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Quality-of-Experience Modeling in High-Density Wireless Network

S. Qaiyum[*], *I. A. Aziz*[a], *and N. Haron*[b]

Department of Computer and Information Science, Universiti Teknologi PETRONAS, 32610 Bandar Seri Iskandar, Perak Darul Ridzuan, Malaysia.

[*]*sqaiyum.cs@gmail.com*, [a]*izzatdin@petronas.com.my*, [b]*nazleeni@petronas.com.my*

Abstract-*With the rapid evolution of smart devices, ease of availability and accessibility of Internet application services, the demand of user's level of satisfaction are constantly growing. This creates challenges when mobile users in large quantity gather at confine places creating a scenario of high-density wireless network environment (HDWN). Guaranteeing high quality of services (QoS) without proper understanding of user's expectations and their Quality of Experience (QoE) may lead to over provisioning of resources. This poses different challenges to network service providers. Moreover, limited studies have been found relating to QoE in dense network. The objective of this paper is to develop mapping mechanism that maps QoS parameters onto QoE metrics in HDWN. This paper proposes fuzzy-genetic algorithm to map QoS-QoE based on the critical comparative analysis of different mechanisms. Preliminary analysis had been done based on mathematical model to establish the correlation between QoS parameters (delay and jitter) and QoE metrics (satisfaction) to determine the maximum and minimum impairment threshold. Further, the correlation between QoS-QoE had been evaluated with varying traffic load to determine the traffic load impact on QoE. Also the load threshold was found, that would help the network providers to take proper measure to maintain user's satisfaction as the maximum threshold limit is reached.*

Keywords: HDWN, QoS, QoE, FIS

1.0 INTRODUCTION

With the growth in human population over the past three centuries and expected to reach 9.6 billion by 2050[1], there has been a large increase in the demand of mobile sector. The Cisco Visual Networking Index forecast global mobile devices and connections are expected to grow to 11.5 billion by 2019 at a CAGR (compound annual growth rate) of 9 percent (Fig. 1(a))[2]. The increasing number of wireless devices worldwide is one of the major contributors to global mobile internet traffic growth. The global IP traffic is expected to nearly triple from 2014-2019. It is likely to grow to 168 exabytes per month by 2019, from 59.9 exabytes per month in 2014 which is a CAGR of 23 percent (Fig. 1(b)).

The rapid evolution of smart devices eases the availability and accessibility of Internet application services, which results in the constant increase of user's demand and their level of satisfaction. This problem becomes adverse when the number of mobile user's gathered in large quantity at a confine location such as shopping complexes, sport stadiums, concerts and

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crowded events. Such situations are considered as High Density Wireless Networks (HDWN) environment, where the demand for network services often exceeds the available capacity of wireless network designs.

Moreover, a dense network has a number of constraints that must be handled by network service providers (NSP) to achieve maximum satisfaction among customers such as traffic scalability, high deployment and maintenance cost, ineffective network resource utilization and inefficient capacity to accommodate the growing user demands[3], [4]. Providing high quality of service to users in dense locations without understanding their expectations and requirements may lead to over provisioning of services[5]. Therefore, maintaining and providing QoS alone is insufficient to satisfy end-user's demand. Thus, several other factors such as user experience, their expectation, smart device usage, location etc must also be considered to evaluate user's QoE.

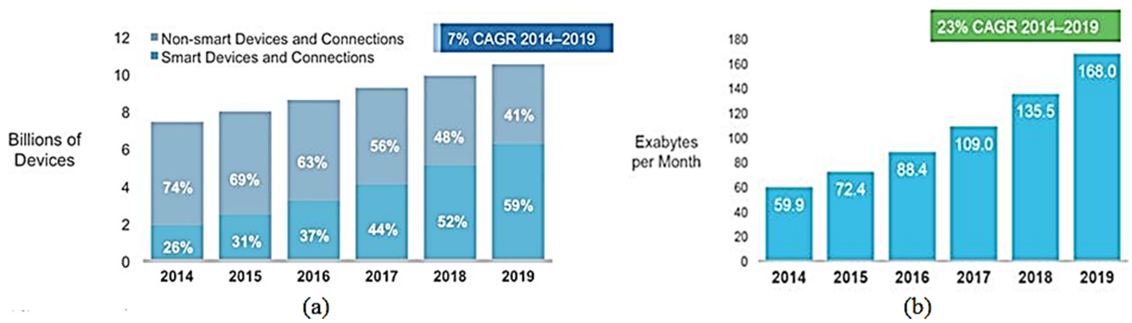

Figure 1: **(a)** Global growth of Smart Mobile devices and their connections **(b)** Global IP Traffic Forecast

Such subjective factors in the context of dense and mobile environment are hard to quantify [6].Therefore, there is a need to understand and measure the quality of wireless services from an end-user perspective. In order to meet the end-user level of satisfaction, the International Telecommunication Union (ITU) are emphasizing on another concept called Quality of Experience. QoE is defined as an overall acceptability of an application or service, as perceived subjectively by the end user, and is influenced by user expectations and context. QoE is a multidimensional concept, relating to both subjective and objective aspects. Subjective aspects are measured from user's experience, expectation, their personal and social background while objective aspects are measured by determining QoS parameters. To better understand and measure QoE it is important to determine the key metrics that identifies the user's expectations. Availability, Accessibility, Retainability, Reliability, Integrity of Service and Satisfaction have been identified as the key QoE metrics by different authors[7]–[10]. Thereby, limited studies [10]–[13] have been found relating to QoE measurement in highly dense and dynamic environment. QoE metrics measurement in comparison to conventional QoS parameters is more complex, in particular in HDWN. Such environment is highly dynamic in nature due to number of uncontrollable factors such as traffic scalability, user's mobility, different smart devices usage and so on [4].

