On Assuring End-to-End QoE in Next Generation Networks: Challenges and a Possible Solution

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ABSTRACT

In next generation networks, voice, data, and multimedia services will be converged onto a single network platform with increasing complexity and heterogeneity of underlying wireless and optical networking systems. These services should be delivered in the most cost- and resource-efficient manner with ensured user satisfaction. To this end, service providers are now switching the focus from network Quality of Service (QoS) to user Quality of Experience (QoE), which describes the overall performance of a network from the user perspective. High network QoS can, in many cases, result in high QoE, but it cannot assure high QoE. Optimizing end-to-end QoE must consider other contributing factors of QoE such as the application-level QoS, the capability of terminal equipment and customer premises networks, and subjective user factors. This article discusses challenges and a possible solution for optimizing end-to-end QoE in Next Generation Networks.

INTRODUCTION

Currently, Wireless Broadband Access (WBA) technologies are rapidly deployed while the traditional telecom networks are migrating to Internet Protocol (IP) technology. The future will witness a clear trend of Fixed Mobile Internet Convergence (FMIC) in Next Generation Networks (NGN) [1]. To realize this convergence, NGN will employ an open architecture and global interfaces to create a multi-vendor and multi-operator network environment. Moreover, NGN will employ multiple networking technologies for the best service provisioning. While core networks in NGN are going to employ a common network layer protocol to carry the current and foreseeable future services, the access networks will use a variety of technologies, such as 2G/3G, LTE, WiMAX, UWB, WLAN, WPAN, Bluetooth, Ethernet cable, DSL, and optical fiber, to meet the diversified requirements from end users. Under the multi-operator, multi-network, and multi-vendor converged network environment, users are expected to experience a heterogeneous wireline and wireless high-bandwidth ubiquitous network access as well as diversified service provisioning.

Since NGN can offer multiple services over a single network, it potentially simplifies network operation and management, and thus operational expenditure (OPEX). While enjoying the benefit of the decreased OPEX, service providers will encounter fierce competition provisioned by the availability of fixed-mobile convergence. In order to sustain and sharpen their competitive edges, service providers need to satisfy users' needs to retain and attract lucrative customers. For this reason, service providers may explore management and control decisions based on user Quality of Experience (QoE). As the ultimate measure of services tendered by a network, QoE is defined as the overall acceptability of an application or service as perceived subjectively by the end-user [2].

Figure 1 illustrates typical constituents in an NGN. The core network consists of four major candidate transport technologies, i.e., ATM, Ethernet, IP, and IP/MPLS, where IP-based core networks possess two QoS models (DiffServ and IntServ) standardized by IETF. The access networks accommodate various wireless and wireline access technologies to provide consistent and ubiquitous services to end users. End-to-End (E2E) communications between users or between a user and an application server may span fixed and wireless mobile networks belonging to multiple operators and employing multiple networking technologies with their respective characteristics from different aspects, such as QoS models, service classes, data rates, and mobility support. The multiplicity of provider domains and diversity of transport technologies pose challenges for network interconnection, interworking, and interoperation, and therefore E2E QoE. QoE includes the complete E2E system effects ranging from users, terminals, customer premises networks, core and access networks, to services infrastructures. Besides the E2E network QoS, QoE is affected by many other factors such as user subjective factors, capabilities of terminal devices, properties of the applications, and characteristics of the user's physical environment. Such a variety of contributing factors of QoE exacerbate the difficulty for assuring E2E QoE.

