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Fuzzy-Based Adaptive Guard Channel Allocation Scheme with Dual Buffer in Mobile Network

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ABSTRACT
Dynamic Guard Channel (DGC) allocations are not sufficient to support the enormous growth of mobile telecommunication services under the conditions of heavy traffic changes. This study addresses the limitations of existing Dynamic Guard Channel (DGC) allocation schemes, which primarily prioritize handoff calls (HC) at the expense of new calls (NC), resulting in high call blocking and inefficient resource utilization. To address this problem, a Fuzzy-Based Adaptive Guard Channel Allocation Scheme (FAGCAS) was developed to guarantee an acceptable QoS for both calls while optimizing limited network resources. FAGCAS applied a dual buffer system with maximum size of 50 to separately manage handoff and new calls, assuming Poisson call arrival rates. The method adopted integrates adaptive channel allocation and fuzzy logic modeling to reduce call dropping and blocking rates. The fuzzy logic system comprising a fuzzifier, rule base, inference engine, and defuzzifier dynamically determines the optimal number of guard channels in the base station for HC. The system was implemented and simulated using MATLAB. The system performance was evaluated using Call Dropping Probability (CDP), Call Blocking Probability (CBP), and Average Total Service Time (ATST), and results were compared with existing schemes (CGCMAHO and ASCS). The results showed that FAGCAS has a lower CDP and CBP value of 0.02 respectively as compared to CGCMAHO (0.10 & 0.52) and ASCS (0.18 & 0.03) respectively over an improved service time (2–18) seconds with higher throughput. Conclusively, the proposed FAGCAS provides an efficient congestion control solution, better resource utilization and enhancing QoS in mobile networks.

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INTRODUCTION

Tremendous development and expansion in network capacity introduce critical congestion issues thus, the expansion of the mobile network must be addressed with a congestion control scheme and an efficient algorithm (Mohammed & Majid, 2025). In modern cellular wireless networks, the rapid mobility of users presents a significant hurdle for network engineers striving to maintain high Quality of Service (QoS). This challenge is intensified by the exponential surge in consumer demand and the heavy influx of multimedia traffic over wireless channels. The primary limitation in these networks is channel availability because the native frequency spectrum is finite, the increasing demand for high-bandwidth capacity creates a severe resource scarcity. A lot of recommended algorithms have been reviewed in order to provide a constancy internet that will enable enormous subscribers of mobile networks to partake in having access to the scarce bandwidth (Ike et al. 2025). However, availability of limited frequency spectrum makes QoS a challenging task (Pankaj & Lobiyal, 2018). Due to the intrinsic scarcity of wireless channels, it is challenging to provide diverse QoS, the consequence is that; it reduces the performance of the

network (Geetanjali & Purohit, 2011; Rangaswamy & Rajabhushanam, 2019). Therefore, congestion control must be applied to utilize all available network resources without creating delays in the buffers provided (Habtegebreil et al. 2021).
Consequently, network providers must find a balance between two competing priorities that is, the Handoff Calls by ensuring ongoing calls are not dropped as users move between cells and the New Calls, while maintaining a low blocking rate for users initiating new sessions. Lawal and Ojesanmi (2017) addressed these constraints by prioritizing handoff calls and stabilizing QoS for all users. This study implements an Adaptive Guard Channel Allocation that dynamically assigning resources based on traffic intensity, a single Buffering Techniques that temporarily holding data or requests to mitigate congestion and a Fuzzy Logic Modeling.
Lawal et al. (2017) emphasizes the importance of prioritizing handoff calls while ensuring an acceptable Quality of Service (QoS) for both handoff and newly initiated calls. To achieve this objective, an adaptive channel allocation approach is utilized, incorporating buffering mechanisms alongside a fuzzy logic-based model to effectively manage the challenge. Ojesanmi et al. (2021) introduced fuzzy logic model to estimate the number of guard channel. A new adaptive channel allocation method based on guard channels was proposed, fuzzy logic model is applied to determine the thresholds as guard channels in the base station. The proposed channel allocation scheme helps to give priority to the handoff call over the new call and also reduce call dropping probability but did not compare the achievement with those of the existing work.
This work prioritized the handover calls over the new calls with the aid of fuzzy logic controller and also maintains an improved quality of service for the new calls. It also involves a comprehensive comparison with the approach of the existing work related to the adaptive shared channel assignment scheme with the queuing of hand off calls and the new calls combined together in the process of channel allocation. The combination of these schemes helps to reduce the probabilities of the call dropping and the call blocking probability and these are the major performance parameters that are used in controlling the congestion in mobile network.