Providing good quality wireless services in highly dense environment pose different challenges onto network providers. On the one hand they have to deal with the huge volume of data traffic generated by internet applications and the efficient utilization of network resources and on the other hand meeting the ever-growing demands of the end-users.The increase in HDWN venues and the growth of different internet applications have overburden the capabilities of existing cellular and Wi-Fi network services [14]. Also, to meet the user's demand the deployment of multiple Wi-Fi networks in the same area may lead to network degradation. Hence, the focus today is shifting towards enhancing the Wi-Fi user-experience, and both network operators and end-users have come to rely on Wi-Fi technology that has been constrained to become more intelligent. Thus, there is a need to continuously monitor and measure QoE in HDWN that helps the NSP's to achieve maximum end-user's satisfaction and optimize the dense environment.

2.0 LITERATURE REVIEW:

Quality of Experience Mapping Mechanism. For understanding and measuring user's QoE, there is a need for a detailed understanding of the different influence factors (IFs) and user's perception. This is achieved by mapping different IFs onto QoE metrics. A QoE IF has been defined as "any characteristic of a user, system, service, application, or context whose actual state or setting may have influence on the Quality of Experience for the user" [15]. There are different mapping mechanisms proposed that aims to model the relationship between different measurable QoE IFs and quantifiable QoE metrics for a given service scenario. These have been grouped into subjective and objective assessment mechanisms, depending on the fact whether users are directly involved in determining their experience with the given service or not.

Table 1. Comparative study of QoE Subjective mapping mechanism

Paper	QoE mapping mechanism	Factors influencing QoE	Targeted application	Pros	Cons
J. Hosek et al, 2014 [19]	MOS	Bitrate, initial delay	Web browsing, downloading and uploading	Accurate and simple method for mobile service quality estimation	The interval of the scale can be perceived differently by different user's
K. De Moor et. al, 2010 [20]	Questionnaire and interviews	Signal strength	Mobile web browsing	User centered approach	Time consuming and costly, and hard to repeat often
K. Wac et al. 2011 [17]	Experience Sampling Method & Day Reconstructio n Method	User routine, Environment, experience, preference, choice, life style and social context	Mobile applications e.g. YouTube, VoIP, instant messaging	Mobile user's experience is evaluated in their natural daily environment	Costly in terms of manpower and time, and also hard to repeat often
T. Hoßfeld et al. 2014 [18]	Crowdsourcin g tests	User environment, personal background, social context, network access technologies	Multimedia applications	Cost effective and provide access to varying subjects from all over the world	Highly uncontrolled assessment environment

QoE Subjective Mapping Mechanism. Most commonly used subjective method for evaluating users' QoE are quality ratings obtained from the users through questionnaires or interviews during or after the service use. These quality ratings are than averaged into Mean Opinion Score (MOS) according to the ITU-T P.800.1 recommendation and has become the de

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facto standard metric for QoE [16]. Besides these standardized subjective QoE estimation models, some additional models have been used to evaluate user experience on long term basis such as experience sampling method [17] and crowdsourcing methods [18] . Even though these subjective methods tend to be more user-centric, they are costly in terms of manpower, money and time, and are often hard to repeat. Moreover, it cannot be implemented to real time application for service quality assessment. Hence, objective methods are gaining popularity since it captures both objective and subjective features of user's experience. Table 1 summarizes the comparative study of different QoE subjective mapping mechanisms.

QoE Objective Mapping Mechanism. Subjective experiments are still the most accurate method to measure the overall quality of service from end-user's perspective that forms the basis for developing QoE objective mapping mechanisms. Table 2, summarizes objective QoE mapping mechanisms based on the following comparison parameters: independent and dependent parameters taken for simulation or experiment, consideration of wireless aspect, type of service, and finally the pros and cons of the given mechanism. Several mechanisms have been proposed to predict QoE in different environments (wired/wireless). However, the listed mechanisms are constrained to wireless environment.

Table 2. Comparative study of objective QoE mapping mechanism.