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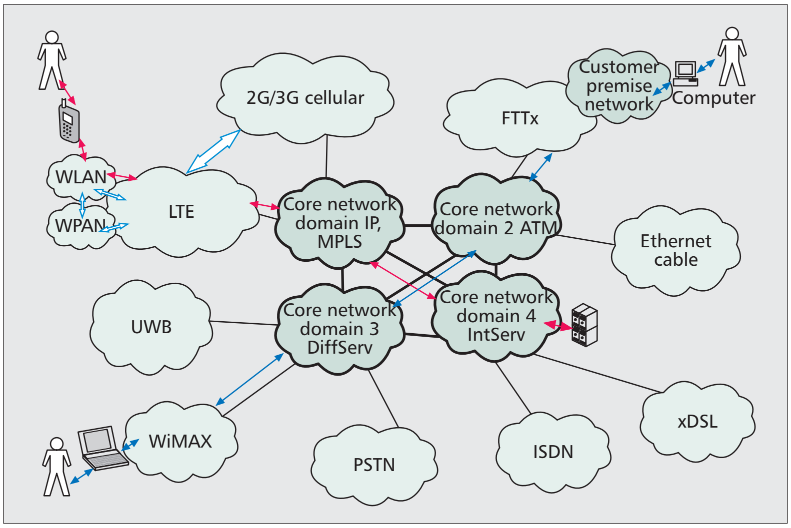

Figure 1. *Typical constituents in NGN.*

From the user's perspective, in order to assure user QoE, transport functions and application-level parameter configurations should be adaptive to other influencing factors of QoE such as user subjective factors. From the network's perspective, the NGN system needs to intelligently allocate its resources among all users and properly adjust its transport functions to satisfy all users' demands. However, many challenging issues, such as QoE measurement, monitoring, diagnosis, and management, must be addressed before these goals can be achieved. It requires efforts across all layers of the protocol stack of each traversed network [13]. That is to say, functions such as admission control, access network selection, routing, resource allocation, QoS mapping, transmission control, session establishment, and source coding are expected to be adaptive to user QoE.

Instead of addressing one of these challenging problems or investigating solutions to assure QoE for one particular application, this article discusses possible challenging issues involved in assuring E2E QoE for all users in an NGN, and describes the general framework of an E2E QoE assurance system, which can possibly be implemented in an NGN to assure user QoE.

The rest of the article is organized as follows. We first discuss the intrinsic properties of QoE. Then, the challenges involved in assuring E2E QoE are described. Finally, we detail the constituents and functions of the proposed E2E QoE assurance system, and then conclude the article.

Properties of QoE

QoE has many contributing factors, among which some are subjective and not controllable, while others are objective and can be controlled [3, 4]. Subjective factors include user emotion, experience, and expectation; objective factors consist of both technical and non-technical aspects of services. The end-to-end network quality, the network/service coverage, and the terminal functionality are typical technical factors, and ease of service setup, service content, pricing, and customer support are some examples of non-technical factors. Poor performance in any of these objective contributing factors can degrade user QoE significantly.

Some of these subjective and objective factors are dynamically morphing during an on-line session, while some others are relatively stable and are less likely to change during a user's session. Dynamically changeable factors include user subjective factors and some technical factors, in particular, network-level QoS. Relatively stable factors include non-technical factors and some technical factors such as network coverage. In addressing the real-time E2E QoE assurance problem in this article, we assume that users are satisfied with the performances of those relatively stable factors. QoE possesses the following properties owing to the variety of contributing factors.

User-Dependent

Users receive different QoE even when they are provided with services of the same qualities. First, users may show different preferences towards their sessions established over the network. For example, residential subscribers and business subscribers may exhibit rather different preferences over on-line gaming and file transfer services, respectively. Second, owing to the differences in user subjective emotion, experience, and expectation, users may yield different subjective evaluations for services with the same objective QoS. Furthermore, users' preferences over sessions, and their emotion, experience, and expectation factors, may not be stable but vary from time to time.

Application-Dependent

NGN will enable and accommodate a broad range of applications, including voice telephony, data, multimedia, E-health, E-education, public network computing, messaging, interactive gaming, and call center services. Applications exert different impacts on user QoE. First, from the user perspective, applications are of different importance to different users. Second, these applications may have diversified network-level QoS requirements [3]. Voice, video, and data constitute three main categories of applications. Generally, voice and video are more delay and jitter sensitive than data traffic is. Each of the three categories further encompasses a number of applications with different QoS requirements. For example, video conferencing and real-time streaming TV belong to the video category; nevertheless, users may have higher requirements on the perceived resolution, transmission rates, delay, and jitter for real-time streaming TV than those for video conferencing. Third, each application may use its own parameters to quantify application-level QoS. Resolution, frame rate, color, and encoding schemes are typical parameters for video applications; HTML throughput and HTML file retrieval time are parameters for web access applications. Different application-level QoS performances bring different effects on user QoE.

