Toward Total Quality of Experience: A QoE Model in a Communication Ecosystem

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Abstract

In recent years, the quality of experience notion has become a major research theme within the telecommunications community. QoE is an assessment of the human experience when interacting with technology and business entities in a particular context. A communication ecosystem encompasses various domains such as technical aspects, business models, human behavior, and context. For each aspect of a communication ecosystem, various models have been developed. However, few models have been designed to integrate all aspects of a communication ecosystem to understand human behavioral needs in a detailed and structured way. While existing models have produced the basic sketch of QoE modeling, more concepts and interdomain mapping are to be incorporated in order to have a clear picture of QoE in communication ecosystems. The aim of the current work is to build on the existing research being conducted in disparate disciplines about human behavior in order to provide a high-level model that can be adapted to many specific contexts and to encourage future research which examines these cross-domain relationships.

Introduction

Along with rapid technological advances, there has been a proliferation of new and innovative systems, services, applications, and end-user devices. Network management concepts are also evolving, and autonomic network management paradigms aspire to bring human-like intelligence to telecommunication management tasks. Thanks to these technical advancements, the fulfillment of customer demands and user experience requirements are becoming the main differentiators for the effectiveness of telecom operators and service providers. In this era of competition, poor customer experience leads to a chain reaction of negative word of mouth, pushing customers into the arms of waiting competitors. Today, humans are quality meters, and their expectations, perceptions, and needs with respect to a particular product, service, and application carry greater value.

Quality of experience (QoE) is a fast emerging multidisciplinary field based on social psychology, cognitive science, economics, and engineering science, focused on understanding overall human quality requirements. QoE is the blueprint of all human quality needs and expectations. Traditionally, technology-centric approaches based on quality of service (QoS) parameters have been employed to ensure service quality to end users. QoE expands this horizon to capture people's aesthetic and even hedonic needs. The International Telecommunication Union Telecommunication Standardization Sector (ITU-T) defines QoE as "The overall acceptability of an application or service, as perceived subjectively by the end-user"[1]. Unlike ITU-T's definition, which only links QoE with subjective human perception, we consider objective human factors as equally important aspects of QoE. We define QoE as a blueprint of all human subjective and objective quality needs and experiences arising from the interaction of a person with technology and with business entities in a particular context.

For understanding user and/or customer requirements, it is pertinent to know the communication ecosystem where various actors interact to produce the service life cycle. The term *ecosystem* has been used in various fields. In ecology, it is defined as "a system involving the interaction between a community of living organisms in a particular area and its non living environment" [2]. A cultural ecosystem is defined as "a collection of living things and the environment in which they live" in [2]; similarly, we define a communication ecosystem as "the systematic interaction of living (human) and non living (technology, and busi-

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ness) in a particular context." A conceptual diagram of a communication ecosystem is presented (Fig. 1).

A communication ecosystem incorporates different disciplines such as technology, business, context, and human behavior. Human-to-technology interaction in a communication ecosystem develops the user experience model to understand user requirements with respect to technology. Various technological aspects such as service features, end-user device functionalities, and QoS parameters influence the feelings, perception, and performance of a user.

Human-to-business interaction in a communication ecosystem develops the customer experience model to understand customer requirements with respect to business aspects. Customer care, cost, promotion, and brand image may influence customers to develop positive and/or negative feelings about a service.

In a communication ecosystem, business-to-technology interactions represent service providers' strategies and business models for their technological infrastructure, and how effectively they can utilize their resources to increase their profit by retaining customers as well as attracting new ones.

Context represents the various situations and circumstances within communication ecosystems. Context is an important influencing factor because it is possible that a person's feelings and perceptions may also change with a change in his/her context. Context-aware systems monitor user context to provide personalized and improved QoS to end users.

