On quality of experience (QoE) for multimedia services in communication ecosystem

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On QoE For Multimedia Services in Communication Ecosystem

Concepts, Methods, Evaluation and Development

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Dedication

In the loving memory of my late father ***Muhammed Jurial Laghari*** *and my sweet uncle* ***Hafiz Imdad Laghari*** *who were my guiding light, great source of inspiration, love and support. I dedicate my research work to them. May they rest in Peace!*

Acknowledgments

“Let us be grateful to people who make us happy; they are the charming gardeners who make our souls blossom”
Marcel Proust French Novelist

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Abstract

Today, the fulfillment of customer demands and user experience requirements are becoming the main differentiators for gauging the effectiveness of telecom operators and service providers. In this competitive market, poor Quality of Experience (QoE) leads to a chain reaction of negative word of mouth, pushing customers into the arms of waiting competitors. Therefore it is important for service providers to ensure superior quality of experience in order to avoid customer disloyalty and negative reputation. QoE is a fast emerging multi-disciplinary field focused on understanding overall human quality requirements from different angles such as technology, business and context of use. The first and foremost challenge is to understand how different influencing characteristics related to business, technology, and context influence human behavior.

In this thesis, initial work addresses this challenge of understanding the influence of disparate domains on QoE. A consolidated QoE interaction model is proposed which links disparate domains (human, business, technology, and context) to understand overall human quality of experience requirements. Then taxonomy is presented for QoE interaction model.

Second contribution in this thesis is based on the first and its main objective is to capture and analyze QoE data through user studies. Based on user data, the influence of technological, contextual and business parameters on QoE are evaluated. Different multimedia services were selected for user study such as video streaming service, telephony (VoIP and PSTN), and 3D audio teleconferencing service. Depending upon multimedia service, different aspects were considered during each user study such as types of multimedia service parameters (QoS, content, context), the types of QoE metrics (subjective, objective cognitive or both), human characteristics (age, gender etc), and human roles (user, or customer). These findings help in understanding the link between QoE and other influencing domains.

The third contribution is based upon ongoing work of developing QoE based tools for video streaming services. Two QoE based tools for the assessment of multimedia services have been presented in this thesis, their main functions are to capture, analyze and report QoE metrics in real time. These QoE tools are useful for real time measurement of QoE metrics.

Résumé de la Thèse[1] en Français

1. 1. Contexte

Avec les progrès technologiques rapides, il ya eu une prolifération de systèmes nouveaux et innovants, services, applications et périphériques pour utilisateur final. Concepts de gestion de réseau sont également en pleine évolution, et les paradigmes autonomes de gestion de réseau aspirent à faire de l'homme-comme l'intelligence à des tâches de gestion des télécommunications [1]. Merci à ces progrès techniques, la réalisation des exigences du client et les exigences de l'expérience utilisateur sont devenus les principaux différenciateurs pour l'efficacité des opérateurs télécoms et les fournisseurs de services. Comme par rapport à la consommation enquête mondiale 2011 pour des services multimédias [2], il a été signalé que la moitié des clients du monde entier cité la «qualité» que leur exigence de haut. En outre, les clients sont prêts à payer pour une meilleure qualité de l'expérience avec les services multimédias [3], mais si les fournisseurs de services multimédias ne parviennent pas à fournir une qualité promise, ce qui conduira à une réaction en chaîne de la parole négative de la bouche, comme indiqué dans [4] que sur les moyennes près de neuf sur 10 clients dans le monde dit que les gens autour d'eux au sujet de leurs mauvaises expériences. Et cette expérience à la clientèle pauvre reste le numéro un effort de poussée clients dans les bras de concurrents en attente.

Objectif fournisseurs de services multimédia est d'avoir une croissance soutenue. La clé d'une croissance soutenue est dans un exemple d'engagement du client fiable pour attirer de nouveaux clients ainsi que de fidéliser les clients existants [5]. Le Sondage auprès des consommateurs Connecté 2012 [6] rapporte que «... le marché européen et aux Etats-Unis pour de nombreux services de télécommunications et des médias de base - comme le haut débit fixe, la voix et la télévision payante - est de saturer. En conséquence, la satisfaction du client et de rétention - qui ont toujours joué un rôle important - sont devenues cruciales ".

Malgré la solidité et la qualité technologique, les résultats surprenants rapportés dans l'enquête [5], que seule 1/4ème de clients restent des clients fidèles. Les clients 2/3rd passer d'un opérateur en raison d'un service à la clientèle pauvre et clients outre 44% ont dit, leur attente est plus élevé que l'an dernier. Cela signifie la satisfaction n'est pas suffisant pour fidéliser le client,

[1] Note: *Translation is done with the help of Google Translator*

il est effectivement d'anticiper et de comprendre les attentes des clients, des besoins et des comportements celles-ci sont en constante évolution et le déplacement à un rythme toujours plus rapide, entraînée par les possibilités apparemment illimitées des services, des applications multimédias, des dispositifs et de colis. Pour résumer, tant du point technologique et commerciale de vue, le conducteur principal est un client / utilisateur. Pour une croissance soutenue et de l'innovation technologique, le client / l'utilisateur doit être centrée sur fait la priorité absolue. Quelques citations de spécialistes de l'industrie sont donnés ci-dessous pour voir leur mot à dire sur l'expérience client.

"Il n'y a qu'un seul patron. Le client. Et il peut tirer tout le monde dans la société du président sur le bas, tout simplement en dépensant son argent ailleurs."

Sam Walton, Walmart [7]

"Dans le monde de l'Internet, il est important de vous souvenir de votre concurrent est un seul clic de souris."

Doug Warner [7]

"Vos clients attendent de votre ensemble de l'opération à tourner autour d'eux."

SAP Annonce

Il a donc, est devenu très essentiel de comprendre l'homme des exigences de qualité centrés sur, et à cet effet le terme de qualité de l'expérience (QoE) a été inventé. QoE est une approche multidisciplinaire fondée sur la psychologie sociale, sciences cognitives, l'économie et sciences de l'ingénieur, axée sur la compréhension globale des exigences de qualité de l'homme. Traditionnellement, basés sur la technologie approches basées sur la qualité de service (QoS) des paramètres ont été utilisés pour évaluer la qualité des services multimédias offerts aux utilisateurs finaux. QoE élargit cet horizon pour capturer l'esthétique des gens et même des besoins hédoniques. QoE fournit une évaluation des attentes de l'homme, les sentiments, les perceptions, la cognition et l'acceptation à l'égard de quelques produits particuliers, des services ou des applications [8].

QoE est complexe approche multidisciplinaire, plusieurs technologique, les entreprises et les facteurs contextuels [9] pourrait affecter QoE comme le montre la figure 1. Les aspects technologiques, tels que; fonctions de service, des fonctionnalités de périphériques des utilisateurs finaux et les paramètres QoS peuvent influer sur les sentiments et la perception d'un utilisateur. De même, les aspects commerciaux, par exemple, service à la clientèle, des offres de services, le coût, la promotion et l'image de marque peut aussi inciter les clients à développer des sentiments positifs et / ou négatifs sur la qualité. La recherche en psychologie du comportement humain prouve également que la variation dans le contexte et les aspects environnementaux influencent également le comportement humain [10]. Par conséquent, afin de comprendre et de mesurer les besoins QoE pour les services multimédias, il est important de savoir l'interaction entre l'humain, la technologie, des affaires et le contexte ainsi que leur effet sur la QoE.

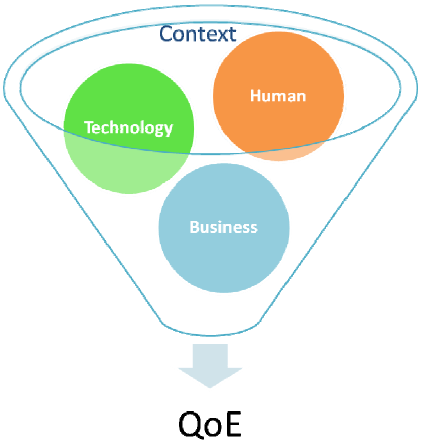

Figure 1: Diagramme conceptuel de QoE et facteurs d'influence

En bref, nous pouvons résumer que les clients et les utilisateurs finaux sont effectivement la force motrice derrière le succès et / ou l'échec de tout produit ou service. Aujourd'hui, les clients sont de plus en plus la demande sur la qualité des services multimédias et d'applications, ce qui nécessite de combler le fossé entre ce que les clients veulent et ce qu'ils expérience. Si les fournisseurs de services multimédias aspirent à devenir leaders du marché en offrant un service de haute qualité à leurs clients, ils ont besoin pour comprendre les exigences QoE utilisateur et l'implication de la mauvaise qualité de l'expérience sur leur propre base de clients et de leur croissance future rentable. Par conséquent, pour conserver les clients existants et de les rendre fidèles, un service doit être conçu et exécuté sur la base des points de repère de la QoE.

1. 2. Définitions de QoE

Nous présentons quelques définitions de montrer comment cette notion de « QoE » est réellement vu par des personnes différentes.

I. Extension de la notion de QoS: "QoE a été défini comme une extension de la traditionnelle qualité de service dans le sens où QoE fournit des informations concernant les services fournis à partir d'un point de l'utilisateur final de vue". [18]
II. Convivialité que QoE: "QoE est de savoir comment un utilisateur perçoit l'utilité d'un service lorsqu'il est utilisé- le degré de satisfaction, il / elle est avec un service en termes de, par exemple, la convivialité, l'accessibilité, retainability et d'intégrité». [19]
III. QoE pour Business: ". La qualité de l'expérience d'un client avec les entreprises dépendent de la conception réfléchie de sites web, les processus rationalisés qui sont conçus pour rendre le travail du client plus facile, les politiques soigneusement respectés, bon service client et une excellente exécution opérationnelle» [20]
IV. Degré de Joie comme QoE: "QoE décrit le degré de plaisir de l'utilisateur d'un service, influencé par le contenu, réseau, périphériques, applications aux attentes des utilisateurs et des objectifs, et le contexte de l'utilisation". [21].
V. L'expérience subjective de l'homme en tant QoE: ". L'acceptabilité globale d'une application ou un service, tel qu'il est perçu subjectivement par l'utilisateur final» [22]
VI. L'expérience subjective humaine et de l'objectif (cognitive) des facteurs humains QoE: "QoE est un ensemble de facteurs humains centrées sur la base de l'homme subjectifs et objectifs aspects cognitifs liés à l'interaction d'une personne avec la technologie et avec des entités commerciales dans un contexte particulier» [8].

Premières trois définitions de la QoE sont plus enclines à un domaine particulier. Ces définitions QoE lien avec QoS, HCI et métriques d'affaires, respectivement. QoE est multidisciplinaire terrain, les parties prenantes afin de définir différents QoE selon leurs propres besoins et de la compréhension. Il y avait une nécessité d'avoir une certaine discipline générale-agnostique définition qui inclut les aspects psychologiques de l'homme. Définitions IV & V bien servir ce but car ils englobent tous les aspects nécessaires qui ont un impact de la subjectivité humaine. Cependant, au fil du temps, il a également appris qu'en plus de l'homme des facteurs subjectifs, il ya aussi des facteurs objectifs de l'homme (par exemple, les aspects physiologiques et cognitives) qui ont également un impact QoE. Et pour rendre plus complète et QoE potentiellement plus valide, il est nécessaire d'inclure les facteurs humains objectives avec subjectives mesures psychologiques [8] [14]. Ainsi la définition VI est une nouvelle définition de QoE qui comprend les deux aspects de l'homme subjectifs et objectifs. Comme QoE devient maturité au fil du temps, des définitions plus détaillées et exhaustives font leur apparition pour mieux comprendre la notion QoE. Et cette tendance se poursuivra à l'avenir aussi, jusqu'à ce QoE atteint sa maturité complète. En suivant, il est discuté comment la notion QoE est entendu ou qui sont traités dans les différentes disciplines. Dans la section suivante, la motivation pour ce travail de recherche est présentée.

1. 3. Motivation

Les services multimédias sont un des principaux moteurs de la TIC d'affaires actuel. Communication multimédia se réfère à l'information à la machine transformés exprimée en Médias multiples, tels que du texte, la voix, des graphiques, des données d'image, audio, vidéo et interactif. En raison des avancées technologiques, les services multimédias comme la téléconférence, VoIP, streaming vidéo, e-learning, e-santé, et e-business sont en croissance significative. Pour leur évaluation, l'approche QoE pourrait être utilisé pour fournir à la clientèle et / ou l'utilisateur final en perspective sur la qualité offerte. Dans ce marché fardée, elle est une tâche essentielle pour le fournisseur de services multimédias pour fournir des services multimédias avec QoE supérieure afin de conserver leurs clients et maintenir leur avantage concurrentiel. Un QoE supérieure multimédia se traduira par des clients satisfaits, ce qui conduit à une perception positive du marché et de l'image de marque pour le mieux.

Si un service ou un produit est conçu sur les repères de la QoE, il génère éventuellement bouche à oreille positif et "wow" facteur pour attirer de nouveaux clients et satisfaire les clients existants. Par conséquent, l'acceptation largement répandue, ce n'est pas seulement important de concevoir des services multimédia sur les repères de la QoE, mais les fournisseurs de services devraient également fournir des services aux end-users/customers avec QoE supérieure.

Cependant, il ya des défis suivants et les goulots d'étranglement à traiter afin d'obtenir QoE totale pour les services multimédias comme décrit ci-dessous:

1. Au stade de la conception, les questions fondamentales qui doivent être abordées sont les suivantes: Est-il besoin de changeur de paradigme de la qualité de service à la QoE? Et quels sont les autres caractéristiques importantes de domaine multi-disciplinaires qui pourraient influencer QoE humaine et d'ailleurs, comment développer une approche holistique et le modèle QoE intégrée basée sur ces domaines disparates?
2. Sont des paramètres de QoS seuls facteurs qui influent sur le contexte et les entreprises ou métrique pourrait également influer sur la QoE humaine.
3. Comment faire usage de théories psychologiques (tels que Technology Acceptance Model (TAM), la théorie du comportement planifié (TPB)) pour QoE?
4. Le comportement humain est aléatoire et subjective dans la nature, la façon de quantifier la subjectivité humaine? Quelle technique pour être utilisé pour mesurer la QoE, par exemple pour des services multimédia, études sur les utilisateurs ou les techniques d'inférence objectives?
5. Quel environnement de test et d'essai mis en place devraient être sélectionné pour l'étude, par exemple l'utilisateur, de laboratoire ou de l'environnement naturel?
6. Est-QoE seulement un facteur subjectif? Ou des facteurs objectifs de l'homme par exemple, la physiologie humaine et les facteurs cognitifs pourrait également être utilisé pour QoE de référence?
7. Est-QoE unique mondial adapté métrique pour chaque utilisateur ou si nous devons modérer QoE basée sur les données démographiques de l'homme et le contexte?
8. Quelle technique à utiliser pour l'analyse des données, quantitative ou qualitative? Paramétrique ou non paramétrique, etc?
9. Pouvons-nous exploiter les résultats QoE de développer certains cadres QoE ou des outils?

Cette thèse est une tentative tout à répondre à ces défis et maintenant une brève description est donnée de discuter de ces défis.

1. 3. 1. Vue conceptuel sur QoE

Changement de paradigme est nécessaire: Les approches traditionnelles pour assurer la qualité et la satisfaction des utilisateurs sont des approches centrées sur la technologie QoS basés. Depuis, la qualité de service repose davantage sur les paramètres de la couche réseau et l'application, il est donc incapable de satisfaire les clients et / ou besoins des utilisateurs finaux. Les solutions existantes à base de QoS pour Internet sont DiffServ IP, IP Intserv ils peuvent garantir l'affectation des ressources cependant, les garanties de service ne suffisent pas à promettre une qualité supérieure de l'expérience [11]. Comme les évaluations de qualité de service de qualité à base ont souvent constaté que grossièrement inexact de prédire l'expérience utilisateur, et en tant que telle ne sont pas applicables à l'évaluation de la qualité multimédia [12]. Par conséquent, il est nécessaire de changer la direction de centrée sur la technologie QoS afin approche QoE humaine centrée.

Importance des facteurs d'influence: En plus de la technologie, il ya des entreprises et caractéristiques du domaine de contexte qui pourrait aussi influencer le comportement humain, donc la qualité de service n'est pas seule caractéristique influencer le comportement humain, mais pourrait être influencée par de nombreux interne (facteurs subjectifs et objectifs les facteurs cognitifs, etc) et externes (entreprises, le contexte) les facteurs [9]. Ainsi, pour une approche holistique et une compréhension conceptuelle de la QoE totale pour les services multimédias dans l'écosystème de communication, il est nécessaire de QoE modèle considérant l'influence de tous ces facteurs internes et externes.

1. 3. 2. La complexité d'analyse de QoE

Une fois sur la compréhension conceptuelle QoE est tout à fait clair, il est nécessaire pour mesurer et analyser les facteurs QoE pour les différents services multimédias. Mais il est assez complexe à saisir métriques QoE compte de l'influence de tous ces facteurs internes et externes en même temps. Nous devons répondre à certaines questions importantes liées à la QoE de mesure et d'analyse tel que décrit ci-dessous.

La subjectivité humaine: Le défi important est lié à l'aléatoire du comportement humain; tous les êtres humains ont des préférences similaires, des sentiments ou perceptions au sujet d'un service particulier et, en outre, leur perception et les préférences changent continuellement au cours du temps. Généralement les paramètres de QoS et d'affaires sont facilement contrôlés et fabriqués en raison de leur nature quantitative, mais que les perceptions et les sentiments humains sont par nature subjective et les niveaux d'attente varient entre les utilisateurs, par conséquent, il est difficile de quantifier et de mesurer avec exactitude la QoE.

Etudes utilisateur vs inférence indirecte (Objectif QoS) méthode: Pour capturer QoE subjective (perceptions, des sentiments, etc), il existe deux méthodes principales: l'une consiste à mener des études sur les utilisateurs, les sondages auprès des clients et des interviews et un autre est une version plus ingénierie qui sous-entend QoE de trafic sur le réseau de données collectées ou QoS basés sur une certaine estimation ou des méthodes de prévision. Méthode subjective prend du temps mais il fournit des résultats plus précis, alors que les méthodes indirectes sont moins de temps, mais leur précision est toujours dépendante de la méthode de prédiction et d'ailleurs ils sont axés sur des données de qualité de service seulement. Ils peuvent aussi manquer l'influence d'autres informations importantes (telles que contextuelle, d'affaires, etc attentes) qui pourraient être recueillies au moyen d'enquêtes et d'études de l'utilisateur. La deuxième partie de la thèse est basée sur des études d'évaluation et QoE subjectives données.

Etude utilisateur dans laboratoire ou dans l'environnement naturel : Certains experts estiment que, comme l'installation de laboratoire ne fournit pas un sens de l'environnement réel, il peut manquer de produire exactement les perceptions de l'homme ou des sentiments [13]. Mais d'autre part, test de laboratoire permet une plus grande flexibilité pour contrôler les facteurs d'influence. Chapitre 5, et 7, de cette thèse traite de laboratoire à base de résultats de l'étude des utilisateurs, tandis que le chapitre 6 est basé sur l'expérience de l'environnement naturel de vrais clients.

Les facteurs de l'homme QoE Objectif: des facteurs objectifs de l'homme sont liés à la physiologie humaine et cognitive du système [14] [9] [8]. Contrairement à l'homme des facteurs subjectifs, les facteurs les plus objectifs sont de nature quantitative et ils fournissent des informations précises sur la cognition humaine et la physiologie (voir chapitre 2, 3 et 4 pour plus de détails). Dans le chapitre 7, un facteur QoE objectif est inventé et son évaluation est présentée à l'égard de son homologue QoE subjective.

QoE mondiale métrique métrique ou segmentée: Certaines des conclusions basées sur QoE peut être globale ou universellement similaire pour chaque utilisateur, mais certainement pas tous, par conséquent devrait être modéré QoE basée sur différents groupes d'âge, le sexe, et les facteurs sociaux? [9].

Système d'évaluation qualitative vs quantitative: les techniques d'évaluation quantitatives travaillé sur des données numériques et statistiques. Régimes qualitatives sont utilisées pour analyser les comportements verbales telles que les mots et les commentaires des utilisateurs et non des chiffres [15]. Régimes quantitatives sont largement utilisés pour l'évaluation des techniques, car ils sont faciles et peuvent produire des résultats concrets, tandis que les données qualitatives sont difficiles à code et elles sont aussi difficiles à déduire des informations significatives de leur part [16].Cependant, avec un large succès du Web2.0, les commentaires des utilisateurs sur les médias sociaux ont augmenté et les régimes donc qualitatives sont également obtenir plus d'attention maintenant.

Outil de développement basé sur QoE : Il existe de nombreux outils disponibles pour mesurer les paramètres de qualité de service, mais QoE des outils spécifiques ne sont guère disponibles pour la mesure et l'évaluation des données de l'expérience utilisateur / client, probablement en raison de la complexité liés à la QoE des données tel que discuté précédemment. Certains des problèmes importants sont le manque d'intérêt des utilisateurs en donnant leurs commentaires, la subjectivité humaine, le coût de la objectives des outils physiologiques, et l'étude du temps et processus d'évaluation. Certaines entreprises ont commencé à développer des outils basés sur QoE mais ils se concentrent essentiellement sur l'objectif de qualité de service / QoE des facteurs tels que l'évaluation perceptive de la qualité vocale (PESQ) technique [17] et le pic de rapport signal sur bruit (PSNR).

Dans la prochaine section, les contributions de cette thèse sont présentées, qui sont axés sur la résolution de certains défis de la recherche présentés dans cette section.

1. 4. Contribution de la Thèse

Les contributions de cette thèse pourraient être divisées en trois parties.

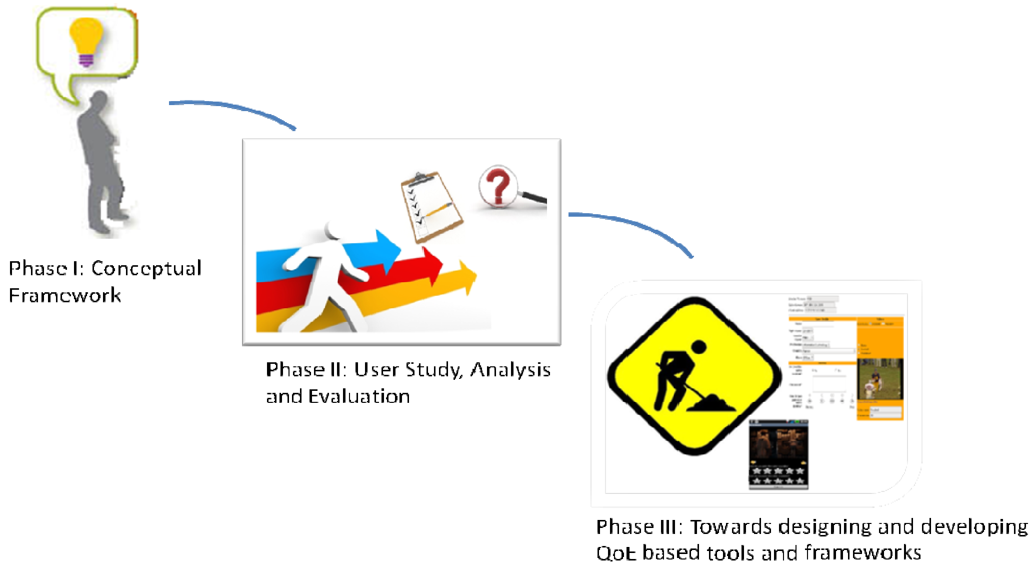

Figure 2: Contribution

1. Proposer un modèle holistique QoE: Dans la première étape, il est important de comprendre la grande image de QoE dire, les différents facteurs internes et externes qui pourraient influer sur le comportement humain. Pour obtenir une vue holistique de la QoE, il est essentiel de réunir les acteurs de l'écosystème de communication disparates (humaines, la technologie, des affaires et le contexte), ainsi que d'une manière systématique, comme le montre la figure 3. Et la figure 4 propose une interconnexion entre paramètres des modèle QoE.

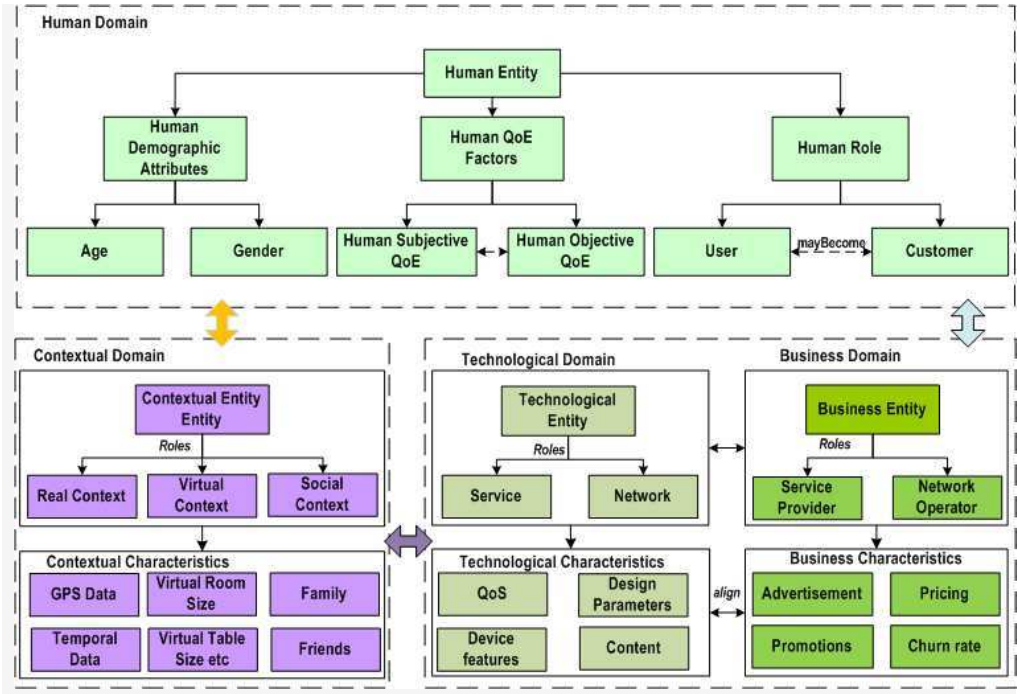

Figure 3. Modèle QoE

Modèles en sciences sociales tentent d'établir des relations causales entre la prévision et variables de résultats [67] [49] [48]. De même, nous divisons tous les facteurs en trois catégories principales: i) les facteurs de prédiction (ii) les facteurs résultats et les facteurs de modération (iii) (cf. Figure 3).

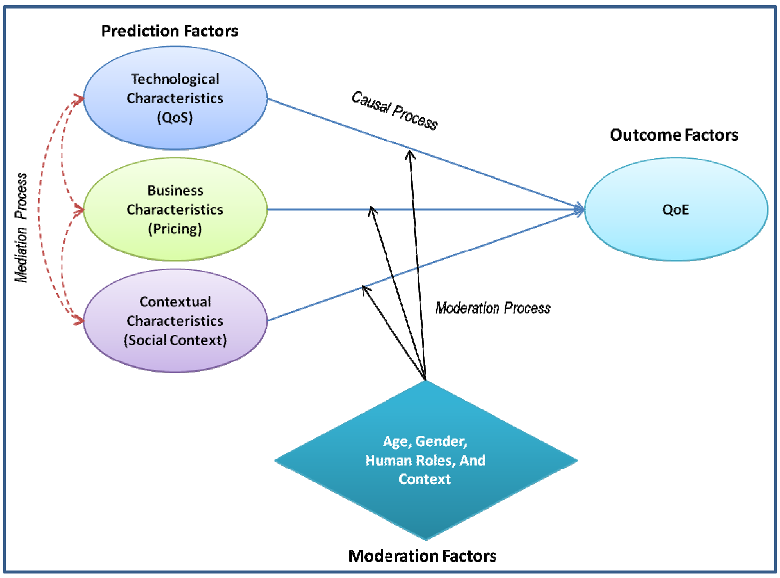

Figure 4. Interaction interdomaine

Facteurs de prédiction sont aussi appelés indépendante ou facteurs d'influence, et ils sont utilisés pour expliquer ou de prédire les changements dans les facteurs de résultats. Dans un écosystème de communication, nous avons trois vaste ensemble de facteurs qui pourraient affecter la prédication QoE tels que les caractéristiques technologiques, les caractéristiques des entreprises et des caractéristiques contextuelles. Facteurs de résultats, également appelés facteurs dépendants de facteurs ou QoE, sont basés sur l'homme facteurs subjectifs et objectifs. QoE est un ensemble de facteurs de résultats dans un écosystème de communication qui sont entraînés par des facteurs d'influence. Une autre catégorie est des facteurs de modération, ils représentent un ensemble de facteurs qui influent sur la direction et / ou la force de la relation entre les facteurs de prédiction et les facteurs de résultats. Exemples de facteurs de modération sont humains attributs démographiques (par exemple, l'âge, le sexe et le revenu), les rôles de l'homme (par exemple, le client, l'utilisateur) et le contexte (par exemple, l'emplacement).Le contexte est un domaine délicat car il pourrait être un facteur de prédiction (par exemple, la pression sociale perçue influence d'une personne à accomplir ou à ne pas exécuter le comportement [49]) ou un facteur de modération (par exemple, les données utilisateur peuvent également être classés selon l'utilisateur l'emplacement).

Une relation de causalité est une «cause-effet», où les facteurs de prédiction directement influer sur les facteurs de résultats. Par exemple, la dégradation des paramètres QoS pour le service VoD pourrait causer une gêne pour l'utilisateur (dégradation de la QoE). Cela signifie qu'il ya relation directe de cause à effet entre la dégradation de la qualité de service et de la réaction humaine. Un processus de médiation est un processus d'intervenir et il se réfère à la situation où un autre facteur a un effet indirect sur la relation de causalité directe entre la prédiction et les variables de résultat.

Gêne l'utilisateur n'est pas uniquement causée par baisse de la QoS d'un service de VoD. Par exemple, lorsque les baisses de qualité de service, un utilisateur peut ou ne peut pas être ennuyé selon les caractéristiques des entreprises, c'est à dire si elles payer pour un service ou non.

Ainsi, il est reconnu dans notre modèle qu'il peut y avoir une relation ou une association entre les aspects commerciaux, technologiques et contextuelles qui influencent indirectement le comportement humain. S'il n'ya pas de médiation entre les domaines, une relation un-à-tête direct est établi, par exemple, comme indiqué dans le chapitre 5, une relation QoE-QoS est établi.

La modération est un processus qui pourrait altérer la force d'une relation causale.Attributs de l'homme (âge, sexe) et les rôles de l'homme (client ou l'utilisateur) sont considérés comme des facteurs modérateurs qui pourraient altérer la force de la relation de cause à effet. Par exemple, les personnes appartenant à différents groupes d'âge peuvent avoir différents niveaux de tolérance à la dégradation de la qualité de service.Ou un client qui achète un service de VoD a une exigence QoE différent de celui d'un utilisateur qui utilise un service de VoD gratuite, donc un des segments de processus de modération ou individualise facteur QoE globale en sous-catégories basées sur l'âge, le sexe, l'utilisateur ou des rôles des clients, etc Contrairement à la médiation , il n'est pas nécessaire pour les facteurs de prédiction et les facteurs de modération pour être corrélés et que la corrélation n'a pas une interprétation particulière. Toutefois, si les facteurs de prédiction et les facteurs de modération sont trop fortement corrélés, il peut y avoir des problèmes d'estimation [67]. Pour plus de détails sur la modération et de médiation des variables, le travail [67] [68] pourrait être renvoyé.

La relation de causalité entre les facteurs de prédiction et les facteurs de QoE est un lien permanent, alors que le processus de médiation et de modération sont facultatifs et ils sont instanciés encas plus de précision et en profondeur de vue sur QoE est nécessaire. L’équation (i) présente une relation simplifiée entre les caractéristiques de domaine.
QoE totale (facteurs de modération) = effet direct (facteurs de prédiction) + Effet indirect (Facteurs médiateurs) (i)

Par conséquent, la motivation est de répondre à ce défi en proposant un modèle conceptuel et holistique QoE comprenant tous les domaines de la communication d'un écosystème. Quelques-uns des aspects notables du modèle proposé sont: (i) les facteurs objectifs (QoE des facteurs physiologiques et cognitives) et leur lien avec des facteurs subjectifs, et (ii) la différenciation des exigences QoE basée sur les rôles de l'homme (client, utilisateur, groupe) et caractéristiques (âge, sexe), (iii) l'influence des aspects techniques et commerciaux et contextuelle sur QoE. Mes papiers I, II, III sont des contributions relatives à cette partie du travail de thèse.

2. QoE analyse basée sur l'évaluation et des services multimédias en temps réel à l'égard de la qualité de service, le contexte, le contenu et les caractéristiques de l'homme (etc âge, sexe,): Cette partie se concentre principalement sur l'approche pratique de la réalisation d'études d'utilisateurs sur les services multimédia (streaming vidéo, VoIP, 3D téléconférence audio) à évaluer et à établir une relation statistiquement significative entre QoE et les facteurs qui influencent (QoS, contexte virtuel) Tableau 1 présente etc résumé des travaux réalisés dans cette phase.

Tableau 1: Résumé de la phase 2 de contribution

	Study I: **Video Streaming Service**	**Study II:** **Telephony (VoIP and PSTN)**	**Study III:** **3D Audio Teleconferencing Service**	**Study IV:** **3D Audio Teleconferencing Service**
Relationship	QoS- QoE	QoS- QoE	Contex-QoE	Contex-QoE
QoE Factors	User Perceived Video Quality and User comments	Perceived Availability, Perceived Call Quality, Customer satisfaction and customer preferences	Localization Performance, Localization Easiness, Spatial Audio Quality and Overall Audio Quality	Localization Easiness and Performance
Influencing Factors	Network and application level QoS	Technical faults and QoS issues	Virtual teleconferencing room size and concurrent talkers	Virtual teleconferencing room size
Moderation Factors	Content characteristics	Age, end-user device type	non	Gender
Study Setup	Lab based user study (Quantitative and Qualitative)	Customer Survey (Quantitive technique)	Lab based user study (Subjective and Objective QoE Factors)	Lab based user study (Subjective and Objective QoE Factors)
Analysis	Descriptive statistics, Rough Set Theory and CCA framework	Basic Statistics, Hypothesis testing based on Chi-Square	Basic Statistics	Point estimators, Adjusted Wald Method, basic statistics

Mes papiers IV, V, VI et VII sont mes contributions liées à ce travail.

3. Conception et développement de prototypes ou des cadres pour la mesure de la QoE pour les services multimédias: Basé sur les deux premières contributions, actuellement deux cadres de mesure du QoE sont en cours d'élaboration.

Le cadre QoE proposé pour les services multimédia (nommé QoM cadre) capture réseau et l'application de couches de données de qualité de service, des données qualitatives et QoE notes des utilisateurs et des informations quantitatives contenu. En utilisant des statistiques descriptives et des régressions linéaires multiples, QoE est évaluée. En cas de baisse de la QoE, un message d'alerte est transmis à l'administrateur (Admin) pour complément d'enquête. Notre cadre nouvellement proposé Qom a été lancé comme un outil open-source QoE d'évaluation pour l'industrie et de la communauté de recherche. Mais il a aussi certaines limites, pour des exemples, Firefox est utilisé comme interface client, il est très sûr et navigateur ne permet pas le script comme un script Java pour fonctionner et d'exécuter la demande du client ou d'un service. C'est la raison pour le client qui veulent utiliser le service, il / elle doit activer le service de capture manuellement en premier, et après que le service fonctionne bien. Cette dépendance à l'égard manuel renifleur de commutation ON est un défi important d'aborder dans la prochaine version du cadre.

En outre, ce cadre permet aux utilisateurs de Qom regarder la vidéo et donner leur avis sous forme de texte (commentaires). Mais dans la version actuelle, l'analyse qualitative n'est pas encore incluse. Comme il s'agit d'en-cours de travail, à l'avenir, nous avons l'intention d'améliorer ce cadre, en résolvant les limitations mentionnées. Des tests d'utilisateurs étendu ne serait pas menée pour évaluer la performance du cadre proposé Qom dans un contexte de véritables réseaux 4G sans fil WiMax.

Cadre Android QoE base pour les services multimédias (AQoM) a été présenté pour évaluer les services de streaming multimédia sur les téléphones intelligents. Projet de cadre AQoM est une application client et il gère "surveiller, d'analyser et de décider" des fonctions sur des données d'utilisateur sur le téléphone intelligent et il ne nécessite aucune autre côté serveur pour l'évaluation des données, d'où il fournit un contrôle de la confidentialité des données utilisateur. Il a l'apprentissage et la mise à jour processus, qui raffine en permanence QoE.

Des données de notation QoS, le contexte et l'utilisateur sont collectées à partir du dispositif de l'utilisateur pour une évaluation meilleure perception utilisateur localement sur le côté client. L'utilisateur a la liberté de donner son feedback sur la qualité offerte à tout moment par *thumbs up* et *thumbs down* icône et / ou de la qualification de l'utilisateur. Il est possible que le comportement de l'utilisateur par rapport à un service particulier dans n'importe quelle situation pourrait changer et donnant ainsi naissance à changer dans ses exigences QoE. Ainsi, notre cadre de QoE proposée produit des exigences QoE personnalisés d'un utilisateur dans n'importe quelle situation.
Ce travail est en cours et les études d'utilisation plus grande sera réalisée afin d'évaluer la performance de AQoM, une fois le cadre AQoM est prêt.

Mon papier et VIII des brevets sont contribution à ce travail.

1. 5. Organisation de la Thèse

Sur la base de contributions à la recherche, cette thèse est également organisé en trois parties;

Première partie couvre le concept, les théories et les modèles autour de QoE. Dans cette partie, nous présentons un large aperçu de la littérature (chapitre 2), puis de présenter notre modèle proposé QoE (chapitre 3).

Le chapitre 2 présente une vue d'ensemble de la littérature liée à QoE concepts à l'égard de la qualité de service, HCI, d'affaires, le contexte, la psychologie et la biologie.Il est subdivisé en deux sections, la section I comprend QoE la recherche connexe, qui est menée dans les différentes disciplines. Et la section II présente un aperçu des modèles existants de QoE proposées pour comprendre QoE.

Le chapitre 3 présente le modèle proposé QoE, comprenant tous les domaines de la communication d'un écosystème. Ce modèle consolidé s'étend avant de travailler sur la modélisation QoE en définissant la nouvelle taxonomie et en reliant tous les domaines de l'écosystème de la communication.

La deuxième partie de la thèse se concentre principalement sur l'approche pratique pour mener des études sur des utilisateurs des services multimédia (streaming vidéo, VoIP, 3D téléconférence audio) et analysant l'impact des différents facteurs qui influent sur le QoE. Cette partie se compose de quatre chapitres ci-dessous.

Le chapitre 4 présente une vue d'ensemble sur les différentes méthodes d'évaluation, les techniques de QoE analyse et d'outils.

Le chapitre 5 présente étude sur les utilisateurs des résultats d'expérimentation I pour évaluer l'impact (combiné) du réseau et des applications au niveau des paramètres de QoS et les caractéristiques de contenu sur la qualité perçue par l'utilisateur pour le service de streaming vidéo. La théorie des ensembles rugueux (TVD) est utilisé pour l'évaluation quantitative et simple CCA (Catégoriser, cataloguer et à analyser) cadre pour l'évaluation qualitative des données de l'utilisateur afin de comprendre l'influence de plusieurs paramètres de services multimédias sur QoE.

Le chapitre 6 présente l'analyse de sondage auprès des clients de l'opérateur pour les services de téléphonie (RTC et VoIP) pour comprendre l'effet de diverses fautes techniques (appelons-déposer, etc écho) sur les facteurs QoE différents tels que la qualité des appels perçue, la disponibilité perçue, préférences des clients et l'ensemble satisfaction de la clientèle. En outre, il est également montré que la façon QoE métriques pourrait également être différenciée en ce qui concerne l'âge du client et les types de dispositif de l'utilisateur final.