MATERIALS AND METHODS

Arun Kumar (2015) in his paper considered two types of channel assignment; firstly, the guard channel model and secondly non- guard channel model. The compared result of both models in terms of dropping and blocking probability indicates that the blocking probability of prioritized model is higher than the non-prioritized model. Also, the dropping probability increases as the new call arrival rates increases.
Nayak et al. (2015) considered an adaptive channel assignment scheme, using guard channels. The number of channels allocated as guard channels is estimated by Markovian model. This approach is able to provide quality of service guarantee in terms of handoff dropping rate. Introduction of queuing system would have produced better result on both the dropping and the blocking probability.
Nwokorie et al. (2023) developed a smart Call Admission scheme that integrate Handoff buffer with Fuzzy Logic controller. The congestion control scheme produced an optimized result with low call dropping probability while the work did not consider introduction of buffer mechanism for new call in their study approach.
Lawal et al. (2017) proposed an improved handover algorithm on existing works by (Arun, 2015) and (Nayak et al. 2015) by incorporating a Fuzzy Logic Controller System. The Adaptive Guard Channel Allocation and queue system in this work will follow a similar problem formulation by (Arun, 2015), (Nayak et al. 2015) and (Osahenvemwen & Odiase, 2016).
This system model involves the design of a Fuzzy-Based Adaptive Guard Channel Allocation Scheme (FAGCAS) with Dual Buffer in Mobile Network. The model considered two types of calls, the handoff calls and the new calls, that are recognized by the base state or mobile switching center at different instances of various parameters of the network, such as call arrival rates, handoff buffer size and new call buffer size. FAGCAS is a handoff management algorithm that integrates an adaptive guard channel assignment scheme with the queuing of hand off calls and the new calls in order to reduce the dropping rate and the blocking rate respectively. The work is implemented in two parts:
Firstly, the work applied an adaptive guard channel assignment and shared channel allocation method that is an improvement on the reviewed works on the channel allocation by jointly considering the dynamic guard and the shared channel assignment rather than using only the static guard channel allocation technique as depicted in FAGCAS Structure in Figure 1. Also, the model introduced an enhanced handoff management that is an improvement over the existing work by using fuzzy logic model to effectively estimate the threshold, which indicates the number of channels that would be allocated for handoff calls. The results are benchmarked with the work done by (Nayak et al. 2015) and (Arun, 2015).
Secondly, the work developed an enhanced handoff algorithm that is an improvement on existing work especially those by (Arun, 2015) and (Nayak et al. 2015) and similarly, the flowchart of the proposed system, FAGCAS showing the detailed analysis of the algorithm was shown in Figure 2. The improvements on the current work are centered on the introduction of fuzzy logic system, two-buffer systems and applied equations i-vi as adapted from Lawal et al. (2017). The improvements on

the existing work are the focus on our algorithm with the consideration of the handoff calls by not reserving channels for handoff calls when they are not available at the expense of new call blocking. This also provides the solution to the existing problem that there is a finite probability that for an ongoing call, while being handed off, it may still get dropped. That is, this scheme minimizes both the dropping of ongoing call during the handoff and the blocking of newly originating calls, which is an important issue for the mobile communication.

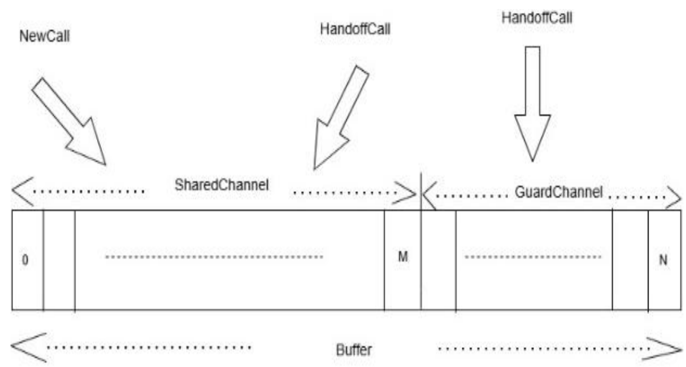

Figure 1: FAGCAS Structure

FAGCAS Handoff Management Algorithm

The algorithm shown in Algorithms 1 presented the Integrated Adaptive Channel Management and Call Admission Scheme as adapted from the previous work of Lawal et al. (2017). The algorithms considered the parameters such as number of handoff call and new call, their buffer length, number of guard channel, shared channel, and the threshold measure of fuzzy system as indicated in the integrated algorithm 1.

