Development Of Fuzzy Inference System-Based Analysis Of Non-Prioritized Handoff Scheme With Statistically Modelled Idlechannel Borrowingmechanism For Cellular Networks

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***Abstract*— This study centers on the use of stochastic data of the call service rate, call duration, call activity factor and the call arrival rate to generate the call blocking probability per call activity factor for each channel. Data for hundred channels was generated using the exponential data distribution format in MATLAB. The models used in the study were the Mamdani fuzzy logic model and the Sugeno fuzzy logic model. Themodels were considered because of their robustness and fast nature of handling stochastic data. The number of membership function considered for each of the input parameters were three (3) triangular model membership functions for both the Mamdani FIS model and the Sugeno FIS model. The blocking probability and call clipping factor for the Mamdani system used nine (nine) triangular membership function with eighty-one rules and Sugeno used constants points for eighty one (81) points as such had 81 rules. The results presented were the values of the call blocking probability and call clipping values for predicted call blocking probability and the call clipping factor plotted against the number of channels for the Sugeno and the Mamdani models. The outcome of the results shows that the Sugeno inference system had a good tracking of the actual call blocking probability and call clipping factor as such is the best in terms of prediction performance. Also, it was observed that as the number of channels increases from ten (10) to hundred (100), the multiplexer gain increases from 1.3 up to 1.45 for the simulated case study dataset. As such, with idle channel borrowing mechanism, the results show that it is possible to support number of users greater than the number of available channels and the percentage of the available idle channels that can be borrowed increases as the number of available channels increases.**

Keywords*— Idle Channel Borrowing, Cellular Network, Handoff, Blocking Probability, Call Clipping Factor, call activity factor, Wireless Network. Sugeno Inference System , Mamdani Inference System.

I. INTRODUCTION

Cellular radio is the fastest growing and most demanding area in the telecommunications industry [1,2]. Cell sizes have decreased to meet this demand, leading to the undesirable consequence of an increase in the number of handoffs and in the probability that a call is forced to terminate [3,4,5]. Microcells are now used to increase the capacity of the systems by reusing the resources more intensively in high-traffic demand areas[6,7,8]. The forced termination of ongoing calls is a less desirable event in the performance evaluation of a personal communications service (PCS) network than the blocking of new calls [9]. As the number of users and mobile devices continue remarkable growth in recent years, it becomes more and more important to develop a sophisticated mechanism for resource allocation with optimal usage efficiency.

Existing study has worked on the subject of idle channel borrowing using empirically derived statistical multiplexer gain, where the system was simulated with 50% talk activity ratio using 10 channels [10,11,12]. These channels were subjected to calls above their carrying capacity and a graph was plotted using the system performance; it was discovered that the channels were able to accommodate 13 calls without any noticeable degradation in the quality of service but beyond 13, the degradation became noticeable. They limited the statistical multiplexer gain for the idle channel borrowing [13,14] to 1.25; in that case with a talk activity ratio of 50% and 10 available channels, 25% of the channel capacity can be borrowed. This information is based on the empirical study. The statistical study on the other hand has shown that higher number of channels will give higher number of statistical multiplexer gain. In order to cater for the increase in cellular traffic, network providers are faced with increasing their number of channels per cell but this requires more hardware installation which will lead to incurring extra cost. However, research has shown that when channels are allocated for calls, 40% to 60% of the time the caller and the callee are silent thus the channels are idle; in cases like this, such channels can be borrowed and allocated to other callers so the channels can be effectively and efficiently utilized [13,15,16,17]. Nevertheless, the concern to

researchers is how much of such channels can be borrowed without degrading the quality of service (QoS).
Consequently, in this research, two Sugeno and the Mamadani inference rules of the fuzzy inference system [18,19,20] were developed and used to predict the call blocking probability and call clipping factor that will occur when idle channel borrowing is implemented for any given number of channels, call activity factor, call service rate, call arrival rate and call duration. The prediction results of the models the number of extra calls that will be supported with the available channels when the idle channel borrowing is implemented. The study utilized stochastically generated network and call parameter values. The information presented in this paper will enable service providers to use the available channels per cell to accommodate more traffic and still maintain the desired quality of service without installing additional hardware. This is because the idle channel borrowing mechanism developed will run as a software within the existing network facilities and will enable the network service providers to increase their carrying capacity. As such it will provide better quality of service for users and more users will have their calls going through instead of getting rejected. At the same time, the service providers will make more money because more calls will get accepted and more calls will be serviced at the same time with the available network infrastructure.

II. METHODOLOGY

In this research, non-prioritized handoff scheme with idle channel borrowing mechanism is studied. Specifically, stochastic and analytical approaches were used to determine the call blocking probability, the call clipping factor and the maximum number of users or calls that can be supported for any given number of available channels in a wireless cellular communication network. Afterwards, Mandani and Sugeno Fuzzy Inference System (FIS) models were developed based on the generated datasets to predict the blocking probability, the call clipping factor and the maximum number of users or calls that can be supported for any given number of available channels in the network. The model input consists of call service rate, call duration, call (or voice) activity factor and call arrival rate. Each of the input variables was generated using random number generator with exponential distribution with a given mean value. The summary of the research process is given in the flow diagram shown in Figure 1.

For this study, the input variable parameter values were obtained for a maximum of hundred (100) channels against several users or calls. The random number with exponential distribution function command (‘EXPRND’ function) in MATLAB was used to generate the input variable data utilized for this study. Then comparative performance analysis of the Mandani and Sugeno Fuzzy Inference System (FIS) models was based on the model with the least prediction error for the blocking probability, the call clipping factor and the maximum number of users or calls that can be supported for any given number of available channels in the network.

