The Design of a Quality of Experience Model for Providing High Quality Multimedia Services

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Abstract. In the last decade, networks have evolved from simple data packet forwarding to platforms that support complex multimedia services, such as network-based personal video recording and broadcast TV. Each of these services has significant quality demands: they are very sensitive to packet loss and jitter, and require a substantial amount of bandwidth. As the quality perceived by the end user gives the most accurate view on the streamed service quality, operators are increasing their focus on this type of metric, commonly described as Quality of Experience. This paper presents the design of a Quality of Experience information model that defines important metrics for measuring service quality. Based on these metrics, we define a novel control loop that represents the relationships among Quality of Experience, the Customer, and network services.

Keywords: Quality of Experience, Multimedia Service, Information Modeling.

1 Introduction

The Internet is now supporting advanced multimedia services such as Internet Protocol Television (IPTV), Video on Demand (VoD), and Voice over IP (VoIP). In addition, network convergence encourages network architecture designs that support different types of network services in a single network. However, such services require high bandwidth and strict service performance due to transferring real-time video and voice data. Furthermore, the concept of Quality of Experience (QoE), which represents a subjective measure of a customer's experiences for services, is attracting more formalized and growing attention [1].

In this paper, we propose a QoE model for managing the quality of multimedia services perceived by customers. This model defines appropriate QoE metrics and their relationship with performance indicators and consumers, and is based on the DEN-ng information model [2]. We also present a control loop to optimize the quality of services based on the measured QoE among networks, end-users and service providers.

The remainder of this paper is organized as follows. Section 2 describes performance indicators for QoE, the DEN-ng information model and previous work on QoE modeling as related work. Section 3 presents our proposed QoE model with a control loop. Finally, conclusions are drawn and future work is discussed in Section 4.

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2 Related Work

In this section, we review performance indicators for QoE, and then explore previous work on QoE modeling. Finally, we briefly introduce the DEN-ng model to set the stage for explaining our extensions to it.

2.1 Performance Indicators

The ITU-T proposed objective and subjective QoE definitions [3]. The former defines Quality of Service (QoS) delivered to the user in terms of measurable service, network, and application performance metrics, while the latter models the quality as perceived by a human in terms of emotions, service billing, and experience. The DSL Forum classified video quality metrics into three layers: service layer, application layer, and transport layer [4]. They suggested guidelines to achieve satisfactory QoE for various services. ATIS classified IPTV QoS into application and network QoS [5]. The application QoS is divided into three quality layers: transaction quality, content quality, and media stream quality. The network QoS contains the transmission quality layer. They also represented the relationships between quality layers, QoS parameters, and QoE indicators. Each layer's quality is represented by QoS parameters, and can be defined as a set of QoE indicators. The Telecommunication Management Forum (TMForum) proposed Key Performance Indicators (KPIs) and Key Quality Indicators (KQIs) for managing service quality [6]. KPIs are quantifiable measurements that reflect the critical successful or unsuccessful factors of a particular resource or service. KQIs provide an indicator for a specific performance aspect of the product or product components (e.g., service or service elements), and draw their data from a number of sources including KPIs. In [7], Korea Telecom (KT) defined relationships between KQIs, KPIs, and Customer Quality Indicators (CQIs). CQIs are quality indicators that are experienced and perceived by customers. A CQI includes metrics for service billing and customer support as well as delivered services such as IPTV or VoIP. KT defined KQIs as the QoS parameters that make up a CQI and KPIs as the metrics that make up a KQI. KQIs are mapped to a CQI and can be computed from several KPIs.

We designed our model to be compatible with the above definitions. The value of our model is that it can serve as a unifying metaphor for combining these different efforts as well as a foundation for defining new functionality. We have focused on the subjective QoE part of the ITU-T QoE definition, but the human factors such as emotions are excluded from our model at this time; this is part of our future work. We use ATIS quality layers to model different kinds of QoE traffic. To model the metrics of QoE, we use enhanced versions of the KQI and the KPI concepts of the TMForum, and enhance the CQI concept of KT. Based on the CQI concept of KT, we propose a Consumer Role Quality Indicator (CRQI) that is related to ConsumerRole in DEN-ng. This builds on the concepts of KT's CQI, but applies them to different consumer, user, and administrator *roles*.

