Development Of A Guard Channel-Based Prioritized Handoff Scheme With Channel Borrowing Mechanism For Cellular Networks

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Abstract— In this paper, development of a guard channel-based prioritized handoff scheme with channel borrowing mechanism for cellular networks is presented. This study was motivated by the urgent need to minimize dropped calls and handoff failure that are prevalent in cellular networks. It focused on the static guard channel-based prioritized handoff with idle channel borrowing mainly due to the fact that handoff failure and dropped calls is a major issue in cellular communication network which GSM users encounter mostly in the developing countries. The impact of handoff failures results in forced call drops which causes poor quality of service rating by network users and subscribers. The idle channel borrowing scheme used in this research is based on statistical multiplexing of voice calls for a given number of channels such that the total number of voice calls supported are greater or equal to the available channel capacity. The idle channel borrowing mechanism is meant to minimizing handoff failure in mobile networks. By using empirical dataset and analytical method, the impacts of various network parameters on the handoff failure and new call blocking probabilities were demonstrated. Basically, in this research, an existing static guard channel handoff scheme called scheme I was improved upon with the introduction of channel borrowing mechanism and it was shown that with the introduction of channel borrowing mechanism along with the priority mechanism, the new called scheme II reduced both handoff dropping probability and new call blocking probability by more than 99.9 %. However, with the priority mechanism alone the scheme I reduced only the handoff dropping probability by about 90 % but it increased the new call blocking probability by over 609 %. Hence, scheme II with idle channel borrowing mechanism along with the priority mechanism is more suitable for the modern cellular networks with teaming population of mobile users with the attendant high handoff traffic rate.

Keywords— Handoff, Prioritized Handoff Scheme, Channel Borrowing, Dropped Calls, Handoff Failure, Statistical Multiplexer, Statistical Multiplexer Gain. Talk Activity Factor.

I. INTRODUCTION

Today, cellular wireless network continues to dominate the industry across the globe [1,2]. In 1947 researchers realized that frequency reuse in small cells with could substantially increase traffic carrying capacity of wireless networks and that gave rise to the basic cellular network which was actually implemented in 1960s and early 1970s [3].

Basically, a cellular network each cell has one or more base stations each with number of radio channels assigned based on the available spectrum and the transmission power constraints. Specifically, channel can be a frequency, a time slot or a code sequence. Any terminal residing in a cell can communicate through a radio link with the BS located in the cell, which communicates with the Mobile Switching Centre (MSC. A user that initiates or receives a call may move around the region that is covered by the network. If the mobile user moves from one cell to another, and the call from/to the user has not finished, the network has to handoff/handover the call from one cell to another at the cell boundary crossing without user's awareness of handoff and without much degradation of the service quality [3]. Handoff or Handover as it is interchangeably used is a process describing the transfer of an on-going call from one cell to another cell as calling subscriber(s) or called subscriber(s) move through the coverage area of the network

Handoff scheme is a very vital mechanism for QoS provisioning in a wireless communication network. Based on resource availability, handoff scheme controls access to the network so as to prevent congestion in the network and degradation of service for already supported users. An originating call request is only accepted if there exist enough free resources to meet the QoS requirements of the arriving calls without violating the QoS for active calls [4]. Handoff mechanisms makes it possible for cellular networks to provide such a facility by allowing active call to be transferred from one cell to another. Different methods have been proposed and adopted in order to enhance handoff service. The principal parameters used to evaluate handoff techniques are usually handoff failure (or call dropping) probability and call blocking probability. Mechanisms such as guard channels and queuing handoff calls decrease the or call dropping while increasing the call blocking probability [5].

Meanwhile, studies have shown that in the process of a telephone conversation between any two subscribers, each communication direction via the telephone channel is used actually for an average of 50 % of the conversation time. Besides, pauses that usually occur between words and phrases introduce additional reduction in the active state the channel. These all lead to a total active state duration of tone-frequency channel of approximately 35– 40% [6,7]. In order to increase the efficiency of channel capacity utilization, the idle durations of one dialogue can be used for the transmission of active state dialogues of other subscribers [6,7]. This is achievable by means of statistical multiplexing mechanism [6,7,8]. Such systems can theoretically increase the efficiency of channel capacity usage by between 20–30% [6,7]. Consequently, in this research, idle channel borrowing based on statistical multiplexing mechanism is proposed. Particularly, a static guard channel based prioritized handoff with idle channel borrowing scheme will be developed for managing the available network channels such that both new call blocking probability and handoff call dropping probability can be simultaneously reduced.

II. REVIEW OF RELATED WORKS

Available studies by [6,7] showed that in the process of a telephone conversation between any two subscribers, each communication direction via the telephone channel is used actually for an average of 50 % of the conversation time. Moreover, pauses between words and phrases also reduces the active state duration of the channel. These all lead to a total active state duration of tone-frequency channel of approximately 35– 40% [6,7]. In order to increase the efficiency of channel capacity utilisation, the idle durations of one dialogue can be used for the transmission of active state dialogues of other subscribers [6,7,9,10]. This is achievable by means of statistical multiplexing mechanism. Such systems can theoretically increase the efficiency of channel capacity usage by between 20–30% [6,7].

Zhuang and Zhuang, [11] developed the Neighbor Cell Channel Sharing (NCCS) scheme for wireless cellular networks. Both co-channel interference and adjacent interference issues regarding the channel sharing were discussed. The NCCS scheme was shown to have lower call blocking probability when compared with the other channel allocation mechanism. However the NCCS has higher intra-cell handoffs.

Alagu and Meyyappan [12] presented a new dynamic channel allocation scheme (DCAS) for cellular networks. The aim of the scheme was to effectively utilize the available resources. In this work, a significant contribution was made in the area of call admission control with the hope of improving the Call Admission Control performance.

Shah and Khatrandi [13] studied the advantages of statistical time division multiplexer (STDM) over random packet loss scenarios in voice communication networks. According to their reviewed works, in dialogue speech the activity (actual talk moments) of user occupies 40%, while the silence (no talk moments) occupies 60% of the total time [13]. Conversely, monologue call are active about 80% of the time and silent about 20% of the time . These silence gaps can be detected using voice activity detector (VAD) on each input speech source of statistical time division multiplexer [13]. Notably, channel utilisation or bandwidth efficiency is typically increased for speech by employing techniques such as time assignment speech interpolation (TASI) for analog, and digital speech interpolation (DSI) for digital domain. The main principle of TASI and DSI is utilization of the inactivity (idle or silent) periods of each active user [13].

According to Shah and Khatrandi [13] when the number of users supported through the more statistical multiplexer is more than the available channels there is bound to be frame loss when the number of active users in active state are more than the available channel. However, with properly selected statistical multiplexer parameters and proper understanding of the talk activity factor and number of available channels, it is possible to support more users than the available channels can accommodate without experiencing significant speech frame losses [13]. Particularly, in their empirical work, STDM was employed in 9 users channels to effectively support 12 users with 3% speech frame losses, which results in effective statistical multiplexer gain of 12/9 = 1.33. According to their findings, the statistical multiplexing gain factor depends on activity factor and the number channels available for sharing [13].

Endres *et al.*, [14] studied the impact of statistical multiplexing on QoS. In their study, they carried, a user can be either in talk spurt (active) state or in a silent (idle) state. The talk spurt and silence lengths are assumed to be exponentially distributed. In order to find out the best tradeoff between gaining capacity through statistical multiplexing and degradation of speech quality they simulated objective QoS parameters such as delay and packet dropping along with, subjective assessment of the speech quality in terms of mean opinion score (MOS). Enderes *et al.*, [14] simulated different statistical scenarios in order to assess the effect of front end clipping on voice quality. They implemented a simulation in a real time demonstration platform utilized to acquire subjective indicators of voice quality by performing a MOS Test. For the test, 6 females and 7 males were selected. The MOS for each scenario is averaged over 24 grades. From their results, there is slight increase in MOS for statistical multiplexing gain from 1.0 to 1.2. Beyond statistical multiplexing gain of 1.2 the MOS drops with the increase in the statistical multiplexing gain. However, the differences in subjective conversation quality between the line-switched case and the statistical multiplexing gain of 1.2 and 1.5 are not significant. Essentially, with the given statistical multiplexer, 120 % of the full load users can be supported without any noticeable degradation in voice quality.

In their conclusion, they stated that a certain amount of front-end clipping does not affect the perceived speech quality. As such, if a MOS value of 3.5 is considered as the acceptable level for communication quality, according to their experimental study a statistical multiplexing gain of 1.54 would be possible. Essentially, through statistical multiplexing the capacity of the network could be increased by 54%.

In the thesis by Zabanoot [15] different analytical models of various handoff schemes and resource re-allocation in homogeneous and heterogeneous wireless cellular networks were developed and investigated. Particularly, an analytical model was developed and analyzed for priority handoff mechanisms, where new calls and handoff calls are captured by two different traffic arrival processes, respectively. Using the analytical model, the optimized number of channels assigned to handover calls, with the aim of minimising the drop probability under given network scenarios, was investigated. Notably, Zabanoot [15] developed a static guard channel prioritized handoff mechanism in a single cell as a means of reducing the dropping probability of a handover call by reserving a fixed number (say g) of channels (referred to as guard channel) exclusively for the handover calls. As a result, separate formulas for the dropping probability of handover calls, and the blocking probability of new calls, are derived. Furthermore, as the number of guard channels increases, the dropping probability will be reduced whilst the blocking probability will increase. Thus, an optimal number of channels was derived subject to given constraints on the dropping and blocking probabilities. The number of channels was optimized with aim to minimize the handoff dropping probability and at the same time keep the new calls blocking probability at its minimum.

