

# Model for the Correlation between Quality of Service and Experience in Cognitive Radio Networks

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## ABSTRACT

This paper proposes a methodology for the development of a correlation model between Quality of Service and Experience in cognitive radio networks. The aim of this research is to provide the cognitive radio networks ecosystem player the tools to assess the contribution of the network performance to the overall level of user's satisfaction. The performance parameters of several types of applications are addressed to highlight how delay, delay variation and information loss affect the service quality. Furthermore we thoroughly discuss, evaluate and test the proposed methodology, i.e., non-linear regression and genetic algorithms, by comparing it to the IETF recommended games MUSE G-Model. The obtained results are very promising. Future work includes verifying the effectiveness of the proposed methodology in the context of more complex fitting equations.

## Categories and Subject Descriptors

C.2.3 [Computer-Communication Networks]: Network Operations – *Network management, Network monitoring.*

## General Terms

Management, Measurement, Performance, Reliability, Human Factors, Verification.

## Keywords

Cognitive Radio, Quality of Experience, Curve fitting, Genetic Algorithm, correlation model, applications characterization.

## 1. INTRODUCTION

In nowadays heterogeneous wireless networks topologies the scarce wireless spectrum can be much better utilized [1]. To answer to this need, opportunistic access cognitive radio (CR) networks, introduced by J. Mitola in 1999 [4], will provide high bandwidth to mobile users via heterogeneous wireless architectures and dynamic spectrum access techniques. Dynamic spectrum access techniques allow for the CR to operate in the best available channel. Opportunistic ways to access spectrum holes have proven to be promising for radio frequency sharing. With emerging CR, unlicensed wireless users (secondary users) can opportunistically sense and access the underutilized spectrum bands, as long as the licensed wireless users (primary users) in these spectrum bands are not disrupted [2]. Hence, the CR paradigm will certainly be used in next generation networks in which a large volume of traffic is expected to be delivered.

Additionally, with the current growth of mobile communication services and applications, it has become very important for operators to accurately measure and improve the Quality of Service (QoS) and Quality of Experience (QoE). However, QoS measurements are generally defined in terms of network delivery

capacity and resource availability, but not in terms of the satisfaction to the end-user. It is therefore important to provide a framework for the correspondence between system parameters and QoE for different backhaul and access network. For such purpose, QoS metrics gathered from various parts of the network must be mapped onto QoE targets, facilitating the inclusion of the end-user perception into a QoE model. The process to obtain the framework for QoS/QoE mapping for each application involves the identification of the relationship between QoS performance and its effects onto QoE. This includes rating QoE through the QoS figures by using some mapping rules [3]. In such context, this paper aims at introducing a model for the correlation between quality of service and experience in cognitive radio networks.

The remainder of this work is organized as follows. Section 2 presents the motivation for evaluating the quality of CR networks through QoE modelling. Section 3 focuses on the characterization of the applications and their QoS requirements. Section 4 addresses the methodology being used to perform this research: non-linear regression, QoS normalization and mean square error verification. Section 5 addresses the verification of the methodology and some initial results. Finally some conclusions are presented in Section 6.

## 2. MOTIVATION FOR THE WORK

Historically, wireless communications have been governed by a fixed spectrum assignment. However, the spectrum resources are becoming scarce and increasingly precious. The CR technology enables the users to determine which portions of the spectrum is available and detect the presence of licensed users when a user operates in a licensed band (spectrum sensing), select the best available channel (spectrum management), coordinate access to this channel with other users (spectrum sharing), and vacate the channel when a licensed user is detected (spectrum mobility). This entire process may induce traffic delay, jitter and packet loss, which are critical network and user experience performance metrics and deserve increasing attention in CR networks. Several research works have been performed on the study and effects of delay in radio cognitive networks; some consider the QoS requirements for systems that carry delay-sensitive applications to both primary and secondary users [5]. Other works propose scheduling algorithms or other methodologies to adjust and optimize CR transmission strategies with the goal of maximizing the QoS [6], [7], [8].