2.2 QoE Modeling

In [8], an autonomic management architecture was proposed to optimize the QoE in multimedia access networks. Their main design goals are to provide a scalable generic design that can support autonomic behavior. In their architecture, a Monitor Plane monitors the network and builds up knowledge about a network, a Knowledge Plane analyzes the knowledge and determines the ideal QoE actions, and an Action Plane enforces these actions in the network. The proposed architecture was validated by simulation. In [9], the authors presented a Web Ontology Language (OWL)/Semantic Web Rule Language (SWRL) based knowledge base that can be used in an autonomous QoE management architecture for the access network. In their architecture, some SWRL rules can detect QoE drops. In addition, the ontology can be used to enable autonomic behaviors, where the right configuration of QoE optimizing actions is computed using SWRL rules. In [10], the authors presented an algorithm that predicts the QoE of progressive download services in real-time. The algorithm only depends on the flow of TCP data and acknowledgement packets. They do not require additional feedback from the client. To our best knowledge, none of the previous QoE models considered a control loop that includes the combination of a consumer, a service provider, and measured QoE data. Through our proposed control loop, we can detect Service Level Agreement (SLA) violations and change network configurations to provide contracted QoE.

2.3 DEN-ng Information Modeling

The DEN-ng [2] is an object-oriented information model that describes different entities of interest in the managed environment. We use it to build a technology-neutral information model (i.e., a model that is independent of technology, platform, and protocol) describing important concepts and mechanisms to represent, measure, and manage QoE. The existing QoE model in DEN-ng will be described in Section 3. The DEN-ng model uses software patterns [11] to more efficiently describe complex architectures and make the model more understandable and extensible. A pattern defines a generic, reusable solution to a commonly occurring problem. When we design a model, we can improve our model's readability by defining software patterns and repeatedly using them in solving similar problems. Two common patterns are the composite pattern [11] and the role-object pattern [12]. The composite pattern is used to define bundles, groupings, and other hierarchical and network-oriented structures that represent part-whole hierarchies. The role-object pattern enables a component object to be adapted to different needs through transparently attached role objects. This pattern is especially useful in separating the intrinsic and contextual characteristics and behavior of an entity. A person is thus modeled as an object that can have multiple roles attached; each role defines different responsibilities and functions of that person. This avoids the trap of altering the definition of a person due to changing responsibilities. The role-object pattern is also useful for other types of entities, and is used extensively in the DEN-ng model.

The policy pattern [2] is an example of a novel DEN-ng pattern. It provides policy-based management governance. In this pattern, policy rules are used to determine the characteristics and behavior of an association using an association class. The association class represents the semantics of a relationship as a class, which enables the relationship to have a set of associated attributes, relationships, and other model elements as required. The attributes (and possibly additional relationships) of the association class are then modified by the policy rules. In DEN-ng, this enables changing context to select new applicable policy rules, which then change the attributes and/or relationships of the selected association accordingly.

3 Proposed QoE Model

This section examines the QoE model in the current DEN-ng model and identifies changes required to better manage the QoE of managed, contracted services.

3.1 The Original DEN-ng QoE Model

Fig. 1 shows the QoE model in DEN-ng. The ResourceFacingService class represents services that are required to support a service that is provided to a customer, but is not visible by that customer. The programming of a QoSService is represented in DEN-ng as a set of NetworkForwardingServices. For example, during the forwarding process, packets can be queued or dropped.

