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APPLICATION OF INTERVAL TYPE-2 FUZZY LOGIC ALGORITHM FOR QOE EVALUATION IN WIRELESS COMMUNICATION NETWORKS

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ABSTRACT – In this work, an application of interval type-2 fuzzy logic algorithm for evaluation of quality of service is proposed. The work uses delay, jitter, and packet loss as input parameters to evaluate the quality of service. The membership function (MF) terms, MF partitions, universe of discourse and linguistic variables is collected for use in designing the fuzzy logic model. The model was implemented using the Java programming language on Netbeans IDE. The implemented model was tested using 15 datapoints from the input module. The results of the system shows that when there is low rate (69) of network DELAY, low rate (10) of JITTER, and high rate (92) of PACKET LOSS then quality of service will not be so good (Moderate quality of service) (61% quality of service).

Key Words: Interval Type-2 Fuzzy Logic Algorithm, QOE Evaluation, Wireless Communication Networks.

INTRODUCTION

Major interference occurs when multiple transmissions occur over links on the same or different codes, thus resulting to diverse problematic issues such as delay, jitter, limited bandwidth, and packet loss (packet drop), etc., which in turn affect quality of service (QoS) performance. For considerable number of years, wireless networks have attracted a remarkable research attention in the general networking and performance community. This has been instigated by recent technological advances in the development of multifunctional and low-cost wireless communication devices. Therefore, in order to deal with the unforeseen quality of this highly dynamic environment, wireless networks need to be able to adjust and adapt to changes in resource availability such as energy, processing power, bandwidth, etc., and control any unpredicted networking issues while meeting a wide range of application requirements.

Recently, multimedia applications in wireless technology have taken a paradigm shift and thus become increasingly popular, yet to a greater degree are faced with the challenges of delay and packet loss. Low multimedia transmission quality caused by packet delay and loss of voice traffic, for instance, is still one of the critical technical barriers of the voice communication system. As a result of the increasing nature and popularity of wireless adhoc network, the QoS support for multimedia transmission has become an important requirement because it is closely related to resource allocation. The objective of QoS support is to facilitate decision on how to reserve resources such that QoS requirements of all wireless ad hoc networks can be satisfied. QoS must be capable of providing guaranteed service quality to real-time transmission in a wireless network with no fixed infrastructure (e.g., no base stations) (Hasib and Schormans, 2003) (D'Antonio, 2003) (Al-Sbou, 2005).

The term QoS can be defined as a set of service requirements to be met by the network in an attempt to transport a packet stream from source to destination. It refers to several related aspects of telephony and computer networks that allow the transport of traffic with special requirements. Intrinsic to the notion of QoS is an agreement or a guarantee by the network to provide a set of measurable pre-specified service attributes to the user in terms of delay, jitter, available bandwidth, packet loss, and so on, depending on the application and management scheme (Nedeljkovic, 2004). Each user of a service expects a certain QoS guarantee from the service provider throughout the duration of its session. Providing QoS guarantee is an important consideration which is very challenging in wireless data networks. The increasing customers' need in terms of communications technology and multimedia services propels operators to facilitate the integration of innovative solutions to service design, deployment, supply, optimization, and maintenance.

Therefore, the evaluation of network performance is crucial to both the service provider and the end-user in determining the level of QoS provided (Oliveira and Braum, 2004) (Urathal and Chandrasekar, 2012). Techniques for measuring, analyzing, and evaluating QoS in communications networks have recently been the subject of intense scientific research. Network performance can be measured by getting information on important end-to-end parameters such as delay, loss, jitter, and throughput, aimed at monitoring and detecting service degradations so as to manage network resources for maximum utilization, etc., as seen in (Lu, 2000).

Reliable network performance is a crucial factor for many network applications. Hence, a good deal of effort is required to seek and unveil the ways of ensuring reliable network performance while at the same time utilizing the total network resources in an efficient manner. These, therefore, require the introduction of an effective mechanism for QoS performance measurement geared towards ensuring acceptability, reliability and customer satisfaction. The performance of the whole QoS toolset is evaluated as a collective effect of service performances, which determine the degree of satisfaction of a user.

The use of fuzzy logic (FL) model to analyze and evaluate service quality in wireless networks is a promising solution. The theory of FL, which emanated from fuzzy set, is a generalization of the Boolean logic (Lee, 1990) (Zadeh, 1996). It encompasses a methodology for handling partial truth values (between completely true and completely false), uncertain and imprecise knowledge aiming at tractability, robustness and low-cost solutions for real-world problems. Fuzzy logic controllers provide an effective mechanism for describing systems that are extremely difficult, ill-defined, ambiguous or too complex for mathematical (traditional) analysis to handle. It is a form of many-valued logic or probabilistic logic that deals with reasoning that is approximate rather than fixed or exact, providing mechanisms for handling nonlinear uncertainties that exist in physical systems.

More so, FL has the tendency to support natural descriptions of inputs and outputs in terms of language, which avoids the complexity to identify the exact numerical values, to model in each situation. FL models are built upon fuzzy set theory and are useful for evaluating network QoS with insufficient knowledge as well as imprecise data.

A fuzzy logic system comprises a knowledge base unit, which includes the information given by the expert in the form of linguistic control rules, a fuzzification unit, which has the capability of transforming crisp data into fuzzy sets, an inference engine, that makes use of fuzzy rules (a control decision mechanism to adjust the effects of certain causes that come from the system) together with the knowledge base to make inference by means of a reasoning method and a defuzzification unit, which transforms the fuzzy control action into a numerical value to obtain real control action (Umoh and Udosen, 2014).