Le chapitre 7 présente étude sur les utilisateurs et l'analyse des données pour étudier la relation entre l'environnement contextuel QoE et virtuel. 3D service de téléconférence audio est sélectionné en tant que service de cas d'utilisation de l'expérimentation. Nous analyser et valider les relations entre les paramètres QoE et contextuelles dans deux différents scénarios de test à travers l'expérimentation de l'utilisateur. Les résultats de l'étude sont présentés utilisateur de montrer que la façon dont les facteurs subjectifs et objectifs QoE sont touchés en raison de l'environnement acoustique virtuel. En outre, il mettra également l'accent sur les effets des différences entre les sexes sur QoE sur la base de l'environnement acoustique virtuel.

Dans la troisième partie des détails de thèse, l'architecture et la mise en œuvre d'outils ou QoE cadre est présenté pour la mesure de la QoE pour les services multimédias.Cette partie comprend deux chapitres ci-dessous.

Le chapitre 8 présente les détails d'architecture et de la mise en œuvre du cadre de QoE pour les services de streaming vidéo.

Le chapitre 9 présente les cadres QoE pour Android basés sur les téléphones intelligents pour évaluer la QoE des applications vidéo.

Enfin, au chapitre 10, la conclusion et de la perspective à notre direction des travaux futurs seront discutés.

1.6. Synthèse des Thèse

Cette thèse est une tentative d'explorer les concepts intéressants mais complexes de QoE pour les services multimédias dans l'écosystème de la communication. Pour explorer ce sujet, il a été décomposée en trois sous-objectifs ou des défis tels que (i) de comprendre de grands tableaux de QoE perdre de vue les influences de différents facteurs appartenant à la technologie, le contexte et les entreprises (ii) analyser et évaluer les interactions et les relations entre QoE et d'autres facteurs qui influent sur (QoS, le contenu et le contexte) (iii) développer des outils ou QoE de cadres intégrés fondés sur les conclusions précédentes.

Pour faire face à, premier défi, un modèle holistique QoE est proposé dans le chapitre 4 et dans le document [9] [8] pour les services multimédias dans l'écosystème de la communication. Le modèle proposé a réuni humaine, technologique, contextuelle et domaines d'activités ainsi que leurs interactions inter-domaines pour obtenir le point de vue holistique QoE. Le modèle n'était pas destiné à être prescriptive, mais de fournir la taxonomie des variables pertinentes et de leurs interactions afin d'aider les praticiens à élargir leur horizon sur les QoE. L'instanciation modèle a été fortement tributaire du contexte dans lequel elle est appliquée: les variables spécifiques serait plus important et se prêtent plus facilement à la mesure. Notre objectif était de fournir un modèle de haut niveau qui peut être adapté à de nombreux contextes spécifiques et à encourager la recherche qui examine l'avenir de ces relations inter-domaines. Le deuxième défi important était d'identifier, de recueillir et d'évaluer les facteurs qui QoE ont été touchés par différents facteurs d'influence. Mais il y avait un problème de taille à résoudre dire, les perceptions et les sentiments humains sont très subjectifs et aléatoires dans la nature, la façon de capturer et de quantifier la subjectivité humaine? La seule solution commune était de mener des études d'utilisateurs et des enquêtes pour connaître les opinions des clients et des sentiments, puis d'évaluer les données en utilisant des techniques quantitatives et qualitatives.

En deuxième partie de la thèse, ce défi a été abordé par la production des résultats des études d'utilisateurs, qui ont été recueillies par la réalisation d'enquêtes et d'études des utilisateurs qui utilisent le service de streaming vidéo, VoIP, RTC et le service de téléconférence audio. Ils ont porté sur la compréhension de l'impact des différents facteurs qui influencent (par exemple, la qualité de service, le contenu et les paramètres contextuels) sur QoE. Dans le chapitre 5, une étude a été présentée à l'utilisateur un lien l'effet combiné de la couche applicative paramètres QoS (par exemple, le débit binaire vidéo), et la couche réseau QoS paramètres (perte de paquets, de retard, un paquet de re-commande) sur la qualité perçue par l'utilisateur pour la vidéo service de streaming. QoE a été animée sur la base de différents types de contenu (c.-à-lent clip conteneur mobile et rapide pince mobile match de football). Les données ont ensuite été évalués en fonction de la technique quantitative; comme la théorie des ensembles rugueux, et de la technique qualitative; tels que (CCA). Pour le meilleur de ma connaissance, ce travail est premier de son genre dans lequel QoE vidéo a été signalé basé sur des techniques qualitatives et quantitatives. Il est appris que tous les paramètres de QoS posent le même niveau de dégradation de la qualité perçue par l'utilisateur et, en outre, des contenus différents ont aussi des exigences différentes de soutien de qualité de service. Comme cette étude a été réalisée dans un environnement contrôlé (laboratoire de l'installation), il a ensuite été décidé de mener une enquête auprès des clients réels pour obtenir des résultats écologiquement valables. Le chapitre 6 de cette thèse est basée sur des données réelles enquêtes sur les clients pour un service de téléphonie (RTC et VoIP) de mener Télécom l'opérateur français, dans ce chapitre, trois aspects principaux ont été évalués, et ceux sont les suivants:

1. La fréquence des défauts techniques et leur impact sur la disponibilité perçue et la qualité des appels perçue

2. L'évaluation des préférences des clients et de leur modération basée sur l'utilisateur final appareil de poche

3. L'évaluation de la satisfaction du client, en ce qui concerne le groupe d'âge des clients.

De l'enquête à la clientèle, on a appris que des défauts différents (QoS et les questions environnementales) ont été traités différemment par les clients. Le bruit de fond a été jugée peu gênant pour les clients du RTPC, tandis que pour les clients VoIP, la chute d'appel, bruit de fond, entrant de défaut de signalisation, de défaut de numérotation de poste, et de pré-numérotation des failles ont été jugées dans la catégorie un peu ennuyeuse.

Pour la préférence du client métrique, on a appris que les clients possédant RTPC filaire et la téléphonie sans fil étaient moins préoccupés par une panne de courant ou de problèmes de dégradation des voix par rapport aux clients VoIP.
Pour la satisfaction globale des clients, Chi-Square hypothèse a été fait et les résultats suggèrent que les clients du groupe d'âge de moins de 40 ont des niveaux similaires de satisfactions à l'égard des services VoIP et PSTN tandis que les clients des groupes d'âge plus de 40 se sentent plus satisfaits que les RTPC VoIP. Cela signifie, malgré une meilleure communication PSTN de mettre en place la performance et la qualité des appels, les clients jeunes sont également satisfaits de la qualité et les services offerts par la VoIP.

Précédent deux études ont été davantage axées sur l'impact des questions de qualité de service et technique sur les facteurs subjectifs QoE. Comme il a été proposé dans le modèle holistique que les aspects contextuels pourraient également influer sur la QoE, dans le chapitre 7, de cette thèse, QoE-contexte de la relation a été évaluée en utilisant la 3D service de téléconférence audio. Suite à des aspects importants ont été la cible;

1. L'impact des caractéristiques du contexte virtuel (taille de la pièce virtuelle, le nombre de concurrents virtuels parleurs) sur QoE.

2. Objectif QoE (performance de localisation: LP) liée à la performance cognitive humaine et sa comparaison avec le facteur QoE subjective (Facilité Localisation: LE).

3. Analyse de la différence entre les sexes dans l'environnement de téléconférence audio 3D virtuelle.

Selon les résultats, les caractéristiques de l'environnement virtuel pourrait affecter QoE utilisateur. En changeant la taille de l'espace virtuel et le type de voix de négociations simultanées, la variation dans les deux facteurs QoE subjectives et objectif a été observée. En outre, les données de l'étude suggèrent que l'utilisateur chambre de taille moyenne téléconférence virtuelle et mixtes parleurs de type voix »(un mâle et d'autres causeur femelle) de fournir une qualité optimale de l'expérience dans la téléphonie 3D basé environnement acoustique virtuel.

LP valeurs ont tendance à augmenter pour la chambre de téléconférence petite virtuel, au contraire, LE scores MOS ont tendance à diminuer pour la chambre de téléconférence petite virtuel, et vice-versa pour grande salle. Mais la valeur LP à la fois et les scores LE s'avèrent le plus élevé dans la chambre de taille moyenne (15 m³). La raison possible pour ce match entre les résultats QoE objectives et subjectives, c'est le fait que, comme les échos et les réverbérations sont plus tendus dans les grandes pièces, il se sent facile à localiser causeurs. Il est rapporté dans la littérature [140] que la réverbération dans des environnements acoustiques est considéré comme un repère fiable dans l'identification distance de la source, mais il a également dégrade légèrement la perception directionnelle [144] et intelligibilité de la parole [145]. En outre, il a également appris que les participants masculins et féminins ont des tendances légèrement différentes entre les taux de rendement (LP) et LE-MOS scores dans les petites entreprises (10 m³) et grande taille (20 m³) chambre, mais leur perception et les capacités de performance convergent vers des tendances similaires dans la chambre de taille moyenne. Il a également été constaté que les participants masculins et féminins »ont obligation QoE légèrement différente dans un environnement virtuel.

Au cours de cette phase d'étude d'utilisateur, on a appris qu'il y avait une pénurie de mesure QoE et des outils d'évaluation, et les outils disponibles étaient pour la plupart se concentrant sur les techniques de QoS basés sur objectives. En gardant en vue la nécessité urgente d'outils adaptés pour capturer la subjectivité humaine (QoE) pour évaluer les besoins des utilisateurs au moment de l'exécution pour le service multimédia, deux outils de Qom et AQoM ont été développés tel que présenté dans la partie 3 (chapitre 8 et 9) de cette thèse.

QoM cadre est l'outil client-serveur basée sur le modèle pour capturer le trafic réseau et les commentaires des utilisateurs (à la fois qualitative et quantitative) pour évaluer QoE pour le service de streaming vidéo. Qom cadre était une tentative de fournir un outil d'évaluation à l'industrie et QoE communauté de la recherche. Il est encore moins dans sa phase de balbutiements, mais après son lancement comme un outil open-source à la recherche communautaire dans un avenir proche, on s'attend à ce qu'il obtiendra maturité rapidement.

AQoM cadre visait à évaluer les services de vidéo mobiles sur Android à base de téléphones intelligents. Il est client de l'application ne QoE qui recueille les commentaires des utilisateurs, la qualité de service et des données de contexte et effectue l'analyse au-dessus sur le temps long. AQoM fonctionne en deux modes; dans le mode d'apprentissage et de l'automatisation. AQoM cadre est en cours de travail, en collaboration avec le français Telco opérateur.

Enfin, on peut affirmer que, malgré le fait que l'évaluation QoE des services multimédias a été très difficile en raison du nombre énorme de facteurs d'influence, d'évaluation complexe et des méthodes d'évaluation; les résultats obtenus sont relativement encourageants. Cette thèse présente une feuille de route pour complément d'enquête dans chacun de ces trois parties afin d'obtenir en profondeur de la vue sur la QoE pour les services multimédias dans l'écosystème de la communication.

1. 7. Direction des travaux futurs

Multimédia processus de développement cadre est en cours; la prochaine étape sera d'achever ce processus, puis en utilisant ces outils, effectuez étude sur les utilisateurs sur le réseau WiMAX 4G pour évaluer la performance d'un cadre de Qom. Dans le cadre de Qom, les fonctionnalités suivantes peuvent être introduites dans sa prochaine version.

Sniffer automatique en cours d'exécution sur les deux côtés (client et serveur)

Mettre en place la théorie des ensembles rugueux analyseur basé sur Pour androïde cadre axé sur les (AQoM), les fonctionnalités suivantes peuvent être incorporés dans sa prochaine version.

Processus de développement complet de la première version

Inclure plus de paramètres de QoS.

Mieux algorithme d'apprentissage et l'utilisation possible de la TVD pour l'analyse En plus de ces tâches de développement d'outils, actuellement, je suis conduire des recherches collectives sur les aspects suivants,

QoE pour le réseau optique passif (PON), en collaboration avec la Corée Institut Supérieur des Sciences et de la technologie (KAIST)

QoE pour le trafic Web en collaboration avec Blekinge Institute of Technologie (BTH) Suède Enfin, j'ai préconisé l'utilisation de facteurs physiologiques objectifs, mais je ne pouvais pas les intégrer dans mon travail actuel. Je suis également intéressé à utiliser des outils physiologiques dans mon futur travail d'analyser les facteurs objectifs QoE.

List of Publications

I. Laghari, Khalil ur rehman., Yahya, I.G.B., Crespi, N.: Towards a service delivery based on customer eXperience ontology: shift from service to *eXperience in Proceedings of the 5th IEEE International Conference on Modeling autonomic communication environments*. Springer Verlag, (2010). pp. 51-61.

II. Laghari, Khalil Ur Rehman, Crespi, N.; Molina, B.; Palau, C.E.; , "QoE Aware Service Delivery in Distributed Environment," *Advanced Information Networking and Applications (WAINA), 2011 IEEE Workshops of AINA Conference on* , vol., no., pp.837-842, 22-25 March 2011.

III. **Journal:** Laghari, Khalil ur rehman., Connelly.K, Crespi, N.: K. Laghari, " Towards Total Quality of Experience: A QoE Model in Communication Ecosystem". **IEEE Communication Magazine April 2012.**

IV. Laghari, Khalil ur rehman., Khan, I, Crespi, N.K.Laghari, " Qualitative and Quantitative Assessment of Multimedia Services in Wireless environment" *MoVid, ACM Multimedia system* USA 22-24 Feb 2012.

V. Hyder,M.; **Laghari, Khalil Ur Rehman**; Hoene, C.; Crespi, N.: "Are QoE requirements for Multimedia Services different for men and women? Analysis of Gender Differences in Forming QoE in Virtual Acoustic Environments" accepted to be published, in IMTIC 2012 to be held on March 28-30, 2012.

VI. **Journal:** Laghari, Khalil Ur Rehman; Hyder,M.; Hoene, C.; Crespi, N.: "Modeling QoE in a Communication Ecosystem: Investigating the Relationship Between QoE and the Virtual Acoustic Environment." **Journal of Universal Computer Science JUCS (Under review)**

VII. **Journal:** Laghari, Khalil Ur Rehman, Yahia, B.I.G., Crespi, N.: "QoE based assessment of VoIP and PSTN services based on operator's customer data". Springer Telecommunication Systems (*Under-review)*

VIII. Laghari, Khalil Ur Rehman, Tung, P.; Nguyen, N.; Crespi, N.: "QoM: A New Quality of Experience Framework for Multimedia Services", Pediswesia ISCC 2012 Turkey. "***Accepted to be published***".

IX. **Journal:** Laghari, Khalil Ur Rehman, Yahia, B.I.G., Crespi, N.: "Analysis of Telecommunication Management Technologies,", International Journal of Computer Science (2010).

X. S.H. Shah Newaz, **Khalil Laghari,**Gyu Myoung Lee, Jung Yun Kim, JunKyun Choi; "*A Simulation Study for Understanding Energy Consumption in EPON and GPON* "; International conference on Electronic, Information and Communication (ICEIC2012), February 1-2, 2012

XI. S.H. Shah Newaz**, Khalil Laghari,** Gyu Myoung Lee, Noel Crespi, JunKyun Choi;" *Energy Efficient Shared WDM-PON*"; International Conference on Advanced Communication Technology (ICACT), Feb 19-22,2012.

XII. T. H. Falk, Khalil Laghari, Sebastian Moller, et al., "Preliminary findings on image preference characterization based on neurophysiological signal analysis. Towards objective QoE Modeling", QoMex 2012 (Under review)

XIII. **Patent:** in collaboration with FT orange**:** "QoE Framework for Smart Phones". "In process".

XIV. SERVERY Deliverable 4.4.1 (QoS indicators specification for SERVERY Marketplace).http://projects.celtic-initiative.org/servery/

XV. SERVERY Deliverable 4.4.2 (SLA Management Mechanism for distributed SERVERY Market place.

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« *Tout a un début, une existence, une fin.* »

Philippe Starck

Chapter 1. Introduction

This chapter outlines the context, motivation, contributions and organization of this thesis.

1. 1. Context

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 the autonomic network management paradigms aspire to bring human-like intelligence to telecommunication management tasks [**1**]. 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. As per global consumer survey report 2011 for multimedia services [**2**], it was reported that half of the customers around the world cited "quality" as their top requirement. Furthermore, customers are willing to pay for better quality of experience with multimedia services [**3**] but if multimedia service providers fail to provide promised quality, this will lead to a chain reaction of negative word of mouth, as reported in [**4**] that on average nearly nine in 10 customers globally told the people around them about their bad experiences. And this poor customer experience remains the number one force pushing customers into the arms of waiting competitors.

Multimedia service providers' goal is to have a sustained growth. The key for sustained growth is in a reliable customer engagement i.e. to attract new customers as well as retain existing customers [**5**]. The Connected Consumer survey 2012 [**6**] reports that "…the European and USA market for many core telecoms and media services – such as fixed broadband, voice and pay TV – is saturating. As a result, customer satisfaction and retention – which have always been important – have become critical."

Despite technological soundness and quality, the surprising results reported in survey [**5**], that only 1/4th of customers remain loyal customers. The 2/3rd customers switch an operator because of a poor customer service and furthermore 44% customers said, their expectation is higher than last year. It means satisfaction is not sufficient to keep customers loyal, it is actually to anticipate, and understand customer expectations, needs and behavior those are constantly evolving and shifting at ever faster pace, driven by the seemingly unlimited possibilities of the multimedia services, applications, devices and packages. To sum up, both from technological and business point of view, the main driver is a customer/ user. For sustained growth and technological innovation, customer/user centricity should be made the top priority.

Few quotes of industry experts are given below to see their say on customer experience.

"There is only one boss. The customer. And he can fire everybody in the company from the chairman on down, simply by spending his money somewhere else."

Sam Walton, Walmart [**7**]

"In the world of Internet, it's important to remember your competitor is only one mouse click away." Doug Warner [**7**]

"Your customers expect your entire operation to revolve around them."

SAP Ad

It, therefore, has become very essential to understand human centric quality requirements, and for this purpose the term Quality of Experience (QoE) has been coined. QoE is a multi-disciplinary approach based on social psychology, cognitive science, economics and engineering science, focused on understanding overall human quality requirements. Traditionally, technology centric approaches based on Quality of Service (QoS) parameters have been employed to assess the quality of multimedia services offered to end-users. QoE expands this horizon to capture people's aesthetic and even hedonic needs. QoE provides an assessment of human expectations, feelings, perceptions, cognition and acceptance with respect to a particular product, services or applications [**8**].

QoE is complex multi-disciplinary approach, several technological, business and contextual factors [**9**] could affect QoE as shown in Figure 1. Technological aspects, such as; service features, end-user device functionalities and QoS parameters may influence the feelings and perception of a user. Similarly, business aspects for example, customer care, service offers, cost, promotion and brand image may also influence customers to develop positive and/or negative feelings about quality. Research in human behavior psychology also proves that variation in context and environmental aspects also influence human behavior [**10**]. Therefore, in order to understand and measure QoE requirements for multimedia services, it is important to know the interaction between human, technology, business and context as well as their effect on QoE.

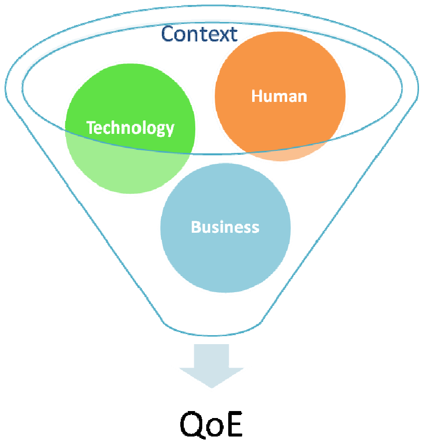


Figure 1: Conceptual diagram of QoE and Influencing factors

In short, we can sum up that customers and end-users are actually driving force behind the success and/or failure of any product or service. Today, customers are becoming increasingly demanding about the quality of multimedia services and application, this requires to bridge the gap between what customers want and what they actually experience. If multimedia service providers aspire to become market leaders by providing high quality service to their customers, they need to understand user's QoE requirements and implication of poor quality of experience on their own customer base and their future profitable growth. Therefore to retain existing customers and make them loyal, a service should be designed and delivered based on the bench marks of QoE. In the next section, the motivation for this research work is presented.

1. 2. Motivation

Multimedia services are one of the main drivers of current ICT business. Multimedia communication refers to machine-processed information expressed in multiple Medias, such as text, voice, graphics, still image, audio, video and interactive data. Due to technological advancements, multimedia services such as teleconferencing, VoIP, video streaming, e-learning, e-health, and e-business are experiencing significant growth. For their evaluation, QoE approach could be used to provide customer and/or end-user perspective about offered quality. In this cutthroat market, it is an essential task for multimedia service provider to deliver multimedia services with superior QoE in order to retain their customers and maintain their competitive edge. A superior multimedia QoE will result in satisfied customers, leading to a positive market perception and ultimately better brand image.

If any service or product is designed on the benchmarks of QoE, it possibly generates positive word of mouth and "wow" factor to attract new customers and satisfy existing customers. Therefore, for widespread acceptance, it is not only important to design multimedia services on the benchmarks of QoE but service providers should also deliver service to end-users/customers with superior QoE.

However, there are following challenges and bottlenecks to be addressed in order to obtain total QoE for multimedia services as described below:

i. At conceptual stage, the fundamental questions which need to be addressed are: Is there any need to changer paradigm from QoS to QoE? And what are other important multi-disciplinary domain characteristics which could influence human QoE and moreover, how to develop a holistic and integrated QoE model based on these disparate domains?

ii. Are QoS parameters sole influencing factors or context and business metric could also influence human QoE.

iii. How to make use of psychological theories (such as Technology Acceptance Model (TAM), Theory of Planned Behavior (TPB)) for QoE?

iv. Human behavior is random and subjective in nature, how to quantify human subjectivity?

v. Which technique to be used to measure QoE for multimedia services e.g., user studies or objective inference techniques?
vi. Which test environment and test set up should be selected for user study e.g., laboratory or natural environment?
vii. Is QoE only a subjective factor? Or human objective factors e.g., human physiology and cognitive factors could also be utilized to benchmark QoE?
viii. Is QoE a unique global metric suitable for every user or we need to moderate QoE based on human demographics and context?
ix. Which technique to be used for data analysis, quantitative or qualitative? Parametric or non parametric etc?
x. Can we exploit QoE findings to develop some QoE frameworks or tools?

This whole thesis is an attempt to answer these challenges and now a brief description is given to discuss these challenges.

1. 2. 1. Conceptual view on QoE

- ***Change of Paradigm is required:*** Traditional approaches for ensuring quality and user satisfaction are technology centric QoS based approaches. Since, QoS relies more on network and application layer parameters, it is therefore unable to satisfy the customers and/or end-user needs. Existing QoS based solutions for internet are IP DiffServ, IP Intserv they may guarantee resource allocation however, service guarantees alone are not sufficient to promise superior quality of experience [**11**]. As QoS based quality assessments have often found to be grossly inaccurate at predicting user experience, and as such are not applicable in evaluating multimedia quality [**12**]. Therefore, there is need to change the direction from technology centric QoS to human centric QoE approach.
- ***Importance of Influencing Factors:*** In addition to technology, there are business and context domain characteristics which could also influence human behavior, therefore QoS is not sole influencing characteristic but human behavior could be influenced by many internal (subjective factors and objective cognitive factors etc.) and external (business, context) factors [**9**]. Thus, for a holistic and conceptual

understanding of total QoE for multimedia services in communication ecosystem, it is required to model QoE considering the influence of all these internal and external factors.

1. 2. 2. QoE Measurement and Analysis complexity

Once conceptual understanding about QoE is quite clear, it is required to measure and analyze QoE factors for different multimedia services. But it is quite complex to capture QoE metrics considering the influence of all these internal and external factors at the same time. We need to address some prominent issues related to QoE measurement and analysis as described below.

- ***Human Subjectivity:*** The important challenge is related to randomness of human behavior; not all humans have similar preferences, feelings or perceptions about a particular service and furthermore, their perception and preferences continuously change over the time. Generally QoS and business parameters are easily monitored and engineered due to their quantitative nature but as human perceptions and feelings are inherently subjective and the levels of expectation vary between users, thus, it is hard to quantify and measure QoE with complete accuracy.
- ***User Studies vs. Indirect inference (Objective QoS) method[2]:*** To capture subjective QoE (perceptions, feelings etc), there are two main methods; one is to conduct user studies, customer surveys and interviews and another is more engineering version which infers QoE from collected network traffic or QoS data based on some estimation or prediction methods. Subjective method is time consuming but it provides more accurate results, while indirect methods are less time consuming but their accuracy is always dependent on the prediction method and moreover they are focused on QoS data only. They may also miss out the influence of other important information (such as contextual, business, expectations etc) which could be gathered through surveys and user studies. The second part of thesis is based on subjective QoE studies and data evaluation.

[2] They are also called objective assessment techniques. Examples are PESQ, PSNR,P.OLQA, E-Model (refer chapter 4 for detail)

- ***Laboratory test vs. field test:*** Should user studies be conducted in controlled lab environment or in natural living environment? Some experts believe that as lab setup does not provide a sense of real environment, it may lack to produce exact human perceptions or feelings [**13**]. But on the other hand, lab test provides more flexibility to control the influencing factors. Chapter 5, and 7, of this thesis discusses Lab based user study results, while chapter 6 is based on natural environment experience of real customers.
- ***Human Objective[3] QoE factors:*** Human objective factors are related to human physiology and cognitive system [**14**] [**9**] [**8**]. Unlike human subjective factors, most objective factors are quantitative in nature and they provide precise information about human cognition and physiology (refer chapter 2, 3 and 4 for more detail). In chapter 7, one objective QoE factor is coined and its evaluation is presented with respect to its subjective QoE counterpart.
- ***QoE global metric vs. segmented metric:*** Some of the QoE based findings may be global or universally similar for every user but certainly not all; therefore should QoE be moderated based on different age groups, gender, and social factors? [**9**].
- ***Qualitative vs. Quantitative assessment scheme:*** Quantitative assessment techniques work on numerical data and statistics. Qualitative schemes are used to analyze verbal behaviors such as words and user comments, not numbers [**15**]. Quantitative schemes are widely used techniques for assessment because they are easy and can produce concrete results, while qualitative data are hard to code and they are also difficult in deducing some meaningful information from them [**16**]. However with widespread success of Web2.0, user comments on social media have increased and therefore qualitative schemes are also getting more focus now.

1. 2. 3. QoE based tool development

There are many tools available to measure QoS parameters but QoE specific tools are hardly available for measurement and evaluation of user/customer experience data, probably due to complexities related to QoE data as discussed earlier. Some of the prominent problems

[3] Objective QoE factor should not be confused with objective QoS parameters.

are users' lack of interest in giving their feedback, human subjectivity, the cost of objective physiological tools, and time consuming study and evaluation process. Some companies[4] have started developing QoE based tools but they mostly focus on Objective QoS/QoE factors such as perceptual evaluation of speech quality (PESQ) technique [**17**] and peak signal to noise ratio (PSNR).

In the next section, the contributions of this thesis are presented which are focused on solving some research challenges discussed in this section.

1. 3. Contribution of the thesis

The contributions of this thesis could be broadly divided into three parts as show in Figure 2.

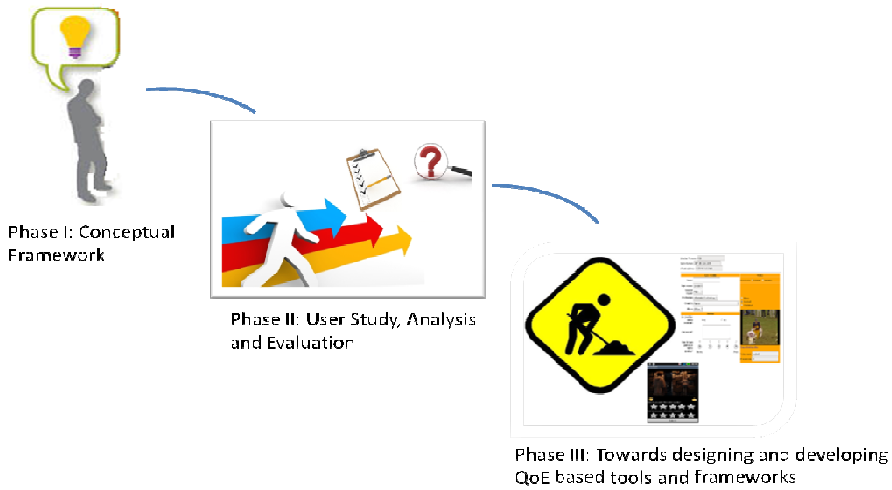


Figure 2: Contribution

1. *Proposing a holistic QoE model:* In the first stage, it is important to understand the big picture of QoE i.e., the different internal and external factors which could influence human behavior. For getting a holistic view of QoE, it is essential to bring disparate actors of communication ecosystem (human, technology, business and context) together in a systematic fashion. Therefore, the motivation is to address this challenge by proposing a conceptual and holistic QoE model comprising all domains of a communication ecosystem.

[4] www.witbe.net, www.ibys.com/, www.qoesystems.com

Some of the notable aspects of the proposed model are (i) the objective QoE factors (physiological and cognitive factors) and their link with subjective factors, and (ii) the differentiation of QoE requirements based on human roles (customer, user, group) and characteristics (age, gender), (iii) the influence of technical and business and contextual aspects on QoE. My papers I, II, III are contributions related to this part of thesis work.

2. *QoE based Analysis and Evaluation of real time multimedia services with respect to QoS, context, content and human characteristics (age, gender etc):):* This part primarily focuses on practical approach of conducting user studies over multimedia services (video streaming, VoIP, 3D Audio teleconferencing) to evaluate and establish statistically significant relationship between QoE and influencing factors (QoS, virtual context) etc. Table 1 presents summary of work done in this phase.

Table 1: Summary of Phase 2 contribution

	Study I: Video Streaming Service	**Study II: Telephony (VoIP and PSTN)**	**Study III: 3D Audio Teleconferencing Service**	**Study IV: 3D Audio Teleconferencing Service**
Relationship	QoS- QoE	QoS- QoE	Contex-QoE	Contex-QoE
QoE Factors	User Perceived Video Quality and User comments	Perceived Availability, Perceived Call Quality, Customer satisfaction and customer preferences	Localization Performance, Localization Easiness, Spatial Audio Quality and Overall Audio Quality	Localization Easiness and Performance
Influencing Factors	Network and application level QoS	Technical faults and QoS issues	Virtual teleconferencing room size and concurrent talkers	Virtual teleconferencing room size
Moderation Factors	Content characteristics	Age, end-user device type	non	Gender
Study Setup	Lab based user study (Quantitative and Qualitative)	Customer Survey (Quantitative technique)	Lab based user study (Subjective and Objective QoE Factors)	Lab based user study (Subjective and Objective QoE Factors)
Analysis	Descriptive statistics, Rough Set Theory and CCA framework	Basic Statistics, Hypothesis testing based on Chi-Square	Basic Statistics	Point estimators, Adjusted Wald Method, basic statistics

My papers IV, V, VI, and VII are my contributions related to this work.

3. *Design and Development of prototypes/frameworks for measuring QoE for multimedia services:* Based on the first two contributions, currently two QoE measurement frameworks are being developed. The main functionalities of both QoE frameworks are to capture, analyze and report multimedia QoE metrics in real time. Both are used for video streaming service, but one is designed for android based smart phones with limited monitoring and evaluating capabilities and second one is exhaustive framework with more capabilities of the QoE measurement and analysis. These QoE tools are expected to be useful for real time measurement and evaluation of multimedia QoE metrics. My paper VIII and Patent[5] are contribution to this work.

1. 4. Organization of the thesis

Based on research contributions, this dissertation is also organized into three parts;

First part covers concept, theories and models around QoE. In this part, we present a broad overview of literature (Chapter 2) and then present our proposed QoE model (Chapter 3).

Chapter 2 presents a broad overview of literature related to QoE concepts with respect to QoS, HCI, business, context, psychology, and biology. It is subdivided into two sections, section I includes QoE related research which is being carried out in different disciplines. And section II presents an overview of existing QoE models proposed to understand QoE.

Chapter 3 presents proposed QoE model, comprising all domains of a communication ecosystem. This consolidated model extends prior work on QoE modeling by defining new taxonomy and by linking all the domains of communication ecosystem.

The second part of dissertation primarily focuses on practical approach to conduct user studies over multimedia services (video streaming, VoIP, 3D Audio teleconferencing) and analyzing the impact of various influencing factors on QoE. This part consists of four chapters as given below.

Chapter 4 presents an overview on different QoE assessment methods, analysis techniques and tools.

[5] Joint patent with Orange France Telecom (in-process)

Chapter 5 presents user study I experimentation results to evaluate the (combined) impact of the network and application level QoS parameters and content characteristics over user perceived quality for video streaming service. Rough Set Theory (RST) is used for quantitative assessment and simple CCA (Categorize, Catalog and Analyze) framework for qualitative assessment of user data in order to understand the influence of multiple multimedia service parameters on QoE.

Chapter 6 presents the analysis of operator's customer survey for telephony services (PSTN and VoIP) to understand the effect of various technical faults (call drop, echo etc) over different QoE factors such as Perceived Call Quality, Perceived Availability, Customer Preferences, and Overall Customer Satisfaction. Furthermore, it is also shown that how QoE metrics could also be differentiated with respect to customer age and types of end-user device.

Chapter 7 presents user study and data analysis to study the relationship between QoE and virtual contextual environment. 3D Audio Teleconferencing service is selected as use case service for experimentation. We analyze and validate relationship between QoE and contextual parameters in two different test scenarios through user experimentation. Findings of user study are presented to show that how subjective and objective QoE factors are affected due to virtual acoustic environment. Furthermore it will also focus on the effects of gender differences on QoE based on virtual acoustic environment.

In the third part of dissertation, architecture and implementation details of QoE tools or framework is presented for measuring QoE for multimedia services. This part includes two chapters as given below.

Chapter 8 presents architecture and implementation details of QoE framework for video streaming services

Chapter 9 presents QoE frameworks for Android based smart phones to evaluate the QoE of video applications.

Finally, in Chapter 10, conclusion and perspective to our future work direction will be discussed.

PART 1. CONCEPTS

Introduction

The notion of “Experience” spans to many different fields, as different stake holders have identified the need to better understand the value, customers/end-users attribute to products and services. The concept of experience brings human centric value for service delivery (Quality of Experience), human-computer interaction research (User eXperience, UX) and industry (Customer Experience). Quality of Experience is a fast emerging multi-disciplinary field based on social psychology, cognitive science, economics and engineering science, focused on understanding overall human quality requirements. Keeping in view the multi-disciplinary approach of QoE, the goal of this part is to learn from existing research in different disciplines to build a conceptual QoE framework.

This part consists of two chapters:

Chapter 2, in which we present a brief overview on how human centricity (QoE) is treated in different disciplines and afterwards, we present existing QoE models or frameworks which try to capture the holistic QoE by integrating different domains (technology, business etc).

Chapter 3 is based on our proposal for holistic QoE model, comprising all domains of communication ecosystem (technology, business, context and human).

*"The words printed here are **concepts.***
You must go through the experiences."

<u>Saint Augustine</u>

Chapter 2. Background: Exploring Quality of Experience

Highlights

- How the notion "Experience" is treated in technology, business and context?
- Psychological models for understanding human behaviour
- How the use of human physiology and cognitive will be beneficial for understanding human reactions (e.g., QoE)?
- Discussion on existing theoretical models for QoE

This chapter presents a high level state of art on QoE. At first, we present definitions of QoE and then we present an overview on how “Experience” notion is studied in different disciplines such as technology (HCI and QoS), business, psychology and context. Afterwards, we present the work of different people who attempted to bring disparate domains together to build a conceptual QoE model or framework.

2. 1. QoE Definitions

We present some definitions to show how this notion “QoE” is actually seen by different people.

i. **Extension of QoS concept:** “QoE has been defined as an extension of the traditional QoS in the sense that QoE provides information regarding the delivered services from an end-user point of view”. [**18**]

ii. **Usability as QoE:** “QoE is how a user perceives the usability of a service when in use **–** how satisfied he/she is with a service in terms of, e.g., usability, accessibility, retainability and integrity”. [**19**]

iii. **Business dependent QoE:** “The quality of a customer’s experience with business is dependent on thoughtful design of web sites, streamlined business processes that are designed to make the customer’s job easier, carefully respected policies, good customer service, and excellent operational execution.” [**20**]

iv. **Degree of Delight as QoE:** “QoE describes the degree of delight of the user of a service, influenced by content, network, device, application, user expectations and goals, and context of use”. [**21**]

v. **Subjective human experience as QoE:** “The overall acceptability of an application or service, as perceived subjectively by the end-user.” [**22**]

vi. **Subjective human experience and Objective (Cognitive) Human factors as QoE:** **“**QoE is a set of human centric factors based on human subjective and objective cognitive aspects arising from the interaction of a person with technology and with business entities in a particular context” [**8**].

First three definitions of QoE are more inclined towards a particular domain. These definitions link QoE with QoS, HCI and business metrics respectively. QoE is multi-disciplinary field, so different stake holders define QoE as per their own needs and understanding. There was a need to have some general discipline-agnostic definition which includes human psychological aspects. Definitions IV & V serve well this purpose as they encompass all necessary aspects which impact human subjectivity. However, over the time, it was also learnt that in addition to human subjective factors, there are also human objective factors (e.g., physiological and cognitive aspects) which also impact QoE. And to make QoE more comprehensive and potentially more valid, it is needed to include objective human factors along with subjective psychological measures [**8**] [**14**]. Thus definition VI is an emerging definition of QoE which includes both human subjective and objective aspects.

As QoE is getting mature over the time, more comprehensive and exhaustive definitions are emerging to better understand QoE notion. And this trend will continue in future too, till QoE reaches to its complete maturity. In next, it is discussed that how QoE notion is understood or being treated in different disciplines.

2. 2. QoE and Technology

Technology has become integrated into almost every sphere of human life. The tremendous technological growth has drastically changed the lifestyle of people in our society. It has both positive impacts and negative implications on human behavior. However, the negative and positive effects of technology depend completely on people's exposure to it and the use that they give it. [**23**]

The field of HCI (Human Computer Interaction) has been incorporating human factors to product/interface designs for many years. However, for network performance and service delivery; there is a recent trend to make a leap from technology centric Quality of Service (QoS) approach to human centric Quality of Experience. Next, we present an overview on how the work in HCI is shifting from interaction to User eXperience (UX) and how paradigm is shifting from QoS to QoE for service delivery.

2. 2. 1. HCI and Interface Design: From Usability to User eXperience

With the advent of personal computers in 1980s, the need for understanding the interaction between human and computer emerged and this led to new discipline called Human-Computer Interaction (HCI). It is defined as "the study of how humans are interacting with computers, and how to design systems that are usable, easy, quick, and productive for humans to use" [**24**].

Ergonomics is widely used in HCI and it is the engineering science concerned with the physical and psychological relationship between machines and the people who use them [**25**]. The ergonomicists take an empirical approach to improve the efficiency of operation by taking into account a typical person's physiological capabilities and physiological stresses, such as fatigue, speed of decision making, and demands on memory and perception.

