Methodical Performance Modelling of Mobile Broadband Networks with Soft Computing Model

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ABSTRACT
The upsurge in Mobile Broadband Networks (MBBN) in recent time is evident with challenges and opportunities for the telecommunication industries. Mobile Broadband Performance represents qualitative and quantitative process that measures and defines performance ratings of typical active network. Basically, as broadband network and internet trend is changing rapidly, the growth in traffic is shifting from voice to data being driven by both increased in smartphone subscriptions and continued increase in average data volume per subscription. This paper explores Mobile Broadband Network Performance Modelling based on commonly used indicators; *Signal Strength, Packet Loss and Speed (Data Rate)*. Indeed, networks have to cope with rapid increasing traffic demands and must offer good Quality of Service (QoS) to subscribers which has led to various significant challenges for networks service providers established for delivering uninterrupted coverage, high networks performance and increased user Quality of Experience (uQoE). Hence, modelling mobile broadband networks will significantly overcome existing challenges. The work considered a *Fuzzy Knowledge-Based (FKB)* approach with Triangular Membership Function (TMF) for evaluation of input parameters. First, performance test was carried out on selected three (3) mobile network operators in Niger Delta region and recordings were made over periods of 21 days. Second, a comparative routine monitoring was carried out on the selected network operators to ascertain service capacity. Thirdly, model for optimizing mobile broadband networks was proposed based on the test data. Results demonstrate that, the selected network operators vary in QoS. Comparison in terms of *Signal Strength, Packet Loss and Data Rate* was done. It was observed that, at the instance of six (6) scenarios, ***Operator x*** provides reasonable **Data rate** of about *51.93mbps* (lowest download speed), ***Operator y*** performed efficiently on **Packet loss** with about 0.01% loss of packet and ***Operator z*** performed excellently well on **signal strength** of 98.23% for networks QoS and uQoE provisioning.

Keywords
MBBN, Signal Strength, Packet Loss Data Rate and user Quality of Experience (uQoE)

1. INTRODUCTION
Mobile Broadband Networks (MBN) forms an integral part of our daily lives along with the development of small and multi-purpose mobile devices such as tablets, smartphones and the availability of high capacity 3G, 4G and 5G internet services. Broadband mobile wireless communications serve as a primary means of offering large-capacity multimedia information and communications access to anyone at any time and place. s. Presently, a great number of people across the world have adopted Mobile Cellular Network (MCN) as their primary means of accessing Internet, voice Communication, entertainment services and text messages, therefore, the demand for mobile network services increases every day [15]. Society has also increased requirement on the Mobile broadband Networks (MBN) adoption which has led to the various significant challenges for different service providers in terms of delivering uninterrupted coverage, high network performance, and increased user Quality of Experience (uQoE). Having a concise knowledge of the present gap will help service providers to further enhance the capabilities of their Mobile broadband Networks (MBN). The main goal of broadband networks is to let subscribers access the internet at a speed of at least 1Mbps and throughput of 300 mbps. As a result of the success of data connection on mobile cellular network, subscribers can use their mobile phones for a wide range of activities, including surfing the internet, purchasing goods and services online, streaming video or music and conducting financial transactions when connected to the internet through broadband network. As different wireless network system communications standards continue to evolve, accompanied with increased mobile user service subscription, one significant area that cannot be ignored is the Quality of Service (QoS) the end user experience from one location to another which is vital in the consideration of mobile broadband network performance. Mobile broadband is required for virtually all consideration of broadband internet policy, industry structure, and network management. Performance is required to monitor and regulate service quality, in order to make an informed decision, and to assess network trends and behavior for possibly detects faults. Hence, this research adopts a fuzzy knowledge-based system in order to model the performance of mobile broadband network for efficient Quality of Service provisioning in Mobile Communications Network (MCN).

2. RELATED WORK
Mobile broadband is the marketing term for wireless Internet access delivered through cellular towers to computers and other digital devices using portable modems, smartphone or tablets. Some mobile services allow more than one device to be connected to the Internet with a single cellular connection using a process called tethering [17]. Broadband Network provides different subscribers with reliable and cost-effective connection to the internet. Before the advent of broadband, accessibility to the Internet was mainly through dial up access which was limited to 56Kbps as opposed to broadband which has traditional capacity of 256Kbps which was later expanded to more than 25 megabits-per-second. Broadband network can be saved as a path for an effective economic growth and social development in the society. In the developing countries all over the world, mobile broadband technologies are widely adopted and mobile broadband is progressively rolled-out with high expectations on its impact on the countries' development. A number of studies have analyzed and evaluate strategies for