Next generation networks are bound to provide various multimedia services. The QoE concept is introduced in these networks to describe the satisfaction of subscriber's quality requirements. Thus QoE evaluation is becoming critical to operators to guarantee their clients degree of satisfaction in nowadays competitive market. QoE is however very subjective in

nature and is composed by parameters such as cost, reliability, availability, usability, and fidelity. To allow for operators (or a system broker [9]) to evaluate the QoE it is important to create a strategy to instantly measure it. This will give operators some sense of the contribution of the network performance to the overall level of user's satisfaction, and enable them to interact with it. There are many network related features (QoS parameters) that affect the way users perceive their experience, i.e., their subjective usage involvement. However they cannot have the same weight or do not relate directly to each other. Hence, to determine the QoE for different types of services and applications, a generic correlation model that represents the QoE as a function of QoS is needed:

$$QoE = f(QoS) \quad (1)$$

This model will then enable to verify the impact of the application of the CR network techniques and methodologies in the achieved user quality of experience. The model for the correlation between QoE and QoS proposed in this work considers network level parameters, such as delay, jitter as well as information loss, to characterize the user's overall perceived QoE.

### 3. SERVICES AND APPLICATIONS CHARACTERIZATION

The first step for the creation of a QoS/QoE correlation model is to understand the different applications QoS requirements. For this purpose we performed a survey on the requirements defined by some of the majors regulator parties and players, i.e., the International Telecommunication Union (ITU) [10], 3rd Generation Partnership Project (3GPP) [11], EU-MESH European project [12] and the WiMAX Forum [13]. The key parameters used for the services characterization impacting the user experience, defined by the ITU [10], are the following:

- Delay - Delay has a very direct impact on user satisfaction depending on the application, and includes delays in the terminal, network, and any servers;
- Delay variation - Delay variation is generally included the transport layer in packetized data systems due to the

as a performance parameter since it is very important at inherent variability in arrival times of individual packets;

- Information loss - Information loss has a very direct effect on the quality of the information finally delivered to the user, whether it is voice, image, video or data.

Considering that next generation wireless networks should provide superior data rates, the targeted throughput, DL and UL speeds, were chosen, among regulators recommendations, and updated by considering the highest value proposed by all the above identities recommendations, Video and voice downlink/uplink (DL/UL) were thoroughly updated according to compression and encoding techniques provided by the WiMAX Forum. Tables 1 and 2 present the characterisation parameters for conversational/streaming and unicast services, respectively, as well as their range of variation. More details can be found in [14]. It can be observed that an example of the difference of requirements between applications is present in VoIP and Video on Demand (VoD), in the first case the required delay variation is 50% inferior and the one-way delay is over sixty times lower than in the second case. These parameters are being used as inputs for the correlation model that maps QoS into QoE.

### 4. METHODOLOGIES FOR QOS/QOE MAPPING

Among the different possible methodologies to perform the research on QoS/QoE mapping, we have chosen the one that seems to be more effective, with reduced degree of complexity as well as a fast and easy verification through root mean square error (RMSE) computation.

First of all, based on mean opinion score (MoS) measurements, non-linear regression is used to obtain a QoE equation, as a function of QoS. The generic QoE/QoS model is validated by RMSE verification. Given that such QoS parameter has a different weight according to the used application, genetic algorithms are also being used to compute the weights for the network level parameters, such as delay and jitter, in order to create a normalized QoS function.

Table 1. Characterization parameters for conversational audio/video and streaming services

| Services       | Application                     | Typical data rates [kbps]                    |         | Interactive [12] | Key performance parameters      |                 |                  | Transmission mode [12] |
|----------------|---------------------------------|--|---------|------------------|---------------------------------|-----------------|------------------|------------------------|
|                |                                 | DL   | UL      |                  | One-way delay                   | Delay variation | Information loss |                        |
| Conversational | VoIP, teleconferencing          | 5-64 <sup>1</sup> [13]                       |         | Yes              | < 150ms (limit <400ms) [9 - 11] | <1ms [9 - 11]   | <3% [9 - 11]     | Unicast/multicast      |
|                | Video-telephony/conferencing    | 32 to 1024 <sup>1</sup> (Typical = 384) [13] |         |                  |                                 |                 | <1% [10][12]     |                        |
|                | Instant messaging (IM)          | 4-25 [12]                                    |         |                  | <250 ms [12]                    |                 | 0% [12]          | Unicast                |
|                | Online chatting                 |  |         |                  |                                 |                 |                  |                        |
| Streaming      | IPTV                            | 1024-3072 [12]                               |         | No               | <10s [12]                       | <2ms [12]       | <1% [12]         | Broadcast              |
|                | Mobile TV                       | 28-512 [12]                                  |         |                  |                                 |                 |                  |                        |
|                | VoD (SD)                        | 1024-3072 [12]                               | <8 [12] | Yes              |                                 |                 |                  | Unicast                |
|                | VoD (HD)                        | 7168-10240 <sup>2</sup> [13]                 |         |                  |                                 |                 |                  |                        |
|                | On-demand streaming media (MoD) | 32-384 [12]                                  |         |                  |                                 |                 |                  |                        |
|                | Internet radio                  | 16-64 [12]                                   |         |                  |                                 |                 |                  |                        |
|                | Video surveillance              | 32-384 [12]                                  |         |                  |                                 |                 |                  |                        |
|                |                                 |  |         |                  | Broadcast                       |                 |                  |                        |