Paper	QoE mapping mechanism	Independent variables	Dependent variable	Wireless aspect	Targeted application	Pros	Cons
C. Tsiaras et al, 2014[21]	Android application	Downlink throughput , uplink throughput, Latency , Time of day, Location	MOS	UMTS	Web browsing, VoIP and Video	Monitors user's experience in real environment	No quantitative measurement taken to evaluate the weight assigned to each parameters in determining MOS
D. Soldani, 2006 [10]	Mobile QoS Agent	Time of day, user's location and position	request & response time and radio parameters	3GSM	Web browsing	can be use as a tool for network planning and optimization	Cannot be used to evaluate large sample size and also does not correlate well with user perception
A. Khan et al, 2010 [22]	Regression analysis	Content type, sender bitrate, framerate and block error rate	MOS	UMTS	H.264 encoded video	Less complex and easy to implement with good accuracy	Does not adapt well with evolving network
J. Rao et al, 2014 [23]	Utility Theory	Number of users, real time traffic pattern, co-channel interference, packet loss rate, latency & goodput	QoE (in the range from 0-100)	802.11n	VoIP TCP Video RTP Video HTTP traffic Unclassified TCP	Accurate and flexible in modeling the behavior of different application types	Analytical model not tested in real environment

V. Menkovski et al, 2009 [24]	Machine Learning (ML)	Video spatial information, video temporal information, video bitrate and framerate	Acceptability (yes or no)	Not specified	Video	High accuracy (above 90%) for estimating QoE and has ability to adapt with changing environment	Requires large training data and training time and also does not consider the inconsistency due to subjective information provided by varying people
G. Rubino 2011[25]	Random Neural Network (RNN)	Bandwidth, traffic pattern, packet loss rate, mean loss burst size	MOS	802.11b wireless home network	VoIP Video	RNN tool train well with small data set belonging to large database and can be generalized	Does not correlate well with human perception
F. Farid et al, 2014[26]	Fuzzy Inference System (FIS)	Packet loss rate, packet loss burstiness and jitter	MOS	Not specified	Video traffic	Easy to compute with high accuracy and also deals well with imprecise and incomplete data	Does not mention how weights are assigned to QoE ratings for evaluating inference rules
J. Pokhrel et al, 2014[27]	Fuzzy rough hybrid expert system	Execution time, availability and reliability	MOS	Not specified	Web browsing	Can automatically acquire the rules for making decisions based on rough set theory	Significant affects of important parameters are not considered
J. Pokhrel et al, 2013 [28]	FIS	Packet loss, delay, jitter, different radio access technologies, number of users	QoS value	Heterogeneous & homogeneous network	Conversational, Video conferencing and Streaming services	Both uncertainty and significant affects of important parameters are considered	Does not correlated the QoS value with end-users Quality of Experience
A. Khan et al, 2008 [29]	Artificial Neural Fuzzy Inference System	Send bitrate, framerate, packet error rate and bandwidth	MOS and Q-value	WLAN	Video streaming	Good prediction accuracy	No subjective assessment performed

From the review of subjective and objective quality assessment methods it has been determined that there is no stable platform to continuously measure QoE in HDWN. They are conducted for specific wireless environments (3GSM, WLAN, UMTS, home network etc) and for specific services (video, voice, internet, video-on-demand etc.). Thus, there is a need for a mapping mechanism that can monitor user's QoE for any type of IP-service in real-time in dense

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environment. The idea should be to identify key IFs and to map them onto QoE metric for any service, on any-device and at anytime. However it is very difficult to determine QoE in dense and wireless environment because of the following reasons: 1) user's feelings, expectations, perception and recognition is uncertain and varies from one user to another depending on their cultural or personal background [29]. 2) Dense and Wireless network environment is inconsistent in nature[6].

Thus, based on the critical review, several criteria's have been determined that must be fulfilled by the mapping mechanism. Criteria for mapping mechanism are (1) can be implemented in real environment (2) easy to compute and achieves high accuracy (3) ability to adapt with changing environment (4) deals well with uncertainty in the context of user and network environment (4) closely resembles human reasoning. Keeping into account all these criteria, the FIS is the most appropriate tool for predicting QoE as it can deal well the uncertainty associated with different user's opinion[30]. In addition, it is also significant to identify key factors influencing QoE to determine the root cause for network degradation.Thus, it is essential to study QoE in dense network environment and help NSP to take correct measure on time before customers perceive them.

2.0 METHODOLOGY

We propose mapping mechanism methodology based on Fuzzy Inference System (FIS). The performance of network layer will be determined by evaluating the following set of QoS parameters; packet loss rate pl, bandwidth b, delay d, jitter j and throughput t. In real mobile environment the QoS parameters are affected by numerous factors (user parameters), few of them are considered here such as: the number of users (U), their mobility rate (M_R) and mean holding time of network (t_H). Thus, if the performance of QoS parameters is influenced by above mentioned factors, it will also have a direct impact on QoE (user satisfaction). Our study, would evaluate the combined effect of parameters on QoE.

2.1 Brief overview about Fuzzy Inference System

Fuzzy Inference System (FIS) or Fuzzy logic became an efficient technique for user modeling that could imitate human reasoning. It is considered as an extension of traditional set theory as statements could be partial truths, which means lying in between absolute truth and absolute false. As shown in Fig. 2 [30], the FIS includes four stages: fuzzifier, rule base, inference engine and defuzzifier.

