

Quality of Service in Cost Models

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Abstract: Several network operators have been deploying Quality of Service (QoS) techniques that help improve customer satisfaction and can have an impact on the cost of telecommunications services. As Long-Run Incremental Cost (LRIC) models are used in various jurisdictions to derive the cost of regulated services, a question that needs to be addressed is how QoS concepts can be included in an LRIC model. This article pursues two goals. First, it describes the main QoS techniques and strategies that could be taken into account in a cost model. Second, it discusses the impact of QoS concepts on an LRIC model. The article shows that the introduction of QoS concepts into a cost model involves a critical review of the following parameters: cost drivers, cost of network elements, traffic supported by network elements, and usage factors.

Key words: QoS, cost model, LRIC, NGN.

The deployment of high-speed fixed and mobile networks provides users with improved access to telecommunications services. Over the years, operators have been competing to provide users with platforms that offer more bandwidth, fewer - or almost no - interruptions of network operations, and less transmission delay. Given the different types of traffic that exist in Internet Protocol (IP)-based networks, and the priorities and preferences of end-users, operators have the possibility of employing Quality of Service (QoS) mechanisms. QoS techniques can also increase network performance and help use network resources more efficiently.

A few services that run over telecommunications networks are regulated and, therefore, can be subject to price regulations. For instance, several National Regulatory Agencies (NRAs) have defined wholesale charges for

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access to the fixed broadband infrastructure and wholesale termination charges for voice services. The value of these charges can be obtained with the elaboration of a cost model. Long-Run Incremental Cost (LRIC) is a cost model employed in numerous jurisdictions around the world to determine the prices of regulated services. For example, in Australia and New Zealand, LRIC has been employed for the determination of a few wholesale charges. In the European Union, the majority of NRAs use the LRIC approach for the calculation of prices for wholesale network infrastructure access (market 4), whereas around half of the NRAs use LRIC models for the determination of prices for wholesale broadband access (market 5) (BEREC, 2011a). Forward-looking LRIC models anticipate costs of network structures, and the values over the next few years are calculated by using current values and extrapolating them into the future. LRIC models calculate an additional increment, which "can be defined narrowly, as a small change in the volume of a particular service, or broadly, as the addition of a whole group of services" (European Commission, 2008).

Moreover, one of the topics mentioned in the network neutrality debate is the possibility that operators could prioritise some type of traffic (BEREC, 2011b; KNEIPS, 2011). One of the issues raised by operators is the fact that video traffic consumes an important amount of network resources and operators do not charge for the delivery of this type of traffic on their networks. A few operators are interested in using traffic management techniques and in charging according to the level of QoS assigned to the different types of traffic transported. The definition of a best-effort service with minimum QoS levels is also part of the network neutrality debate (CAVE & CROcioni, 2011). This is a topic related to the features of a service that should be provided as part of the Universal Service provision (SCHRAMM, 2009). The questions that can be posed from the cost modelling perspective are: What is the cost of a service provided with a specific level of QoS? What would be the cost of a best-effort service with minimum levels of QoS?

As network operators have been deploying QoS techniques in the networks, and as LRIC models could in various cases be used for the determination of the cost of services that utilise QoS techniques, a research topic that should be addressed is the impact of QoS concepts on LRIC models. Distinct studies available in the literature have dealt with the topic of pricing of networks with QoS (JIN & JORDAN, 2004; WANG *et al.*, 1996; YÄICHE *et al.*, 2000). Even though a number of aspects described in these articles are related to the economics of QoS, the objective of such studies is not to explain in detail how QoS concepts can be incorporated in cost models. In terms of cost definition, the implementation of QoS in IP networks

has a few implications. First, the LRIC model should be based on an efficient network with state-of-the-art QoS techniques. The definition of an efficient network with QoS for cost modelling purposes is still an open issue. NRAs and operators have decades of experience with the definition of efficient network architectures for circuit-switched telephony services. A few telecom regulators also have some experience with cost models based on packet-switched broadband networks, such as for the calculation of the bitstream service, but generally in these cases QoS is not contemplated. Second, in comparison with a network without QoS levels, a network with QoS levels might lead to different cost elements and cost drivers. Third, the traffic features of services provided with QoS should be incorporated in the cost model.

This article discusses the main challenges in the implementation of QoS in cost models. In particular, the two research questions that are addressed in the article are, 1) What are the main QoS techniques and strategies that could be taken into account when elaborating a cost model?, and 2) How can QoS concepts be implemented in LRIC models?