Currently, performance evaluation of QoS is an area of interest carried out by many researchers in the field. The approaches discussed in the literature use mathematical modeling and soft computing models with varying QoS parameters for evaluating QoS in a typical multimedia network. The intrinsic QoS metrics evaluate service quality according to traditional parameters such as the percentage of lost packets or delay caused by packet transmission, etc. Unfortunately, these parameters are incapable of rejecting the real end user satisfaction by using particular service. As deduce from Mohammed et al, 2011, the work employs main QoS parameters such as delay, jitter and packet loss for evaluation and management of network QoS. The study applies triangular membership functions method for the input and output variables MF evaluation in the system.

In (Shrivastava, 2013), QoS metric such as delay, jitter and loss are explored and evaluated using Gaussian membership functions method for the network QoS. However, the study is not considering one of the major application layer parameters being packet loss which can cause various challenges to the network QoS. Also, in Asuquo and Umoh, 2015, analytic hierarchical process (AHP) works better when variables are quantitative and a number of criteria are not high. However, many times beside the measurable variables, there exist qualitative variables with inherent uncertainties and imprecision.

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In this situation, AHP approach lacks the ability to capture inherent uncertainties, subjectivity (or fuzziness) and imprecision of the QoS service evaluation process. Moreover, several types of research are presented in network control and management, which have exhaustively explored certain parameters such as speed, power transmission, multi-speed, multipath and energy with the aim of meeting a desirable quality of service. But these approaches with respect to fixed parameters pose a considerable challenge, thus cannot present the desired network QoS.

This paper proposes a type-1 fuzzy logic model which deals with uncertainties and imprecision for the evaluation of QoS in wireless communication network as an effective mechanism for QoS management. The paper aims at evaluating and minimizing the impact of three major QoS parameters; delay, jitter, and packet for sustaining reliability of data deliveries and improve the overall system performance.

Statement of Objectives

The aim of this work is to develop a type-2 fuzzy logic-based quality of service evaluation system for wireless communication networks.

Specific Objectives are;

1. Collect, analyze linguistic variables, membership function, and rule base for evaluation of service quality in wireless communication networks.
2. Design and develop an interval type-2 fuzzy logic algorithm for evaluation of quality of service in wireless communication networks.
4. Evaluate the performance of the interval type-2 fuzzy logic algorithm using sample user input.

Methodology

The wireless network quality of service evaluation system is based on the interval type-2 fuzzy logic (IT2FL) model. This model accepts inputs called the crisp input and then transforms it to a crisp output using the processes presented in Figure 1.

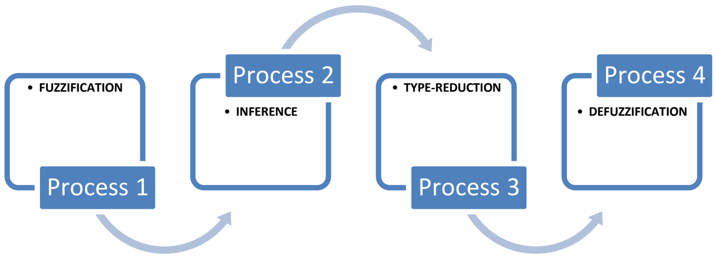

Figure 1: Fuzzy Logic Processes

This system uses quality of service indicators called fuzzy linguistic variable to model the effect of delay, jitter, and packet loss on the quality of service of a wireless communication network. The interval type-2 fuzzy logic (IT2FL) model fuzzifies the inputs using a fuzzification method based on an interval type triangular membership function presented as a 4-tuple (x, a, b, and c) or (x, a_1, a_2, a_3), representing the input (x), left leg of the membership function (a or a1), center of the membership function (b or a2), and right leg of the membership function (c or a3) respectively.

The Inference Engine reasons about the rules in the rule base using a Mamdani type inference mechanism and returns an interval type-2 fuzzy set which is converted to a type-1 fuzzy set using the Karnik-Mendel type reduction algorithm. The model computes the final crisp output using the center of gravity (Centroid) Defuzzification method.

The conceptual framework of this system comprises of the input module, fuzzification module, Inference Engine, Knowledge Base, Membership function, Type reduction, and Defuzzification module. This framework is presented in Figure 2.