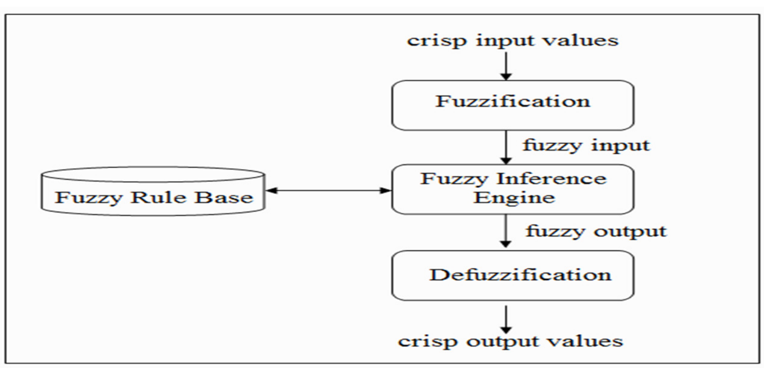

Figure. 2. A brief overview of Fuzzy Inference System

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a. Fuzzification: the process of converting crisp input values into fuzzy input values.
b. Fuzzy Inference Engine: capable of extracting fuzzy output based on the rules.
c. Fuzzy Rule Base: rules are generated either from numerical data or predefined by the experts.
d. Defuzzification: the process of converting fuzzy output into crisp output values

2.2 Fuzzy Inference System-based QoE Mapping Mechanism

In order to develop objective QoE mapping mechanism, a methodology based on FIS as shown in Fig. 3. will be followed. It consists of subjective data set in order to build a learning set that will establish the correlation between the QoE IFs and QoE metrics. Based on the correlation the membership functions will be designed and the rules will be extracted for the Fuzzy Inference System to evaluate the QoE metric.

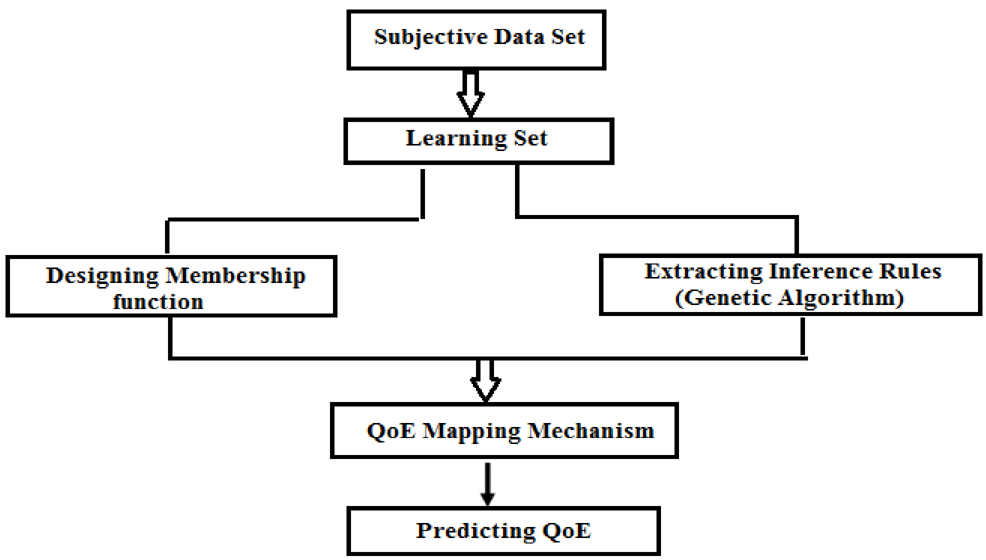

Figure 3: Methodology for QoE mapping mechanism in HDWN

Subjective Data Set. Subjective data set is required to build learning set that correlates the QoS parameter values to QoE metric for each of the considered application. Learning set is important to design membership functions and to extract rules based on the correlation. Thus for the research work, the subjective data will be obtained from the publicly available datasets. Different video datasets are made publicly available to the research community. The research focus will be on live mobile video obtained from database that consists of 200 distorted videos based on 10 raw HD videos [31].

Designing Membership Function. A membership function is designed for the fuzzy inference system to estimate the degree to which a particular QoS parameter value belongs to different QoE scores. For the research work the membership function will be designed from the learning set based on the expert opinion [26]. For designing first labels will be identified for QoS parameters as excellent, good, fair, bad, and poor. These labels will correspond to the number of regions the universe of discourse will be divided, such that each label describes the behaviour of the region. Trapezoidal and triangular shaped membership functions will be used in this model because of their simplicity and efficiency. The trapezoidal curve is a function of a vector x and depends on four scalar parameters a, b, c and d given by (1):

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$$\mu_{trp}(x;a,b,c,d)=\begin{Bmatrix} 0, & x\le a \\ \dfrac{x-a}{b-a}, & a\le x\le b \\ 1, & b\le x\le c \\ \dfrac{d-x}{d-c}, & c\le x\le d \\ 0, & d\le x \end{Bmatrix} \tag{1}$$

Where, the parameters a and d locate the feet of the trapezoid and the parameters b and c locate the shoulders. The triangular curve is a function of a vector x and depends on three scalar parameters a, b and c given by:

$$\mu_{tri}(x;a,b,c)=\begin{Bmatrix} 0, & x\le a \\ \dfrac{x-a}{b-a}, & a\le x\le b \\ \dfrac{c-x}{c-b}, & b\le x\le c \\ 0, & c\le x \end{Bmatrix} \tag{2}$$

Where, the parameters a and c locate the feet of the triangle and the parameter c locates the peak.