Modeling Mobile Broadband performance. We summarize a representative sample of the existing works. Eric and Sammy [8] carried out, study on the Performance Modeling of Video-on-Demand Systems in Broadband Networks. Their study focusses on the performance evaluation of distributed true video-on-demand (T-VoD). In their study, a connected video server network architecture for video on demand (VoD) systems was considered, this was achieved under the assumptions of uniform loading and symmetrical network. Different models were proposed for two server selection strategies (Random and Least Loaded) and for two reservation schemes (strict reservation and residual reservation). A queueing model for the distributed video on demand (VoD) system was developed and focus on the derivation of the blocking probability and the bandwidth cost (on the fully connected core network) given the capacity of video servers. Other performance measures, such as the end-to-end service response delay, the amount of video buffers required, the network capacity required were not treated on their research. Gurjeet [11]. Carried out Comparative Analysis and Security Issues in Broadband Wireless Networks. Their research provides a technical analysis for implementing last-mile wireless broadband services. From their analysis, different issues pertaining to security aspect of broadband technology was considered. Meanwhile a Comparison between 802.11(Wi-Fi) and 802.16(WiMAX) wireless network was carried out based on frequency, band, coverage, security, radio technology, modulation and data rates etc. On the aspect of security has it concerns broadband network, Denial of Service (DoS) attack, Distributed Flooding attack, Rogue and selfish backbone devices attack and Node deprivation attack were all considered. Srikanth et al [25], considered Measuring Home Broadband Performance. In their study, Internet access link performance was measured directly from home routers some indication on access-link performance were identified, since link performance measurements can either be done from an end-host inside the home (from the "inside out") or from a server on the wide area Internet (from the "outside in"). since these tools run from end-hosts, they cannot analyze the effects of confounding factors such as home network cross-traffic, the wireless network, or end host configuration. Also, many of these tools run as one-time measurements and, without continual measurements of the same access link, cannot establish a baseline performance level or observe how performance varies over time. Hence, in their study, broadband Internet performance was measured directly from the router that is connected to the user's ISP. Measuring the access link from the home router offers several advantages over conventional methods. Martin [18], wrote an article on Fiber-Wireless (FiWi) Broadband Access Networks in an Age of Convergence: Past, Present, and Future. In their article, an integrated fiber-wireless (FiWi) broadband access networks were described in great details. Also, a brief review of literature was carried out in order to identified various ongoing research activities on the field of broadband access network. Meanwhile a fiber wireless (FiWi) access networks, an advanced survivability technique, and integration of wireless and fiber optic sensors, towards realizing adaptable, dependable, and future-proof broadband access networks based on both wireless and shared passive fiber Media was achieved. Furthermore, their article discuses a service, application, business, and operation related aspects, in order to motivate access technology to move into a substantially different direction in the long run than continued capacity provisioning. Ivanovic [12] Carried out a research on Economic Interests and Social Problems in Realization of Broadband Network. Their study looks at Investments in broadband access as very useful for local communities, especially for the underdeveloped and developing countries all over the world. Their emphasis was on the importance of broadband infrastructure and the use of Internet in the world. Their research points to the model of regional approach to building broadband infrastructure that can be a good model for all developing countries. It was established that the complex issue of building broadband infrastructure further aggravates the number of models of possible use of telecommunication technologies, as each of them has its advantages and disadvantages. It was therefore important to get acquainted with all the essential elements in the process of broadband access planning. Finally, it was established that there is no single detailed recipe for planning and implementing investments in infrastructure installations, especially in the fast-growing technology sector. However, the basic professional framework must be taken into account, whereby the essential elements for the development and dynamics of the process will be determined according to local circumstances. Dahunsi & Akinlabi [6], presented a study on the measuring of broadband performance in Nigeria 2G and 3G network. In their study, a crowdsourced based approach to mobile broadband performance metric measurement and evaluation was adopted. Furthermore, a mobile broadband performance measurement application (MBPerf) was developed using Java and Extensible Markup Language (XML) and installed on volunteers' Android Smartphones to measure and collect data relating to 4 (four) QoS metrics – download and upload speeds, latency and DNS (Domain Name Service) lookup; and user data such as mobile phone information, network information, and location information. It was inferred that network performance is highly unpredictable and variable during the day (between 8am and 5pm) but greatly improves at the early hours of the morning (between 12am to 6am) with a difference of about 69% between the peak and worst performance. Their study indicates that performance deteriorates at peak times (between 7pm and 11pm). The work of [28] demonstrated that, congestion, packet loss and delay have strong influence on the performance of WSNs. In order to implement a realistic sensor network policy to resolve the problem of data delay and avoidance of collisions that lead to packet losses, their work develop a system that guarantees QoS in WSNs using Fuzzy Logic Controller (FLC) for sensitivity analysis of the effect of adaptive forward error correction (AFEC). [27] proposed a Handover Manageability and Performance Model for Mobile Communication Networks then formulated a model for soft handoff in CDMA networks by initiating an overlap region between adjacent cells which facilitating the derivation of handoff manageability performance model. The paper employed an empirical modeling approach to support their analytical findings, measure and investigated the performance characteristics of a typical communication network over a specific period in an established cellular communication network operator.

3. PROPOSED MODEL DESIGN

Model-Based Design (MBD) is a mathematical and visual method of addressing problems associated with designing complex control, signal processing and communication systems. Model formulation is the step where our knowledge of a natural system is translated. in mathematical form. It involves two steps: the construction of a conceptual model. and the formulation of this conceptual model into mathematical equations.

3.1 Conceptual Framework

Architecture is the essential organization of a system personified in its components, their relationship to each other and the environment, and its principles governing its design and development.