In a communication ecosystem, different domains interact with each other and may also have different approaches. For instance, technical people try to provide a better user experience by ensuring network and service performance based on QoS models. Business people develop economic models and strategies to assess profit, cost, and customer loyalty. Psychologists and social scientists analyze human attitude, intentions, and cognition to understand human behavior in a particular context. While these domains of a communication ecosystem may have different vocabularies, semantics, and models, they have a similar goal to provide a rich QoE. To get a holistic and unified view of human needs and behavioral requirements, these different approaches in business, technology, psychology, and cognitive science should be integrated into one framework. The QoE notion is thus a converging approach that combines the influences of all these aspects to produce QoE requirements.

Background: Survey of Key QoE Models

To fully understand the human experience, a QoE framework must integrate different perspectives from business, technology, context, psychology, and cognitive science to capture human aesthetic and hedonic needs. Table 1 breaks down the prior attempts to provide integrated QoE conceptual frameworks.

Yan Gong *et al.* [3] developed a QoE model with quantifiable metrics for QoE-based evaluation of service usage. They defined five QoE factors (usability, availability, service instantaneousness, service integrity, service retainability); however, they only focus on the relationship between QoS and QoE, considering neither the contextual nor the business domain. In addition, they do not differentiate QoE requirements based on various human roles and characteristics.

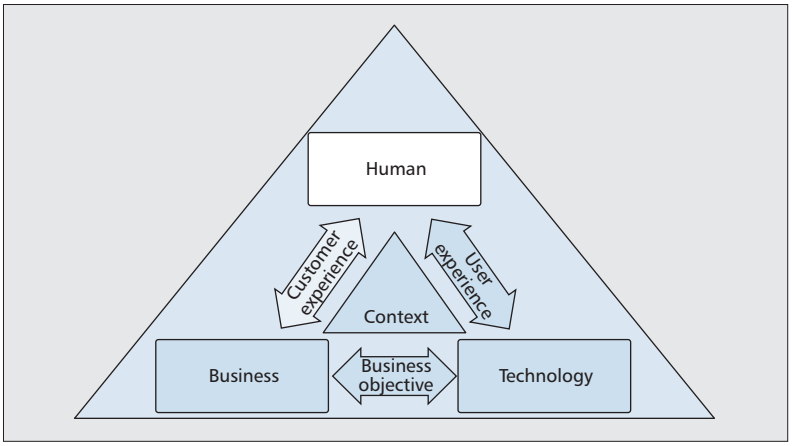

Figure 1. *Communication ecosystem.*

Andrew Perkis *et al.* [4] present a QoE model for measuring user experience of multimedia services. Their model produced very interesting categorization of QoE, QoS, and business aspects based on measurable and non-measurable parameters. They consider technical parameters as measurable and subjective user parameters such as satisfaction and attitude as non-measurable. However, in our view, subjective human factors can also be quantified using some empirical approaches.

Möller *et al.* [5] present a more detailed taxonomy of the QoS and QoE of multimodal human-machine interactions. They divide the QoS taxonomy into influencing factors and interaction performance parameters, define subjective and objective human attributes associated with QoE, and consider environmental and service factors as contextual aspects. Since their model targets multimodal human-machine aspects, their focus is limited to specific contextual aspects and does not include business aspects. Their taxonomy defines user attributes and user roles, but they do not consider multiple roles (e.g., customer or group).

Kilkki's model [6] presents a simple and intuitive interaction between a person, technology, and business. However, it provides neither a classification of QoE factors into subcategories nor any details on the taxonomy. More important, Kilkki's model does not define contextual parameters in any way.

The ITU-T's G.1080 proposes a QoE model that classifies QoE factors into two parts: subjective human components and objective QoS parameters [7]. This model classifies the technical QoS parameters as part of the human objective QoE factor; whereas we believe that QoS could influence human behavior like any other business factor (pricing), but it is not an inherent

Model	Human Domain			Technological Domain	Contextual Domain	Business Domain
	Human Roles and Human Demographic Attributes	Subjective QoE Factor	Objective QoE Factor			
Yan Gong *et al.*	No	Limited	Limited	Yes	No	No
Andrew Perkis *et al.*	No	Yes	No	Yes	No	Yes
Sebastian Moller *et al.*	No roles	Yes	Yes	Yes	Limited	No
ITU-T G.1080	Unclear	Yes	No	Yes	Limited	No
Kilkki' Model	Yes	No Taxonomy Available	No Taxonomy Available	Yes	No	Yes
David Geerts *et al.*	Limited (user role only)	Yes	Yes	Yes	Yes	Yes
Khalil Laghari *et al.*	Yes	Yes	Yes	Yes	Yes	Yes