Extracting Inference Rules. Inference rules are generated to map the fuzzy input values onto fuzzy output values. The rule base can be extracted either from numerical data or predefined by experts. In dense and mobile environment the QoE IFs increases in addition to that of the fixed environment. Thus, predicting QoE in dense and mobile environment becomes a challenge with the increased number of key IFs as the rules increases exponentially which makes the design difficult by expert. FIS is good at making decisions with imprecise and uncertain data and representation of human reasoning, however they cannot automatically obtain rules for making decisions [27]. Thus, in HDWN environment where there are number of uncontrollable factors influencing QoE [6], there is a need for self-learning and generalization of rules. This could be achieved through hybridization of decision making techniques with FIS [27], [32]. Table 3, shows the comparative study of different decision making techniques for generation of rules. From the critical analysis of different techniques it has been observed that Genetic Algorithm (GA) although with high computation time will be most suitable for generating inference rules as it provides flexibility to interface with existing models and are easy to hybridize[33]. Moreover, GA is robust general purpose algorithm that uses principles inspired by natural population genetics to evolve solutions to the problems. Hence, hybridization of GA and FIS will help to achieve the advantages of both techniques. This approach will automatically evolve rules for QoE mapping in HDWN environment.

QoE Mapping Mechanism. The proposed mapping mechanism is based on FIS that will predict QoE through a learned membership functions and a set of fuzzy inference rules. Fig. 4. explains the QoE mapping mechanism. The QoS parameters will be continually fed to the FIS that will map the degree to which the QoS parameter values belong to different QoE scores by learning through pre-defined membership functions.

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Table 3. Comparative study of different decision making techniques for generation of rules

Authors	Techniques	Disadvantages
Abe and Lan [34]	Clustering algorithm	The extracted rules will be independent of the membership functions, so there is no guarantee that the fuzzy system obtained will have sufficiently good performance
Nozaki et al [35]	Classification method using fuzzy grid	Generates large number of fuzzy rules
Nozaki et al [36]	Heuristic	May not achieve high accuracy
Kim and Russel [37]	Inductive reasoning	Not suitable for dynamic dataset where membership function continually changes with time
Nauck and Kruse [38]	Artificial Neural Network	Self-evolution of rules not possible
Yuan and Zhuane [39]	Genetic Algorithm	Optimization time is high compared to other techniques

Further, based on extracted inference rules the FIS will map the obtained fuzzy input values onto fuzzy output values that will define the fuzzy mapping between QoS parameters and QoE metrics. This process will make the FIS an intelligent system that will predict QoE taking into account the human perception.

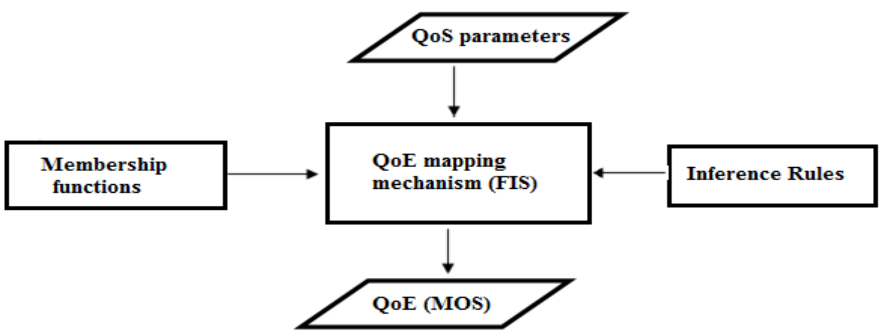

Figure 4: QoE mapping mechanism

Predicting QoE. The inference rules generate the fuzzy output set. These output sets are then mapped onto crisp output values through Defuzzification process. For the research Center of Gravity (CoG) method will be used to defuzzify the fuzzy output into crisp output since it is most popular and widely used method in real applications. CoG method calculates the center of area of the fuzzy output set and determines the value at which this occurs as the defuzzified output. The CoG calculation is done as shown in equation (3).

$$CoG(z) = \frac{\int_u \mu_{B^i_{y_i}}(y_i).y_i dy_i}{\int_u \mu_{B^i_{y_i}}(y_i) dy_i} \tag{3}$$

Where y_i is fuzzy output and $\mu_{B^i_{y_i}}$ is membership function associated with the fuzzy output.

3.0 RESULTS AND DISCUSSION

3.1 Simulation and assessment method

In this paper simulation was conducted to determine the correlation between QoS parameters (Delay and Jitter) and QoE metric (Satisfaction). Further, the relationship between the two was established in highly dense environment. For simulation and QoE determination, publicly available video datasets [31] was used. The LIVE Mobile Video Quality Assessment (VQA) database consists of live image/video database that has been distorted based on delay and jitter parameters. A specification of the video used in simulation and QoE assessment is described in Table 4**.** In this paper, video services were transmitted using TCP protocol as it offers retransmission of lost packets.

To evaluate the user's experience of watching mobile video services, Network-QoS parameters were considered. The QoS parameters having an effect on QoE metrics are packet loss, burst, delay, jitter etc. These parameters are suggested by the standard organizations like ITU-T and IETF. Delay and jitter are two important network-QoS parameters that affect mobile video quality. The correlation between QoS parameters and QoE metrics had been studied from previous research works[40]–[42].