Terminal-Dependent

Currently, a variety of terminal devices are available to accommodate an application. For video applications, the terminal device can be a cell phone, a PDA, a computer, or a TV. Each of these devices is characterized by its own media processing and terminal capabilities, such as resolution, color, panel size, coding, and receiver sensitivity. The capabilities of terminal devices may blur the perceptual difference between network provisioned functionalities and terminal enabled functionalities. Terminal equipment (TE) affects users' QoE in three main ways. First, owing to the powerful processing and storage capabilities of the devices, users with more powerful devices may experience higher QoE when they are provisioned with the same network-level QoS. Second, in order to capitalize on the merits of devices, users with more powerful devices may require the network to provision higher QoS. For example, as compared to users with the standard definition TV, users with the high definition TV may have higher expectations on their received QoS, and are likely to desire higher bit rate and lower data loss of TV signal transmission. Third, user QoE may greatly depend on the performances of terminal devices, such as energy consumption of cell phones and PDAs.

Time-Variant and Difficult to Control

Many contributing factors of QoE change over time and are difficult, if not impossible, to control. First, user subjective factors may fluctuate and cannot be controlled by transport functions and application-layer configurations. Second, in wireless communications, multi-path propagation and shadowing induce dynamically changing wireless channel conditions, which will have significant impact on user received signal strength, and thus network-level QoS, and finally QoE.

Owing to the above properties, QoE is desired to be managed on a per-user, per-application, and per-terminal basis in a real-time manner in NGN. However, to achieve this goal many challenging issues need to be addressed.

Challenges in E2E QoE Assurance

This section discusses several important challenging issues in assuring a sustained user QoE in real-time. These issues include but are not limited to QoE measurement, monitoring, diagnosis, and management.

QoE Measurement: For online QoE measurement, there are two general approaches: the subjective approach and the objective approach [4].

With the subjective approach, users evaluate and give scores to their experienced services in real-time. The subjective method may generate accurate measurement results since QoE reflects users' subjective perception to the service. However, users are usually unlikely to spend time in evaluating their experienced services unless poor QoE is experienced [5], let alone provide detailed information about causal factors of their poor experience in real-time. Such limited information provided by the subjective approach challenges the following QoE diagnosis process, which is an essential part of QoE assurance. Besides, with the subjective approach alone, users may take advantage of the measurement system to demand higher quality than they deserve or maliciously consume network resources and degrade other users' QoE.

The objective approach derives the subjective user QoE by using algorithms or formulas based on the objective parameters of networks, application, terminals, environment, and users. This method usually models QoE as functions of application-level and network-level QoS parameters, and then refines the model by theoretical derivation [6] or testing subjective QoE [4]. Machine learning or computational intelligence, such as neural networks and genetic algorithms, may be employed to learn user subjective perception based on the historical QoE information of users to deduce the subjective measurement [7]. Recently, many research efforts have been made to improve the accuracy of objective measurement. However, there is no standard technology to map objective parameters to QoE for all applications, all terminal devices, and all user subjective factors.

QoE Monitoring and Feedback: Since QoE characterizes the perception of services experienced by end users, accurate QoE performance should be measured and monitored at end users, and then fed back to the network [8].

In order for the NGN system to respond promptly to a degraded QoE, the QoE of end users is expected to be fed back to each network in real-time. However, it takes some time for the QoE value to reach networks and sources that can be users or application servers. QoE values may be outdated by the transmission delay that will further mislead the transport function adjustment and the application-layer parameter configurations. On the other hand, frequent reporting or probing QoE and QoS parameters can help transport networks and sources track the user status more accurately, but the extra injected traffic may increase the network burden.

In order to prevent QoE degradation, it is necessary to monitor the status of each network element in the E2E path of a user session [9]. Core routers, edge routers, access nodes, and wireless channels are typical network elements. However, for one particular network element, it is hard to tell the degree of the impact of its performance on the E2E QoE without the information of all the other network elements' performances. Therefore, ideally, each network element needs to be monitored in real time. This will introduce high monitoring overhead. Moreover, the performances of all network elements need to be incorporated together to obtain the E2E effect. However, this is difficult to achieve in an NGN that is distributed and heterogeneous in nature.