Table 1. *Comparison of QoE models.*

part of the human domain. QoE is set of human-centric factors, not technology-centric parameters. Therefore, we are of the view that QoS is out of the human domain and is an external influencing factor. Alternatively, like the work in [8], we also consider human physical and psychophysical factors (e.g., human reaction time, human audio-visual system, and human mental processing capabilities) that are absent in the ITU-T's model to be objective QoE factors.

David Geerts *et al.* [9] present a QoE model that includes business, technology, and contextual aspects. They have extended [5] by including the most recent insights from HCI research, where, for example, user expectations change over time, and different layers of context play an important role. However, they primarily focus on modeling user experience from an HCI perspective; they do not define any other roles such as a customer or part of a group. We believe the differentiation of roles is quite helpful in segmenting QoE requirements as per different human roles. For instance, a customer who pays for online video on demand (VoD) service may have stricter video quality requirements than a user who uses free VoD service. Furthermore, a father who buys a video gaming service for his child plays the role of a customer, while his child is the actual user of the service. It is quite possible that they both would have different QoE requirements.

In [10] we have already presented an initial conception of a QoE framework with a special focus on human behavior, technology, and business. We demonstrated its application through a use case based on service delivery of composed services. The initial QoE conceptualization needed further enhancement and improvement of more concepts, taxonomy, and interdomain mapping.

Building on these prior works in QoE modeling, we propose an extended version of these models by integrating the technology, business, context, and human domains. Furthermore, we define new characteristics in each domain and present the QoE taxonomy.

Proposing Quality of Experience Model

Human behavior is shaped by internal and external factors. Internal aspects include biological, psychological, and cognitive factors, while external aspects are related to social, economic, and technical factors. In psychology, drive theory discusses how a person's internal (physiological and mental) state affects a person's behavior, while incentive theory discusses how an external stimulus (e.g., the environment) affects a person's behavior [11]. Thus, it is necessary to capture both internal and external aspects for a more complete understanding of human behavior. In our proposed QoE-based communication ecosystem (Fig. 2), human internal factors are part of the human domain, and external influencing factors are divided into technological, business, and contextual domains.

In a communication ecosystem, there is a kind of control loop of interactions between various domains that develops consolidated QoE requirements. A domain represents a set of knowledge, activity, or influence in our model; we have defined four domains: Human, Context, Technology, and Business. The major interdomain interactions are:

- Human ↔ Context
- Human ↔ Technology
- Human ↔ Business
- Technology ↔ Business
- Context ↔ Techno-Business

Within each domain, there are three levels of abstraction: entity, roles, and attributes/characteristics. An entity is a real-world concept or item that exists on its own. In our model, there are four entities: human entity, contextual entity, business entity, and technological entity. Each entity could have multiple roles; for example, a human entity could perform the role of a user or customer; similarly, a business entity could be a service provider or device manufacturer. Each entity has some attributes, For instance, human

