Paper

Telecom Operator's Approach to QoE

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https://doi.org/10.26636/jtit.2022.159522

Abstract—Telecommunication networks are ever more frequently relying on artificial intelligence and machine learning techniques to detect specific use patterns or potential errors and to take automated decisions when these are encountered. This concept requires that methods be employed to measure the level of quality of a given telecommunication service, i.e. to verify quality of service (QoS) metrics. In a broader context, methods assessing the entire user experience (quality of experience – QoE) are required as well. In this article, various approaches to assessing QoS, QoE and the related metrics are presented, with a view to implement these at an FTTH network operator in Poland. Since this article presents the architecture of the system used to analyze QoE performance based on a number of QoS metrics collected by the operator, we also provide a comprehensive introduction to the QoS and QoE metrics used herein.

Keywords—quality of experience, quality of service.

1. Introduction

In the telecommunications industry, quality of service is measured based on three parameters: throughput, delay, and jitter. This simplified approach is often further restricted to bandwidth only by crowdsourcing websites which measure the network's speed (e.g. speedtest.net or fireprobe.net). Statistics collected by such websites are often used to create Internet speed rankings listing specific countries or operators [1].

Throughput is relatively easy to measure and is often well understood by inexperienced users. On the other hand, many people are still unaware of what maximum download speed of their Internet connection is. For them, comfortable access to the services they use is far more important. Parameters assessing the quality of a given service from the technical point of view are known as quality of service (QoS) metrics. QoS is also relied upon to describe a set of methods used to define how the network prioritizes the resources available.

In contrast, quality of experience (QoE) is a measure that aims to reflect human perception of a given service that technical key performance indicators (KPIs) are unable to reflect. In some cases, the perception does not coincide with these KPIs [2].

In this article, we describe a different approach to QoS and QoE assessments, as well as the QoS and QoE metrics available to telecom operators. In addition, we present a practical implementation of QoE metrics by Fiberhost – an FTTH network operator from Poland that was spun off from INEA. Since this article presents the architecture of an QoE performance analysis system implemented by Fiberhost which relies, due to the specific needs, on numerous QoS metrics collected by the operator, we also provide a comprehensive introduction to the QoS and QoE metrics used.

2. Quality of Service Methods

In today's converged (fixed and mobile) IP networks, all traffic shares the same network resources. However, historically, voice and data services were rendered using separate networks. In order to enable converged IP networks to deal with different types of traffic, QoS mechanisms are implemented today, allowing different types of services to be distinguished, prioritized and forwarded according to the required characteristics of a given traffic category. In some extreme scenarios, routing decisions may also be based on QoS requirements. A group of services that share similar QoS requirements is often referred to as a class of service (CoS). A common approach in today's IP networks is to classify services into classes based on QoS requirements concerning throughput, delay, jitter and packet loss. The QoS DiffServ model [3] utilizes a 6-bit DS field in the IP header to define up to 64 different classes services. QoS methods relied upon by modern network devices define per hop behavior only. Consequently, they fail to monitor and control the services' overall performance. Therefore, we propose to deploy the QoS metrics described in the next section.

2.1. QoS Metrics

Many different metrics and KPIs may be distinguished. Their design may be based on two techniques:

- active probing – when probing packets are sent as part of the service in order to measure a given set of quality-of-service metrics (such as throughput, latency, jitter and packet loss). RFC 2544 [4] and ITU-T Y.1564 [5] documents provide examples of methodologies concerned with such active probing;

- passive probing – when network devices monitor the traffic flow in order to estimate quality-of-service metrics (such as throughput, latency, jitter and packet loss). Passive probing may be implemented by observing SNMP [6] counters specifying packet loss and throughput values, etc.

Various metrics and KPIs used for assessing QoS are available. In this paper, we present the most typical of them. throughput is the most frequently mentioned metric and it is often referred to as Internet speed.

Throughput a.k.a. Internet speed. While throughput is well understood by the telecommunications community, there are additional issues that network operators have to deal with. For example, in the European Union (as defined in [7]), each Internet service provider (ISP) should specify, in the contract offered to the end customer, not only the maximum Internet speed, but also they must precisely determine:

- how traffic management measures, throughput constraints or other quality-of-service parameters may affect the quality of Internet service,
- minimum, normally available, maximum and advertised download and upload speeds of Internet services for fixed networks, or estimated maximum and advertised download and upload speeds for mobile networks,
- on remedies available to the end user in the event of any continuous or recurring discrepancy between the actual performance of the Internet service in terms of speed or other QoS parameters and the performance indicated in the contract.