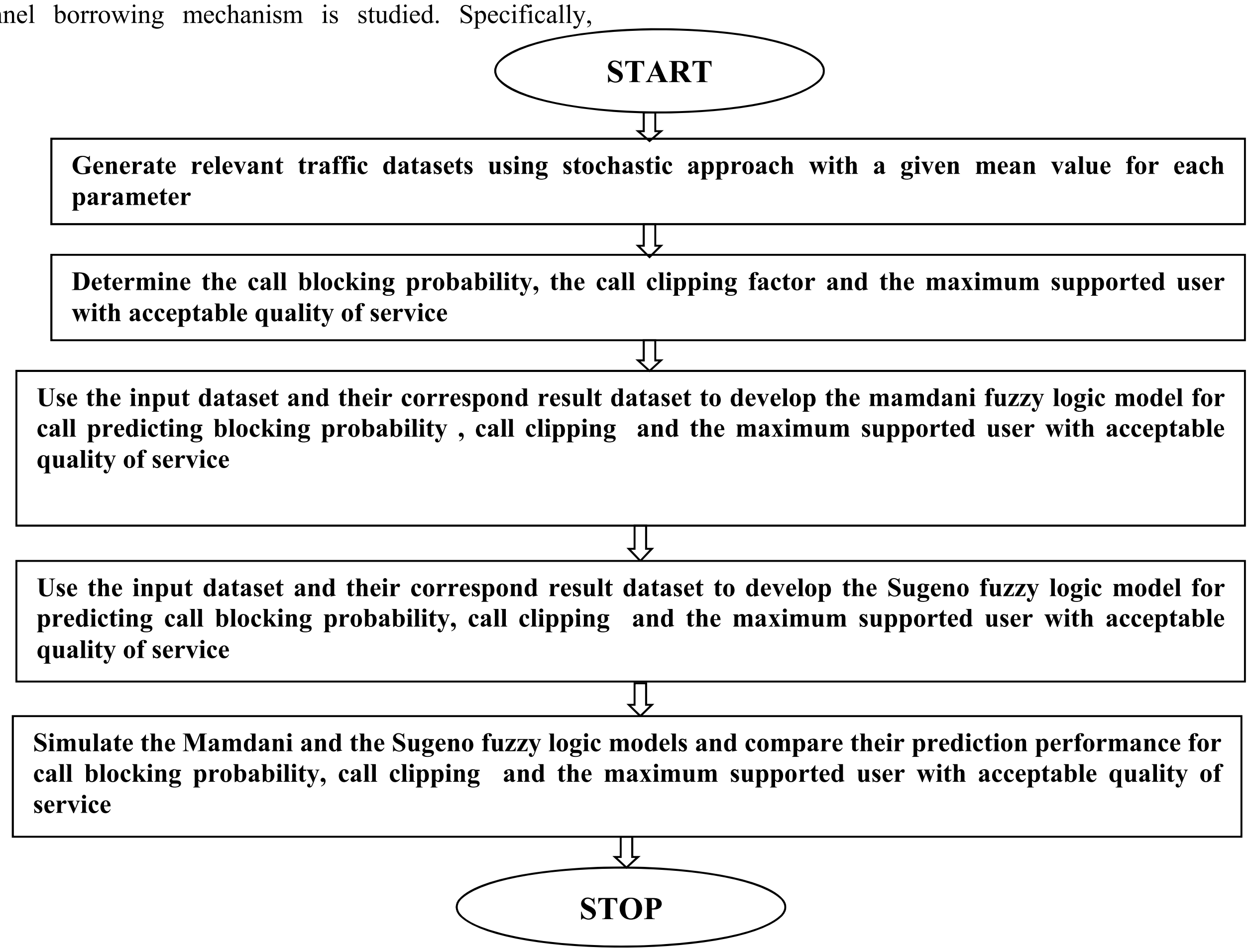

Figure 1: Flow diagram for the research process.

The input parameters for the channels and the users or calls include: call service rate, call arrival rate, call duration and call activity factor. These parameters were the input variable to the intelligent models utilized to determine the blocking probability and the call clipping factor of each of the 100 channels. Specifically, the input dataset for each of the input parameters; call service rate, call arrival rate, call duration (secs) and call activity factor is generated using the random number generator with exponential distribution given as;

$$r = \text{exprnd (mu)} \quad (1)$$

The exprnd (mu) command generates random numbers from the exponential distribution with the parameter mean value of mu. Table 1 shows sample parameter data values for up to 20 channels.

Table 1:The input parameter data for the first channel

Serial Number of the Channels	Call service rate	Call arrival rate	Call duration (secs)	Call activity factor	Serial Number of the Channels	Call service rate	Call arrival rate	Call duration (secs)	Call activity factor
1	0.0032	0.4487	112.175	1.1279	11	0.0022	0.5352	102.5703	0.1664
2	0.0034	0.6383	106.3294	0.1531	12	0.0035	0.4251	104.6274	0.2627
3	0.0022	0.4934	115.8548	1.2639	13	0.0034	0.4687	108.3603	0.011
4	0.0034	0.5586	109.7222	1.0555	14	0.0027	0.674	103.0707	0.1729
5	0.0029	0.4497	105.716	0.2603	15	0.0032	0.4457	116.5748	0.0891
6	0.0021	0.5806	118.658	0.9343	16	0.0022	0.6477	102.2848	0.316
7	0.0024	0.4789	117.2707	0.0803	17	0.0026	0.5615	102.9703	0.3354
8	0.0028	0.5962	110.1034	0.0806	18	0.0034	0.6988	101.7556	0.0768
9	0.0034	0.6068	111.6945	0.13	19	0.0032	0.4235	103.0086	0.9933
10	0.0034	0.6244	110.915	0.7592	20	0.0034	0.5328	107.5854	0.8064

A. Model for the Call blocking Probability and the call clipping probability

In order to obtain the data for the call blocking probability, the traffic intensity (ρ) was obtained as follows;

$$\rho = \frac{\lambda}{\mu} \quad (2)$$

where λ is the call arrival rate for each channel, T is the call duration and μ is the call service rate (where $\mu = \frac{1}{T}$) of each channel. The call blocking probability, P_{cb} for various numbers of channels was determined as follows;

$$P_{cb} = \frac{\left(\frac{\rho^n}{n!}\right)}{\sum_{i=0}^{n}\left(\frac{\rho^i}{i!}\right)} = \frac{\left(\frac{\left(\frac{\lambda}{\mu}\right)^n}{n!}\right)}{\sum_{i=0}^{n}\left(\frac{\left(\frac{\lambda}{\mu}\right)^i}{i!}\right)} \quad (3)$$

where a is the traffic intensity and n is the number of channels. The quality of service provided is given as;

$$QoS = 1 - P_{cb} \quad (4)$$

In a statistical multiplexer system for voice network that has M channels and N calls or sources connected to it, where each of the calls or sources has average voice activity factor of α, then the average number of busy channels is given as:

Average number of busy channels, M_b = α*N
where M ≤ N (5)

Voice traffic clipping occurs in the network if M or more sources are in the activity phase simultaneously. Therefore, the probability that M or more sources are active gives the clipping probability, $Prob(clipping)$. This is determined from the poison equation as:

$$Prob(clipping), P_{cL} = \sum_{j=M}^{\infty} P_j(t = M_b) \quad (6)$$

$$Prob(clipping), P_{cL} = 1 - \left(\sum_{j=0}^{M-1} P_j(t = M_b)\right) \quad (7)$$

$$Prob(clipping),\ P_{cL} = 1 - \left(e^{-M_b}\right)\left(\frac{(M_b)^0}{0!} + \frac{(M_b)^1}{1!} + \frac{(M_b)^2}{2!} \ldots + \frac{(M_b)^{(M-1)}}{(M-1)!}\right) \quad (8)$$

$$P_{cL} = 1 - \left(e^{-(\alpha*N)}\right)\left(\frac{(\alpha*N)^0}{0!} + \frac{(\alpha*N)^1}{1!} + \frac{(\alpha*N)^2}{2!} \ldots + \frac{(\alpha*N)^{(N-1)}}{(M-1)!}\right) \quad (9)$$

B. Determination of the maximum number of users and the statistical multiplexer gain

The call blocking probability (P_{cb}) and the call clipping probability (P_{cL}) are computed for different input data combinationsIn this work , the acceptable quality of service (QoS) is such that the Call blocking Probability (P_{cb}) ≤ 2 % and the call clipping probability (P_{cL}) ≤ 0.2 %. As such, in order to determine the maximum number of users that can be supported for any number of available channels, the number of calls are increased until the maximum number of calls is reached beyond which any of the two QoS conditions is violated.

In this paper, for any given number of available channels (M), the number of users or call sources (N) is increased from M, to M+1 , M +2 , until M+K+1 at which point either the call blocking probability (P_{cb}) > 2% or the call clipping probability (P_{cL}) > 0.2%. In that case, the number of calls that can be supported for the M available channels is M +K calls. The channel borrowing mechanism is based on statistical multiplexer. As such, the statistical multiplexer gain is given as;

$$Statistical\ Multiplexer\ gain = \frac{Number\ of\ Users}{Number\ of\ Channels} \quad (10)$$

In order to develop the FIS models for predicting the maximum number of users that can be supported for any given available number of channels and input dataset values, Table 2 is generated from the mean values of the input datasets and their corresponding results on call blocking probability (P_{cb}), the call clipping probability (P_{cL}) and the maximum number of users that can be supported for any given available number of channels.

Table 2: The template of the dataset used for developing the FIS models

1	2	3	4	5	6	7	8	9
Number of Channels	**Mean Call service rate**	**Mean Call arrival rate**	**Mean Call duration (secs)**	**Mean Call activity factor**	**Maximum Number of Users supported at acceptable quality of service**	**Call blocking Probability (%)**	**Call Clipping Factor (%)**	**Statistical Multiplexer gain**
100	0.0025	0.6384	108.3639	0.6887	M+K	≤2%	≤0.2%	>0.2%

Table 2 has nine (9) columns. The FIS models are meant to take the items in column one (1) to column five (5) as inputs and then predict the item in column five (5) which is the maximum number of users supported at acceptable quality of service. The models can also predict the call blocking probability (P_{cb}) and the call clipping probability (P_{cL}) for any given input dataset. The detailed flow diagram for the determination of the call blocking probability (P_{cb}), the call clipping probability (P_{cL}) and the maximum number of users that can be supported for any given available number of channels and input dataset values is given in Figure 2 and Figure 3 respectively.