Alagu and Meyyappan [12] describe the use of novel and efficient data structure which dynamically allocates guard channel for handoffs and introduces the concept of channel borrowing strategy. Their basic idea in their work is to allow guard channels to be shared between new calls and handoff calls. This approach maximizes the channel utilization. The simulation results from the simulation showed that there was improvement in the overall throughput when the channel borrowing scheme is used. The dynamic guard channel allocation with channel borrowing strategy (DGCA-CBS) method was simulated for a part of full network with six cells. The main and common disadvantage of the fixed channel allocation, static guard channel allocation and the dynamic guard channel allocation scheme without channel borrowing strategy was new calls starving for channels while the guard channels remain unused. The concept of channel borrowing was incorporated in the DGCA-CBS scheme which gave improvement in the new call blocking rate.

Battulga and Sato [16] also presented network design for high speed vehicle installed base station. They analyzed the blocking probabilities in their network design using a non-prioritized handoff scheme. The network design model can provide spatial information about the load of a cell in a cellular system. The analytical handoff call blocking probabilities results were evaluated through simulation of the non-prioritized handoff scheme with relevant network and traffic parameters

Akpan *et al.*, [4] developed an improved handoff scheme for minimizing handoff failure due to poor signal quality by using various parameters that include signal strength, number of channels, call duration, call arrival rates and the direction of mobile station which is modeled as mobility factor. The M+G scheme [4 ,17] is combined with the concept of mobility to develop a new handoff scheme to minimize call drop probability caused by poor signal strength. The analytical modeling approach was adopted to develop and evaluate the model the handoff scheme. Various analytical models were developed for computing the different metrics for assessing the handoff scheme. The model’s performance was evaluated using a software developed in MATLAB. The metrics for the performance analysis includes the Handoff failure probability and the new call blocking probability. Furthermore, the effects of the direction and the speed of mobile station was also investigated. The system cell is made of a total of C channels and priority was given to the handoff calls. The given priority was implemented by the use of the guard channel method. Out of the C channels, R channels were reserved exclusively for handoff calls while the remaining M = C - R channels were for both handoff calls and new calls. Accordingly, if a handoff requests on its arrival finds all channels (both shared (M), and reserved (R), the call will be dropped with probability [4]. The mobility factor, signal strength and guard channel-based handoff scheme presented by [4] has received wide application and citations in recent studies. First, the mobility factor, signal strength and guard channel-based handoff scheme presented by [4] were used by Ujarari and Kumar [18] to model handoff scheme that will minimize both (handoff) drop probability and blocking probability.

III. METHODOLOGY

There are basically three techniques for networks performance evaluation in telecommunication and they include: analytical modeling, simulation and empirical techniques. In this paper, two techniques, namely, analytical modeling and simulation approaches were adopted. Notably, two handoff schemes were considered, namely guard channel-based prioritized handoff scheme without idle channel borrowing mechanism and guard channel based prioritized handoff scheme with idle channel borrowing mechanism. In the study static guard channel-based mechanism was considered.

Specifically, a static guard channel-based handoff scheme with idle channel borrowing (SGCHSICB) mechanism was developed. A simulation environment in MATLAB was developed and used for comparative performance analysis of the existing static guard channel-based prioritized handoff scheme (SGCHS) without idle channel borrowing mechanism and the newly developed SGCHSICB mechanism. Requisite empirical data sets were obtained from cellular network service providers in Nigeria. The empirical data sets were then used in the simulation. The results of the simulation were presented in Tables and graphs plotted along with discussions on the performances of the different handoff schemes considered in the research.

The procedure used in conducting the research is summarized in the flow diagram of Figure 1

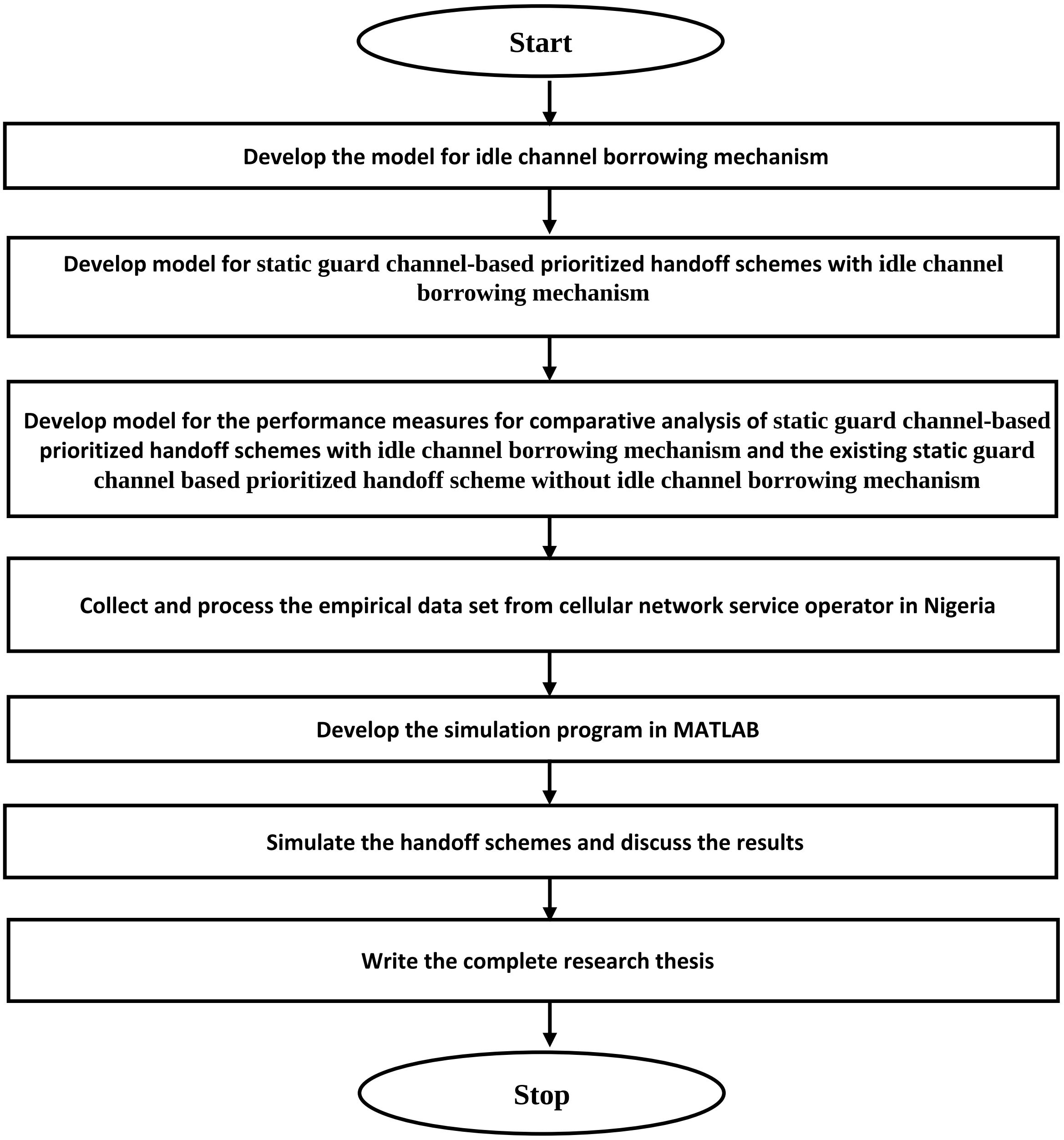

Figure 1: The flow diagram for the research process.

A. *Model Description for Scheme I: Static Guard Channel-Based Prioritized Handoff Scheme (SGCPHS) without Idle Channel Borrowing Mechanism*

In this scheme, the cell is made of a total of C channels. Priority is given to the handoff calls. This is because mobile users are more sensitive to handoff failure (call drop) than new call blocking. The given priority is implemented using the guard channel (GC) method. Out of the C channels of the cell, R channels are reserved exclusively for the handoff calls while the remaining M = C-R channels are shared by the handoff calls and new calls. The channel sharing model is as shown in Figure 2.

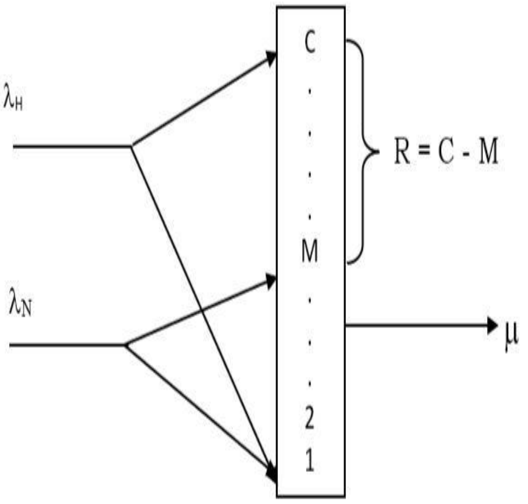

Figure 2: The channel model of the (SGCPHS) Scheme I.