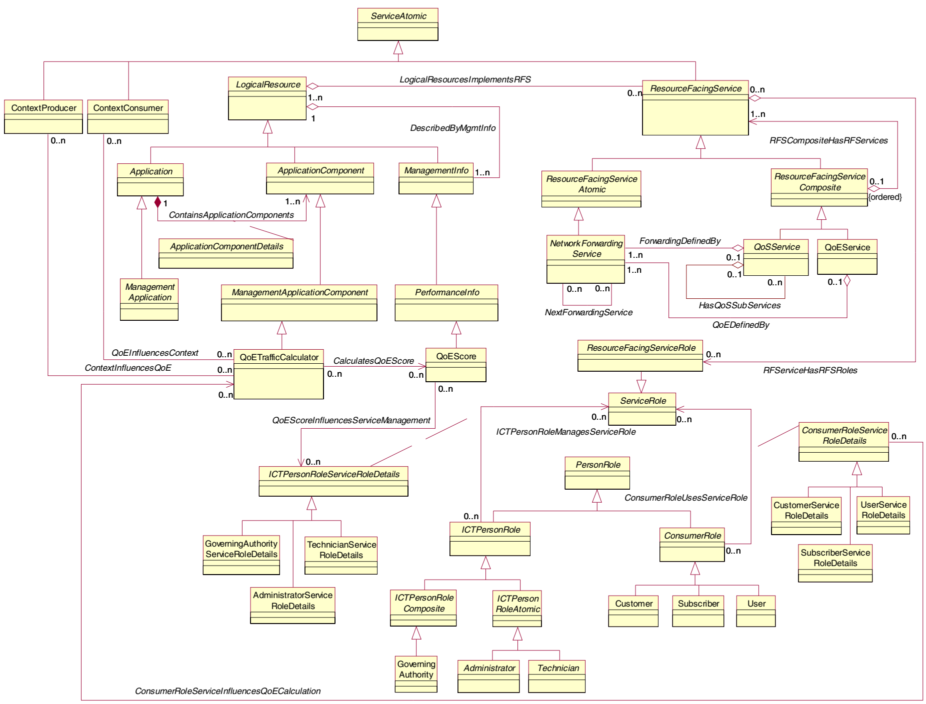

Fig. 1. DEN-ng QoE Model

QoE related classes. The DEN-ng model has three main classes for representing QoE concepts: QoEService, QoEScore, and QoETrafficCalculator. The QoEService class is defined as a type of ResourceFacingServiceComposite, because it can use one or more ResourceFacingServices to define and measure the quality of the traffic as experienced by the end user. QoEService is a generic specification for defining the different types of sub-Services that are required to implement a specific type of QoS used to provide the contracted QoE. This enables business rules to be mapped to the network, and define services that the network provides. The QoETrafficCalculator calculates the QoEScore, which defines the value of the QoE for a particular type of traffic in a given Context. The QoEScore class represents the calculation of the QoE for a particular type of traffic in a given Context. The QoETrafficCalculation class models the calculation of QoE for a particular type of traffic. The overall context in which this traffic exists, as defined by the ContextInfluencesQoE association, can affect the types of calculations performed.

The first problem with the QoETrafficCalculation class is that it has no subclass. As we mentioned in Section 2, the QoE can be divided into several types of QoEs, each of which represents the perceived quality about a specific aspect of the service. So, the QoETrafficCalculation class should have subclasses for calculating the QoE for each service aspect. The second problem is that there is no metric for defining or measuring the QoE. In the DEN-ng model, there is a class that represents the performance information of a service, PerformanceInfo. The PerformanceInfo has two classes for representing the quality of the network services: the KQI and the KPI. To indicate the QoE, a new class for representing the perceived quality is needed. In addition to that, the KQI and KPI classes should be refined to represent a more detailed and clear meaning.

Overall relationship between the QoE related classes. DEN-ng models the QoE related classes and the relationships between them. We can calculate the QoEScore using QoETrafficCalculator as a function of the context of the traffic service and the consumer related information. The calculated QoEScore influences the management of consumer services; this is modeled by relating the ICTPersonRole that represents the role of a person who manages the traffic service with the QoEScore. In the current DEN-ng model, there is no explicit relationship between a QoE model and an SLA. This prevents the checking of SLA violations and defining appropriate changes to manage services to provide better QoE based on the measured QoE. Thus, relationships between the existing QoE model and classes for measuring the QoE are needed. The QoETrafficCalculator can use those relationships and classes.

3.2 QoE Control Loop Model

This section describes a control loop for managing services based on the measured QoE. We explain it using a concrete example of the QoE service, a cache service.

QoE Control Loop. To provide a satisfactory QoE, a control loop that manages services based on the measured QoE is required. The QoE is a function of both the quality perceived by a consumer as well as the specific network performance provided by a service provider. Therefore, the control loop should include a network, a consumer, and a service provider, as shown in Fig. 2.

Fig. 3 shows how the control loop in Fig. 2 is designed in the DEN-ng model. The QoETrafficCalculator and the QoEServiceFeedback comprise the QoEControl part. The QoETrafficCalculator calculates the QoEScore, which represents the calculated QoE; the QoEServiceFeedback monitors the SLA (which is a subclass of ContractualAgreement) and makes changes to the NetworkForwardingServices as required in order to ensure that the SLA is not violated. The ContractualAgreement represents the SLA part. The ContractualAgreement represents agreements that have contractual