Usability is most widely recognized metric in HCI and it is defined as “the effectiveness, efficiency and satisfaction with which specified users achieve specified goals in particular environments” [**26**]. User experience includes all the users' emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviors and accomplishments that occur before, during and after use [**26**]. The aim of usability metric is to design an easy to use product. User eXperience (UX) is about feelings. It is defined as “a person's perceptions and responses that result from the useor anticipated use of a product, system or service” [**27**]. Unlike usability metric, UX is purely a subjective metric. To understand the difference between usability and UX, take an example of a web site, the aim of usability is to make that web site easy to use whilst the aim of user experience is to make the user happy before, during and after using that web site. Thus, usability relates to the ease with which users can achieve their goals while interacting with a web site while user experience is concerned with the way users perceive their interaction with that web site [**28**] . A shift away from usability engineering to a user experience makes user's feelings, motivations, and values as core set of parameters for HCI.

In HCI, there is also an on-going effort to extend the boundary of HCI to incorporate not only hedonic quality but also business aspects, as it is done in [**29**].

Though the term “QoE” is not explicitly employed in HCI yet we see terms like "Usability”"and "User Experience" being used frequently in HCI [**29**] [**30**], which closely relate to QoE notion. As product/interface design principles are getting UX-centric, there is also need for the transformation of networks and service delivery paradigms to become QoE-centric, so that user could enjoy a service from design to delivery with superior quality of experience.

2. 2. 2. From Technology-centric QoS to Human-centric QoE

Quality of Service (QoS) is defined as the collective effect of service performance which determines the degree of satisfaction of a user of the service [**31**]. Traditionally, QoS metrics are defined, measured and controlled to achieve a satisfactory level of service quality. These QoS parameters can be grouped under Application-level QoS (AQoS)—which deals with parameters such as content resolution, frame rate and codec type; and Network-level QoS (NQoS)—which deals with parameters such as bandwidth, delay, jitter and packet loss. These QoS metrics are typically used to indicate the impact on the service quality from the technological point of view. However these technical parameters cannot provide complete assessment about user feelings and perceptions. Consequently, the need for accurate understanding of human perceptions, feelings and requirements lead to a new concept called Quality of Experience.

There are ongoing efforts both in industry and academia to link QoS with QoE to understand the impact of technical parameters over quality of experience. Like in [**32**] the relationship between QoE and QoS is investigated and authors proposed logarithmic dependencies between QoS and QoE in order to understand the quantitative relationships and causality issues between these two quality concepts. In [**33**], the QoE and QoS relationship is analyzed based on IQX hypothesis and they proposed exponential interdependency not only between QoE and packet loss but also between QoE and packet reorder for iLBC codec. In [**16**], we presented quantitative and qualitative assessment results for understanding relationship between multiple QoS parameters and QoE in video streaming service. There are different qualitative and quantitative assessment methods for QoS and QoE relationship evaluation (cf. chapter 4 for detail). For measuring total quality experience, work on QoS is critical, but not sufficient, because considering QoS as sole representative construct of QoE may not satisfy all human needs. Other important aspects also need to be considered such as, user contextual information, type of multimedia content, demographic attributes, role of marketing, social and organizational pressures, pricing, etc. Table 2 presents comparison of HCI and QoS-QoE work.

Table 2: QoE and HCI

Factors	QoS- QoE	HCI
Focus	Network and Service (Delivery Aspects)	Interface and Applications (Design Aspects)
Experience Terminology	Quality of Experience	User eXperience (UX)
Classification of QoE Factors	Subjective and Objective QoS Metrics	Subjective and objective (physiological) metrics
Standardization	ITU-T, ETSI	ISO 9241 Series
Consideration of contextual (environmental) factors	Minor	Medium to Major
Business aspects	Minor	Medium

2. 3. Business: From Service to Customer Experience

In today's cutthroat market, how a business entity differentiates itself from the others is the main challenge and only the viable solution for a business entity is to improve and enhance the customer experience. The traditional marketing approach focuses on the four Ps (Product, Price, Promotional activity and Place) and it is based on notion that any customer is a good customer [**34**]. 4P approach is focused on attracting new customers through price and packages, and, of course, companies spend millions on marketing and advertisement. But 4P lacks to address how to retain existing customers or make customers more loyal to company. A new approach has emerged to address weaknesses of 4P, it is named as 3R (Retention, Related sales and Referral) [**34**]. 3R approach focuses on existing customers to make them more loyal to service by providing a rich customer experience. A loyal customer will prefer to buy related products from the same company and s/he can refer product to others and this will definitely boost profitability. Considerable research in marketing and management has already been done to analyze customer retention and customer satisfaction with service experiences [**35**] [**36**]. In [**37**], the authors presents result of a customer study to understand customer intentions to stay loyal and satisfied based on various factors such as price perception and service attributes.

Business people are trying to improve customer experience, while at the same time improving their revenue and throughput. In [**38**], the authors present a Pareto-optimal strategy that aims to satisfy customer experience requirements while at the same time improving business parameters like revenue and throughput of the service providers. Since customer experience is a subjective term, without a concrete meaning or value attached to it, it cannot be precisely measured. In [**39**], the concept of QoBiz (quality of business) metrics and evaluation is introduced which builds up an evaluation framework relating QoS, QoE and QoBiz factors. Authors try to model their interaction in order to quantify the customer experience and the business return, respectively.

In [**40**], we presented a customer experience based ontological model to make service design and configuration more customer centric. In TMF forum, customer experience is the main theme in their reports and standardization efforts [**41**]. They present customer experience model for multimedia services and they discuss two way value chain of revenue sharing. They use Key Factor analysis to map customer experience needs with service features and QoS parameters [**41**].

Business metrics do have a big impact on shaping customers' buying decisions. Most of the work in marketing and customer relationship management revolves around customer surveys and it provides sufficient information, however business people may not understand complete picture of customer experience requirements unless they have a clear view to technological aspects.

2. 4. Contextual information: Towards Personalized and Customized Experience

Context is any information that can be used to characterize the situation of an entity and it is typically the location, identity and state of people, groups, and computational and physical objects [**42**]. In simple words, we can define it "context represents the situation and circumstances in communication ecosystem." Research in human behavior psychology also proves that variation in context and environmental aspects influence human behavior [**10**].

In HCI, context is one of the key influencing factors, there is one standard ISO 9241-11 [**43**] which introduces the concept of a work system, consisting of users, equipment, tasks and a physical and social environment, in order to achieve a particular goals. This standard focuses on the importance of context of use for any service or application in use.

Today dynamic growth of mobile communication technologies has fueled the efforts to realize the mantra of *Any Where, Any Time, Any Service;* it makes context awareness a key component for service customization and personalization. There are many researches available in literature [**44**] [**45**] [**46**] which discuss about context-aware personalized services. Context aware personalized services produce better service personalization and user experience based on user context, however they are not widely used because of the lack of effective infrastructure to support these features [**44**].

In addition to real context, the virtual environment also plays an important role in interactive multimedia services such as audio teleconferencing, E-learning, and interactive gaming. A 3D audio teleconferencing system generates a virtual teleconferencing room.

It could be summarized that the research in context aware personalized services could be helpful addition to improve quality of experience in telecommunication ecosystem based on contextual data (GPS etc). Furthermore, with the growth of interactive multimedia services, the people to people interaction through virtual environment is also increasing, and therefore the influence of virtual context over human behavior should also be studied. We conducted user study to evaluate the impact of virtual environment characteristics on QoE (cf. chapter 7) and we learnt that with change in virtual room size, the QoE value also changes. Table 3 summarizes the QoE related work in each domains discussed in current part.

Table 3: Comparison of various disciplines w.r.t QoE

Interaction	Discipline	QoE related terms	Positioning
Human-to-Technology	HCI and Interface Design	User Experience and Usability	Service Design Phase
Human-to-Technology	Networks and Service	Quality of Experience, User Experience	Service Delivery Phase
Human-to-Business	Business	Customer Experience and Customer Satisfaction	Industry: Customer Touch points, CRM, Marketing, Sales
Human-to-Context	Context aware services, Interactive multimedia services	Personalization, Customization, Localization Easiness etc	Service design and delivery

2. 5. Understanding Human Behavior: A look into Human Psychological Models

The human behavior is studied in human Psychology. In [**47**], Psychology is defined as “the study of the mind and behavior. It embraces all aspects of the human experience — from the functions of the brain to the actions of nations, from child development to care for the aged, in every conceivable setting from scientific research centers to mental health care services”. Psychologists tend to understand human behavior and cognitive capabilities. Various technology adoption models have been proposed to understand how different factors influence human behavior in making a decision to adopt a product or not. Few of them are presented below.

2. 5. 1. Adoption Theories and Models

The psychological models such as Technology Acceptance Model (TAM), Theory of Planned Behavior (TPB) and Unified Theory of Acceptance and Use of Technology (UTAUT) consider *“intention”* as the main driving factor for human behavior [**48**]. Intentions are normally triggered by some motivational factors which influence human behavior; they are indicators of how hard people are willing to try, of how much of an effort they are planning to exert, in order to perform the behavior [**49**].

A widely recognized model is the Technology Acceptance Model (TAM) which is a derivative of the Theory of Reasoned Action (TRA) [**50**]. TAM is applied to a broad range of information technologies to predict both human intentions and system usage. There are two major predictors of behavioral intention based on theory of reasoned action:

- **Attitude:** describes individual’s internal positive or negative feelings to perform some behavior or not.
- **Subjective Norm/Social Norms (SN):** denotes the fundamental social pressures on an individual’s perception to perform some behavior or not.

Meanwhile, TAM proposes that perceived ease of use and perceived usefulness of technology are predictors of user attitude towards using the technology [**50**]. However, the TAM model severely lacks to address the fact that behaviors are often not under volitional control [**49**]. To address this issue, the Theory of Planned Behavior (TPB) was introduced by I. Ajzen [**49**] (Figure 3 shows TPB model diagram). I. Ajzen proposed an extension to TRA by adding one additional aspect called Perceived Behavioral Control (PBC) in order to reduce the limitations of TRA/TAM. PBC factors refer to whether the person feels in control of the action in question. System complexity, pricing, and facilitating conditions are factors of PBC.

There is also an extended version of TPB called Decomposed TPB (DTPB) which includes detailed sub classification of parameters. The DTPB model was found to have better predictive power compared to the traditional TPB model and the TAM model [**51**], further more it provides a comprehensive way to understand how an individual's attitude, subjective norms and perceived behavioral control can influence his or her intention, taking into account following factors:

- **Personal attitude factors:** usability, usefulness, comfort, and happiness
- **Social factors:** friend & family, organizational pressures, and legal aspects
- **Perceived Behavioral Control:** Cost, complexity, help desk and other facilitating conditions

TPB and DTPB model sums up the influence of internal human factors (attitude) and external factors (social norms) and control factors (price, complexity of system etc) to get precise human behavior.

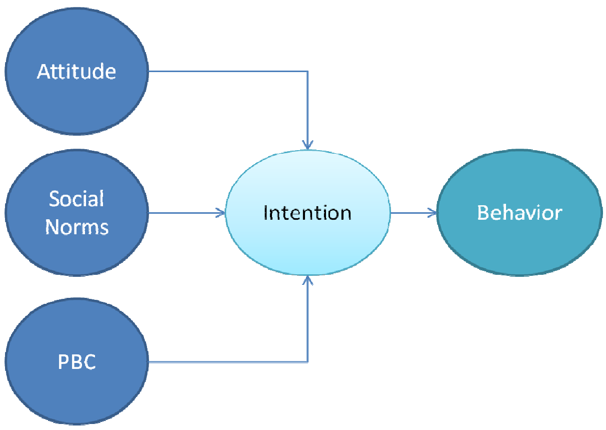


Figure 3: TPB Model

These psychological models could be used in user studies for understanding the influence of various factors (attitude, social norms, PBC) over human behavior. Wanmin Wu et al. in [**52**] propose the use of TAM model as QoE construct in distributed interactive multimedia environment. In [**53**] author uses a TAM model for pervasive computing to understand human behavior towards adoption of pervasive computing. Psychological models such as TAM, TPB, and UTAUT are more focused on understanding human behavior in terms of technology (product/service) acceptance. But they do not consider human behavior during service use and/or the impact of service delivery characteristics over human behavior. Therefore, there is also need for some model which also provides assessment about in-service customer/user requirements.

2. 6. Physiological and Cognitive Factors

In addition to human psychology, there is an on-going effort to understand human behavior using physiology, psycho-physics and cognitive science.

Physiology is a life science and it studies various biological organs and systems. Examples of human physiological aspects are brain waves, heart rate, blood volume pressure, respiration, and skin conductivity.

Cognitive science and mental models are also used to understand human task performance. These models provide precise quantitative information about human performance and cognitive capabilities. Examples of human cognitive aspects are task performance, memory, attention, human activity, language and human reaction time.

Psycho-physics is the branch of psychology concerned with quantitative relations between physical stimuli and their psychological effects on human sensation and perceptions [**54**]. The use of psycho-physics for audio-visual systems has received increased attention with the innovation and development of teleconferencing, computer games, and virtual reality systems. Physiology, psycho-physics and cognitive science could make a significant contribute to a massing of relevant data about human biological and mental capabilities.

HCI has been using human physiology and cognitive science to understand human cognitive capabilities. In [**55**], a technique is proposed which aims at psychologically interpreting physiological parameters (skin conductance and heart rate), and producing a continuous extraction of the user's affective state during human computer interaction. We also incorporate human physiological and cognitive aspects in our proposed model as objective QoE factors (refer chapter 3), various techniques are presented in chapter 4 on how to capture human physiological and cognitive information.

2. 7. Existing Models for Understanding Quality of Experience

In this section, some of the prior attempts to provide integrated QoE model is presented

Yan Gong et al. [**56**] proposed 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.

Andrew Perkis et al. [**57**] present a QoE model for measuring user experience of multimedia services. Their model consists of measurable technical parameters and non-measurable, subjective, user parameters. All service parameters are considered to be measurable parameters, while user factors such as satisfaction, attitude and habit are considered as non-measurable. In their model, they do not consider objective QoE factors. Objective QoE factors are based on human physiology and biology and thus can be measurable. Subjective human factors can also be quantified using some empirical approaches. Finally, they ignore the impact of context in their model.

Möller et al. [**58**] present a more detailed taxonomy of the QoS and QoE of multi-modal, 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. However, their work is focused on multi-modal human-machine aspects; their focus therefore is limited to specific contextual aspects. Their taxonomy defines user characteristics and user roles, but they do not consider multiple roles (e.g. customer or group). They neglect all business aspects in their model.

Kilkki's model [**59**] presents a simple and intuitive interaction between a person, technology and business as illustrated in Figure 4a. However, it provides neither a classification of QoE factors into sub categories, nor provides any detailed (as shown by the red question marks in the Figure 4a). More importantly, Kilkki’s model does not define contextual parameters in any way.

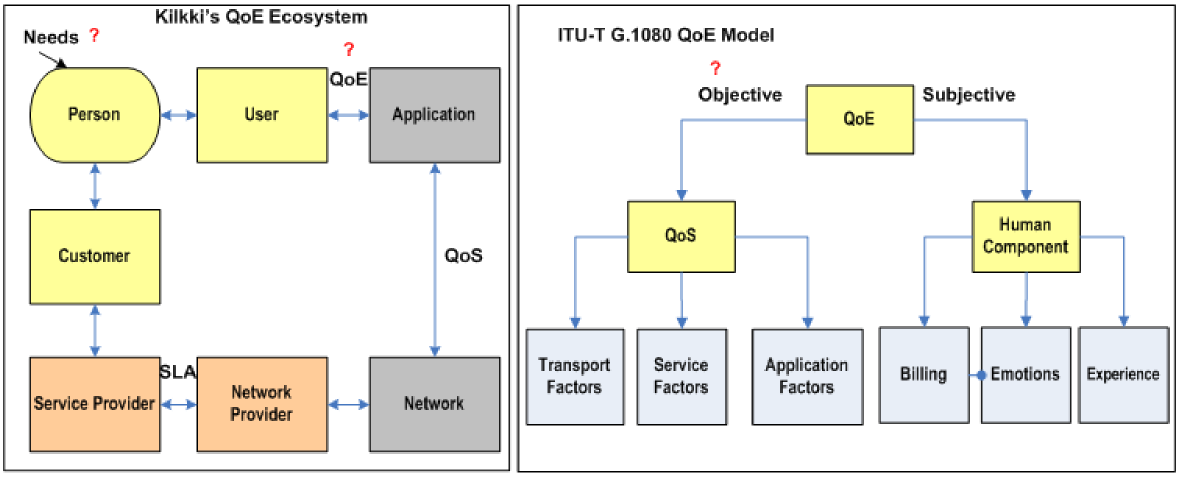


Figure 4: (a) Kilkki' Model (b) ITU-T Model

The ITU-T's G.1080 proposes a QoE model that classifies QoE factors into two parts: subjective human components and objective QoS parameters [**60**] as shown in Figure 4b. 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 part of 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 it is an external influencing factor. Alternatively, like [**14**], we also consider human physical and psycho-physical 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 (refer Chapter 3).

David Geerts et al. [**61**] present a QoE model which includes business, technology, and contextual aspects. They have extended [**58**] 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 with 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 into classes as per different human roles. For instance a customer who pays for online VoIP service may have stricter quality requirements than a user who uses free online voice chat service. Furthermore a father, who buys video gaming service for his child, plays a role of a customer while his child is the actual user of the service. It is quite possible that they would have different QoE requirements.

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

*"All these constructions and the laws connecting them can be arrived at by the principle of looking for the mathematically simplest **concepts** and the link between them."*
Albert Einstein

Chapter 3. Holistic QoE Model in Communication Ecosystem

Highlights

- Conceptual model for multimedia services in communication ecosystem
- Interaction between various domains in communication ecosystem
- Cross-domain mapping
- Comparison between proposed and existing QoE models

3. 1. Introduction

In previous chapter, QoE related concepts and several existing QoE models were presented. Building upon these prior works in QoE modeling, an extended model is presented in this chapter. The holistic QoE model provides a high level theoretical view on the formation of QoE in a communication ecosystem. To understand a big picture of QoE Notion, we define communication ecosystem.

3. 1. 1. Communication Ecosystem

A communication ecosystem represents the interaction between different domains such as technology, business, context and human behavior. 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* [**62**].”A cultural ecosystem is defined as *"a collection of living things and the environment in which they live* [**62**]*.”*

In [**63**], A communication ecosystem was presented comprising of user, technology and business. Our definition extends that work by adding context as part of communication ecosystem. We define communication ecosystem as "*the systematic interaction of living (human) and non living (technology, and business) in a particular context”*. A conceptual diagram of a communication ecosystem is presented in Figure 5. A communication ecosystem consists of technology, business, context and human.

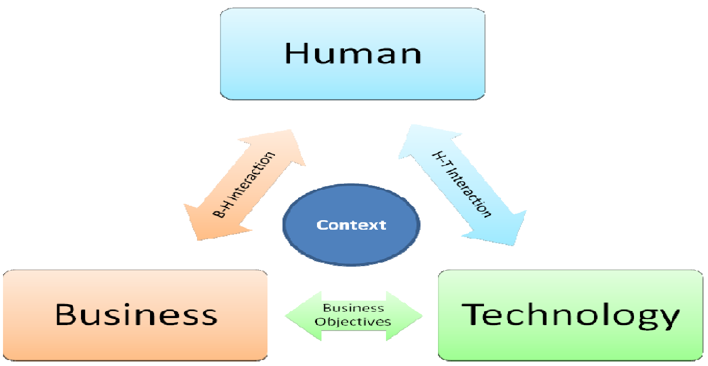


Figure 5: Proposed High level Communication Eco system

A communication ecosystem produces high level blue print of interaction between human, technology, and business in particular context. In Figure 5, Human-to-Technology interaction represents in-service user experience. Various technological aspects such as service features, end-user device functionalities and QoS parameters influence the feelings, perception and performance of a user during this interaction. Similarly, Human-to-Business interaction is based on business models and marketing strategies. Business-to-Technology interactions represent service providers' strategies and business models for their technological infrastructure and how effectively they could make use of their resources to increase their profit by retaining customers as well as attracting new ones. This is also vital link for research; however this is not the focus of current PhD work. Context represents the possible 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.

3. 2. Proposing QoE 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 [**64**]. 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 (Figure 6), human internal factors are part of the Human domain and external influencing factors are divided into technological, business and contextual domains.

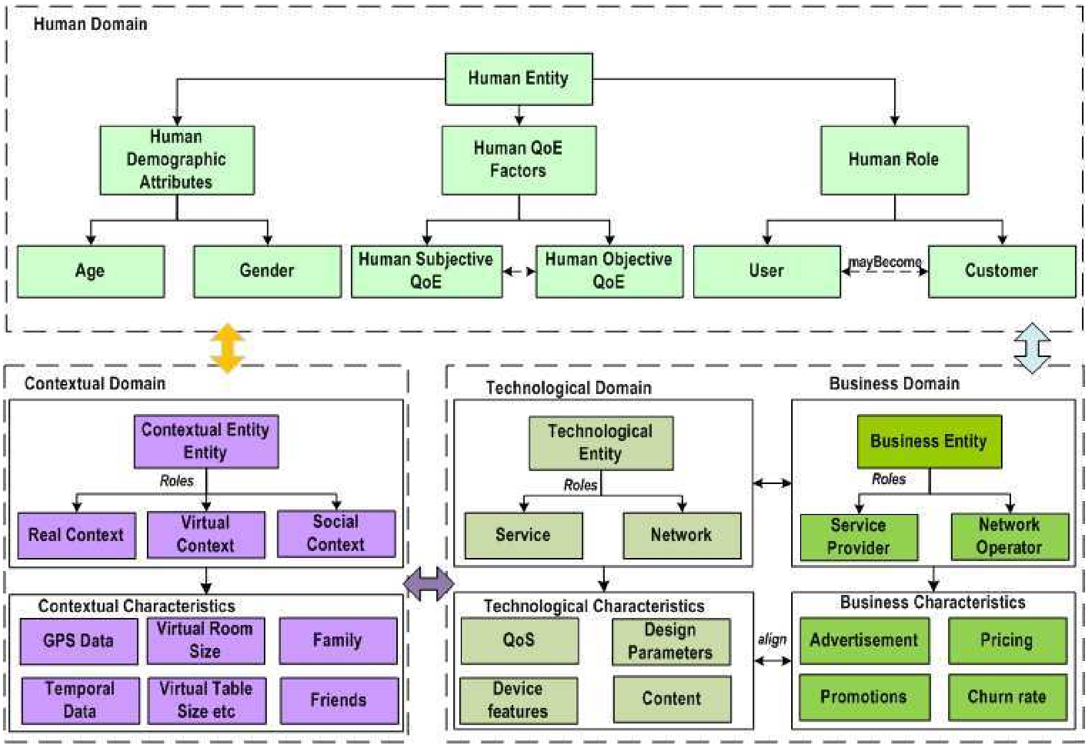


Figure 6: High Level Diagram for QoE Interaction in Communication Ecosystem

In a communication ecosystem, there is a kind of control loop of interactions between various domains which develops consolidated QoE requirements. The major interactions are Human↔Context, (ii) Human ↔ Technological (iii) Human ↔ Business (iv) Technology ↔ Business (v) 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 such as 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 factors include subjective and objective QoE factors, whereas technological characteristics include QoS and end-user device parameters. Each attribute could be transformed into metric; a metric is a mathematical set of relevant, quantifiable attributes.

The principle concept therefore is to understand, agree, and define QoE indicators which are affected by key influencing factors (such as QoS, context, business) for the service or product that collectively can be amalgamated to form a Quality of Experience metric through an empirical, functional, multi-dimensional or complex relationship. A holistic QoE model is thus a conceptual representation of inter & intra-domain relationships in a communication ecosystem. Now we briefly define different concepts related to the QoE interaction model.

3. 2. 1. Human Domain

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.

3.2.1.1 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 about human needs and requirements and 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 [**8**][9]. The selection of suitable psychological methodologies depends upon the nature of service and environment. Subjective QoE factors can be captured and analyzed using qualitative and quantitative techniques as described in chapter 4. In Table 4, examples of subjective QoE factors and evaluation methods are presented.

Objective QoE Factors: These are mostly quantitative factors associated with human physiological, psycho-physical and cognitive capabilities. However objective QoE factors could also be qualitative in nature for example color blind aspects etc of human.

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 4, examples of objective QoE factors and evaluation methods are presented.

Table 4:QoE Factors and Evaluation Methods

	Evaluation Methods	**Example Factors**
Subjective	Surveys, user studies, and customer interviews are popular means for quantifying subjective QoE factors. Through user studies, user perceptions and comments 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. Qualitative techniques such as CCA framework [**16**] could also be used for subjective 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 [**65**]) could be used to gather objective QoE data. Normally, objective QoE factors are quantitative 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.

3.2.1.2 Human demographic attributes and Roles

In addition to QoE factors, a human entity has roles (i.e., customer, user) and demographic attributes (i.e., age, gender etc). People in different demographics (e.g. age and gender) may have different QoE requirements. Roles can be classified into three main types (user, customer, and group).

Customer: A customer is one who subscribes to a service and is the legal owner of that service; however s/he may or may not be the primary user of the service.

User: 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.

Group: A group is a collection of entities that share certain characteristics, interact with one another or have established certain relations between each other.

We have presented high level roles but even subcategories could also be developed such as expert users, and normal users of a service or active or passive customers according to their buying trends. Based on three main roles of 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 customer general attributes, his/her intentional and cognitive characteristics, and the task which s/he intends to perform in certain environments. Customer experience is mostly influenced by business models of service providers. Business domain characteristics like pricing, promotion, advertisement, customer service 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 as user experience. While the customer experience presents more business specific human view of a product and/or of a service, user experience provides the assessment of user feelings, perceptions and performance with respect to technical performance and the quality of a product and/or of a service. User experience is influenced by service features, functionalities, and by the quality of service parameters in a particular context.
- **Group Experience:** A Group experience represents a shared experience between entities in a group. Multiparty conferencing, social web or multiparty online gaming are a few examples of the services which 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 characteristics helps to obtain more accurate QoE data.

3. 2. 2. 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 as technological entities (e.g. services, network resources and end-user devices), while their associated technical parameters (e.g. QoS) and specifications (e.g., features and functions) are technological characteristics.

Technological entities and their characteristics have a profound influence on a user's experience, and it is very important to analyze their influence on QoE factors.

3.2.2.1 Technological Entity

Technological entity represents set of services, applications, networks and devices offered by business entity. The roles of technological entity include services, applications, networks and end-user devices, while their associated technical parameters (e.g. QoS) and specifications (e.g., features and functions) are termed as technological characteristics.

3.2.2.2 Technological Characteristics

They represent all key parameters and indicators related to services, network resources and end-user devices, for example, network failure, packet losses and video encoding rate have profound influence on perceived video quality. It’s highly important to map technological characteristics with QoE factors. The QoS-QoE relationship is investigated (cf.chapter 5&6), the results of user study to evaluate combined effect of multiple QoS parameters on QoE is presented.

3. 2. 3. Business Domain

The business domain represents a holistic view of business aspects, linked to a particular service offering. Today, effective management of the customer experience is one of the single most important differentiators in this highly competitive market. From the 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.

3.2.3.1 Business Entity

The business entity possesses technical entities (network infrastructure etc) 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 intended goals. Business Entities may have also sub classes such as customer touch point, kiosks, customer complaint center etc. The interaction between customer and provider can be direct or indirect (e.g., online), but in both cases this interaction experience develops positive and/or negative feelings.

3.2.3.2 Business Characteristics

The business entity has properties (e.g., a business model and strategy) which define the direction of its business. The business model is defined in [**66**] as the sum of how the organization does business (how it is organized, what it sells, how it delivers products and services, how it adds value), the business management rules governing its strategy, and how it wants to measure the performance of the business.

In broader terms, a multimedia service business value chain consists of customer model characteristics, intra and inter-enterprise business characteristics. Customer-centric characteristics include advertizing, pricing, promotion, customer care, and brand image. Intra-business characteristics include multimedia provider’s goals, business strategies (sales, marketing), available resources and their utilization. Inter-enterprise characteristics are vital characteristics for multimedia providers because today multimedia service delivery value chain is not within the monopoly of one provider, but it is shared between different business entities (e.g., content provider, service provider, and network operator). Inter-enterprise business characteristics are related to legal, financial and SLA (Service Level Agreement) aspects to fix the responsibilities between different stakeholders.

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

3. 2. 4. Contextual Domain

In a communication ecosystem, context represents the circumstances, communication situations and environment at the time of interaction between human, technology and business entities. Research in human behavior psychology also proves that variation in context and environmental aspects influence human behavior, leading us to argue that context cannot be ignored when modeling QoE in a communication ecosystem. Contextual aspects influence the human perceptual experiences, resulting in a significant impact on the overall QoE.

3.2.4.1 Contextual Entity

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

- **Real context**: represents the real situation of interaction between the various domains of a communication ecosystem. Few examples include temporal, spatial, and climatic context. Temporal context is related to time information like the time zone of the customer/user, the current time or any virtual time. Spatial context is related to physical objects and spatial attributes like some one's location. Climatic context is related to climate and weather information like sunny or rainy weather.
- **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 on-line 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, co-workers, and relatives.

3.2.4.2 Contextual Characteristics

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

To provide improved customization and better user experience, technological and business domains should be agile and adaptive enough to understand human quality requirements in each context.

3. 3. Mapping

3. 3. 1. Inter-domain Mapping

Social science models attempt to establish causal relationships between prediction and outcome variables [**67**] [**49**] [**48**]. Similarly, we divide all factors into three main categories (i) Prediction factors (ii) Outcome factors and (iii) Moderation factors (cf. Figure 7).

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 set of predication factors which 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 set of outcome factors in a communication ecosystem which are driven by influencing factors. Another category is moderation factors; they represent a set of factors which 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 (for instance, perceived social pressure influences a person to perform or not to perform the behavior [**49**]) or a moderation factor (for instance, user data can also be categorized as 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 user (degradation in QoE). It means there is 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 direct causal relationship between prediction and outcome variables.

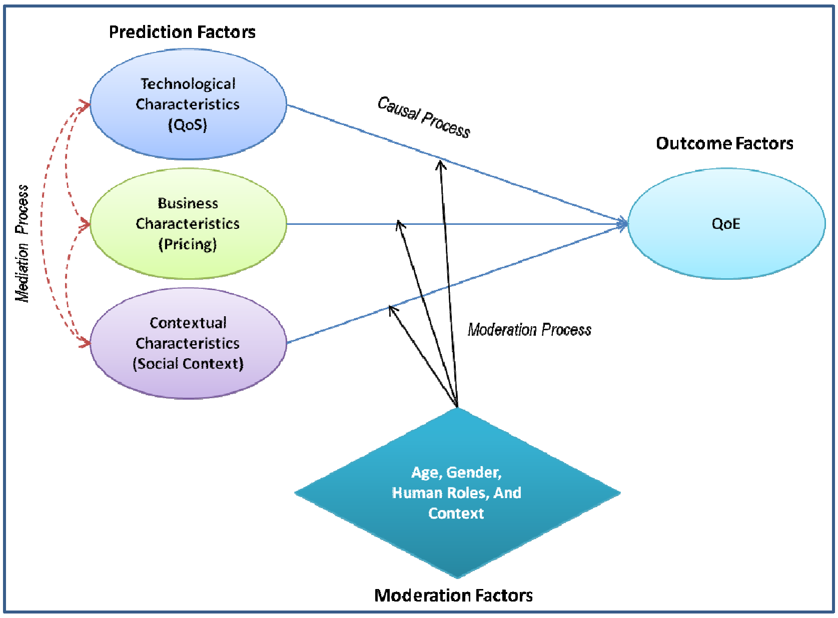


Figure 7: Inter-domain Interaction

User annoyance is not solely caused by decline in QoS of a VoD service. For example, when QoS declines, a user may or may not be annoyed depending upon 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 which indirectly influence human behavior. If there is no mediation between domains, a one-on-one direct relationship is established; for example, as given in chapter 5, a QoE-QoS relationship is established.

Moderation is a process which could alter the strength of a causal relationship. Human attributes (age, gender) and human roles (customer or user) are considered as moderating factors which could alter the strength of causal relationship. For example, people belonging to different age groups may have different level of tolerance towards 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 global QoE factor into subcategories based on age, gender, user or customer roles etc. 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 [**67**]. For more detail about moderating and mediating variables, work [**67**] [**68**] could be referred.

The causal relationship between the prediction factors and QoE factors is a permanent link, while mediation and moderation process are optional and they are instantiated incase more accuracy and in-depth view on QoE is required. Equation (i) presents a simplified relationship between domain characteristics.

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

3. 4. Comparison with Existing models

The proposed QoE model brings all disparate pieces of communication ecosystem together to understand total QoE. Our proposed consolidated QoE model extends prior work on QoE modeling by defining new taxonomy and by linking all the domains of communication ecosystem. In 2.7, various QoE frameworks/models were discussed and now we sum up their main points in order to compare them with our proposed QoE frame work.

Table 5: Comparison between our proposal models with respect to other models

Main Features		QoE Frame works						
		Yan Gong et al.	Andrew et al.	Sebastian Moller et al.	ITU-T G.1080	Kilkki' Model	David Geerts et al.	Khalil et al.
Human Domain	Demographic Attributes	No	No	Yes	No	Yes	Yes	**Yes**
	Roles	Limited	No	No	Limited	Yes	Limited	**Yes**
	Subjective QoE	Limited	Yes	Yes	yes	No	Yes	**Yes**
	Objective QoE	Limited	No	Yes	No	No	Yes	**Yes**
Technological Domain	Technological Entity (roles)	Yes	Yes	Yes	Yes	Yes	Limited	**Yes**
	TE Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	**Yes**
Business Domain	Business Entity (roles)	No	No	No	Limited	Yes	Limited	**Yes**
	BE Characteristics	Limited	Yes	No	Limited	Yes	Yes	**Yes**
Contextual Domain	Contextual Entity (roles)	No	Limited	Yes	Limited	Limited	Yes	**Yes**
	CE Characteristics	No	No	Yes	No	No	Yes	**Yes**
Focus		QoE- QoS (Delivery) + Usability	QoE- QoS (Delivery)	(QoE- QoS) Multimodal Human Machine Interaction	QoE-QoS (Delivery)	Comm: Ecosystem	HCI + QoE-QoS Link	**Comm Ecosystem (Design to Delivery)**

From Table 5, it is clear that our proposed frame work provides more comprehensive and consolidating view to QoE than others because our proposed model not only concentrates on subtle details of human domain but it also bring together work in QoS, HCI, business, psychology and physiology together.

3. 5. Conclusion

As the era of human centric services, product design and delivery flourishes, the focus is shifting towards multi-disciplinary Quality of Experience approach. The first challenge is to integrate the effects of different actors of a communication ecosystem to better understand human behavior. Conventionally, engineers, economists and psychologists investigate human behaviour with different perspectives and objectives. However QoE is a converging approach therefore it requires bringing all stake holders together to agree on holistic QoE vision with appropriate taxonomy.

A more abstract notion of QoE is introduced which allows us to construct a general framework in which every participant in a communication ecosystem deals with QoE, technology and business concerns at its own level of abstraction. QoE Interaction model help us to understand what is going on in the interaction between a human entity and rest of domains. It addresses the translations between what the user wants and what the system does.

Holistic model provides the conceptual view to QoE formation process. Conceptually we link disparate domains of communication ecosystems together to understand total QoE. Each domain represents a different terminology, functional requirements, and even management. However in practice, it is quite difficult to measure and manage simultaneously the combined effect of all influencing factors belonging to different parts in service life cycle.

This model is not meant to be proscriptive, but to provide 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 which examines these cross-domain relationships.

Part 2: QoE Methods

Study, Measurement and Evaluation

Introduction

In the digital age, there is a rapid growth of various multimedia applications and services, such as teleconferencing, video streaming, VoIP and IP television (IPTV). Meanwhile, network management concepts are also evolving, and the autonomic network management paradigms aspire to bring human like intelligence to telecommunication management tasks [**1**].With continuous technological advancement and mounting competition between service providers, there is an increasing demand for accurately and effectively evaluating and improving Quality of Experience (QoE) of multimedia services. For accurate evaluation, it is important to understand all those aspects which could impact user's quality of experience.

There are many network-dependent, application-specific, content-based, business and context oriented factors which influence multimedia QoE. The task is highly challenging because it require multi-disciplinary knowledge of multimedia communication, human perception systems, psychology, human physiology, context, business aspects and even sociology.

All actors of communication ecosystem may vary at a time but to simplify our work, throughout chapter 5 to chapter 7, we modify characteristics of only a particular domain to verify its impact on QoE, while considering other domain's characteristics as constant.

In this part of thesis, the focus will be on practical studies and analysis methods, used for the evaluation of QoE. In chapter 4, we present an overview on QoE based assessment methods and techniques. In chapters 5, 6, and 7, we instantiate QoE model and present user study results, conducted over multimedia services to understand link between QoE and other

"Being exposed to theory, stimulated by a basic love of concepts and mathematics, was a marvelous experience."
Rudolph A. Marcus

Chapter 4. QoE based Methods and Analysis Techniques for Multimedia Services

Highlights

- Multimedia Services and QoS requirements
- How to quantify and analyze Quality of multimedia experience?
- Subjective Assessment Methods and Objective Assessment Methods

4. 1. Multimedia

Multimedia services were long projected as the future revolution in computing, until the mid-90s, they were uncommon due to the expensive hardware performance requirements and cost. But with increases in performance and decreases in price, multimedia is now everywhere. Nearly all personal computers and smart phones are capable of handling multimedia content, though the available quality depends on the power of the computer's video adapter and microprocessor. Multimedia communications refers to machine-processable information expressed in multiple media, such as text, voice, graphics, still image, audio, video and interactive data as shown in Figure 8.

Figure 8: Types of Multimedia Data

Definitions are given below for different types of multimedia data. Text is collection of fonts, their style and special effects. Still Image is a digital representation of non-textual information, such as a drawing, charts or photographs. The two most common file formats for graphical files are JPEG (Joint Photographic Experts Group) and GIF (Graphics Interchange Format).

Animation is an artificial movement of text or objects in particular sequence. Audio content consists of speech, music and other types of sound. The sound is captured using a microphone, CD-ROM, radio, musical device or any other audio input device [**69**]. Video is collection of images. There is special video production material for capturing, digitizing, editing video and transmitting it. Due to the size of video files, incorporating video into a multimedia application is often a challenge. The Motion Pictures Experts Group has defined a standard for video and audio compression and de-compression, called MPEG. Video compression has played important role in the spread of multimedia video content [**69**]. Interactivity requires certain input from the user in order to deliver a set of information through words, graphics, images, or videos. Virtual reality is important sub factor of interactivity. It is actually the simulation of a real or imagined environment that appears as a three-dimensional (3-D) synthetic space. And it has dynamic properties specified by software [**69**]. Virtual Environment is created for various multimedia services such as 3D Teleconferencing, Online gaming etc.

4. 1. 1. Types of multimedia services

Multimedia services can be subdivided based on their temporal and data symmetry requirements, as shown in Figure 9.

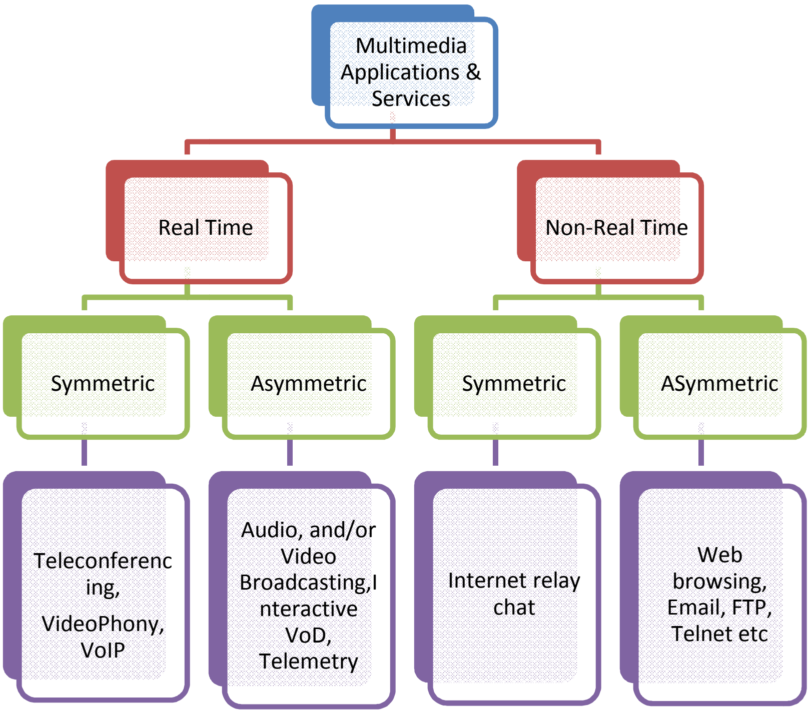


Figure 9: Types of Multimedia Services

Time dependence and symmetry are two important aspects on understanding the categories of multimedia services.