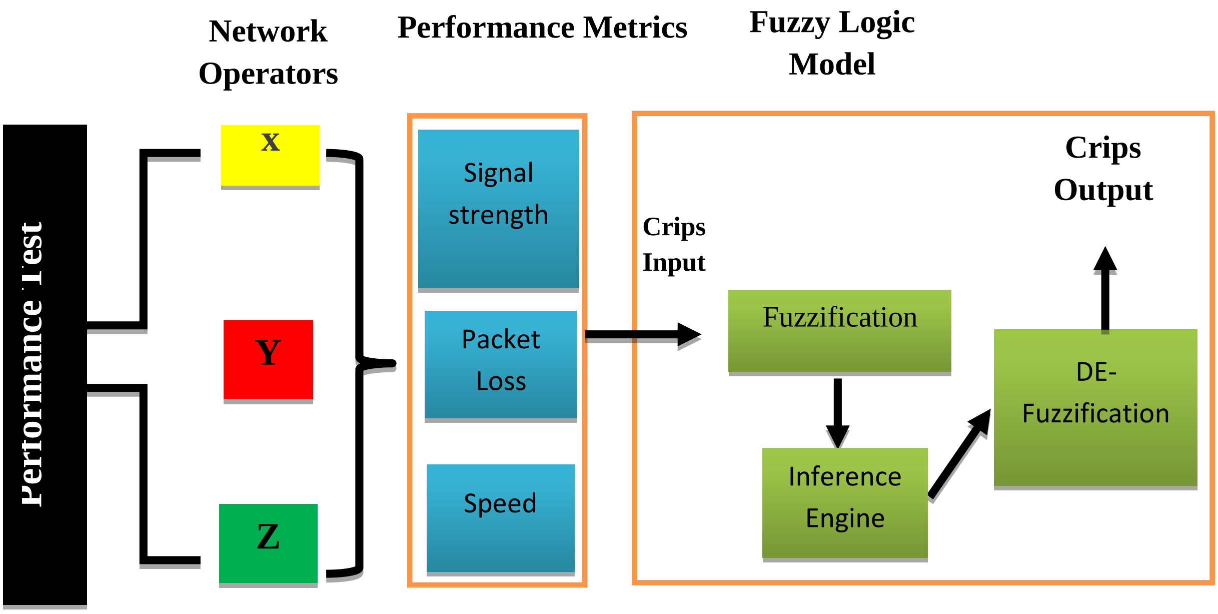

Fig 1: Architecture of the Proposed Model

3.2 Description of Key Components

i. Network Operators

A Network Operator is a provider of wired and wireless communications services that owns or controls the infrastructure necessary to deliver services to Mobile Network Operators (MO), Virtual Network Operators, and end users which are the subscribers including radio spectrum allocation, wireless network infrastructure and other necessary components. In this section of network operators, we selected three network operators in Nigeria for the purposed of this research and we modeled it as operator x, y and z which we will use during our performance test.

ii. Performance Metrics

Performance metrics measures the behavior, activities, and performance of a business. This metric indicates the form of data that measures required data within a range, giving basis to be formed supporting the achievement of overall goals. Hence, this section considers performance metrics such as signal strength, speed and packet loss that will be considered as a determining factor or criteria in mobile broadband performance.

iii. Fuzzy Logic Model

Fuzzy models show a mathematical means of representing vagueness and imprecise information. These models have the capability of reorganizing, representing, manipulating, interpreting, and utilizing data and information that are vague and lack certainty. Fuzzy logic has been applied to many fields, from control theory to artificial intelligence. Hence, this section models the mobile broadband performance data for effective Quality of Service (QoS) provisioning.

4. DATA COLLECTION

There are many diverse ways to model the performance of mobile broadband network, as each broadband network is different in nature and design. The Performance matrices considered in this research are signal strength, packet loss, and speed (upload and download). Signal Strength is an important metrics when considering performance of a broadband network. It is a kind of measurements of how well a broadband device can sense a signal from access point or router. Its value is useful in determining if you have enough signal to get a good wireless network connection. Speed is also a vital metrics when considering modeling of broadband performance. The speed in our broadband is made up off both the upload and download speed which the device can receive data from the internet and also upload data to the internet. Furthermore, Packet loss is very vital in mobile broadband modelling, this occurs when one or more packets of data travelling across a computer network fail to reach their destination. Packet loss is either caused by errors in data transmission, typically across wireless networks, or network congestion. Thus, it is important to measure and monitor with in-depth understanding the impact of signal strength, speed on mobile broadband performances, in order to create an efficient model for broadband performance as well as Quality of Service (Qos) provisioning. Nevertheless, data was collected over a period of seven (7) days using different tools such as 3G/4G Long

Term Evolution **(LTE)** network device which serves as a **Wi-Fi** and **Mifi** platform for the connected devices. A mobile **phone-Goinee m6 mini** was used to connect and read data for the test result. Hence, three (3) software tools were used for data reading which are - *Wi-Fi analyzer, internet speed* and *ping tool.* A detailed depiction and analysis of the data collected for this work will be discussed in the performance test section.

4.1 Performance Test

Performance testing was carried out to determine the speed, responsiveness and stability of a network, software program or device under a workload. Performance testing can involve quantitative tests done in a lab, or occur in the production environment in limited scenarios. In this research performance test was carried out on three (3) network service providers which are label as x, y and z which depicts Mtn, Airtel and Glo. Each of these networks was tested based on three performance metrics which were signal strength, packet loss and speed. They performance testing was carried out in a rural environment to be precise Ibiono Ibom Central 1, Ididep, Akwa

Ibom State Nigeria. They aim was to tests the performance of mobile broadband device on the three (3) service providers in rural environment, in order to achieve an efficient quality of service provisioning for service provides. The performance testing by operators are depicted below;

In each operator, three distinct metrics was tested at different time intervals and recorded for one to three days using five (5) tools which were 4G/3G Mobile broadband Lte, one Gionee M6 mini Phone and three software's for recordings which are ping tool, internet speed and wifi analyzer.

Operator X:

Signal strength was measured first in operator x using wifi analyzer to measure and records the signal strength of the network operator on different time intervals the data exported are depicted below;

Table 2: Signal strength records for operator x using wifi analyzer

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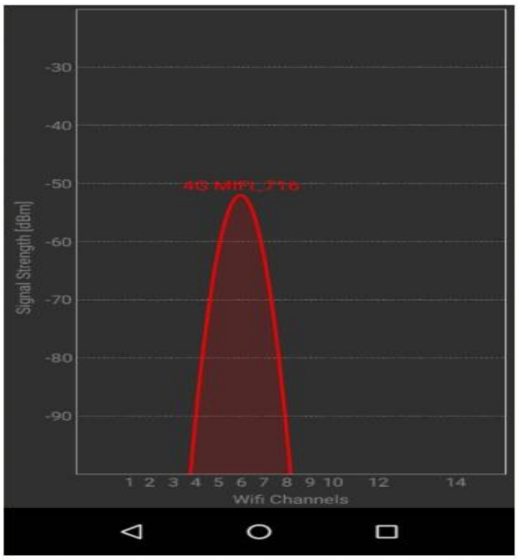