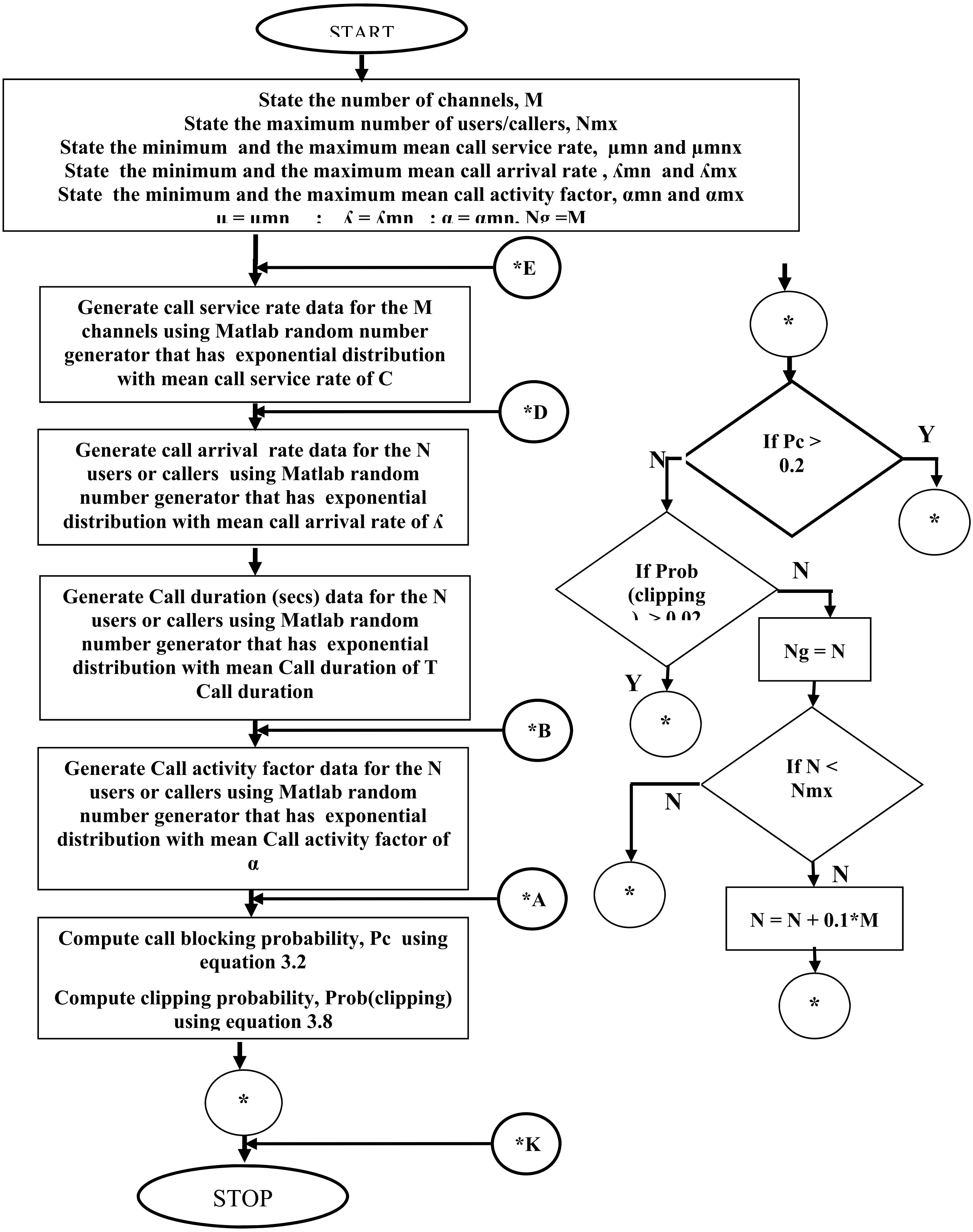

Figure 2: The part I of the detailed flow diagram for the determination of the call blocking probability (P_{cb}), the call clipping probability (P_{cL}) and the maximum number of users that can be supported

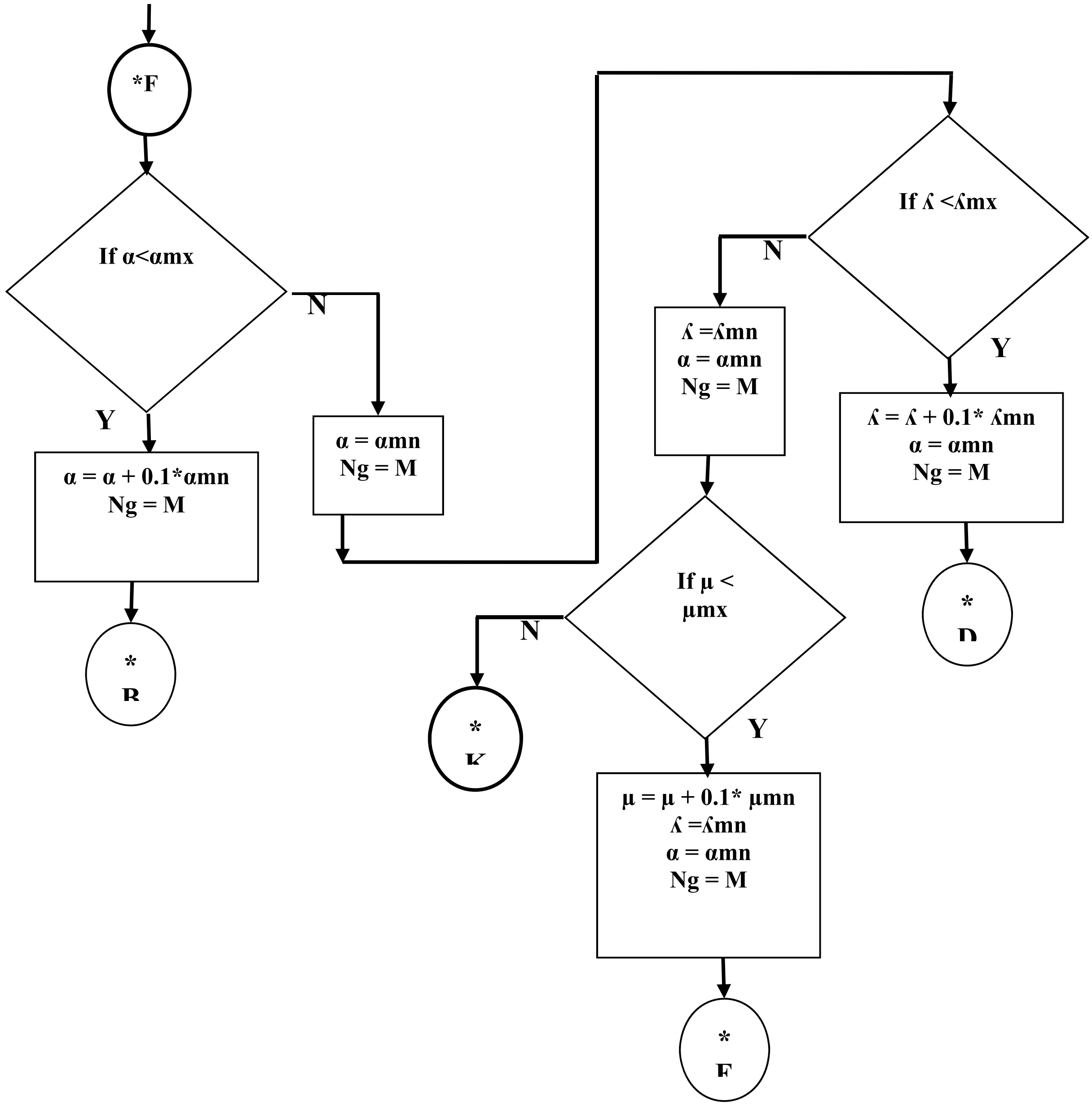

Figure 3: The part II of the detailed flow diagram for the determination of the call blocking probability (P_{cb}), the call clipping probability (P_{cL}) and the maximum number of users that can be supported

C. Development of the Mamdani and Sugeno System of fuzzy logic Model

The fuzzy logic environment used for this study is shown in Figure 4. In this environment, it requires the five input parameter data namely; call arrival rate, call service rate, call duration, number of channels and number of users. The call blocking probability is the output variable of the FIS model.