Any application that has stringent timing requirements is termed as real-time and otherwise non real-time application. An application's symmetry property means that the requests and responses are comparable in terms of resource consumption. While in terms of asymmetry, requests are considerably less resources consuming than response. Web browsing and FTP are examples of non real-time and asymmetric services as they neither have stringent timing requirements nor equal resource consumption on both ends. VoIP is an example of a real time symmetric audio application. This application requires real time request and response with equal resource consumption on both host machines.

On the other hand, video streaming service such as Video-on-Demand (VoD) is time sensitive but asymmetric since it consumes much more resources in the VoD server (response) than in client machine (request). Real time applications have stringent QoS requirements for adequate user experience. The packet loss and jitter requirements are essential for transmitting data at a constant, reliable rate. The delay requirements are strict in order to maintain system timing.

The ITU-T Recommendation G.1010 [**70**] provides guidance on key factors that influence Quality of Service (QoS) from the perspective of the end-user. The key parameters used by the ITU-T to describe human requirements for audio and video applications are given in Table 6.

- degree of symmetry (one-way or two-way communication)
- data rates
- delay variation (also referred to as jitter)
- information loss (which includes bit errors, packet loss, and also coding artifacts)
- Other aspects like adequate echo control, synchronization between streams and packet loss concealment

In short, there are many network-dependent, application-specific, content-based, business and context oriented factors which influence multimedia QoE. For instance, packet loss, packet reorder and delay are the major network-dependent factors, frame rate, and coding rate, are the major application-specific factors, content characteristics (e.g., slow and fast moving video content) are the main content-based factors, which affect overall quality of experience. Moreover, business factors (such as advertisement, price and billing) may also influence customer's intentions and behavior, for instance a customer using a paid Video on Demand (VoD) service may have higher quality requirements than a customer using a free VoD service (e.g., YouTube).

Table 6: QoS for Multimedia Services (ITU-T G.1010)

	Audio Services			Video Services	
Applications	Conversational voice	Voice messaging	High quality streaming audio	Videophone	Streaming
Degree of symmetry	Two-way	Primarily one-way	Primarily one-way	Two-way	One-way
Data Rates	4-64 kbit/s	4-32 kbit/s	16-128 kbit/s	16-384 kbit/s	16-384 kbit/s
One-way delay	<150 ms preferred <400 ms limit	< 1 s for playback < 2 s for record	< 10 s	< 150 ms preferred <400 ms limit	< 10 s
Delay Variation	< 1 ms	< 1 ms	< 1 ms		
Information Loss (%)	< 3% packet loss ratio (PLR)	< 3% PLR	< 1% PLR	< 1% PLR	< 1% PLR
Other				Lip-synch: < 80 ms	

All these influencing factors jointly affect QoE. Based on these influencing factors, accurate assessment of QoE metrics is crucial to network planning, in-network quality monitoring, and quality assurance to end-users.

QoS parameters represent the quality of multimedia services from technological point of view; and QoE is needed to provide accurate assessment of quality of multimedia services from user's point of view. Hence, there is need to move towards quantifying QoE and next linking QoE with QoS to get accurate user experience assessment. In next, QoE assessment methods are presented.

4. 2. QoE Assessment Methods

QoE is based on several psychological and cognitive factors such as such as habits, moods, expectations, needs, etc. For service providers, it is important to quantify QoE and measure it with accuracy. Quantifying QoE means translating user perception and performance into statistical and interpretable values. There are two main methods for measurements and analysis of QoE as given in Figure 10.

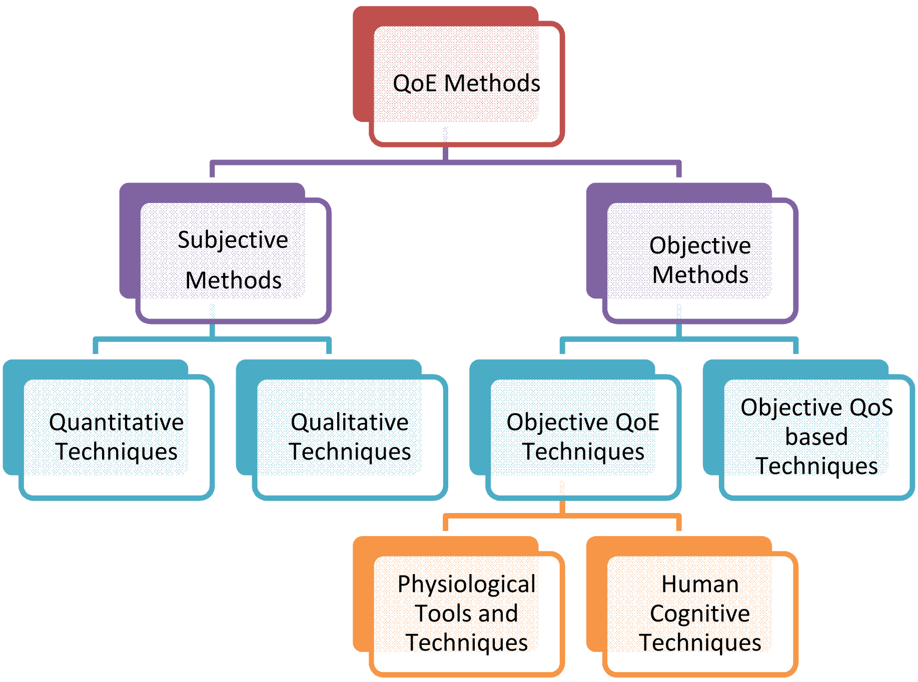


Figure 10: QoE Assessment Methods

4. 2. 1. Subjective Assessment Method:

The Subjective Assessment (SA) is based on surveys, interviews and statistical sampling of users and customers to analyze their perceptions and needs vis-à-vis service and network quality. There are two broader techniques for conducting subjective studies:

(i) Qualitative techniques (ii) Quantitative techniques.

4.2.1.1 Qualitative Technique

Qualitative techniques capture human perceptions, feelings and opinion through verbal behavior. Qualitative data represent verbal behavior and consist of words and observations, not numbers [**15**]. Open-ended survey questions, customer interviews, testimonials, comments on blogs, and social media produce bulk of qualitative data. The participant observation, in-depth interviews, and focus groups are three most common qualitative methods [**71**]. Each method is particularly suited for obtaining a specific type of data. The common examples of qualitative data are narrative sentences, videos and audios. These three methods generate field notes, audio (and sometimes video) recordings, and transcripts.

4.2.1.2 Qualitative Data Analysis

For the analysis of qualitative data, simple CCA (Catalog, Categorize, and Analyze) framework is used [**16**]. The most meaningful metric related to verbal behaviors is the ratio of positive to negative comments [**72**]. It follows three preliminary steps as show in Figure 11. The three simple steps of CCA framework are Catalog, Categorize, and Analyze. CCA catalogs and categories the ratio of positive to negative comments and produces results in histogram formats etc.

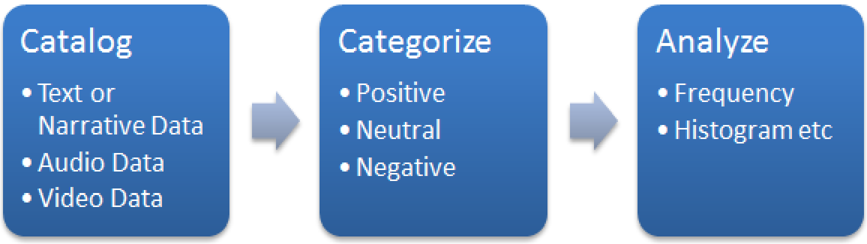


Figure 11: CCA Frame work

There are also more advanced approaches for in-depth analysis of subjects verbal behavior such as grounded theory [**73**]. In Chapter 5, we present subjective study to understand QoS and QoE relationship based on both quantitative and qualitative assessment.

4.2.1.3 Quantitative Techniques

This is based on surveys, and user studies. This method captures human perceptions, feelings and cognition in the form of numbers and quantifiable data. Closed-ended questions with ratings and scales produce quantitative data. This method typically involves the construction of questionnaires and scales.

For data analysis, parametric and non parametric statistics is used. Other powerful data mining techniques such as Rough Set Theory (RST) could also be used [**74**]. Throughout user data analysis in current thesis; parametric, non parametric tests and rough set theory were employed. A brief description of various important steps is given below to understand the process of subjective user study and quantitative data analysis.

Step 1: Study Planning: First of all, prediction (influencing factors) and outcome (QoE factors) should be defined for a multimedia service under study. The first task is to develop some questionnaire based on QoE conceptual model. In [**75**] [**76**], a detailed discussion is presented on how to develop a questionnaire for user study based on some psychological model. In questionnaire, it is important to know which rating method and scale to use. An overview is presented below;

- **Rating Methods:** There are three main rating methods. ACR (Absolute Category Rating) method, DCR (Degradation Category rating), and PC (Paired Comparison. ACR is a category judgment method, where the test sequences are presented one at a time to subjects and they rate it on categorical scale [**77**]. This method is also called single stimulus method. Another method of rating is DCR (Degradation Category rating), where subjects are asked to rate the impairment of the second stimulus with reference to the original stimuli. A Paired Comparison (PC) is simply a binary choice. With the method of paired comparisons, a set of stimuli, or items, is judged, usually by presenting all possible pairs of the items to each respondent who chooses for each pair the item that better satisfies the specified choice criterion (for example, more preferred, more serious, more beautiful) [**78**]. Advantages of paired comparisons as a method for eliciting human judgments include the method's simplicity and its use of comparative judgments. But when a large number of items are to be evaluated in the same test, the procedure based on the PC method tends to be lengthy. In such a case an ACR or DCR test may be carried out first with a limited number of observers, followed by a PC test solely on those items which have received about the same rating [**77**].

  ACR is easy and fast to implement and the presentation of the stimuli is similar to that of the common use of the systems. Thus, ACR is well-suited for qualification tests. When it is important to check the fidelity with respect to the source signal, DCR method should be used. DCR should also be applied for high quality system evaluation in the context of multimedia communication. Discrimination of imperceptible/perceptible impairment in the DCR scale supports this, as well as comparison with the reference quality.

- **Scales:** Scales quantify human subjectivity. Different types of scales are used to capture user perception and feelings. User scores are actually the value we gather and analyze in order to infer QoE. Thus it is important to select a suitable scale for subjective user study. There are three main types of scales, nominal, ordinal and interval or ratio scales. The most basic scale is a nominal (binary) scale. It is simply a binary category of 0 and 1. This scale is used to capture discrete categorical information, for instance, this scale could represent personal liking, for instance 0 means "no" and 1 means "yes" or it is also used to capture gender information, for example, 0 for "female" and 1 for "male".

  In ordinal scale, there is a clear ordering of the variables. It represents ranking in order. For example, top five songs in chart, or 10 favorite movies of a subject. ITU-T has also proposed ordinal MOS (Mean Opinion Score) scale [**79**] which is normally used for perceived subjective quality measurement. MOS scale is also called Likert Scale. In fact, ITU-T ACR MOS scale and DCR impairment scale are five category ordinal scales as shown in Table 7. Even though we can order MOS score from excellent to bad score, the spacing between the values may not be the same across the levels of the variables.

  Table 7: MOS Scale

Quality Rating	Impairment Rating	MOS Score
Excellent	Imperceptible	5
Good	Perceptible but not annoying	4
Fair	Slightly annoying	3
Poor	Annoying	2
Bad	Very annoying	1

  Interval-level data possess the characteristics of ordinal data with the added characteristic of equal distance between levels of the variable [**80**]. Interval scale has either no labels or labels only at each end of the scale as shown in Figure 12 (b).

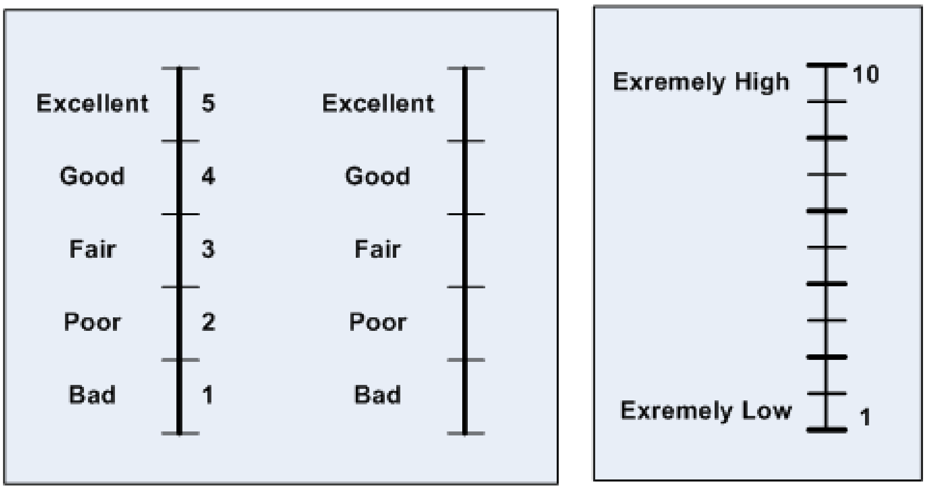


Figure 12: (a) Ordinal Likert Scale (b) Interval Scale

Non-parametric statistics is normally used for the analysis of ordinal data, while parametric statistics is used for interval scales, thus the use of Pearson correlation and regression equations should be avoided for the analysis of ordinal scale data [**14**] [**81**], otherwise there is possibility of making wrong analysis and hence judgment. But there is another school of thought, which believes that parametric statistics can be used with Likert scale (MOS scale), with no fear of coming to the wrong conclusion [**82**].

- **Demographic Information:** It is also important to include the basic information about subject's demographic attributes (such as age, gender, education and income) in questionnaire. Age and gender are considered as moderating factors in UTAUT Psychological model [**48**]. In previous chapter, we also discussed that for accurate assessment, it is essential to segment QoE based on human demographic attributes. This information may be used to moderate overall QoE findings on the basis of these factors.

Step 2: Test Setup: Once the questionnaire is ready, the test setup is needed to conduct test. The environmental condition of test lab, number of subjects, tools employed for testing should be prepared as per any suitable testing standards [**77**] [**79**].

- **Number of the Subjects:** About the number of subjects, there is no simple answer to this questions but a small user study can be a waste of resources for not having the capability to produce useful results, while an over-sized one uses more resources than are necessary [**83**] . As per ITU-T's recommendation [**77**], four is the absolute minimum number of subjects for statistical reasons, while there is rarely any point in going beyond 40. In general, ITU-recommendation P.910 suggests at least 15 observers should participate in the experiment.

- **Laboratory test vs. Field test:** Though ideally field tests with real customers or users is recommended for more accurate assessment, based on the context of study and its requirements, a special environment could be developed for user study.
- **Lab Environment:** If user test is to be conducted in lab environment, special care should be taken to ensure near to real-environment experience to test users/subjects in the lab. To get accurate and bias free assessment, extraneous variables should be controlled in lab environment. Extraneous Variables are undesirable variables that influence the relationship between the variables that an experimenter is examining [**84**]. Extraneous variables include situation and participant variables. Situation variables are aspects of the environment that might affect the participant's behavior e.g. noise, room temperature, lighting conditions, time, seating arrangements, listening and viewing conditions etc [**77**] [**79**,**85**]. Situational variables should be controlled so they are the same for all participants. Participant / Person variables refer to the ways in which each participant varies from the other, and how this could affect the results e.g. mood, intelligence, anxiety, nerves, concentration, background, age and gender etc [**85**]. For example, if a participant that has performed a user test was tired, ill, or had poor eyesight, this could affect their performance and the results of the experiment. The experimental design chosen can have an effect on participant variables.
- **Test equipment setup:** There are suitable test tools available to capture traffic and even shape the traffic as per test requirements.
  - **Traffic capturing tools:** Wireshark is popular network traffic capture tool and it is open source multi-platform network protocol analyzer [**86**]. It captures data from a live network. Other data capture tools are Tcpdump, EtherApe, and Kismet [**87**].

- **Traffic shaping tools:** Traffic shaping regulates network data transfer to meet certain level of quality of service (QoS) requirements. Traffic shaping is used in network emulation to analyze the impact of network on protocols and applications. Network emulation is one way to evaluate the network performance in a controlled and repeatable environment [**88**]. It is implemented at network edges to control the incoming and outgoing traffic of the network. The common network traffic shapers used to shape network traffic are NetEm [**89**], Dummynet [**90**], NIST Net [**91**]. NIST Net is a Linux kernel extension provides emulation of network such as delay, packet duplication and packet loss. NIST Net and Dummynet do not have their own filtering and queuing procedure [**92**]. NetEm provides Network Emulation functionality for testing protocols by emulating the QoS parameters such as variable delay, packet loss, packet duplication and packet re-ordering [**89**].

Step3. Training Session: Prior to conducting a formal user study, pre-testing evaluation of test setup should be done, and a training session should be conducted to educate subjects about the objective of the test.

4.2.1.4 Data Analysis Techniques

Once user study is complete, data are to be analyzed using some statistical or data mining approaches. Conventionally, non-parametric statistics is used for ordinal and nominal data, while parametric statistic or descriptive statistics is used for interval or ratio data. In following Table 8, based on work [**93**] [**81**], parametric tests and analogous nonparametric procedures are presented.

Rough Set Theory (RST) could also be used [**16**] for quantitative data analysis,. RST is a powerful mathematical tool to process indefinite and inconsistent data [**74**]. RST focuses on discovering patterns, rules and knowledge in data - a modern data mining theory. Compared with other data mining technologies, rough set theory has many advantages, such as it does not have information loss, and it is both flexible, and extendable.

Table 8: Parametric and Non-parametric Procedures

Parametric Statistics	Non-Parametric Statistics	Analysis Type
Two-sample t-test	Wilcoxon rank sum test	Compare means between two distinct/independent groups
Paired t-test	Wilcoxon signed rank test	Compare two quantitative measurements taken from the same individual
Analysis of variance (ANOVA)	Kruskal-Wallis test	Compare means between three or more distinct/independent groups
Pearson coefficient of correlation	Spearman's rank correlation	Estimate the degree of association between two quantitative variable

RST has obtained widespread application in machine learning, data mining, policy-making analysis, process control, and pattern recognition. It is widely employed to refine and classify the captured raw data into usable data. For detailed knowledge about RST, readers can refer to [**74**]. In [**94**] rough set theory has been used for the assessment of customer churn rate and loyalty for telecommunication services. In [**95**], RST and Multiple Linear Regression (MLR) techniques were investigated and authors observed that MLR had less value of accuracy and quality of approximation in comparison to reductions resulting from Rough Sets analysis. It means RST performs better than MLR. Rosetta software is open source RST tool and it provides user friendly interface [**96**].

In RS theory, data are presented in an Information System (IS). QoE data can be analyzed by formulating it in information system concept of RST. Basic definitions and concepts are given below.

Definition: $IS=(\mathbb{U},A,V,f)$,where $\mathbb{U}$ represents the universal set with finite set of n Objects $\{x1,x2,\ldots n\}$,A is non empty, finite attribute set $(a1,a2\ldots n)$.

One attribute corresponds to one equivalence relation, i.e., $A = C \cup D, and\ C \cap D = \emptyset$, C is called condition attribute set and D is called as decision attribute set. V is domain value of attribute set a and f is decision function called information function. This distinction between conditional and decisional attributes allows us to establish a causal relation between attributes. Defining QoE factors as decisional variables and influencing attributes (QoS, business metrics, & context) as a conditional variable, the RST enable us to see how conditional attributes (e.g., QoS) influence the decisional attribute (QoE).

Some of the important properties of Rough Set Theory (RST) are given below which are used to classify and reduce data to important data and achieve CORE influencing QoS factors.

I. **Indiscernibility of Objects:** Using this operation of RST, one can analyze the similarities between the user responses in a given survey. It is defined as.

$IND\ (C) = \{(x, y) | (x, y) \in \mathbb{U}\text{^}2, \forall a\ \in C(a((x) = a(y)\}$ (ii)

That is, if user x and y are ‘‘indiscernible’’ by a set of condition attributes C (denoted by$IND\ (C)$, shown as in equation (ii), this indicates that there exists an indiscernibility among x and y with regard to *C*. This indiscernibility relation, $IND\ (C)$, splits the given set of users in the survey ($\mathbb{U}$) into a family of equivalence classes $\{\boldsymbol{X1}, \boldsymbol{X}, \boldsymbol{X3}, \ldots \boldsymbol{Xr}\}$ called elementary sets.

II. **Rough Set Approximation:** The three main concepts are upper approximation, lower approximation and boundary region. If $\boldsymbol{P} \subseteq \boldsymbol{A}$ is a set of condition attributes and $\boldsymbol{X} \subseteq \mathbb{U}$ is set of users, then

$\boldsymbol{P}_{*}\boldsymbol{X} = \{\boldsymbol{x} \in \mathbb{U}{:}[\boldsymbol{x}]_{\boldsymbol{P}}\ \subseteq \boldsymbol{X}\}$ (iii)

$\boldsymbol{P}^{*}\boldsymbol{X} = \{\boldsymbol{x} \in \mathbb{U}{:}[\boldsymbol{x}]_{\boldsymbol{P}} \cap \boldsymbol{X} \neq \emptyset\}$ (iv)

Equation (iii) and (iv) represent the lower approximation and upper approximation of a rough set. The lower approximation is a complete set of objects that can be *positively* (i.e., unambiguously) classified as belonging to target set *X*. The upper approximation is the complete set of objects that are *possibly* members of the target set *X*. The *boundary region* is given by set difference between $\boldsymbol{P}^{*}\boldsymbol{X} - \boldsymbol{P}_{*}\boldsymbol{X}$ and it consists of those objects that can neither be ruled in nor ruled out as members of the target set *X*.

III. **Attribute Reduction and CORE:** RST helps to reduce the huge list of attributes to only effective ones which truly matters. CORE is the set of indispensably important factors. If Service Providers will not be able to support “CORE” factors, then it will definitely result in a poor customer experience.

IV. **Decision Table and Rules:** Helps to understand the reason of user's acceptability/unacceptability based on influencing (condition) attributes. The decision table and probabilistic analysis describe the set of rules about user experience factors. With every decision rule two conditional probabilities, called the accuracy (i.e., certainty) and the coverage coefficient, are associated. The accuracy coefficient expresses the conditional probability that an object belongs to the decision class specified by the decision rule. The coverage coefficient gives the conditional probability of reasons for a given decision [**94**]. We calculate support, accuracy and coverage of condition attributes from [**94**] corresponding to decision rules.

Support of the Rule:

$$\sigma_{\boldsymbol{x}}\,(\boldsymbol{C},\boldsymbol{D}) = \frac{\boldsymbol{supp_x}\,(\boldsymbol{C},\boldsymbol{D})}{|\mathbb{U}|} \qquad \text{(v)}$$

Accuracy of the Rule:

$$Cer_{\boldsymbol{x}}\,(\boldsymbol{C},\boldsymbol{D}) = \frac{\sigma_{\boldsymbol{x}}\,(\boldsymbol{C},\boldsymbol{D})}{\boldsymbol{\pi}\big(\boldsymbol{C}(\boldsymbol{x})\big)}, \qquad \text{(vi)}$$

where $\boldsymbol{\pi}\big(\boldsymbol{C}(\boldsymbol{x})\big) = \frac{|\boldsymbol{C}(\boldsymbol{x})|}{|\mathbb{U}|}$

Coverage factor of the decision Rule:

$$Cov_{\boldsymbol{x}}\,(\boldsymbol{C},\boldsymbol{D}) = \frac{\sigma_{\boldsymbol{x}}\,(\boldsymbol{C},\boldsymbol{D})}{\boldsymbol{\pi}\big(\boldsymbol{D}(\boldsymbol{x})\big)} \qquad \text{(vii)}$$

where $\boldsymbol{\pi}\big(\boldsymbol{D}(\boldsymbol{x})\big) = \frac{|\boldsymbol{D}(\boldsymbol{x})|}{|\mathbb{U}|}$

4. 2. 2. Objective (QoS based) Techniques

In this approach, QoE is inferred from QoS data. Normally these techniques are known as objective assessment techniques, because unlike subjective user data, they produce concrete quantitative data. This approach is technical people friendly approach, as engineers are more comfortable with handling machines and network traffics than dwelling into psychological or subjective user models.

4.2.2.1 Objective Assessment Techniques for Video Quality

Various objective video quality assessment techniques have been developed and they may be classified into three categories:

Full Reference (FR) methods compute the quality difference between an "original" version of the image/video and a "distorted" version. No Reference (NR) methods estimate the quality of the signal without any knowledge of an "original" version. Reduced Reference (RR) methods have access to partial information regarding an "original" version to compare to the quality of a distorted signal.

The common objective techniques for the assessment of video quality/fidelity of multimedia content are PSNR, SSIM and VQM. Peak Signal to Noise Ratio (PSNR) is the classical and widely known FR objective measurement parameter which calculates the mathematical difference between every pixel of the encoded video and the original video [**97**]. Structural SIMilarity (SSIM) is another FR technique, which compares information about luminance, contrast and structural similarity between original and processed picture [**98**].

Video Quality Metric (VQM) is a VQA algorithm developed at the National Telecommunications and Information Administration (NTIA) [**99**]. Due to its excellent performance, the VQM methods were adopted by International Telecommunications Union Recommendations (ITU-T J.144 and ITU-R BT.1683, both adopted in 2004). VQM is used for FR quality assessment for television, and reduced-reference (RR) and no-reference (NR) quality assessment for television and multimedia [**100**]. For more information about objective video quality metrics, the surveys of objective video-quality metrics [**101**] [**102**] could be referred.

4.2.2.2 Objective Assessment Techniques for Audio Quality

ITU-T has proposed two processes for objective assessment of audio services and applications, intrusive mode, non-intrusive mode. "Intrusive mode" means that the quality assessment system requires that a signal is injected into the system under test in order to generate a degraded output signal. This implies that the channel must be taken out of service for normal traffic. Examples of intrusive mode are PSQM (Perceptual Speech Quality Measure), PESQ (Perceptual Evaluation of Speech Quality), PAMS (Perceptual Analysis Measurement System). PAMS is British Telecom proposal for speech quality evaluation. ITU-T recommended PSQM in its recommendation P.861 [**103**] but it was recognized as having certain limitations in specific areas of application. It was replaced by P.862, known as PESQ [**17**] which contains an improved objective speech quality assessment algorithm. Most recently ITU-T recommended P.863 P.OLQA (Perceptual Objective Listening Quality Assessment) [**104**] to form a new voice quality testing standard.

Conversely, for “non-intrusive mode”, the quality assessment system can be used whilst live traffic is carried by the channel, without the need for any active test signals. Various standards have been developed. The ITU-T recommendation G.107 [**105**] has proposed E-Model to evaluate QoE for audio services. E-Model is an objective model, in which QoS is correlated with Mean Opinion Score (MOS).The E-model is combines a number of different impairments to calculate an overall quality measure called “R-Factor” or simply R. The scale is typically from 50 to 100, where everything below 50 is clearly unacceptable and R-value 94 is maximum value to be achieved in order to provide very satisfactory experience to user as shown in Figure 13.

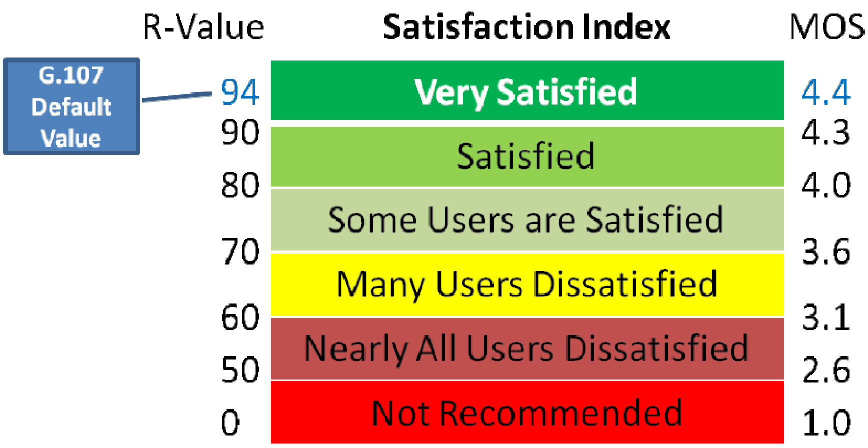


Figure 13: E-Model and R-factor [105]

4. 2. 3. Objective Assessment Techniques for Objective QoE Factors

The application of psychological models for understanding human intentions and behavior provide a global subjective assessment of user/customer requirements corresponding to a particular service and product, but the use of cognitive science and mental models provide precise information about human cognition.

Objective QoE factors are based on human physiological and cognitive factors. In broader terms, they can be divided into two categories (i) cognitive factors and (ii) physiological factors [**9**].

4.2.3.1 *Physiological Techniques*

There are special physiological tools (e.g., MRIs, Galvanic Skin Response (GSR) and Body sensors) to gather human physiological data. For a young and healthy adult, physiological and cognitive estimates are presented in [**106**] and they are summarized in Table 9.

Table 9: Human Physiological and Cognitive factors

Objective Human Factors	Mean	Range
Eye moment time	230 ms	70-700 ms
Perceptual processor cycle time	100 ms	50-200 ms
Motor Processor cycle time	70 ms	30-100 ms
Cognitive processor cycle time	70 ms	25-170 ms
Decay half-life of visual image storage	200 ms	90-1000 ms
Effective working memory capacity	7 items	5-9 Items

4.2.3.2 *Cognitive Techniques*

The Human Process Model (HPM) and cognitive psychological models are very effective techniques to understand human cognitive capabilities which use reaction time (RT) as the primary performance measure to infer the possible structure of mental systems [**107**]. Human reaction based on delay in service response is given in Table 10. This table is based on work [**108**] [**109**] and it shows how the delay in web page loading and delay in telephony talk could change human behavior and generate different emotions. It is obvious from Table 10, that human reaction time is directly related to system reaction time. This information enables a system designer to predict the performance in terms of the amount of time and effort it takes a person to complete a task. Considering its utility, the use of such objective cognitive factor was proposed as important QoE factor in previous chapter. In Human Computer Interaction (HCI) and Interface Design, some cognitive human performance models are also used to capture human task performance such as GOMS [**107**].

Table 10: Response time of webpage download and Telephony vs. Human reaction

Service	Response Time	Human Reaction
Audio Telephony	<=150 ms	Normal, Imperceptible delay
	150 to 300 ms	Perceptible delay, "cold" conversation
	300 to 500 ms	Glitches, Difficult
	>500 ms	Long Pause, Unacceptable
Web environment	0.1 to 0.3 Sec	User feels that system is reacting instantaneously
	1.0 to 2.0 Sec	The limit for user's flow of thought to stay uninterrupted even though the user will notice the delay
	8.0 Sec	Focus of attention lost. User probability moves over to other task
	>15 Sec	Motivation lost, user gets annoyed.

These models can provide precise quantitative information of individual's cognitive performance. The task performance could be assessed by giving subjects a particular task to accomplish within duration *t* and once they finish their task, their performance is analyzed on the basis of how successful they were in completing the given task and how long did it take them to accomplish this task. For instance, we also tested subjects' localization performance (cf. chapter 7) by asking them to locate the position of two simultaneous talkers in virtual teleconferencing room and if they successfully located the position of simultaneous talkers, they get 1 score otherwise 0. In this fashion, we can also calculate task performance factor.

4. 3. Conclusion

In this chapter, an overview on QoE assessment method was presented. For the assessment of subjective QoE factors; mostly quantitative subjective techniques (Survey, user studies) are used however, in modern research, most psychologists tend to adopt a combination of qualitative (interviews, focus group) and quantitative approaches, which allow statistically reliable information obtained from numerical measurement to be backed up user qualitative data (i.e. user comments).

Subjective QoE assessment techniques need a great effort, time, cost, and establishing tools for measuring the objective human factors, but they make it possible to get accurate information about human perceptions and feelings.

The objective assessment techniques bring objective and precise information about human quality requirements. The objective QoS measurement techniques and automatic calculation using appropriate quality estimation models is generally much faster and cheaper, but the accuracy of the final evaluation depends on the accuracy of those objective models [**110**]. Furthermore, techniques like PESQ, PSNR, VQM, P.OLQA etc are evaluated from technological point of view, thus, they lack to include the influence of other important factors such as business aspects, context and human characteristics. That's why, with these techniques, the accurate data about human perception and judgment is hard to achieve. Finally, the objective QoS based assessment techniques can only provide a global QoE score with reference to technical parameters, since they cannot include the effects of moderating factors such as human demographic attributes (age, gender etc), or roles (customer, user), therefore, they cannot provide moderated QoE for each group.

Another objective assessment techniques produced in this chapter was objective QoE technique. It is used to produce precise and reliable information on human cognition, performance and physiology. But physiological tools are expensive and they are complex to operate. However, for the accurate and actual evaluation of multimedia services, based on the particular context of a service, the use of both subjective and objective QoE techniques will be beneficial.

"Users perceive service in their own unique, idiosyncratic, emotional, irrational, end-of-the-day, and totally human terms. Perception is all there is!" ***-Tom Peters***

Chapter 5. Study 1: QoS-QoE Evaluation for Video Streaming Service

Highlights

- Subjective QoE Study for Video streaming service to evaluate QoE-QoS.
- Assessment: Quantitative Assessment based Rough Set Theory (RST)
- What is it Qualitative assessment and what is its use?
- Is this study enough to understand QoE and QoS relationship?? What else to do?

5. 1. Motivation

This chapter presents results of a user study conducted in order to understand the combined impact of QoS and content types on QoE. To understand this QoE-QoS link, other influencing characteristics related to business and contexts were not considered in this study, only QoS parameters and content types were modified to see their effect upon perceived user quality. For this study, video streaming service was selected as our use case. Video streaming is being widely used for video conferencing, video on demand, telemedicine and e-learning etc. Video streaming service has stringent quality requirements both from technological point of view (QoS) and user's point of view (QoE). The video streaming based services are strongly perceptual experience and users are known to make aesthetic judgments of these instantly.

Various QoS parameters affect user QoE with varying degrees of the influence. Packet loss is network layer QoS parameter and it degrades video quality and it is highly important factor in wireless environment. The causes of packet loss include network congestion, inadequate signal strength at the destination, lower layer bit error rate, network element failure, excessive system noise, hardware failure, or software corruption. For instance, in Wi-Fi environment, given the combination of collisions, signal fades, and data rate selection process, it is not at all uncommon for Wi-Fi to operate with an underlying packet error rate up to 5 percent [**111**]. In general, packet losses derived by congestion are identified and treated differently from packet losses caused by the radio link and mobility. This is one of the fundamental differences that discriminates wired and wireless Internet applications.

UDP protocol is often used for video streaming. Unfortunately when video is transmitted using UDP over wireless environment, the predictive coding strategies employed in techniques, such as MPEG-4, place a new set of constraints on traffic sequencing. For example, predictive coding introduces temporal dependencies into the video data that improve compression ratios, but can result in greater error propagation in the event of packet loss or late arrival [**112**] and it is further investigated in work [**113**], that demonstrate that H.264/MPEG4 provides quality similar to MPEG-2 at no more than half the bit rate for the coding-only case. Their assessment shows that the advantage of H.264 diminishes with increasing bit rate and all but disappears when one reaches about 18 Mbps. For packet loss case, results from the study indicate that H.264 suffers a large decrease in quality whereas MPEG-2 undergoes a much smaller decrease.

In addition to packet loss and video bit rate, packet reorder is also important QoS aspect which may degrade video quality and it is characterized as having varying delays that could cause out of order packets. Depending on the actual implementation, an application might be able to handle delay and jitter by using an appropriate buffer size, however, reordered packets might be more difficult to deal with at application layer and hence result into significant QoE degradations. In addition to QoS parameters; the impact of content type on QoE is also investigated.

5. 2. Research Model

Research model presents prediction, outcome and moderation factors (refer Figure 14). In this user study, the prediction factors or influencing factors are three Network QoS (NQoS) parameters and one Application QoS (AQoS) parameter. The objective is to assess the combined effect of prediction factors over perceived video quality. Perceived Video Quality (PVQ) is QoE metric which represents user perception about the quality of a video clip. During user study, this QoE factor is collected on the basis of user ratings/scores (quantitative process) and user comments (qualitative process). The type of video content is considered as moderation factor in this study to see if different content types produce similar or different user experience.

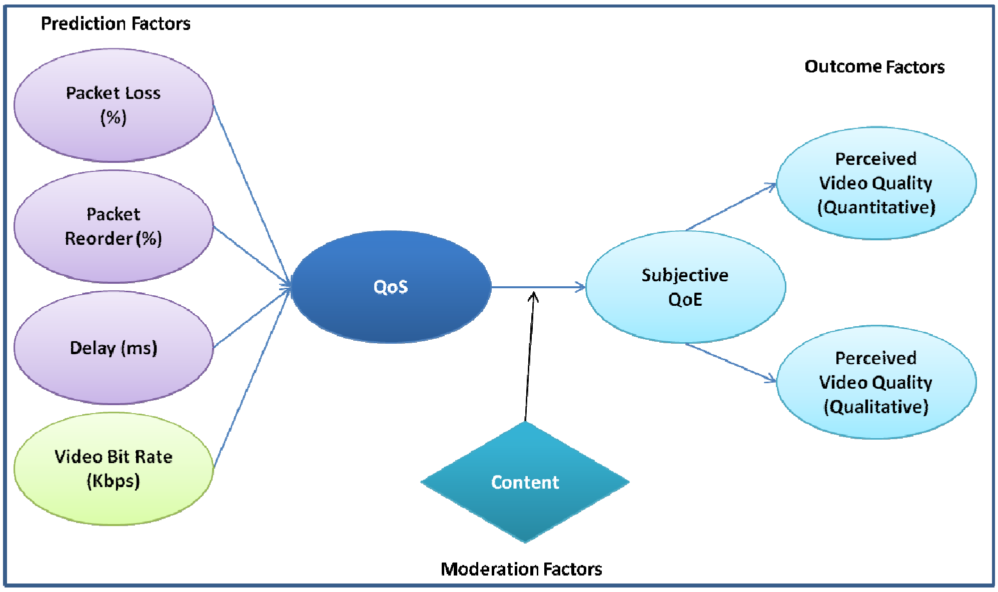


Figure 14: Research Model of Video Streaming Study

5. 3. Methodology

The experiments were conducted using a Wi-Fi network which also poses challenges to the design of the wireless networks because of the dynamics of the wireless channels. In real environment, any QoS parameter could vary and emerge together; therefore, in our current work, we study and investigate the combined effect of multiple QoS parameters (e.g., packet loss, packet reorder, delay and video bit rate) over the user QoE.

To investigate the combined effect of QoS parameters on QoE, we conducted subjective study based on ITU-T recommendations [**77**], along with qualitative assessment methodology. We repeat these experiments with different content types (e.g., football and container video) to investigate the influence of content types and characteristics on user perception for video quality.