To address the first question, the 2nd section identifies the state-of-the-art and most frequently implemented QoS techniques in fixed broadband networks and shows where they are implemented in the different sections of a Next Generation Network (NGN). The 3rd section provides an answer to the second question by describing what could be modified in an LRIC model in order to derive the cost of services provided with QoS. Finally, the last section addresses the conclusions.

■ Quality of service techniques

QoS can be defined as a set of technical mechanisms needed for the improvement of the end-user's satisfaction level regarding a transmission over a telecommunications network. This is a user-centric perspective that has been adopted by the International Telecommunication Union (ITU) (IBARROLA *et al.*, 2011). The Internet Engineering Task Force (IETF) has a different view; it uses a network-centric approach, where QoS techniques can help achieve a transmission with better quality in comparison to a best-effort transmission quality (FIEDLER *et al.*, 2010). Delay, delay variation, and packet loss ratio are the three main factors that affect the end-user's

perception of the quality of a transmission ¹. A few studies have defined QoS requirements for a set of different traffic classes (BRENNER *et al.*, 2007; ITU-T, 2002).

The term Quality of Experience (QoE) is defined by the ITU as the "overall acceptability of an application or service, as perceived subjectively by the end-user" (ITU-T, 2008). Every end-user has a perception of the applications' performance in the network and, for this reason, the end-user has an idea of the effectiveness of the network or application he/she is working with.

Main QoS solutions

Operators can deploy QoS techniques at different levels. The QoS solutions can be classified into the following groups: Public Switched Telephone Networks (PSTN) QoS solutions, Open System Interconnection (OSI) Layer-2 solutions, IP QoS solutions, and OSI transport-layer and application-layer solutions. Table 1 contains a summary of the main solutions that are used in different types of networks. These techniques can be applied independently at each layer. This procedure has its roots in the OSI approach, which recommends that in an end-to-end communication the layer of an end node must exchange information with the same layer of the other end node. It is not the purpose of this section to discuss which technique is most efficient in terms of performance, but rather to explain which techniques are most widely used among the telecom operators.

Table 1 - Summary of QoS solutions

<i>QoS Solutions</i>	<i>Characteristics</i>
PSTN QoS solutions	Admission control, resource reservation, resource allocation in an exclusive way.
Layer-2 QoS solutions	Implemented in Ethernet, ATM, and Frame Relay networks.
IP- QoS solutions	Capacity reservation (Integrated Services), prioritisation (Differentiated Services), over-provisioning.
Transport-Layer and Application-Layer solutions	Any solution that is implemented at the transport or application layer.

Source: Based on information provided in XIAO, 2008

¹ There are also other factors that could be taken into account, such as bit error rate and bandwidth.

The PSTN QoS solution has the following features: admission control, resource reservation, and resource allocation in an exclusive way ². When a user tries to place a call, the admission control determines whether there are enough resources available in the network. If this is the case, an end-to-end circuit will be set up, which will be used exclusively by one voice communication.

Ethernet, Asynchronous Transfer Mode (ATM), and Frame Relay networks implement Layer-2 QoS solutions. Metro Ethernet or Carrier Ethernet is currently the dominant Layer-2 technology and has been substituting ATM and Frame Relay networks over the last years. The main Ethernet QoS solution is based on the IEEE 802.1p standard and consists of classifying, marking and prioritising the Ethernet frames.

The most important techniques for the implementation of QoS in IP networks are capacity reservation, prioritisation, and over-provisioning. Integrated Services (IntServ) is a capacity reservation technique that consists of reserving capacity along the end-to-end path between the sender and the receiver before a transmission takes place. Resource Reservation Protocol (RSVP) and RSVP-Traffic Engineering (TE) are two of the most important signalling protocols that belong to this category. In the Differentiated Services (DiffServ) prioritisation model, the network devices (routers, switches, etc.) prioritise packets according to the traffic class to which the packets belong. The over-provisioning model involves deploying enough capacity in order to avoid congestion in any situation ³.

With MultiProtocol Label Switching (MPLS), the labelled packets are directly switched through the routers, not needing a routing table look up or a routing decision; thus it is possible to reduce routing delays. Strictly speaking, MPLS is not a QoS technique in itself. Some operators use IP/MPLS networks because there is a common perception that MPLS improves end-to-end QoS capabilities. Mechanisms that help improve Quality of Experience can also be deployed at the transport and application layers.