The effective service time for states zero to M is given as

$$\mu = \mu_N + \mu_H \tag{1}$$

The state transition diagram for the model is shown in Figure 3. The effective service time for states M+1 to C is given as μ_H.

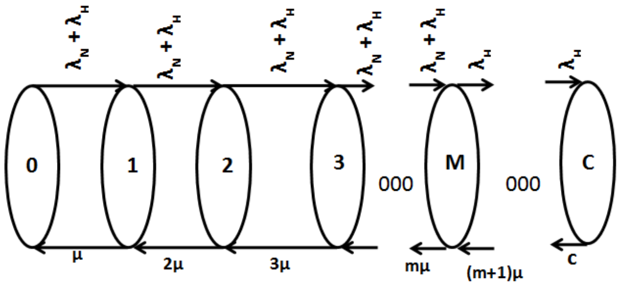

Figure 3: State transition diagram for (SGCPHS) Scheme I.

The effective incoming rate for state 0 to M is λ

$$\lambda = (\lambda_N + \lambda_H) \tag{2}$$

From the state transition diagram above, from the state M, the effective incoming traffic rate is λ_h

$$\lambda_h = \lambda_H \tag{3}$$

This is because, from state M up to C, only handoff calls can be accepted while new calls are blocked. Let the state of the call be denoted as the number of calls in progress for the BS containing that call as S, where S = 0, 1,2,3, ... M, (M+1) … (C-1), C.

The flowchart of the handoff scheme I is shown in Figure 4. The probability that the BS is in state S is given as P(s) can be solved as usual using the birth-death process. The state balance equations from the states transition diagram (Figure 3) are

$$\begin{cases} S\mu\, P(s) = \lambda P(S-1) & \text{for } 0 < S < M \\ S\mu\, P(s) = \lambda h\, P(S-1) & \text{for } M+1 < S < C \end{cases} \tag{4}$$

Where $\lambda = (\lambda_N + \lambda_H)$

$$\lambda_n = \lambda_H \tag{5}$$

The normalization condition is

$$\sum_{S=0}^{C} P(s) = 1 \tag{6}$$

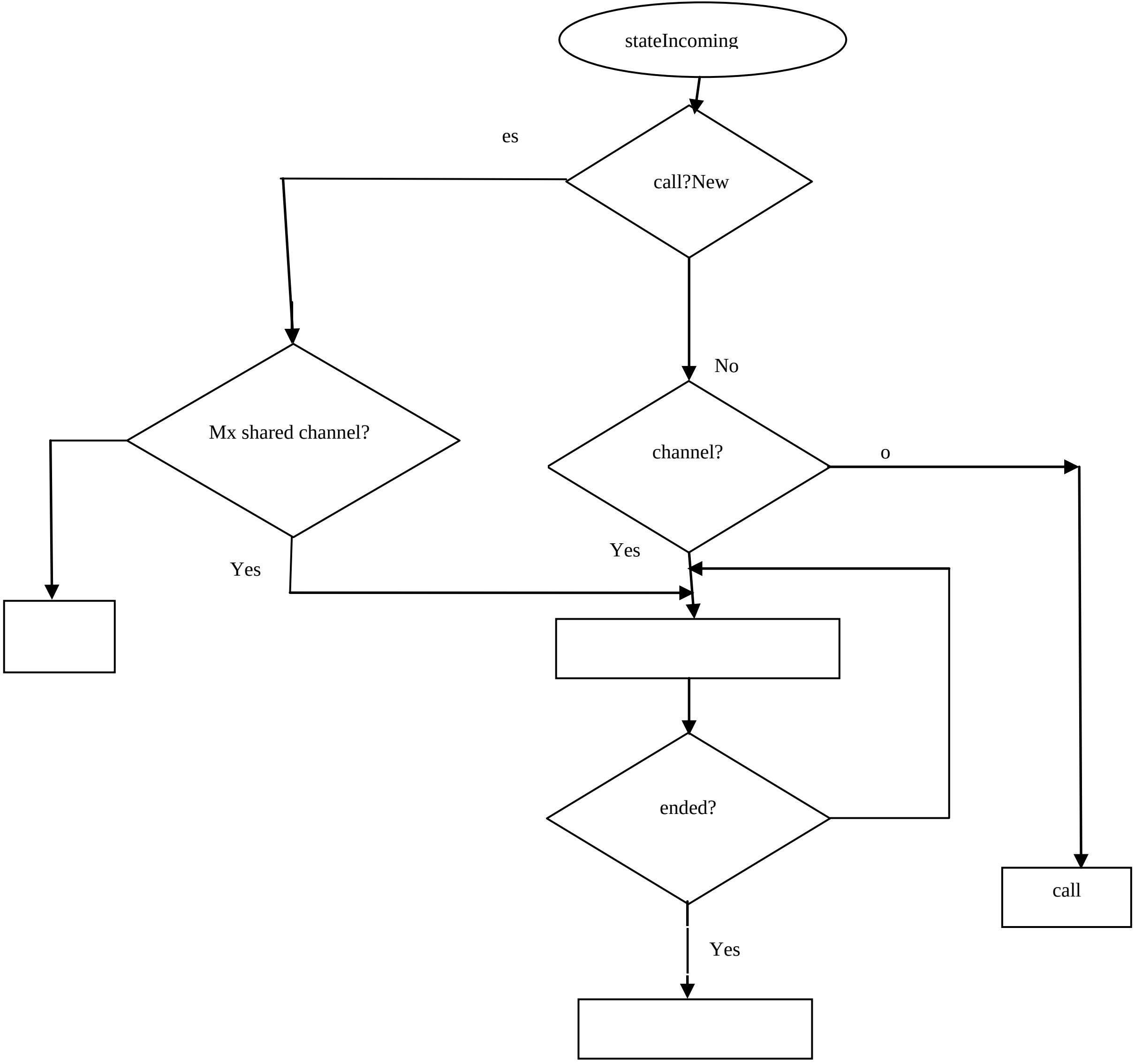

Figure 4: The flowchart of the Static guard channel-based prioritized handoff scheme (SGCPHS) without Idle Channel Borrowing Mechanism (Scheme I).

The steady-state probability P(s) can be found as;

$$P(S)=\begin{cases}\frac{1}{S!}\left(\frac{\lambda}{\mu}\right)^{S}P(0) & 0\le S\ \le M\\ \frac{1}{M!}\left(\frac{\lambda}{\mu}\right)^{M}\frac{1}{(S-M)!}\left(\frac{\lambda_h}{\mu_H}\right)^{(S-M)}P(0) & (M+1)\le S\ \le C\end{cases} \quad (7)$$

$$P(0)=\left\{\sum_{S=0}^{M}\frac{1}{S!}\left[\frac{\lambda}{\mu}\right]^{S}+\sum_{S=(M+1)}^{C}\frac{1}{M!}\left[\frac{\lambda}{\mu}\right]^{M}\frac{1}{(S-M)!}\left(\frac{\lambda_h}{\mu_H}\right)^{(S-M)}\right\}^{-1} \quad (8)$$

$\frac{\lambda_N+\lambda_H}{\mu_N+\mu_H}=\frac{\lambda}{\mu}$ denotes the offered traffic for states zero (0) to M and $\frac{\lambda_H}{\mu_N+\mu_H}$ denotes the handoff traffic for states (m +1) to C. For simplicity, let

$$\rho=\frac{\lambda_N+\lambda_H}{\mu_N+\mu_H}=\frac{\lambda}{\mu} \quad (9)$$

$$\rho_H=\frac{\lambda_H}{\mu_N+\mu_H} \quad (10)$$

And S – M = R represents the reserved (Guard) channels .When a new call finds all shared channels (M) busy at its arrival, it will be blocked with probability

$$P_{BN_{(\mathbf{SGCPHS})}}=\sum_{S=M}^{C}P(s) \quad (11)$$

The new call blocking probability denoted as $P_{BN_{(\mathbf{SGCPHS})}}$ is given as ;

$$\mathrm{PBN}_{(\mathrm{SGCPHS})}=BN(c,\rho)_{(\mathrm{SGCPHS})}=\frac{\sum_{S=M}^{C}\left(\frac{\rho^{M}\left[(\rho_H)^{(S-M)}\right]}{S!}\right)}{\sum_{S=0}^{M-1}\left(\frac{\rho^{S}}{S!}\right)+\rho^{M}\left[\sum_{S=M}^{C}\left(\frac{(\rho_H)^{(S-M)}}{S!}\right)\right]} \quad (12)$$

Accordingly, if a handoff requests on its arrival finds all channels occupied (both shared; M, and reserved; R) the call will be dropped. The handoff call blocking or handoff failure probability denoted as P_{BH} is given as:

$$\mathrm{PBH}_{(\mathbf{SGCPHS})}=BH(c,\rho)_{(\mathbf{SGCPHS})}=\frac{\frac{\rho^{M}\left[(\rho_H)^{(C-M)}\right]}{C!}}{\sum_{S=0}^{M-1}\left(\frac{\rho^{S}}{S!}\right)+\rho^{M}\left[\sum_{S=M}^{C}\left(\frac{(\rho_H)^{(S-M)}}{S!}\right)\right]} \quad (13)$$