5. 3. 1. Experimentation Setup

A private LAN with 3 laptops connected to a wireless router was established. One of the laptops was used for video streaming and other for receiving it. The third laptop was used as a gateway. Figure 15 shows the setup of the experiments. The video was projected onto a flat screen LCD TV through VGA output of the receiving laptop. The TV was mounted using the wall bracket at the height of 3.5 feet from the ground. The viewers of video were standing at the distance of 6 feet from the screen having viewing angle from 70 degree to 110 degree.

The open source media player VLC Player [**114**] was used for streaming the video and then receiving it at the receiver side. Two laptops were running windows operating system and for the gateway, we used Ubuntu to emulate the varying network conditions by using '*NetEm*' [**89**] that come with many new Linux distributions. *Netem* can be used to emulate the functionality of a network by emulating various parameters. This is particularly useful for testing the behavior of applications and protocols before actual deployment. We have used the same concept to analyze the effects of varying network conditions on QoE by changing various network parameters. Basically we have created a rule for the scheduler of the wireless interface 'wlan0' by making it to add X ms delay to every packet. Similarly values of jitter, packet loss, re-order, duplication were also specified.

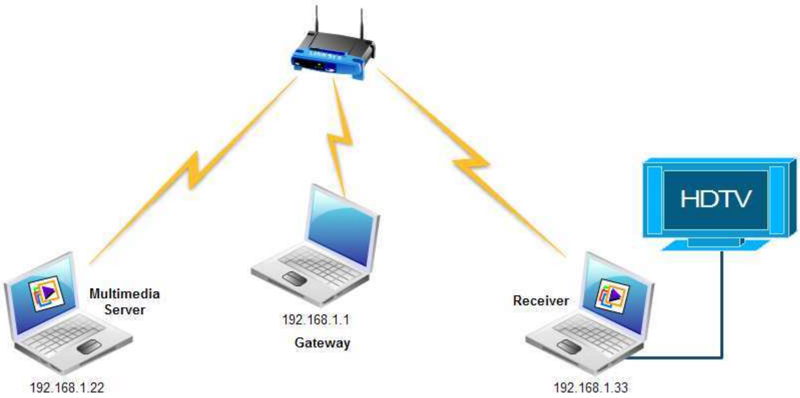


Figure 15: Experimentation Setup

5. 3. 2. Content

In total two video clips were used, one fast moving video clip of football match and other was slow moving container; both were taken from source [**115**] for experimentation purpose. The video frame rate was 30 fps, with CIF resolution the videos for QoE study were of 12 second duration. The media-content was encoded with the H.264/MPEG-4 video coding standard and streamed using UDP protocol over wireless network IEEE 802.11n.

5. 3. 3. Procedure

We conducted user experiment with 24 subjects; among them 6 were female and 18 were male subjects aged between 20 to 35 years. Subjects were provided with questionnaire and they were asked to provide their profile information and feedback about video quality. The perceived video quality metric is measured with a 5-point interval scale with labels at each end such as 1 (Worse/Strongly dissatisfied) to 5 (Excellent/Strongly satisfied). Unlike traditional ordinal MOS scale, the interval scale has either no labels or labels only at each end of the scale. One open question was asked to collect user comments: *"How do you perceive video quality? Pls give your comments?"*

Various parameters used during 9 experiments are given in Table 11.

Table 11: Test Setup Table

Exp No.	Packet Loss (PL) %	Packet Reorder (Pr) %	Delay (ms)	Video Bit Rate (VBR) Kbps
1 (Reference)	0	0	0	800
2	1	1	10	800
3	3	5	50	800
4	3	10	100	800
5	15	20	200	800
6	0	0	10	400
7	1	5	100	400
8	0	0	10	100
9	1	5	100	100

5. 4. Results and Analysis

In this section we provide quantitative and qualitative assessment of user study and discuss our findings.

5. 4. 1. Quantitative Assessment Method

Our goal is to understand the relative importance of each QoS influencing factor with respect to QoE. We also like to find the core influencing factors and possible link between QoE and QoS explained through some inductive reasoning. These all assessment requirements could be fulfilled by using powerful Rough Set Theory (RST) approach [**74**].

5.4.1.1 Quantitative Analysis

Traditionally, QoE data were analyzed by using statistical methods such as multivariate analysis [**116**], however these techniques are based mainly on assumption that prior knowledge of independencies, numerical scale of attributes and uniform probability distributions among the independent attributes [**117**]. The Bayesian assessment principle, and fuzzy theory are related examples of data analysis approaches, however, these methods have short comings, such as the decision of a prior probability is relatively difficult in Bayesian Algorithm [**118**].

Using RST, raw data could be transformed into useful information, and we can classify and analyze the impact of any numbers of parameters on QoE. Finally using rules, a relationship between important QoS parameters and QoE factors could be established. For quantitative data analysis, Rosetta software based on RST is used [**96**], because it provides user friendly interface and all required RST functions needed for an assessment.

Table 12 presents various parameters with possible values as tested in user experimentation. For detailed discussion on the use of rough set theory, the works are recommended to refer [**117**] [**94**].

In RS theory, data are presented in an Information System (IS). QoE data can be analyzed by formulating it in information system concept of RST.

Definition: *IS=(𝕌,A,V,f)*,where 𝕌 represents the universal set with finite set of *n* Objects *{x1,x2,…n}*,*A* is non empty, finite attribute set *(a1,a2…n)*. One attribute corresponds to one equivalence relation, i.e., $A = C \cup D, and\ C \cap D = \emptyset,$ C is called condition attribute set and D is called as decision attribute set. V is domain value of attribute set *a* and *f* is decision function called information function. In current work, condition attributes consists of QoS parameters, decision attributes describe the user scores.

Table 12: Experimental Data (Raw Decision Table)

Exp No.	Condition Attributes				Decision Attributes	
	PL %	PR%	D (Ms)	VBR (Kbps)	PVQ MOS ±CI (Football)	PVQ MOS ±CI (Container)
1	0	0	0	800	**4.417±0.288**	**4.583±0.235**
2	1	1	10	800	**2.708±0.21**	**3.375±0.21**
3	3	5	50	800	**1.792±0.357**	**2.583±0.388**
4	3	10	100	800	**1.538±0.21**	**2.122±0.22**
5	15	20	200	800	**1.292±0.243**	**1.292±0.27**
6	0	0	10	400	**4.24±0.19**	**4.39±0.16**
7	1	5	100	400	**2.646±0.30**	**3.375±0.342**
8	0	0	10	100	**3.84±0.24**	**4.12±0.23**
9	**1**	**5**	**100**	**100**	**2.104±0.349**	**3.958±0.321**

5.4.1.2 Case I: Container Video Clip (Slow Moving clip):

We analyze user experience data which was gathered through user survey .In this first case, subjects watched the slow moving container clip and afterwards, they gave their scores. User data were analyzed by following given steps;

Step 1: Discretize data: Discretization amounts to searching for "cuts" that determine intervals [**119**]. All values that lie within each interval are then mapped to the same value, in effect converting numerical attributes to attributes that can be treated as being categorical. The search for cuts is performed on the internal integer representation of the input decision table. The first step is to normalize divergent data using naïve algorithm [**119**]. This was done using Rosetta software. To simplify results, QoE five-level ratings are reduced into three levels (i.e., 3= User Acceptance, 2=Normal/Fair, 1=User Rejection). Following Table 13 presents discretized version of Table 12.

Table 13: Discretized Data Table

Exp No.	PL %	PR%	D (Ms)	VBR Kbps	Container Video Clip Decision Score
1	[*, 2)	[*, 3)	[*, 30)	[600, *)	**3**
2	[*, 2)	[*, 3)	[*, 30)	[600, *)	**3**
3	[2, 9)	[3, 8)	[30, 75)	[600, *)	**2**
4	[2, 9)	[8, 15)	[75, 150)	[600, *)	**2**
5	[9, *)	[15, *)	[150, *)	[600, *)	**1**
6	[*, 2)	[*, 3)	[*, 30)	[*, 600)	**3**
7	[*, 2)	[8, 15)	[75, 150)	[*, 600)	**3**
8	[*, 2)	[*, 3)	[*, 30)	[*, 600)	**3**
9	**[*, 2)**	**[8, 15)**	**[75, 150)**	**[*, 600)**	**3**

Step 2: Classify and reduce attribute set. The second step is to reduce and classify data. Using equation (ii), (iii), and (iv) as described in previous chapter, a reduct set can be achieved manually. The same results were obtained using Rosetta RST tool and reduct set was found to be {Packet Loss} as shown in Figure 16. It shows that packet loss is a core attribute which matters the most for slow moving "container" video. This can also be confirmed from Table 12, where variation in video bit rate did not show any significant negative influence on user PVQ score.

	Reduct	Support	Length
1	{PL}	100	1

Figure 16: Screenshot of Core set of QoS parameters for container video

Step 3. Generation of Decision Rules: This is very important step. The decision rules are generated based on Johnson's greedy algorithm [**120**] using Rosetta software. The equations (v), (vi) and (vii) described in chapter 4, are used to calculate strength, accuracy and coverage factors of every rule. Rosetta tool also provides support, accuracy and coverage factor linked with each individual rules. Following Figure 17 shows the screen shot of achieved decision rules.

No name

	Rule	LHS Support	RHS Support	RHS Accuracy	LHS Coverage	RHS Coverage	RHS Stability	LHS Length	RHS Length
1	PL([*, 2)) => container(3)	6	6	1.0	0.666667	1.0	1.0	1	1
2	PL([2, 9)) => container(2)	2	2	1.0	0.222222	1.0	1.0	1	1
3	PL([9, *)) => container(1)	1	1	1.0	0.111111	1.0	1.0	1	1

Figure 17: Screen shot of Rules for container video

The decision rules are generated using Rosetta based on Johnson's greedy algorithm [19].

Findings: From above Figure 17, we see 3 rules are generated. The first rule shows that *If* the users are watching "container" video clip *AND* the packet loss remains less than 2% *Then* the users' acceptability to video would be 3 (acceptable range). It means perceived video quality is dependent on packet loss more than any other parameters for slow moving video clip like container, so multimedia service providers should place more attention to packet loss. In this way, using a simple rule, an accurate relationship between service parameters and QoE could be established. The rule support, accuracy and coverage are calculated using equation (v), (vi) and (vii) respectively. The accuracy of rules is found to be very strong 1.00.

The acceptable, unacceptable and partially acceptable limits of QoE are influenced by a particular range of QoS and content aspects. It is also evident that slow moving container clip receives more user acceptance scores than fast moving football match clip because it demonstrates more resilience to tolerate the deteriorating QoS conditions.

5.4.1.3 Case II: Football Video Clip

Step 1. Discretize data: The first step is to normalize divergent data using naïve algorithm [**119**]. This was done using Rosetta software. To simplify results, QoE five-level ratings are reduced into three levels (i.e., 3= User Acceptance, 2=Normal/Fair, 1=User Rejection). Table 14 presents discretized version of Table 12.

Table 14: Discretized Data Table

Exp No.	PL %	PR%	D (Ms)	VBR Kbps	Football match clip (Decision Score)
1	[*, 1)	[*, 1)	[*, 5)	[600, *)	**3**
2	[1, 2)	[1, 3)	[5, 30)	[600, *)	**2**
3	[2, *)	[3, 8)	[30, 75)	[600, *)	**1**
4	[2, *)	[8, 15)	[75,150)	[600, *)	**1**
5	[2, *)	[15, *)	[150, *)	[600, *)	**1**
6	[*, 1)	[*, 1)	[5, 30)	[250, 600)	**3**
7	[1, 2)	[8, 15)	[75,150)	[250, 600)	**2**
8	[*, 1)	[*, 1)	[5, 30)	[*, 250)	**3**
9	**[1, 2)**	**[8, 15)**	**[75,150)**	**[*, 250)**	**2**

Step 2. Classify and reduce attribute set. For football video, using RST, a core set was found to be Core= {Packet Loss, Video Bit rate} as show in Figure 18. It means packet loss and video bit rate are two key influencing factors, while delay and packet reordering don't have significant impact on user perceived video quality.


No name

	Reduct	Support	Length
1	{PL, VBR}	100	2

Figure 18: Core set of QoS parameters for Football clip

Step 3. Generation of Decision Rules: The decision rules are generated based on Johnson's greedy algorithm [**120**] using Rosetta software. The equations (v), (vi) and (vii) described in chapter 4 could also be used to calculate strength, accuracy and coverage factor of every rule. Rosetta tool also provides support, accuracy and coverage factor linked with each individual rules. Following Figure 19 shows the screen shot of seven decision rules.

No name

	Rule	LHS Support	RHS Support	RHS Accuracy	LHS Coverage	RHS Coverage	RHS Stability	LHS Length	RHS Length
1	PL([*, 1)) AND VBR([600, *)) => Football(3)	1	1	1.0	0.111111	0.333333	1.0	2	1
2	PL([1, 2)) AND VBR([600, *)) => Football(2)	1	1	1.0	0.111111	0.5	1.0	2	1
3	PL([2, *)) AND VBR([600, *)) => Football(1)	3	3	1.0	0.333333	0.75	1.0	2	1
4	PL([*, 1)) AND VBR([250, 600)) => Football(3)	1	1	1.0	0.111111	0.333333	1.0	2	1
5	PL([1, 2)) AND VBR([250, 600)) => Football(2)	1	1	1.0	0.111111	0.5	1.0	2	1
6	PL([*, 1)) AND VBR([*, 250)) => Football(3)	1	1	1.0	0.111111	0.333333	1.0	2	1
7	PL([1, 2)) AND VBR([*, 250)) => Football(1)	1	1	1.0	0.111111	0.25	1.0	2	1

Figure 19: Rule set for Football video clip

Findings: Seven decision rules are generated as shown in Figure 19. Take the first rule as an example, which describes: *If* the users are watching “football” match video clip *AND* the packet loss remains less than 1% *AND* video bit rate is more than 600 Kbps, *Then* the users’ QoE would be 3 (acceptable range). In this way, using simple rule, we establish relationship between service parameters and QoE. The rule support, accuracy and coverage are calculated using equation (v), (vi) and (vii) respectively. The accuracy of rules is very strong 1.00. If we reverse the order of this rule, it becomes: *If* (QoE is acceptable range i.e., 3) *Then* packet loss has range ([*, 1)) AND video bit rate is in the range of ([600,*)). For this inverse rule, coverage factor represents its degree of accuracy. As a simple rule of thumb, as condition set grows long, the coverage decreases, while the accuracy increases. Thus one has to balance the tradeoff between these two measures.

For this analysis, multimedia service providers can realize that the user video perception is dependent on packet loss and video bit rate more than others, so they should pay more attention to these service aspects; and also, from the subsequent user feedback, they can classify correctly which user is more satisfied and how to adjust the QoS aspects according to the user’s feedback. Furthermore, it is suffice to conclude that H.264/MPEG-4 provides better video quality even at lower video bit rates especially for slow moving content.

5. 4. 2. Qualitative Data Analysis

Qualitative Data represent user comments. We collect user comments and we analyze those user comments based on CCA frame work (Catalog, Categorize, and Analyze).

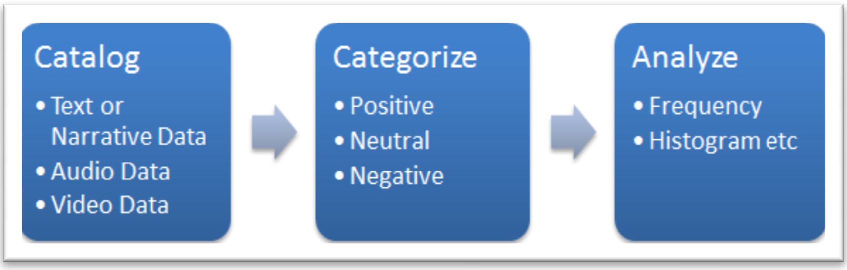


Figure 20: CCA Frame work

At first, all user comments and opinions were cataloged. Then as second step all comments were arranged in following categories.

1. **Positive Comments:** reflect user satisfaction with video quality for example "*Excellent quality*", "*Very satisfactory*", "*I am happy with video quality now*" etc.
2. **Neutral Comments:** Neutral comments reflect neutral opinions such as "*Normal quality*", "*nearly fair quality*" etc but it is observed that some neutral comments have also negative tendencies for instance user wrote like "*Video is fair but still not clear*" or "*Normal quality but still need improvement*".
3. **Negative comments:** Seeing different levels of negative comments, negative comments were subdivided into two categories; negative-suggestive and purely negative. Purely negative comments reflect user annoyance, dissatisfaction, and anger for instance subjects used words like "*Catastrophic*", "*Terrible*", "*Worse*", "*Video has very bad quality*", "*I'll never buy such type of VoD service*", "*Strongly dislike with -2 score*" etc. Negative-suggestive comments represent user comments in the boundary line of negative and fair comments or more specifically users' problem description along with some suggestions for instance, "*Video freezes or pauses*", "*Don't like because video resolution is too small*", "*Video is slower in the start and then stops in the middle*", etc.

Third step is to analyze and for this purpose, verbal data were converted into histograms. For simplicity, we selected random experiment results as presented in Figure 21 and 22.

5.4.2.1 Qualitative Data Results

- Exp. 1 is a reference video with all QoS parameters at appropriate level. In Exp. 1, the container video clip gets 86% positive comments with 0% negative comments. And football clip gets 74% positive comments and 5% negative comments. There are also 5% negative suggestive comments and they are mainly about user complaint due to lower resolution of CIF video. Some subjects also commented that they disliked this video because it was not HD like experience.

- Exp.4 and Exp.5, in Figure 21 & 22 are cases, network QoS parameters were changed while application QoS parameters were kept constant at their default values (e.g., VBR=800 Kbps). It is observed that for Exp.4 and 5, positive comments have reached to their minimal value 3% for football video clip and 9% for container clip. While at the same time, the negative and negative-suggestive comments have raised significantly for both video contents as shown in Figure 21 and Figure 22. For Exp.5 some subjects literally shouted and gave very bad comments about the video quality. The variation in network QoS brought very negative influence resulting in huge number of negative word of mouth. If we also compare qualitative data results with user ratings in Table 12, we can see that users rate Exp.4 and Exp.5, as poor and bad.

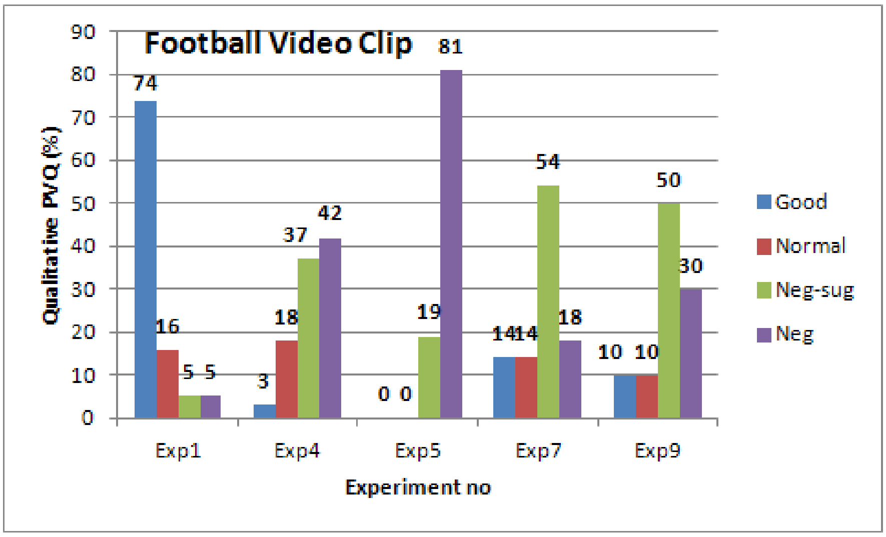


Figure 21: Qualitative PVQ (%) for Football Video

- The Exp.7 and 9, in Figure 21 & 22 are cases, when video bit rate was changed (400 kbps and 100 kbps), while packet loss was 1%. The football video got the highest negative-suggestive comments 54% in Exp.7 and 50% in Exp:9. On contrary to football video clip, we experienced very interesting thing that with the decrease in video bit rate, the slow moving container video were perceived even better and people gave even more positive comments in Exp.9 than Exp.7. The possible reason is that at low bit rates, the packet loss may have lower impact on slow moving video.

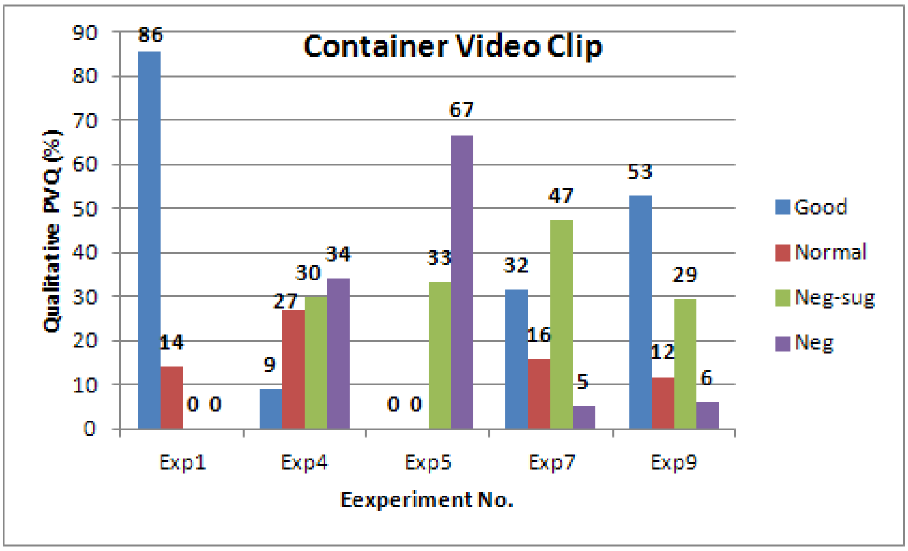


Figure 22: Qualitative PVQ (%) for Container Video

Remarks: During qualitative assessment, we learnt following things about assessment.

- The one important observation is about negative-suggestive comments, as it was observed that when users encounter any video quality degradation event, they at first tend to describe the nature of the problem or fault; but incase the degradation of quality continues, they instantly turn harsh and even start complaining loudly. It means they generate negative word of mouth only when they encounter the worst quality. To avoid negative word of mouth, multimedia service providers should give importance to negative-suggestive comments which provide them an overview of users' interpretation of quality problems.
- Second observation is about user forgiveness factor, for instance, if video quality improves from the worst quality to an average quality, users turn very positive and give generous comments. It means users may forget and forgive the bad experience instantly if worst quality span is shorter.

5. 5. Critique

We performed user experimentation in lab environment with 24 subjects. User experimentation in lab environment is not perfect replacement of natural environment or original experience. It is a programmed environment for users and that's why exact experience data are sometimes difficult to get. We noticed from collected user data that some subjects' ratings and comments were entirely out of context. We had no choice but to remove them from data.

The CIF resolution for video clips was used during study and as it is not very common for viewing experience. It was noticed that some subjects were not ready to accept video quality lesser than HD video or video with CIF resolution. Therefore to neutralize them, the pre-test user training session is very important.

In current work, QoE data were moderated on the basis of type of video content, but not on subject's age, or gender. It is possible that users of different age group may have different levels of satisfaction. However in next chapter 6, we differentiate customer satisfaction metric based on customer age. And in chapter 8, we segment users based on their gender.

In current work, only one QoE factor "Perceived Video Quality" was tested, and for the evaluation of this factor, two video clips were used for video experimentations; and only 9 iterations of experiments were done for four QoS parameters. Through additional experiments with more video clips and with more QoS parameter iterations, more accurate and in-depth findings could have been achieved. However, thanks to RST's powerful accuracy and coverage factor, our findings based on available data are completely accurate. In next studies (chapter 6, 7, 8), more QoE factors are defined and their results are based on detailed experimentations.

5. 6. Conclusion

In this chapter, we presented the results of subjective user study to evaluate the combined effect of QoS parameters and content characteristics on QoE. In real environment, multiple QoS parameters may work interdependently and they jointly cause degradation in quality and hence poor user experience.

For quantitative assessment, Rough Set Theory was used. With this assessment, it is learnt that the different types of content require different level of QoS support. Furthermore QoS parameters at network layer and application layer have also different level of impact on QoE. For fast moving football match clip, the core set of parameter consists of packet loss and video bit rate and while for slow moving container clip, the main influencing factor is packet loss only. It is learnt that not all QoS parameters pose similar degradation in user perceived quality.

Though results may look quite intuitive in the presence of four QoS parameters to decide which one is vital, in real environment as the number of influencing factors increase (including business parameters, all QoS parameters, contextual parameters etc), then understanding the interdependence among them gets more complex and even it turns hard to find actual core attribute set. However using RST, any set of raw data can be turned into usable date and important core attributes could be found easily with considerable accuracy.

Qualitative assessment builds on user opinions and comments. The assessment of user comments based on CCA framework shows that slow moving container clip gets more positive comments and less negative comment than fast moving video clip. Furthermore variation in network QoS parameters causes the generation of abundant number of negative comments for both video contents, however variation in video bit rate has not that severe trend. The slow moving container video clip generates significant number of positive comments and only few negative comments, but the fast moving football clip gets more negative comments and lesser number of positive comments than slow moving container clip. It is obvious from results that the overall trend in qualitative comments matches with quantitative data assessment.

"Customer complaints are the schoolbooks from which we learn"

Unknown

Chapter 6. Study 2: Evaluation of Technical issues on QoE for VoIP and PSTN based on Operator's customer survey data

Highlights

- QoE- QoS Relationship
- Real field customer survey
- Impact of technical faults on QoE
- Differentiation of Customer Preferences with respect to End-user Device.
- Different Age groups have different level of QoE?
- **Case Study:** VoIP and PSTN
- Collaboration work with French Telecom Operator Orange

6. 1. Introduction

In previous chapter, we presented a lab based user study results for video streaming service to understand the combined effect of QoS parameters over single QoE factor “Perceived Video Quality”.

In this chapter, we present real customer survey for telephony services to understand the impact of various technical faults on different QoE factors such as Perceived Call Quality, Perceived Availability, Customer preferences, and Overall Customer Satisfaction. Perceived Call Quality (PCQ) is investigated on the basis of voice degradation related faults, call drop background noise, and echo. Perceived Availability (PA) is investigated on the basis of call setup related issues. And we present differentiation of customer preferences based on customer telephone handset (wireless telephone handset or landline phone). Human demographic factor such as age is an important characteristic of human entity as described in our model chapter 3. Overall customer satisfaction is not considered as single global metric with same levels for every individual customer but we try to investigate how customers within different age groups perceive their satisfaction towards offered telephony service.

Over the first half of the current century, the global population comprising of 60 years old or over is projected to expand by more than three times to reach nearly 2 billion in 2050 [**121**]. There is huge chunk of old age people, who probably have different QoE requirements vis-à-vis service than young customers. In work [**122**], authors present their analysis which shows individuals’ age has a negative effect on their propensity to switch PSTN telephony companies, meaning that older users are less likely to switch service providers than younger ones. The report [**123**] shows a strong association between age and PSTN telephony, and in particular, the apparent reluctance by consumers aged over 35 to relinquish their fixed line telephone service. This report suggests that in Australia, highest percentage of VoIP customers are in the age range of 25 to 44 years. Seeing the importance of age as moderating factor, in current chapter, we moderate customer data based on customer age groups.

For our case study, we have selected PSTN (Public Switched Telephone Network) and VoIP. PSTN is traditional fixed telephony service and it has been enjoying unparallel success since decades but with advent of internet era, Voice over IP (VoIP) telephony has emerged as strong competitor to conventional telephony. VoIP services use the IP networks to transmit data packets as opposed to the circuit switched PSTN telephony system. Following Table 15 briefly presents comparison of both PSTN and VoIP telephony service.

Table 15: Comparison between PSTN and VoIP

Functions	PSTN	VoIP
Switching Technique	Circuit Switched	Packet Switched
Channels	Dedicated Channel	Best Effort
Intelligence	Core of the Newtork (SS7, switches and Intelligent Networks)	At the edge of the network (PC, smartphones)
Signaling	SS7	H.323, SIP
QoS Distortions	Analog Channel Noise Attenuation, attenuation distortion, Echo	Delay, Jitter, Packet Loss, Echo
Call Quality	High	Medium
Coding	PCM G.711	G.723
Quantitzation Noise	Negligible Impact	Considerable Impact
Telephone Handset activity during Power outage	Usually remain active	Inactive

PSTN telephony was designed to offer real time telephony service, however internet only provides best effort service because it was not specifically designed for real time services. Customers are accustomed to the quality of PSTN telephony service and now for VoIP service providers; this is a challenge to either supersede in quality or at least match voice quality with fixed telephony service.

6. 2. Motivation

In the current work, our focus is to understand how technical faults are actually perceived by customers[6]. Customer reports faults, and their complains to customer complaint center while technical O&M team relates those faults and complaints with QoS parameters and they try to fix faults by adjusting network and service level QoS parameters. If a customer faces numerous faults and technical issues, it is highly likely that s/he not only develops negative opinion but s/he could also convey negative word of mouth to many other people. To avoid customer annoyance, it is necessary to analyze PSTN and VoIP service on the bench marks of QoE. Following intriguing questions will be addressed in the current work.

- How technical faults impact upon customers' feelings and perceptions?
- What are the most critical and annoying faults for customers related to VoIP and fixed line telephony service?
- What are customer preferences and expectation? Do End-user devices have any impact on customer preferences?
- Do the different age group customers and end-users have similar level of satisfaction with VoIP and PSTN service or not?

6. 3. Research model

We presented consolidated QoE model in [**9**] and in chapter 3. In the current work, a simple QoE research model is presented to show the relationship between various influencing factors and QoE factors (see Figure 23).

[6] The term customer is used in this chapter; it is defined in chapter 3 (subsection 3.2.1.2). In current study, a person is not only subscriber of the service, but s/he is also a primary user of the service. That is why, we have used term “customer” throughout this chapter.

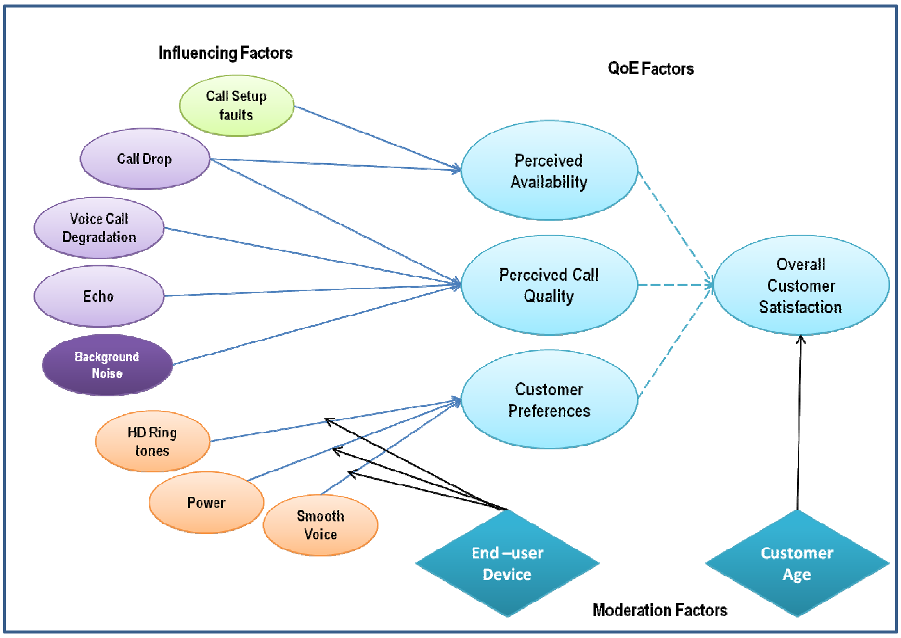


Figure 23: Research Model

6. 3. 1. QoE Factors

In current work, four QoE factors are benchmarked for the assessment of the VoIP service and fixed telephony service as described below.

6.3.1.1 Perceived Availability

It refers to the human perception about the availability of a service. The first thing which influences human perception of availability with telephony is typically based on the call setup performance. A user cares about whether he gets a dial tone, whenever he picks up phone or not and does the call connects successfully within reasonable time or not? Thus human perception of availability revolves around the performance of call setup system of telephony service. The frequent occurrence of call setup faults may cause annoyance in customer and they start perceiving call as unavailable.

Availability is perceived to be very high if caller successfully completes whole call connection process from dial tone to normal call termination process within an appropriate time limit. For example, a caller wants to hear a dial tone when s/he picks up the phone; *no* *dial tone* means service is unavailable. Next, when a caller dials a phone number, s/he expects to hear *ringing* or a network *busy signal tone*. Finally, when call connection is setup, caller expects to be able to complete the call without being disconnected; but some serious QoS problems (such as network failure, hard ware failure, software failure, and bandwidth congestion) may also cause abnormal *call drop* and it also equates to being a service unavailable.

In short, availability of a call is highly dependent upon the performance of call setup processes. Call setup faults such as incoming and outgoing call faults could deteriorate this metric. Additionally call could drop due to various other QoS factors. For assessing perceived availability for VoIP and PSTN, we primarily focus on understanding the impact of call setup faults upon perceived availability. During survey, customers were asked to rate how frequently they experience call setup faults.

6.3.1.2 Perceived Call Quality (PCQ)

It represents customer perception about the offered call quality. An acceptable value for PCQ is achieved when voice call is intelligible, clear, interruption free and smooth. During survey, customers were asked to rate how frequently they experience voice degradation faults and other technical and environmental issues.

As a rule of thumb, the higher the frequency of technical faults and voice degradation issues is, the lower is perceived call quality.

6.3.1.3 Customer Preference

It is a set of customer requirements which motivates him/her to adopt a particular service based on some personal preferences such as quality, cost, end-user terminal capabilities etc. In the current study, customers were asked to express their priorities on following aspects (1) Smooth conversation without any technical problems (2) Uninterrupted call in the wake of power failure (3) HD quality for ring tones (4) None of these (5) Don’t know. It is noticed during survey that customers were using different types of end-user terminal (wired and wireless telephone handsets), so customer preferences were moderated on the basis of end-user terminal.

6.3.1.4 Overall Customer Satisfaction

Given technological faults and issues related to fixed telephony and VoIP, it is important to understand how customer feels about these two services. In this work, we evaluate this metric based on the different age groups. It's highly possible that customers of different age groups may have different satisfaction levels with offered quality.

6. 3. 2. Influencing Factors

Here follows description on some important influencing parameters which could deteriorate QoE.

6.3.2.1 Call Setup Faults (CSF)

There are two types of call setup faults (i) Outgoing Call Setup Faults (OCSF) and Incoming Call Setup Faults (ISCF) and their classifications are given below (see Figure 24).

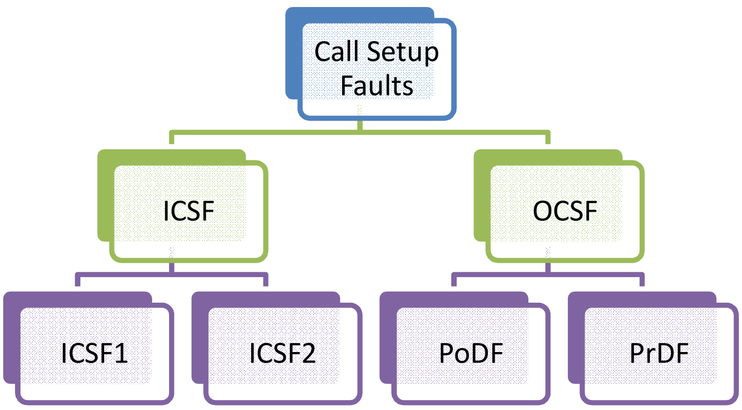


Figure 24: Classification of Call Setup Faults

OCSF is again subdivided into two parts as given below.

Post Dialing Faults (PoDF): It refers to the post dialing situation, when caller receives message that callee is inaccessible.

Pre-dialing Faults (PrDF): It refers to the pre-dialing situation, when caller cannot make a call because s/he either receives busy tone or no tone at all.

Second category of call setup fault is about Incoming Call Setup Faults (ICSF). It is again subdivided into two parts.

ICSF1: It refers to the situation when callee doesn't receive a call either due to unavailability of ringing tone or he receives automatic message (audio or text etc).

ICSF2: It refers to the situation when callee picks up the phone on the reception of ringing tone but he does not hear other party or he hears busy tone on the reception of the call.

6.3.2.2 Voice Quality Degradation

PSTN offers dedicated channel for voice call with QoS assurance, therefore voice call degradation issues are less common in PSTN. Nevertheless sometimes analog noise and cross talk attenuation may also cause some distortion in voice. In the context of VoIP, the degradation of voice quality is a big issue. Internet wasn't really designed for real-time communication. Due to inherent nature of Internet, variety of factors could create these degradations e.g., end to end delay, jitter, packet loss, insufficient bandwidth etc.

Voice quality degradation is manifested in five forms such as delayed voice, distorted voice, chopped voice, slow voice and beep during communication as shown in Figure 25. Chopped and distorted voices are caused by latency or packet loss in the ISP network, and it is highly possible that the connection is not fast enough to process the voice data. This is often the result of congestion during peak hours or heavy network usage from activities like online video gaming or downloading. End-to-end delay and jitter may also cause voice data to be delayed.

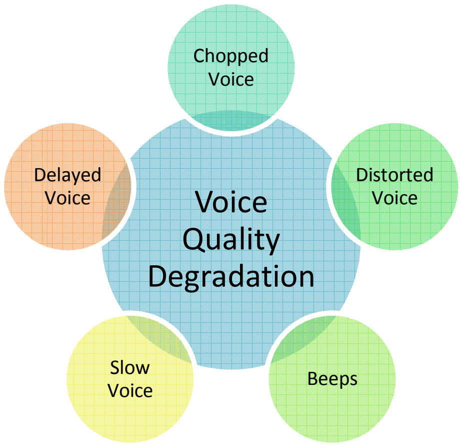


Figure 25: Voice Quality Degradation

6.3.2.3 Echo

It is the sound of the talker's voice returning to the talker's ear. The effects of an echo depend on delay and the strength of the reflected signals. In analogue PSTN telephony, the main source of the echo is the 2/4 wire hybrid. In the context of VoIP, there are two sources for echo [**124**]: (i) the acoustic coupling from the receiver (loudspeaker) to the microphone of the terminal (ii) the electrical coupling between the wires of the handset cord. The connection delay could also increase the annoyance caused by echo [**124**].

6.3.2.4 Call Drop

A call that is terminated unexpectedly as a result of some technical reasons is called call drop. Call drop could also cause annoyance to customers.

6.3.2.5 End-user terminal characteristics

Power Issues with Telephone handsets: Landline phones usually remain active during power outage because they are powered directly from PSTN Local exchange. But power issues also persists with traditional analog service in areas where many customers purchase modern wireless telephone handset or that have other modern phone features, such as built-in voicemail or phone book features. However this is not the case with VoIP based phones. In the event of power outage at user end, they may not function any more. However some VoIP providers provide backup batteries with VoIP handset provide an uninterrupted service during power outage.

Ring tone quality: Handset ring tones are also one of customer attraction aspect of end-user terminal.

Price: The price of handset is also one of the key factors

6.3.2.6 Environmental Characteristics

Background noise: It is one of the important environmental aspects that could disturb call quality. Background noise is a secondary sound element that tends to distract or in some manner interfere with the ability of the individual to hear or be heard [**125**]. Background noises cause irritation and distraction which degrades perceived call quality.

6. 4. Methodology

6. 4. 1. Method

Normally, lab based user experimentation is conducted to assess the QoE. However the work in the current chapter is based on operator's survey with real customers. The lab based QoE testing in simulated environment are sometimes limited in scope as it tries to mimic real world scenarios to collect QoE data with limited experience. It may not be completely effective in reflecting genuine needs, problems and the feelings of the customers. In real time study, customer feedback is based on his/her experience and interaction with service for long time (months and years), s/he has more clear opinions about offered service.