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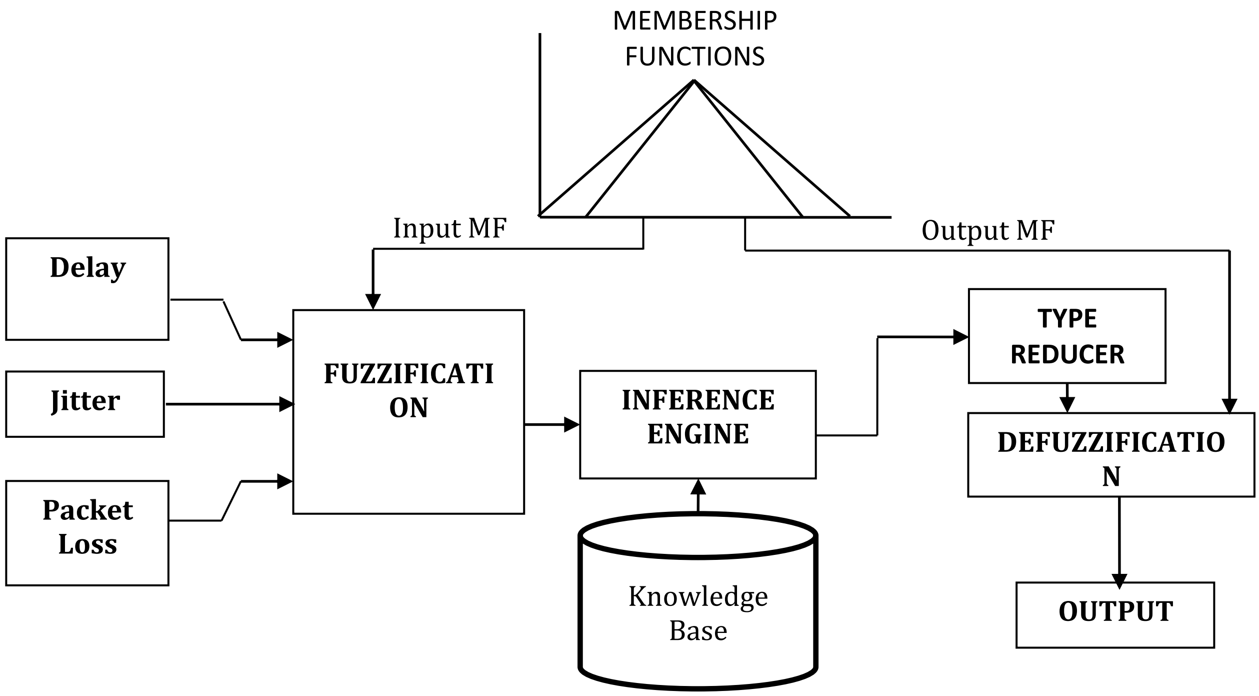

Figure 2: System Framework

Components of Interval Type-2 Fuzzy logic Model

The following components constitute the interval type-2 fuzzy logic model used in this work;

1. **Fuzzification Module**: This module maps the crisp input to a type-2 fuzzy set using a triangular membership function.
2. **Inference Engine**: This module evaluates the rules in the rule base against the type-2 fuzzy set gotten from Fuzzification to produce a new type-2 fuzzy set.
3. **Type Reducer**: Type reducer uses Karnik-Mendel algorithm to reduce an interval type-2 fuzzy set to type-1 fuzzy set
4. **Defuzzification Module**: this module maps the fuzzy set to a crisp output using center of gravity Defuzzification method.
5. **Knowledge Base**: This is a database of rules (rules are generated from experts' knowledge) to be used by the inference engine.
6. **Membership Function**: This is a mathematical equation that helps the fuzzification module converts the crisp input into a fuzzy set.

i. Interval Type-2 Fuzzy Logic model for QOE Evaluation

This work uses the interval type-2 fuzzy logic model which is based on a triangular membership function. In this section we will design all the components of this algorithm as well as manually executing this algorithm based on a chosen input vector. The interval type-2 fuzzy logic model used in this work is described below;

1. Fuzzification

Fuzzification is the transformation of crisp input into a fuzzy set using a defined membership function. For each input and output variable selected, three (3) membership functions (MF) are defined, namely – Delay, Jitter, and Packet loss. A category called partitions is defined for each of the variable. These partitions are called fuzzy term such as low, average, and high. A triangular membership function which has three points (left, center and right) is employed to compute a degree of membership for a given input crisp value. A triangular membership function use in this work is presented below;

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Volume: 03 Issue: 01 | January-February 2021

$$f(x;a,b,c) = \begin{cases} 0, & x \le a \\ \frac{x-a}{b-a}, & a \le x \le b \\ \frac{c-x}{c-b}, & b \le x \le c \\ 0, & c \le x \end{cases}, \; a \in [a_1, a_2],$$

$b \in [b_1, b_2]$ *and* $c \in [c_1, c_2]$

$$\underline{\mu}_{\tilde{A}_{im}}(x_i) = \begin{cases} 0, & x \le a_1 \\ \frac{x-a_1}{b-a_1}, & a_1 \le x \le b \\ \frac{c_1-x}{c_1-b}, & b \le x \le c_1 \\ 0, & c_1 \le x \end{cases}, \underline{\mu}_{\tilde{A}}(x)$$

$$= N(a_1 b, c_1; x)$$

$$\overline{\mu}_{\tilde{A}_{im}}(x_i) = \begin{cases} 0, & x \le a_2 \\ \frac{x-a_2}{b-a_2}, & a_2 \le x \le b \\ \frac{c_2-x}{c_2-b}, & b \le x \le c_2 \\ 0, & c_2 \le x \end{cases}, \overline{\mu}_{\tilde{A}}(x)$$

$$= N(a_2 b, c_2; x)$$

Where:

a_1, a_2 – are the left leg of the lower and upper triangular membership functions respectively.

b_1, b_2 – are the centers of the lower and upper triangular membership functions respectively.

c_1, c_2 – are the right leg of the lower and upper triangular membership functions respectively.

x_i – is the input of ith variable

$\overline{\mu}_{\tilde{A}_{im}}(x_i)$ – is the degree of membership of input x_i in variable i of linguistic term m.

a. Universe of Discourse

The Universe of Discourse is the range of all possible values for each linguistic variables used in the Interval Type-2 fuzzy logic system. The following universe of discourse is defined for our linguistic variables.