B. *Modelling of the Service Rate and Call Duration Model for the Static guard channel-based prioritized handoff scheme without Idle Channel Borrowing Mechanism (SGCPHS)*

A model for call duration without borrowed idle state is shown in Figure 5 The requisite parameters are identified and defined as follows:

i. Active Call busy state duration (τ_{on})
ii. Active Call idle state duration (τ_{idl})
iii. Total duration (T) for the active call, where;

$$T=\tau_{on}+\tau_{idl} \quad (14)$$

iv. Call service rate for the system is denoted by symbol μ, Where

$$\mu=\frac{1}{T} \quad (15)$$

v. Call activity factor (δ) is defined mathematically as;

$$\delta=\left(\frac{\tau_{on}}{\tau_{on}+\tau_{idl}}\right)=\left(\frac{\tau_{on}}{T}\right) \quad (16)$$

$$\tau_{on}=\delta(T) \quad (17)$$

$$1-\delta=1-\left(\frac{\tau_{on}}{\tau_{on}+\tau_{idl}}\right)=\left(\frac{\tau_{on}+\tau_{idl}-\tau_{on}}{\tau_{on}+\tau_{idl}}\right)=\left(\frac{\tau_{idl}}{\tau_{on}+\tau_{idl}}\right)=\left(\frac{\tau_{idl}}{T}\right) \quad (18)$$

Therefore;

$$\tau_{idl}=(1-\delta)T \quad (19)$$

So, for the system without idle channel borrowing mechanism the total call duration consists of the busy state (active voice state) duration (given as (δ)T) and the idle state (no voice; silent) duration (given as (1 − δ)T).

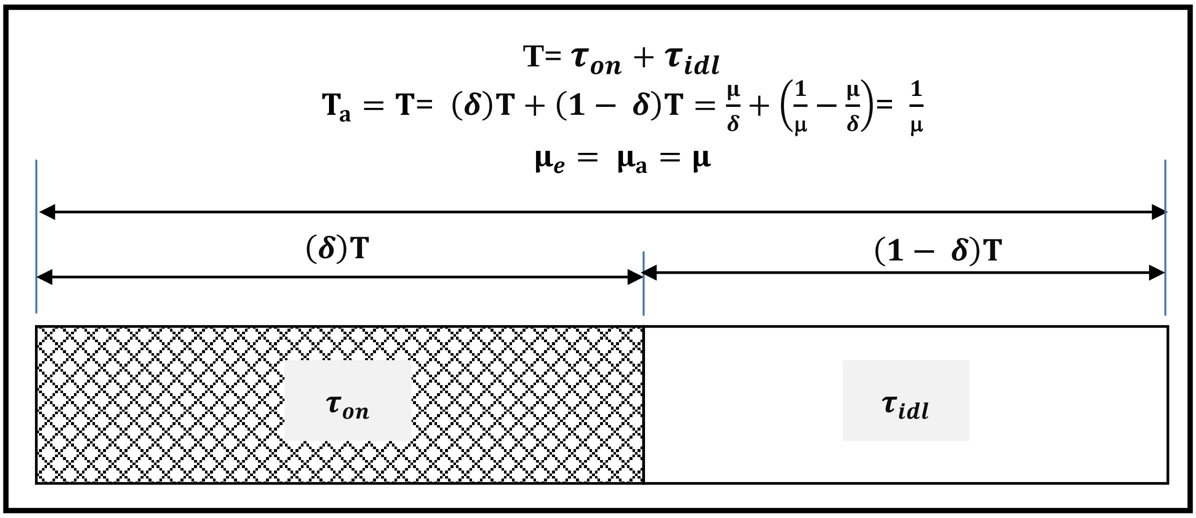

Figure 5: Call duration without borrowed idle state.

The average of actual service rate for SGCPHS (without idle channel borrowing) is denoted as μ_a and the average actual service time (without borrowed idle state) is given as T_a where from Figure 5. According to Figure 5, the total service time (T) in the system is defined as;

$$T_a = (\delta)T + (1 - \delta)T = T \tag{20}$$

$$T_a = T \tag{21}$$

$$T_a = T = \frac{\mu}{\delta} + \left(\frac{1}{\mu} - \frac{\mu}{\delta}\right) = \frac{1}{\mu} \tag{22}$$

$$\frac{1}{\mu_a} = T_a = T \tag{23}$$

$$\mu_a = \frac{1}{T_a} = \frac{1}{T} = \mu \tag{24}$$

In this case, when there is no borrowed idle state, then, the effective average service rate seen by the SGCPHS (without idle channel borrowing) is denoted as μ_e and is given as;

$$\mu_e = \mu_a = \mu \tag{25}$$

C. Derivation of the Equation for the Statistical Multiplexer Gain Factor

The idle channel borrowing mechanism relies on statistical multiplexing of calls. The performance of the idle channel borrowing technique depends on the call (voice) activity factor and the statistical multiplexer gain factor. The requisite parameters are identified and defined as follows:

i. Number of active calls carried (N_v)
ii. Effective number of active calls carried (N_{ve})
iii. Maximum number of active calls carried (N_{vmax})
iv. Number of channels (C)
v. Statistical multiplexing gain (g)

$$g = \frac{N_v}{C} \tag{26}$$

Statistical multiplexing maximum gain (g) is related to the call activity factor (δ) as follows;

$$g_{max} = \frac{1}{\delta} = \frac{N_{vmax}}{C} \tag{27}$$

Where

$$\delta = \left(\frac{\tau_{on}}{T}\right) \tag{28}$$

Statistical multiplexer does not achieve the maximum gain, $g_{max} = \frac{1}{\delta}$. Rather, the effective statistical multiplexer gain (g_e) is used whereby;

$$g_e = \frac{N_{ve}}{C} \tag{29}$$

If idle channel borrowing technique is to be used, the effective statistical multiplexing gain (g_e) must be greater than or equal to 1.Now, $g_e \geq 1$ Hence;

$$N_{ve} \geq C \tag{30}$$

Let the statistical multiplexer gain factor be denoted by symbol ϱ where

$$\varrho = \frac{g_e}{g_{max}} \tag{31}$$

But $g_{max} = \frac{1}{\delta}$ and $g_e = \frac{1}{\delta_e}$ then,

$$\varrho = \frac{g_e}{g_{max}} = \frac{\delta}{\delta_e} \tag{32}$$

Since $g_{max} \geq g_e$

$$\varrho = \frac{g_e}{g_{max}} = \frac{\delta}{\delta_e} \leq 1 \tag{33}$$

$$\delta_e = \frac{\delta}{\varrho} = \left(\frac{g_{max}}{g_e}\right)\delta \tag{34}$$

D. Derivation of the Equation for the Idle Channel Borrowing Gain Factor

The effective idle channel borrowing mechanism excess carried traffic factor for the system is denoted by symbol ε_e where;

$$\varepsilon_e = g_e - 1 = \frac{1}{\delta_e} - 1 \tag{35}$$

$$\text{But } \delta_e = \frac{\delta}{\varrho}$$

$$\varepsilon_e = \frac{1}{\delta_e} - 1 = \frac{\varrho}{\delta} - 1 \tag{36}$$

$$\frac{\varrho}{\delta} = 1 + \varepsilon_e \tag{37}$$

For the statistical multiplexer to achieve excess carried traffic ε_{ef}, the following condition must be met $\varepsilon_e \geq 0$ and since $\varrho \leq 1$, hence;

$$\frac{\varrho}{\delta} - 1 \geq 0 \text{Where } \delta \leq \varrho \leq 1 \tag{38}$$

That means, the maximum effective activity factor denoted as δ_{emax} for any given ϱ is $\delta_{emax} = \varrho$ at which point $\frac{\delta_{emax}}{\varrho} = 1$.

$$\therefore \qquad \delta_e = \frac{\delta}{\varrho} \text{Where} \delta \leq \varrho \leq 1 \tag{39}$$

For instance, based on research findings, for a given actual voice activity factor, $\delta = 0.5$, the maximum achievable statistical multiplexing gain $g_{max} = \frac{1}{\delta} = \frac{1}{0.5} = 2$. Also, based on findings from the same research, for the given actual voice activity factor, $\delta = 0.5$ the $g_e = 1.2$, hence,

$$\delta_e = \frac{1}{g_e} = \frac{1}{1.2} = 0.8333333333333333$$

where $\delta = 0.5$ $\varrho = \frac{g_e}{g_{max}} = \frac{\delta}{\delta_e} = \frac{1.2}{2} = 0.6$ and $\varepsilon_e = \frac{\varrho}{\delta} - 1 = \frac{0.6}{0.5} - 1 = 1.2 - 1 = 0.2$. If $\delta = \delta_{emax} = \varrho = 0.6$ then; $\varepsilon_e = \frac{0.6}{0.6} - 1 = 1.0 - 1 = 0.0$

At the call activity factor of $\delta = \delta_{emax} = \varrho = 0.6$, the statistical multiplexer with the statistical gain factor $\varrho = 0.6$ cannot be used to achieve any excess carried traffic. However, statistical multiplexer with statistical gain factor $\varrho > 0.6$ can still be used to achieve improved carried traffic.

