for the users, who are usually not familiar with the technical details, but also for the providers as well, because it determines the user-to-network and network-to-network interfaces and also the responsibilities of the providers.

Finally, it says how IAS quality should be measured and how the results can be interpreted and compared between different providers and their end-users. It is especially important in the light of European regulation [11] on the rights of users to be informed about the quality of their services.

III. IAS measurements

Identifying the parameters that may affect the Quality of Service (QoS), locating the points at which the measurements should be performed and specifying the measurement scenarios is a sequence that should be done before the measurements. Simply speaking, one should specify "what, where and how" should be measured to provide ISPs and users with a thorough knowledge of the QoS.

The measurements fall into two groups: so called "In-net" and "Over-The-Top" (OTT). The first case covers the ISP's area - the area on which it acts. European Consumer Center (ECC) Report [10] specifies a list of technical quality parameters proposed to be measured during a technical evaluation of IAS.

Many National Regulatory Authorities (NRAs) or other national institutions agree that the list is too long. They also consider it to be too complicated and incomprehensible to the average user. Thus, they propose the selection of a subset of parameters. After consulting an abundance of documents [8][10][12] and different points of view, the ECC has

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proposed a list of minimum technical parameters that take their influence on the most popular Internet applications into account. Table 1, based on [10], illustrates popular services and the relevance of the network performance parameters to the performance or quality of those services. The relevance ranges from “−” (irrelevant) to “+++” (very relevant). The following quality metrics have been selected: data transmission rate, delay, delay variation, packet loss ratio, and packet error ratio.

TABLE I. RELEVANCE OF NETWORK IMPAIRMENT PARAMETERS TO VARIOUS APPLICATIONS

Service	*Data transmission speed*		*Delay*	*Delay variation*	*Packet loss*	*Packet error*
	Down	*Up*				
Browse (text)	++	−	++	−	+++	+++
Browse (media)	+++	−	++	+	+++	+++
Download file	+++	−	+	−	+++	+++
Transactions	−	−	++	−	+++	+++
Streaming media	+++	−	+	−	+	+
VoIP	+	+	+++	+++	+	+
Gaming	+	+	+++	++	+++	+++

The data transmission rate is probably the most relevant parameter, nearly mentioned in every ISP’s offer. It is defined as the data transmission rate that is achieved separately for downloading and uploading specified test files between a remote website and a user’s terminal equipment [8]. The next parameter is delay, defined as half the time (in ms) that is needed for an ICMP packet to reach a valid IP address. This parameter also has a significant influence on many applications available over the Internet and is already being used by many NRAs, operators and Web-based speed meters. There are also some applications that are very sensitive to delay variation and this parameter is therefore selected for measurements. The exact definition of delay variation can be found in [12][13].

IP packets can sometimes be dropped, e.g., due to a small buffer size of the network nodes or poor (radio) connection, even if the transmission rate, delay, and delay variation remain good enough. Such packet loss can significantly affect all data-based applications. Moreover, UDP-based applications, such as Voice over IP may also not work properly in such conditions. Packet loss ratio can be defined as the ratio of the total lost IP packet occurrences to the total number of packets in the population under examination [13]. The parameter that may have an influence on the quality of service is the packet error rate and was therefore also included in the basic set of measured parameters shown in Table 1. The IP packet error ratio is sometimes called the packet error ratio and is defined as the ratio of the total faulty IP packet occurrences to the total number of successful IP packet deliveries plus the faulty IP packet occurrences within a population of interest.

Internet access is no longer provided by a single network or service provider, as was the case with traditional voice communication in Public Switched Telephone Networks (PSTNs). Nowadays, a user gains an indirect access to the public Internet, as shown in Figure 1. Therefore, the overall quality of services (or, in general, Internet access) is a combination of the performance of all the elements involved in the connection.

Different approaches to QoS measurements are discussed in literature. One of the classifications points out the methods as follows:

- carried out by the carefully selected users running the measurement tests from designated locations (or users’ homes) and using special purpose equipment [10][14][15],
- large-scale user-driven tests, performed by software agents installed on PCs, tablets, smartphones, etc. [14].