Table 4: A specification of video used in simulation and QoE assessment per user

Items	Parameters
Video length	15 sec
Video format	H.264
Video codec	SVC (scalable video codec)
Resolution	1280 x 720
File size	10.6 Mbytes
Frame rate	30
File format	HD

The normalized QoS value was calculated through the formula (4), where QoS (X) represents normalized QoS value obtained, K is constant means the whole QoS quality determinant which was selected according to the type of the transmission system for video services. For example, we can assign 1 to K in unicasting.

$$QoS(X) = K\{L \times W_l + D \times W_d + J \times W_j + \ldots\} \tag{4}$$

Moreover, weight of QoS parameters was assigned based on relative degree of importance determined from previous studies[43], [44]. The numerical formula model to measure the subscriber's video QoE by using the normalized QoS value is as follows:

$$QoE = Q_r \times (1 - QoS(X))^{(QoS(X) \times A/R)} \tag{5}$$

where Qr is the upper bound of the video quality of experience according to the network type. For wireless network Qr value is 0.953. Next, the QoS(X) is the QoS value which is calculated by the formula (4), and is determined by quality parameters of the network layer. The constant A expresses the subscribed service class such as SDTV and HDTV. The other constant R is determined as the constant reflecting the structure of the video frames according to the GoP (Group of Picture) length. For our study A= 250 and R=12 was considered.

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3.2 Correlation between QoS and QoE

Several factors have been identified that influence user's QoE [6]. In the context of dense and mobile environment, traffic scalability is the main issue degrading network performance and thus affecting QoE[5], [45]. Different research had been conducted to determine the correlation between different QoS parameters and QoE metrics. However, the impact of traffic load on the relationship is not well known. Since, QoE is subjective in nature, it is important to determine it more realistically, considering user's environment. Hence, the correlation between QoS parameters (delay and jitter) and QoE metric (satisfaction) was determined to form the basis to evaluate the impact of traffic load on user's experience.

Relation between the QoS parameters and QoE metric presented in figure 5 and 6 shows a negative correlation. Fig. 5. represents the relation obtained for delay vs. user's satisfaction. Test was conducted such that the value of delay was increased from 0-800 ms to determine the minimum and the maximum impairment threshold. The graph thus obtained was divided into three regions. In region 1, the value of delay was kept between 0 and 150 ms and maximum user's satisfaction was observed. Since, there was no disturbance during video transmission. In the region 2, it was observed as the value of delay started to increase from 150 – 500ms , the user's experience of watching video services started to decline from being good to fairly ok. Finally, in region 3 the QoE declined sharply and the experience was bad as delay value increased beyond 500ms. Hence, it could be established that minimum impairment threshold for watching video is 150 ms and maximum is 500ms. Thus, it can be concluded that to attain maximum user's satisfaction the delay should be maintained below 150ms.

Fig. 6. presents the relation obtained between jitter and user's level of satisfaction. Experiment was done such that the value of jitter increased from 0-70 ms. The graph obtained was divided into three regions according to user's level of satisfaction. In region 1, it was observed when the value of jitter was less than 17ms the user's were satisfied with the services. In region 2, as the value slowly approached 30ms user's satisfaction gradually declined from being good to fairly ok. In region 3, as the jitter value goes beyond 30ms watching video becomes intolerable.

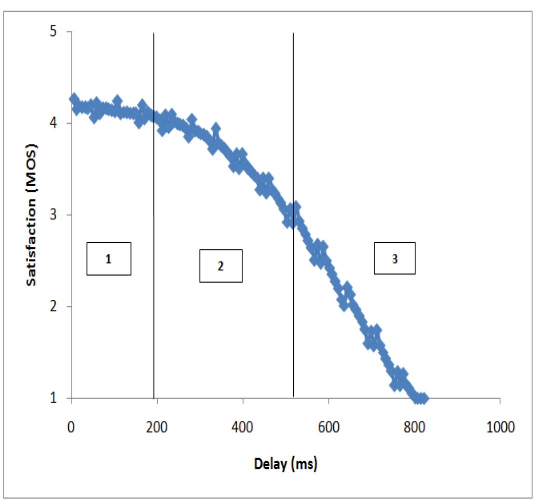

Figure. 5. Correlation between Delay and Satisfaction

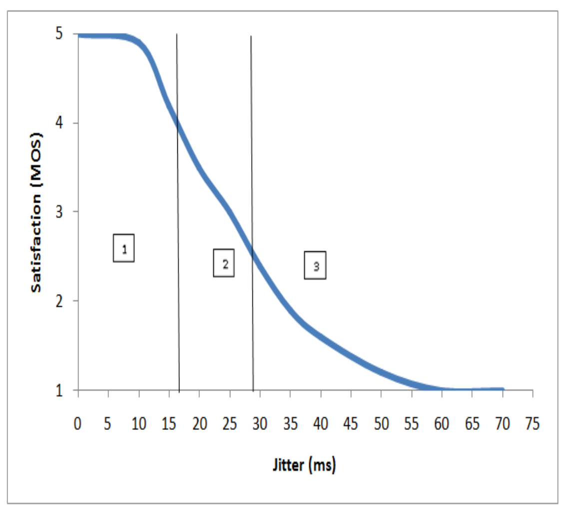

Figure. 6. Correlation between Jitter and Satisfaction

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This was due to the fact that with the increase in value of jitter, the interarrival time of packets increased and thus, packets were arriving late. This would result in long buffering time. Thus, it was established that the minimum impairment threshold is 17ms and maximum is 30ms. It can be concluded that the value of jitter should lie between 0-17ms to achieve maximum user satisfaction.