QoE Diagnosis: When poor QoE is experienced, it is better to figure out the causal factor of QoE degradation so as to improve QoE. However, this may not be easy to achieve for three reasons. First, since user subjective factors are dynamically morphing and difficult to measure, it is not easy to distinguish the variation of subjective factors from causal objective QoS performance degradation. Second, performances of some contributing factors of QoE, especially non-technical aspects of services, may not be available for diagnosis. Inaccurate diagnosis may be resulted without the comprehensive information of all contributing factors. Third, network-level QoS performances are determined by all

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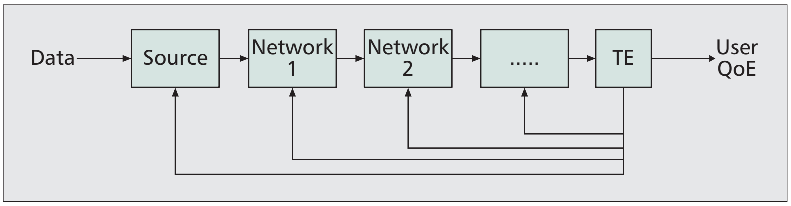

Figure 2. *The abstraction of the E2E QoE assurance in NGN.*

traversed networks, which may belong to different domains and do not disclose detailed information to each other. As a result, it may be difficult to know the exact network element that causes the poor performance.

QoE Management: First, as a multitude of users with a variety of applications and terminal devices are being developed and accommodated at a rapid pace in NGN, managing QoE on a per-user, per-application, and per-terminal basis raises the scalability issue. Second, achieving a target QoE requires that the performances in each QoS metric satisfy certain quantitative requirements. However, guaranteeing quantitative QoS is a challenging issue in networks with qualitative QoS control such as DiffServ. Third, achieving a given QoS requires proper adjustment of transport functions such as access network selection, routing, QoS mapping, QoS budget allocation, resource allocation, admission control, scheduling, queuing, and transmission control [10]. Any of these functions may not be easily addressed.

E2E QoE assurance may involve some other challenging issues. For a given application, some unique issues may exist in assuring QoE, and hence calling for specific solutions. In particular, QoE assurance for VoIP and IPTV applications has received intensive research attention recently [11–13]. Rather than addressing the above described challenging issues or addressing the QoE assurance problem for one particular application, we propose one possible E2E QoE assurance system that aims at ensuring QoE for all users in an NGN.

An E2E QoE Assurance System

In this section, we will describe the general framework of a proposed E2E QoE assurance system, which can possibly be implemented in NGN to assure user QoE.

The E2E QoE assurance system is designed based on two assumptions. First, motivated by bettering their own experiences, users are ready to enable their devices with the function of reporting their received QoE and QoS performances by using some particular chips or software in their TE. Second, motivated by attracting more customers, service providers would like to maximize user QoE in allocating resources and configuring their networks.

Figure 2 shows the abstraction of the E2E QoE assurance system, which is modeled as a closed-loop control system. Generally, TE measures user QoE/QoS performances and feeds back these values to networks and sources; networks and sources adjust their respective functions accordingly based on their received QoE/QoS measurement results. Theoretically, the overall data transmission system is considered as a closed-loop control system, with user QoE as the system output, and source and network configuration parameters as control variables. QoE is determined by the network and source configurations, which are in turn configured based on QoE.

Figure 3 describes the major constituents of the QoE assurance system as well as their functions. The system contains two major components: the QoE/QoS reporting component at TE, and the QoE management component at networks and sources. The QoE/QoS reporting component collects user QoE/QoS parameters, and then reports them to networks and sources. The QoE management component receives QoE/QoS reports, analyzes them locally, and adjusts their transport functions or reconfigures application parameters accordingly. After the adjustment, the QoE management component estimates the up-to-date QoE/QoS performances of end users, and then sends the updated information further to other networks and sources.