Fig 2: Wifi analyzer screenshot

Also, packet loss was measured and recorded using a ping tool for the operator x, we carried out a ping on www.google.com for 10 times which is depicted below;

Table 3: Ping on operator x

id	Packet size	Response time (ms)	Ttl	Time Stamp	Status	received packets	transmitted packets	Min time (ms)	Avg time (ms)	Max time (ms)	packet loss (%)
1	64	210	116	9/30/2020 7:56		1	1	210	210	210	0
2	0	0	0	9/30/2020 7:56	No answer for ICMP echo request	1	2	210	210	210	50
3	0	0	0	9/30/2020 7:56	No answer for ICMP echo request	1	3	210	210	210	66.6667
4	64	775	116	9/30/2020 7:56		2	4	210	492.5	775	50
5	64	85.6	116	9/30/2020 7:56		3	5	85.6	356.87	775	40
6	64	135	116	9/30/2020 7:56		4	6	85.6	301.4	775	33.3333
7	64	585	116	9/30/2020 7:56		5	7	85.6	358.12	775	28.5714
8	64	354	116	9/30/2020 7:56		6	8	85.6	357.43	775	25
9	64	352	116	9/30/2020 7:56		7	9	85.6	356.66	775	22.2222
10	64	177	116	9/30/2020 7:56		8	10	85.6	334.2	775	20

Furthermore, mobile broadband speed was also measured and recorded using internet speed software for the operator x, upload and download speed was considered at different time intervals measured in megabytes per seconds (mbps) which is depicted in figure 3.

Fig 3: Internet Test Speed for Operator X

Operator Y:

Also, in operator y, Signal strength was measured first in operator y using wifi analyzer to measure and records the signal strength of the network operator on different time intervals the data exported are depicted below;

Table 4: Signal strength records for operator y using wifi analyzer

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Also, packet loss was measured and recorded using a ping tool for the operator y, we carried out a ping on www.google.com for 10 times which is depicted in table 4;

Table 5: Ping on operator y

Id	Packet Size	Response time (ms)	ttl	Time Stamp	status	Received Packets	Transmitted packets	Min time (ms)	Avg Time (ms)	Max Time (ms)	Packet loos%
1	64	112	55	10/3/2020 0:31		1	1	112	112	112	0
2	64	110	55	10/3/2020 0:31		2	2	110	111	112	0
3	64	133	55	10/3/2020 0:31		3	3	110	118.3333359	133	0
4	64	712	55	10/3/2020 0:31		4	4	110	266.75	712	0
5	64	222	55	10/3/2020 0:31		5	5	110	257.7999878	712	0
6	64	143	55	10/3/2020 0:31		6	6	110	238.6666718	712	0
7	64	177	55	10/3/2020 0:31		7	7	110	229.8571472	712	0
8	64	188	55	10/3/2020 0:31		8	8	110	224.625	712	0
9	64	241	55	10/3/2020 0:31		9	9	110	226.4444427	712	0
10	64	256	55	10/3/2020 0:31		10	10	110	229.3999939	712	0

Furthermore, mobile broadband speed was also measured and recorded using internet speed software for the operator y, upload and download speed was considered at different time intervals measured in megabytes per seconds (mbps) which is depicted in figure 4.

Fig 4 Internet test speed for operator y

1. Operator z:

The last operator which is z, Signal strength was measured first in operator z using wifi analyzer to measure and records the signal strength of the network operator on different time intervals the data exported are depicted below;

Table 6: Signal strength records for operator z using wifi analyzer

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Also, packet loss was measured and recorded using a ping tool for the operator y, we carried out a ping on www.google.com for 10 times which is depicted in table 6;

Table 7: Ping on operator Z

id	packet size	response time (ms)	ttl	timestamp	Status	received packets	transmitted packets	min time (ms)	avg time(ms)	max time (ms)	packet loss (%)
1	0	0	0	10/4/2020 8:51	No answer for ICMP echo request	0	1	0	0	0	100
2	64	286	116	10/4/2020 8:51		1	2	286	286	286	50
3	64	247	116	10/4/2020 8:51		2	3	247	267	286	33.333
4	64	100	116	10/4/2020 8:51		3	4	100	211	286	25
5	0	0	0	10/4/2020 8:51	No answer for ICMP echo request	3	5	100	211	286	40
6	0	0	0	10/4/2020 8:51	No answer for ICMP echo request	3	6	100	211	286	50
7	64	78.3	116	10/4/2020 8:51		4	7	78.3	178	286	42.857
8	64	84.7	116	10/4/2020 8:51		5	8	78.3	159	286	37.5
9	0	0	0	10/4/2020 8:51	No answer for ICMP echo request	5	9	78.3	159	286	44.444
10	64	119	116	10/4/2020 8:51		6	10	78.3	153	286	40

1. Furthermore, mobile broadband speed was also measured and recorded using internet speed software for the operator z, upload and download speed was considered at different time intervals measured in megabytes per seconds (mbps) which is depicted in figure 5.

Fig 5: Internet test speed for operator z

5. MODEL FORMULATION

Modelling mobile broadband performance is a very important measures when considering service quality of a network as seen by the network subscriber. There are many different ways to model the performance of a mobile broadband network, as each network operator is different in nature and design when used in a mobile broadband device. Performance can also be modeled and simulated instead of measured; one example of this is using state transition diagrams to model the performance or to use a Network Simulator. To model broadband network performance, parameters like signal strength, packet loss and speed (upload and download) and many others, depending on the application and measurement scheme. In this research work, the general mobile broadband performance metrics considered are; Signal strength (SS), Packet Loss (PL) and Speed(S). These will serve as input variables for our fuzzification process in the Fuzzy Logic Model.