The speed of the Internet itself does not reflect QoS well, and speed is also not directly proportional to QoS.

Delay and jitter metric. Delay and jitter are mostly caused by packets queuing at every transmission hop from the source to the destination, but may also stem from physical distance, topology of the network, forwarding mechanisms used by the networking devices and the QoS control methods implemented. Generally, when packet queueing takes place in any network device, a bottleneck may be created at some point that will affect latency and jitter and, consequently, service response time. When latency is significant, the end-user may observe what is sometimes referred to as the "spinning wheel of death". Both delay and jitter may be measured using the methods described in RFC 2544 [4].

2.2. QoS Layers

An obvious but interesting observation concerning QoS metrics is that a specific value may differ depending on whether we focus on theoretical or measured values, and may depend significantly on the measurement methodology applied. Therefore, as a result of two European Projects titled "Mapping of fixed and mobile broadband services in Europe (SMART 2014/0016)" and "Study on Broadband and Infrastructure Mapping (SMART 2012/0022)" described in mapping project [8], three layers of QoS parameters are analyzed:

- QoS-1 – calculated availability of service, theoretical calculations the coverage offered by network operators,
- QoS-2 – measured provision of service, with the value measured using test equipment, without taking into account the end user's environment,
- QoS-3 – measured experience of service, where the value is determined via crowd sourcing tools, like online speed tests, and takes into consideration the end user's environment.

Usability and correlation of the metrics collected with respect to these three levels require that further studies be conducted. Unfortunately, data collected at these levels may be biased. For example, measurements sources during wireless test drives are often collected during business hours, when qualified technical teams are available, not but not during service peak hours. Also, speed tests performed by end users themselves are often conducted in response to service interruptions, and users treat those tests as a diagnostic tool. Therefore, such systematic errors must be taken into account when investigating the correlation between QoS-1, QoS-2, and QoS-3.

3. Quality of Experience

To an inexperienced user, simple QoS measurements may seem fairly unrelated to end user experience. It is not easy to estimate how specific values of throughput, delay, jitter and packet loss affect the quality of service. Therefore, the more complex quality-of-experience measure has been devised to reflect people's perception of a given service. Both ETSI and ITU-T proposed methods and recommendations for measuring the quality of service from the end-user's point of view. Many of other scoring methods rely on various methodologies that are difficult to compare. Their detailed descriptions are not publicly available in many instances and they are not prepared for performing QoE testing [2].

It is widely known that quality measurements might be subjective or objective in nature. ITU-T defined the mean opinion score (MOS) parameter that covers both of the aforementioned types of measurements. In the first type, the arithmetic mean of the values collected from observations is calculated. This type of assessment might be considered as difficult to conduct by telecommunications operators such as Fiberhost, due to the fact that such a task is time consuming and due to the scale factor. Hence, at Fiberhost, we use a subjective metric called the Net Promoter Score [20]. It is a sampled metric that is updated annually. In the implementation described in this article, we focused on QoS metrics we can monitor and aggregate on a daily basis. It is also worth to mentioning that subjective assessments may not be reliable due to human factors, i.e. the observer's condition or mood, as well as due to experiment environment-related factors, such as acoustic conditions, equipment used, etc. Objective assessments are based on predictive calculations that should reflect the subjective evaluation.

Objective models rely on external factors that are free from subjective judgement. In the process of creating objective models, the main issue is to find the relevant factors that cover specific network parameters or service stream packets. The main advantage is the repeatability of the evaluation process, its easy scalability, as well as real-time judgement. Nowadays, the objective methods might be realized with the use of machine learning models that may be more accurate than the standard approach due to the incremental learning process and due to their ability to analyze larger data sets.

3.1. QoE Assessment for Voice Services

The process of gathering data and assessing the quality of voice services might be based on intrusive or non-intrusive methods. The former are based on a probe that attempts to connect with the end user's terminal and collect specific information. The non-intrusive method requires a physical probe installed at the user's terminal, and is difficult to accomplish from the point of view of the telecom operator. In the case of a fixed network operator, voice quality might refer to VoIP services. Depending on whether the operator offers voice services in conjunction with other services, such as television or Internet access, quality assessment should be performed both for the VoIP service alone and for VoIP while taking advantage of other services [11].