Essentially, the two key parameters for achieving improved carried traffic are;

(i) the call activity factor, δ which is a function of the voice traffic profile
(ii) the statistical gain factor, ϱ which is a function of the statistical multiplexer mechanism

E. Call Duration Model for the M/M/n/n Queue with Idle Channel Borrowing Technique (ICBT)

A model for call duration with borrowed idle state is shown in Figure 6. Among the requisite parameters is the effective call activity factor ($\boldsymbol{\delta_e}$) which has already been defined mathematically as $\delta_e = \frac{\delta}{\varrho} = \left(\frac{g_{max}}{g_e}\right)\delta = \frac{1}{g_e}$. Then, the total duration (T) for the active call is defined as;

$$T = (\delta_e)T + (1 - \delta_e)T \tag{40}$$

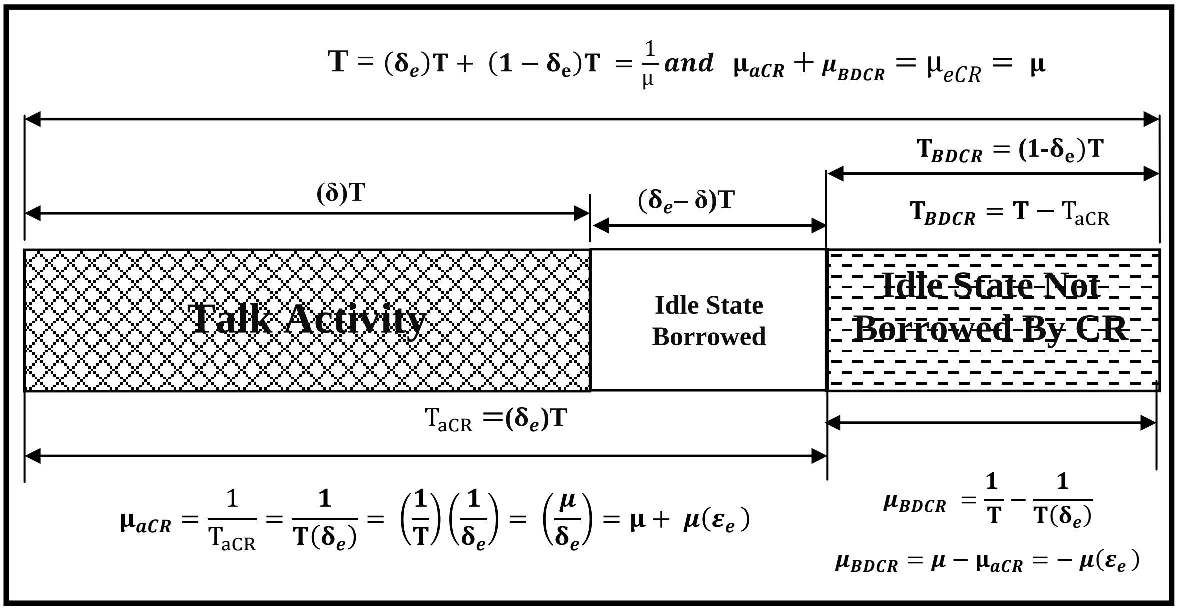

Figure 6: Call duration with borrowed idle state of the active calls.

This means that the total service time $\mathrm{T} = \frac{1}{\mu}$ is the sum of the effective busy state duration $(\delta_e)\mathrm{T}$ and the borrowed idle state duration $(1-\delta_e)\mathrm{T}$ of the active call. The average of actual service rate with the ICBT is denoted as μ_{aCR} and the average actual service time (excluding borrowed idle state) is given as $\mathrm{T}_{\mathrm{aCR}}$ where;

$$\mathrm{T}_{\mathrm{aCR}} = \mathrm{T}(\delta_e) \tag{41}$$

$$\frac{1}{\mu_{aCR}} = \mathrm{T}(\delta_e) \tag{42}$$

$$\mu_{aCR} = \frac{1}{\mathrm{T}(\delta_e)} = \left(\frac{1}{\mathrm{T}}\right)\left(\frac{1}{\delta_e}\right) = \left(\frac{\mu}{\delta_e}\right) = \mu + \mu(\varepsilon_e) \tag{43}$$

But $\frac{1}{\delta_e} = (\varepsilon_e + 1)$

$$\mu_{aCR} = \frac{1}{\mathrm{T}(\delta_e)} = \left(\frac{\mu}{\delta_e}\right) = \mu(1+\varepsilon_e) = \mu + \mu(\varepsilon_e) \tag{44}$$

So, with the ICBT, the actual average service rate (excluding borrowed idle state) denoted as μ_{aCR} is higher by the idle channel borrowing gain factor, $\boldsymbol{\varepsilon_e}$ than the given average service rate μ without the ICBT.

$$\mu_{aCR} = \mu(1+\varepsilon_{\mathrm{e}}) = \mu + \mu(\varepsilon_{\mathrm{e}}) \tag{45}$$

Average service rate in the borrowed idle state is denoted as μ_{BDCR} and the average waiting time in the borrowed idle state is given as T_{BDCR} where;

$$\mathrm{T}_{BDCR} = \mathrm{T}(1-\delta_{ef}) \tag{46}$$

$$\mu_{BDCR} = \frac{1}{\mathrm{T}_{BDCR}} = \frac{1}{\mathrm{T}} - \frac{1}{\mathrm{T}(\delta_e)} = \mu - \left(\frac{\mu}{\delta_e}\right) = \mu - \left(\mu + \mu(\varepsilon_e)\right) = -\mu(\varepsilon_e) \tag{47}$$

So, when the borrowed idle state is considered, then the effective average service rate seen by the system with the ICBT is denoted as μ_{eCR} and is given as;

$$\mu_{eCR} = \mu_{\mathrm{aCR}} + \mu_{\mathrm{BDCR}} = \mu + \mu(\varepsilon_{\mathrm{e}}) - \mu(\varepsilon_{\mathrm{e}}) = \mu \tag{48}$$

Hence, with idle channel borrowing technique, a total service rate of μ is achieved, whereby an average service rate of $\mu(1+\varepsilon_{\mathrm{e}})$ is used to service the calls arriving at an average rate of $\lambda(1+\varepsilon_{\mathrm{e}})$. Within the service time $\mathrm{T} = \frac{1}{\mu}$, an average of serviced call traffic $\rho_{eCR} = \frac{\lambda(1+\varepsilon_{\mathrm{e}})}{\mu(1+\varepsilon_{\mathrm{e}})} = \frac{\lambda}{\mu} = \rho$ are sent with blocking probability $, B(c, \rho_{eCR}) = B(c,\rho)$. Furthermore, additional $\rho(\varepsilon_{\mathrm{e}})$ calls are serviced by borrowing some portions of the idle state of the channel without violating the blocking probability $B(c,\rho)$set by the number of channel, C and the traffic intensity ρ.

F. Derivation of Call Blocking Probability and Hand Off Failure Probability for the M/M/n/n Queue with Idle Channel Borrowing Technique (ICBT)

As illustrated in Figure 7 and Figure 8, the following assumptions are adopted in the M/M/n/n queue with ICBT.

i. Both the new call and handoff arrival rates in the cell form a Poisson process with mean values of λ_{aCRN} and λ_{aCRH} respectively.
Therefore, total arrival rate is $\lambda_{aCR} = \lambda_{aCRN} + \lambda_{aCRH}$

ii. New call and handoff completion rate are exponentially distributed with mean rates of μ_{aCRN} and μ_{aCRH} respectively. Therefore, the effective service rate is $\mu_{aCR} = \mu_{aCRN} + \mu_{aCRH}$. As illustrated in Figure 7 and Figure 8, the service time T = is the sum of the effective busy state duration $(\delta_e)\mathrm{T}$ and the borrowed idle state duration $(1-\delta_e)\mathrm{T}$ of the active call.

iii. The change in arrival rates is moderate in that the network reaches steady state between any two changes in the arrival rate. Therefore, the incoming traffic rate (call arrival rate) is $\lambda_{aCR} = \lambda_{aCRN} + \lambda_{aCRH}$

iv. When the channels are busy new calls or handoff calls that arrive are blocked or dropped respectively. Therefore, the total of the new calls block rate and handoff calls or drop rate is λ_{BCR} while the effective serviced call arrival rate is λ_{eCR}as illustrated in Figure 8.

v. As illustrated in Figure 7 and Figure 8, the actual service time $\mathrm{T}_{\mathrm{aCR}} = (1-\delta_e)\mathrm{T}$ and the actual service rate μ_{aCR} where

$$\mu_{aCR} = \frac{1}{T_{aCR}} = \left(\frac{\mu}{\delta_e}\right) = \mu(1 + \varepsilon_e) \quad (49)$$

Hence, given that $\mu_a = \mu_{aN} + \mu_{aH} = \mu$ and $\frac{\delta}{\varrho} = 1 + \varepsilon_e$ then;

$$\mu_{aCR} = \mu(1 + \varepsilon_e) = \mu_a(1 + \varepsilon_e) = \mu_a\left(\frac{\delta}{\varrho}\right) \quad (50)$$

Similarly;

$$\mu_{aCRN} = \mu_{aN}(1 + \varepsilon_e) = \mu_{aN}(1 + \varepsilon_e) = \mu_{aN}\left(\frac{\delta}{\varrho}\right) \quad (51)$$

$$\mu_{aCRH} = \mu_{aH}(1 + \varepsilon_e) = \mu_{aH}\left(\frac{\delta}{\varrho}\right) \quad (52)$$