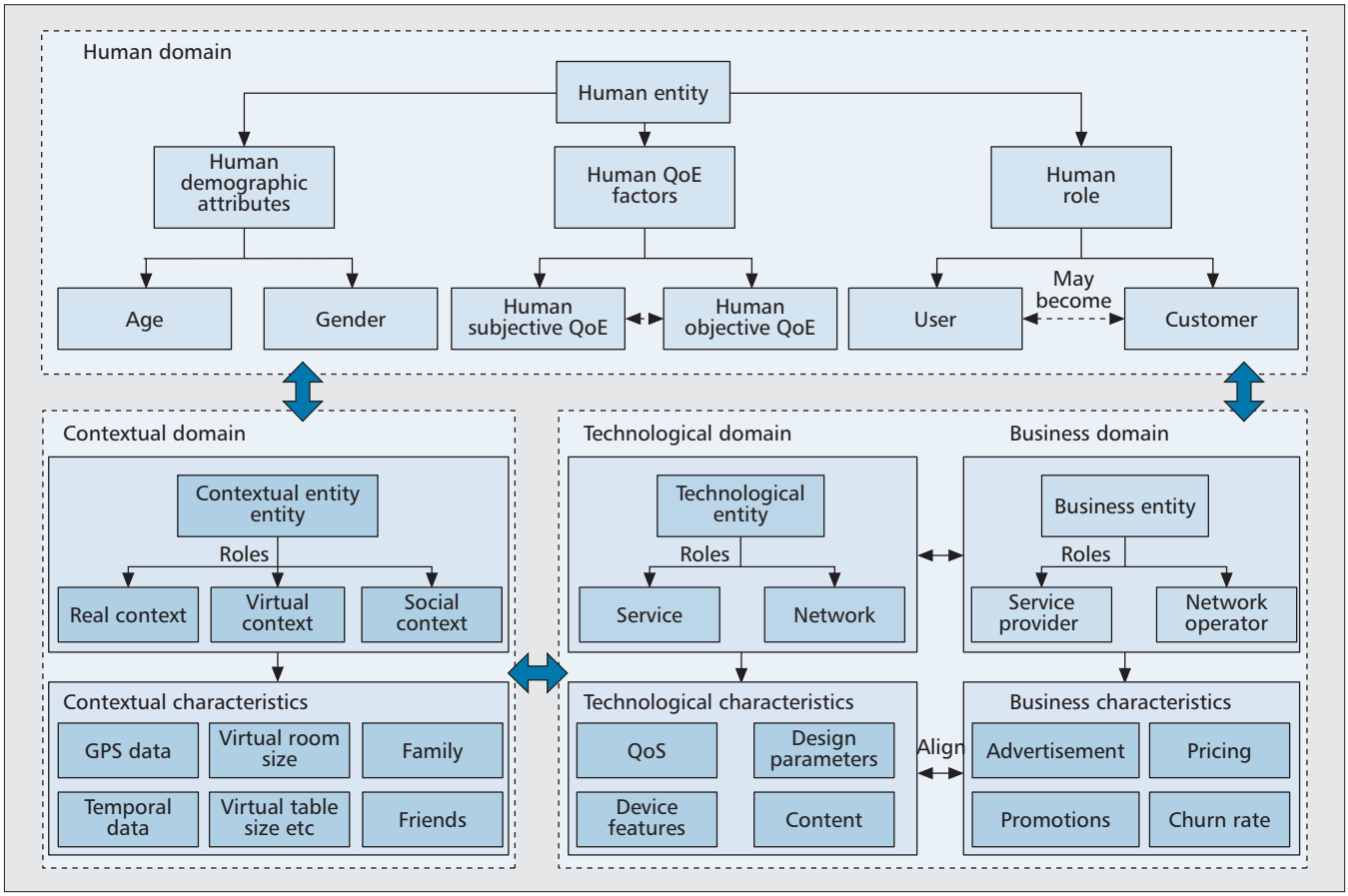

Figure 2. *High level diagram for QoE interaction model in communication ecosystem.*

factors include subjective and objective QoE factors, whereas technological characteristics include QoS and end-user device parameters. A holistic QoE model is thus a conceptual representation of inter- and intradomain relationships in a communication ecosystem. Now we briefly define different concepts related to the QoE interaction model.

Human Domain and Human Entity

The human domain represents a human entity, which in turn has various demographic attributes (e.g., age, gender), plays different roles (e.g., customer or user), and, when interacting with technology, has a variety of experiences (i.e., QoE factors). The human domain interacts with other domains, and this interaction with other domains in the communication ecosystem forms QoE requirements.

Human QoE Factors — QoE factors are the heart of the human domain, and they represent the overall assessment of human needs, feelings, performance, and intentions. QoE factors are classified as subjective and objective factors based on psychological and physiological factors as described below.