² These QoS solutions are typical of a PSTN network but are also deployed in other types of networks.

³ In this article we have considered over-provisioning as a technique that helps to improve the QoS. It has to be mentioned that for network operators, usually over-provisioning and QoS methods are distinct alternatives. If a network provider keeps the network load light by over-provisioning, then the QoS control is alleviated. Alternatively, if the network load becomes heavy, then the QoS control becomes necessary. The network provider can invest thus in either more capacity (over-provisioning) or in more intelligent networks nodes that support QoS.

Soft-assurance and hard-assurance models for QoS provisioning

The type of QoS that is contracted between the end-user and the network service provider is specified in the Service Level Agreement (SLA). In general, network service providers employ two QoS business models: the soft-assurance model and the hard-assurance model (XIAO, 2008). The difference between these models lies in the QoS that can be provided during normal and abnormal network conditions, and by the level of penalty that is imposed on the network service provider in case the QoS specified in the SLA is not met.

In the soft-assurance model, the user pays a fee for the regular connectivity and an additional fee for QoS provisioning. Despite the fact that the SLA can contain information about the values of a few QoS parameters such as bandwidth and delay, there is not a strict guarantee that these values will be respected. No service quality assurance during abnormal network conditions is provided in the soft-assurance model. Furthermore, it is characterised by mild penalties that should be paid in case SLA conditions are not fulfilled.

In the hard-assurance model, it is expected that the network service provider will guarantee service quality all the time. The network should be designed so that the negative effects of abnormal network conditions are minimised, and network availability is usually guaranteed to be high. Nevertheless, catastrophic events or large-scale Denial of Service (DoS) attacks could lead to an interruption of the service provided. In these cases, the penalties stipulated in the SLA might be high. The hard-assurance model implies more technical challenges than the soft-assurance model, due to the fact that network reliability conditions are much stricter.

State-of-the-art/most used QoS mechanisms

As LRIC models are based on efficient, state-of-the-art networks available in the market, this section describes the main ideas that should be taken into account when designing an efficient network with QoS capabilities. The technical literature contains a plethora of QoS techniques that are constantly being developed by researchers. Numerous techniques have been evaluated through simulations or in labs, but they have not gone through the standardisation process or have not been implemented yet. This means that if there is an innovative or better technique that has not been implemented yet, it should not be considered in the cost model.

There is not a single answer to the question of which QoS technique to consider in a cost model due to the following reasons: a) there are different fixed access networks (fibre-based, copper-based, and cable); b) there are multiple QoS mechanisms available; c) operators have different targets/levels of QoS (soft-assurance and hard-assurance models); and d) a number of operators are upgrading their networks or are in the process of migration to NGN networks, which creates uncertainty about the network architecture that will be finally adopted. However, based on the possibilities that are being pondered by operators, it is possible to outline the type of QoS techniques that could be used in the definition of an efficient network architecture with QoS.

Table 2 summarises the main QoS techniques deployed in different sections of the network. An NGN network consists of the following sections: core network, aggregation network, and the subscribers' access network. Fixed networks are considered in this article. The core network is based on IP, whereas the aggregation network usually works with Metro Ethernet. The techniques shown in Table 2 are by no means all the techniques that are considered by operators when designing the network architecture ⁴. Nevertheless, all these QoS mechanisms are used by many operators and can be incorporated in the design of an efficient network architecture for cost modelling purposes.

Table 2 - Main QoS techniques used in different sections of a Next Generation Network

<i>QoS technique</i>	<i>Access network</i>	<i>Aggregation network</i>	<i>Core network</i>
DiffServ	A few operators use it	A few operators use it	It can be used
Ethernet IEEE 802.1p	A few operators use it	A few operators use it	It can be used
Over-provisioning	It can be used if there is enough capacity ^(*)	Frequently used	Frequently used
Admission Control ^(**)	Frequently used	It can be used	It can be used

^(*) For instance, if a copper-based x Digital Subscriber Line (xDSL) access network with limited capacity is used, it would be difficult to provide over-provisioning. Conversely, if a fibre-based access network is used, then over-provisioning would be feasible.

^(**) A Resource and Admission Control Subsystem (RACS) can be used to prevent the entrance of traffic that can cause the rest of the traffic performance degradation. If there are no resources to support the QoS demand of a user, then the access will be denied.