The work applied (FLCS) to prioritize channels on the basis of traffic intensity due to its ability to model uncertain or ambiguous data. The fuzzy logic system comprises of the following components for approximate reasoning:

i. Fuzzifier: maps the crisp/numeric input signals of the available total channels, handoff buffer length and new call buffer length, into fuzzy data/ membership functions by using the fuzzy rules defined in the rule base interface. Then, the inputs are mapped corresponding to fuzzy rules.
ii. Rule Base**:** is the stage that consists of set of fuzzy–if-then rule which define the control actions. That is, the fuzzy rule base contains a set of linguistic rules (conditions and output). These linguistic rules are expressed using linguistic values and linguistic variables. Different linguistic values can be assigned to a linguistic variable. These linguistic values are modeled as fuzzy sets.

Lawal et al. (2017) proposed a rule base table as indicated in table 1 showing a rule construction procedure with 27 rules, including a combination of high (H), medium (M), and low (L).

Table 1: Fuzzy Rule-base Table (Lawal et al. (2017)

Serial Number	Total Channel	Handoff buffer length	New call buffer length	Threshold\Guard channel
1	H_C	H_{ho}	H_{nc}	H
2	H_C	H_{ho}	M_{nc}	H
3	H_C	H_{ho}	L_{nc}	H
4	H_C	M_{ho}	H_{nc}	M
5	H_C	M_{ho}	M_{nc}	M
6	H_C	M_{ho}	L_{nc}	M
7	H_C	L_{ho}	H_{nc}	L
8	H_C	L_{ho}	M_{nc}	L
9	H_C	L_{ho}	L_{nc}	L
10	M_C	H_{ho}	H_{nc}	M
11	M_C	H_{ho}	M_{nc}	M
12	M_C	H_{ho}	L_{nc}	M
13	M_C	M_{ho}	H_{nc}	M
14	M_C	M_{ho}	M_{nc}	M
15	M_C	M_{ho}	L_{nc}	M

Serial Number	Total Channel	Handoff buffer length	New call buffer length	Threshold\Guard channel
16	M_C	L_{ho}	H_{nc}	L
17	M_C	L_{ho}	M_{nc}	L
18	M_C	L_{ho}	L_{nc}	L
19	L_C	H_{ho}	H_{nc}	L
20	L_C	H_{ho}	M_{nc}	L
21	L_C	H_{ho}	L_{nc}	L
22	L_C	M_{ho}	H_{nc}	L
23	L_C	M_{ho}	M_{nc}	L
24	L_C	M_{ho}	L_{nc}	L
25	L_C	L_{ho}	H_{nc}	L
26	L_C	L_{ho}	M_{nc}	L
27	L_C	L_{ho}	L_{nc}	L

iii. Fuzzy Inference Engine: The fuzzy inference engine combines membership functions with control rules, which is related to human knowledge) to set the threshold as the fuzzy output. The associated control outputs are arranged in the look up table (table 1 as proposed in Lawal et al. (2017)).

iv. Defuzzifier: defuzzifier is the stage that converts fuzzy set output to a crisp value/output that the fuzzy logic controller uses to determine the number of guard channel in the base station.

In order to obtain an enhanced QoS for handoff and originating calls by reorganizing guard channels with variations in traffic density, three parameters, total channels, buffer length for the handoff calls and buffer length for the new calls serve as input into the fuzzy system. These parameters are fed into fuzzifier, which transforms the real time measurements into fuzzy sets. The output variable is the number of guard channels. Fuzzy sets contain elements that have a varying degree of membership in a set which are low, medium and high. This indicates that an element in a fuzzy set can have a membership in more than one set. The membership values are obtained by mapping the values for a particular parameter onto a membership function.