Table 1: Universe of Discourse

INPUT VARIABLES AND THEIR UNIVERSE OF DISCOURSE			
Delay (ms)	Jitter (ms)	Packet Loss (%)	QOS
[0, 300]	[0, 30]	[0, 100]	[0, 100]

The definition of the triangular membership functions used in this work are presented as follows;

a. Membership function for Delay

$$\mu_{Low}(x; [13.6,0], [50,50], [85.3, 100]) = \begin{cases} 0, & x \le [13.6,0] \\ \frac{x - [13.6,0]}{[50,50] - [13.6,0]}, & [13.6,0] \le x \le [50,50] \\ \frac{[85.3, 100] - x}{[85.3, 100] - [50,50]}, & [50,50] \le x \le [85.3, 100] \\ 0, & [85.3, 100] \le x \end{cases}$$

$$\mu_{Average}(x; [66.1, 50], [125,125], [183, 200]) = \begin{cases} 0, & x \le [66.1, 50] \\ \frac{x - [66.1, 50]}{[125,125] - [66.1, 50]}, & [66.1, 50] \le x \le [125,125] \\ \frac{[183, 200] - x}{[183, 200] - [125,125]}, & [125,125] \le x \le [183, 200] \\ 0, & [183, 200] \le x \end{cases}$$

$$\mu_{High}(x; [166,150], [225,225], [285,300]) = \begin{cases} 0, & x \le [166,150] \\ \frac{x - [166,150]}{[225,225] - [166,150]}, & [166,150] \le x \le [225,225] \\ \frac{[285,300] - x}{[285,300] - [225,225]}, & [225,225] \le x \le [285,300] \\ 0, & [285,300] \le x \end{cases}$$

b. Membership function for Jitter

$$\mu_{Low}(x; [1.43,0], [5,5], [8.468,10]) = \begin{cases} 0, & x \le [1.43,0] \\ \frac{x - [1.43,0]}{[5,5] - [1.43,0]}, & [1.43,0] \le x \le [5,5] \\ \frac{[8.468,10] - x}{[8.468,10] - [5,5]}, & [5,5] \le x \le [8.468,10] \\ 0, & [8.468,10] \le x \end{cases}$$

$$\mu_{Average}(x; [6.68, 5], [12.5,12.5], [18.2,20]) = \begin{cases} 0, & x \le [6.68, 5] \\ \frac{x - [6.68, 5]}{[12.5,12.5] - [6.68, 5]}, & [6.68, 5] \le x \le [12.5,12.5] \\ \frac{[18.2,20] - x}{[18.2,20] - [12.5,12.5]}, & [12.5,12.5] \le x \le [18.2,20] \\ 0, & [18.2,20] \le x \end{cases}$$

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www.journalsresearchparks.org/index.php/IJHCS e-ISSN: 2615-8159|p-ISSN: 2615-1898
Volume: 03 Issue: 01 | January-February 2021

$$\mu_{High}(x;[16.7,15],[22.5,22.5],[28.12,30]) = \begin{cases} 0, & x \le [16.7,15] \\ \dfrac{x-[16.7,15]}{[22.5,22.5]-[16.7,15]}, & [16.7,15] \le x \le [22.5,22.5] \\ \dfrac{[28.12,30]-x}{[28.12,30]-[22.5,22.5]}, & [22.5,22.5] \le x \le [28.12,30] \\ 0, & [28.12,30] \le x \end{cases}$$

c. Membership function for Packet Loss

$$\mu_{Low}(x;[5.893,0],[20,20],[33.7,40]) = \begin{cases} 0, & x \le [5.893,0] \\ \dfrac{x-[5.893,0]}{[20,20]-[5.893,0]}, & [5.893,0] \le x \le [20,20] \\ \dfrac{[33.7,40]-x}{[33.7,40]-[20,20]}, & [20,20] \le x \le [33.7,40] \\ 0, & [33.7,40] \le x \end{cases}$$

$$\mu_{Average}(x;[36,30],[50,50],[64.1,70]) = \begin{cases} 0, & x \le [36,30] \\ \dfrac{x-[36,30]}{[50,50]-[36,30]}, & [36,30] \le x \le [50,50] \\ \dfrac{[64.1,70]-x}{[64.1,70]-[50,50]}, & [50,50] \le x \le [64.1,70] \\ 0, & [64.1,70] \le x \end{cases}$$

$$\mu_{High}(x;[66.32,60],[80,80],[93.9,100]) = \begin{cases} 0, & x \le [66.32,60] \\ \dfrac{x-[66.32,60]}{[80,80]-[66.32,60]}, & [66.32,60] \le x \le [80,80] \\ \dfrac{[93.9,100]-x}{[93.9,100]-[80,80]}, & [80,80] \le x \le [93.9,100] \\ 0, & [93.9,100] \le x \end{cases}$$

d. Membership function for Quality of Service (QOS)

$$\mu_{BadService}(x;[5.27,0],[20,20],[34.1,40]) = \begin{cases} 0, & x \le [5.27,0] \\ \dfrac{x-[5.27,0]}{[20,20]-[5.27,0]}, & [5.27,0] \le x \le [20,20] \\ \dfrac{[34.1,40]-x}{[34.1,40]-[20,20]}, & [20,20] \le x \le [34.1,40] \\ 0, & [34.1,40] \le x \end{cases}$$

$$\mu_{AverageService}(x;[35.4,30],[50,50],[64.45,70]) = \begin{cases} 0, & x \le [35.4,30] \\ \dfrac{x-[35.4,30]}{[50,50]-[35.4,30]}, & [35.4,30] \le x \le [50,50] \\ \dfrac{[64.45,70]-x}{[64.45,70]-[50,50]}, & [50,50] \le x \le [64.45,70] \\ 0, & [64.45,70] \le x \end{cases}$$

$$\mu_{GoodService}(x;[65.9,60],[80,80],[94.11,100]) = \begin{cases} 0, & x \le [65.9,60] \\ \dfrac{x-[65.9,60]}{[80,80]-[65.9,60]}, & [65.9,60] \le x \le [80,80] \\ \dfrac{[94.11,100]-x}{[94.11,100]-[80,80]}, & [80,80] \le x \le [94.11,100] \\ 0, & [94.11,100] \le x \end{cases}$$

b. Membership function plot

The membership function plot for delay, jitter, packet loss, and quality of service is presented below;