⁴ For example, the Transmission Control Protocol (TCP) congestion avoidance technique plays an important role in reducing congestion in IP-based networks.

Operators can simultaneously use several types of mechanisms that improve QoS: DiffServ, over-provisioning, admission control, etc. ARAVANTINOS & PAPAGIANNOPOULOS (2008) argue that in Fibre to the Home (FTTH) access networks, DiffServ in combination with MPLS could be used to improve the Quality of Service.

Strategies for the implementation of QoS techniques

Regarding the strategies followed by operators for the implementation of the above-mentioned QoS techniques, usually operators follow one of the two following approaches:

- Over-provisioning and admission control;
- Over-provisioning, admission control and additional QoS techniques.

The majority of operators employ option number 1. They prefer to use over-provisioning in the aggregation and core networks together with admission control in the access network ⁵. Operators constantly monitor the usage of the links and they can predict where more capacity will be needed. For example, if the traffic load reaches 60% of the link capacity, additional links are deployed or the capacity of the link is upgraded (e.g. from 1Gbps to 10Gbps). In the access network, admission control mechanisms are used to limit the transmission capacity of every user.

An alternative consists of using over-provisioning, admission control and additional QoS techniques, such as capacity reservation and prioritisation. A few operators follow this approach to manage the traffic generated by corporate users. However, the use of additional QoS techniques usually implies a complex management of the network, which leads, among other issues, to the necessity of dispensing more intelligent network elements and employing qualified personnel with the corresponding increase in Operational Expenditures (OPEX). Operators have, therefore, to choose between the relative simplicity of deploying over-provisioning and admission control - with the corresponding investment in extra-capacity - and the complexity of managing additional QoS techniques.

⁵ ROBERTS (2004) points out that the use of only over-provisioning might have some disadvantages. It would be more convenient to use it together with a QoS technique based on admission control, such as flow-aware networking (OUESLATI & ROBERTS, 2005).

■ QoS in LRIC models

The objective of this section is to discuss how QoS concepts can be incorporated into LRIC cost models.

Main components of an LRIC model

The approach taken for the analysis consists of identifying the main components of an LRIC model and how they could change when working with different QoS classes. To identify the possible modifications, the basic formula used to determine the cost of a service will be explained first, and then which changes could be taken into account when calculating the cost of a service with QoS will be explained. For the determination of the cost of a service in an IP-based network, the following formula is employed:

$$\text{Cost_per_Kbps}_{\text{Service}_i} = \sum_{\text{NetworkElements}_j} \text{Unit_costs}_{\text{NetworkElement}_j} * \text{UF}_{\text{NetworkElement}_j}^{\text{Service}_i} \quad [1]$$

where UF is the usage factor that defines how much of the network element is being used by a specific service. In this formula the cost driver is the Kilobit per second (Kbps). The Unit Cost corresponds to the annual cost of a network element divided by the annual traffic supported by the network element. It is calculated with the following formula:

$$\text{Annual Unit Cost of a Network Element}_i = \frac{\text{Annual_Cost_of_network_element}_i}{\text{Annual_traffic_on_network_element}_i} \quad [2]$$

After inspecting both equations, it can be deduced that the following parameters that appear in the equations might be subject to changes:

- *Cost drivers*: for IP-based applications, the main cost drivers are the transmission rate, which is measured in Kbps, and the volume of data transmitted, which is measured in Kbytes. It should be determined whether applications provided with QoS could have a different cost driver.
- *Cost of network elements*: due to a possible difference in the design of the network architecture, network elements of applications provided with QoS might not be the same as the network elements of a network without QoS capabilities.

- *Traffic carried by IP networks:* The nature of the traffic of applications provided with QoS might be different from the traffic of applications transmitted with a best-effort service.

- *Usage factor of a network element that provides a service with QoS:* The utilisation of a network element that provides a service with QoS could probably lead to a different frequency of utilisation of the nodes and links, which will be reflected in a change of the value of the usage factor.

Each one of these factors is explained in more detail in the next section.

Particularities of a cost model for services with QoS

Cost drivers

Multiple cost drivers can be used for cost modelling purposes. The following cost drivers are examples of cost drivers that have been used in the telecommunications business:

- number of calls,
- number of lines,
- call duration,
- transmission distance,
- transmission throughput,
- data volume.

Number of calls, number of lines, call duration and transmission distance are typically used as cost drivers in circuit-switched networks, whereas transmission throughput and data volume are used in packet-switched networks. The discussion about which cost driver to use for applications with QoS requires a definition of a cost driver.