In order to maintain the offered traffic intensity, ρ then

$$\frac{\lambda_{aCR}}{\mu_{aCR}} = \frac{\lambda}{\mu} = \rho \quad (53)$$

$$\lambda_{aCR} = \left(\frac{\lambda}{\mu}\right)\mu_{aCR} \quad (54)$$

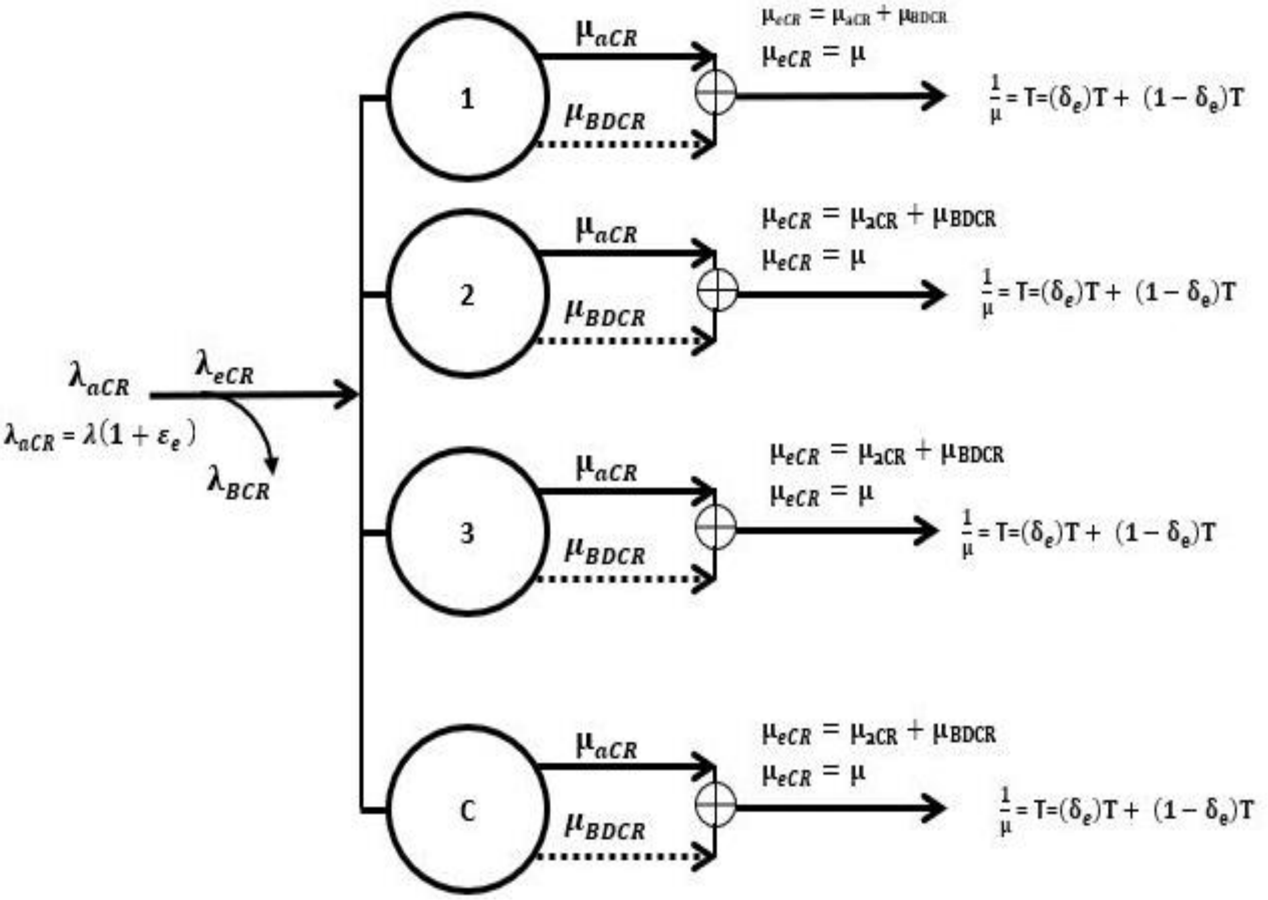

Figure 7 : Model for the effective arrival rate and completion rate for M/M/C/C system with idle channel borrowing technique (ICBT).

Given that $\mu_{aCR} = \left(\frac{\mu}{\delta_e}\right)$ and $\frac{1}{\delta_e} = \frac{\delta}{\varrho} = 1 + \varepsilon_e$, then

$$\lambda_{aCR} = \left(\frac{\lambda}{\mu}\right)\left(\frac{\mu}{\delta_e}\right) = \left(\frac{\lambda}{\delta_e}\right) = \lambda(1 + \varepsilon_e) = \lambda\left(\frac{\delta}{\varrho}\right) \quad (55)$$

Similarly;

$$\lambda_{aCRN} = \lambda_N(1 + \varepsilon_e) = \lambda_N(1 + \varepsilon_e) = \lambda_N\left(\frac{\delta}{\varrho}\right) \quad (56)$$

$$\lambda_{aCRH} = \lambda_H(1 + \varepsilon_e) = \lambda_H\left(\frac{\delta}{\varrho}\right) \quad (57)$$

The behaviour of the cell with ICBT M/M/C/C queue with state transition diagram of Figure 8 can be described as a (C+1) states Markov process, where C is the channel size. The states are always represented by integer n where n = 0,1,2,3, …, …… C- 1, C. The state transition diagram for the M/M/C/C queue with ICBT is given in Figure 8.

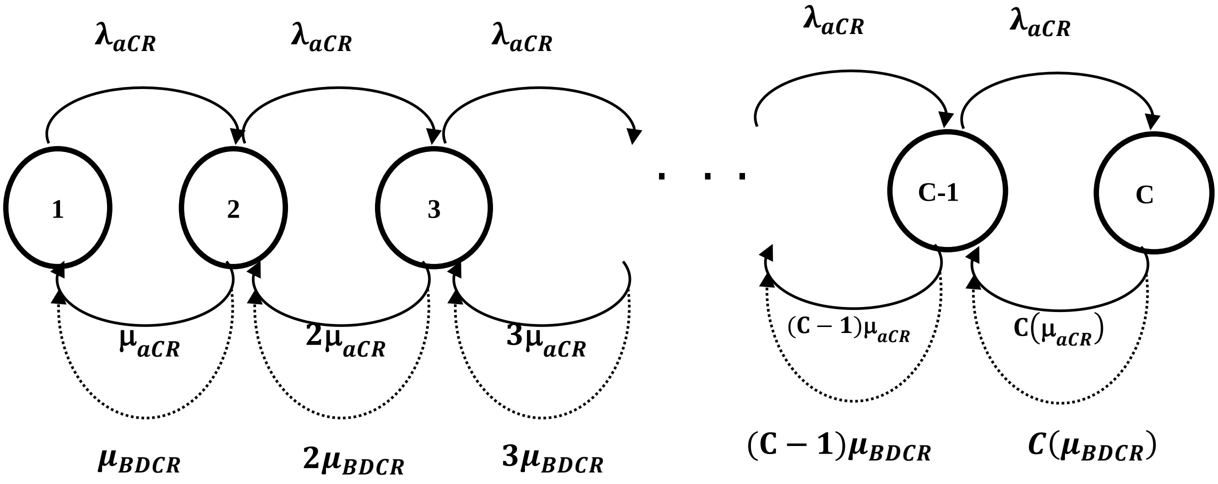

Figure 8: The state transition diagram for the M/M/C/C queue with ICBT.

If the probability that the system is in state n is represented by P(n), then considering the state transition diagram in Figure 8, P(n) can be found using the birth-death process as follows;

$$P(n) = \frac{\lambda_{aCR}}{n(\mu_{aCR})}(P(n-1): \quad 0 < n < C \tag{58}$$

The normalization condition equation is such that;

$$\sum_{n=0}^{c} P(n) = 1 \tag{59}$$

Employing the normalization condition in P(n) gives the steady state (SS) probability P(n) as

$$P(n) = \frac{{\lambda_{aCR}}^{n}}{n!{\mu_{aCR}}^{n}} P(0) \tag{60}$$

$$= \frac{1}{n!}\left[\frac{\lambda_{aCR}}{\mu_{aCR}}\right]^{n} P(0) \qquad 0 \le n \le C \tag{61}$$

The traffic intensity or offered traffic load represented by ρ_{aCR} is the one serviced within the effective busy state duration (δ_e)T. The traffic intensity or offered traffic load serviced within the borrowed idle state duration $(1-\delta_e)$T of the active call is given as $\rho_{BCR}$where;

$$\frac{\rho_{BCR}}{\rho_{aCR}} = \frac{1-\delta_e}{\delta_e} \tag{62}$$

$$\rho_{BCR} = \left(\frac{1-\delta_e}{\delta_e}\right)\rho_{aCR} = \left(\frac{1}{\delta_e} - 1\right)\rho_{aCR} = (\varepsilon_e)\rho_{aCR} \tag{63}$$

$$\rho_{BCR} = \left(\frac{1}{\delta_e} - 1\right)\rho_{aCR} = \left(\frac{\varrho}{\delta} - 1\right)\rho_{aCR} = (\varepsilon_e)\rho_{aCR} \tag{64}$$

Therefore, the effective traffic intensity or offered traffic load for the ICBT M/M/n/n queue is represented by ρ_{eCR} where;

$$\rho_{eCR=}\rho_{aCR} + \rho_{BCR} \tag{65}$$

$$\rho_{eCR} = \rho_{aCR} + (\varepsilon_e)\rho_{aCR} = (1+\varepsilon_e)\rho_{aCR} = \left(\frac{\varrho}{\delta}\right)\rho_{aCR} \tag{66}$$

G. The Static Guard Channel Prioritized Handoff with Idle Channel Borrowing (SGCPHICB) Scheme (Scheme II)

In the SGCPHICB scheme, idle channel borrowing technique is used to ensure that portions of the idle state of active calls are borrowed without violating the call drop probability of the calls. However, the SGCPHICB scheme applies the Idle Channel Borrowing mechanism to only the handoff calls. In that case, the new calls do not benefit from the channel borrowing provided by the Idle Channel Borrowing mechanism. Rather the achievable Idle Channel Borrowing gain ε_e is applied only to the handoff calls.