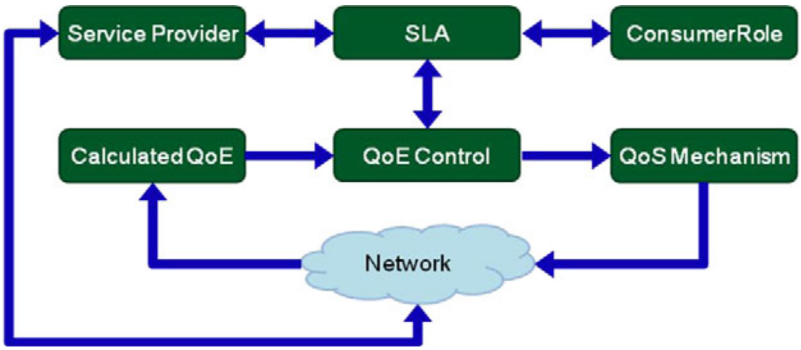

Fig. 2. QoE Control Loop - High-Level View

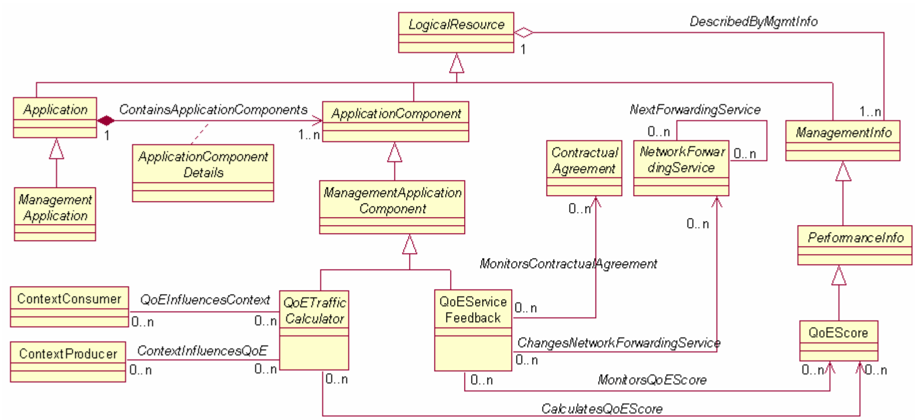

Fig. 3. QoE Control Loop - Model View

obligations, along with optional compliance and violation conditions. The ICTPersonRole (in Fig. 1) represents the different people or groups of people that manage network devices, while the ConsumerRole part represents three different types of people (Customers, Subscribers, and Users) that have different relationships with Service Providers (specifically, they represent the roles of buying/receiving, ordering and/or subscribing to, and using products and services, respectively). Note that both ICTPersonRole and ConsumerRole are subclasses of PersonRole. In contrast, the ServiceProvider portion of Fig. 2 is a subclass of OrganizationRole (shown in Fig. 4); both PersonRole and OrganizationRole are subclasses of PersonOrOrgRole, which is a type of Role. Hence, roles are used to describe how providers and users of services are related to an SLA.

The QoEServiceFeedback class triggers one or more changes to network device configurations according to management policy when any SLA violation is detected. The QoEServiceFeedback compares the measured QoEScore with appropriate parameters of the ContractualAgreement and changes the network service parameters to ensure compliance with the ContractualAgreement. A combination of QoE and QoS mechanisms are used for this change. The NetworkForwardingService, which has QoEService and QoSService as two of its subclasses, implements this. By using the QoE control loop, we can provide better service quality based on the measured QoE. More importantly, as the QoE changes, our QoE control loop can respond to these changes and adjust the QoS mechanisms used to ensure that the delivered QoE meets the user's expectations. Our QoE control loop, which includes the combination of a consumer, a service provider, and measured QoE data, has never been proposed in previous work on QoE modeling.

The parameters used by the QoETrafficCalculator depend on the type of the QoE. Therefore, the QoETrafficCalculator is divided into different subclasses, each targeted to a specific aspect of QoE (e.g., the transaction QoE). Also, the measurement location, the measurement method, and the calculation of the QoE are dependent on the type of the QoE.