The fuzzy inference process combines the membership functions with the control rules that generates the specific number of outputs referred to as threshold in form of the guard channels after defuzzification. Fuzzy inference system applying fuzzy-IF-THEN rules was indicated in algorithm 1

Algorithm 1: Combined Adaptive Channel Management and Call Admission Scheme

Begin

```
Initialize Network Parameters
For each NC
If SharedChannel Is available then
  assignchannel
  Update SharedChannel State
        else if
          NCBuffer is free then
          Store In NCbuffer
      else
        blockNC
        endIf
else If Call=HC, then
        If SharedChannel Is available, then
          assign SharedChannel
          update SharedChannel State
else If GuardChannel Is Available then
          assign GuardChannel
          update GuardChannel State
else If HOBuffer Is free then
        store In HOBuffer
          else
                          drop call
          endIf
          endIf
  End
```

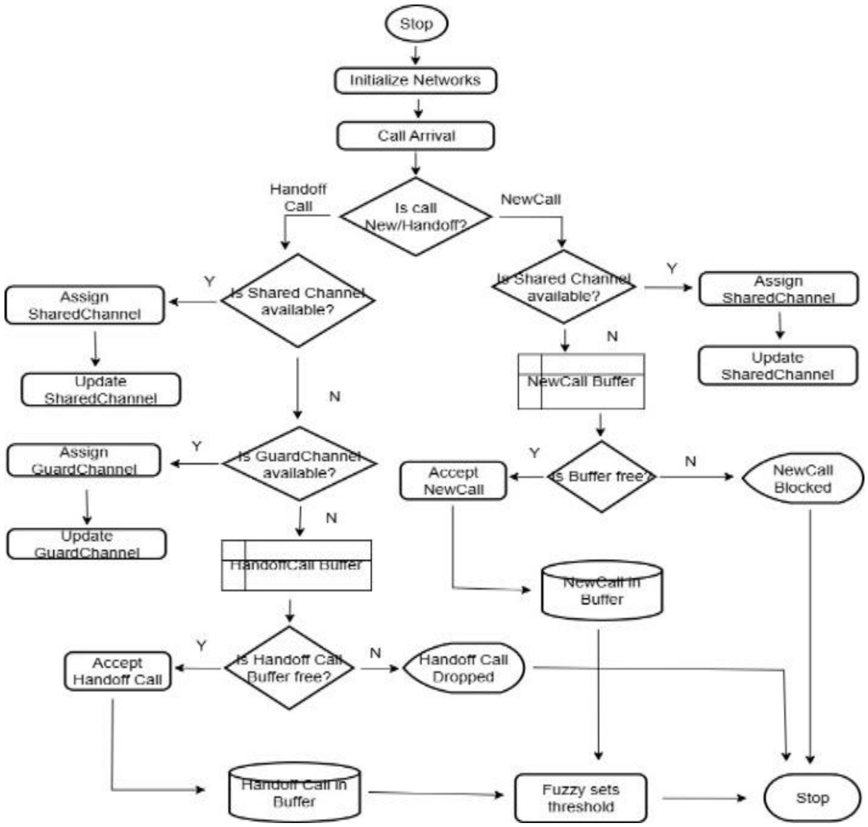

Figure 2: FAGCAS Flowchart

Performance Metrics

The performance of the research work is evaluated with the following metrics: Size of the buffer (L), time of Channel Allocation (W), number of customers in buffer (W_q), Number of customers in service (W_s), Number of customers in the system (W), Time a customer spends in system (Ts), Total number of calls blocked (T_N calls blocked), Total number of new calls (T_N NC initiated), Total number of calls dropped (T_N calls dropped), Total number of handoff calls (T_N HC), Call dropping probability (CDP), Call blocking probability (CBP), Percentage call blocked (P_{CB}), Percentage call dropped (P_{CD}),

The parameters stated above were used under the assumption that all the channels in the base station have passed the constraint test. Also, a minimal delay is encountered in order not to make the Quality of Service (QoS) to degrade below an acceptable level.

The parameter used for the derivative of system model is expressed in equation (1-8):

$$L_l = \frac{\lambda_h}{\mu - \lambda_h} \quad (1)$$

$$L_s = \frac{\lambda_n}{\mu} \quad (2)$$

$$L_q = \frac{\lambda_h}{\mu\,(\mu - \lambda_h)} \quad (3)$$

$$T_w = \frac{1}{\mu - \lambda_h} \quad (4)$$

$$W_s = \frac{1}{\mu} \quad (5)$$

$$W_q = \frac{\lambda_h}{\mu(\mu - \lambda_h)} \quad (6)$$

$$CBP = \frac{T_N\, calls\ blocked}{T_N\, NC\ initiated} \quad (7)$$

$$CDP = \frac{T_N\, calls\ dropped}{T_N\, HC} \quad (8)$$

Simulation Parameters

Maximum number of handoff call generation is 850, maximum number of new call generation is less than 2000 and for the service rate, the system processed between 920 and 2492 calls within a total service time window of 2 to 18 seconds. Therefore, the service rate μ of the system is 2492 calls divided by18 seconds which is pproximately138.4calls/second. The number of simulation runs is maximum of 30 at different instances of traffic intensity for FAGCAS, CGCMAHO and ASCS.