Also, the portions of the achievable Idle Channel Borrowing gain applied to the two different call request types are fixed; particularly, in the analysis, no (or zero) Idle Channel Borrowing gain will be assigned to the new calls whereas the whole achievable Idle Channel Borrowing gain ε_e is applied only to the handoff calls. The implication is that $\varepsilon_N = 0$and $\varepsilon_H \ge 0$.When $\varepsilon_N = 0$ then

$$g_N = 1 + 0 = 1 \tag{67}$$

Also, when $\varepsilon_H \ge 0$ then

$$g_H = 1 + \varepsilon_N \ge 1 \tag{68}$$

Then, in the SGCPHICB scheme the condition is;

$$\left.\begin{matrix} g_N = & 1 \\ g_H \ge & 1 \end{matrix}\right\} \text{where} \quad \varepsilon_N = 0 \text{ and } \varepsilon_H \ge 0 \tag{69}$$

The flowchart for the proposed SGCPHICB Scheme II is shown in Figure 9.

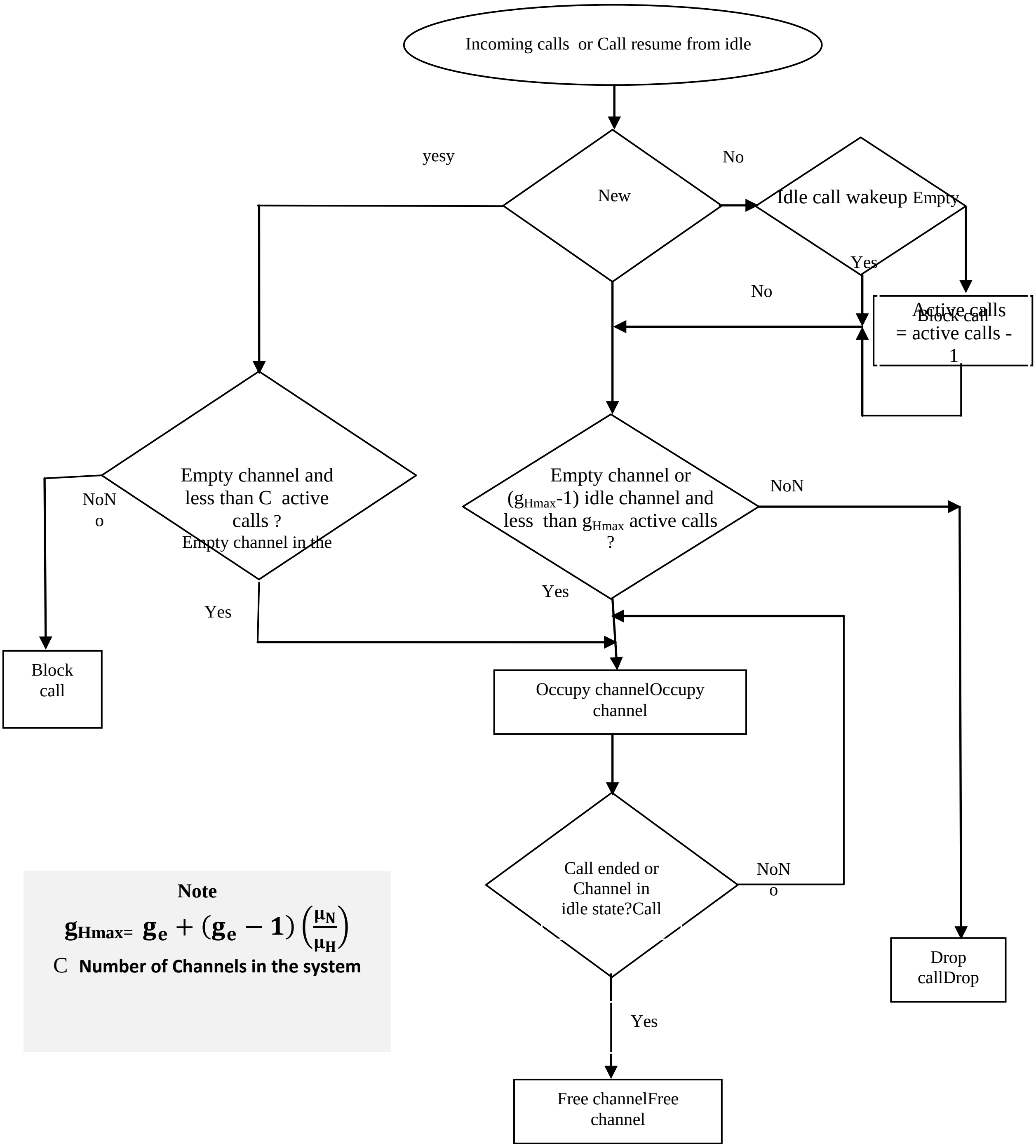

Figure 9: The flowchart for SGCPHICB Scheme II.

Then, $g_N(\mu_N) + g_H(\mu_H) = g_e(\mu_N + \mu_H)$ gives;

$$\mu_N + g_H(\mu_H) = g_e(\mu_N + \mu_H) \qquad (70)$$

$$g_H = \frac{g_e(\mu_N + \mu_H)}{\mu_H} - \frac{\mu_N}{\mu_H} \qquad (71)$$

$$g_H = \frac{g_e(\mu_H)}{\mu_H} + \frac{g_e(\mu_N)}{\mu_H} - \frac{\mu_N}{\mu_H} \qquad (72)$$

$$g_H = g_e + (g_e - 1)\left(\frac{\mu_N}{\mu_H}\right) \text{where } \; g_N = 1 \qquad (73)$$

$$g_H = g_e + \varepsilon_e\left(\frac{\mu_N}{\mu_H}\right) \text{where } \; g_N = 1 \qquad (74)$$

So, for the SGCPHICB scheme, the statistical gain for the new call given $g_{N(\mathrm{SGCPHICB})}$ and the statistical gain for the handoff call given as $g_{H(\mathrm{SGCPHICB})}$ are as follows;

$$\left.\begin{matrix} g_{H(\mathrm{SGCPHICB})} = g_e + (g_e - 1)\left(\frac{\mu_N}{\mu_H}\right) \\ g_N = g_{N(\mathrm{SGCPHICB})} = 1 \end{matrix}\right\} \text{where } \; \varepsilon_N = 0 \text{ and } \varepsilon_H \geq 0 \qquad (75)$$

Probability of a call being blocked in Scheme II is denoted as B (c,$\rho_{a(\mathbf{SGCPHICB})}$) 0 <δ ≤ ϱ). The call blocking probability denoted as $PB_{a(\mathbf{SGCPHICB})}$= B (c,$\rho_{a(\mathbf{SGCPHICB})}$)

$$PB_{a(\mathbf{SGCPHICB})} = \frac{\left(\frac{\left(\frac{\rho}{g_e}\right)^C}{C!}\right)}{\sum_{n=0}^{C}\left(\frac{\left(\frac{\rho}{g_e}\right)^n}{n!}\right)} \qquad (76)$$

The new call blocking probability denoted as $PBN_{a(\mathbf{SGCPHICB})}$ is given as:

$$PBN_{\mathrm{a}(\mathbf{SGCPHICB})} = \frac{\left(\frac{\left(\frac{\rho}{g_{N(\mathrm{SGCPHICB})}}\right)^{\mathrm{C}}}{C!}\right)}{\sum_{n=0}^{C}\left(\frac{\left(\frac{\rho}{g_{N(\mathrm{SGCPHICB})}}\right)^{\mathrm{n}}}{n!}\right)} = \frac{\left(\frac{\left(\frac{\rho}{\boldsymbol{g_e}}\right)^{\mathrm{C}}}{C!}\right)}{\sum_{n=0}^{C}\left(\frac{\left(\frac{\rho}{\boldsymbol{g_e}}\right)^{\mathrm{n}}}{n!}\right)} \quad (77)$$