"A cost driver is a variable, such as the level of activity or volume, that causally affects costs [...]. That is, there is a cause-and-effect relationship between a change in the level of activity or volume and a change in the level of total costs" (HORNGREN *et al.*, 2006).

In the telecommunications arena, the definition of the cost driver is related to the type of traffic that is transmitted. In circuit-switched networks, for example, the voice traffic transmitted is measured in minutes, whereas an Erlang is a statistical measure of the offered traffic load. On the contrary, IP networks carry IP packets that can transport any type of information: voice, video, data, etc. In best-effort IP networks, network designers

estimate the amount of traffic that will be carried out in the network. The unit used for the calculation of the traffic is the average capacity consumption of the network in the peak hour, which can be Kbps, Mbps, or Gbps, and that depends on the volume of traffic to be transmitted. Therefore, it makes sense to consider the capacity of the network as the main cost driver. The capacity defines the maximum volume of traffic (or the maximum amount of packets) that can be transported at a time through the network. When designing the necessary resources that need to be allocated to Voice over IP (VoIP) or IP Television (IPTV) users, operators assign a specific bandwidth to each session⁶. For example, for IPTV services, operators usually allocate 4 Mbps for a Single Definition (SD) and 8 Mbps for a High Definition (HD) end-to-end video transmission.

A cost driver that is usually not taken into account in IP-based networks is the distance of the transmission. In IP-based networks the distance between the subscriber and the remote server or user is not the metric unit used for the calculation of costs.

Next, the cost driver of a service when the three IP-level QoS mechanisms (over-provisioning, prioritisation, and capacity reservation) are used will be analysed. For the design of a network with over-provisioning, network designers will have to take into account the additional transmission capacity. If the capacity of a link is not large enough to meet customers' demand for traffic, then it will be necessary to deploy more links. For fibres that are already deployed, additional wavelengths (colours) could be used, which will enlarge the transmission capacity. Therefore, the cost driver of the additional increment will be measured in capacity. For network nodes, such as routers and switches, it might be necessary to utilise more routers, switches, and Network Interface Cards (NICs), which improve the overall capacity. Capacity is then the cost driver to consider when using over-provisioning in the nodes and links.

With regard to prioritisation techniques, the capacity of the network remains the same and the traffic routed with the prioritisation techniques will consume a certain transmission capacity of the network. Therefore, capacity is a cost driver. However, when using prioritisation, what changes is the way the resources are allocated. Prioritisation techniques may use more of the routers and switches' processors computing power. Therefore, processing

⁶ A description of the impact of VoIP network architectures on cost models appears in RENDON SCHNEIR & PLÜCKEBAUM (2010).

power in the routers and switches is a complementary cost driver to be considered. In the links, the only cost driver is the transmission capacity.

Regarding capacity reservation, the transmission capacity is one of the cost drivers. The transmission capacity reserved is employed exclusively by the user during the transmission of information. Moreover, due to the signalling traffic additional processing power is needed to provide capacity reservation in the routers or switches.

Therefore, what can be concluded is that the applications' main cost driver is the capacity that can be supported by network elements (the transmission bandwidth). Processing power is another cost driver that could be considered in the nodes. Table 3 summarises the cost drivers used according to the QoS technique deployed.

Table 3 - Cost drivers for different IP-level QoS techniques

<i>QoS Technique</i>	<i>Over-provisioning</i>	<i>Prioritisation</i>	<i>Capacity Reservation</i>
Links	Transmission capacity	Transmission capacity	Transmission capacity
Nodes	Transmission capacity	Transmission capacity Processing power	Transmission capacity Processing power

Cost of network elements

The network elements are pieces of hardware and software that belong to a network architecture. For cost modelling tasks it should be identified if there are additional elements that need to be installed in the network architecture to provide QoS. For example, with over-provisioning more capacity is needed and, as a consequence, more links and routers/switches are needed. This can have an important impact on the cost. Integrated Services might need more network elements to control the communications. On the contrary, with DiffServ there might not be a significant additional investment in equipment, because several manufacturers include the DiffServ functionality as part of the software/hardware that is delivered with the router; this functionality permits reading the Type of Service (ToS) field in the IP header and forwarding the packet accordingly. However, a cost that should be taken into account when using the DiffServ functionality is the cost of programming the routers. Running this software consumes additional processor power and thus causes costs even if there is no additional cost of software. A relevant cost for QoS techniques, such as capacity reservation, might be the OPEX related to the equipment maintenance.