3.2. QoE Assessment for Video Services

The quality of video services should be considered separately for IP television (IPTV) and for adaptive streaming. Video quality in IP television services is covered by ETSI standards, both for linear content and for video-on-demand services. The standards describe viable indicators enabling to perform an objective assessment based on models or evaluations performed by robots simulating end user behaviors. Service availability may be measured based on channel and service group availability, i.e. on the number of successful channel start-ups divided by the number of attempts.

Video quality evaluation relies on ITU-T recommendations and uses the MOS indicator with the ACR rating scale. It is worth mentioning that video quality measurements must be objective, i.e. computed by a known QoE algorithm. The main requirement is to use "no reference" models, while the choice of the method is the operator's decision, as no specific algorithms or models are imposed by ETSI. "No reference" algorithms do not refer to the original signal or any part of that signal. The predictions created by the abovementioned models may be based on network parameters, IPTV stream data or infrastructure-related parameters. As in the case of video, audio quality must be analyzed with the use of a "no reference" model, and cannot be performed based on speech quality assessment models [12].

From the point of view of a telecommunications operator, over-the-top (OTT) services might be considered as two different entities. One of them includes typical OTT applications, i.e. YouTube, Netflix, HBO Max etc., while the other is an own television system that might be based on adaptive streaming with the use of the HTTP standard, just as it is the case in classic OTT applications, but is provided with the use of the operator's network. The abovementioned television architecture may rely on multicast technology not only in the core network, but also in the last mile network. OTT television systems are often referred to as IPTV 2.0.

The assessment of quality of adaptive streaming services is provided for in the ITU-T P.1204 recommendation [13] and in the ETSI TR 103 488 report [14]. Adaptive streaming systems may use different protocols, for example HTTP live streaming (HLS) or dynamic adaptive streaming over HTTP (DASH). Quality measurements may be performed for pure OTT applications and for television services based on adaptive streaming provided on a managed network. A comprehensive overview of developments related to visual quality monitoring is presented in [19].

3.3. Compound STQ Metric

In addition to single parameter metrics, such as throughput, delay and jitter, compound QoS metrics may be distinguished as well, including speech and multimedia transmission quality (STQ) [15]. STQ describes the best practices for benchmarking a mobile network and is also widely adapted and used by ISPs in wired networks. This document focuses mainly on the aspects of STQ that are significant for ISPs and allow the quality of the services provided to be evaluated. ETSI recommends mainly a clear interpretation of the benchmark results. All results must include information about:

- the scoring model used,
- basic KPIs values measured in the test,
- number of samples and/or number of tests,
- methodology used (including hardware configuration, connection sequences, test servers and test pages),
- data collection areas and packages (tariff plans) for data collection.

Tests should be performed on the same servers by all operators. The location of servers should not favor any service provider. The choice of the test page can have an impact on the test results. Therefore, to provide a representative comparison, it is necessary to prepare various and reliable pages for the test. In [15], ETSI suggests using a minimum of 6 tests, while 10 or more are recommended. Eliminating a single web page from the overall pool should not affect the diversity of those pages. The ranking should use pages that are popular among customers. Their minimum size should exceed the download success criterion. The principle of proportion of active pages should be applied – 4 common and 6 country dependent. It is not recommended to block ads and use websites operating within one CDN. Web pages that are mainly accessible through dedicated apps should not be used for testing as well. The pool used in the ranking should not contain subpages with discriminatory and indecent content or those prohibited by law.

STQ sets the scoring benchmark for mobile networks operating across large geographic regions. The overall result is calculated from the individual measurement results and aggregation is performed using a weighted factor. The authors distinguish four levels presented in Fig. 1. The highest index is important for the business assessment of the quality of the entire network of a given operator and for comparing it with other ISPs.