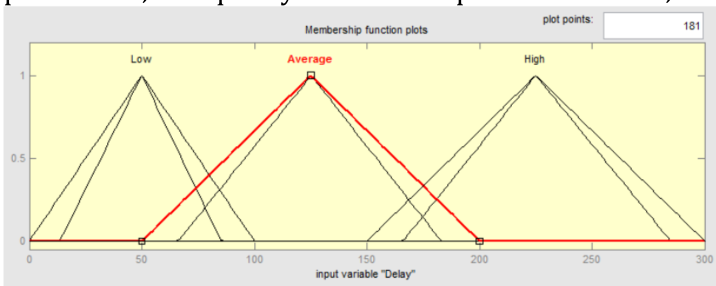

Figure 3: Membership function for Delay

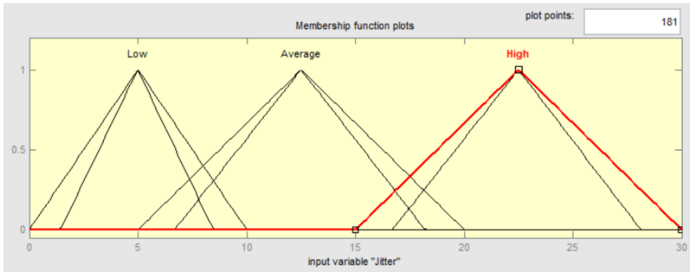

Figure 4: Membership function for Jitter

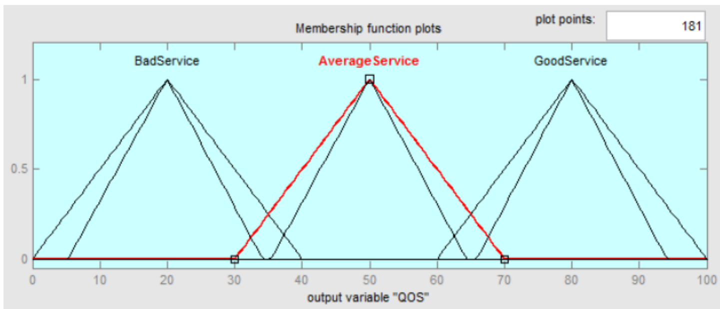

Figure 6: Membership function for QOS

c. Fuzzy Rule Base

The general form of a **fuzzy rule** is defined as a conditional statement in the form:

$R^l: IF\ x_1\ is\ \tilde{F}_1^l\ and\ \dots\ x_p\ is\ \tilde{F}_p^l\ THEN\ y\ is\ \tilde{G}_1^l$

Where:

$l = 1, \dots, M$

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Volume: 03 Issue: 01 | January-February 2021

In this work, fuzzy rules are defined using the standard form as;

IF *Delay is Low and Jitter is High and PLoss is Average THEN QOS is Average.*

Where Delay, Jitter, and PLoss are the input linguistic variables and QOS is the output linguistic variable. Low, Average and High are linguistic terms. The rule base for this work is made up of 27 rules calculated as V^T, where V is the number of input variables and T is the number of linguistic terms. Here V = 3 and T = 3, hence 3^3 = 27. The rulebase for this work is presented in Table 2.

Table 2: The Rulebase

Delay	Jitter	Ploss	QOS
Low	low	Low	Good Service
Low	low	Average	Good Service
Low	low	High	Good Service
Low	average	Low	Good Service
Low	average	Average	Good Service
Low	average	High	Average Service
Low	high	Low	Average Service
Low	high	Average	Average Service
Low	high	High	Average Service
Average	low	Low	Good Service
Average	low	Average	Average Service
Average	low	High	Average Service
Average	average	Low	Average Service
Average	average	Average	Average Service
Average	average	High	Good Service
Average	high	Low	Average Service
Average	high	Average	Bad Service
Average	high	High	Bad Service
High	low	Low	Good Service
High	low	Average	Average Service
High	low	High	Bad Service
High	average	Low	Average Service
High	average	Average	Average Service
High	average	High	Bad Service
High	high	Low	Bad Service
High	high	Average	Bad Service
High	high	High	Bad Service

d. Membership Matrix

The membership matrix shows the effect of the different input values on each membership functions. The membership matrix is computed by substituting a crisp input to each of the triangular membership functions defined in this work. The values presented in the membership matrix is the degree of membership of an input value of a particular variable in a particular membership function. To speed up the process of membership function computation, a software called "Membership Matrix Eval" is developed for this purpose. The membership matrix is presented in Figure 7;