Traffic supported by a network element

This section describes how the value of the traffic generated by services provided with QoS can be included in a cost model. An important input to a cost model is the annual traffic. The following formula defines the annual traffic that may be carried out by a network element:

$$\text{Annual Traffic} = \left(\frac{\text{Busy Hour Traffic}}{\text{Percentage Busy Hour Day}} \right) * \text{Number of Days} \quad [3]$$

This formula is used to convert the Busy Hour Traffic into annual traffic. It extrapolates the Busy Hour Traffic to the traffic the network element could carry, assuming the same (peak) amount of traffic will be produced throughout the (relevant days of a) year. The Busy Hour Traffic defines the amount of traffic that is supported by a network element in the hour with maximum total traffic load in a day. The percentage of the busy hour in a day represents the share of daily traffic carried out during the busy hour. Thus, the quotient describes the maximum amount of traffic the network element could carry per day. The number of days is not 365, but rather the number of typical business days in one year.

The values of traffic can be obtained by utilising statistical analysis based on queuing theory and/or by installing network analysers that measure the traffic consumption⁷. The implementation of QoS mechanisms in the network will probably generate different traffic patterns and traffic volumes in comparison to a network without QoS.

Usage factor of a service with QoS

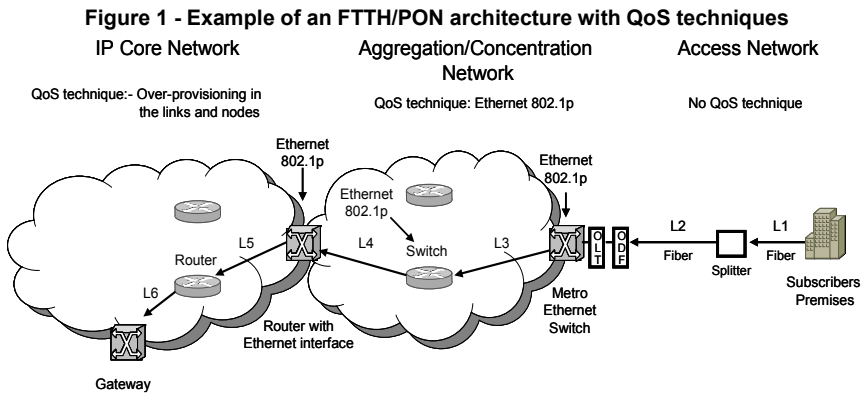
While the traffic value is related to the intensity of use of a specific network element, the usage factor, which is also called the routing factor, represents the frequency of use, i.e. the number of times a given element is used by a specific service (UMet *et al.*, 2004; ZABALLOS & MONEDERO, 2009). The usage factors are included in the routing matrix.

⁷ For example, a study for the German telecommunications regulator uses queuing theory to derive the traffic consumption for different QoS levels (HACKBARTH *et al.*, 2011). GARCIA *et al.* (2010) obtain the traffic consumption and the unit cost of a network element in an NGN network when using different IP-level QoS techniques by performing simulations based on queuing theory.

The question that arises at this point is whether the usage factor of a network element can change when QoS is provided. We believe that the answer is positive, because the frequency of use of a network element can change according to the number of resources required by every class of service. There could be different classes of services, such as Gold, Silver, and best-effort services (Bronze), and each class of service could use the network elements with a different frequency. For example, if a Gold Service must provide a reliable transmission that should be available 100% of the time, then redundant nodes and links could be allocated. The routing path taken by the traffic of an application provided with QoS could be different from the routing path taken by an application that is not provided with QoS. Therefore, the value of the usage factor of the nodes and links will be different. The following Section provides an example that explains how a routing matrix with usage factors is constructed.

In an NGN network, the capacity of the links and nodes will be shared by several applications such as VoIP, video, and web browsing. Distinct authors have studied cost sharing and cost allocation techniques when there are shared resources (CASIER *et al.*, 2006; CLARK, 1995; FRIEDMAN & MOULIN, 1999). For LRIC modelling purposes, cost allocation is implemented by determining the frequency of use of a network element by a specific service (the usage factor) and the corresponding traffic supported by the network element.