3.3 Determination of Traffic Load (Erlang)

Traffic load was evaluated in terms of Erlang (E_r) which is dimensionless unit [46]. $E_r$is calculated as the ratio of total number of calls per unit time to the average holding time for telecommunication traffic. However, the situation is slightly different for data traffic environment. The radio channel required for data transfer is shared among multiple streams and the data are transferred in form of packets of various lengths for various applications. Thus, the packets per second represent the throughput i.e. the amount of data transferred per unit time. In general the traffic generated is determined for the time period of 1 hour.

In this paper the focus was on video streaming services using TCP protocol. Video files were transferred into packets of predefined size CBR (constant bit rate) and were encoded using H.264 codec. However the results can be generalized to any CBR stream. The traffic load for data traffic in terms of Erlang was determined as

$$A = \lambda \times T \quad (6)$$

Where,

$A \rightarrow$ the traffic load in Erlangs
$\lambda \rightarrow$ the amount of data transferred per unit time i.e. total number of packets transferred per unit time
$T \rightarrow$ average packet transmission time i.e. total packet transmission time per total number of packets transferred

The traffic load evaluated in Erlang is presented in Table 5. To determine the traffic load, the amount of data transferred and the average packet transmission time must be determined. The total number of packets generated (P_T) for HD video over TCP connection per user were determined as the ratio of video file size (F_s) and packet size (P_s) as shown in equation (7).

$$P_T = F_s / P_s \quad (7)$$

Where,

F_s- video file size (10.6 Mbytes)
P_s-packet size (1500 bytes)

Average packet transmission time was determined as the ratio of packet size (P_s) and bit rate of video (R). Since, the packet was of fixed size the packet transmission time remains constant for all the packets transferred.

$$T = P_s / R \quad (8)$$

Where,

P_s-packet size (1500 bytes)
R-Bitrate (2500 kbps)

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Average packet transmission time from equation (7) was calculated to be 0.0179257 seconds. A sport stadium covering about 20,000 seats is considered as reference model. The possibility of all 20,000 seated users's connecting to internet services using their smart devices is almost zero. Moreover, the number of connections may grow or shrink with time. In this paper, the assumption is made that traffic will increase consecutively by 10% of the total number of user's where 2Mbps of data is generated by each user. Considering an event at full capacity all 20,000 users will be active at once generating about 39Gbps of data. Further, assuming the user's are seated and their mobility are negligible.

If one radio channel is occupied continuously for 1 hour that would represent 1E_r and if two are busy all the time 2E_r [46]. Thus, if 4116.667 packets were transferred in time period of 1 hour 737.7 E_r of traffic was generated, as per above mentioned strategy it would mean 737.7 radio channels were continuously busy for 1hour.

3.4 QoE analysis in HDWN

The correlation between QoS parameters and QoE metrics were determined with varying traffic load. This was done to understand the impact of changing traffic load on the user's level of satisfaction and determine the maximum load threshold. This would help the network providers to maintain user's satisfaction by optimizing network as the traffic load reaches maximum threshold limit.

Table 5. Traffic load determination

Percentage of active mobile users (M_U)	Total packets generated (T_P)	Total packets transferred per unit time (λ)	Traffic Load (A) in E_r
10	14820000	4116.667	73.77066667
20	29640000	8233.333	147.5413333
30	44460000	12350	221.312
40	59280000	16466.67	295.0826667
50	74100000	20583.33	368.8533333
60	88920000	24700	442.624
70	103740000	28816.67	516.3946667
80	118560000	32933.33	590.1653333
90	133380000	37050	663.936
100	148200000	41166.67	737.7066667

Impact of traffic load on correlation between delay and satisfaction. Figure 7, represents the impact of varying traffic load on delay that ultimately affects the user's satisfaction. When the traffic load reached about 147.54E_r the value of delay started to increase slowly. However, the user's experience remained satisfied while video watching. As the traffic load approached to 442.62E_r the slow decline in users experience was observed and MOS was between 4 and 3 i.e. users were fairly satisfied. When traffic density goes beyond 442.3E_r a sharp decline was observed in user's satisfaction. Thus, the proposed model can handle around 442.3E_r traffic load i.e. when 60% of the users were active all at once and the delay observed was considerable bearable by users. Thus, the maximum load threshold limit for the proposed dense network was found to be 442.3E_r.

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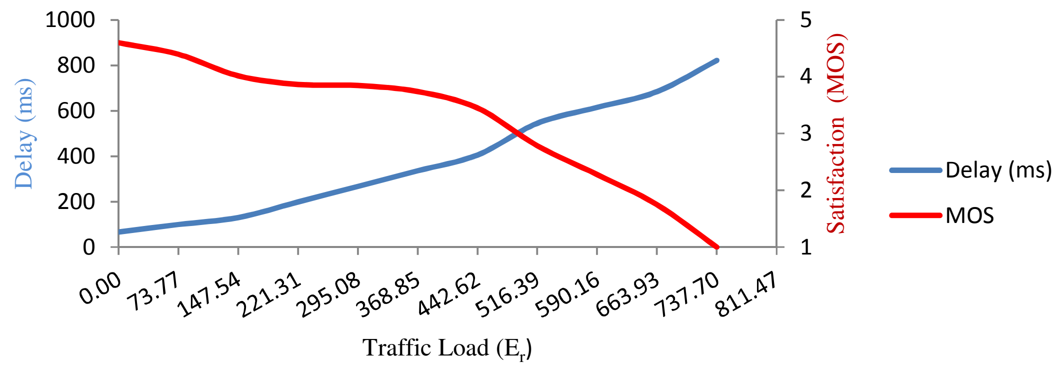