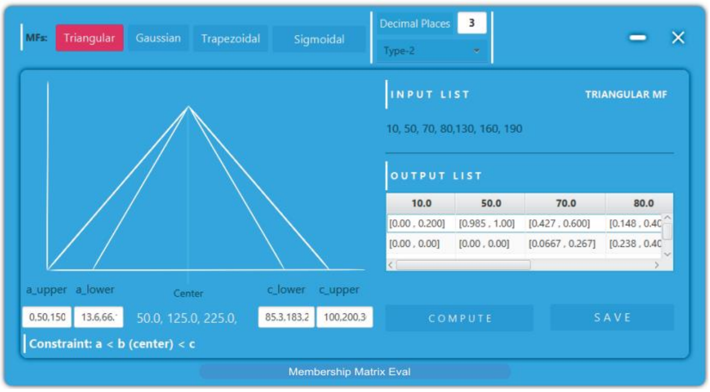

Figure 7: Membership Matrix Evaluator

1. Membership Matrix for Delay

Table 3: Membership matrix for Delay

FUZZY SET $[\underline{\mu}^1, \bar{\mu}^1]$	CRISP INPUT						
	10	**50**	**70**	**80**	**130**	**160**	**190**
Low	[0.00 , 0.200]	[0.985 , 1.00]	[0.427 , 0.600]	[0.148, 0.400]	[0.00, 0.00]	[0.00, 0.00]	[0.00, 0.00]
Average	[0.00 , 0.00]	[0.00 , 0.00]	[0.0667 , 0.267]	[0.238, 0.400]	[0.907, 0.933]	[0.393, 0.533]	[0.00, 0.133]
High	[0.00 , 0.00]	[0.00 , 0.00]	[0.00 , 0.00]	[0.00, 0.00]	[0.00, 0.00]	[0.00, 0.133]	[0.403, 0.533]

2. Membership Matrix for Jitter

Table 4: Membership matrix for Jitter

FUZZY SET$[\underline{\mu}^2, \bar{\mu}^2]$	CRISP INPUT						
	4	**8**	**12**	**18**	**23**	**27**	**30**
Low	[0.730 , 0.800]	[0.133 , 0.400]	[0.00 , 0.00]	[0.00 , 0.00]	[0.00 , 0.00]	[0.00 , 0.00]	[0.00 , 0.00]
Average	[0.00 , 0.00]	[0.229 , 0.400]	[0.924 , 0.933]	[0.0347 , 0.267]	[0.00 , 0.00]	[0.00 , 0.00]	[0.00 , 0.00]
High	[0.00 , 0.00]	[0.00 , 0.00]	[0.00 , 0.00]	[0.228 , 0.400]	[0.897 , 0.933]	[0.196 , 0.400]	[0.00 , 0.00]

INTERNATIONAL JOURNAL ON HUMAN COMPUTING STUDIES

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Volume: 03 Issue: 01 | January-February 2021

3. Membership matrix for PLoss

Table 5: Membership matric for PLoss

FUZZY SET[$\underline{\mu}^3,\overline{\mu}^3$]	CRISP INPUT						
	10	20	30	40	50	60	70
Low	[0.295 , 0.500]	[0.985 , 1.00]	[0.266 , 0.500]	[0.00 , 0.00]	[0.00 , 0.00]	[0.00 , 0.00]	[0.00 , 0.00]
Average	[0.00 , 0.00]	[0.00 , 0.00]	[0.00 , 0.00]	[0.285 , 0.500]	[0.996 , 1.00]	[0.292 , 0.500]	[0.00 , 0.00]
High	[0.00 , 0.00]	[0.00 , 0.00]	[0.00 , 0.00]	[0.00 , 0.00]	[0.00 , 0.00]	[0.00 , 0.00]	[0.267 , 0.500]

2. Fuzzy Inference Mechanism

The inference engine evaluates the rules in the rule base using the model presented in equation below;

$$F^i(x') = \left[\underline{f}^i(x'),\ \overline{f}^i(x')\right] \equiv \left[\underline{f}^i,\ \overline{f}^i\right]$$

$$\underline{f}^i(x') = \underline{\mu}_{\tilde{F}_1^i}(x') * \dots * \underline{\mu}_{\tilde{F}_1^i}(xp')$$

$$\overline{f}^i(x') = \overline{\mu}_{\tilde{F}_1^i}(x') * \dots * \overline{\mu}_{\tilde{F}_1^i}(xp')$$

Given the crisp input vector v = [70, 18, 10] for delay, jitter and packet loss, their degree of membership computed from respective triangular membership functions are given as;

Table 6: Fuzzified value

LINGUISTIC VARIABLE		
Delay[$\underline{\mu}^1,\overline{\mu}^1$]	*Jitter*[$\underline{\mu}^2,\overline{\mu}^2$]	*PLoss*[$\underline{\mu}^3,\overline{\mu}^3$]
μ_{Low} [0.427, 0.6]	μ_{Low} [0.0, 0.0]	μ_{Low} [0.295, 0.5]
$\mu_{Average}$ [0.0667, 0.267]	$\mu_{Average}$ [0.0347, 0.267]	$\mu_{Average}$ [0.0, 0.0]
μ_{High} [0.0, 0.0]	μ_{High} [0.228, 0.4]	μ_{High} [0.0, 0.0]

From Table 6 above, the firing rules are presented in Table 7;

Table 7: Firing rules

Firing Rules				
Rule No.	*Delay*	*Jitter*	*PLoss*	QOS
4	Low	Average	Low	Good Service
7	Low	High	Low	Average Service
13	Average	Average	Low	Average Service
16	Average	High	Low	Average Service

Evaluating rules 4, 7, 13 and 16 against the fuzzy set in Table 6 yields the following result;