5.1 Model Design

The Following are the steps used to design the fuzzy Logic of our proposed System.

i. Assign Linguistic Labels SS, PL, and S variables.

ii. Define rules for the rule base and obtain a set of firing rules for each range of inputs based on the linguistic labels and membership functions of input variables.

iii. Convert the membership functions into Set for the rules that fired using the equations above.

iv. Obtain the non-zero minimum of the fired rules with their consequence from the composed rules.

v. Perform inference mechanism using Mamdani's method on the linguistic labels.

vi. Composition of the membership and non-membership with the results (of step 5) to obtain the crisp input.

5.2 Fuzzification

The fuzzification process is carried out on the values of the selected input variables using the membership functions to determine their degree of membership. This converts the crisp quantities into to fuzzy values. This is then used to map the output value specified in the individual rules to an intermediate output measuring fuzzy sets.

The fuzzy linguistics variables and terms for each input parameter are defined as follows;

i. Signal Strength [Strong, Medium and Weak]

ii. Packet loss [Low, Mid, and High]

iii. Speed [Low, Mid, and High]

The Network Performance Output (NPO) output represents level of subscriber satisfaction with service quality. The output fuzzy linguistic variable and its terms are

defined as Network performance output [Good, Average, Bad]

The universe of discourse for the input and output parameters based on our performance test are as follows;

i. Signal strength [-90, -30] decibel

ii. packet loss [0, 100] percent

iii. Speed [0, 100] mbps,

iv. Network Performance Output [0, 1], respectively.

The crisp input and output values are converted to fuzzy values by the input and output MFs respectively. A Triangular membership functions (MFs) is used for the evaluation. A Triangular MF curve depends on three parameters a1; a2, and a3, depicted below;

$$\mu(x) = \begin{cases} & if\ x < a \\ 0 \ \ (x - a1)/(a2 - a1) & if\ a1 \le x < a2 \\ 0 \ \ (a3 - x)/(a3 - a2) & if\ a2 \le x < a3 \\ & if\ x > a3, \end{cases} \quad (4.1)$$

where a2 defines the triangular peak location, while a1 and a3 defines the triangular end points.

5.3 Input variable Analysis

From the data set obtained from our performance test, we discover trends that determined the success or failure that affects mobile broadband performance. The data for all the network operators indicates that broadband performance is largely dependent on the terrain and the time interval where the usage is taking place. As long as the condition of the signal quality is stable, the overall service performance will be better. From the facts gathered from our performance test data, we have defined three Linguistic Variables: Signal Strength (SS), packet loss, and Speed(S), for this we analyzed records through pinging google, and also, we test our internet upload and download speed. Conventionally, wireless signal Strength is measured in decibel mill watts (dBm) and represented using negative values. Wireless Signal Strength is categorized as shown in Table 8.

Table 8: Wireless Signal Categorization

Signal Strength	**Signal Quality Evaluation**	**Recommended Usage**
-30 dBm	Maximum signal Strength. The mobile terminal (user) is less than 200 meters from the Access Point	Best for any data needs.
-50 dBm	Excellent Signal Strength	
-60 dBm	Good reliable Signal Strength	
-67 dBm	Reliable Signal Strength	This is the minimum for any data or mobile service depending on a reliable connection and signal strength such as voice over Wi-Fi and non-HD video streaming
-70 dBm	Fairly Strong Wireless Signal	For minimal browsing and emailing
-80 dBm	Unreliable Signal Strength	Not suitable for most wireless network services
-90 dBm	Very low signal Strength	The chances of connection to this signal is very low

Table 9: Input Variables

Input V1.	**Signal Strength (SSS) (dBm)**			
	Linguistic Range	Low	High	Symbol
Linguistic Term	High	-50	-30	HG
	Medium	-70	-50	MD
	Weak	-90	-70	WK
Input V2	**Packet loss (%)**			
	Linguistic Range	Low	High	Symbol
Linguistic Term	High	60	100	HG
	Medium	30	60	MD
	Low	0	30	LW
Input V3	**Speed (mbps)**			
	Linguistic Range	Low	High	Symbol
Linguistic Term	High	60	100	HG
	Medium	24	60	MD
	Low	0	24	LW
OUTPUT	Optimized Handoff Decision (OHD)			

	Linguistic Range	Low	High	Symbol
Linguistic Term	Good	0.70	1.00	G
	Average	0.35	0.70	AVE
	Bad	0	0.35	B

Table 10: Fuzzy Inputs Universe of Discourse

Input Variables and their Universe of Discourse			
SS (dBm)	PL (%)	S (mbps)	NPO
[-90, -30]	[0, 100]	[0, 100]	[0, 1]

5.3.1 Membership Function Definition

As earlier established in the previous subsection, we employ the triangular membership function above. Individual range of inputs and output variables is outlined to relate with a fuzzy set that has the same name as the range. We have identified three Linguistic input variables and defined three fuzzy sets for these input variables as well as three fuzzy sets for the output variables. The tables below present a summary of the Linguistic Universe of Discourse. Triangular membership function in this research are presented equation 4.2, 4.3, 4.4 and 4.5 respectively;

i. Signal Strength

$$SS(x) = \begin{cases} if -90 < x \leq -70, & "Weak" \\ if -70 < x \leq -50, & "Medium" \\ if -50 < x \leq -30, & "High" \end{cases} \quad (4.2)$$

ii. Packet Loss

$$PL(x) = \begin{cases} if\ 0 < x \leq 30, & "Low" \\ if\ 30 < x \leq 60, & "Medium" \\ if\ 6 < x \leq 100, & "High" \end{cases} \quad (4.3)$$

iii. Speed

$$S(x) = \begin{cases} if\ 0 < x \leq 100, & "Low" \\ if\ 100 < x \leq 200, & "Medium" \\ if\ 200 < x \leq 300, & "High" \end{cases} \quad (4.4)$$

iv. Network Performance Operator

$$NPO(x) = \begin{cases} if\ 0 < x \leq 0.40, & "Bad" \\ if\ 0.40 < x \leq 0.60, & "Average" \\ if\ 0.60 < x \leq 1.00, & "Good" \end{cases} \quad (4.5)$$

The following membership plots shows how rules are applied in constructing the different membership plots is shown in Figure.6.