Figure 7: User's level of satisfaction in terms of MOS with varying Delay and Traffic Load

Impact of traffic load on correlation between jitter and satisfaction. Figure 8. represents the impact of varying traffic load on jitter that eventually affects user's satisfaction. When the traffic load reached about 221.31E_r the value of jitter started to increase slowly beyond minimum threshold value. However, the user's experience was good while watching video. It was observed that even when the traffic load reached 442.3E_r user's satisfaction slowly starts to decline but did not reached the maximum impairment threshold. This case scenario is totally different from what was observed for delay parameter. It was found that jitter parameter was less affected with the increase in the traffic. Thus, it can be concluded that even when the threshold limit of 737.7E_r is reached the network providers does not have to take measures to improve the value of jitter.

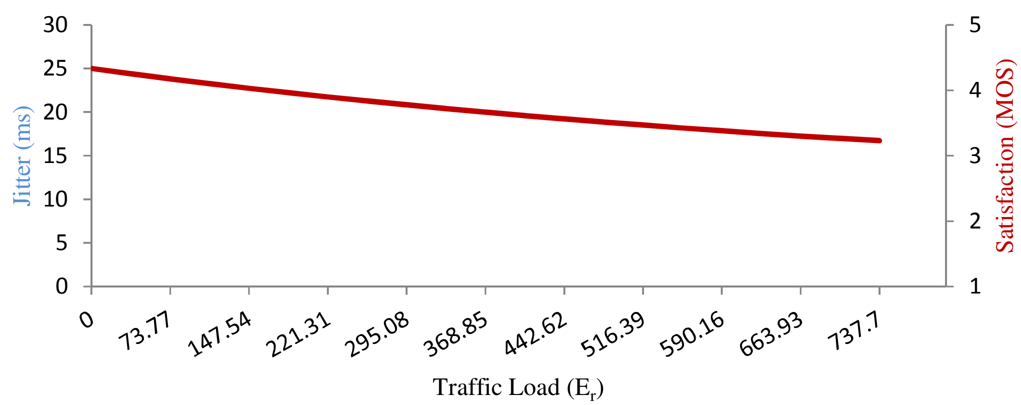

Figure 8: User's level of satisfaction analysis in terms of MOS with varying Jitter and traffic load

From the analysis of QoE in HDWN it was established that the delay parameter was affected most with the increase in traffic and jitter was affected least. Thus, the root cause for decrease in QoE with the increase in traffic load was determined to be delay parameter. This would help network providers to take proper measure to maintain user's satisfaction as the maximum threshold limit is reached.

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4.0 CONCLUSION

In this paper, the problem relating to QoE measurement in dense environment has been identified that creates challenges for NSP's in satisfying user's demands. The need to establish a stable platform for continuous monitoring and measurement of QoE is realised. This will work towards improving the user experience in the most effective and cost-efficient way for network providers to achieve customer loyalty and maintain competitive edge. The objective is to develop an objective mapping mechanism that closely correlates with human reasoning and measures the uncertainty involved in user's opinion. To achieve the objective the critical analysis of different mapping mechanisms was conducted. Fuzzy Inference System was found to be the most appropriate technique to map different QoE IF's onto QoE metrics since, it can deal well with the uncertainty associated with human reasoning and the dense mobile environment. However, fuzzy cannot generate rules automatically to make decisions. Thus, hybridization of Genetic and fuzzy algorithm has been proposed to achieve the advantages of both the techniques.

Some preliminary analysis has been done to show the significant contribution of the future research work. Most of the current research has been done to map QoS parameters onto QoE metrics to understand user experience. However, in dense and dynamic wireless environment where traffic may grow or shrink depending on user's demand, simply understanding the correlation may not sufficient. Therefore, it is important to determine the root cause of network QoS parameters degradation. The traffic intensity has been found as one of the contributing factors affecting the quality of wireless services. Thus, the correlation between QoS parameters and QoE metrics were determined with varying traffic load. This was done to understand the impact of changing traffic load on the user's level of satisfaction and determine the load threshold. This would help the network providers to maintain user's satisfaction by optimizing network as the traffic load reaches maximum threshold limit. It was found that increase in traffic intensity had significant affect on delay parameter which had negative impact on user's satisfaction while on the other hand jitter parameter was less affected and as a consequence QoE had less impact. From this knowledge, the NSP's would take proper measure to encounter the delay problem due to increased traffic load.

In the future the correlation between key influence factors and QoE metric will be established in dense, wireless and mobile environment by exploiting fuzzy-genetic approach. Moreover, the HDWN model will be proposed to be used as simulation testbed to validate QoE mapping mechanism. Finally, based on the obtained feedback the dense environment will be optimized to maximize end-user experience.

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