Subjective QoE Factors — These factors represent both quantitative and qualitative aspects of human needs and requirements; they reflect human perceptions, intentions and needs. Primarily, subjective human factors are based on human psychological aspects. The use of psychological models such as the Technology Acceptance Model (TAM), Theory of Planned Behavior (TPB), and Demodified Theory of Planned Behavior (DTPB) could be of great value to understand human intentions and behavior [10]. The selection of suitable psychological methodologies depends on the nature of the service and environment. In Table 2, examples of subjective QoE factors and evaluation methods are presented.

Objective QoE Factors — These are objective factors associated with human physiological, psycho-physical, and cognitive capabilities.

In our proposed model, the dotted line between subjective and objective human factors suggests that they could possibly be inferred from each other through some mechanism (e.g., a change in human biological and cognitive parameters could also influence human subjective perceptions and feelings or vice versa). For total QoE, both subjective and objective factors are inevitable. In Table 2, examples of objective QoE factors and evaluation methods are presented.

Human Role and Demographic Attributes — Human QoE requirements could be moderated into different groups based on demographic attributes (e.g., age and gender). Roles can be classified into three main types: user, customer, and group. A customer is one who subscribes to

	Evaluation Methods	Example Factors
Subjective	Survey and user studies are popular means for quantifying subjective QoE factors. Through user studies, user perceptions are translated into numerical and interpretable values. Afterward, some statistical techniques (Pearson correlation, multiple linear regressions, ANOVA, or Structured Equation Modeling) or data mining (Rough Set Theory) are used for data analysis.	Psychological: Ease of use, joy of use, usefulness, perceived quality, satisfaction, annoyance, and boredom.
Objective	For objective QoE factors, there are special physiological tools (e.g., Galvanic Skin Response (GSR) and Body sensors) used for capturing human biological parameters. While for cognitive data, human performance models (e.g. GOMS [12]) could be used to gather objective QoE data. Normally, objective QoE factors are quantitive in nature; they could easily be mapped with influencing factors using some statistical method.	Physiological: Brain waves, heart rate, blood volume pressure, respiration, and skin conductivity.
		Cognitive: Memory, attention, human activity, human task performance, language and human reaction time.

Table 2. *QoE factors and their evaluation process.*

a service and is the legal owner of that service; however, s/he may or may not be the primary user of the service. The user is the person who actually uses the service. The dotted line between the user and customer boxes shows the possibility of interchanging roles of the two. A person can also be part of a larger group that defines the QoE, such as in social networking sites. Based on the three main roles of a human entity, we define three subcategories of QoE.

Customer experience: Customer experience is a complete assessment of customer needs and desires. It is based on general customer attributes, his/her intentional and cognitive characteristics, and the task s/he intends to perform in certain environments. Customer experience is heavily influenced by the business models of service providers. Business domain characteristics like pricing, promotion, advertisement, customer care, and brand image are influencing factors for a customer. Customer experience is also related to any pre-service needs and to a customer's interaction with customer sales personnel or interface.

User experience: How a user feels, performs, and perceives the quality during service usage is termed the user experience. User experience is influenced by service features, functionalities, and the QoS parameters in a particular context.

Group experience: A group is a collection of entities that share certain characteristics, interact with one another, or have established certain relations between each other. Group experience represents a shared experience between entities in a group. Multiparty conferencing, social web, or multiparty online gaming are a few examples of services that involve groups of people who interact with each other during the use of a service, and this combined experience is called a group experience.

This sort of differentiation of human roles and attributes helps to segment people as per their specific QoE.

Technological Domain

The technological domain represents a blueprint of all technological aspects of the service life cycle from service design to delivery. All aspects that are designed, deployed, and delivered during a service/product life cycle are considered technological entities. The roles of technologies include services, network resources, and end-user devices, while their associated technical parameters (e.g., QoS) and specifications (e.g., features and functions) are termed technological characteristics.

A technological entity has influence on multimedia service delivery at access, content, and transmission points. This is imperative for multimedia providers to understand the impact of technological characteristics over QoE so that they can ensure superior quality of experience during service delivery. However, another challenge is that a multimedia service chain is dependent on different business entities (e.g., content provider, network operator, and service provider) for service delivery. In such a distributed management environment, it becomes rather challenging to ensure end-to-end service delivery based on QoE requirements.