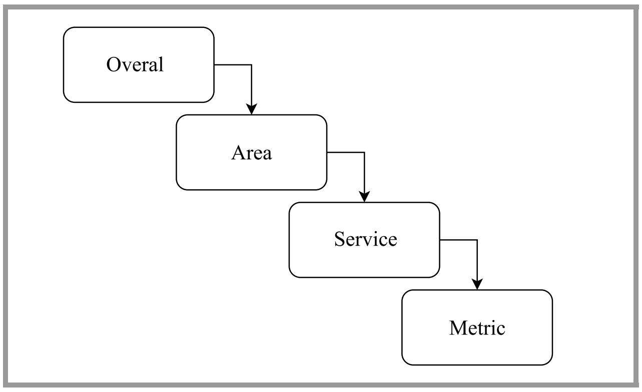

Fig. 1. Scoring layers.

The quality of a stationary cable network, unlike in the case of any mobile networks, does not depend on the geographical location of the customer's device. It is economically viable for an ISP to aim for a similar level of network saturation in all locations. Therefore, the "area" layer is not applicable in the weighting of stationary cable network's score. However, it may still be of interest for the operator, as a tool for comparing different parts of the network. In this context, a given "area" does not have to describe specific geographic coverage, but may also be an area in terms of the services provided based on the same technology or devices (e.g. OLT or aggregation router).

User profile is an important element of STQ, as it affects the "service" and "metric" layers. Different users have different service requirements and expectations. The recommendation is to rate the services based on the profile level associated with the highest requirements.

Research is being conducted at Fiberhost to define profiles and evaluate services in the context of different customer types. It has been assumed that profiles will be created on the basis of DNS queries collected over a period of time, though this is only one of the potential approaches.

The "service" level is the next aspect that may be assessed, as it covers the basic services provided. The division proposed in STQ is shown in Fig. 2.

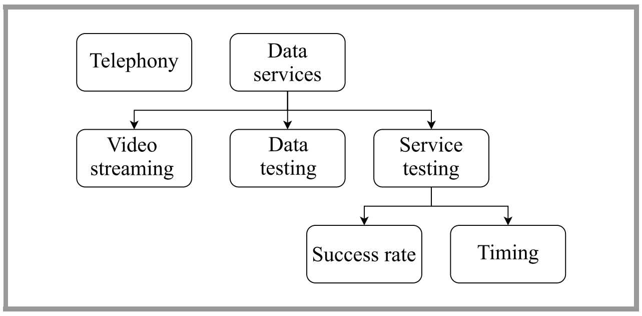

Fig. 2. Services testing.

At the lowest level, each service is assessed based on the metrics' basis obtained during the tests. The KPIs are mostly described in the document ETSI TS 102 250-2 [16] document. Table 1 lists the metrics for each of the services. Telephony is separated from data transmission services, due to the high impact of delays and errors on the assessment of its quality.

Each of the tests is multi-layered, with the overall test score at the top – a value calculated on the basis of the weighted results from the test scenarios for telephony and data services. The data service index consists of video, data, and service testing results. The total weight of the components at each level is always 100%.

STQ suggests the scoring and the weighting for each metric. Here, we are considering the general concept of QoS testing and parameter evaluation details are not covered here. Examples of weighting factors, limits and thresholds are provided in Annex A of ETSI TR 103 559 V1.1 [9].

3.4. Network Performance Score

Network performance score (NPS) is a proposal aiming to implement the good testing practices presented in STQ [18]. NPS, similarly to STQ, is designed primarily for mobile networks, but the concept is universal and is considered at Fiberhost. As it was the case STQ, NPS indicators are divided into 3 levels.

At the highest level, the coefficients from level 2 to one index describing the entire network are aggregated. However, when used in Fiberhost, instead of a weight based on geographic location, a weight was proposed based on the number of customers connected behind a given aggregation device (equivalent of a region in mobile networks).

The second level aggregates the service results by weighting. The indicator at this level shows the QoS in a given case, at a given time and location. In the case of an ISP, the location should be understood as the physical location of the infrastructure service.