With French Telco[7] operator's collaboration, VoIP and PSTN telephony customer survey data was collected in order to ascertain their actual experience and perceptions. Responses from one thousand Orange customers were collected, 500 customers were using PSTN and rest of half

[7] Orange France Telecom

was using VoIP telephony service for at least last one year. This survey was conducted in April 2010. It encompasses all types of calls (short duration calls, long calls etc).

6. 4. 2. Procedure and Data Analysis

Our questionnaire and survey process were partially based on the guidelines of ITU-T P.800 subjective test. Our questionnaire was consisting of 14 questions; 12 questions were about the frequency of different faults and issues, 1 was about customer expectations and 1 was about overall customer satisfaction.

6.4.2.1 Customer experience data about faults

To know how frequently customers face various kinds of technical faults, we used categorical scale (i) Often (ii) Sometimes (iii) Never.

Customer responses were converted into percentage and analyzed based on impairment scale. Impairment scale consists of five categories such as imperceptible, perceptible but not annoying, slightly annoying, annoying, very annoying. The percentage of customer responses belonging to often and never category will be tested on this impairment scale. For instance, if more than 80 % customers respond that they often encounter particular technical faults, it means as per often category impairment scale (refer Figure 26), customers' reaction will be very annoyed. In ideal case, the customer rating for never category should be equal to 100% and often category should be equal to 0%, it means they never encountered any faults. As a rule of thumb lesser the number of the faults a customer face, higher is the probability of customer satisfaction and loyalty. On the other hand, higher the number of faults a customer face, lesser is the probability of customer loyalty and satisfaction. Based on above scales, we evaluate customer experience data for perceived availability and perceived call quality.

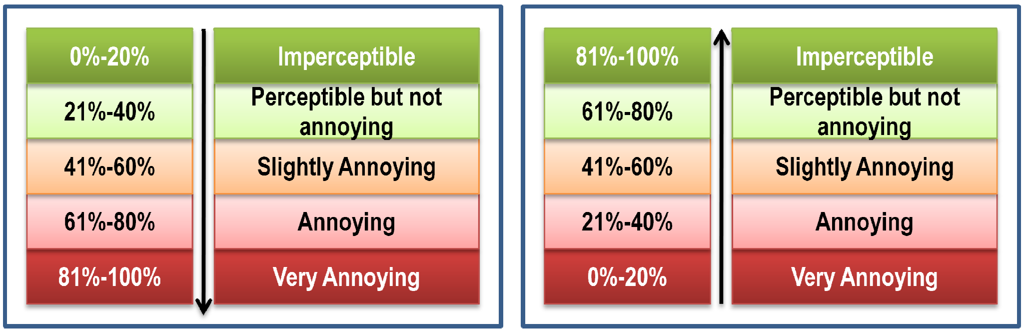


Figure 26: (a). Impairment Scale for often category (b) for never category

6.4.2.2 Customer preferences

For customer expectation and preferences, we ask customers to select one of stated five choices. We differentiate customer expectations and preferences based on customer's end-user terminal. Out of 500 PSTN customers, 234 customers possess land line wired telephone had set, and 266 use wireless telephone handset. Out of 500 VoIP Customers, 87 use wired VoIP handset, and rest of the customers use wireless handset. Customer preference choices were converted into percentage scores for evaluation purposes.

6.4.2.3 Overall customer satisfaction

For overall customer satisfaction, we user five point MOS scale (i) Very Satisfied (ii) Satisfied (iii) Fair/Normal (iv) Unsatisfied (v) very Unsatisfied. To evaluate any difference in the level of satisfaction with respect to age groups, we divided customers into 4 groups (i) less than 40 years (ii) 41 to 55 (iii) 56 to 64 (iv) More than 65 years. Hypothesis testing based on Chi-Square is used for validation of satisfaction scores. MS Excel 2007 and SPSS 19 were used for data analysis.

6. 5. Results

6. 5. 1. Perceived Availability

Customers reported their experience on how frequently they encountered call setup faults. Table 16 shows the customer data result for call signaling quality.

Table 16: Perceived Availability versus Call Setup Faults

Faults	PSTN Customer Rating (%)			VoIP Customer Rating (%)		
	Often (%)	Sometimes (%)	Never (%)	Often (%)	Sometimes (%)	Never (%)
PoDF	4.4	30.4	65.2	7	34.2	58.8
PrDF	3.2	23.8	73.0	9.4	36.8	53.8
ICSF1	2	11.4	86.6	17.6	35	47.4
ICSF2	7	26.6	66.4	6.2	26.8	67
Overall Call Setup Faults	4.15	23.05	**72.8**	10.05	33.2	**56.75**

6.5.1.1 Call Setup Performance in PSTN

Table 16 presents the frequency of call setup faults for fixed telephony. It shows that ICSF1 is least frequently occurring fault, only 2 percent customers said they had *often* encountered this problem, while 86.6 percent customers reported that they had *never* encountered ICSF1 fault over a year. As per impairment scale for never category, customer percentage scores for ICSF2, PoDF, PrDF (refer Table 16) lie in “perceptible but not annoying” category.

Overall perceived availability score for PSTN telephony is 72.8% as per customer “*never*” category rating and 4.15%, as per “*often*” category. It means due to lesser frequency of call setup faults, PSTN customers are not bothered with perceived availability.

6.5.1.2 Call Setup Performance in VoIP

Table 16 presents the overall all trends of VoIP call setup faults. In PSTN telephony, ICSF1 has 86% score but in VoIP, ICSF1 has the lowest “*never*” category score 47.47%, meaning that this fault is more persistent in VoIP than PSTN. Furthermore, as per impairment scale for “*never*” category, except ICSF2, the other three call setup faults ICSF1, PoDF, PrDF lie in “slightly annoying” category. Overall availability score for VoIP telephony as per customer “*never*” category rating is 56.75%, it means, VoIP customers encounter these issues so frequently that customers feel slightly annoyed due to these faults.

It is safe to conclude that fixed line telephony customers face less call setup faults than VoIP customers. And furthermore PSTN customers are not annoyed with PSTN service due to lesser number of calls setup faults, but VoIP customers are slightly annoyed with VoIP service due to call setup faults as shown in Table 18. Thus it is safe to assume that PSTN offers better service call setup quality than VoIP service.

6. 5. 2. Perceived Call Quality (PCQ)

Once the call is established, a customer expects to have a smooth call conversation, free from any technical issue. Customer's perception about call quality is affected by various technical and environmental aspects.

Table 17: Perceived Call Quality versus Technical Faults

Faults	PSTN Customer Rating (%)			VoIP Customer Rating (%)		
	Often (%)	Sometimes (%)	Never (%)	Often (%)	Sometimes (%)	Never (%)
Slow Voice	1.2	17.8	81.0	3.6	17.8	78.6
Delayed Voice	0.4	7.4	92.2	1.8	11	87.2
Distorted Voice	0.8	8.8	90.4	3.8	16.6	79.6
Chopped Voice	3	16	81	2.6	24	73.4
Beep in Communication	2.2	20	77.8	5.6	23.2	71.2
Call Drop	4.2	32	63.8	8.2	31	60.8
Echo	4.6	27.8	67.6	9.6	36	54.4
BG Noise	9.2	44.4	46.4	6.6	37.2	56.2

6.5.2.1 PCQ for PSTN

Table 17 shows the overall all trend of perceived call quality assessment for PSTN telephony. It shows that 80% of PSTN customers reported that they had *never* experienced these four voice degradation faults (slow voice, distorted voice, chopped voice, delayed voice), only a slight number of customers (less than 5 %) reported that they had *often* encountered these four voice degradation faults. It means frequency of these four faults is quite lower in PSTN resulting in better perception for voice quality.

For three faults (i.e. Beep in communication, echo, call drop), more than 60% customers rated that they had *never* faced these faults and less than 5% customers reported that they had *often* encountered these problems. Around 20 to 37% customers replied that *sometimes* they had encountered these problems. Only back ground noise was reported with “slightly annoying” score; as 44.4% customers said that they *sometimes* faced this problem. Hence as per impairment scale for *“never”* category, out of 8 faults, 4 faults had “imperceptible” category scores, 3 had “perceptible but not annoying” scores and 1 (background noise) got “slightly annoying” score.

6.5.2.2 PCQ for VoIP

Table 17 presents the overall all trend of perceived call quality assessment for VoIP telephony. It shows that more than 80% VoIP customer reported that they had never encountered delayed voice, and distorted voice. Due to lower frequency of these faults, they are considered “imperceptible” to customers as per impairment scale for never category scale. Around 71 % to 79% customers reported that they had *never* experienced beeps in communication, chopped voice, and slow voice. Less than 6% customers reported that they had *often* faced these three faults. Thus they are in “perceptible but not annoying” category score. Around 54% to 60% customers reported that they had *never* experienced echo, call drop and background noise issues. And around 38% percent customers reported they *sometimes* experienced these three faults. Thus they are in “slightly annoying” category as per impairment scale for never category.

Hence as per impairment scale for *“never”* category, out of 8 faults, 2 faults (delayed and distorted voice) got “imperceptible” score, 3 faults (slow voice, chopped voice, beep in communication) got “perceptible but not annoying” scores and 3 (call drop, echo and background noise) got “slightly annoying” scores. The results are also summarized in Table 18.

Table 18: Comparative Analysis of PSTN and VoIP Faults

Impairment Scale	PSTN	VoIP
Imperceptible	**Call Setup Faults (CSF)** :ICSF1 **Call Quality Faults (CQF):** Delayed voice, distorted voice, chopped voice, slow voice	**CSF**: Nil **CQF:** Delayed voice, distorted voice
Perceptible but not annoying	**CSF**: PoDF, PrDF,ICSF2 **CQF:** Call drop, Echo, and beep in call.	**CSF**: ICSF2 **CQF:** Slow voice, chopped voice, beep in call
Slightly Annoying	**CSF:** Nil **CQF:** Background Noise	**CSF:** ICSF1, PoDF, PRDF, **CQF:** Call drop and background Noise

Findings: As per Table 18, the slightly annoying faults for PSTN customers is background noise, and while for VoIP customers, ICSF1, PoDF, PRDF, background noise and call drop.

Background noise is common fault in both PSTN and VoIP, and it is negatively affecting call quality. As per Table 18, for PSTN telephony, no call setup related fault is stated in "slightly annoying" category. The possible reason for lower frequency of call setup faults with PSTN telephony is its use of dedicated signaling system known as SS7 (or C7) which provides very sophisticated additional call control and transaction control capabilities.SS7 protocol (MTP2 and MTP3) has robust keep-alive and error correction mechanisms. VoIP signaling is mostly based on SIP and H.323 signaling links. SIP does not use a separate signaling path, but relies on the IP connectivity from the originator to a Server and serve to the terminating party. SIP is basically based on UDP [**126**], so a lot of error correction and retransmission has to be done using the SIP protocol to account for the unreliability of the UDP protocol. Though H.323 requires both TCP and UDP during the call setup, its implementation is complex and time-taking [**126**].

Call drop is also stated as "slightly annoying" problem for VoIP customer. There may be many different reasons for call drop such as network failure, hard ware and software failure and network congestion. If a call drops after a specified period of time, it's highly likely that operator has set this time limit to drop call either based on some billing options or saving network resources and if call drops with fast busy tone, it is highly likely that another device is interfering with the line [**127**]. Answering machines, dial-up modems, alarm systems and caller ID devices are devices which normally share the phone line. They may interfere with phone line causing call drop [**127**].

On the basis of customer experience data, it is safe to conclude that PSTN offers better call quality than VoIP on the basis of low percentage of technical faults. Because the frequency of faults and customer complaints related to call quality are more frequent with VoIP service than fixed telephony.

6. 5. 3. Preferences

Customer preferences were differentiated based on their type of telephone handset in use. Table 19 shows the comparison between customer preferences segmented on the basis of end-user telephone device. Preference 1 is about uninterrupted call even during power (supply) failure. Preference 2 is having smooth voice quality; Preference 3 is HD ring tone.

Table 19: Customer Preferences based on Customer Handset

Preferences	PSTN Wired Handset	PSTN Wireless Handset (Hands free)	VoIP Wired Handset	VoIP Wireless Handset (Hands free)	Overall Customer Preference
No. of Customers	**234**	**266**	**87**	**413**	**1000**
Preference 1	30.34%	48.12%	48.28%	58.60%	48.30%
Preference 2	20.09%	23.68%	22.99%	27.36%	24.30%
Preference 3	15.38%	7.52%	20.69%	12.11%	12.40%
None of these	15.81%	9.77%	3.45%	0.73%	6.90%
Don't Know	18.38%	10.90%	4.60%	1.21%	8.10%

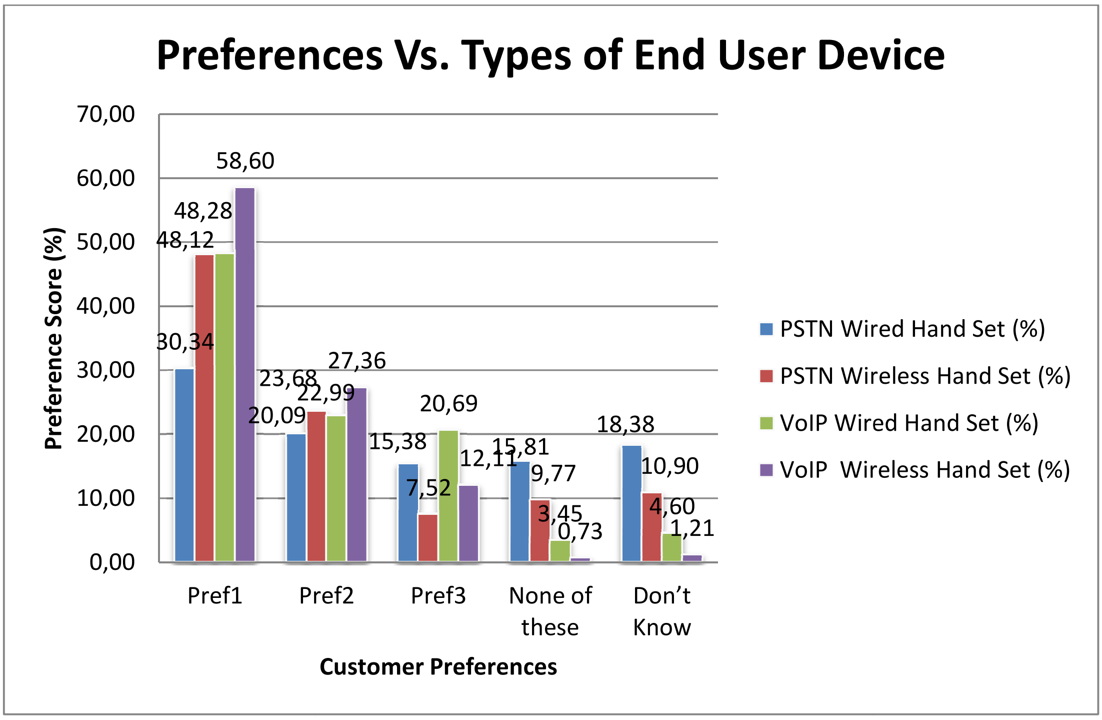


Figure 27: Customer Preferences based on Customer Telephone Handset

It is clear from the Table 19 and Figure 27; the demand for preference 1 is higher in customers with wireless handsets (48 % PSTN and 58% VoIP customers) than with wired handsets (30% PSTN, 48% VoIP customers). Secondly, it is also noticed that there is more VoIP customers who expect to have uninterrupted call during power outage than PSTN customers.

The possible reason is that the landline PSTN handsets usually remain active during power outage because they are powered directly from PSTN local exchange. However this is not the case with VoIP based phones. But sometimes power issues also persist with traditional analog service in areas where many customers purchase wireless telephone handset or that have other modern phone features, such as built-in voicemail or phone book features. In the event of power outage at user side, they may not function any more. In the context of VoIP phone, some VoIP providers offer backup power supplies with VoIP handset to ensure an uninterrupted service in case of power failure.

Second preference refers to customer expectation about smooth call quality with clear voice. 20% PSTN customers and 22% VoIP customers with wired handset want to hear a smooth sound and problem free conversational quality. 23% PSTN customers and 27% VoIP customers expect the same. It is evident that less number of customers possessing wired handset demand for this preference than customers possessing wireless handset; it is highly possibly that wireless environment, mobility and the capabilities of wireless hand held device could cause some additional problems in call quality. Secondly it is also clear that more VoIP customers demand for smooth voice quality than PSTN and it is also understandable that PSTN is mature technology offering a dedicated voice channel with QoS assurance, while due to inherent problems with Internet, VoIP still lacks to provide smooth call quality compared to PSTN as discussed earlier.

Third preference refers to customer expectation about ring tone. The results of survey suggest that customers possessing wireless set are more satisfied with ring tone of their sets than with wired handsets. It means there is room for improvement in wired handsets' ring tone quality. Secondly as per Table 19, more VoIP customers expect to get HD ring tone quality than PSTN customers.

There are also 15 % customers who do not know about their preferences or at least don't care about these three preferences. These are also unexplored chunk of customers whose expectations are unknown.

6. 5. 4. Overall Satisfaction

This metric represents the level of customer satisfaction with offered quality. Table 20 shows customer satisfaction MOS score for PSTN and VoIP service based on different age groups. It seems from MOS scores that customers of all age group are more satisfied with fixed telephony service than VoIP but it may be only the matter of chance in survey, therefore it is important to test the significance whether this assumption is based on pure chance or it could be generalized. For this purpose, we conducted hypothesis testing based on chi-square test χ^2 for homogeneity.

Chi-square test is very powerful technique to test hypotheses for frequency distribution based on categorical or nominal data [**128**] as given in following equation.

$$\chi^2 = \sum_{i=1}^{n} \frac{(Oi-Ei)^2}{Ei} \text{ -- } \textbf{(viii)}$$

Where

χ^2= Pearson's cumulative test statistic, which asymptotically approaches a χ^2 distribution.

O_i = an observed frequency of Customer satisfaction data

E_i = an expected frequency of Customer satisfaction data

n = the number of cells in the Table.

But before proceeding to apply Chi-Square test, we present some important Chi-Square test requirements which are (i) quantitative data set (categorical or nominal data) (ii) Adequate sample size (At least 10), (iii) Independent observations (iv) data in frequency form. Our data meets all these requirements and now we use Chi-Square (**χ^2**) to find out if there is a significant difference between the observed and expected frequencies for the VoIP and PSTN customers in the levels of satisfaction. We first define Hypotheses:

6.5.4.1 Hypotheses:

H0: *Customer satisfaction level of particular age group customers is homogenous or same for both PSTN and VoIP service.*

Ha: *Customer Satisfaction Level of particular age group customers is NOT homogenous or same for PSTN and VoIP Service.*

Table 20: Overall Satisfaction differentiated based on Customer Age

Age Group	Overall Satisfaction with PSTN MOS Score	Overall Satisfaction with VoIP MOS Score	Degree of Freedom	Chi square Critical Value at p= 0.05 and DF=3	Obtained χ^2 Value	Hypothesis
less than 40y	4.2	4.08	3	7.82	2.76	**H0**
41 to 55y	4.05	3.63			15.7	**H1**
56 to 66y	3.82	3.55			7.86	**H1**
More than 65y	3.98	3.71			9.21	**H1**

We will use the Chi-square for homogeneity [**128**] to test these hypotheses. The level of significance (α) is 0.05. The critical value of χ^2 when degree of freedom is 3 and α is 0.05 could be referred to Appendix A.1 and it is χ^2 (0.05) =7.82 as shown in Table 20.

Age group less than 40 years: The obtained χ^2 value is 2.76 and it is less than critical value (7.82); thus we accept H0 hypothesis. It means for the customers of age group less than 40 years, overall satisfaction levels with PSTN and VoIP quality are similar and they do not perceive any statistically significant difference in VoIP and PSTN's offered quality. MOS score for VoIP (4.08) is slightly less than PSTN (4.20). It is safe to conclude that this age group is comfortable with VoIP service.

Age group 41 to 55 years: The obtained χ^2 value is 15.7 and it is greater than critical value (7.82); hence we reject H0 hypothesis. And an alternate hypothesis (Ha) is correct; thus customer satisfaction level for this age group is different from PSTN to VoIP. MOS score also suggests that in this age group customers are slightly more satisfied with fixed line telephony (4.05) than VoIP (3.55) as shown in Table 20. And Hypothesis testing does suggest that there is difference in customer satisfaction levels for PSTN as well as VoIP. It is safe to conclude that customers of this age group are more satisfied with PSTN than VoIP.

Age group 56 to 64 years: The obtained χ^2 value is 7.86 and it is greater than critical value (7.82); hence we reject H0 hypothesis. And an alternate hypothesis (Ha) is correct; thus customer satisfaction level for this age group is different from PSTN to VoIP. MOS score also suggests that in this age group customers are slightly more satisfied with fixed line telephony (3.98) than VoIP (3.71) as shown in Table 20.

Age group more than 65 years: The obtained χ^2 value is 9.21 and it is greater than critical value (7.82); hence we reject H0 hypothesis. And an alternate hypothesis (Ha) is correct; thus customer satisfaction level for this age group is different from PSTN to VoIP. MOS score also suggests that in this age group customers are slightly more satisfied with fixed line telephony (3.15) than VoIP (3.0) as shown in Table 20.

6. 6. Conclusion

In this chapter, we presented results of the customer survey study to investigate the impact of various kinds of faults upon quality of customer experience. We presented a simple applied research model to conceptually link prediction parameters with QoE factors. Customer survey was conducted to gather data from real customers belonging to leading French telecom operator Orange.

QoE based assessment suggests that in terms of perceived availability and perceived call quality, PSTN outperforms VoIP telephony. The occurrence of call setup faults and network faults are more recurrent in VoIP telephony than PSTN.

Customer preference data are classified on the basis of end-user device. We found that customers with wireless handset have more stringent requirements for interruption free call in the wake of power outage as well as for smooth call quality during conversation than customer possessing wired handset. Customer preference metric shows that PSTN customers possessing wired and wireless telephony are less worried about power outage or voice degradation issues as compared to VoIP customers.

For overall customer satisfaction with VoIP and/or fixed telephony service, MOS scores were calculated and Chi-square based hypothesis testing was conducted. The results shows customers of age group less than 40 have similar levels of satisfactions towards VoIP and PSTN service while customers of age groups more than 40 feel more satisfied with PSTN than VoIP. It means, despite PSTN’s better call setup performance and call quality, young customers are somehow satisfied with quality of VoIP.

*"Always design a thing by considering it in its next larger **context** - a chair in a room, a room in a house, a house in an environment."*
*-**<u>Eliel Saarinen</u>** (Finish Architect)*

Chapter 7. Study 3: QoE and Virtual Acoustic Environment

Highlights

- QoE-Context relationship
- Impact of Virtual Acoustic Environment on QoE
- Subjective and Objective QoE Factors
- **Case Study:** 3D Audio Telephony
- Work done in collaboration with Tubingen University Germany

7. 1. Introduction

In this chapter, the impact of contextual parameters on QoE is investigated. We define and bench mark QoE factors. The relationship between QoE and contextual parameters will be evaluated in two different test scenarios through user experimentation. 3D Audio teleconferencing service is selected as use case service for experimentation purposes.

Classic teleconferencing often suffers from issues such as low intelligibility, limited ability of the participants to discern (in particular) unfamiliar interlocutors, to separate different speakers and to communicate over a long time without substantial fatigue [**129**]. 3D Telephony is a possible solution to address the shortcomings of traditional teleconferencing service. 3D Telephony provides 3D sound and virtual acoustic environment which improves quality of experience of teleconferencing service. Virtual acoustic environment helps participants of a conference call to spatially separate each other, locate concurrent talkers in space and understand speech with clarity. Further, virtual acoustic environment provides teleconferencing participants a level of freedom to modify specifications of virtual environment like room size, Table size and even place talkers at specific distance and direction as per their own requirements and ease.

It is also interesting to investigate the difference in QoE with respect to gender in virtual environment. The previous research has also revealed that there are gender differences in perceptions and behaviors as well [**130**] [**131**]. In [**132**], superior performance by women on a task requiring object location memory has challenged the traditional view that men excel on all spatial tasks. A significant departure from the expected findings on sex differences has been the discovery that women excel also on a test of location memory for objects [**133**].

Following research questions will be investigated in this chapter:

- Do virtual contextual parameters influence on QoE?
- What is impact of voice types on QoE in 3D virtual acoustic environment?
- What is impact of virtual room size on QoE in 3D virtual acoustic environment?
- Is there any difference in QoE with respect to gender of test participants?
- Is there any difference between subjective QoE factors (Localization Easiness) and objective QoE (Localization Performance)?

7. 2. Telephony Architecture

The 3D Telephony [**134**] architecture is presented in Figure 28. 3D Telephony setup is based on a point-to-point architecture using a different virtual environment for each user, whereas each user keeps full control over the virtual environment placed at his or her end of the connection. All audio streams are only rendered locally and played back directly to the headphones of the respective user. Here, multiple avatars, one for the local caller and one for each remote call party, are created. The incoming audio stream is then forwarded to the rendering engine and outputted on the headphones of the local caller. Head-tracking is enabled by connecting to all hosts supplying local virtual environments and modifying the position of the local as well as of the remote avatars.

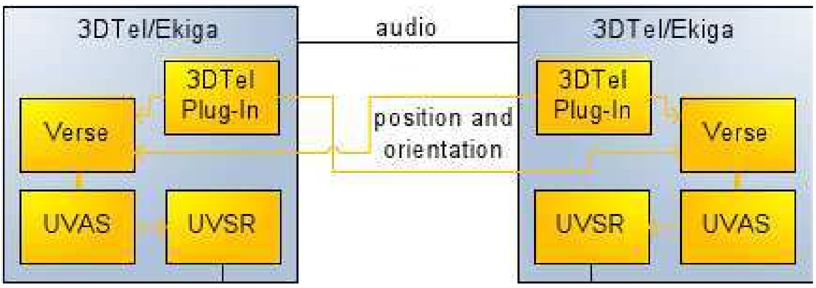


Figure 28: 3D Telephony Architecture

Implemented system is based on the open-source VoIP soft-phone Ekiga, which has been enhanced by a plug-in to control the virtual environment in order to support QoE requirements. As a rendering engine, we utilized Uni-Verse [**135**] acoustic simulation framework which is open-source software for developing 3D games [**136**]. In our research, we use only the features that are needed for spatial audio rendering. The Asterisk telephony toolkit was employed as a conference bridge and enhanced by a dial-plan application that connects to the rendering front-end. Asterisk is an open-source telephony software framework developed by Mark Spencer [**137**]. The current prototype system can be installed on any desktop computer or laptop running an Ubuntu/Debian based operating system. Further details about 3D Telephony and associated information can be found in [**138**] [**134**].

7. 3. Research Model

To evaluate 3D Audio Teleconferencing tool and analyze the impact of virtual acoustic environment over users, we present a research model for 3D Telephony. From high level QoE interaction model (chapter 3), we see the interaction between QoE-&-technology, QoE-&-business and QoE-&-context domains. In the current contribution, we concentrate to study the relationship between QoE-&-context domains. More specifically we try to compare and correlate QoE with 3D virtual acoustic environment as shown in Figure 29.

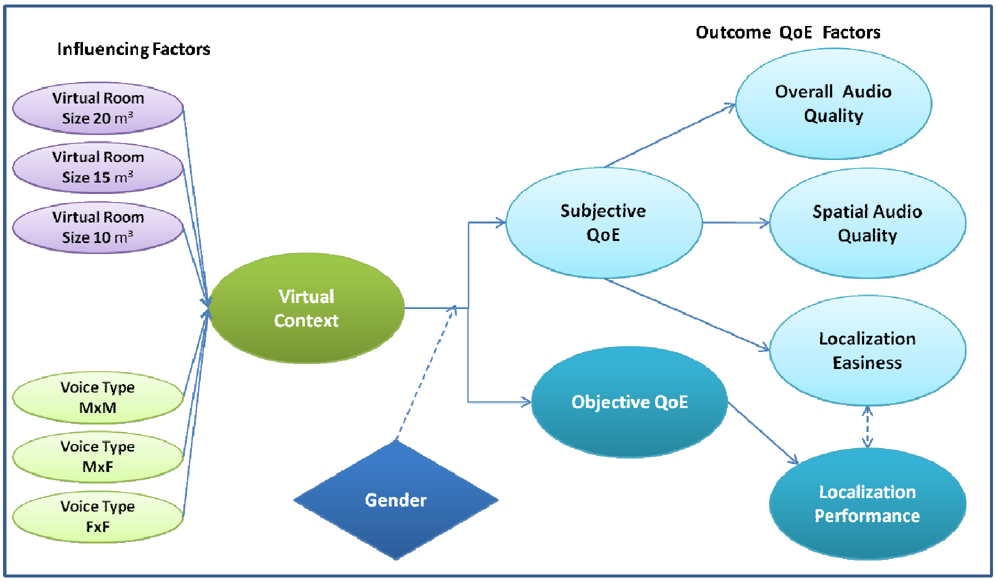


Figure 29: QoE- Contextual Domain

7. 3. 1. QoE Factors

To understand human quality requirements during interaction with virtual acoustic environment, we define four QoE factors as given below. These QoE factors represent human perception and performance about two important aspects i.e., localization of talkers and perceived audio quality in virtual acoustic environment.

7.3.1.1 Localization Performance (LP)

LP is an objective human factor. We define LP as "an assessment of how correctly listeners could locate the positions of the concurrent talkers in virtual teleconferencing room". LP data are quantitative data based on actual performance of listeners. LP represents listener's ability to locate either both simultaneous talkers correctly or only one talker or none of the talkers in virtual acoustic environment. LP data are presented with percentage score.

We define three subjective human factors, (i) Localization Easiness (ii) Spatial Audio Quality (iii) Overall Audio Quality.

7.3.1.2 Localization Easiness (LE)

It represents human perception and feelings about localizing talkers. We define LE as "how easy listeners feel it to locate concurrent talkers in VAE?" Subjects were asked to give their opinion ratings on five point MOS scale.

7.3.1.3 Spatial Audio Quality (SAQ)

This factor is also perception and feeling related parameter with respect to 3D audio quality. We define it as "how do listeners perceive and feel the spatial separation of talkers and pleasantness of 3D speech on audio quality?" Subjects were asked to give their opinion ratings on five point MOS scale.

7.3.1.4 Overall Audio Quality (OAQ)

It represents overall acceptance of the 3D acoustic environment and 3D sound effects. Subjects were asked to give their opinion about how they perceive the overall quality of the 3D audio telephony.

7. 3. 2. Influencing Factors: Virtual Context Characteristics

The Quality of Experience in virtual acoustic environment depends upon specifications of virtual acoustic environment such as virtual room size, virtual table size, voice types of the talker in virtual environment, number of concurrent talkers in the virtual conference etc. In the current chapter, the focus is on two contexts (i) virtual room size (ii) voice types.

For the size of virtual room, three room sizes were considered such as 10 m^3, 15 m^3, and 20 m^3. By changing the size of rooms one by one, we analyzed their impact upon QoE factors. In voice type for concurrent talkers, three scenarios are possible i.e. both talkers' were males, or females or mixed i.e., one male and one female. By changing voice type of concurrent talkers in virtual acoustic environment, we analyzed its impact upon listener's perception and performance and hence overall quality of experience is evaluated.

To validate this model and investigate relationship between QoE and virtual acoustic environment, and user studies were conducted based on following methodology.

7. 4. Methodology

In order to evaluate QoE and 3D virtual acoustic environment, the formal listening-only tests were conducted to study various teleconferencing scenarios. User experiments were conducted with 31 paid subjects, 13 of them female and 18 of them male, according to ITU-T P.800 recommendations [**77**] as far as possible. All tests were conducted in a quiet listening room on a computer using a specially designed user interface (as shown in Figure 30) on Linux operating system.

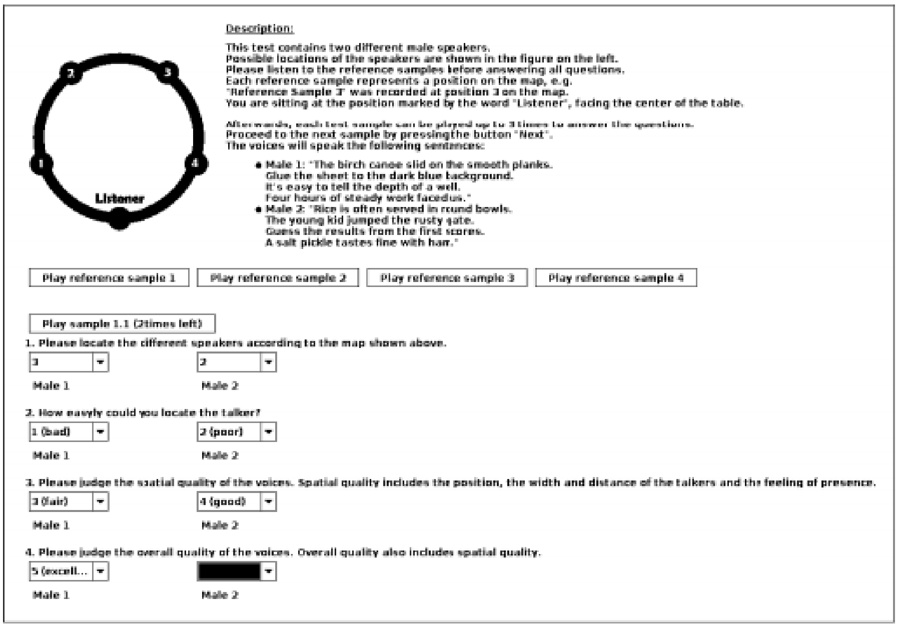


Figure 30: user interface

To enable participants to distinguish the different talkers contained in each sample, each talker was represented by a number as well as its spoken text. Each participant was asked a series of questions to be answered for each talker contained within each sample.

Localization performance of each test participant was measured separately by presenting him/her a map with possible talker locations. Localization easiness, spatial and overall audio quality were measured using discrete MOS-LQSW (Listening Quality Scale Wide-band) scores with the values 1 (bad), 2 (poor), 3 (fair), 4 (good) and 5 (excellent). All audio samples consisted of anechoic speech samples taken from the ITU-T Rec. P.50 Appendix 1 library. They were prerecorded from and processed by the open-source 3D audio rendering engine Uni-Verse [**136**] at a sampling rate of 16 kHz. The speech samples were recorded using three different male and three different female voices, each speaking four sentences in American English. Selection of scenarios and sub-scenarios to form QoE Modeling has been taken on the following facts and grounds.

Virtual Room Size: In this scenario, we analyze how varying virtual room size and sound source/talker-to-wall distance impact upon QoE factors. How participants' opinions and performance vary with varying room size. To determine the effect of room size and sound source/talker-to-wall distance on all QoE scores, this test uses three different rooms with dimensions of $10m^3$, $15m^3$ and $20m^3$. The average lengths of the presented stimuli add up to 14:38s, 14:65s, and 14:43s for the three tests.

Voice Type: In this scenario, the goal was to test the impact of relative and absolute differences in voice types (such as two concurrent male, female or mixed gender talkers) on QoE. Therefore, the three tests within this setup were conducted, Voice Type-1 utilize two simultaneous female talkers with an average signal length of 13:03s, and Voice Type-2 with two mixed gender talkers with an average signal length of 14:42s and Voice Type-3 is for two concurrent male talkers with speech signals of average length of 14:38s, from four possible locations distributed around the virtual table.

7. 5. Results & discussions

7. 5. 1. Reliability and Validity Testing

Before proceeding to results, it's important to verify reliability and internal consistency of QoE constructs (LP, LE, SAQ, and OAQ) utilized in various scenarios. Cronbach Alpha test is normally employed to verify reliability and validity of data. QoE factors at each sub scenario level and as whole are tested and the results are presented in Table 21. The cutoff threshold is 0.6 and it is evident from the results that all values are more than 0.6, thus it suggest a high level of reliability of construct variables and underlying measurement items [**139**].

Table 21: Cronbach's-Alpha

QoE Factors	Scenario		Cronbach Alpha
Localization Performance (LP) Localization Easiness (LE) Spatial Audio Quality (SAQ) Overall Audio Quality (OAQ)	Virtual Room Size	$10m^3$	.867
		$15m^3$	.844
		$20m^3$	.813
		Overall	.893
	Voice Type	M*M	.813
		F*F	.839
		M*F	.814
		Overall	.903

7. 5. 2. Results

In this section, we present our results about two main scenarios based on virtual room size and voice types of participants.

Table 22: **Relationship-results--LP-and-MOS Scores**

Virtual Acoustic Environement		⇒	Localization Performance	⇒	MOS LE (with 95% CI)	MOS SAQ (with 95% CI)	MOS OAQ (with 95% CI)
Room Size	$20\ m^3$	⇒	63,44%	⇒	$3{,}68 \pm 0{,}11$	$3{,}84 \pm 0{,}10$	$3{,}86 \pm 0{,}10$
	$15\ m^3$	⇒	71,77%	⇒	$3{,}77 \pm 0{,}10$	$3{,}79 \pm 0{,}10$	$3{,}74 \pm 0{,}10$
	$10\ m^3$	⇒	72,31%	⇒	$3{,}62 \pm 0{,}11$	$3{,}58 \pm 0{,}11$	$3{,}53 \pm 0{,}11$
Voice Type	Male Talkers	⇒	63,44%	⇒	$3{,}68 \pm 0{,}11$	$3{,}84 \pm 0{,}10$	$3{,}86 \pm 0{,}10$
	Female Talkers	⇒	48,66%	⇒	$3{,}70 \pm 0{,}13$	$3{,}81 \pm 0{,}11$	$3{,}81 \pm 0{,}11$
	Mixed Talkers	⇒	76,61%	⇒	$3{,}83 \pm 0{,}12$	$3{,}97 \pm 0{,}10$	$3{,}87 \pm 0{,}11$
Parameters		⇒	Performance Comparison	⇒	MOS score Compariosn		

7.5.2.1 QoE Factors and Virtual Room Size

In this experiment, on the basis of change in the size of virtual teleconferencing room, quality of experience factors are analyzed.

Objective QoE Factor: Results from Table 22 and Figure 31 (a) suggest that there is very small decrease in localization performance value when the size of room is switched from small room (10 m^3) to medium size room (15 m^3). When the size of virtual room is switched from medium to big room (20 m^3) size then sudden decrease in localization performance (around 7%) was noticed. The overall trend suggests a strong negative spearman correlation (-0.89) between virtual room size parameters and localization performance factor. It means that with increasing room size, the subjects' performance to locate concurrent talkers in virtual room decreases.

Subjective QoE Factors: Results from Table 22 and Figure 31 (b) suggest that Localization Easiness follows opposite pattern with respect to LP values. LP scores are higher in smaller room while LE scores are lower in smaller room, and vice versa for big room. But both LP value and LE scores are found to be the highest in medium size room (15 m^3). We can conclude that for optimal localization experience, medium size room is better choice for teleconferencing.

To assess the spatial audio quality and overall audio quality experience in virtual teleconference rooms, we look at the Table 22 and Figure 31 (b) and they show that subjective spatial audio quality and overall audio quality scores are gradually improving with increasing in the size of virtual rooms. Unlike LP, strong positive correlation is found for both SAQ (0.94) and OAQ (0.98).It means that subjects localization performance is decreasing with increase in room size, while spatial and overall audio quality increase with increase in virtual room size.

The possible reason for this match between objective and subjective QoE results is the fact that as the echoes and reverberation are more stretched in larger rooms, it feels easy to locate talkers. It is reported in literature [**140**] [**141**] [**142**] [**143**] that reverberation in acoustic environments is considered as a reliable cue in identifying source distance but it also modestly degrades directional perception [**144**] and speech intelligibility [**145**] [**146**]. In addition to this, it is reported [**147**] that reverberation enhances the distance perception but degrades localization performance.