Example of a routing matrix for an FTTH/Passive Optical Network (PON) architecture with QoS techniques



This section describes an example that illustrates how a routing matrix is filled out with usage factors derived by using QoS. Figure 1 above shows an NGN network based on an FTTH/PON architecture that contains network elements with two QoS levels. This case corresponds to an on-off-net transmission. The links employed are L1, L2, L3, L4, L5, and L6, whereas the nodes are the splitter, the Optical Distribution Frame (ODF), the Optical Line Terminal (OLT), the Metro Ethernet switch, the switch in the aggregation network, the router with the Ethernet interface, the router in the core network, and the gateway. The Optical Network Terminal (ONT) in the subscriber's premises has not been considered. The example shows a simplified case where only the above-mentioned links and nodes are used. Generally the IP traffic has several routing options, which involves the use of more links and nodes. In this example, over-provisioning is used in the core network, whereas Ethernet 802.1p is used in the aggregation/concentration network. The access network does not have any type of QoS technique.

The routing matrix of this network is shown in Table 4 (following page). The first column describes the most relevant network elements of the example: the links L1, L2, L3, L4, L5, and L6 and the nodes of the access, aggregation, and core networks. The columns titled QoS level 1 and QoS level 2 contain the usage factors of network elements that belong to these QoS levels. The usage factor indicates how frequently a network element is used during a transmission. The cost driver used in this example is capacity. The cost driver of the ODF and the splitter is the amount of customers served, and in this case they are not affected by the deployment of QoS techniques.

Challenges in the implementation of QoS in cost models

When defining the input values of a cost model (of a service provided in fixed or mobile networks), there tend to be discrepancies between the different operators and regulators in a number of items. Among other issues, typical matters of discussion are the definition of the Weighted Average Cost of Capital (WACC), the traffic forecast and the cost of network elements. With the implementation of QoS techniques in the networks these controversies might continue, but new discussion points will probably be added. Table 5, below, summarises the main topics that will most likely be affected by the introduction of QoS in a cost model.

Table 4 - Example of a routing matrix

Network elements	Prioritisation (IEEE802.1p) in the aggregation network		Over-provisioning in the core network	
	QoS level 1	QoS level 2	QoS level 1	QoS level 2
L1 in the access network	-	-	-	-
L2 in the access network	-	-	-	-
L3 in the aggregation network	C3 ¹	C3 ²	-	-
L4 in the aggregation network	C4 ¹	C4 ²	-	-
L5 in the core network	-	-	C5 ¹	C5 ²
L6 in the core network	-	-	C6 ¹	C6 ²
Splitter	-	-	-	-
ODF	-	-	-	-
OLT	C9 ¹	C9 ²		
Metro Ethernet Switch	C10 ¹	C10 ²	-	-
Switch in the aggregation network	C11 ¹	C11 ²	-	-
Router with Ethernet interface	C12 ¹	C12 ²	C12a ¹	C12a ²
Router in the core network		-	C13 ¹	C13 ²
Gateway	-	-	C14 ¹	C14 ²

Table 5 - Summary of main challenges for the implementation of QoS in cost models

<i>Item</i>	<i>Description</i>
QoS classes	Which QoS classes are in effect being provided in the network? Does a best-effort service have minimum levels of QoS?
Network architecture with QoS classes	Which is the most efficient network architecture with different levels of QoS? Which strategy is being used for the implementation of QoS in the network?
Cost drivers	Are capacity and processing power the cost drivers that should be utilised or should another one be taken into account?
Cost of network elements	The cost of hardware and software elements should be determined. A matter of controversy might be the maintenance cost (OPEX) of equipment needed for the complex implementation of a few QoS techniques (e.g. capacity reservation).
Traffic	There are three main possibilities to derive the value of traffic: to use a network analyser to obtain empirical values, to use statistical analysis based on queuing theory, or to possibly employ a combination of both techniques.
Usage factor	Statistical analysis and/or measurements taken by traffic analysers can be used.

■ **Conclusions**

The article has described which QoS techniques can be taken into consideration when creating a cost model of a network that provides users with different QoS levels, and how the utilisation of Quality of Service techniques can be included in an LRIC model. To improve the consumer's Quality of Experience there are a variety of QoS techniques that can be used at different levels of the OSI layer model. With regard to the cost modelling of services provided with QoS, the following parameters of the formulae of the LRIC model might change: the cost drivers, the network elements and their cost, the traffic generated by QoS applications, and the usage or routing factor of network elements that provide QoS.

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