RESULTS AND DISCUSSION

The mobile applications were developed in MATLAB; Fuzzy Logic System (FLS) was implemented with the integration of the handoff codes generated from the Fuzzy tool box in MATLAB. The Fuzzy Logic Toolbox use the generated code from the inbuilt framework of the simulator in MATLAB for the Adaptive Congestion

Control System, defining all other network parameters stated in algorithm 1 and the constraints experienced in real case scenarios such as all the channels used in the base stations have passed the constraint test and the dual buffer that is employed have a tolerable delay. The impact of various network parameters were considered within Mobile Network of Cell and Base Stations

This section gives a description of the system developed in this work (i.e. FAGCAS) and result obtained from various simulations carried out. The simulations were created both in MATLAB environment. The discussions of the results are focused on the result obtained by analyzing FAGCAS in relation to the value of the call dropping probability (CDP) and call blocking probability (CBP). Also, by comparing the FAGCAS algorithm with the two existing works known as combined guard channel and mobile assisted handoff (CGCMAHO) and Adaptive Shared Channel Assignment Scheme (ASCS).

Result of Comparison of Existing System with FAGCAS

CDP of Existing Scheme and FAGCAS

Figure 3 compares the CDP of FAGCAS with the various existing schemes. The CDP of the FAGCAS was between 0.02 and 0.13 even at higher value of call arrival rate. The CDP of Queueing analysis of combined guard channel and mobile assisted handoff on prioritized channel assignment for cellular network (CGCMAHO) and Adaptive Shared Channel Assignment Scheme (ASCS) read up to 0.70 and 0.89 respectively. FAGCAS has therefore proved to be more efficient with a far lower CDP than the other two existing schemes.

CBP of Existing Schemes and FAGCAS

Figure 4 compares the CBP of FAGCAS with the various existing schemes. The CBP of ASCS was as low as 0.03, CGCMAHO lowest value was 0.52, while for the FAGCAS, the lowest CBP value was 0.02. The CBP of FAGCAS did not exceed 0.23 but that of CGCMAHO and ASCS 0.99 and 0.28 respectively at the same traffic intensity. The result shows that, FAGCAS clearly outperforms other schemes at the same call traffic intensity within few seconds that is between 4secs to 18 secs than the other existing scheme that takes up to a minute.

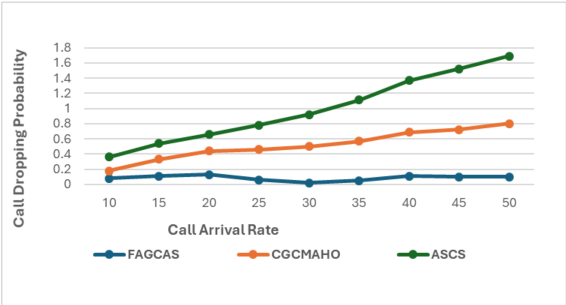

Figure 3: CDP of Existing Schemes and FAGCAS

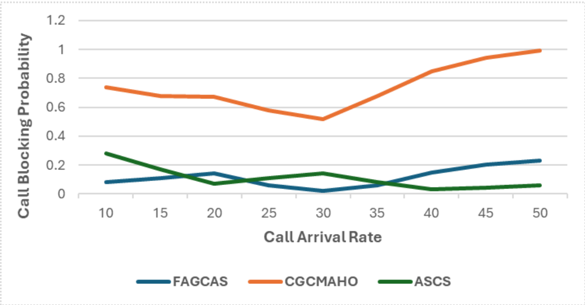

Figure 4: CBP of Existing Schemes and FAGCAS

The FAGCAS therefore help to control the congestion problem by ensuring adequate QoS for both the handoff and the new calls.

Result of Comparison of FAGCAS with Single Buffer and Dual Buffer

Figure 5 shows the graph of the total number of handoff calls serviced versus total service time using single buffer system for handoff calls only. Total calls between 934 and 1607 calls were serviced between the time intervals of 3-13 secs, this implies that the delay introduced in terms of the total service time through the use of handoff buffer in checking reduction in the number of handoff calls as a result of non-availability of channels during the period of handoff process is tolerable.