We shall next detail the constituents and functions of the QoE/QoS reporting component and the QoE management component.

QoE/QoS Reporting Component

As described in Fig. 4, the QoE/QoS reporting component contains four blocks: the network-level QoS measurement block, the application-level QoS measurement block, the user subjective QoE measurement block, and the QoE/QoS reporting block. Both network-level

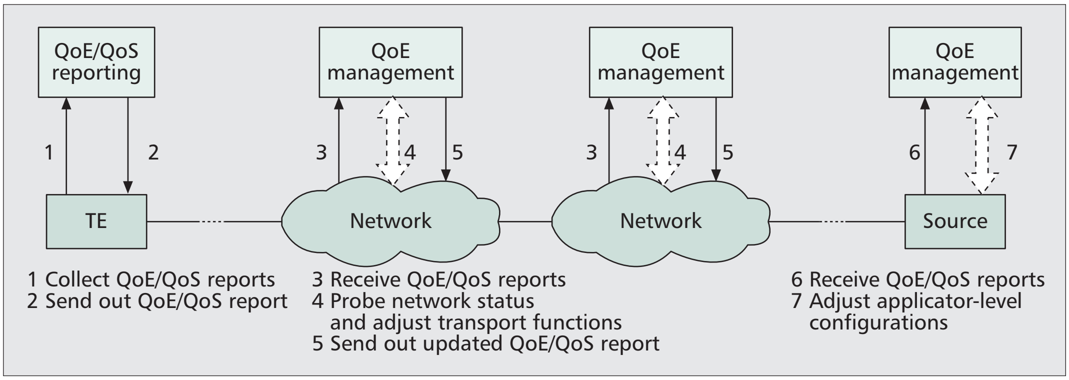

Figure 3. *The major functions of the E2E QoE assurance system.*

QoS and application-level QoS can be derived by analyzing the received packets. For subjective QoE measurement, we assume that users will interact with the terminal device when they experience poor performances, and the interactions between the user and the terminal device can help derive user subjective QoE.

The function of the QoE/QoS block is to prepare and send out the report message. The report message can be sent out periodically or only when performance degradation happens. The latter approach can reduce the extra traffic injected into the network as well as the cost related to reporting. Regarding the report message, it may contain all these three kinds of measurement results such that networks and sources can have comprehensive information about the user. However, this may incur a big report message. An alternative way is to report the performances of the QoS metrics, which do not meet the requirements. This intelligent reporting scheme implies some QoE diagnosis capability within the QoE/QoS reporting block.

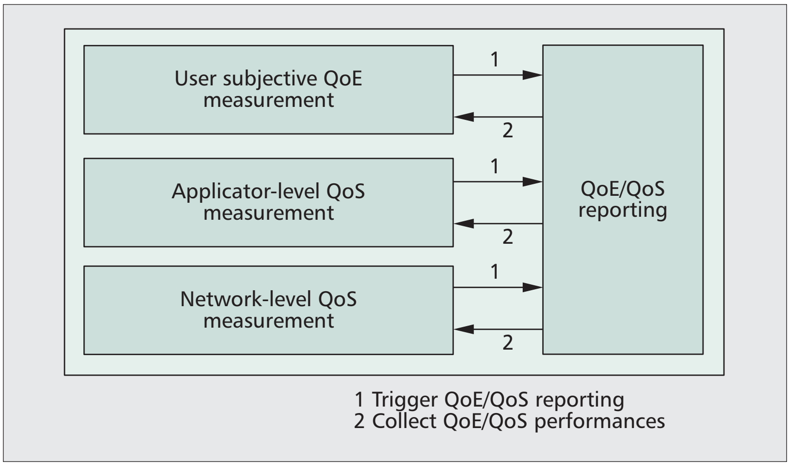

Figure 4. *The block diagram of the QoE/QoS reporting component.*

QoE Management Component

Figure 5 shows the implementation of the QoE management block in NGN. Functions implemented in the QoE management component belong to the service stratum. In order to manage user QoE, the QoE management component interacts with the Network Attachment Control Function (NACF) and Resource and Admission Control Functions (RACF) in the transport stratum to negotiate network-level QoS and adjust transport functions accordingly.