The technological domain is the most studied of the domains in the context of QoE [3,7], so we do not further elaborate here.

Business Domain

The business domain represents a holistic view of business aspects, linked to a particular service offering. The business domain directly affects the final intention of purchasing a service and the price at which a service provider can offer the service [13]. Today, effective management of the customer experience is one of the single most important differentiators in this highly competitive market. From the multimedia service provider's point of view, it is very important to know how business characteristics such as advertisement, pricing, and billing aspects should be designed to satisfy customer needs.

Business Entity — The business entity possesses technical entities (e.g., network infrastructure), and it may have different roles such as service provider, network operator, marketplace provider, content provider, and device manufacturer. Customers establish interactions with business entities to subscribe to services that fulfill their needs. The interaction between customer and provider can be direct or indirect

(i.e., online), but in both cases, this interaction experience can develop positive and/or negative feelings.

Business Characteristics — The business entity has properties (e.g., a business model and strategy) that define the direction of its business. In broader terms, a multimedia service business value chain consists of customer model characteristics, and intra- and interenterprise business characteristics. Customer-centric characteristics include advertising, pricing, promotion, customer care, and brand image. Intrabusiness characteristics include a multimedia provider's goals, business strategies (sales, marketing), available resources, and their utilization. Inter-enterprise characteristics are vital characteristics for multimedia providers because today the multimedia service delivery value chain is not within the monopoly of one provider, but is shared between different business entities (e.g., content provider, service provider, and network operator). Interenterprise business characteristics are related to legal, financial and service level agreement (SLA) aspects to fix the responsibilities between different stakeholders.

For providing superior QoE to customers, there must be an alignment of these three broad business characteristics with customer QoE requirements. Furthermore, it is also essential to bring the technological and business characteristics closer in order to create an integrated technical and business solution (thus, the box around these two domains in Fig. 2 to show their tight coupling).

Contextual Domain

In a communication ecosystem, context represents the circumstances, situations, and environment at the time of interaction between human, technology, and business entities. Contextual aspects influence the human perceptual experiences, resulting in a significant impact on the overall QoE.

Contextual Entity — The contextual entity is a representation of the situational and various other circumstances within a communication ecosystem. It is broadly classified into three categories: real, virtual, and social.

Real context: The real situation of interaction between the various domains of a communication ecosystem. Examples include temporal, spatial, and climatic context.

Virtual context: An image of the real environment that tries to bring a natural feeling to a virtual world. A virtual environment may be utilized to bring innovation to how people communicate, play online games, participate in remote classrooms, or any other possible application of virtual reality.

Social context: The social aspects of context. Usually, interpersonal relations are social associations, connections, or affiliations between two or more people. For instance, social relations can contain information about friends, enemies, neighbors, coworkers, and relatives.

Contextual Characteristics — Each contextual entity may have some specific characteristics and parametric specifications, for example, GPS data for location, the echoes and reverberations of teleconferencing rooms, and the size of a virtual teleconferencing room. Changes in contextual aspects have the tendency to influence human behavior. A person participating in a teleconference call who is sitting in a quiet room has different QoE requirements than a person conducting a call while standing in a railway station.

Multimedia service providers can gather real contextual information using context-aware tools, while virtual environment is generated by multimedia services. For instance, 3D telephony generates a virtual acoustic environment for teleconferencing that means it is already within the control of a multimedia service provider. Thus, it is possible for multimedia service providers to provide contextualized QoE by taking care of user contextual information. However, it raises some privacy and security issues that also need to be considered.