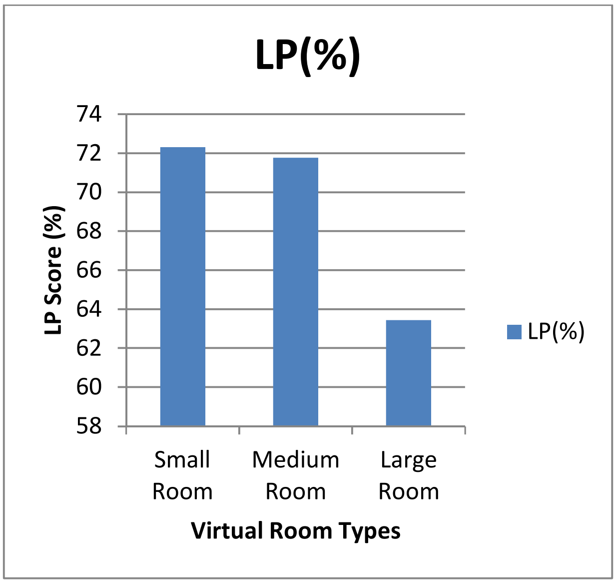


Figure 31(a). Objective QoE vs Virtual Room Size

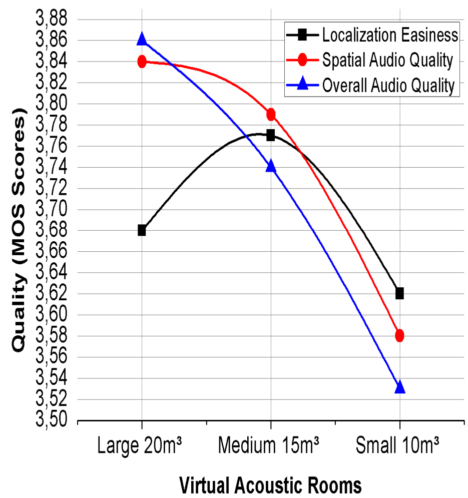


Figure 31(b). Subjective QoE vs Virtual Room Size

It is sufficient to conclude that a small size room provides better localization performance but it has the lowest localization easiness, spatial audio quality and overall audio quality scores, while in big room scenario, subjects give the highest scores to spatial and overall audio quality. Thus a medium size room is optimal choice where both localization performance and audio quality scores are in suitable range.

7.5.2.2 Experiment II: QoE Factors and Voice type.

Since, this is listening only experiment, we change the voice type of talkers in order to verify if participants' QoE scores change based on changes in talkers' voice type.

Objective QoE Factor: As per Table 22 and Figure 32 (a), the results suggest that, listeners' location performance greatly reduce with female voice type samples (both concurrent talkers were female) and they could not perform well to locate female talkers' position correctly in virtual conference room. LP value was poor (48.66 %) for concurrent female talkers. For simultaneous male talkers, it was observed that listeners' localization performance improved (63.44%). The highest localization performance value was obtained i.e 76.61% with mixed gender voice type (one male and one female voice type).

Subjective QoE Factors: For localization easiness, subjects gave almost similar rating to male as well as female talkers' voice type i.e. 3.68 and 3.70 respectively. The lowest scores for spatial audio quality and overall audio quality are found for concurrent female voices. However, the mixed gender voice type got the highest ratings for LE (3.83), SAQ (3.97) and OAQ (3.87).

Results show that both localization performance and localization easiness obtain the highest values with mixed gender voice type since both voices can be distinguished more easily than the concurrent voices of the same gender.

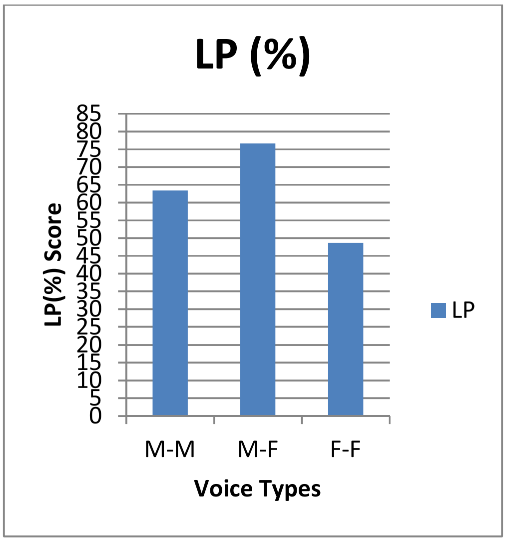


Figure 32(a). Objective QoE vs. Voice Type

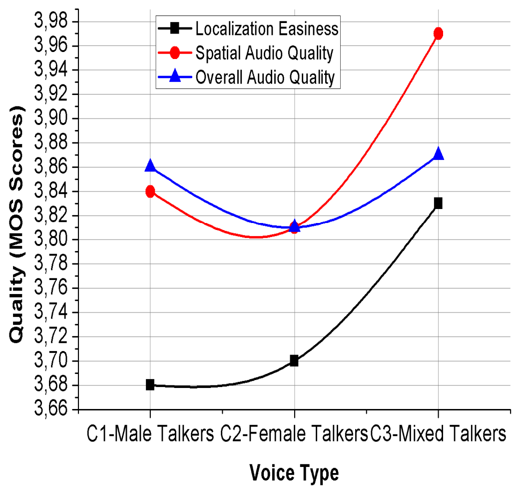


Figure 32 (b). Subjective QoE vs. Voice Type

7.5.2.3 Experiment III: QoE Moderation based on Gender

In experiment 7.5.2.1, It was discussed that how the size of virtual room could impact various QoE factors. Now, our interest is to see, if there is any different in QoE vs. virtual room size relationship with respect to the gender of subjects. As there are total 31 subjects, 18 male and 13 female, so, it was decided to take equal samples (13 male and 13 female) and then compare their LE and LP scores to investigate any gender based difference in QoE results. But seeing the lesser number of samples which may give erroneous results, it was decided to use more powerful techniques to measure LP with more accuracy.

The most common way to measure a successful task completion is to divide the number of participants who successfully completed the task (x) of localizing talkers in virtual environment by the number of participants who attempted the task (n) to estimate p, the population probability of successful completion. The equation for general point estimator is given as below [**148**].

$$p = \frac{(x+c^2/2)}{(n+c^2)} \text{ --- (ix)}$$

Other point estimators are special cases of general point estimator which are given below.

When c=0, it becomes Maximum Likelihood Estimator (MLE);

$$p = x/n \text{-- (x)}$$

When c=1, it becomes Jeffrey's point Estimator;

$$p = (x + 0.5)/(n + 1) \text{--- (xi)}$$

When c=√2, it becomes LaPlace;

$$p = (x + 1)/(n + 2) \text{-- (xii)}$$

When c=2, it becomes Wilson's point Estimator;

$$p = (x + 2)/(n + 4) \text{--- (xiii)}$$

For the estimation of task performance, the Wilson point estimator is recommended, if proportion of success (x/n) is less than 0.5. Maximum Likelihood Estimation (MLE) is used, if the proportion of success(x/n) lies between 0.5 to 0.9 and LaPlace method may be used when proportion of success (x/n) is greater than 0.9 [**148**] . These estimation techniques produce statistically significant result about user localization performance.

For calculating p, it is also important to calculate Confidence Interval (CI). CI is used to indicate the reliability of an observed data by a certain confidence level. The confidence interval is double of the margin of error and it tells us the likely range the population means and proportion will fall in. There are many techniques to calculate confidence interval. In [**149**], they present methods (Wald, Adjusted Wald, Clopper Pearson Exact, and Score) to compute CI. They found that the Adjusted Wald technique is suitable technique to calculate error margin and confidence interval.

We calculate localization performance based on various point estimates, and CI will be computed using Adjusted Wald method.

Localization Performance Measurement Process:

First of all, data were classified into successful and unsuccessful gender groups of test participants with respect to each virtual room as given in Table 23.

Table 23: VAE and successful & unsuccessful gender groups of test participants

Virtual Acoustic Environement		⇒	Groups	Number of Participants
Room Size	20 m³	⇒	Successful Males	6
		⇒	Unsuccessful Males	7
		⇒	Successful Females	8
		⇒	Unsuccessful Females	5
	15 m³	⇒	Successful Males	10
		⇒	Unsuccessful Males	3
		⇒	Successful Females	9
		⇒	Unsuccessful Females	4
	10 m³	⇒	Successful Males	11
		⇒	Unsuccessful Males	2
		⇒	Successful Females	8
		⇒	Unsuccessful Females	5
Virtual Acoustic Environment		⇒	Successful and Unsuccessful Gender Groups of Test Participants	

From Table 23, values for x (successful participants) and n (total numbers of participants) are obtained. Point estimators are used to calculate localization performance proportion “p” and adjusted Wald to compute CI. The results of computation are presented in Table 24.

Table 24: Analysis of Human QoE Factors in relation to Virtual Acoustic Environment

Virtual Acoustic Environement		⇒	Human QoE Factors			
			Proportion of Performance		Quality scores on Human Localization Easiness	
			Male (p) + CI	Female (p) + CI	Male	Female
Room Size	20 m³	⇒	0.4703 ± 0.2384	0.6154 ± 0.2350	3.82 ± 0.22	3.58 ± 0.27
	15 m³	⇒	0.7692 ± 0.2172	0.6923 ± 0.2280	3.85 ± 0.17	3.87 ± 0.15
	10 m³	⇒	0.8214 ± 0.2018	0.6154 ± 0.2350	3.64 ± 0.39	3.90 ± 0.31
Virtual Acoustic Environment		⇒	Analysis of Human QoE Factors in relation to Virtual Acoustic Environment			

Male Participants: It is evident from the Table 24 and Figure 33 that localization performance increases for male participants as the size of virtual room decreases. The overall trend suggests indirect relationship between localization performance rate and virtual room size.

It means male participants successfully localized more concurrent talkers in small-sized room (10 m^3) than big-sized room (20 m^3).

Female Participants: Unlike male participants' data, female localization performance is same (0.6154) in both big room (20 m^3) and small room (10 m^3). However their highest localization performance proportion rate (0.69) is achieved in a middle size room. It means female participants' perform better localization in middle size room (15 m^3), while the small and big size room bring no considerable difference in their localization performance.

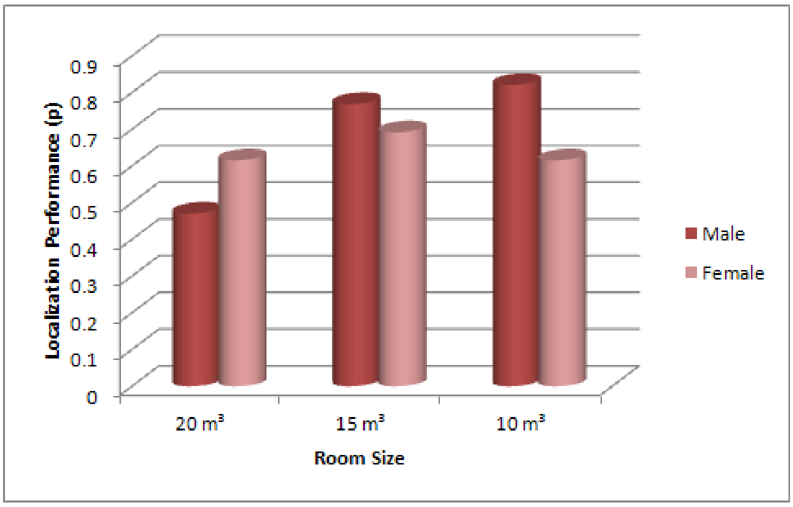


Figure 33: Comparison of LP for male and female participants

Comparison: It is quite clear from the Table 24 and Figure 33, that both male and female have some noticeable difference in their localization performance capabilities.

Localization Easiness

Since, easiness measures a person's belief in his or her ability to perform a particular task [**150**], therefore, in this study, we were particularly interested to investigate whether quality scores for localization easiness of test participants play any clear role in performing localization of concurrent talkers in virtual acoustic environment. Further, distribution of quality scores on human localization easiness is reported in Table 24, Figure 34.

Male Participants: Male participants' perception of easiness is the highest in middle size room (15 m^3) which is 3.85 MOS score and the lowest is in small size room (10 m^3) which is 3.64. It means male participants feel more easiness in localizing concurrent talkers in big room than in small room.

Female Participants: For female participants, the MOS score data trend suggests that localization easiness and virtual acoustic room size are inversely proportional, i.e., as room size reduces, the perceived localization easiness scores increases. It means female participants feel easier in localizing concurrent talkers in small rooms than big room.

Comparison: The data trend in Table 24 and Figure 34 suggest that male participants feel more easiness in localizing talkers in big room; conversely, female participants feel the opposite, they feel that they can more easily localize talkers in small room. However both male and female participants have similar range of scores in middle size room (15 m³). It means the male and female participants also keep different perceptual levels.

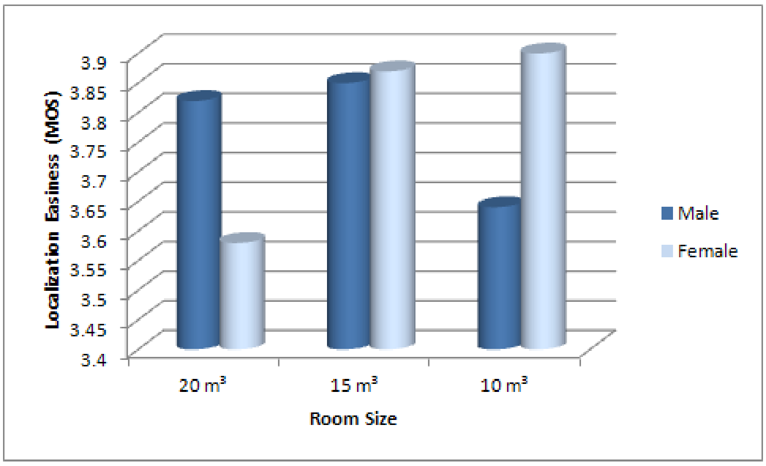


Figure 34: LE for male and female participants in virtual acoustic rooms

Localization Performance vs. Localization Easiness:

Male Participants: In big-sized room (20 m³), male participants gave considerably good MOS score (3.82) which means they feel that they can more easily locate concurrent talkers in big-sized rooms. But in reality, when they were asked to locate the talker positions, they showed poor localization performance. While in small-sized room (10 m³), the LE MOS score is 3.62, which is lesser than big-sized room (20 m³). But LP score was the highest (0.82). It means male participants perceive it easy to localize talkers in big-sized room (20 m³) room. But when male participants were asked to locate the talkers in (20 m³), their localization performance was the lowest. At medium-sized room (15 m³), both LP and LE start to converge. It suffices to conclude that male perception and performance differ in both small and large room. But both LP and LE converge to similar trend in middle size room.

Female Participants: LP rates are similar in both big-sized room (20 m^3) and small-sized room (10 m^3), but LE-MOS scores differ in these rooms. In large room (20 m^3), female participants perceive it harder to locate participants than small-sized room. In reality when they were asked to localize talkers in both large and small room. They performed equally well in both rooms. However in middle-sized room (15 m^3), both LP and LE scores converge to similar trend.

7. 6. Conclusion

In this chapter, we focused upon the influence of contextual aspects on QoE, while the influence of technological and business parameters is considered in previous chapters. To evaluate and validate the QoE and context relationship, a (listening-only) user study was conducted using 3D Audio teleconferencing. The user study results present assessment of the QoE factors like localization performance, localization easiness, spatial audio quality and overall audio quality with respect to changing characteristics of contextual aspects.

According to results, contextual aspects have influence on QoE constructs. With change in the size of virtual room and voice type of concurrent talks, the change in the values/scores of QoE factors were noticed. It is also noticed as the size of virtual room changes, there appears a noticeable difference in human perception and performance in virtual acoustic environment. Furthermore, it was investigated that how gender difference affect QoE- virtual environment relationship. The results suggest that male participants' localization performance increases as the size of virtual room decreases, but unlike male participants' data trend, female participants' localization performance is same (0.6154) in both big room (20 m^3) and small room (10 m^3).

For subjective QoE data results, it is obvious that male participants feel more easiness in localizing talkers in big room; conversely, female participants feel more easiness in localizing concurrent talkers in small room.

Though male and female participants have slightly different trends between performance rates (LP) and LE-MOS scores in small-sized (10 m^3) and big-sized (20 m^3) room but their perception and performance capabilities converge to similar trend in middle size room.

Part 3. Implementations and Architectures

Introduction

There are many tools and frameworks available for the measurement of network traffic but as QoE is still emerging field, there are not many QoE monitoring and evaluation tools available. In first two parts of thesis, we moved from concepts to practical study, now based on previous experience, we are going to present work in-progress to introduce some tools for an effective monitoring, evaluation, and management of QoE for multimedia services.

This part contains two chapters:

Chapter 8 presents a QoE framework for Multimedia services (QoM).This framework is client-server model and it provides web-based client interface for accessing videos and user feedback. Most of the processing and analysis is done at server side. Admin is alerted incase of decline in QoE.

Chapter 9 is about QoE framework for multimedia services based on Android based smart phones. This tool evaluates QoE at client side.

An idea that is developed and put into action is more important than an idea that exists only as an idea."
Buddha

Chapter 8. QOM: A new QoE Framework for Multimedia Services

Highlights

- QoE framewOrk for Multimedia services (QoM)
- Architecture of QoM
- How this framework functions?
- In-progress work

8. 1. Introduction

This framework is an attempt to provide a QoE evaluation tool to industry and research community. It is still at its infancy stage but we intend to present this open-source tool to research community soon and in this way, we expect it to get matured over the time. This framework is named as QoE framework for Multimedia services (QoM) and it is intended to perform the functions of monitoring data, analyzing it and then reporting it to administrator (Admin).

The goal of QoM framework is to perform three main functions as shown in Figure 35. QoM framework captures network traffic, video parameters and user rating, and it does analysis over captured data based on simple statistics to advanced techniques such as multiple linear regressions to Rough Set Theory (RST) and qualitative analysis. The important task of QoM is to report periodic updates to Network Administrator and alert them with message in the event of degradation in QoE score.

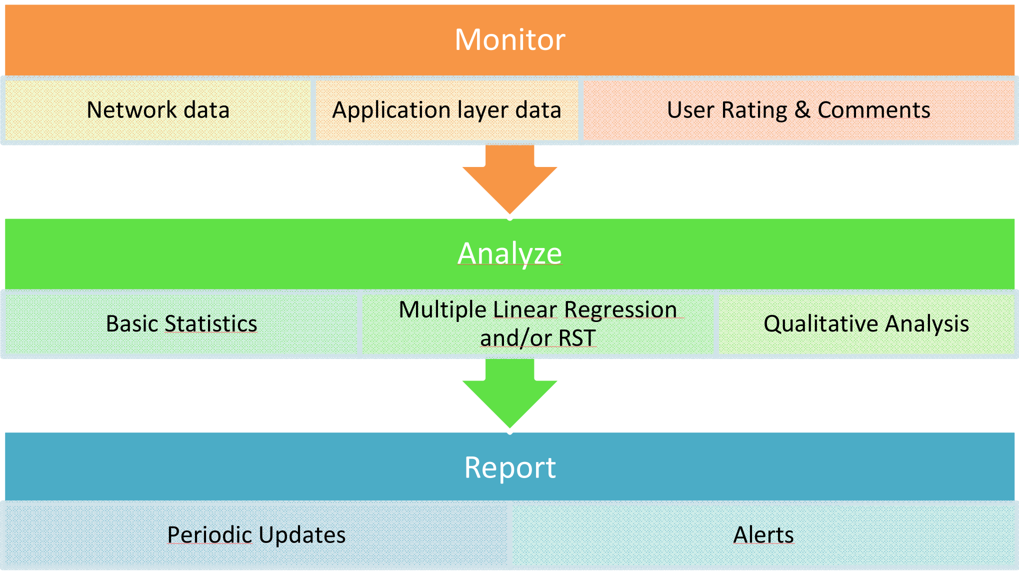


Figure 35: Basic Functions of QoM

In next, some related work is presented.

8. 2. Related work

Some niche vendors[8] have started developing QoE based tools but they mostly focus on objective QoS/QoE factors such as perceptual evaluation of speech quality (PESQ) technique [**17**] and peak signal to noise ratio (PSNR). In academia, there is also on-going effort to propose QoE monitoring and evaluation frameworks. One such work is [**151**], where authors propose a QoE monitoring framework for video delivery networks. Their framework is based on PSQA (Pseudo Subjective Quality Assessment) technology. Another framework is subjective assessment framework MintMos [**12**] which provides quantitative analysis of both network and application level QoS parameters to predict QoE scores (MOS). In [**152**], Authors proposed a model and framework to evaluate video quality based on application level QoS parameters. Our framework supports subjective assessment and for data analysis both quantitative and qualitative methods could be used. Table 25 presents summary of comparison between different available frameworks.

Table 25: Comparision of different Video Quality tools with QOM

QoE Framework	***MintMos***	***Taichi Kawano et al***	***Niche vendors***	***QOM Framework***
Parameters	NQoS+ AQoS	AQoS: Video Blur and Blocking	PESQ, PSNR, VQM	NQoS+AQoS
Monitoring Support	Yes	Yes	Yes	Yes
Analysis Support	Yes (Quantitative Only)	Yes (Quantitative Only)	Yes (Quantitative Only)	(Quantitative +Qualitative)
Reporting	No	No	Yes	Yes
Remarks	Subjective Evaluation)	Subjective Evaluation	Objective Evaluation	Subjective Evaluation

[8] www.witbe.net, www.ibys.com/, www.qoesystems.com

8. 3. Architecture of QoM Framework

QoE framework for Multimedia services (QoM) is build on J2EE model. The important components of this framework are QoE Manager, QoE database, Video streaming server, Web-based client interface, Web-based admin interface. The Figure 36 shows the detail architecture of QoE framework, sniffer tools are deployed at two sides of the service model, one at server side and one at client side. With this deployment, all service parameters could be captured. QoE manager performs the analysis and management functions on captured data. VLC server provides the VoD service over the client web browser. All the objects of the framework are synchronized with the MySQL (QoE) database. We discuss one by one each of these components of the framework.

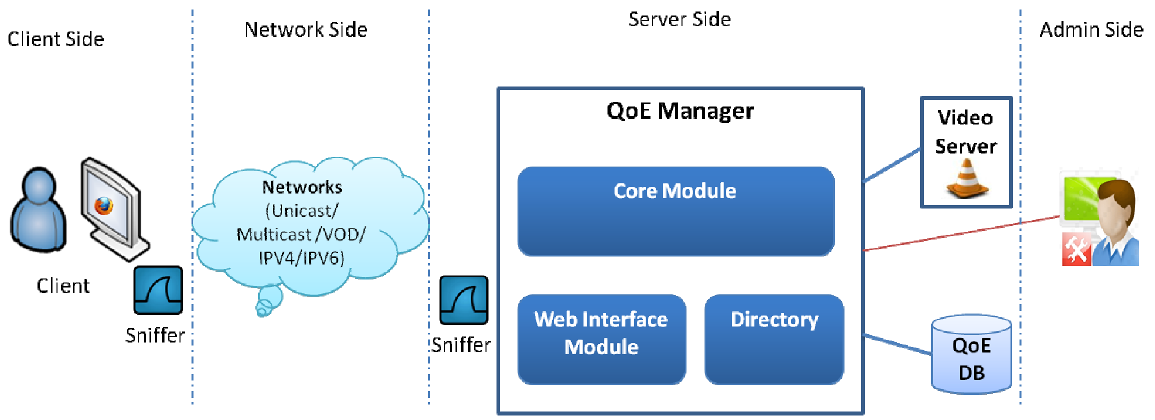


Figure 36. Architecture Diagram of QoM

8. 3. 1. Client Interface

A web-based client interface is developed to facilitate users to watch videos online and give their QoE ratings. Client interface consists of user profile information, QoE rating tab and video section as shown in Figure 37. User profile information consists of user demographic information (age, gender, profession, country, and location). QoE rating consists of quantitative scales 5-point scale, bi-nominal ratings and qualitative comments. Different QoE scales provide users a facility to give their response about quality based on these scales. Video part of client interface permits users to watch any of given video content (e.g., News, Football, and Container) by using any of two resolutions (360x240 or 640x480).

8.3.1.1 Client Side System Requirements:

Latest Firefox browser is used for the current version of framework as client interface. However, client interface also supports Google chrome. Client side machine should have latest version of Firefox or Google Chrome with VLC plug-in utility. As client interface is based on web browsers, it can run on any operating system which supports Firefox and Google chrome.

Secondly client machine should contain a Wireshark utility in their machine so that client side data capturing could be done.

Each time, a user wants to watch video, s/he will be allotted a unique random session number. And S/he has to insert client IP address before processing video test.

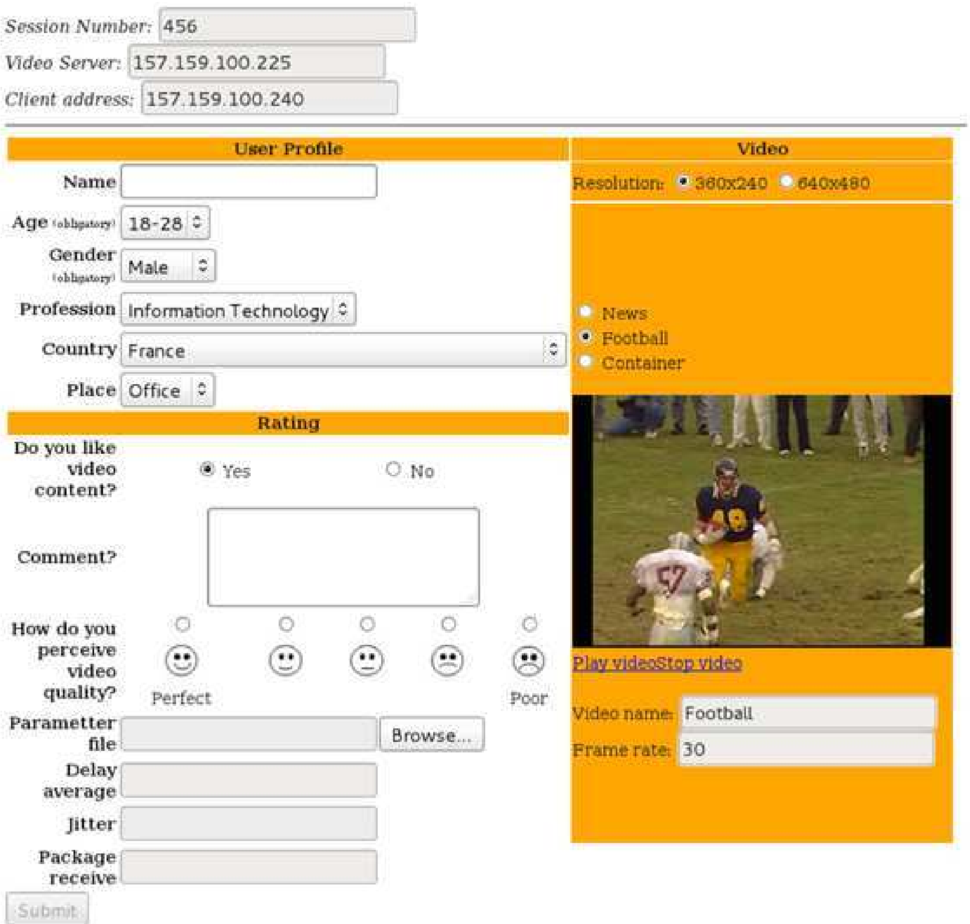


Figure 37: Screen shot for Web based client Interface

A client comes to the VoD service web page and chooses the video contents and its resolution. After watching demanded video, client will provide his personal information such as name, age, profession, gender, country, place, like or not the video content, comments, resolution selected. However the client interface is not dumb terminal, it has ability to calculate client side QoS information such as Jitter, one-way delay, number of packet received, and resolution. Upon clicking submit button on client interface, the information will be transferred to QoE manager for further processing.

8. 3. 2. Sniffers

In proposed framework, TShark is used as sniffer. TShark is a terminal oriented version of Wireshark designed for capturing and displaying packets when an interactive user interface isn't necessary or available [**153**]. Using TShark, packet data can be captured from a live network, or read packets from a previously saved capture file, either printing a decoded form of those packets to the standard output or writing the packets to a file [**154**]. TShark's native capture file format is libpcap format, which is also the format used by tcpdump and various other tools.

Sniffers are used both at client side and server side. Sniffer at the client side is used to sniff the packet data (UDP) transmitted by client and received from server. The captured data will be written into a file in the client's terminal, so that after VoD session, the client's terminal can provide the information such as the number of packet received, delay and jitter to QoE Manager.

Sniffer at server side will be triggered at the time, when user chooses to start the video service test. Client needs to run wire shark manually and s/he will be asked to turn off sniffer at the end of session, while sniffer at server side will start automatically and it will turn off after an elapsed time t (i.e., 3 min). Two Wireshark processes should be configured with the same filtering parameters such as client's IP address, server's IP address, and UDP protocol.

8. 3. 3. QoE Manager

QoE Manager is the heart of framework and it consists of three important modules: Core module, Web-interface module, Log directory. Both the core module and the web-interface module run on Glassfish Application server.

Web interface module consists of JSP, and Java Servlet. JSP is used for displaying information. Java servlet is responsible for interconnection between the core and client/admin interface. Log directory stores logs of every video streaming session.

There is a Glassfish server [**155**] that contains the beans, objects, classes and core functions of the service. The core module is based on Java beans and it is responsible for taking all necessary management actions. It comprises of three main component functions i.e., object definition, operations and DB processing. Core module defines four categories of objects such as user, session, QoS and video. Operation part of Core module is responsible for conducting all analysis, processing and management functions of this framework. DB processing is also a type of operation processing between the core module and QoE- DB and the log directory.

Beside the core module, we created the web interface module. This module is based on JSP and Java Servlet to facilitate communication between the core module and the web-based client/admin interface module. The web interface module receives the request from a client and/or an admin interface and transfers them to the core module for further action. The core module processes data and send output data to the web interface module to enable client/admin terminals to display/access data.

Directory is responsible for storing data log file captured from sniffer at server side. All the packets coming in each side will be reported into log files.

Inside the J2EE platform [**156**], we had to build some function that connect to the outside sniffing module, therefore, almost all the step capturing the packet, writing into sessions' log files, analyzing the log files, calculating the QoS parameters and displaying the information to administrator and client are automatically processed.

Inside the framework, each session has its own session id, and for each session, the sniffer at server side captures information which is stored in Log directory. And, the QoE manager can obtain the parameters like delay, jitter, packet received from the client side. The QoE Manager then uses batch processing to update all the session parameters and calculate packet loss, predicted QoE. This batch processing method will avoid the situation that when client finish his session but the sniffing process of server is still operational. We encounter this phenomenon because the QoE Manager captures the packet and at the same time, it has to write into the log file. Thus wire shark at the server side takes some time to turn off.

8. 3. 4. Parameter Measurement

The sniffer tools (i.e., TShark) is responsible for capturing the entire UDP packet transmission during a particular session. Based on captured data, the QoS parameters are calculated such as average delay, jitter and packet loss as given in equation below.

8.3.4.1 Delay calculation:

$$averagedelay=\frac{1}{N}\sum_{i=1}^{N-1} interval_i \text{ ------------------------(xiv)}$$

N is the total number of packet captured. Interval is time between the arrival of two consecutive packets and it is extracted from the log file of TShark. The average delay is calculated by taking the average of all the intervals of captured packets.

8.3.4.2 Jitter calculation:

Jitter is calculated by following formula;

$$jitter=\frac{1}{N}\sum_{1}^{N-1}\left(interval_{i+1}-interval_i\right)^2 \text{ -----------(xv)}$$

8.3.4.3 Packet loss calculation:

Packet loss is calculated by following formula;

Packet Loss= 100* (1-Pktreceived/Pktsent) -------------------(xvi)

The packet received is the number from the client side and packet sent is the number from the server side, we can calculate the packet loss of each session based on the number of packet captured in the both sides.

8.3.4.4 Predicted QoE

The data mining and estimation techniques are used to predict QoE from available captured data. For the current version of framework, Multi Linear Regression (MLR) technique is used to predict QoE based on multiple QoS factors. Formally, the model for MLR, given n observation is presented as given in equation (xvii),

$$QoE_i = \beta_0 + \beta_1 QoS_{i1} + \beta_2 QoS_{i2} + \ldots \beta_p QoS_{ip} + \varepsilon_i \text{ for } i = 1,2, \ldots n. \text{---------------} \quad (xvii)$$

Where β_0 is constant term, and β_1 *to* β_p are the coefficients relating the p explanatory (QoS) variables to the variables of interest. For more details about MLR, one can refer to this tutorial [**157**].

Based on available captured data, predicted QoE will be calculated using multiple linear regression method.

Y = AX

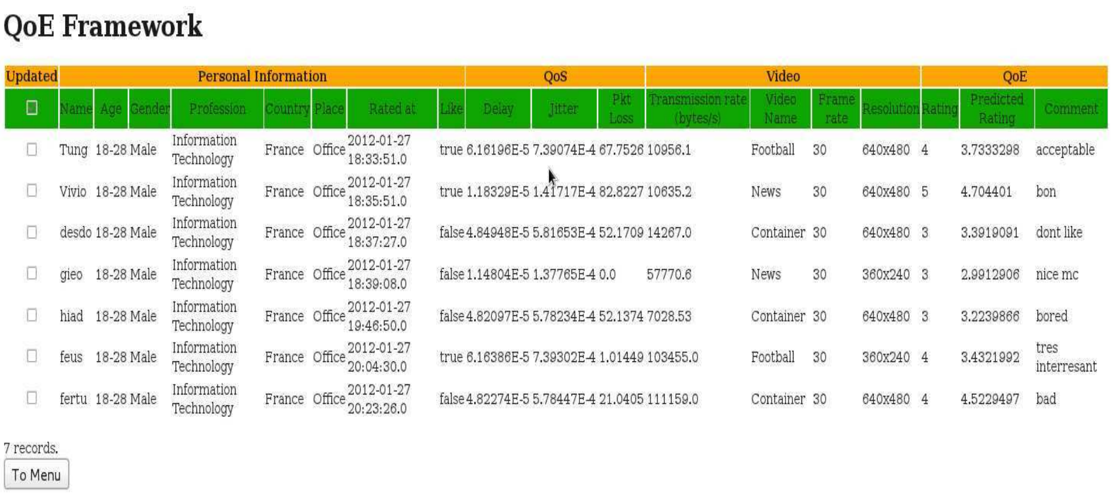
Y: the matrix of QoE rating from the client.

X: the matrix of parameters obtained such as Average Delay, Jitter, Packet Loss and Transmission rate.

A: the matrix of co-efficient

By using regression algorithm, we have the input matrix X and Y. We have the matrix A as an output. And after that, we multiply matrix X by matrix A transposed, we will have the matrix Y(matrix of predicted rating QoE). After performing analysis function, QoE manager stores parametric file to QoE database.

Following Figure 38 shows the record of QoE and QoS information.



QoE Framework

Updated	Personal Information								QoS			Video				QoE		
	Name	Age	Gender	Profession	Country	Place	Rated at	Like	Delay	Jitter	Pkt Loss	Transmission rate (bytes/s)	Video Name	Frame rate	Resolution	Rating	Predicted Rating	Comment
	Tung	18-28	Male	Information Technology	France	Office	2012-01-27 18:33:51.0	true	6.16196E-5	7.39074E-4	67.7526	10956.1	Football	30	640x480	4	3.7333298	acceptable
	Vivio	18-28	Male	Information Technology	France	Office	2012-01-27 18:35:51.0	true	1.18329E-5	1.41717E-4	82.8227	10635.2	News	30	640x480	5	4.704401	bon
	desdo	18-28	Male	Information Technology	France	Office	2012-01-27 18:37:27.0	false	4.84948E-5	5.81653E-4	52.1709	14267.0	Container	30	640x480	3	3.3919091	dont like
	gieo	18-28	Male	Information Technology	France	Office	2012-01-27 18:39:08.0	false	1.14804E-5	1.37765E-4	0.0	57770.6	News	30	360x240	3	2.9912906	nice mc
	hiad	18-28	Male	Information Technology	France	Office	2012-01-27 19:46:50.0	false	4.82097E-5	5.78234E-4	52.1374	7028.53	Container	30	640x480	3	3.2239866	bored
	feus	18-28	Male	Information Technology	France	Office	2012-01-27 20:04:30.0	true	6.16386E-5	7.39302E-4	1.01449	103455.0	Football	30	360x240	4	3.4321992	tres interresant
	fertu	18-28	Male	Information Technology	France	Office	2012-01-27 20:23:26.0	false	4.82274E-5	5.78447E-4	21.0405	111159.0	Container	30	640x480	4	4.5229497	bad

7 records.

To Menu

Figure 38: Data Table

8. 3. 5. Video Server

VLC is selected as video server and protocol used for streaming is UDP- RTSP with port number 5554. Before conducting test, video streaming server should be operational.

8. 3. 6. QoE Database

With standard J2EE model, we create data tables from the object created. And MySQL server is used as a database for the framework. It is connected to QoE manager through JDBC (java database connector). There are four tables, the Session table, QoS, Video and User table as shown in Figure 39. The Session table stores the session's id and foreign key of other tables QoS, Video and Users. The QoS table stores the information of all the network parameters. It includes Transmission Rate, Delay, Jitter, Packet loss, Packet received, Packet sent.

The Video table stores application level QoS parameters such as video name, frame rate, resolution. All the videos are stored in a specific folder of the server. We store video's information such as video name and video frame rate in the database so that this information will be shown to the client when they watch them.

The User table stores all the personal information and the rating information of sessions. After watching the video clip, client will be asked to provide their information, rating and comments. User information will be stored in the database for further analysis.

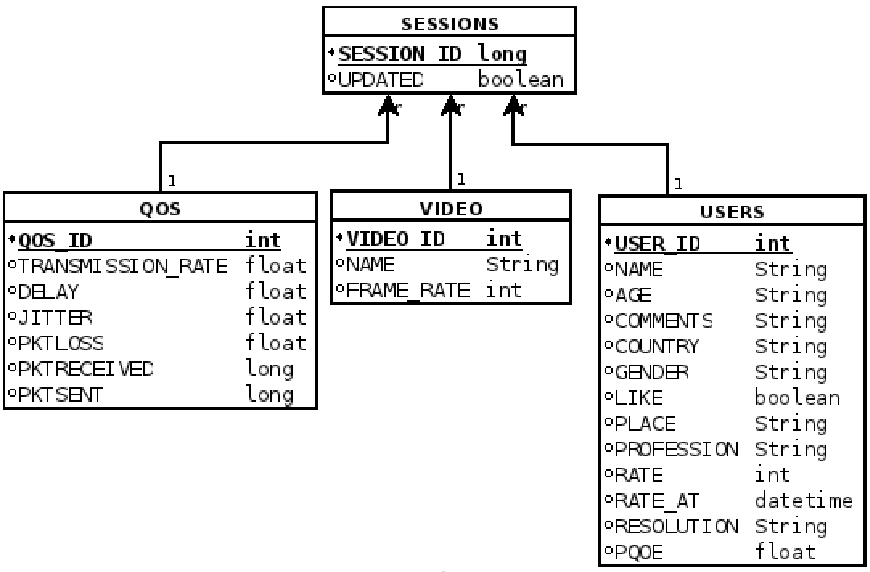


Figure 39: Database structure

8. 3. 7. QoE Admin Tool

It is web-based admin interface and it performs two main functions: view data records, update data records by initiating batch processing as shown in Figure 40.

Figure 40: QoE Admin Tool Screen Shot

Admin at any time can view the available data records (QoS and QoE status) of a VoD service. Admin can get updated information of various sessions by initiating batch processing (Admin Clicks Batch-processing button on his interface) and QoE manager performs batch processing to analyze data and provide updated records. QoE manager also periodically checks data records and if it finds any anomaly (e.g., QoE ratings are less than 3), it will report to Admin for further investigations and actions.