Figure 6 describes constituents of the QoE management component. It contains four blocks: the user QoE database, the QoE/QoS performance receiving/transmitting block, the QoE inference/diagnosis block, and the QoE control/management block.

QoE database: Owing to the properties of QoE, the QoE database is organized on a per-user, per-terminal, and per-service basis. For a given service and TE, QoE of the user is considered as a function of network-level QoS performances, application-level QoS performances, and user subjective factors.

Based on the fact that poor performance in any of objective parameters may result in significant QoE degradation regardless of good performances in all other factors, each QoS metric may need to satisfy certain threshold requirements in order to achieve a given QoE value. For some QoS metrics, such as packet loss ratio, delay, and jitter, the threshold requirements are the maximum allowable value, while for some other QoS metrics, such as throughput and picture resolution, the threshold requirements are the minimum allowable value. These threshold requirements can characterize QoE functions, and are stored in the QoE database.

User subjective factors affect user QoE and impact the threshold requirements on objective QoS performances. Considering the dynamically changing user subjective factors, the above threshold requirements of objective QoS metrics are not deterministic, but vary within some ranges. These variation ranges are stored in the QoE database as well.

QoE/QoS receiving/transmitting block: The function of this block is to receive the QoE/QoS reports, and report to other networks with the updated QoE/QoS performances. After the QoE management component adjusts network transport functions, QoE/QoS performances of end users change accordingly. This block gets the updated QoE/QoS performances from the QoE inference/diagnosis block and reports them to other networks.

QoE inference/diagnosis block: This block has two main functions. One is to infer QoE by