On the other hand, the measurements can be performed by network or service providers, regulators or designated third-party institutions. Different solutions are used in different countries. Many providers do it individually but their results may be regarded by users as non-objective. Thus, external institutions are needed here. Such institutions are very often national regulators or the external companies hired by the regulators. The first solution is used, e.g., in Portugal [14], while the second approach, based on “QoS Memorandum” [16], is used in Poland.

At the European level, the minimum set of QoS parameters and measurement methods for retail Internet Access Service has been described in [10]. According to this, the measuring points to be used during the IAS quality assessment may be specified (Figure 2).

Three evaluation methods (scenarios) are relevant to the measurements connected with IAS quality assessment. The methods encompass an examination of the access network, the ISP network and the network connections to NXP or IXP.

Their names are listed below:

- QoS evaluation within the ISP leg,
- QoS evaluation between the Network Termination Point (NTP) and NXP(s),
- QoS evaluation between the NTP and IXP(s).

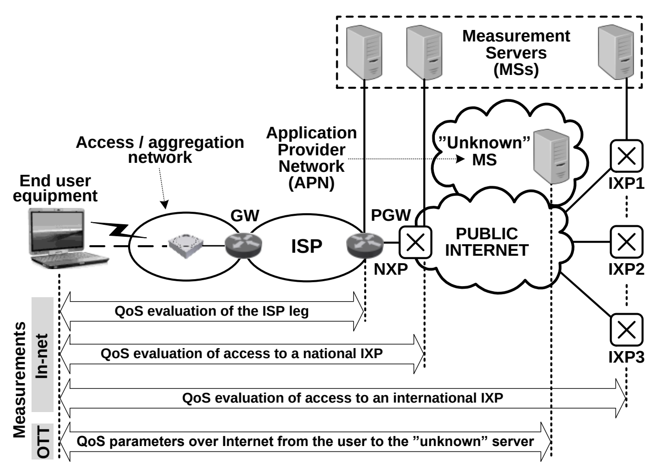

Figure 2. Internet Access Service quality assessment.

Depending on the scenario, the measurement server should be located in the right place (cf. Figure 2).

In order to only test the access network, the test server should be located as close as possible to the gateway (GW) between the access network and the ISP network. In the case of evaluating the entire ISP leg quality, the test server should be placed near the public Internet interface (PGW in Figure 2). Locating the test server in the National eXchange Point (NXP) allows the network performance parameters of different ISPs to be compared. The quality results achieved in this scenario seem to be far closer to the quality of Internet connection, as perceived by users, than the results in the "ISP leg" scenario.

It can be seen that the Internet Access Service quality assessment is therefore a very demanding issue, especially as users care about their own quality experience, which is commonly understood as unrestricted, high-quality and having a reliable access to the applications they use and the content they seek out online. This is the reason for performing the second type of measurements presented in Figure 2. They were called "OTT measurements", because they allow the performance parameters of specific applications run by the users to be tested and thus they, in general, better reflect the quality of service as perceived by the user. Nonetheless, these are measurements of the objective parameters and, in the next step, should be transformed into the quality measures as perceived by users. Mapping the measured QoS factors to the QoE ones is often quite a complicated process. The next paragraph presents an example of WWW service quality assessment as perceived by users.

IV. Service Quality Perceived By Users

In this paragraph, we present an example of the service quality assessment procedure based on the WWW service. The WWW is one of the most popular services, if not the most important of all, used by Internet users. Many of them assess the Internet quality through the lens of Web browsing and information searching on the Internet. The main parameter that influences the service quality, as perceived by the user, is Web page opening (loading) time. In other words, the end-to-end (e2e) delay between the user's request and the time when the page is open on the user's display is the most important. The WWW service quality evaluation procedure will be treated as one of the factors that influence the user's perception of the IAS. The WWW service evaluation in the real network may be performed as shown in Figure 3.