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Mapping

Interdomain Mapping

Social science models attempt to establish causal relationships between prediction and outcome variables [14, 15]. Similarly, we can divide all factors into three main categories:

- Prediction factors
- Outcome factors
- Moderation factors (Fig. 3)

Prediction factors are also called independent or influencing factors, and they are used to explain or predict changes in outcome factors. In a communication ecosystem, we have three broad sets of predication factors that could affect QoE such as technological characteristics, business characteristics, and contextual characteristics. Outcome factors, also called dependent factors or QoE factors, are based on human subjective and objective factors. QoE is a set of outcome factors in a communication ecosystem that are driven by influencing factors. Another category is moderation factors; they represent a set of factors that affect the direction and/or strength of the relationship between prediction factors and outcome factors. Examples of moderation factors are human demographic attributes (e.g., age, gender, and income), human roles (e.g., customer, user), and context (e.g., location). Context is a tricky domain as it could be a prediction factor (e.g., perceived social pressure influences a person to perform the behavior or not [14]) or a moderation factor (e.g.,, user data can also be categorized per user location).

A causal process is a "cause-effect" relationship, where prediction factors directly influence outcome factors. For example, degradation in QoS metrics for VoD service could cause annoyance to a user (degradation in QoE). It means there is a direct causal relationship between degradation in QoS and human reaction.

A mediation process is an intervening process, and it refers to the situation where another factor has indirect effect over the direct causal relationship between prediction and outcome variables. User annoyance is not solely

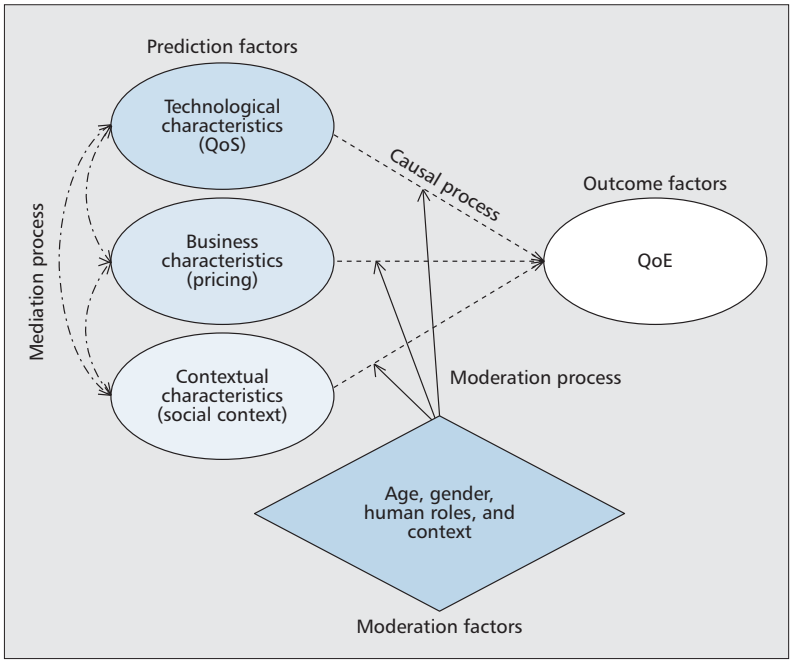

Figure 3. *Inter-domain interaction.*

caused by decline in QoS of a VoD service. For example, when QoS declines, a user may or may not be annoyed depending on the business characteristics (i.e., if they pay for a service or not).

Thus, it is recognized in our model that there may be a relationship or some association between business, technology, and contextual aspects that indirectly influences human behavior. If there is no mediation between domains, a one-on-one direct relationship is established; for example, as given in [4], a QoE-QoS relationship is established.

Moderation is a process that could alter the strength of a causal relationship. Human attributes (age, gender) and human roles (customer or user) are considered moderating factors that could alter the strength of a causal relationship. For example, people belonging to different age groups may have different levels of tolerance toward QoS degradation. Or a customer who buys a VoD service has a different QoE requirement than a user who is using a free VoD service. Thus, a moderation process segments or individualizes a global QoE factor into subcategories based on age, gender, user or customer roles, and so on. Unlike mediation, there is no need for prediction factors and moderation factors to be correlated, and that correlation has no special interpretation. However, if prediction factors and moderation factors are too highly correlated, there can be estimation problems [15]. For more detail about moderating and mediating variables, refer to [15].

The causal relationship between the prediction factors and QoE factors is a permanent link, while mediation and moderation processes are optional and are instantiated if more accuracy and an in-depth view of QoE is required. Equation 1 presents a simplified relationship between domain characteristics.