By default, the membership function model for the input parameters was the trapezoidal model and the output had triangular model as the membership function model, as shown in Figure 4. The type of deffuzification used for this study is the centroid diffuzification type. Specifically, Figure 4 shows the system of fuzzy logic model after inserting the input parameters and the output parameter values. The type rule model used as shown in the figure is the Mamdani system of modeling. The fuzzy logic environment with the sugeno system of model is shown in Figure 5.

The difference between the two models in Figure 4 and Figure 5 is function for the output variables membership system variables models. The membership functions for the Mandani model is displayed in Figures 6.

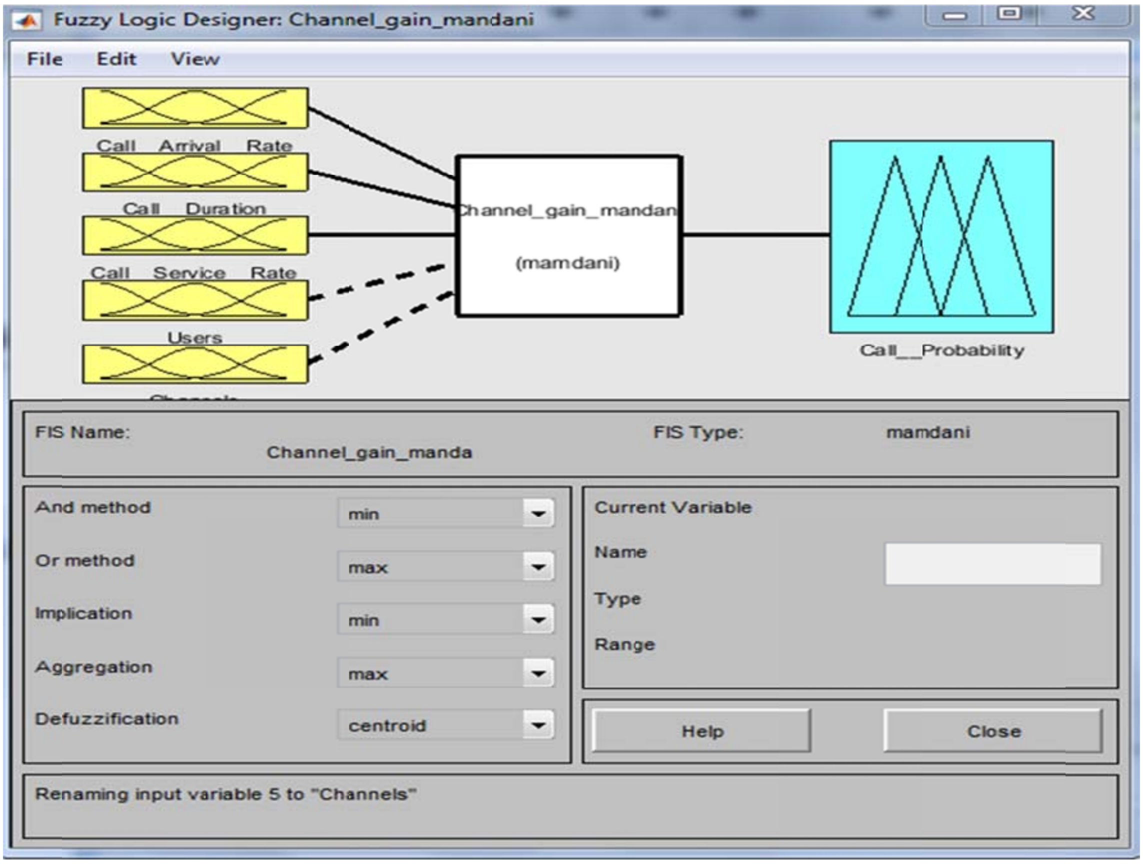

Figure 4: Fuzzy inference system GUI after inserting the input and output parameters for Mamdani system of rules.

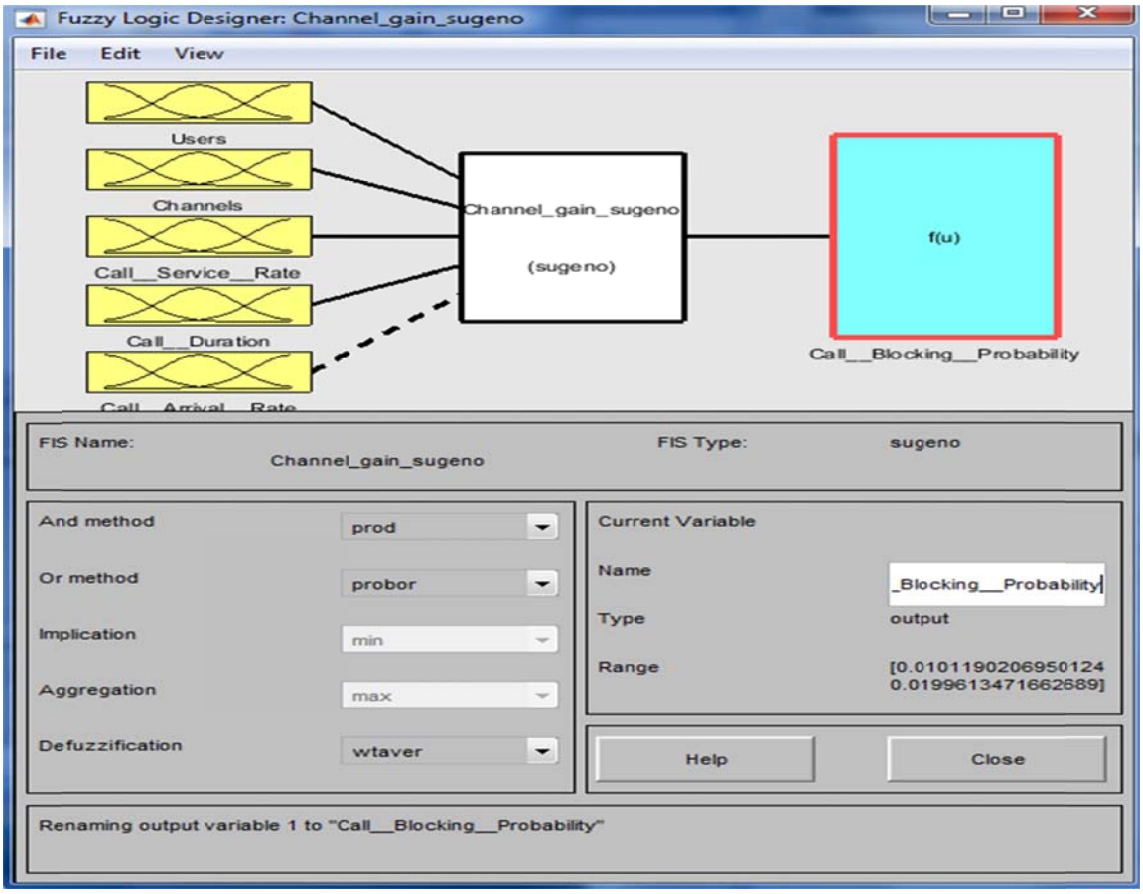

Figure 5: Fuzzy inference system GUI after inserting the input and output parameters for Sugeno system of rules.