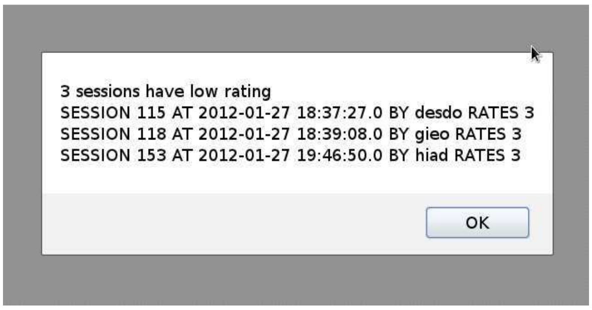


Figure 41: Screen shot for Alert Report

Based on the idea of the framework that the level of satisfaction of client is very important to the service (business), the server will update all the rating information from client's session. If there is any session in which the client gives the bad rating, the server will display an alert message on the administrator's screen as shown in Figure 41. Next we present an example of policy rule for alert. We have made a simple policy rule, however many different policies and rules can be developed based on the requirement of service and admin.

Example: Policy for Reporting Alert

Reload Admin's screen with updated QoE ratings every 5 seconds

if (session is new (not updated) && rating of session is equal or less than 3) then

put session's information of rating, user's information into the alert message;

session is setupdated;

end if

8. 4. Procedure of QoM

Here, we produce sequence diagram to understand how this framework operates to produce QoE evaluation for multimedia services. We present three actions as shown in Figure 42.

- At the start of the session, user manually starts Wireshark at his side and then opens web based client interface to watch video clips. Sniffer at server side will be triggered at the time, when user chooses to run the VoD service. User request for video content will be routed to VLC server through QoE Manager. VLC start streaming specific video content to a client. At the end of video clip, user gives his rating and uploads client side data log file. Web-based client interface calculates number of packet received, delay and Jitter and sends them to QoE Manager. Upon the reception of client side data, QoE Manager analyzes log data to compute packet loss, basic statistics on data (Mean etc) and predicted QoE (based on Regression). Once data analysis process completes, the attribute file is stored in QoE database. And updates on attribute could also be sent to Admin.

- Admin can also view the records of available evaluated data and for this purpose, QoE Manager is contacted, which gets attribute records from data base and sends them to Admin.

- QoE manager also periodically verifies the records, for this purpose, after every 5 seconds, he gets updated records and based on some policy rule, it takes decision, for instance, if QoE rating is equal to or less than 3, it generates alerts for Admin to investigate the decline of QoE.

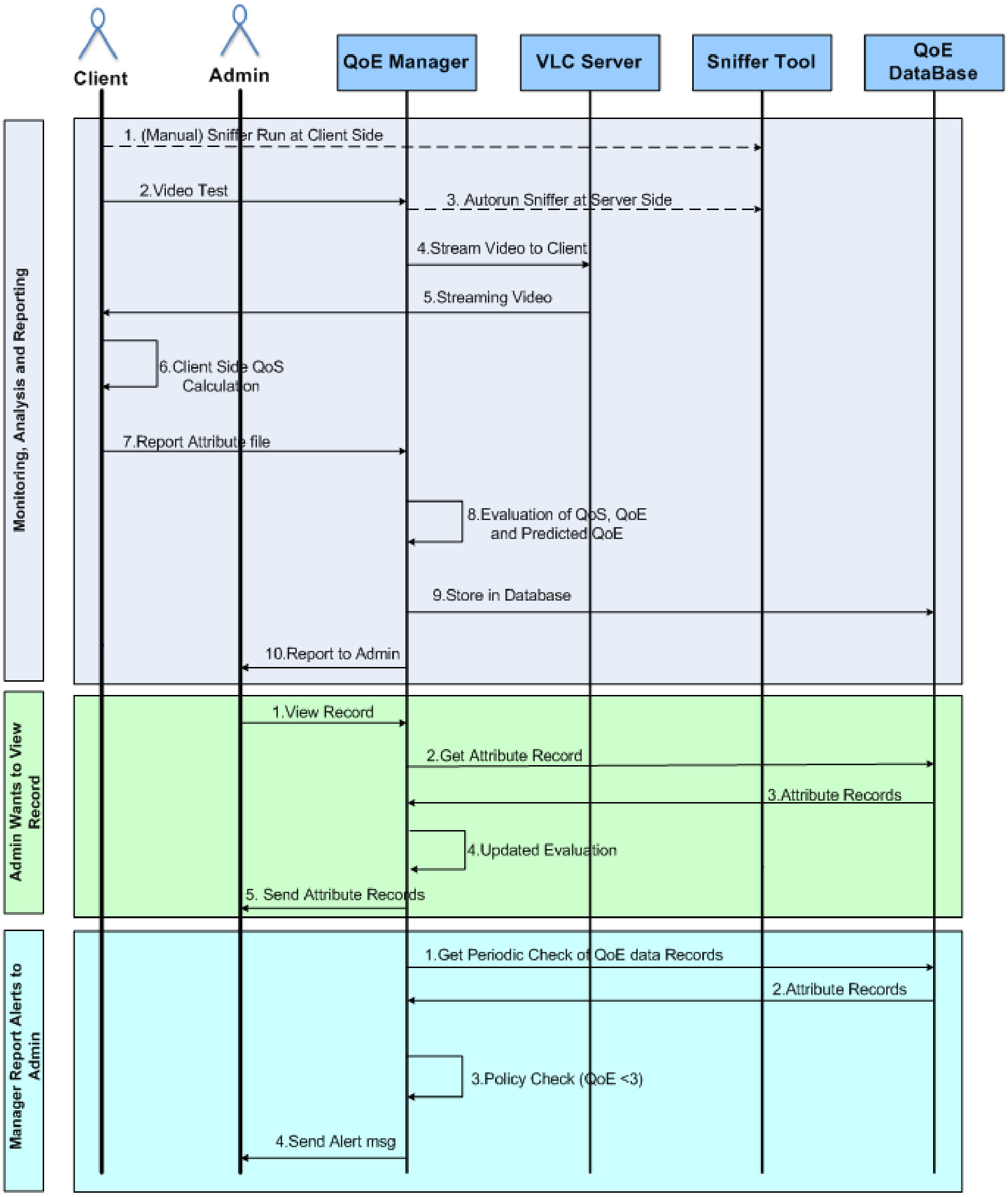


Figure 42: Sequence Diagram

8. 5. Conclusion

In this chapter, a new framework for the monitoring, evaluation and management of video streaming service based on quality of experience is presented. The proposed QoE framework for Multimedia services (named as QoM framework) captures network and application layer QoS data, qualitative QoE data and quantitative user ratings and content information. Using descriptive statistics and multiple linear regressions, QoE is evaluated. In case of any decline in QoE, an alert message is conveyed to the administrator (Admin) for further investigation. Our newly proposed QoM framework is being launched as an open-source QoE evaluation tool for the industry and research community.

But it has also some limitations, for examples, Firefox is used as a client interface, it is very secure browser and it does not allow the script such as Java script to run and execute the client's application or service. That's the reason the client who want to use the service, s/he must activate the capturing service manually first, and after that the service will work well. This dependency on manual switching sniffers ON is important challenge to address in next version of the framework.

Furthermore, this QoM framework permits users to watch video and give their feedback in textual format (comments). But in the current version, qualitative analysis is not yet included.

As this is work in-progress, in future, we intend to improve this framework by solving the limitations mentioned. Extensive user tests would be conducted to evaluate the performance of the proposed QoM framework in a context of real 4G Wimax wireless networks.

“Listening to customers must become everyone's business. With most competitors moving ever faster, the race will go to those who listen (and respond) most intently.”
Tom Peters

Chapter 9. AQOM: Android based QoE Framework for Smart Phones

Highlights

- Android based QoE framewOrk for Multimedia services (AQoM)
- Architecture of AQoM
- Use case and evaluation
- In-progress work
- **Confidential work:** Patent with France Telecom (Final-stage of Acceptance)

9. 1. Introduction

The use of smart phones has changed the landscape of ICT, because it brings huge set of applications within one touch of customer. Due to advanced operating capabilities of smart phones, multimedia applications are being developed in a big numbers and stored in Google store and apple store. In mobile environment, the context of user may continuously change, which in turn influences user behavior. Furthermore multimedia services have also stringent QoS requirements. Given the changes in technical and contextual parameters, there is possibility that user experience will also change accordingly. In this situation, there is dire need to understand user Quality of Experience demands and requirements for mobile multimedia application. For understanding QoE requirements, the mapping between user subjective ratings, QoS and contextual parameters should be done.

We propose an innovative user-centric, context aware solution for measuring QoE over smart phones. The objective is to design a simple, user friendly and intelligent QoE framework for Android based smart phones to analyze and evaluate user experience requirements for multimedia services and application vis-à-vis context of use, smart phone parameters, and QoS. The solution aims to gather contextual information (e.g. battery level, GPS data) from the user device (e.g. Smartphone) and user scores for a given multimedia service. These collected data are analyzed to generate a QoE model to assess the user perception regarding the studied service. The framework is simple, user friendly, and stand alone intelligent QoE application installed on smart phone which not only captures QoS, contextual parameters and user ratings but also analyzes and generates personalized QoE results for a given user session. Furthermore, QoE is never a fixed value; it keeps updated over time with respect to change in QoS or contextual parameters.

The novelty of our solution is the collection of QoS, contextual and user ratings locally on user smart phones and then analyzing and generating personalized QoE model locally on smart phones. The data are analyzed as soon as user finishes interacting with the studied service or after a consequent changes in the user perception via thumbs up/down flags.

9. 2. Background

In [**158**], the authors proposed a QoE measurements method for smart phones. The method is based on the collection and the processing of QoS data on the user terminal and reporting QoE based on objective (QoS) assessment. Hence they do not require any user feedback. However our work is based on subjective assessment scheme and it provides more reliable and accurate user QoE results for each user in mobile multimedia environment.

In [**159**], they produce QoE frame work for smart phones and they use subjective assessment technique for the measurement of QoE, and their framework is based on client-server model. Once, user data is collected; server side takes control of all user data and it makes analysis over it. Their user interface or client side application is merely information exchanging utility consuming resources for reporting data to a server side and it is not intelligent enough to make any analysis over data and/or produce personalized QoE results for smart phone users.

Our proposed Android based QoE framework for multimedia services (AQoM) is simple, intelligent and self functioning QoE framework which not only monitors contextual, QoS and user ratings but it also makes QoE analysis and decisions on its own at client side. It does not require any third party servers for data analysis and it produces run time QoE Evaluation.

9. 3. The architecture of AQOM

We propose a new way for measuring QoE parameters directly from the user device. The local management of QoE parameters avoids the need for uploading them to a server to process them and aggregate these parameters from multiple users as used by existing frameworks. Thus, enabling the generation of a personalized QoE model and preserving user privacy by storing and processing user information locally on his device.

Figure 43 depicts our architecture for measuring user quality of experience (QoE) for a multimedia service. We consider VOD (Video on Demand) example of streaming videos from YouTube over a 3G/WiFi connection.

Figure 43: QoE measurement architecture for multimedia services

Our client-server architecture is composed of an Android application running on the user Smartphone for measuring user QoE; YouTube server from which the videos will be streamed over a 3G connection via the RTSP (Real Time Streaming Protocol) protocol. Figure 44 presents main components of the Android application responsible for QoE measurement, interaction with the end-user and with the remote multimedia service provider (MSP).

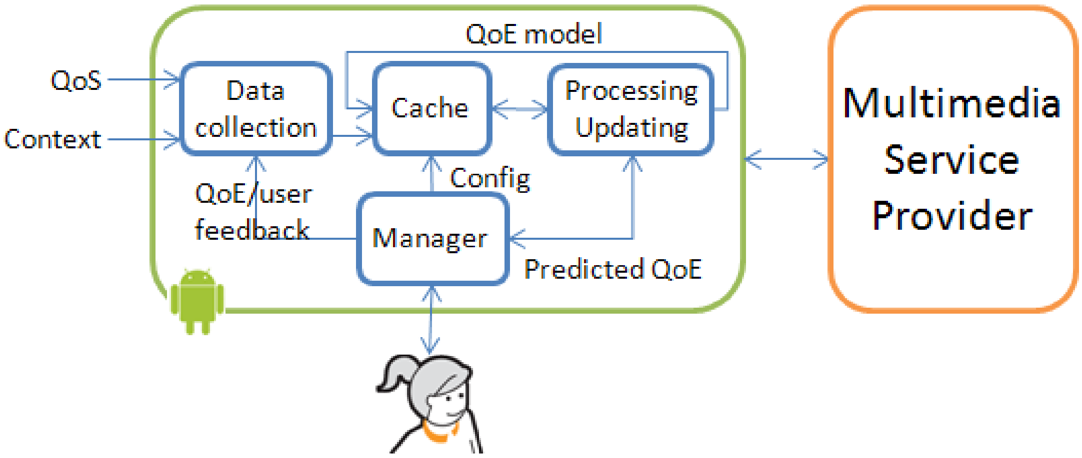


Figure 44: Architecture of the Android application for QoE measurement

The Manager (MC) is the main component responsible for interacting with the outside world (user and service provider) and managing rest of the system components.

The Data collection component (DCC) is responsible of acquiring QoS (e.g. jitter, packet loss) and user context (e.g. GPS data) related information. The collected data from the user device belonging to the following categories:

- Ratings of the different questions we asked the user to answer after viewing a video
- Information about CPU usage (e.g. percentage consumed by our application)
- Information about memory usage (e.g. amount of memory needed by our application)
- Video parameters like timing of watching video or a time when a user encounters an error during the process of watching video.

- QoS parameters like delay and jitter
- Location information like the name of the location provider, altitude, longitude, etc.
- Phone related information like software version, network type (e.g. UMTS, GPRS)
- Battery related information like level, health (e.g. good), and status (e.g. charging).

The cache component (CC) is responsible of caching temporary a set of collected data (QoS, context and QoE) and the generated QoE model.

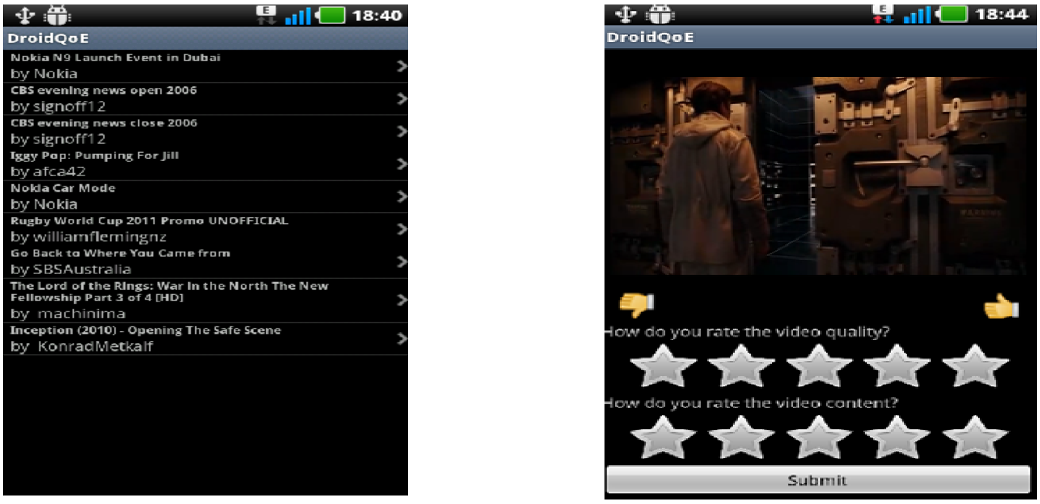
The Processing/Updating component (PUC) works in two modes: learning and automation modes. In the learning mode, this component uses a supervised learning algorithm (for instance a linear regression) to generate a personalized QoE model and stores it into the cache component. The generated model is updated continuously with the cached data and each time the cached data is consumed, the cache is emptied.

In the automation mode, the component is responsible for predicting QoE parameters (e.g. did the user like the video content?), with the use of the cached QoE model. The framework can be part of a multimedia service as a specialized component of evaluating the experience of user regarding the usage of the service. In this case, predicted QoE values can be for instance sent to the multimedia service provider in order to personalize the recommended videos.

9. 3. 1. Implementation details

The different components in Figure 46 are implemented as Android threads *AsyncTask* except the cache that is implemented as an Android *ContentProvider* able to store data locally into the Android *SQLite* database. The application has two Android activities: the first one displays a list of videos; the second one displays the chosen video. We used YouTube API to stream videos from the multimedia service provider.

When the application is started, list of videos that can be viewed are displayed. The user can choose one video to view. While he/she is watching the video, QoE can be reported with the help of thumbs up/down buttons. At the end of the video, user can report QoE by answering questions.



(a) (b)

Figure 45: Screenshots from the QoE measurement application

Figure 45 depicts a screenshot from an implementation of the QoE measurement frame work. The GUI (graphical user interface) showed in ‘a’ displays a list of videos. The one in ‘b’ is composed of a top area where the video is displayed. In the middle, the user can use the thumbs up/down buttons to express his current perception of the displayed video. At the bottom, there is a button for submitting user answers of the asked questions.

9. 4. Learning and Processing

Our learning algorithm, implemented by the processing/updating component, is based on multivariate linear regression where input parameters are QoS and contextual information and QoE is the output or target variable.

For each learning phase, size of the training set or number of samples is ‘m’ size of the cache. The hypothesis (h) represents the model to be learned for predicting future values of QoE for a giving sample ($y_{predicted} = h(X)$). Mathematically, h is defined in equation (xviii), where n is the number of input parameters, θ_j are the parameters to be learned.

$$h(X) = \theta_0 x_0 + \theta_1 x_1 + \theta_2 x_2 + \ldots + \theta_n x_n, \text{----------------------------(xviii)}$$

The learning algorithm tries to predict the best values of the hypothesis parameters (vector of θ values) minimizing the difference between the outputted QoE value and real value ($y_{predicted}$

– y_{real}). Equation (xix) defines mathematically the cost function '**J**' which is based on a model (vector of θ values) to output the cost of this model by the summation of squared distances between predicted values $h_\theta(x)$ and real values y for all samples (rows) of the dataset.

$$J(\theta) = \frac{1}{2m}\sum_{i=1}^{m}(h_\theta(x^i) - y^i)^2 \qquad \text{------------------(xix)}$$

To predict best values of θ parameters, Batch Gradient Descent (BGD) [**160**] is also used for available set of data, but in our case, all the data is not available at a single time but it is gathered continuously and progressively over the time. We need to modify BGD to suit this need. The proposed algorithm called M-BGD (Modified Batch Gradient Descent) is an iterative optimization algorithm that operates on a data stored into the cache when 'm' (cache size) samples become available, i.e. when cache becomes full.

The captured data have different format, it is necessary to normalize it and for this purpose, equation (xx) is used.

$$Normalized\ P = \frac{P - mean(P)}{\max(P) - \min(P)} \qquad \text{(xx)}$$

Where P represents input parameters and this normalization aims to project data into the [-1, 1] interval in order to avoid parameters scaling problem that may influence the resulting model.

Second, M-BGD updates θ values continuously until convergence or stagnation at a local minimum given the following algorithm:

Initialize θ parameters (e.g. to 0);

Repeat until convergence: $\theta_j := \theta_j - \alpha * \frac{d}{d\theta_j}J(\theta)$ j=1, n

By replacing J derivative with its value, the last loop becomes:

Repeat {

$\theta_j := \theta_j - \alpha * \frac{1}{m} * \sum_{i=1}^{m}(h(X^i) - Y^i) * X_j^i$

}

x^i is a vector representing the i^{th} sample/input features, y^i is the QoE value corresponding to the i^{th} row of the training set, and θ_j represents the learned parameters corresponding to the j^{th} feature/column. The later are initialized the first time to zero. Then, after each training phase, θ_j are stored to be reused the next phase as initialization values.

The cost function 'J' is a convex function; it has then a unique minimum which is the global minimum at which θ values are best values that gives the minimal distance between predicted and real output values. Convergence to best values is guaranteed but gradient descent is an iterative algorithm and it is known to be too slow as the all data sets are used at each iteration many times, hence 'α' parameters needed to be well chosen to speed up the algorithm convergence.

9. 5. Evaluation

We implemented the original Batch Gradient Descent (BGD) algorithm and our variant Modified BGD (M-BGD) algorithm to compare their performance in term of evolution of the outputted cost function value (equation xix) after each algorithm step. Figure 46 depicts the graphs related to cost function calculated for each algorithm. To generate these graphs we used some data collected from a previous QoE study [**16**] of a multimedia service (video streaming). The data is composed of output parameters (QoE values given by users) and input parameters:

- Video category: '0' for fast videos (e.g. football match), and '1' for slow videos (a ship moving in the large sea).
- QoS parameters: packet loss, packet reorder, video bit rate.

In case of BGD, cost function is calculated for the whole dataset each time and this is why its graph is smooth (it can be represented with a linear function) and the cost value is decreasing in a steady way. At the other hand, the cost function of M-BDG is calculated only for the available data in the Cache component which makes the cost value oscillate continuously as the model may fit the current data while not perfectly fit the next set. The BGD need more data to output a low cost value, while M-BGD is able to output an acceptable cost (less than 1).

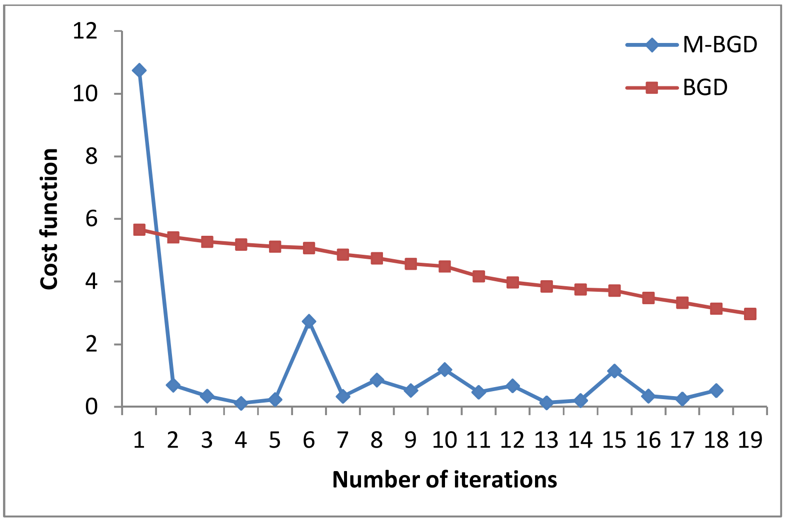


Figure 46: Cost function graphs of two methods

9. 6. Use Case

Figure 47 illustrates the sequence diagram. When the user reports its QoE, the Manager sends this value to the data collection component. It collects user ratings, the current QoS and user context information, and stores them into the cache. When the stored examples in the cache reach a certain value (configurable parameter), the processing-updating component is notified to consume them and to generate an updated version of user QoE model.

When the multimedia service provider requests a QoE value for the currently streamed video, the manager component sends back the user reported QoE (if there is) or a predicted value generated by the processing-updating component.

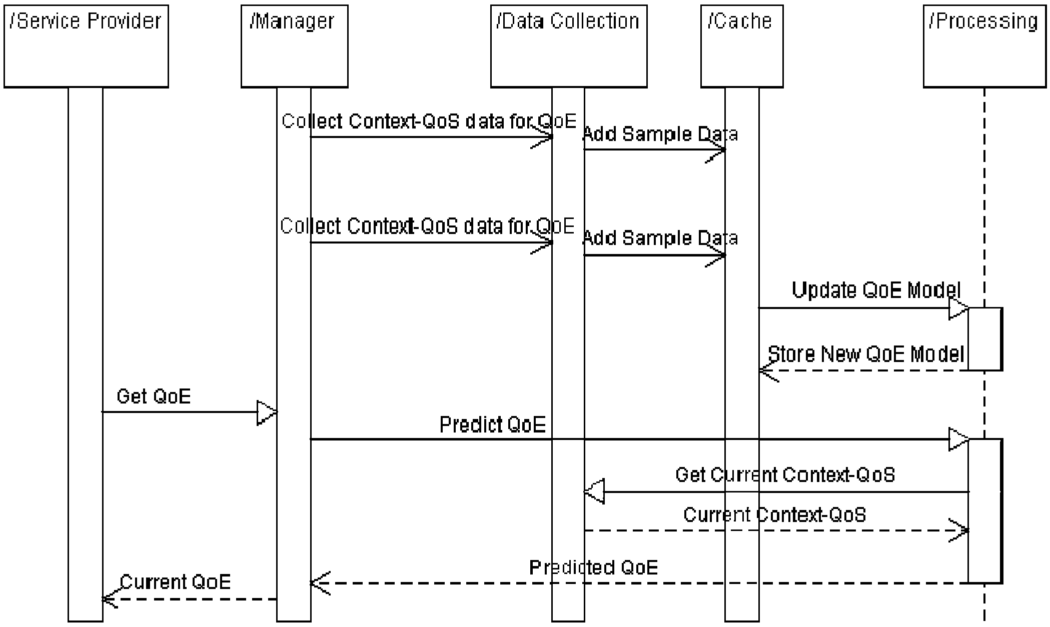


Figure 47: Sequence diagram for QoE management

9. 7. Conclusion

In this chapter, Android based QoE Framework for Multimedia services (AQoM) was presented to evaluate multimedia streaming services on smart phones. Proposed AQoM framework is client application and it handles “monitor, analyze and decide” functions on user data on smart phone and it does not require any other server side for data evaluation, hence it provides a privacy control to user data. It has learning and updating process, which continuously refines QoE.

QoS, context and user rating data are collected from the user device for a better user perception assessment locally at client side. User has freedom to give his feedback about offered quality at any time through thumbs up and thumbs down icon and/or user rating. It is possible that the user behavior with respect to a particular service in any situation could change, hence giving rise to change in his/her QoE requirements. Thus our proposed QoE framework produces personalized QoE requirements of a user in any situation.

This work is in progress and extensive user studies will be conducted to evaluate the performance of AQoM, once AQoM framework is ready.

“Toute bonne chose à une fin”

de Proverbe québécois

Chapter 10. Conclusion of Thesis

10. 1. Summary of Conclusion

This thesis was an attempt to explore the interesting but complex concepts of QoE for multimedia services in communication ecosystem. To research this topic, it was broken down into three main sub-goals or challenges such as (i) understand big pictures of QoE keeping in view the influences of different factors belonging to technology, context and business (ii) analyze and evaluate the interactions and relationships between QoE and other influencing factors (QoS, content, and context) (iii) develop some QoE tools or frameworks based on previous findings.

To address, first challenge, a holistic QoE model is proposed in chapter 4 and in paper [**9**] [**8**] for multimedia services in communication ecosystem. The proposed model brought together human, technological, contextual and business domains as well as their cross-domain interactions to get holistic view on QoE. The model was not meant to be proscriptive, but to provide taxonomy of the relevant variables and their interactions in order to help practitioners to broaden their horizon about QoE. The model Instantiation was depended heavily on the context in which it is applied: specific variables would be more important and lend themselves more easily to measurement. Our goal was 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.

The second important challenge was to identify, collect, and evaluate QoE factors which were affected by different influencing factors. But there was a daunting problem to resolve i.e., human perceptions and feelings are very subjective and random in nature, how to capture and quantify human subjectivity? The one common solution was to conduct user studies and surveys to know customer opinions and feelings and then to evaluate data using some quantitative and qualitative techniques.

In second part of thesis, this challenge was tackled by producing the results of user studies, which were gathered by conducting surveys and user studies using video streaming service, VoIP, PSTN and audio teleconferencing service. They were focused on understanding the impact of various influencing factors (e.g., QoS, content and context parameters) on QoE. In the Chapter 5, a user study was presented to link the combined effect of application layer QoS parameters (e.g., video bit rate), and network layer QoS parameters (packet loss, delay, packet re-order) over user perceived quality for video streaming service. QoE was moderated based on different types of content (i.e., slow moving container clip and fast moving football match clip). The data was then evaluated based on quantitative technique; such as Rough Set Theory, and qualitative technique; such as (CCA). To the best of my knowledge, this work is first of its kind in which video QoE has been reported based on both qualitative and quantitative techniques. It is learnt that not all QoS parameters pose similar level of degradation in user perceived quality and moreover, different contents have also different QoS support requirements. As this study was done in a controlled environment (lab setup), it was then decided to conduct a real customer survey to get ecologically valid results.

Chapter 6 of this thesis is based on real customer survey data for telephony service (PSTN and VoIP) from leading French Telecom operator, in this chapter, three main aspects were evaluated, and those are:

1. The frequency of technical faults and their impact over perceived availability and perceived call quality
2. The evaluation of customer preferences and their moderation based on end-user handheld device
3. The evaluation of customer satisfaction, with respect to customer age group.

From customer survey, it was learnt that different faults (QoS and environmental issues) were treated differently by customers. Background noise was found to be bit annoying for PSTN customers, while for VoIP customers, call drop, background noise, incoming signaling fault, post dialing fault, and pre-dialing faults were found to be in the slightly annoying category.

For customer preference metric, it was learnt that PSTN customers possessing wired and wireless telephony were less worried about power outage or voice degradation issues as compared to VoIP customers.

For overall customer satisfaction, Chi-Square hypothesis was done and the results suggested that the customers of age group less than 40 have similar levels of satisfactions towards VoIP and PSTN services while customers of age groups more than 40 feel more satisfied with PSTN than VoIP. It means, despite PSTN's better call set up performance and call quality, young customers are also satisfied with quality and services offered by VoIP.

Previous two studies were more focused on the impact of QoS and technical issues over subjective QoE factors. As it was proposed in the holistic model that contextual aspects could also influence QoE, in chapter 7, of this thesis, QoE-Context relationship was evaluated using 3D audio teleconferencing service. Following important aspects were targeted;

1. The impact of virtual context characteristics (virtual room size, number of virtual concurrent talkers) on QoE
2. Objective QoE (Localization Performance: LP) related to human cognitive performance and its comparison with subjective QoE factor (Localization Easiness: LE).
3. Analysis of gender difference in 3D Audio teleconferencing virtual environment

According to results, the characteristics of virtual environment could affect user QoE. By changing the size of the virtual room and the voice type of concurrent talks, variation in both subjective and objective QoE factors was observed. Further, user study data suggest that medium size virtual teleconferencing room and mixed voice type talkers' (one male and other female talker) provide optimal quality of experience in 3D telephony based virtual acoustic environment.

LP values tend to increase for small virtual teleconferencing room, on the contrary, LE MOS scores tend to decrease for small virtual teleconferencing room, and vice versa for big room. But both LP value and LE scores are found to be the highest in medium size room (15 m^3). The possible reason for this match between objective and subjective QoE results is the fact that as the echoes and reverberation are more stretched in larger rooms, it feels easy to locate talkers. It is reported in literature [**140**] that reverberation in acoustic environments is considered as a reliable cue in identifying source distance but it also modestly degrades directional perception [**144**] and speech intelligibility [**145**]. Furthermore, it was also learnt that male and female participants have slightly different trends between performance rates (LP) and LE-MOS scores in small-sized (10 m^3) and big-sized (20 m^3) room, however their perception and performance capabilities converge to similar trends in middle size room. It was also found that male and female participants' have slightly different QoE requirement in virtual environment.

During this user study phase, it was learnt that there was a dearth of QoE measurement and evaluation tools, and the available tools were mostly focusing on QoS based objective techniques. Keeping in view the dire need of suitable tools for capturing human subjectivity (QoE) to evaluate user requirements at run time for multimedia service, two tools QoM and AQoM were developed as presented in part 3 (Chapter 8 and 9) of this thesis.

QoM framework is client-server based model tool for capturing network traffic and user feedback (both qualitative and quantitative) to evaluate QoE for video streaming service. QoM framework was an attempt to provide a QoE evaluation tool to industry and research community. It is still at in its infancy stage but after launching it as an open-source tool to research community in near future, it is expected that it will get mature quickly.

AQoM framework was intended to evaluate mobile video services on Android based smart phones. It is client only QoE application which collects user feedback, QoS and context data and does the analysis over it on run time. AQoM operates in two modes; in the learning and automation mode. AQoM Framework is in-progress work in collaboration with French Telco[9] operator.

[9] Orange France Telecom

Finally, it can be stated that despite the fact that QoE evaluation of multimedia services was very difficult due to enormous number of influencing factors, complex assessment and evaluation methods; the achieved results are relatively encouraging. This thesis presents a road map for further investigation in each of these three parts in order to get in-depth view on QoE for multimedia services in communication ecosystem.

10. 2. Future work direction

Multimedia framework development process is work in-progress; the next stage will be to complete this process and then using these tools, perform user study over Wimax 4G network to evaluate the performance of QoM framework. In QoM framework, the following functionalities may be introduced in its next version.

- Automatic Sniffer running at both sides (client and server)
- Qualitative analysis

For Android based framework (AQoM), following functionalities can be incorporated in its next version.

- Complete development process of first version
- Include more QoS parameters
- Better learning algorithm and possible use of RST for analysis

In addition to these tool development tasks, currently, I am conducting collaborative research on following aspects,

- QoE for Passive Optical Network (PON) in collaboration with Korea Advanced Institute of Science and Technology (KAIST) and this work focuses on the impact of energy saving mechanisms on QoE.
- QoE for web traffic in collaboration with Blekinge Institute of Technology (BTH) Sweden

Finally, I have advocated the use of objective physiological factors but I could not incorporate them in my current work. I am trying to establish collaboration with INRS Montreal Canada for some joint work on the application of physiological and cognitive tools for QoE.

Appendix

A1. Test Questionnaires

QoE Study on VoD (Chapter 5)

Pls do not forget to fill this.

Name: (Optional):____

Age: ____________________________________

Gender: Male or Female

Nationality: _______________________:

Level of Education or Profession:____________________________

Experiment 1. How do you perceive Video Quality? Pls encircle below.

:______1________:______2________ : ______3________ : ______4________ : ______5______ :

Worse **Excellent**

Experiment 1: Pls give your opinion about current video experience. (In English or French)

……..

Experiement 1: Do you like video content? Encircle

Yes or **No**

Customer Survey for evaluation of PSTN and VoIP Services (Chapter 6)

Q1 Par rapport au fonctionnement de votre téléphone par internet / ligne fixe, vous diriez que vous êtes:

Très satisfait	O
Satisfait	O
Normal	O
Peu satisfait	O
Pas du tout satisfait	O

Q2a Je ne peux pas appeler : après avoir composé le bon numéro, j'ai un message m'informant que celui-ci n'est pas joignable

Q2b Je ne peux pas appeler : j'ai une tonalité d'occupation immédiatement ou je n'ai pas du tout de tonalité

Q2c Je ne peux pas recevoir d'appels: le téléphone ne sonne pas/ l'appelant est dirigé vers la messagerie ou a un message (film audio)

Q2d Le téléphone sonne, je n'entends pas mon interlocuteur après avoir décroché (tonalité d'occupation ou vide)

Souvent	O
Parfois	O
Jamais	O

Q3 Phénomènes rencontrés pendant votre communication au cours des 12 derniers mois

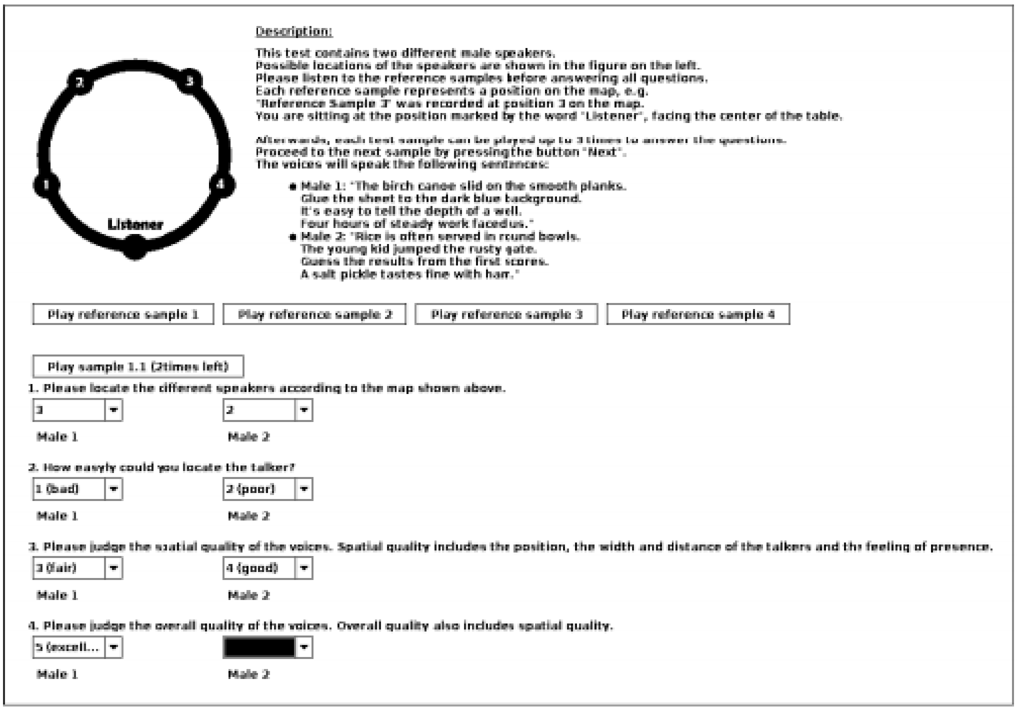
Q3A - L'appel se coupe en cours de communication
Q3B - Mon interlocuteur ne m'entend pas
Q3C - Je n'entends pas mon interlocuteur
Q3D - Bruits de fond (grésillements, interférences...)
Q3E - Voix affaiblie
Q3F - Voix déformée
Q3G - Blancs pendant la communication /micro-coupures /voix hâchée
Q3H - Je m'entends parler (écho)
Q3I - Bip pendant la communication
Q3J - Son décalé (chez moi ou mon interlocuteur)
Q3K - Autres

Souvent	O
Parfois	O
Jamais	O

Q4. Concernant vos attentes sur l'évolution du service de téléphonie, quel est pour vous le critère prioritaire parmi les critères que je vais vous citer ?

Pouvoir appeler et recevoir des appels en cas de panne d'alimentation en électricité	O
Pouvoir mener une communication sans dysfonctionnements	O
Avoir une qualité sonore de type HD (haute définition)	O
Aucun autre critère prioritaire	O
NSP	O

Questionnaire for QoE over 3D Audio Teleconferencing (Chapter 7)



Description:

This test contains two different male speakers.
Possible locations of the speakers are shown in the figure on the left.
Please listen to the reference samples before answering all questions.
Each reference sample represents a position on the map, e.g.
"Reference Sample 3" was recorded at position 3 on the map.
You are sitting at the position marked by the word "Listener", facing the center of the table.

Afterwards, each test sample can be played up to 3 times to answer the questions.
Proceed to the next sample by pressingthe button "Next".
The voices will speak the following sentences:

- Male 1: "The birch canoe slid on the smooth planks.
  Glue the sheet to the dark blue background.
  It's easy to tell the depth of a well.
  Four hours of steady work faced us."
- Male 2: "Rice is often served in round bowls.
  The young kid jumped the rusty gate.
  Guess the results from the first scores.
  A salt pickle tastes fine with ham."

Play reference sample 1 | Play reference sample 2 | Play reference sample 3 | Play reference sample 4

Play sample 1.1 (2times left)

1. Please locate the different speakers according to the map shown above.

   3 — Male 1 | 2 — Male 2

2. How easyly could you locate the talker?

   1 (bad) — Male 1 | 2 (poor) — Male 2

3. Please judge the spatial quality of the voices. Spatial quality includes the position, the width and distance of the talkers and the feeling of presence.

   3 (fair) — Male 1 | 4 (good) — Male 2

4. Please judge the overall quality of the voices. Overall quality also includes spatial quality.

   5 (excell... — Male 1 | — Male 2

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