Figure 6 shows the graph of total calls serviced against total service time with the introduction of single buffer system for new calls only. Total calls between the range of 1188 and 1675 was serviced with an interval of 4-12 secs, which imply that that the delay introduced through the use of buffer is tolerable in terms of total service time with higher throughput. As this would assist to have reduction in the number of new calls that might have been blocked due to non-availability of channels during the period of initiating fresh calls in order to establish communication. This is an improvement over the previous work of ASCS that serviced 1/6 call/s and 0.08-0.25 for new calls and handoff respectively.

Figure 7 illustrate the graph of the total service time versus total calls serviced, using dual buffer for both the handoff calls and the new calls. The least number of total calls serviced is 920 while the highest number of calls serviced is 2492, the total service time was between 2 to 18 secs.

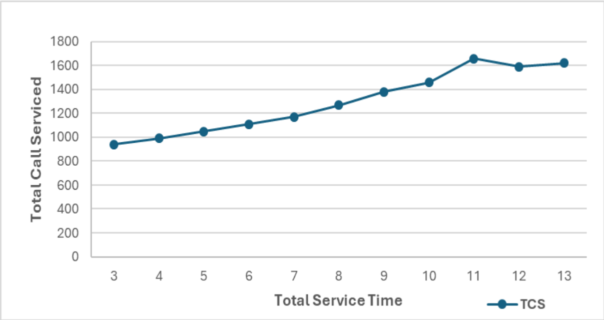

Figure 5: Graph of the Total Number of Calls Serviced Versus Total Service Time (with Handoff Calls Buffer Only)

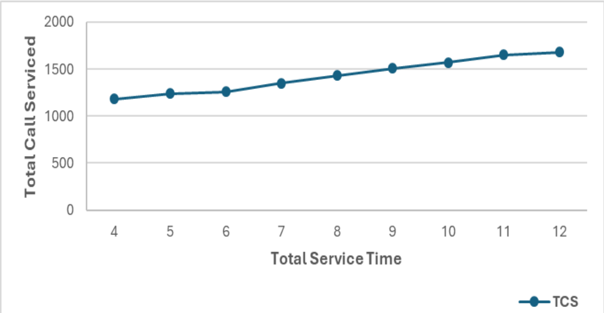

Figure 6: The graph of Total Calls serviced against Total Service Time (with New Call Buffer only)

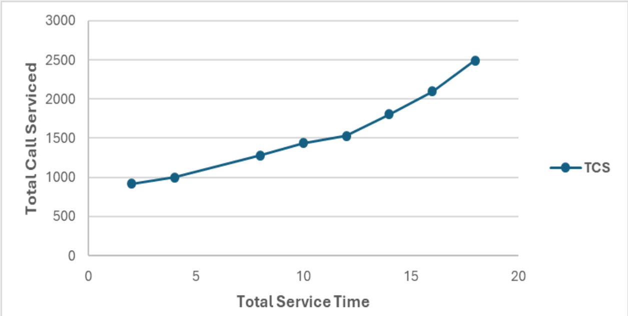

Figure 7: The graph of Total Calls Serviced versus Total Service Time, (with Dual Buffer)

Comparison of the result was indicated in Figure 7, which made use of dual buffer for both handoff calls and new calls while Figure 5 and 6 showed single buffer for handoff calls and new calls respectively. The minimum number of total calls serviced in Figure 5 was 934 calls at 3 seconds, and Figure 6 is 1188 at 4 seconds, while the maximum number of calls serviced are 1670 at 12 seconds and 1675 at 12 seconds respectively. Although 1188 minimum total number of calls were serviced at 4 seconds while introducing new call buffer only, this is slightly greater than 920 total minimum number of calls at 3 seconds in the case of the dual buffer. In the three cases, the maximum number of total calls serviced of 2492 at 18 seconds was achieved with the dual buffer system only.

The result shows that introducing dual buffer with the application of fuzzy logic system will not lead to the delay that cannot be tolerated in terms of the total service time only but it will also service more calls which would eventually produce better result compare to the work of both CGCMAHO with the call arrival rate of 5 to 40 calls/minute for both handoff and new calls and ASCS that serviced 1/6 call/s and 0.08-0.25 for new calls and handoff respectively. Unlike the ASCS that serviced the total calls within 4-15 calls/minute (each for handoff and new calls) with the application of Markovian model. This implies that the fuzzy logic system changes the threshold value continuously within a very short interval of seconds based on the call traffic intensity to attend to larger number of calls from subscribers.