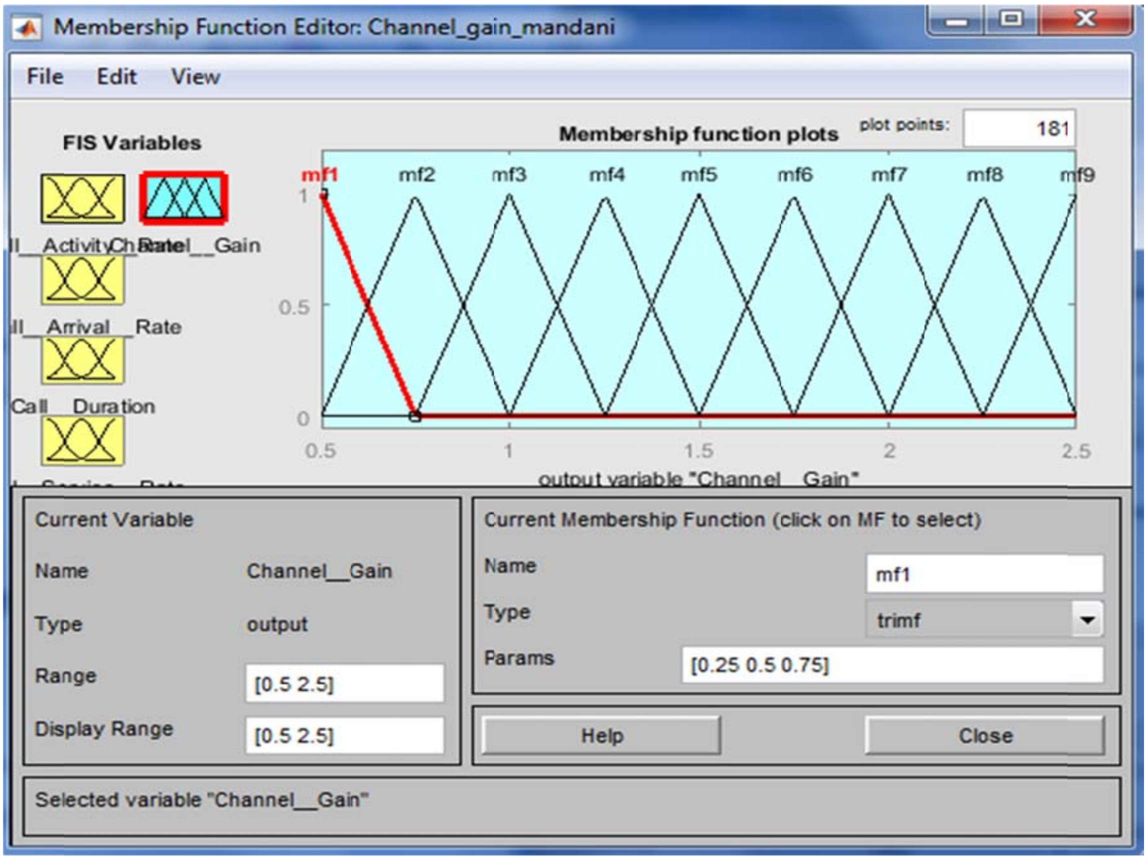

Figure 6: Mamdani Fuzzy inference system model.

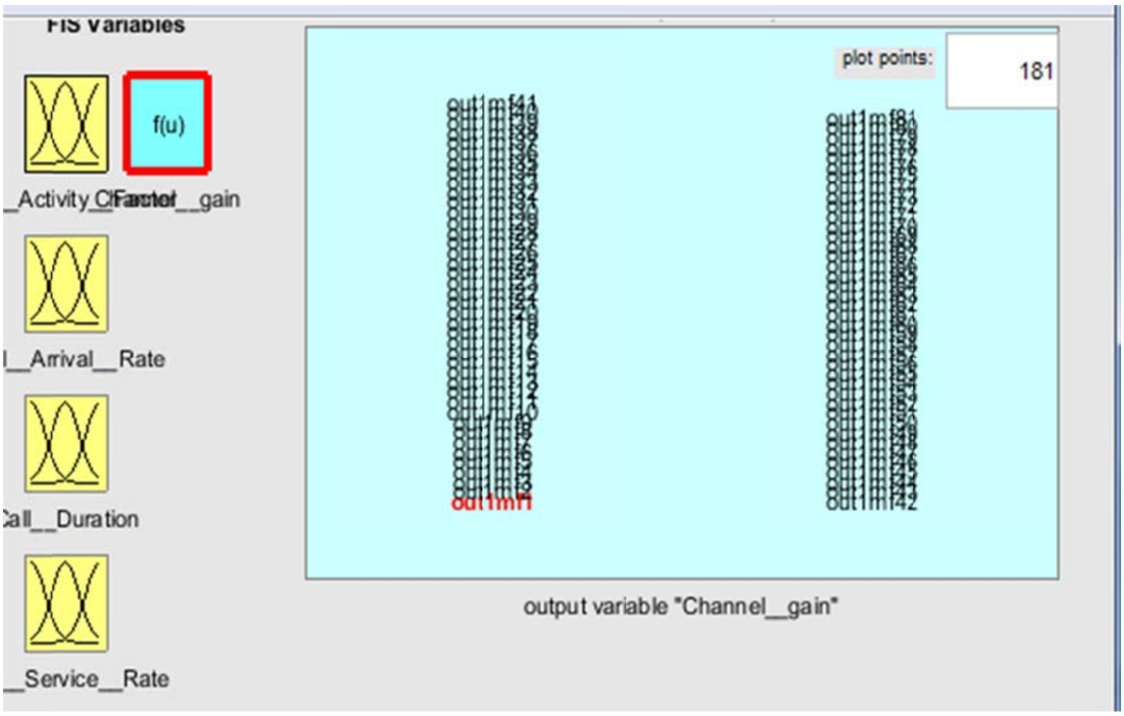

Figure 7: Constant variable for the Sugeno system of fuzzy logic model

Figure 7 shows the Sugeno system of fuzzy logic model. Here, the type of model used for the statistical gain factor is the constant parameter consisting of 101 points as indicated in the figure. Sugeno system of model is limited to the linear model and the constant points whereas Mamdani contains the triangular function, trapezoidal models and much more (the same models as the input parameters). The membership functions for all the inputs parameters are all the same and the range differ per parameter. The input membership function for input variable is shown from Figure 8.

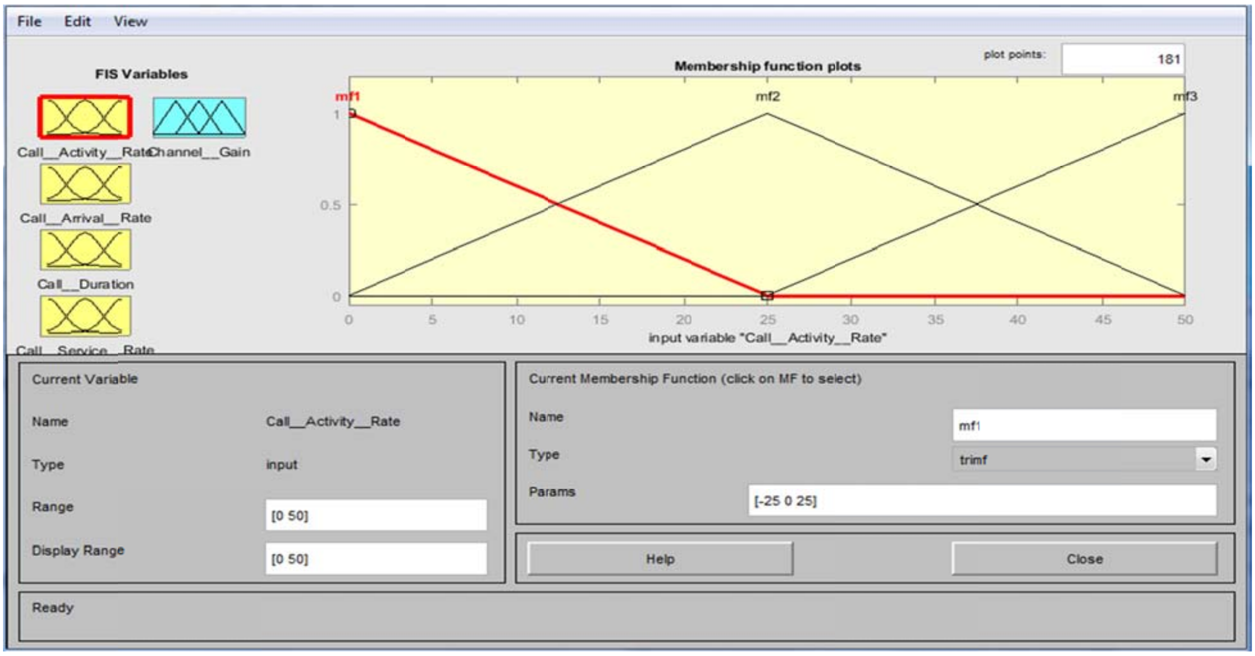

Figure 8: Membership function for the call activity rate.