<sup>1</sup> Depends of encoding schemes; <sup>2</sup> H.264 video compression

**Table 2. Characterization parameters for unicast transmission mode services**

| Services                  | Application                  | Typical data rates [kbps] [12] |      | Interactive [12] | Key performance parameters               |                                   |
|---------------------------|------------------------------|--------------------------------|------|------------------|--|-----------------------------------|
|                           |                              | DL                             | UL   |                  | One-way delay                            | Information loss                  |
| Interactive               | Interactive gaming           | 4-25                           |      | Yes              | <150ms [13]                              | 0% [12]                           |
|                           | Real-time gaming             | 32-64                          |      |                  | <75ms [11] [12]                          | <3% (preferred)<br><5% limit [11] |
|                           | Voice mail                   | 30-50                          | 4-25 |                  | <2s [12]                                 | <3% [12]                          |
|                           | Collaborative working        | >500                           |      |                  | <2s/transact. [12]                       |                                   |
|                           | ASP services                 |                                |      |                  |  |                                   |
|                           | E-commerce                   |                                |      |                  | <10s [12]                                |                                   |
| Control of remote devices | <28                          |                                |      |                  |  |                                   |
| Multimedia sharing        | Peer-to-peer file sharing    | >500                           |      | No               | <15s (acceptable <60s) [12]              | 0% [12]                           |
|                           | User-created content sharing | 32-64 kbps                     | >500 |                  | <2s/upload [12]                          |                                   |
| Internet                  | Web browsing                 | 10 to 2048                     | 4-25 | No               | <2s/page (acceptable <4s/page) [10] [12] |                                   |
|                           | Email                        | >500                           |      |                  | <2s (acceptable <4s) [10] [12]           |                                   |
|                           | File transfer                | >2048                          | 4-25 | Yes              | <15s (acceptable <60s)                   | 0% [11][12]                       |
|                           | Telnet                       | 4-25                           |      |                  | <200 ms [10]                             |                                   |

### 4.1 MoS measurements

The first step in the creation of the QoS/QoE correlation model is to obtain an adequate number of MoS measurements/values. Therefore, several researchers have been contacted in order to obtain such data (at this time, we are currently waiting for some replies). With this data and the validation of this methodology a full QoS/QoE correlation model for any type of application will be created. We have chosen to use results for the MoS experiments available in the literature because the validation of this research is more straight-forward if we utilise data used or recognized by the main regulation bodies such as the Internet Engineering Task Force (IETF), presented in Section 5, ITU, 3GPP, etc.

### 4.2 Non-linear regression

The non-linear regression is performed by using the MathWorks® Matlab surface and curve fitting toolbox. Based on the obtain MoS measurements from [15], this application allows to obtain a QoE equation as a function of a given QoS parameters. Figure 1 shows the variation of the MoS as a function of the ping and jitter, the QoS parameters that have been chosen. The blue dots represent the MoS inputs and the white ones represent the values obtained during the fitting. Additionally, these tools compute the RMSE, as shown in Table 3. Hence, the degree of inaccuracy of the fitting is automatically computed, allowing for optimizing the fit. The goal of this methodology is to obtain an equation with the following parameters (the example provided is an exponential equation, but the obtained regression could also be a logarithmic or a polynomial equation):