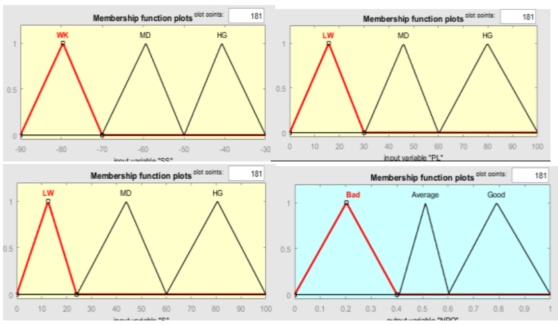

Fig 6.: Fuzzy Rules

Fuzzy Rules

Rules describes the relationship between the input and output linguistic variable which is constructed by their linguistic term.

The general form of a fuzzy rule is defined as a conditional statement. The fuzzy rules are defined using the standard form below.

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

Where 1 = 1,…., M

We have four (3) input variables and each of these variables have three (3) sets each. From combinational logic, we understand that a truth table of N inputs contains 2^N rows, one for each possible value of the inputs. From the 4 input variables, the maximum possible number of rules to be used in defining our rule base is given as $3^3 = 27$. As stated earlier, the rule is a collection of $IF - THEN$ statements. The fuzzy rules are defined based on observation from data collected from a service provider and from expert experience. An expert, in this case, is the network, table 10 shows the rule based generated for the model.

Table 11: Rule Base

Rule No.	SS	PL	S	NPO
	WK	LW	LW	BAD
	WK	MD	LW	BAD
	WK	HG	LW	BAD
	WK	LW	MD	AVERAGE
	WK	MD	MD	AVERAGE
	WK	HG	MD	BAD
	WK	LW	HG	AVERAGE

	WK	MD	HG	AVERAGE
	WK	HG	HG	AVERAGE
	MD	LW	LW	AVERAGE
	MD	MD	LW	AVERAGE
	MD	HG	LW	BAD
	MD	LW	MD	AVERAGE
	MD	MD	MD	AVERAGE
	MD	HG	MD	BAD
	MD	LW	HG	AVERAGE
	MD	MD	HG	AVERAGE
	MD	HG	HG	AVERAGE
	HG	LW	LW	GOOD
	HG	MD	LW	AVERAGE
	HG	HG	LW	AVERAGE
	HG	LW	MD	GOOD
	HG	MD	MD	GOOD
	HG	HG	MD	AVERAGE
	HG	LW	HG	GOOD
	HG	MD	HG	GOOD
	HG	HG	HG	AVERAGE

6. RESULTS EVALUATION

Results Evaluation is an objective assessment of an on-going or completed project. The purpose is to determine the relevance level of achievement of project objectives, development effectiveness, efficiency, impact and sustainability. This paper adopted a fuzzy logic system that consist of a rule viewer used for varying of different input parameters to determine how the output varies based on different instigation figure 7 shows a rule viewer for the optimized system.

Fig. 7: NPO Contributing Variables and NPO Output

From figure 7, the input variables, RSS is set at -60 dBm which portrays a Medium Signal Strength, SS is set at -60 dBm (Medium, Signal Strength), PL is set at 50% (Medium packet loss) and Speed is set at 50 milliseconds (Medium) and just as the rules define, our output which is the Network Performance Operator (NPO) is set at 0.5 and according to our defined rules means *Average network.* By the output average, the system indicates that the current quality of service of the user or mobile subscriber should had all the metrics on a fair quality experience which was able to send packets and delivered to its destination with a minimum loss an average speed. The NPO output variable varies and indicates the performance Decisions such "Bad" or Good" depending on how the input parameters are varied based on the defined rules.

6.1 Discussion of Results

6.1.1 Surface plots

Using the linguistic variables which are factors identified to have the potential of influencing the Performance Mobile broadband network designed a predictor using the MATLAB IDE. From the Linguistic Variables, we defined four linguistic variables for the predictor using the Mamdani Algorithm. Surface plots in fuzzy logic is use depicts 3D representation of each individual variables how it varies in respect to output. Figure. 8a shows a Surface Plot for PL (Packet Loss) against SS (Signal Strength), the surface plot of PL against SS shows that when there is an increase in signal strength, and Packet Loss from the source to destination will delivery of packets will also be fast leaving a medium drops in packets, the NPO decision factor will initiate an average performance command since there is better signal strength.

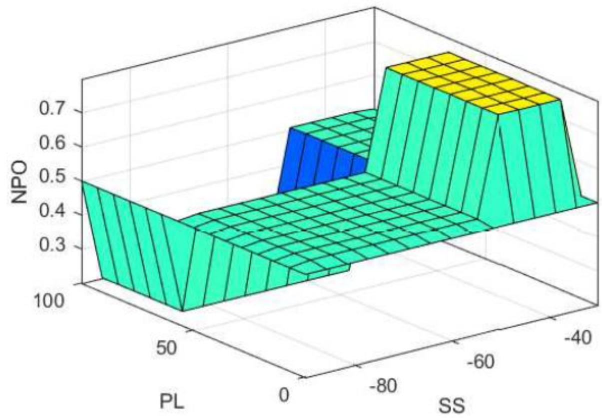

Fig. 8 a Surface Plot for PL against SS

Furthermore, figure. 8b shows a Surface Plot for S (Speed) against SS (Signal strength), the surface plot of RSS against CNT shows that when there is an increase in signal strength, and the Speed also high, the Npo decision factor will initiate a Good command since there is high signal and there is also and increased speed in the broadband it will be difficult for the performance of the network to be bad.