The data generated for this variable was displayed for the first channel in Table 1. In the Figure 8, there are 3 membership functions with triangular model. The range of data inputted and displayed for this system is between 0 to 50. The lower part of the triangular membership function was indicated with mf1 (membership function 1) followed by mf2 (membership function two) and the highest point is mf3 (membership function three). The membership function for the call arrival rate is shown in Figure 9. The range chosen for this case was between 0 and 100. It has three membership functions named mf1, mf2 and mf3 respectively.

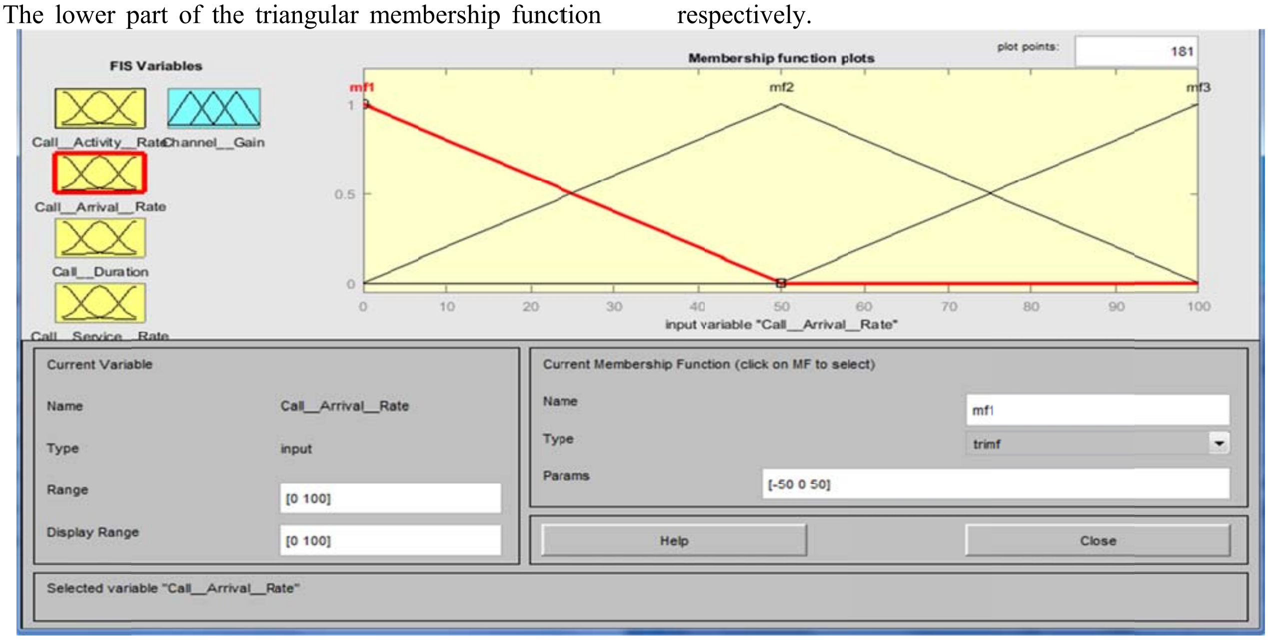

Figure 9: Call Arrival rate membership function.

The membership functions for the call duration is seen in Figure 10. The range was between 0 to 70 seconds per call. It contains three triangular membership functions namely; mf1 (the lowest), mf2 (second lowest) and mf3 (the highest). The range of the mf1 as shown in figure 3.9 was -35 to 35. The membership for the call service rate is displayed in Figure 11.

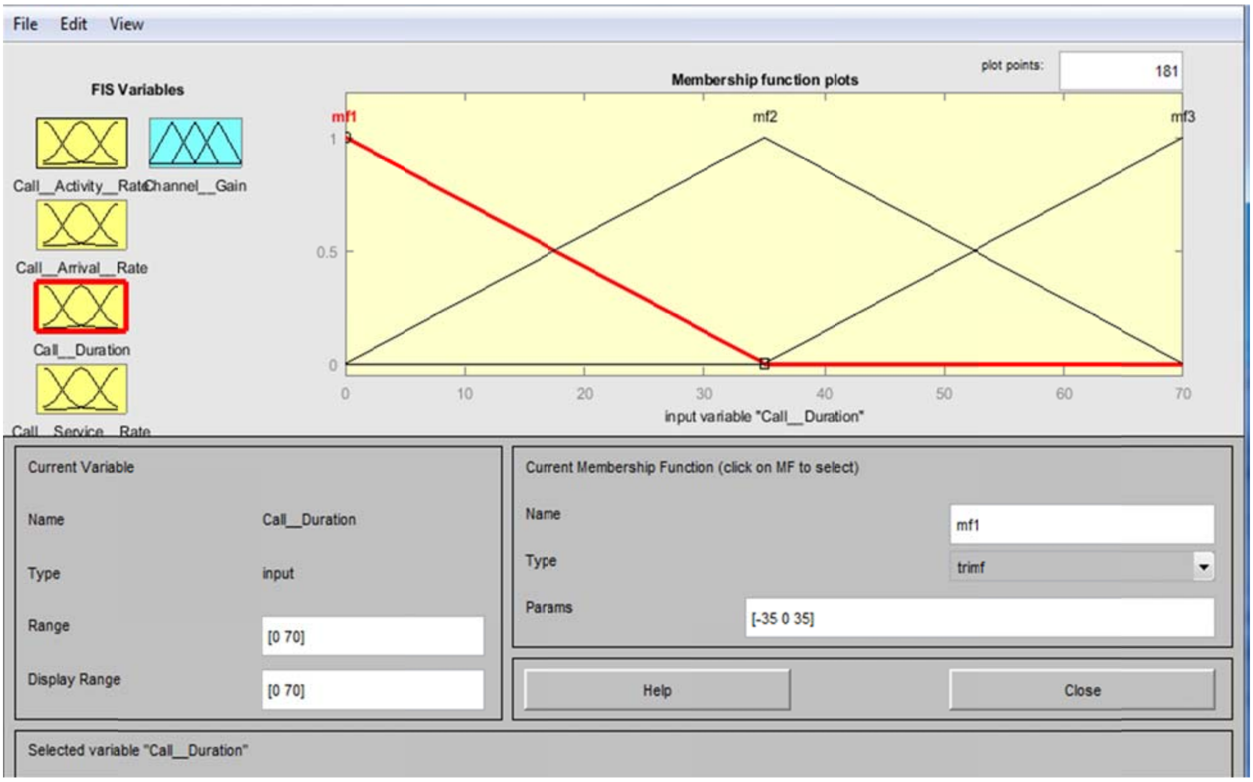

Figure 10: Membership function for the call duration.