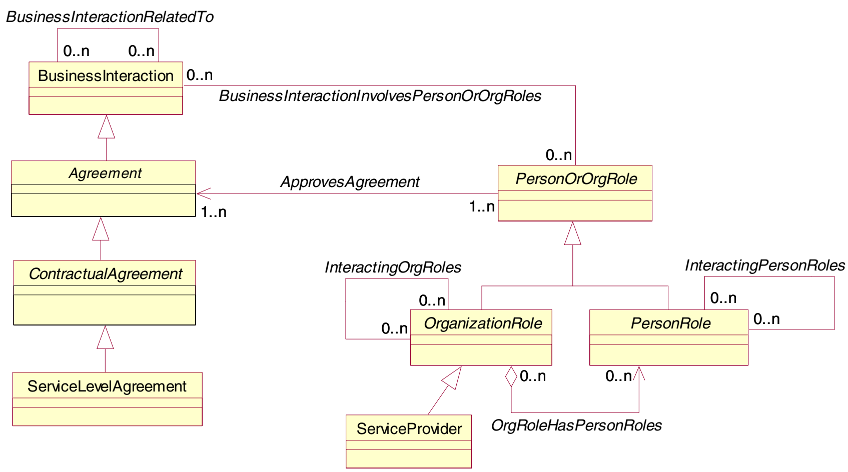

Fig. 4. OrganizationRole, PersonRole, and Agreements

We made four subclasses of the QoETrafficCalculator class based on the ATIS quality metrics: TransactionQualityCalculator, ContentQualityCalculator, MediaStreamQualityCalculator, and TransmissionQualityCalculator; these are shown in Fig. 5. The TransactionQualityCalculator and the ContentQualityCalculator calculate the QoE for customer premise equipment. The TransactionQualityCalculator calculates the quality of operations involving customer premise equipment, such as channel change delay. The ContentQualityCalculator calculates the user's satisfaction with the video and/or audio content received at the customer premise equipment. The content quality can be measured in terms of Mean Opinion Score (MOS) [13]. The MediaStreamQualityCalculator and the TransmissionQualityCalculator calculate the QoE on the physical routers in the network infrastructure. The MediaStreamQualityCalculator calculates the quality of the media stream delivered by the network. The TransmissionQualityCalculator calculates the quality of the traffic sent and received.

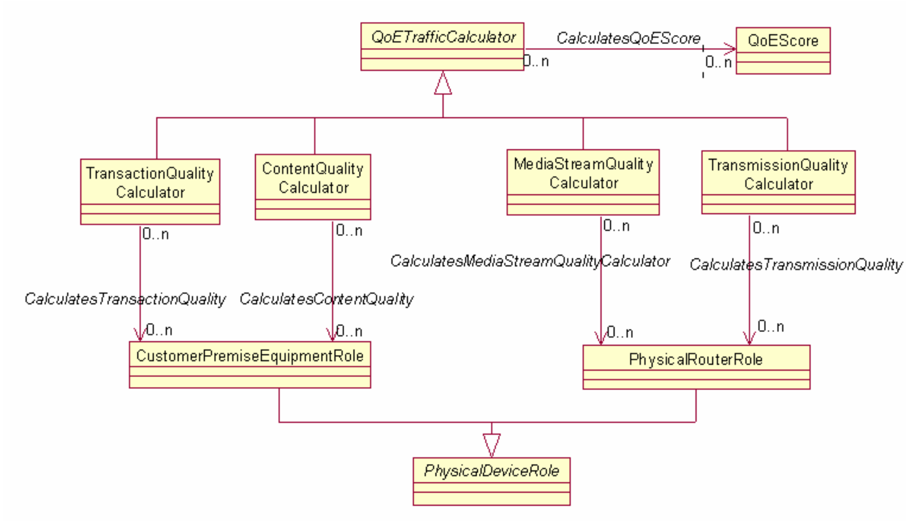

Fig. 5. QoE Traffic Calculator

Network Service for QoE. The DEN-ng model includes three kinds of traffic services to provide QoE: QoETrafficAddingService, QoETrafficModifyingService, and QoETrafficStoreAndForwardService. The QoETrafficAddingService introduces additional traffic into an existing session (e.g., Forward Error Correction (FEC) encoding). The QoETrafficModifyingService modifies the actual payload of packets (e.g., content transcoding). The QoETrafficStoreAndForwardService influences future traffic delivery based on information about the current session (e.g., caching mechanism). We model the cache service, as an example of a QoETrafficStoreAndForwardService. The cache service provides a better quality service to the user by keeping some of the data in local storage. We define a model for managing the QoE based on Cisco's Video Quality of Experience (VQE) solution [14].

The QoETrafficStoreAndForwardService is composed of three parts: the QoE traffic service component (shown in Fig. 6), the customer premises equipment component (which can be any type of device, such as a router or a modem; due to this flexibility, this component is modeled as one or more *roles*, as shown in Fig. 7), and the QoE policy management component (shown in Fig. 8).

Fig. 6 defines the high-level structure of a cache service. A cache can have a hierarchy, so we use the composite pattern to model it. The CacheServiceAtomic is divided into two classes: ContentMonitoringService and ContentDistributionService. The former provides data to the TransmissionQualityCalculator, which calculates the transmission quality using the monitoring results. The latter includes error repair and content delivery. The CDErrorRepairService specifies the cache service related error handling service. The ContentDeliveryService specifies the content delivery service between a content server and cache servers.