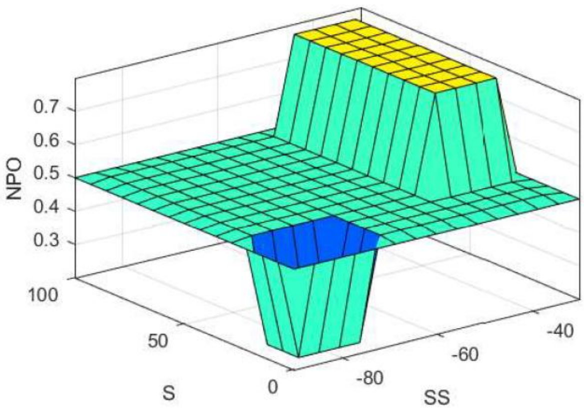

Fig. 8 b Surface Plot for S against SS

6.1.2 Comparative Performance Analysis of Results

This research work provided a framework for the modelling of mobile broadband network performance. In the course of this, different tests were conducted, ranging from signal strength test, ping test and speed test were all considered for the three choice of mobile operators that was chosen for this research work. All the test carried out was measured and recorded in order to ascertain the performance of each network operator performance based on the three-performance metrics that was chosen. The recordings were subjected to data examination in order for us to filter noisy data and remove redundant data as well. The result is presented in tables 12.

Table 12: signal strength data

Freq	Signal Level(dbm)			CenterFreQ0	CenterFreq1
	X	Y	Z		
2437	-40	-46	-21	0	0
2437	-42	-57	-29	0	0
2437	-35	-46	-28	0	0
2437	-42	-53	-31	0	0
2437	-39	-53	-36	0	0
2437	-49	-41	-32	0	0

The signal level as represented in the device template is as shown in Figure 9.

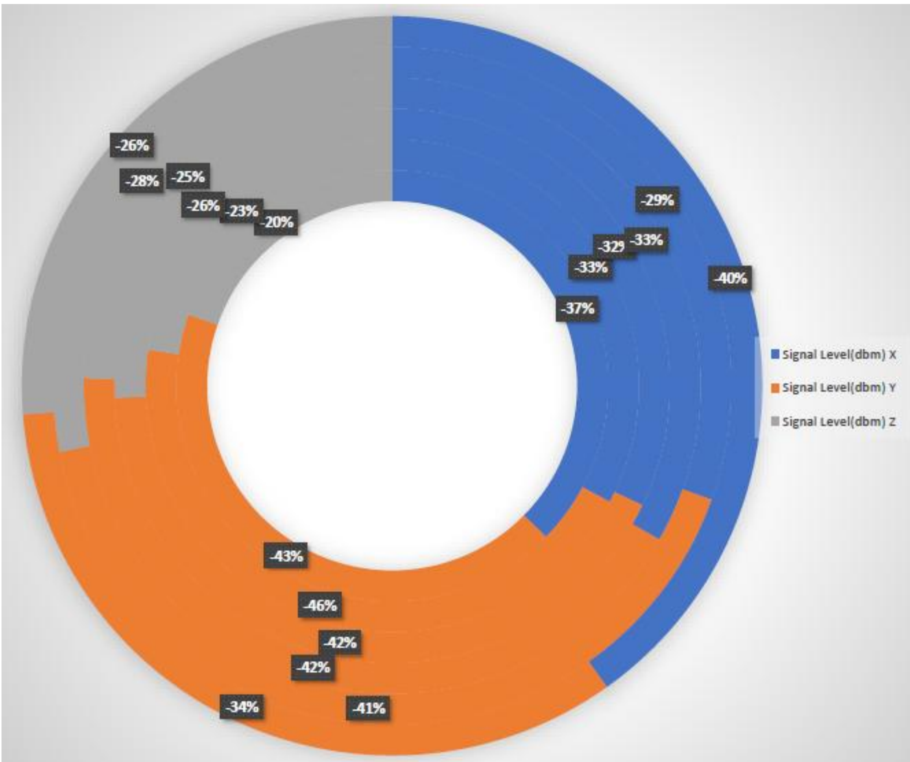

Fig 9 Signal level

The graph of signal level of our performance test based on wifi analyzer software recorded is shown in Figure. 4.8. The graph presented the signal level of each operator measured in decibel. From the graph, the operator that had a very high-level signal strength was operator z followed by x and y respectively.

Table 13: Ping test data

Id	Response Time (Ms)			Time to Live (TTL) (Ms)			Packet Loss (%)		
	X	Y	Z	X	Y	Z	X	Y	z
1	64	112	0	116	55	0	0	0	100
2	0	110	286	0	55	116	50	0	50
3	0	133	247	0	55	116	66.6667	0	33.333
4	64	712	100	116	55	116	50	0	25
5	64	222	0	116	55	0	40	0	40
6	64	143	0	116	55	0	33.3333	0	50
7	64	177	78.3	116	55	116	28.5714	0	42.857
8	64	188	84.7	116	55	116	25	0	37.5
9	64	241	0	116	55	0	22.2222	0	44.444
10	64	256	119	116	55	116	20	0	40

The ping time, measured in milliseconds, is the round-trip time for the packet to reach the host and for the response to return to the sender. Ping response times are important because they add overhead to any requests made over the Internet. Hence, figure 10 shows the response time of each individual operators' performance. figure 10 shows

that the overall response time of operator x was better and shortest in the delivery of 10 packets to it destination which was "www.ggogle.com" that was ping to times as compared to operator z and y response time respectively in terms of duration.