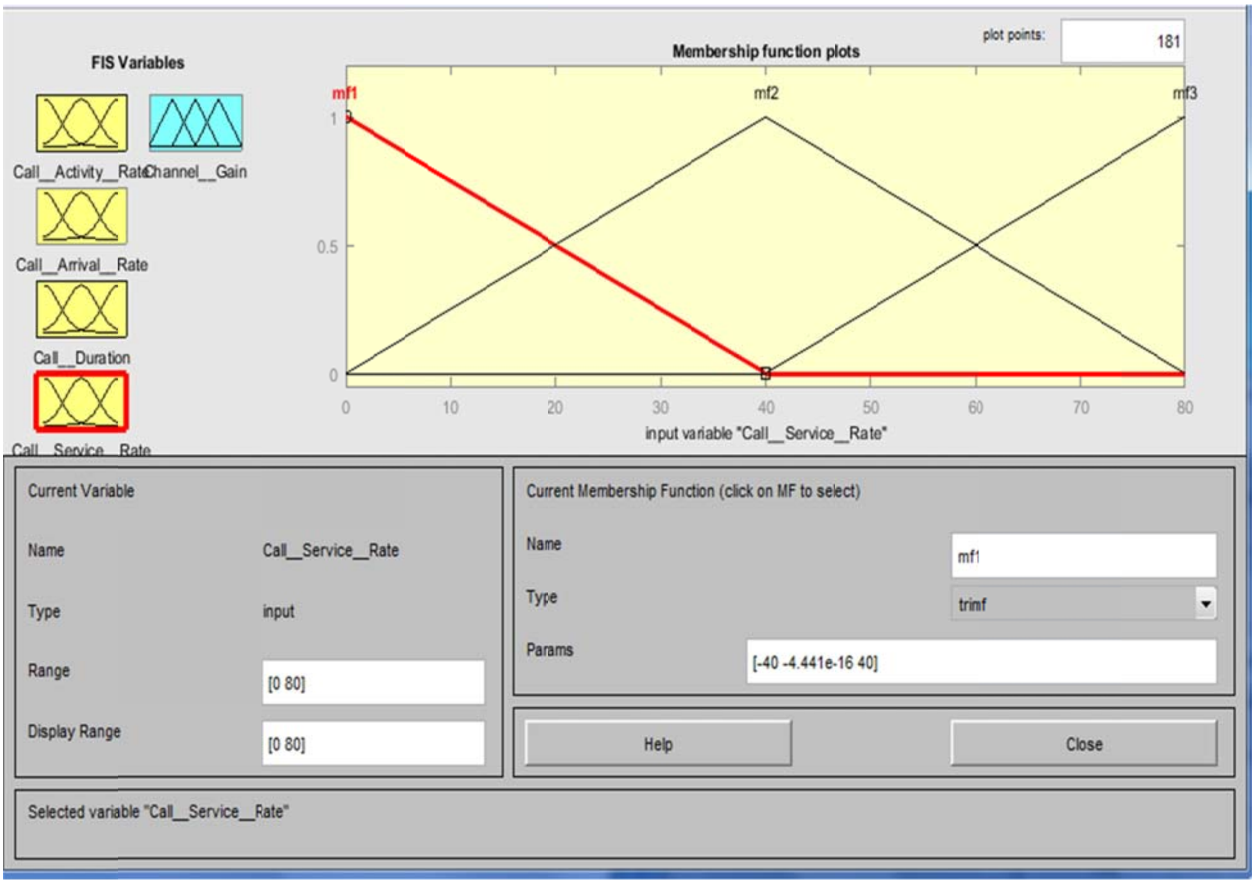

Figure 11: Membership function for call service rate.

The range 0 to 80. Like other input parameters, this utilizes three membership function namely; mf1, mf2 and mf3 with ranges of mf1 being -40 to 40 as shown in Figure 11. Figure 12 shows the system of formulating the rules in Mamdani model. All the input variables contains 3 membership function with the output having nine triangular membership function as such, eighty ones rules where generated from this model.

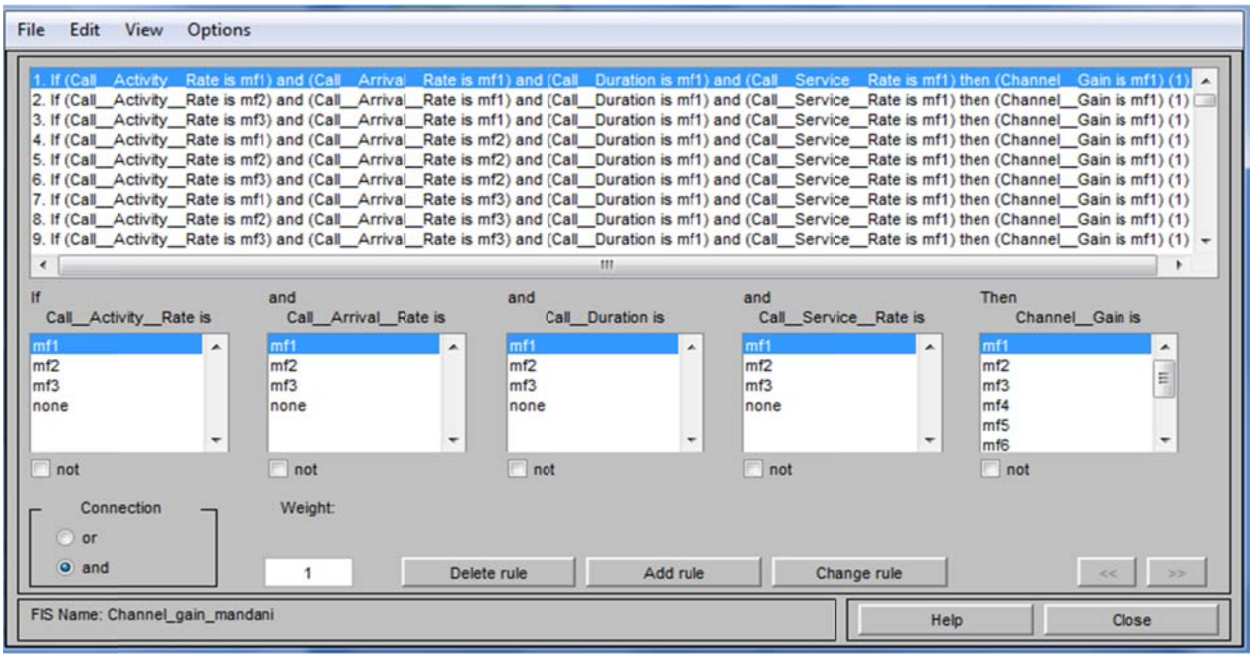

Figure 12: Mamdani rule system.

III. RESULT AND DISCUSSION

The MATLAB simulation runs were used to generate the call blocking probability and call clipping factor from call duration, call arrival rate, call service rate and call activity factor for different number of channels.

The result of the MATLAB simulations used to generate the call blocking probability and call clipping factor for ten (10) channels is shown in Table 2; for fifty (50) channels is shown in Table 3 and for hundred (100) channels is shown in Table 4.

Table 2: Simulation result for call blocking probability and call clipping factor at ten (10) channels

Number of Users	Call blocking Probability (%)	Call Clipping Factor (%)
11	0.1594	0.01993
12	0.31895	0.039868
13	0.63789	0.079736
14	1.9758	0.215947
15	2.16	0.27

Table 3: Simulation result for call blocking probability and call clipping factor at fifty (50) channels

Number of Users	Call blocking Probability (%)	Call Clipping Factor (%)
55	1.29E-05	1.62E-06
60	0.00041	5.17E-05
65	0.01324	0.00165
70	0.42363	0.05295
75	2.36	0.295

Table 4: Simulation result for call blocking probability and call clipping factor at hundred (100) channels

Number of Users	Call blocking Probability (%)	Call Clipping Factor (%)
110	9.17E-11	1.15E-11
120	9.39E-08	1.17E-08
130	9.62E-05	1.20E-05
140	0.098469	0.01231
145	0.138469	0.18231
150	3.11	0.38875

It can be seen from Table 2 that for 10 channels, about 13 users can be supported without call blocking probability being greater than 2 % and without call clipping factor (%)being greater than 0. 2 % . This is gives a statistical multiplexer gain of 13/10 = 1.3. Also, Table 3 shows that for 50 channels, about 70 users can be supported without call blocking probability being greater than 2 % and without call clipping factor (%)being greater than 0. 2 % . This is gives a statistical multiplexer gain of 70/50 = 1.4. Similarly, Table 4 shows that for 100 channels, about 145 users can be supported without call blocking probability being greater than 2 % and without call clipping factor (%)being greater than 0. 2 % . This is gives a statistical multiplexer gain of 145/5100 = 1.45. In all, it was observed that as the number of channels increases, the multiplexer gain increases from 1.3 up to 1.45 for the simulated case study dataset. As such, with idle channel borrowing mechanism , the results show that it is possible to support number of users greater than the number of available channels and the percentage of the available idle channels that can be borrowed increases as the number of available channels increases.

A. Results of the comparison of the blocking probability prediction performance of the FIS Models

Comparative plot generated with the FIS models for blocking probability prediction for 10 channels is shown in Figure 13; for 50 channels is shown in Figure 14 and for 100 channels is shown in Figure 15. From the graphs, the inference rules with Sugeno inference system had a better prediction because it tracks the actual call blocking data and call clipping factor better than that of the Mamdani inference system.