Table 8: Rule Evaluation

Rule No.	Firing Interval	Consequent
R4	$[\underline{f}^4, \overline{f}^4]$ = [0.427^ 0.0347^0.295, 0.6^0.267^0.5] = [0.0347, 0.267]	$[\underline{y}^4, \overline{y}^4]$ = *Good Service* [40,45]
R7	$[\underline{f}^7, \overline{f}^7]$ = [0.427^ 0.228^0.295, 0.6^0.4^0.5] = [0.228, 0.4]	$[\underline{y}^7, \overline{y}^7]$ = *Average Service* [51, 67]
R13	$[\underline{f}^{13}, \overline{f}^{13}]$ = [0.0667^ 0.0347^0.295, 0.267^0.267^0.5] = [0.0347, 0.267]	$[\underline{y}^{13}, \overline{y}^{13}]$ = *Average Service* [78, 81]
R16	$[\underline{f}^{16}, \overline{f}^{16}]$ = [0.0667^ 0.228^0.295, 0.267^0.4^0.5] = [0.0667, 0.267]	$[\underline{y}^{16}, \overline{y}^{16}]$ = *Average Service* [62, 73]

3. Type Reduction

The leftmost point (y_l)and the rightmost point (y_r) are given by the equation below;

$$y_l = \min_{L\in[1,N-1]} \frac{\sum_{n=1}^{L} \overline{f}^n \underline{y}^n + \sum_{n=L+1}^{N} \underline{f}^n \underline{y}^n}{\sum_{n=1}^{L} \overline{f}^n + \sum_{n=L+1}^{N} \underline{f}^n}$$

$$y_r = \max_{R\in[1,N-1]} \frac{\sum_{n=1}^{R} \underline{f}^n \overline{y}^n + \sum_{n=R+1}^{N} \overline{f}^n \overline{y}^n}{\sum_{n=1}^{R} \underline{f}^n + \sum_{n=R+1}^{N} \overline{f}^n}$$

From the equations above, for L=3 and R = 1

$$y_l = \frac{\overline{f}^1\underline{y}^1 + \overline{f}^2\underline{y}^2 + \overline{f}^3\underline{y}^3 + \underline{f}^4\underline{y}^4}{\overline{f}^1 + \overline{f}^2 + \overline{f}^3 + \underline{f}^4}$$

$$y_l = \frac{0.267 * 40 + 0.4 * 51 + 0.267 * 78 + 0.0667 * 62}{0.267 + 0.4 + 0.267 + 0.0667}$$

$y_l = 56.0414/1.007$

$y_l = 56$

$$y_r = \frac{\underline{f}^1\overline{y}^1 + \overline{f}^2\overline{y}^2 + \overline{f}^3\overline{y}^3 + \overline{f}^4\overline{y}^4}{\underline{f}^1 + \overline{f}^2 + \overline{f}^3 + \overline{f}^4}$$

$$y_r = \frac{0.0347 * 45 + 0.4 * 67 + 0.267 * 81 + 0.267 * 73}{0.0347 + 0.4 + 0.267 + 0.267}$$

y_r =69.4795/0.9687

y_r = 71.7244

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Volume: 03 Issue: 01 | January-February 2021

4. Defuzzification

We defuzzify the fuzzy set by using the average of y_l and y_r. Hence the deffuzified crisp output equation is $y_k(x) = \frac{y_l + y_r}{2}$
$y_k(x) = \frac{56 + 71.7244}{2} = 63.86$, Hence the quality of service is **"Average"**.

Results and Discussion

The results gotten from this work includes the screen shots of the system, QOE input data, QOE plot of input data, QOE numerical result. These results are presented below;

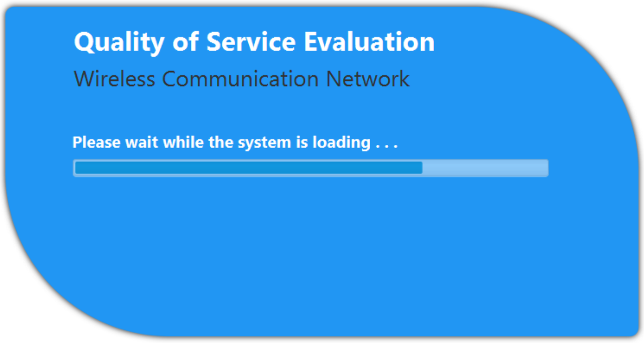

Figure 8: The splash screen

The system splash screen allows the system to load necessary data and also get the system ready to start the login, input and output module. The data prepared by the splash screen includes initialization of Juzzy API, and JFoenix API for interval type-2 fuzzy logic implementation and UI design respectively.

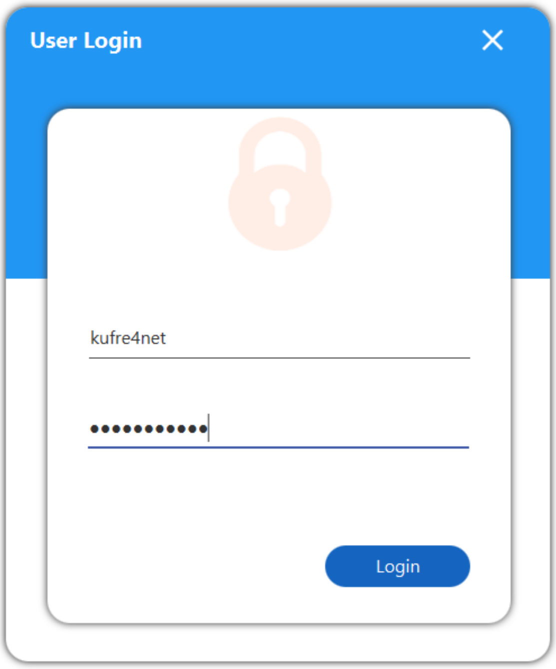

Figure 9: The Login

The system login grants access only to authorized users. The login screen accepts username and password as login credentials, verifies the credentials against the database and authenticates a user. The essence of this module is to provide a level of security to the system so that only Doctors are allowed in the system.