Total QoE (Moderation factors) = Direct effect (Prediction factors) + Indirect effect (Mediating factors) (1)

In this section, we have focused on interdomain mapping, while these three same processes could also be instantiated for intradomain characteristics, which is not part of our investigation in the current work.

Example Use Case

Our model presents a holistic view of QoE comprising multiples domains; however, instantiation of the model will depend heavily on the context in which it is applied. Take a simple use case (Fig. 4) where a multimedia service provider (MSP) has a VoD service. They are formulating their business strategy for the next three years and need to have a better understanding of what impacts their customer QoE. As per our model, the MSP defines and verifies the influence of the predictor, moderator, and outcome factors and their interaction as briefly presented here:

Predictors:

- QoS levels as measured by the operation and maintenance center (OMC) of the MSP.
- Service features offered by the MSP, use of which can be measured by usability testing.
- Pricing as provided by VoD service contracts.
- During off-peak hours, resource availability could be exploited to offer service with promotional rates, which in turn may also make a positive effect on QoE. Therefore, resource availability and promotional rates link business models, service features, and QoS parameters.

Moderators:

- Customer demographic attributes (e.g., age and gender) have a moderating impact on QoE.

Outcome:

- QoE as measured by subjective QoE questionnaires and customer retention rates.

After measuring each factor and determining the model (e.g., the weights on each link), the MSP gains a clearer understanding of the QoE of their VoD service. For example, they may learn if a particular demographic is more interested in pricing and off-peak promotional rates. They can use this to inform decisions on pricing plans and investments in technology/service they should make for the future. If they determine that off-peak pricing has only a limited impact on QoE for their main demographic, they may choose to market aggressively to another demographic, investigate alternative pricing mechanisms, and/or upgrade their delivery infrastructure to improve QoS.

Conclusion

As the era of human-centric service and product design and delivery flourishes, the focus is shifting toward a multidisciplinary human-centric quality of experience approach. In this article, we have proposed a holistic QoE model by bringing all disparate pieces of the communication ecosystem together to understand total QoE. Once this link between QoE and other domains

of the communication ecosystem is established, we obtain an authentic and complete assessment of human quality of experience requirements.

This model is not meant to be proscriptive, but to provide a taxonomy of the relevant variables and their interactions in order to aid practitioners in thinking more broadly about QoE. Instantiating the model will depend heavily on the context in which it is applied: specific variables will be more important and lend themselves more easily to measurement. Our goal is to provide a high-level model that can be adapted to many specific contexts and to encourage future research that examines these cross-domain relationships.

Our future work will include developing a QoE-based testbed and conducting a user study in order to validate this model.

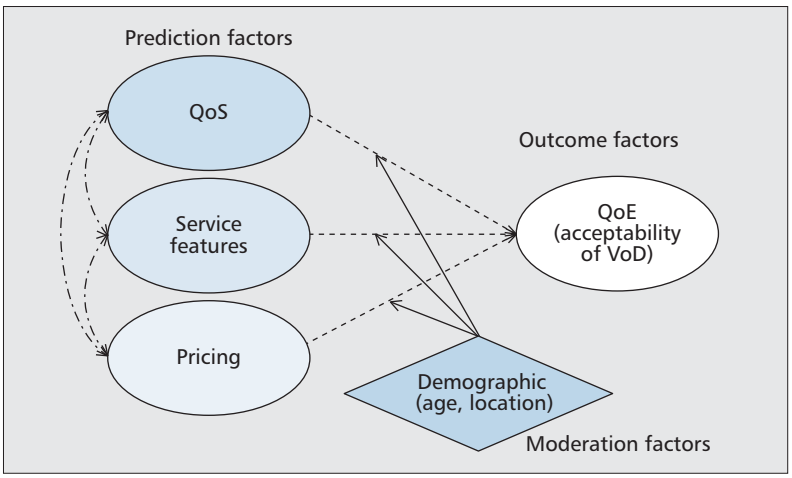

Figure 4. *QoE for VoD service.*

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