Figure 8 shows the case of various numbers of arrivals of total new calls within the range of 1630 to 1920 and various value of call blocking probability from 0.28 to 0.71 that is of higher value compared to ASCS with the CBP within the range of 0.03 to 0.28. FAGCAS achieved guard channel allocation method that is not at the expense of new calls with the application of fuzzy logic system that processed far above 1500 new calls within few seconds compared to CGCMAHO with the call arrival rate of 5 to 40 calls/minute for both handoff and new calls) that has lower throughput. The result still guarantees an improvement over that of ASCS.

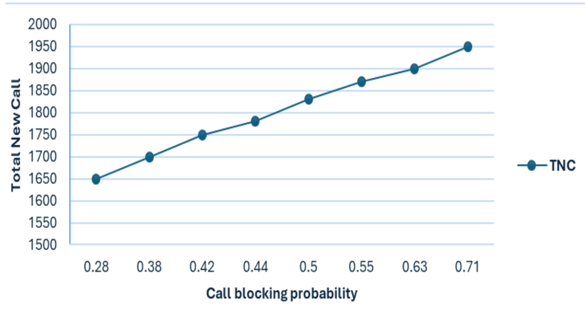

Figure 8: Graph of Total New Calls Versus CBP

Figure 9 represent the graph total handoff calls against CDP, with CDP within the range of 0.02 to 0.13 for the total handoff calls of 698 to 850, this enhanced more throughput with high call processing capacity within less than one minute. The CDP of FAGCAS was greatly reduced with higher throughput compared to the work of CGCMAHO (with the call arrival rate of 5 to 40 calls/minute for both handoff and new calls) that had CDP of 0.10 to 0.70 FAGCAS prioritized the handoff calls over the new calls and made use of fuzzy logic system to derive dynamic guard channel thereby improving the probability of a successful handoff calls because they are reserved exclusively for handoff calls. The fuzzy logic result of higher throughput was an improvement over the Markovian model used by ASCS.

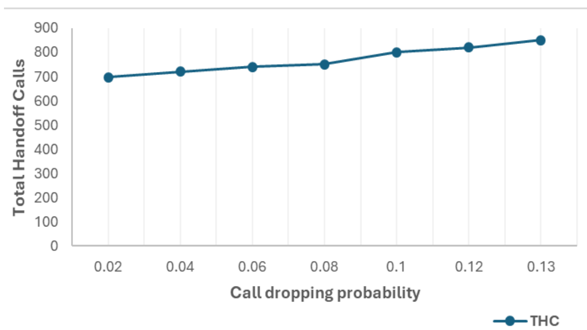

Figure 9: Graph of total handoff calls against CDP

CONCLUSION

MATLAB was used to develop simulation environment used in benchmarking with the existing works. The study considered all the parameters used under the assumption that all the channels have passed the constraint test and that the buffer employed would have a tolerable delay. The work has been successful in achieving these goals.

Based on the implementation of the study approach, handover calls were prioritized over the new calls and the work also maintain an improved quality of service for the new calls. The adaptive shared channel assignment scheme with the queuing of hand off calls and the new calls are combined together in the process of channel allocation. The performance results that were derived from this study indicate that the combination of these schemes helps to reduce the probabilities of the call dropping and the call blocking probability. That is for CDP, FAGCAS achieves a lower and higher value of 0.02 & 0.13 respectively, compared to CGCMAHO with 0.10 & 0.70 respectively and ASCS with 0.18 & 0.89 respectively. This indicates that prioritizing handoff calls using dynamic fuzzy guard channels drastically lowers call termination rates. Although, in case of CBP**,** FAGCAS new call blocking probability value is as high as 0.23 but as low as 0.02. This represents a lower blocking probability compared to the low and high value of CGCMAHO with 0.52 & 0.99 respectively and ASCS with 0.03 & 0.28 respectively. Furthermore, System service time occur within 4 to 18 seconds for FAGCAS, with higher throughput than the existing models.

Thus, the proposed FAGCAS enhance QoS and it also provides an efficient congestion control solution in mobile networks compared to the existing models.

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