Table 1
Services test metrics

Service	Metric	Description
Telephony	Telephony success ratio	Success rate of the call
	Setup time	Time from the initiation of the connection to the calling of the other party to the connection
	Listening quality	The value is calculated on a sample basis, using recommendations from ITU-T P.863 [17]
Video testing	Video streaming service success ratio	Success rate of the video stream received
	Setup time	Time from stream request to the displaying of the first picture
	Video quality	Video service metering has already been described in this document
Data testing	Success ratio	Success rate for HTTP uploads and downloads
	Throughput	Data rate or throughput for HTTP uploads and downloads
Services	Browsing	Success rate of all download and page open attempts, page response times to those operations
	Social media	The ratio of success user interacts with the media to all interaction and response times to those operations
	Messaging	The ratio of success sending message to sending message and delivery time

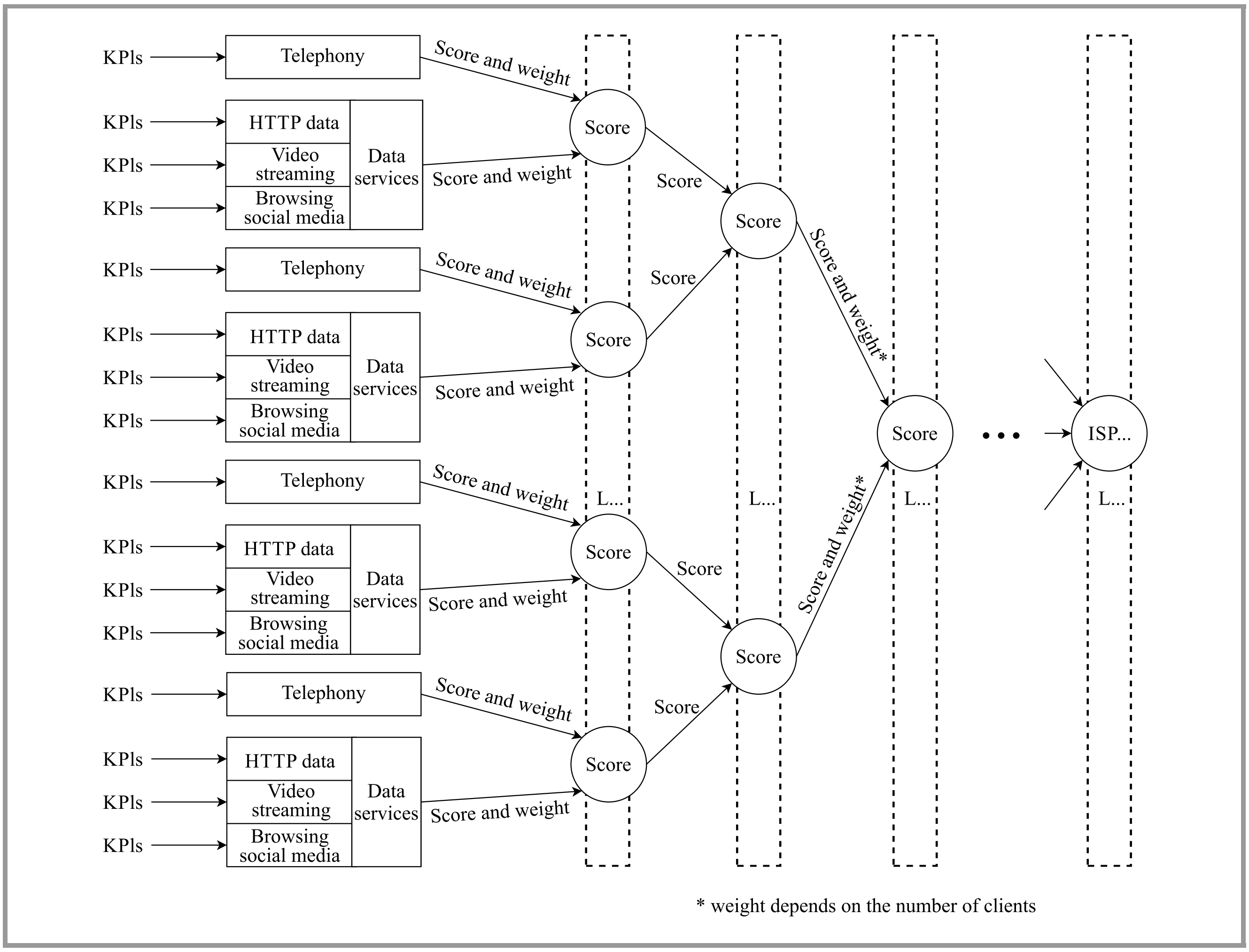

Fig. 3. Example implementation of DX based on NPS.