The customer premises equipment component deals with the measurement and the management of the QoE on the customer side. A simplified model of customer premise equipment is shown in Fig. 7; note that many classes have been elided for

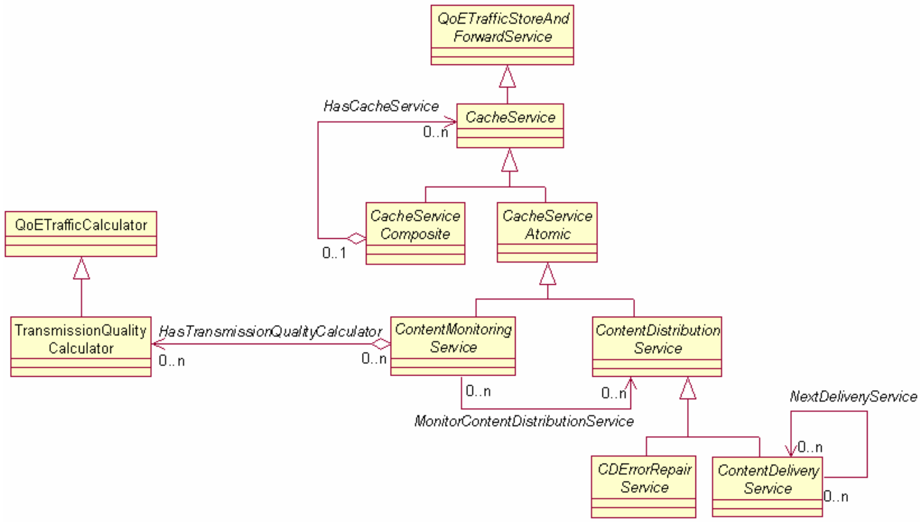

Fig. 6. QoE Traffic Service Component

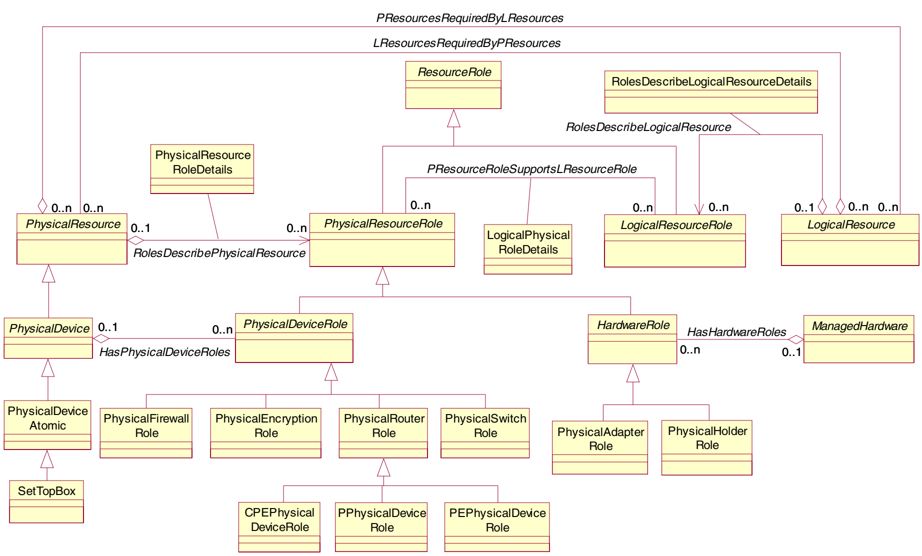

Fig. 7. The Use of Roles in Modeling CustomerPremiseEquipment

simplicity. Since a set-top box (STB) is a subclass of PhysicalDevice, it inherits the RolesDescribePhysicalResource aggregation, enabling it to take on as many roles (physical or logical) as required to model its functionality (note that LogicalResource roles have been elided for simplicity). In the case of the IPTV service, the STB is the customer premises equipment. The STB provides the interface between the customer

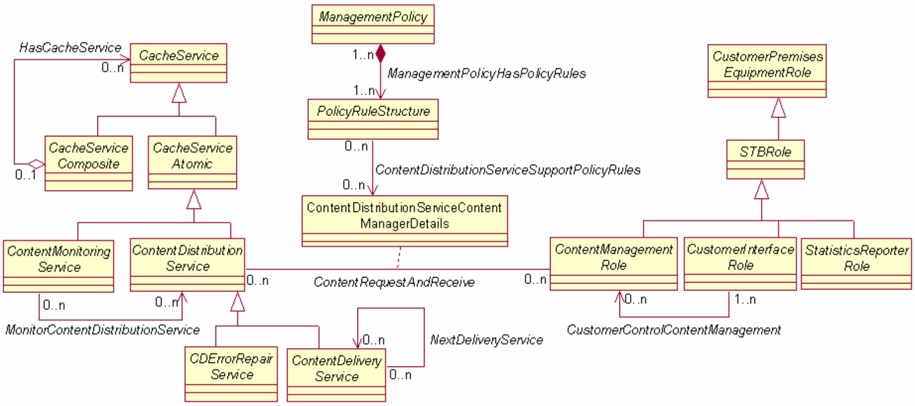

Fig. 8. QoE Management Policy Component

and the service provider. To manage the QoE on the STB, statistics about the service must be collected so that the media QoE and the transaction QoE can be calculated.