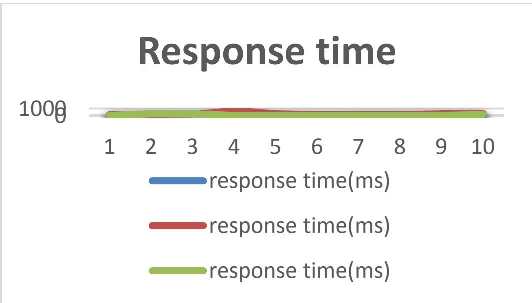

Fig 10 Response time

Again, Time-to-live (TTL) is a value in an Internet Protocol (IP) packet that tells a network router whether or not the packet has been in the network too long and should be discarded. Figure 11 depicts the TTL for the three operators. Here, operator y had the least time live the source to it destination while delivering of packets as compared to both operator x and y.

Furthermore, Packet loss occurs when one or more packets of data travelling across a network fail to reach their destination. Packet loss is either caused by errors in data transmission, typically across wireless networks, or network congestion. Figure 12 depicts the level of loss in packets for the three operators, operator y performs efficiently well by having zero loss of packets during it transmission on 10 pings as compare to others operators.

Fig 11: Time to Live (TTL)

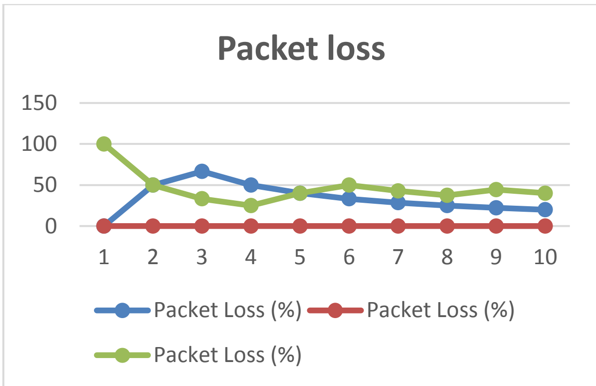

Fig 12 Packet loss

Table 14: Download and Upload Data

Freq.	Speed (Mbps)					
	Download			Upload		
	X	y	Z	X	Y	z
1	0.39	13.46	24.21	0.88	0.24	0.21
2	17.55	0.1	10.55	0.68	0.23	0.52
3	17.61	13.27	13.77	0.78	0.34	0.38
4	15.67	10.24	6.99	0.49	0.17	0.29

5	0.61	14.54	13.74	0.56	0.23	0.23
6	0.1	24.2	17.98	4.96	0.04	0.19

Internet speed refers to how much data and information can be transferred over the web on a single connection at any given time. This is important for subscribers because internet speed determines good networks service delivery, as well as how many devices can be connected. Figure 13 and 14 depicts the upload and download speed operator x, y and z respectively.

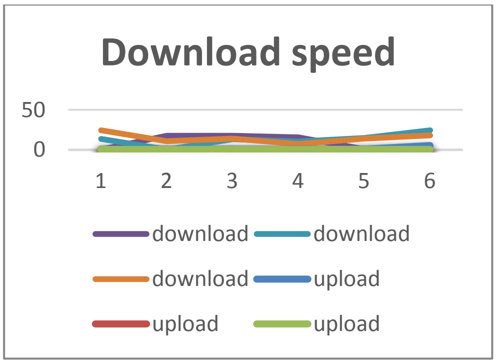

Fig 13 Download speed

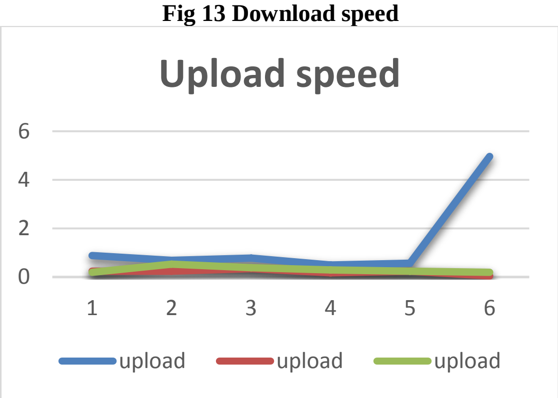

Fig 14 Upload Speed

7. CONCLUSION

The demand for better and good Quality of Service (QoS) in mobile broadband networks is a vital requirement in today's world of Information System (IS). Information has become the highest dealt commodity in the global community. Modern businesses, educational institutions, governments and individuals depend largely on daily information that has to be accessed in real time. Access to information at any place and time, demand good quality of service provisioning. To achieved this, a better networks performance is desirable. The problems on quality of service (QoS) delivery are more intricate for wireless networks access systems than for wired line networks since wireless access networks experience high bit error rate **(BER),** limited bandwidth, user contention frequent mobility, radio inference and diverse traffic characteristics. Hence, wireless access issues have brought about data delivery problems such as slow peripheral access, data errors, dropouts, unnecessary retransmissions, traffic congestion, out of sequence data packets, packet loss, speed, etc. Therefore, there is serious need for an intelligent approach to be adopted and integrated for an efficient modelling of the networks. Especially, mobile broadband network (mbbn) needs to be optimized to enhance mobile subscribers' satisfaction through user quality of experience **(uQoE)** and increase revenue for networks service providers. Though various performance models have been formulated for mobile broadband networks with incidences of numerous challenges encountered during network performance such as, data uncertainties handling. In this paper, the demand for Quality of service (QoS) provisioning, and Quality of Experience (QoE) as well as good network performance for mobile subscribers is resolved through computational intelligence approach using Type 1 Fuzzy knowledge-based system. This optimal network performance modelling provide solution to some of the problems user experienced through response time during packets delivery, upload and download speed within a broadband network and mobile subscribers' device. Hence, the system demonstrates reasonable **Data rate** on ***Operator x,*** (about *51.93mbps*), ***Operator y*** performed efficiently on **Packet loss** (about 0.01% loss of packet) and ***Operator z*** performed excellently well on **Signal Strength** of 98.23% for networks QoS and uQoE provisioning.

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