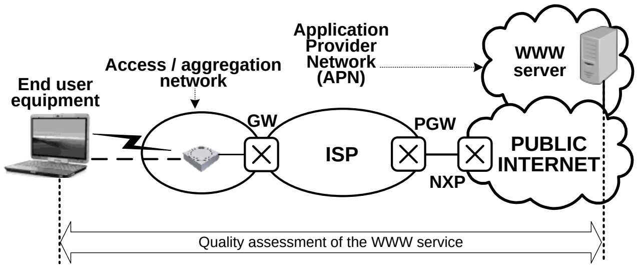

Figure 3. WWW service quality assessment.

After objective measuring of the Web page opening times, the service quality perceived by the end-users, i.e., the relation between QoS and QoE, should be found. In other words the QoE model for the service should be determined. By presenting the WWW quality assessment, the author would like to underline that measuring and presenting only the network performance parameters to the customers, discussed in previous sections of the paper, may not be sufficient for determining the IAS quality as perceived by the users. There is a need to check the service quality experienced by them and building such a model requires a special laboratory environment. The one used here is presented in Figure 4.

The laboratory test-bed consists of a WWW client with a measuring tool, a test server that hosts a set of special prepared WWW pages and the Network Emulator (NE). All the machines and software run under the MS Windows operating system. As a user client, the Mozilla Firefox browser was used while the measuring tool was the Wireshark protocol analyzer. The NE was capable of emulating the impairment parameters such as network delay, jitter and packet loss. This stage of the measurements only studied the impact of the delay on the service quality as perceived by the users. The delays were randomly generated by the NE while the users tried to open the Web pages on the test server. Next, the packets were captured by the Wireshark and analyzed. The users did not know the strict values of the delays, but they did see the effects and tried to assess them.

It was clear that the Web page opening times had a decisive influence on QoS values for the WWW service. It was to be expected that increases in end-to-end delay would lead not only to deterioration of QoS but to QoE values as well. Quality of Experience was expressed by the user's evaluation grades according to the Mean Opinion Score (MOS) scale [17]. The first observations confirmed these expectations, but it was also noticed that the subjective opinion of users depended highly on the page properties, i.e., their content, layout, construction (static, dynamic), etc. For subjective measurements the WWW reference page was needed. Static Web pages were launched on the test server and the contents of these pages were different. One of them was prepared according to ETSI reference page requirements [18], while in the second case a photo gallery was used. In that case a special scenario of the WWW pages presentation and evaluation was prepared.

The scenario assumed that every user, when evaluating Web opening times (equivalents of end-to-end delays during normal Web browser use), should give his grade after seeing several photos so that he would be better able to make a judgment.

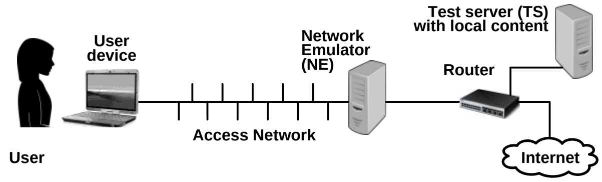

Figure 4. The laboratory test-bed for the WWW QoE assessment.

The test was performed on a user's PC (WWW client with a measurement tool). Additionally, Wireshark software installed on the client's PC (as a second tool) was used to capture IP packet streams and to register the end-to-end delay time. This was defined as the difference between the point in time at which the Web page was requested and the point in time at which all data needed for the display of the Web page were received. The end-to-end delay was varied throughout the course of the experiment using the NE. It was noticed that the Web page opening times that were registered at the user site played a crucial role in the subjective evaluation of WWW service quality (QoE). There were several groups of professional users (each group of 10) taking part in the experiment (more than 70 users in total). They gave their subjective grades for WWW service quality in a range from 1 to 5 on the MOS scale. More than 1500 test measurements were conducted. In the next step the statistical analysis has been performed.

V. THE QOE MODEL

The measurements show that the grades of users are inversely proportionate to the Web page opening times. To speak in more detail, the people who took part in the evaluation test were quite critical with regards to the service under analysis: a rapid decrease in the quality can be observed for the Web page opening times (*T*) covered in the first few seconds. It shows that users are very critical in their opinions and do not accept long delays. The longer the Web opening times, the lower grades users give. For the delays exceeding 10 s, the grades of users tend to be significantly lower at a level of 2, which means that such long times are unacceptable for WWW users.