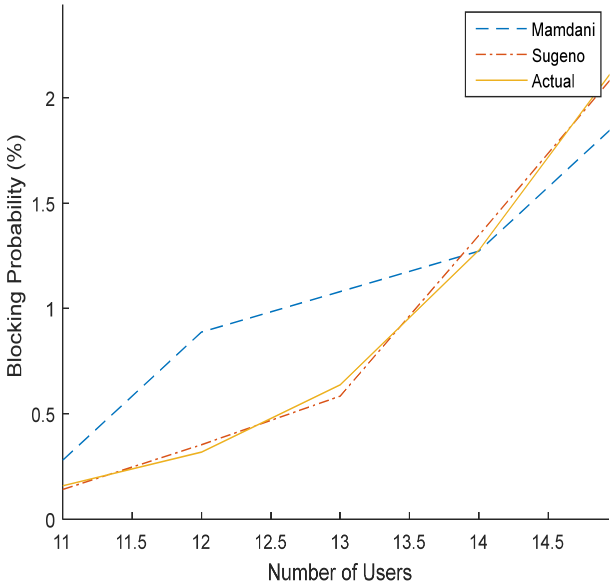

Figure 13: Comparative plot of the FIS models for blocking probability prediction for 10 channels.

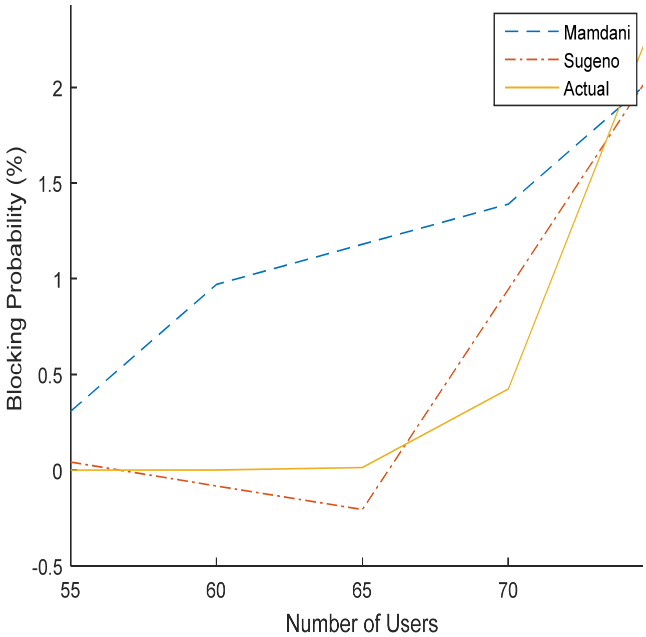

Figure 14: Comparative plot of the FIS models for blocking probability prediction for 50 channels.

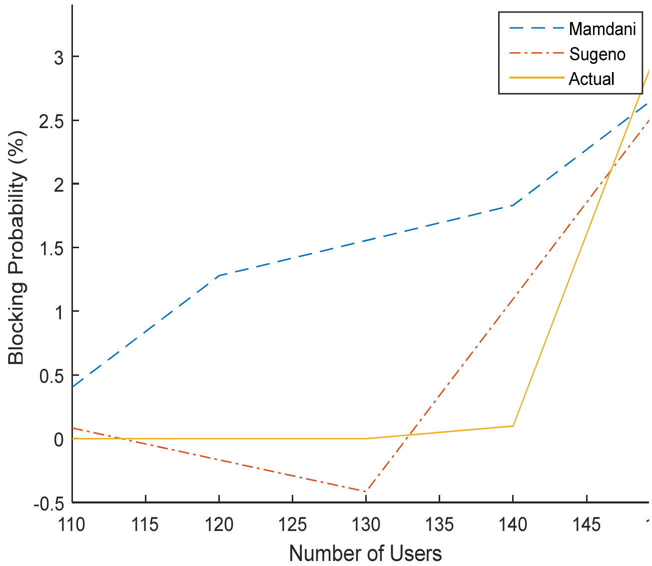

Figure 15: Comparative plot of the FIS models for blocking probability prediction for 100 channels.

B. Results of the comparison of the call clipping factor prediction performance of the FIS Models

The comparative analysis of call clipping prediction with the inference rules are shown in Figure 16 for 10 channels, Figure 17 for 50 channels and Figure 18 for 100 channels.

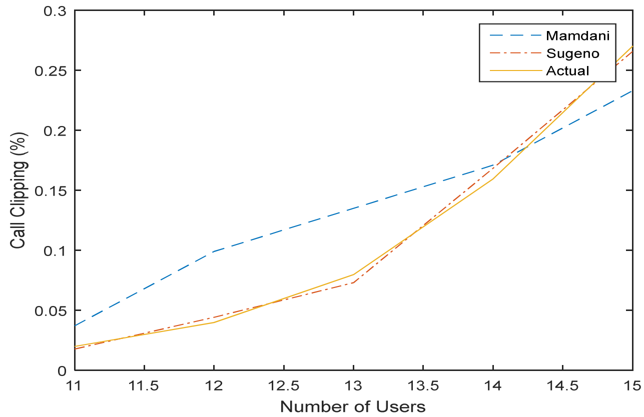

Figure 16; Comparative plot of the FIS models Call Clipping prediction for 10 channels

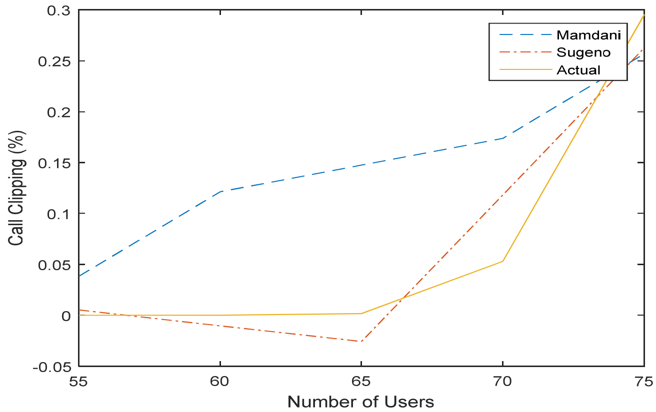

Figure 17; Comparative plot of the FIS models for Call Clipping prediction for 50 channels

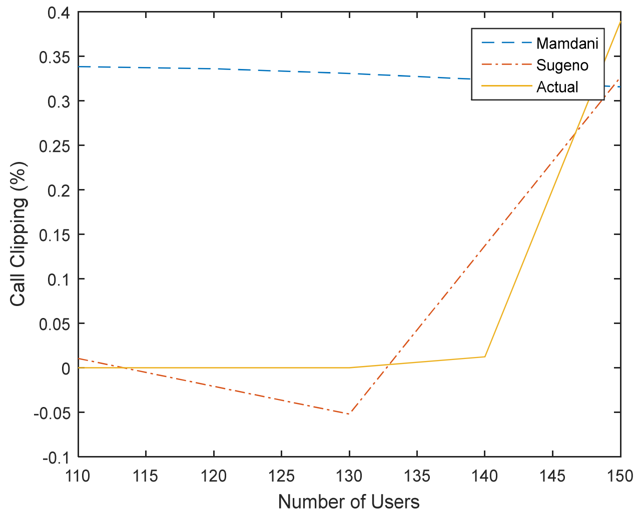

Figure 18; Comparative plot of the FIS models for Call Clipping prediction for 100 channels

IV. CONCLUSION

From the study, it has been clarified that the stochastic pattern of determining the quality of service via stochastic is the most efficient because it depicts the real life analysis of the call blocking and call clipping factor. The stochastic data for the call arrival rate, call service rate, call duration and call activity factor generated exponential at different mean values of each input parameters. Stochastic pattern was introduced in the determination of the call blocking factor and the call clipping factor. On the implementation with the Sugeno and Mamdani inference rules of the fuzzy inference system, it was seen from the results that the Sugeno inference rule had a better prediction of the call blocking probability and the call clipping factor.

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