At the lowest (third) level, the recommendation is to divide QoE indicators into 3 groups:

- service availability – access and response time only,
- waiting for action – time between the request and commencing or ending the requested task,
- quality – media quality (video, voice, images).

Only those indicators that are decoded by human perception have an impact on the result. They all have to be normalized to the same scale and they must have a certain weight. STQ and NPS do not define the method of filtering data noise which can occur upon test device failure or a local power failure. Such filtering needs to be provided to show the overall condition of the services and not the extreme cases resulting from measurement errors and noise. There is also no definition of the scoring computation intervals at the aggregation levels. Excessively long sampling intervals will average out many short variations of the individual parameters and will reduce their impact on the overall result. Too frequent readings will introduce a lot of noise due to the number of measurements and potential local errors of the test equipment. Each ISP has to assess and define the above from their own perspective.

Figure 3 shows a sample NPS implementation customized to satisfy the needs of Fiberhost. Aggregation of the results by location (device) may occur on many levels, depending on the topology of the telecom operator's network. The division of the network into aggregation nodes for which the score is calculated may depend on a number of factors, such as physical and logical topology, geographic extension and the service provision model.

Both STQ and NPS fail to address issues related to the correctness of QoE representation by the KPIs. These issues were discussed in [17].

On October 4, 2021, a global failure of Facebook, the largest social networking site, occurred. As a result, telecom operators faced a new challenge in the form of an increase in the number of DNS queries to recursive servers. In the case of INEA, the number of requests doubled at 17:43 and during the peak hours it reached 250% of the normal query load, compared to the reference value recorded on Monday of the previous week. The problem was solved at 23:27. A conclusion was drawn from this failure, according to which service quality indicators used in telecommunications networks need to be verified and modified. In the recommendations, such as STQ (ETSI) and their proposed implementations, such as network performance score (NPS), the impact of the "quality" of social media services used by users is set at 15%. However, these types of situations prove a much greater impact on the overall indicator and the quality level perceived by the customer. The issue concerns an OTT service and the operator has little impact on its quality, but the failures have a large impact on the users themselves. ISPs do not have accurate data for such services and cannot optimize OTT services. Therefore, failures of this type are not included by INEA in its CX and DX logs. If we manage to develop, in the future, a form of cooperation providing better visibility of the quality of OTT services, we will be able to influence the level of that quality, and then quality scoring will be added to CX and DX.

The scoring should also distinguish between normal operation and a failure occurring outside the operator's network, such as the aforementioned unavailability of Facebook or problems at the interface with other operators or at traffic exchange points.

4. Implementation Example

In this section, we present the effort of Fiberhost – an FTTH operator from Poland – aiming at implementing a system for monitoring not only QoE related to the services offered, but all the interactions with the services and the operator as such. The aim was to compare the performance of different geographic areas of the operator's network, taking into account not only the average quality of experience in a given area, but also all interactions between the end user on the one hand, and the operator and the services purchased on the other. Thus, the definition used in this scenario was even of a broader nature that in the case of NPS or STQ, as described in previous sections. Because of such a broad scope of the study, Fiberhost realized that no third-party systems that are ready for use are available and decided to develop this system in-house. At Fiberhost, the system is referred to as CX. CX stands for Customer eXperience and is defined as:

$$CX = DX + AX.$$

Thus, CX is the sum of Digital eXperience (DX) which involves the measurements of complex QoE metrics similar to NPS, and Analog eXperience (AX), aiming to capture all human operator interactions, including purchasing the services, troubleshooting, payments, promotions, etc. AX is related to the operator's operational efficiency and covers the following: customer complaints made by phone or with the use of other forms of interaction, complaint handling time, installation time, number of customer complaints resolved during the first contact, etc. DX focuses on all digital services, taking into account such indicators as: availability of the services, scheduled works, maintenance, service failures, service degradation, CPE logout time, physical signal parameters, L2 (layer 2) or L3 (layer 3) transport performance metric, and network saturation events. Each metric contributing to DX is, just as it is the case with NPS or STQ, summed up and weighted in order to create a compound overall indicator.

Both CX components are structured in a similar way to NPS, so they form a weighted sum of all partial parameters and may be aggregated at different levels. Figure 3 shows details of the DX implementation. While AX is structured in the same way, it includes non-technical parameters related to purchasing the services, troubleshooting, payments and promotions, so we decided to exclude AX from the scope of this paper. The specific weighting of the various DX and AX parameters and, consequently, CX as well, are not disclosed by Fiberhost. However, all metrics are weighted and summed up to form a CX value that ranges from 0% to 100%.