The QoE management policy component deals with the policy rules that are used to manage the quality of the service delivered to the consumer. The ContentRequestAndReceive relationship models the QoS of the content received at the STB. This relationship is dependent on both of the ContentDistributionService and the ContentManagementRole, so it is modeled as an association class whose attributes can be set by one or more policy rules (i.e., using the Policy Pattern). This represents an extensible method for managing different content based on context and role.

3.3 QoE Measurement

In this section, we introduce the QoE measurement method, and model QoE metrics using KPI, KQI, and CRQI.

Measurement methods and metrics. The DSL Forum defines three video QoE measurement methods [4]:

- *"Subjectively*, using a controlled viewing experiment and participants who grade the quality using rating scales such as MOS"
- *"Objectively*, at the service layer – using electronic test equipment to measure various aspects of the overall quality of the video signal (e.g. Peak Signal to Noise Ratio (PSNR))"
- *"Indirectly*, using measurements of network impairments (loss, delay, jitter, duration of the defect) to estimate the impact on video quality, where there is an established relationship between QoE and QoS."

The first method requires many participants using the same equipment to watch the same content. It is unrealistic, because each customer uses different kinds of equipment in different contexts. The second method needs additional equipment for measurement. Thus, the third method is the most realistic; we modeled QoE metrics based on the third method.

KPIs, KQIs, and CRQIs. In DEN-ng, KQIs and KPIs are modeled as subclasses of ManagementInfo, which is used to represent different types of management information for a ManagedEntity that is obtained in a managed environment. PerformanceInfo is a subclass of ManagementInfo, and represents various performance and other operational characteristics of ManagedEntities, Each subclass of the PerformanceInfo class defines the detailed characteristics and behaviors of a specific type of performance information. This is shown in Fig. 9.

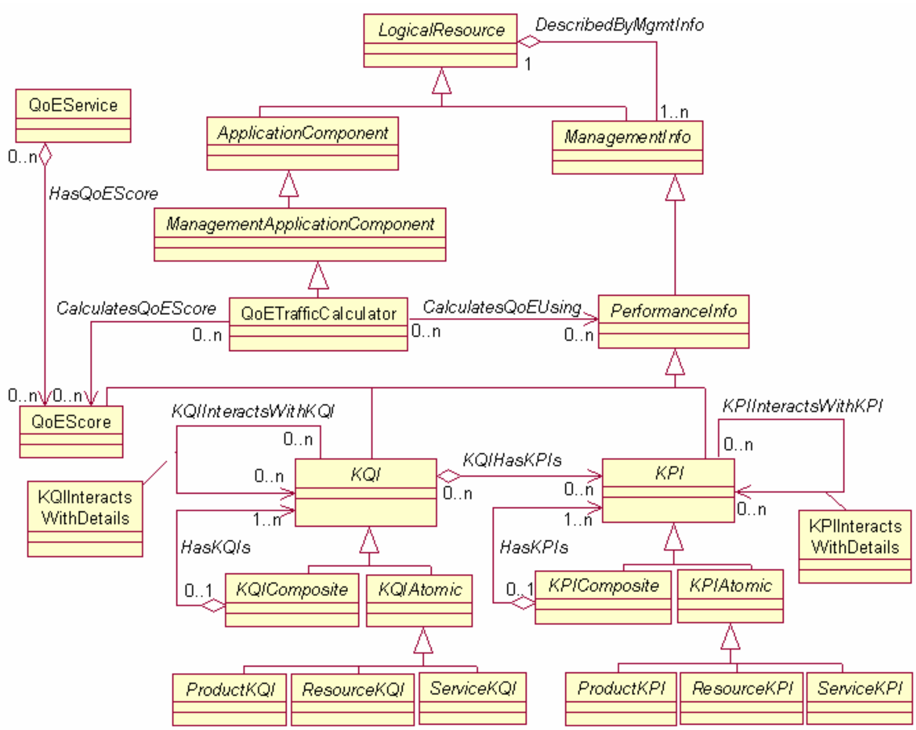

Fig. 9. Relationships among KQI, KPI, and QoEScore

We modeled KQIs and KPIs using the composite pattern. A KQIAtomic represents a KQI that can be used as a stand-alone metric, while a KQIComposite represents a measurement or a set of measurements that are made up of multiple elements (either KQIComposites and/or KQIAtomics) that are each individually manageable. The KQIAtomic is classified into three types of KQIs: ProductKQI, ServiceKQI, and ResourceKQI; KPI has similar subclasses. A KQI can contain one or more KPI(s). The relationships among KQI, KPI, and QoEScore are shown in Fig. 9.