$$QoE = \alpha e^{-\beta QoS} + \gamma \tag{2}$$

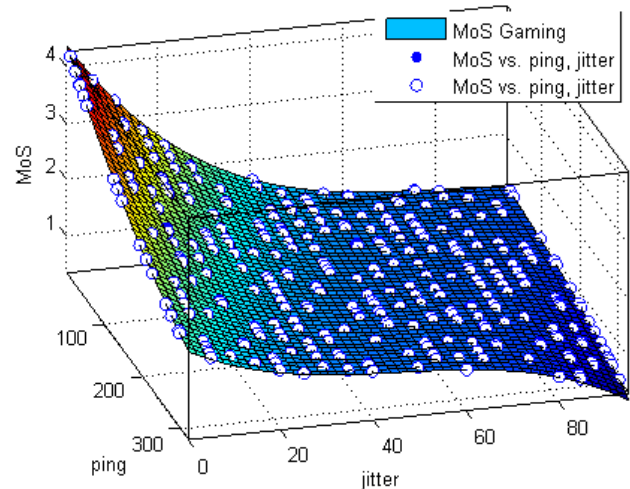
Where  $\alpha$ ,  $\beta$  and  $\gamma$  are constants to be obtained during the fitting.

### 4.3 Genetic Algorithm for QoS normalization

As stated above, the QoS normalization requires calculating the weight of each parameter. This usually implies heavy computation and thus genetic algorithms are being used to obtain this information. For this purpose, the MathWorks® Matlab genetic algorithm toolbox is being used. The aim is to obtain:

$$QoS = a \times ping + b \times jitter + c \times delay \tag{3}$$

Where  $a$ ,  $b$  and  $c$  are the weights for the parameters.



**Figure 1. MathWorks® Matlab surface fitting.**

Table 3. MathWorks® Matlab goodness of fit and validation

| Goodness of fit           |          |                           |                         |
|---------------------------|----------|---------------------------|-------------------------|
| SSEs                      | R-square | Adjusted R-square         | RMSE                    |
| 2.878·10 <sup>-27</sup>   | 1        | 1                         | 3.047·10 <sup>-15</sup> |
| Goodness of validation    |          |                           |                         |
| SEE                       |          | RMSE                      |                         |
| 2.90488·10 <sup>-27</sup> |          | 3.01293·10 <sup>-15</sup> |                         |

## 5. FIRST RESULTS AND EVALUATION OF THE METHODOLOGY

### 5.1 MUSE G-model

For the purpose of the evaluation of the methodology we decided to consider the first person shooter (FPS) games MUSE G-model multi-dimensional regression analysis from [15], also applied by the authors from [16]. This means we did not use actual MoS measurements, instead we used the obtained predict MoS gamer's quality, expressed by:

$$MoS = -0.00000587x^3 + 0.00139x^2 - 0.114x + 4.37 \quad (4)$$

where  $x$  denotes the network impairment, and is defined as

$$x = 0.104 \times ping\_average + Jitter\_average \quad (5)$$

For the purpose of simplicity in the notation, from now on, we will refer to  $ping\_average$  and  $Jitter\_average$  as  $ping$  (related to en-to-end delay) and  $Jitter$  (delay variation). It can be observed that equation (5) corresponds to our previously defined normalized QoS, equation (3), whereas equation (4) corresponds to our QoE as function of the QoS, equation (1).

### 5.2 Application of the Non-linear regression

We simulated MoS measurements by using equation (4) and introduced this data into the MathWorks® Matlab fitting toolbox, Figure 1. The toolbox allows us to try several types of fitting, "Interpolant", "Polynomial", "Custom equation" and "Lowess". Trough MSE verification, as showed in Table 3, we found that the fitness with the lower MSE value is a third degree polynomial equation (6):

$$MoS = 4.37 - 0.01186 \times ping - 0.114 \times jitter + 1.503 \cdot 10^{-5} \times ping^2 + \mathbf{0.0002891} \times ping \times jitter + 0.00139 \times jitter^2 - 6.603 \cdot 10^{-9} \times ping^3 - \mathbf{1.905 \cdot 10^{-7} \times ping^2 \times jitter} - \mathbf{1.831 \cdot 10^{-6} \times ping \times jitter^2} - 5.87 \cdot 10^{-6} \times jitter^3 \quad (6)$$

As expected, it can be observed that the obtained fitness is very close to the original MUSE G-model. If we replace the network impairment,  $x$ , in equation (4) and compute this equation, are obtained:

$$MoS = 4.37 - 0.114 \times (0.104 \times ping + jitter) + 0.00139 \times (0.104 \times ping + jitter)^2 - 5.87 \cdot 10^{-6} \times (0.104 \times ping + jitter)^3 = \mathbf{4.37} - 0.01186 \times ping - 0.114 \times jitter + 1.503 \cdot 10^{-5} \times ping^2 + 0.00139 \times jitter^2 - 6.603 \cdot 10^{-9} \times ping^3 - 5.87 \cdot 10^{-6} \times jitter^3 \quad (7)$$

The main differences between equations (6) and (7) are highlighted in bold in equation (6). The corresponding coefficients are so low that we believe that their contribution can be considered null.