The analysis of the results leads to the conclusion that users had a considerable problem with evaluating Web page opening times with very high fluctuations. The measurement results obtained are consistent with those presented in literature [19]. It can be noticed that users are willing to award very high grades for the service (MOS = 5) when opening times are under 2 s, while the lower grades (MOS less than 2) are given when opening times are 8 s and more. In individual cases the evaluation grades may differ significantly from the majority of the scores and thorough statistical analysis should therefore should be carried out. As can be seen in Figure 5, the mean values for the specific page opening times were not only determined, but min and max values and standard deviation as well.

The correlation between the opening times and the user grades achieved here is at a level of 80 %. The standard deviation is indicated by the dashed boxes in Figure 5, while whiskers represent the distances between the minimal and maximal values of the captured page opening times. This shows a high level of user uncertainty during the evaluation process.

As it is known from the former experiments [19][20], during long waiting times many users begin to consider whether waiting for the page to open makes sense, and many of them resign. To find a precise relation between the captured values of Web opening times and the quality experienced by users, a regression model was used.

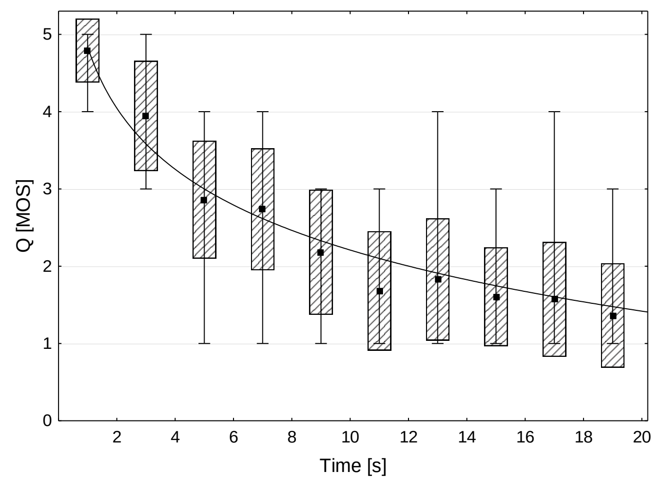

Figure 5. Subjective evaluation of WWW page opening times in MOS scale.

The model we derived can be described by the following formula:

$$Q = 4.84 - 2.63 \log_{10} T, \qquad (1)$$

where: *T* is the Web page opening time.

The logarithmic line (Figure 5) represents the *Q* value (in MOS scale) as a function of Web opening times. The statistical analysis proved that the model fits the data very well, with the coefficient of determination (R2) above 0.9. It means that the obtained outcomes are replicated by the model in at least 90 % of the time. Confirmation of such a user's QoE distribution can be found in the analysis results presented by the above-mentioned ITU-T recommendation [19], where attention had also been drawn to the logarithmic nature of the relation between QoS and QoE in such a case.

A possibility of determining the prospective MOS value by managing the opening times is very valuable and more convenient for the provider than performing the subjective evaluations, which are time consuming and more expensive.

VI. CONCLUSION AND FUTURE WORK

Internet Access Service is a key factor that influences a user's perception of all the services provided on the Web. Thus, service providers have to do all their best to offer a good quality IAS. Moreover, they should monitor the network transmission parameters and be up to date with their values. Usage of the appropriate measurement methods is therefore very important. The methods can use different scenarios. In order to make the results credible and comparable with others, these scenarios should be clear and measurement interfaces and procedures have to be clearly defined. The paper shows the different measurement solutions that can be used. In the second part of the paper the author stressed the importance of subjective quality assessment methods, which are based on the experience of users and give more information about their perception. They assess the Internet Access quality through the quality of the services that they use. One of the most popular is the WWW service. Therefore, the author presented the example of a Web browsing quality evaluation scenario, specified the key quality parameter and showed the results of measurements. At the end, the QoE model was proposed and discussed. The main conclusion is that the quality measurements should not only take into account the objective parameters, but subjective parameters as well. Obviously, the set of the parameters depends on the service. Future work will be devoted to WWW QoE model enhancement by specifying a wider set of parameters to be measured and to also build reference Web pages that will be more representative for current Internet content.

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