In DEN-ng, the role-object pattern is used to model people and organizations that have different functionality. A ConsumerRole includes various types of end-user roles: Customer, Subscriber, and User. To model the relationship between the perceived quality and ConsumerRole, we define the Consumer Role Quality Indicator (CRQI) concept, which is shown in Fig. 10. The CRQI is similar to the CQI in [7];

however, the CRQI is related to ConsumerRole, and hence can model different relationships in addition to those with a customer. Since different customers have different QoE expectations, a CRQI is defined as an association class, enabling it to define different characteristics for a *pair* of ConsumerRoles and QoE data.

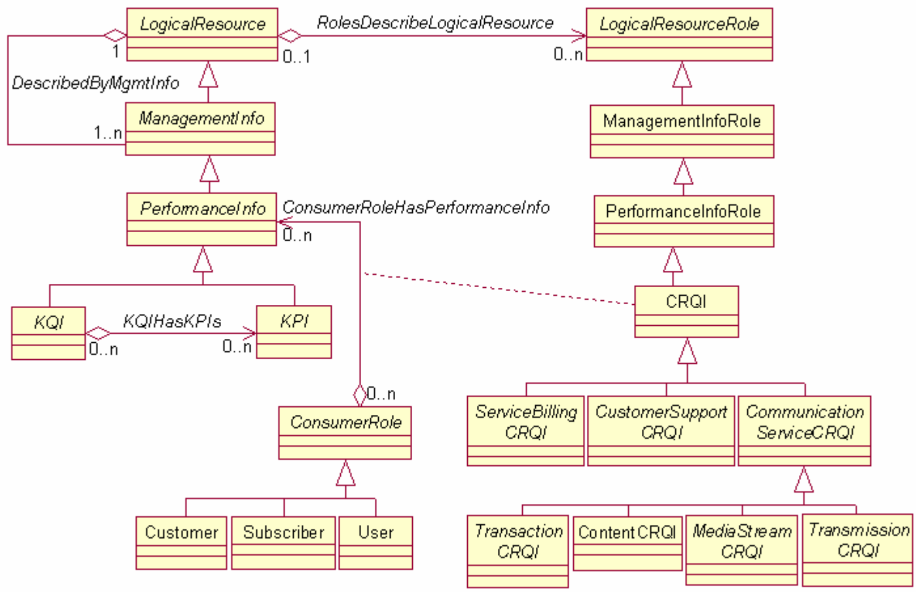

Fig. 10. Relationships among PerformanceInfo, ConsumerRole, and CRQI

A CRQI provides a measurement of a specific aspect of the quality of a product, service, or resource as perceived by a particular ConsumerRole. CRQIs can be described by a set of KQIs. Since a CRQI is defined as an association class, we can easily apply the policy pattern to it in order to explicitly represent the relationship between specific types of ConsumerRoles and PerformanceInfo. We have defined three types of CRQIs: ServiceBillingCRQI, CustomerSupportCRQI, and CommunicationServiceCRQI, which describe the perceived quality of service billing, customer support, and communication services, respectively. Note that a CRQI includes service billing and customer support aspects because they are a part of the service experience, even though they are not related to network performance. The CommunicationCRQI is based on ATIS QoE metric classification. The QoETrafficCalculator calculates a QoEScore by using these CRQIs.

4 Concluding Remarks

In this paper, we proposed a QoE model based on DEN-ng model. In our model, we proposed a QoE control loop among networks, end-users and service providers for managing services based on the measured QoE. As an example of the QoE service, we presented a design of a cache service. To model the metrics of the QoE, we extended the DEN-ng model. We proposed the CRQI that represents indicators for perceived quality. As future work, we will extend our QoE model with mapping to Management Information Bases (MIB). And then, we will develop an autonomic SLA management system using ontologies built from our QoE model. The SLA management system's goal is detecting SLA changes by relating MIB data to SLA data. We will also extend our model to incorporate human factors components to better represent the objective features of QoE.

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