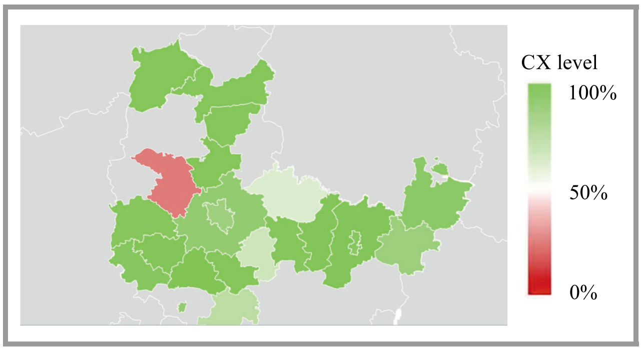

Fig. 4. Example of a CX aggregation calculated for a specific geographical area.

CX is calculated on a monthly and annual, per-customer basis and aggregated CX values may be used to visualize QoE measurements related to a given part of the network. An example of aggregation of CX values pertaining to a specific geographic area is shown in Fig. 4. The map shows the average value of CX for all customers using services provided by the operator in a given geographic area. The areas marked in dark green represent the highest CX rating close to 100%, and correspond to areas where most customers experience no technical issues (represented by the DX component in CX) or are affected by other non-technical issues (represented by the AX component in CX). The red areas represent the lowest CX score close to 0% and correspond to areas where the majority of customers have technical or other non-technical problems.

By presenting DX in the form of a map, we are able to have a good overview of the expected level of CX. However, such an approach fails to illustrate many technical and operational details. Therefore, at Fiberhost, the map is not the only analytical tool and is accompanied by reports that provide detailed information on all the components that make up a given CX value. These reports allow to conduct a detailed analysis in order to identify specific technical or operational aspects that require improvement.

CX is an attempt to reflect customer perceptions of service quality and customer experience in a broad context that includes all digital and analog interactions. CX has enabled Fiberhost to conduct in-depth technical and operational analyses. By providing such a complex metric, Fiberhost was able to determine what the average expected CX score was in all areas. this, in turn, served as a basis for identifying those areas where the CX score was too low and which required immediate attention to improve the maintenance parameters that affect the quality of experience or other non-technical parameters.

The implementation of CX allows Fiberhost to use ML methods for identifying more complex network dependencies and for optimizing service performance. However, ML-based optimization is planned as a future task. Current efforts are aimed at improving CX levels in all of the underperforming areas.

Although this paper does not provide any numerical results, it does provide an insight into the real live implementation of a QoE assessment system deployed by a telecom operator. Therefore, we hope that it will be a valuable guidance for other operators and companies willing to implement similar systems.

5. Conclusions

There are many QoS and QoE metrics available to telecom operators. Simple QoS metrics are easy to collect but do not reflect end user observations. Therefore, in order to compare different networks, by area or country, it is better to use QoE metrics that are meant to reflect human perception. However, any QoS and QoE metrics may be significantly influenced by the methodology, specific hardware, testing intervals, information source, etc. This error should be removed from the collected data to ensure that the QoE metric reflects the actual customer experience.

In this article, we analyze typical QoS and QoE metrics that are currently used by telecom operators. Additionally, we present a complex QoE metric known as CX (Customer eXperience), implemented by Fiberhost in order to get in-depth information about the complex experiences of its customers, including the quality of the service offered and all other interactions.

QoE metrics, such as STQ, NPS or CX, are very important for network operators planning to optimize their infrastructure by deploying machine learning mechanisms, since the first step preceding any optimization consists in understanding current performance of the network. By providing complex measurements of various parameters, QoE metrics are a source of reliable feedback that may be harnessed by artificial intelligence solutions in order to achieve what is often referred to as the intent network, i.e. a network whose operations are defined by the operator's ultimate intent, not the use of any technical terms.

Acknowledgements

The research was carried out as part of the Implementation Doctorate Program of the Ministry of Education and Science in 2021–2024 (Agreement no. DWD/4/24/2020 from 6.11.2020).

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