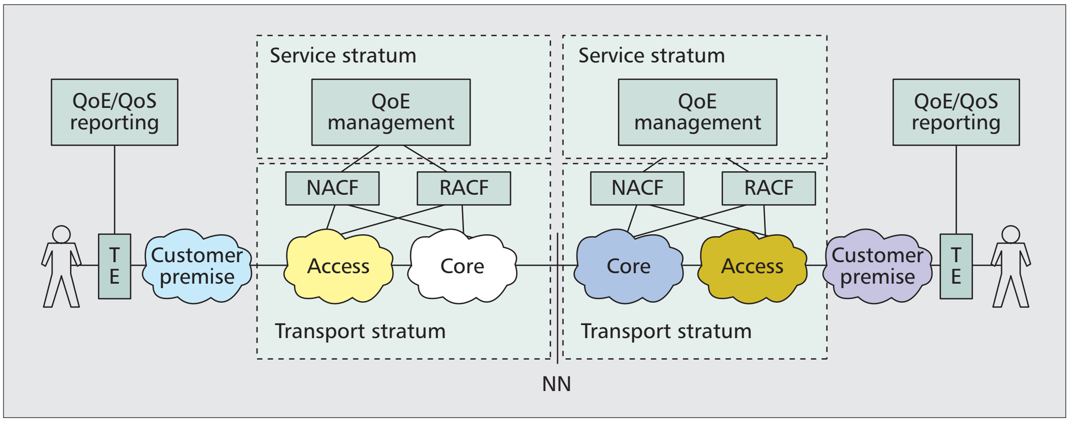

Figure 5. *The implementation of the QoE management component in NGN.*

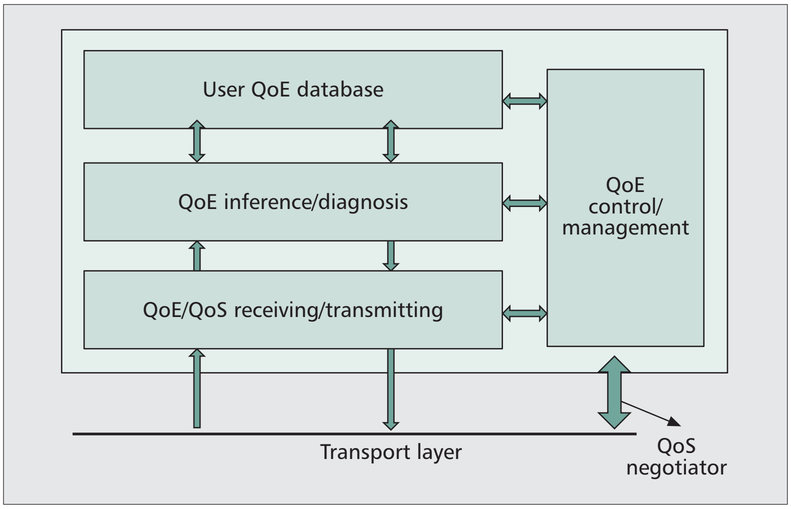

Figure 6. *The block diagram of the QoE management component.*

using the objective QoE measurement approach; the other is to diagnose the causal factors leading to QoE degradation. For given QoS performances, the corresponding QoE can be inferred from the information stored in the QoE database. QoE diagnosis is the reverse process of QoE inference. QoE diagnosis can be fulfilled by comparing the actual QoS performances with the threshold requirements for a target QoE.

Besides QoS performances, the report may contain the user QoE value measured by the subjective approach at the user end. There may exist disagreement between the inferred QoE and the reported QoE value. To narrow down their difference, the objective QoE measurement model is dynamically modified by adjusting the threshold requirements of QoS metrics.

QoE control/management block: The function of this block is to determine the target QoE for users and negotiate with the Resource Admission Control Function (RACF) and the Network Attachment Control Function (NACF) in the transport stratum to achieve the target QoE. In the ideal case, the network resources can assure every user with the largest QoE. When users have large traffic demands and the ideal case cannot be achieved, equalizing QoE among users, or maximizing the sum of QoE of all users, can be regarded as the objective of QoE management. After determining the target QoE of users, this block communicates with the QoE inference/diagnosis block to derive the corresponding required QoS performances, and then negotiates with the RACF and NACF functions to achieve these QoS requirements. Solutions for determining the target QoE of users and adjusting transport functions to achieve this QoE are rather network specific. Generally, it is much easier to be addressed in networks with quantitative QoS control such as IntServ and RSVP than networks with qualitative QoS control such as DiffServ. Addressing these two problems, though important and critical, is not the focus of this article.

In the proposed E2E QoE assurance system, each network independently and locally maximizes the QoE of its users. If all networks in the NGN implement the same QoE management functions and regard equalizing QoE of its users as the management objective, all users in the inter-connected NGN environment will be provided with the same QoE when the closed-loop system enters into the stable status. In the real implementation, the inside detailed constituents and functions of the QoE management component are decided by each network itself. Different networks may have different objective QoE measurement models. Some networks may not want to implement a QoE management component, and some networks may want to maximize the sum of QoE of its users rather than equalizing the QoE of all users. Owing to these differences, users may experience different QoE depending on the networks their sessions traverse. When the networks traversed by a session cannot provide the desired network quality for the user to achieve a good QoE, the user and source may try to adjust parameters at their sides or select other networks to traverse.

Conclusion

Owing to the time-variant, user-dependent, application-dependent, and terminal-dependent properties of QoE, E2E QoE assurance is particularly challenging in the multi-vendor, multi-provider, and multi-network environment of NGN. E2E QoE depends on the effects of the whole system, including networks, terminals, customer premises networks, and users. To assure user QoE, network operations in all vertical network layers of all network elements may need to be performed based on user real-time QoE. However, achieving this goal needs to address many challenging issues, among which QoE measurement, monitoring, diagnosis, and management are typical ones. In this article, we propose an E2E QoE assurance system that contains two major components: a QoE/QoS performance reporting component installed at TE, and the QoE management component installed at networks and sources. The QoE/QoS reporting components measure QoE and QoS performances received by users, and then report them to networks and sources. The QoE management components adjust transport functions and reconfigure application-layer parameters to maximize user QoE. Since each network independently and locally maximizes the QoE of its users, the E2E QoE assurance system can possibly be implemented in an NGN that is distributed and heterogeneous in nature. Generally, E2E QoE assurance in an NGN still needs to address many research issues, and will receive intense research attention from both academia and industry, driven by the strong desire to generate revenues and increase the competitiveness of service providers.

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