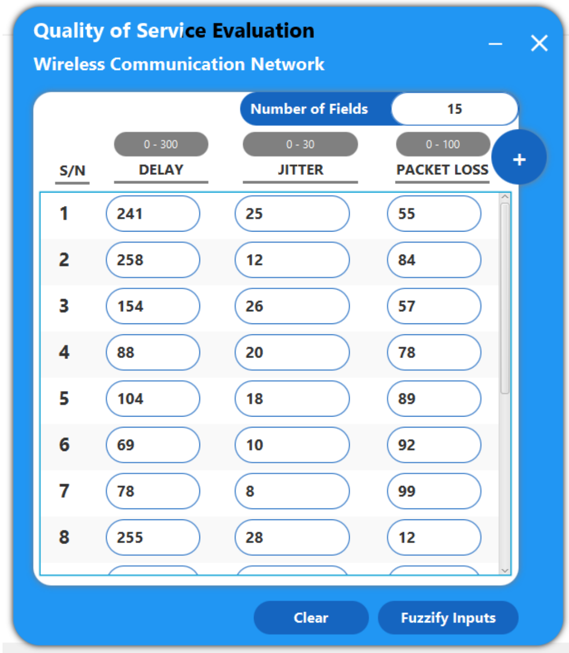

Figure 10: Input Screen

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The input screen accepts user inputs. The user input is comprised of delay, jitter and packet loss for use in evaluating the quality of wireless communication networks. The user is expected to click the "Fuzzify Inputs" button in other to activate the interval type-2 fuzzy logic algorithm.

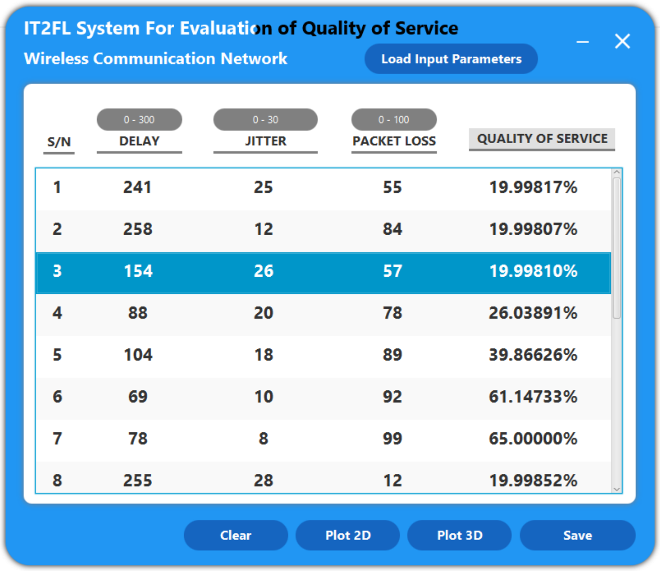

Figure 11: Output Screen

The output screen of this system carries out interval type-2 fuzzy logic algorithm and presents the result (Quality of Service).

Table 9: QOE Evaluation Result

		QOS		
S/N	DELAY	JITTER	PACKET LOSS	QOS
1	241	25	55	19.99817%
2	258	12	84	19.99807%
3	154	26	57	19.99810%
4	88	20	78	26.03891%
5	104	18	89	39.86626%
6	69	10	92	61.14733%
7	78	8	99	65.00000%
8	255	28	12	19.99852%
9	291	17	19	35.00000%
10	154	13	68	69.84130%
11	187	22	51	19.99800%
12	165	27	75	19.99808%
13	89	17	54	46.94630%
14	92	14	39	55.78169%
15	165	18	88	39.86626%

Table 9 presents the numerical result of this system. This result is comprised of the input values for delay, jitter, packet loss and the output values called quality of service.

The quality of service presented in Table 9 is visualized using Figure 12.

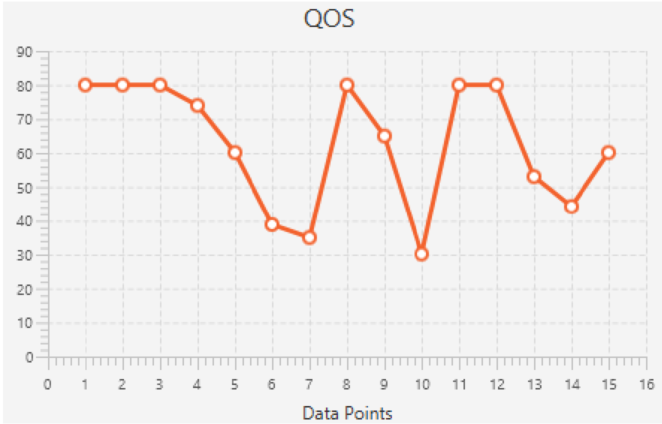

Figure 12: Plot of quality of service

Conclusion

In this work, a soft-computing approach was employed in the evaluation of quality of service in wireless communication network. The work stated by collecting relevant information for use in type-1 fuzzy logic model (soft-computing model). The triangular membership function was used. Fuzzy partitions were obtained from the collected data. The fuzzification process was carried out to transform the user's input (jitter, delay and bandwidth) to a fuzzy set. The inference process was used in conjunction with the rule base to evaluate the fuzzy set from fuzzification thereby transforming it to a new fuzzy set used by the defuzzification process to produce a crisp output called the quality of service. The model was tested using sample user's input. The results of this system show that soft-computing model performs optimally in the evaluation of quality of service in wireless communication network. The system was implemented using java programming language on Netbeans IDE.

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