## 5.3 Application of the Genetic Algorithm

The genetic algorithms are used to compute the weight of each parameter,  $ping\_weight$ ,  $jitter\_weight$  and the argument by which they will be multiplied as in (4). Due to the complexity of the equation we will break it into several portions,  $p_1$ ,  $p_2$  and  $p_3$ :

$$p_1 = 0.01186 \times ping - 0.114 \times jitter$$

$$p_2 = 1.503 \cdot 10^{-5} \times ping^2 + 0.00139 \times jitter^2 \quad (8)$$

$$p_3 = -6.603 \cdot 10^{-9} \times ping^3 + 5.87 \cdot 10^{-6} \times jitter^3$$

In particular the genetic algorithm computes the weights of the  $ping$  and  $jitter$  as well as their arguments so that each equation from 8, i.e., each portion is found:

$$(argument_1 \times ping\_weight - 0.01186) - (argument_1 \times jitter\_weight - 0.114) = 0 \quad (9)$$

$$(argument_2 \times ping\_weight^2 - 1.503 \cdot 10^{-5}) - (argument_2 \times jitter\_weight^2 - 0.00139) = 0 \quad (10)$$

$$(argument_3 \times ping\_weight^3 - 6.603 \cdot 10^{-9}) - (argument_3 \times jitter\_weight^3 - 5.87 \cdot 10^{-6}) = 0 \quad (11)$$

This methodology is applied until all arguments are obtained. The initial population of the genetic algorithm is randomly created by the Matlab's toolbox. However, we can observe in equations (9), (10) and (11) that an infinite number of values enable to achieve the desired results. For this reason we choose an initial population range of [0,1], and a population size of 100, to guarantee an higher accuracy. The selection function that provided the best values is the stochastic uniform one. A number of 500 generations was selected as stopping criteria.

Through this process we obtained the equation:

$$QoS = 0.06084 \times ping + 0.585 \times jitter \quad (12)$$

And finally:

$$QoE(QoS) = -0.1949 \times QoS + 4.06166 \cdot 10^{-3} \times QoS^2 - 2.932 \cdot 10^{-5} \times QoS^3 + 4.37 \quad (13)$$

One may observe that the arguments in equations (12) and (13) are not similar to the ones in (4) and (5). However, it can also be observed that, in both cases, the ratio between the weights of the  $jitter$  and the  $ping$  is, 9.61538. Besides, if one replaces the QoS in (13) by equation (12) the resulting equation is (7). Although this methodology was only applied to a polynomial equation it will also be applicable to more complex equations.

## 6. CONCLUSIONS

The scarce spectrum resources are leading to the creation of CR for better channel and radio management. Besides, the increase demand for user's satisfaction has been creating the necessity for operators to map their QoS network performance into user QoE metrics. The goal of this research is to propose a correlation model between QoS and QoE for the evaluation of CR networks performance, i.e., to immediately evaluate if the network is able to offer the required user QoE. The first part of this work appraised different applications QoS requirements. It was found that, according to the types of services, the one-way delay, delay information and information loss constraints are highly different from one application to another and have different impact into QoE. The second part of this proposal consisted of validating the proposed methodology. The MSE obtained value for the surface fitting was, as expected, approximately null, i.e.,  $3.047 \cdot 10^{-15}$ .

Although different values have been obtained with the genetic algorithm, it was found that the QoS weight ratio is equal to the one defined by Muse G-model, i.e., 9.61538. By replacing equation (12) in (13) the resulting obtained equation is the G-Model from (7). Future work intends to demonstrate the efficiency of this methodology with more complex equations. Besides, another goal of this research will be to obtain further real MoS measurements to fully propose a correlation model for any kind of application.

## 7. ACKNOWLEDGMENTS

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