The handoff call blocking or handoff failure probability denoted as $PBN_{\mathrm{a}(\mathbf{SGCPHICB})}$ is given as:

$$PBH_{\mathrm{a}(\mathbf{SGCPHICB})} = \frac{\left(\frac{\left(\frac{\rho}{g_{\mathrm{H}(\mathrm{SGCPHICB})}}\right)^{\mathrm{C}}}{C!}\right)}{\sum_{n=0}^{C}\left(\frac{\left(\frac{\rho}{g_{\mathrm{H}(\mathrm{SGCPHICB})}}\right)^{\mathrm{n}}}{n!}\right)} =$$

$$\frac{\left(\frac{\left(\frac{\rho}{\left[g_e+(g_e-1)\left(\frac{\mu_N}{\mu_H}\right)\right]}\right)^{\mathrm{C}}}{C!}\right)}{\sum_{n=0}^{C}\left(\frac{\left(\frac{\rho}{\left[g_e+(g_e-1)\left(\frac{\mu_N}{\mu_H}\right)\right]}\right)^{\mathrm{n}}}{n!}\right)} \quad (78)$$

In order to compare the various performance parameters of the different handoff schemes, it is better to compare them under the same overall offered traffic (ρ) and number of channel (C). In this case, for the Scheme II the offered traffic (ρ) is given as;

$$\rho = \frac{\lambda_{\mathrm{a}(\mathbf{SGCPHICB})}}{\mu_{\mathrm{a}(\mathbf{SGCPHICB})}} \quad (79)$$

In this case, the overall blocking probability denoted as B(c,ρ)is given as;

$$\mathrm{B}(\mathrm{c},\rho) = \frac{\left(\frac{\rho^{\mathrm{C}}}{C!}\right)}{\sum_{n=0}^{C}\left(\frac{\rho^{\mathrm{n}}}{n!}\right)} = \frac{\left(\frac{\rho^{C}}{C!}\right)}{\sum_{n=0}^{C}\left(\frac{\rho^{\mathrm{n}}}{n!}\right)} \quad (80)$$

H. The Case Study Cellular Network Data

An Ericsson test mobile system TEMS investigation drive test tool was used to measure necessary cellular network traffic data from a GSM network in Nigeria; particularly measured data were captured from the MSC located in Uyo Local Government Area (LGA) in Akwa Ibom. The accessories required for Ericsson TEMS investigation tool included: a laptop, TEMS phone, GPS, and power supply unit (PSU). The laptop houses the operating system and the Ericsson TEMS software. The TEMS phone was used to initiate calls during the data collection. The GPS enables the system to locate the longitude and latitude of the place. The power supply unit provides the power required by the whole system. The drive test accessories were connected as shown in Figure 10. The empirical measurement was carried out over a period of 8 consecutive days between 6th of March 2019 and 13th of March 2019. Within this period, the drive test tool was mounted on a vehicle and driven along routes within the coverage area of base stations in the selected MSC.

Particularly, during the drive test, calls were initiated by the TEMS phone until it was established and the resulting key performance indicators (KPIs) of the network such as handover successes, completed calls, call setup successes, call setup failures, dropped calls and other Radio frequency parameters were recorded by the TEMS software. The KPIs data obtained from field measurement using the TEMS investigation software of the following; number of active base stations, traffic intensity per day (Erlang), call setup success rate (CSSR), drop call rate (%), number of call attempts in busy hour, 3G availability rate and 3G throughput (Kbps).

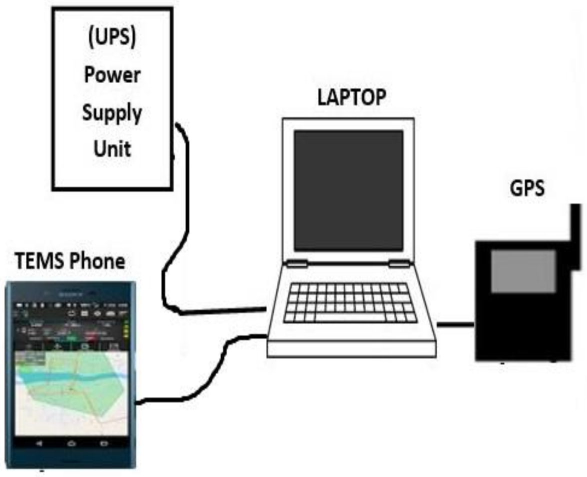

Figure 10 : Schematic diagram of the experimental setup.

The collected network traffic data were analyzed (using the expressions in equations 81 to 91 to determine the core traffic parameter values per base station.

i. **Blocking probability**

$$\text{Blocking probability} = 1 - \left(\frac{\text{call set up success (cssr)}}{100}\right) \quad (81)$$

ii. **Number of drop call in the MSC**

$$\text{Number of drop call per msc} = \left(\frac{\text{Drop call rate (\%)}}{100}\right)\text{Number of call attempts in busy hour}$$

iii. **Number of drop call per cell**

$$\text{Number of drop call per cell} = \frac{\text{number of drop call per msc}}{\text{number of active base stations in the msc}} \quad (83)$$

iv. **Traffic intensity per cell (erlang)**

$$\text{Traffic intensity per cell (erlang)} = \frac{\text{Traffic intensity in the msc per day (erlang)}}{\text{number of active base stations in the msc}} \quad (84)$$

v. **Number of call attempts in busy hour per cell**

$$\text{Number of call attempts in busy hour per cell} = \frac{\text{Number of call attempts in busy hour in the msc}}{\text{number of active base stations in the msc}}$$

vi. **Call arrival rate in busy hour (calls/sec)**

$$\text{Call arrival rate in busy hour (calls/sec)} = \frac{\text{Number of call attempts in busy hour per cell}}{3600} \tag{86}$$

vii. **Call duration (sec)**

$$\text{Call duration (sec)} = \frac{\text{Traffic intensity per cell (erlang)}}{\text{Call arrival rate in busy hour}} \tag{87}$$

viii. **Call service rate (calls/sec)**

$$\text{Call service rate (calls/sec)} = \frac{1}{\text{call duration (sec)}} \tag{88}$$

ix. **Channel utilization**

$$\text{Channel utilization} = \left(\frac{\text{traffic intensity per cell (erlang)}}{\text{Average number of channels per cell}}\right)\left(\frac{1}{\text{effective statistical gain}}\right) \tag{89}$$

x. **Handoff call arrival rate (calls/s)**

$$\text{Handoff call arrival rate} = \text{call arrival rate in busy hour} - \text{new call arrival rate} \tag{90}$$

xi. **Handoff call service rate (calls/sec)**

$$\text{Handoff call service rate} = \text{call service rate} - \text{new call service rate} \tag{91}$$

In particular, the traffic intensity; number of call attempts; number of dropped calls; call duration and drop-call probability were estimated per BS for MSC. Similarly, the required radio channel and traffic parameters were also estimated for the MSC. The data are shown in Table 1.

Table 1: The computed mean values of the KPIs data obtained from field measurement using the TEMS investigation software.

S/N	Parameter Title	Parameter Value	S/N	Parameter Title	Parameter Value
1	**3G Site Number**	AK0036	13	**Channel Utilization**	94.5165
2	**Mobile Switching Centre (MSC) Site Name**	Nung-Oku, Off Aka-Nung-Udoe Rd	14	**New Call Arrival Rate (Calls/S)**	0.3781
3	**LGA In Akwa Ibom State**	UYO	15	**Handoff Call Arrival Rate (Calls/S)**	0.3365
4	**Number of Active Base Stations**	98	16	**New Call Service Rate (Calls/S)**	0.0028642
5	**Traffic Intensity Per Day (Erlang)**	7984.75	17	**Handoff Call Service Rate (Calls/S)**	0.0057284
6	**Call Setup Success Rate (CSSR)**	98.77	18	**Service Rate (Calls/S)**	0.0085926
7	**Drop Call Rate (%)**	1.76	19	**Blocking Prob.**	0.0123038
8	**Number of Call Attempts in Busy Hour of the base station**	143315.79	20	**3G Availability Rate**	100
9	**Average Number of channels per cell**	98	21	**Number of Call Attempts in Busy Hour Per Cell**	1492.87
10	**Number of Drop call**	2524.71	22	**Call Arrival Rate (Calls/S)**	0.7147
11	**Number of Drop call Per Cell**	26.3	23	**Call Duration (Sec)**	116.3789
12	**Traffic Intensity Per cell (Erlang)**	83.17			

The radio channel related parameters are: number of channels and channel utilization factor, while the traffic parameters are: call arrival rate, call duration as well as the service duration. The statistical mean values of these parameters were estimated per cell for the MSC.

4. RESULTS

The simulation parameters for the SGCPHS Scheme I and the SGCPHICB Scheme II based on the case study cellular network data collected from the MSC in Uyo LGA are shown in Table 2. However, the effective statistical gain for the SGCPHICB (scheme II) is equal to 1.25. In the SGCPHS (scheme I) the reserved channels for the handoff calls is 10 (that is 98 - 88) whereas the SGCPHICB (scheme II) assigned higher statistical gain (1.393315536) to the handoff calls and lower statistical gain (1.12244898) to the new calls. The difference of 0.270866556 between the two statistical gains determines the amount of idle channel state that the SGCPHICB scheme can use to carry additional handoff calls or new calls. In the static priority schemes, the shared channels and statistical gains are maintained as they are assigned at the beginning of the network operation.

Table 2: Simulation parameters for the SGCPHS (scheme I) **and the SGCPHICB (Scheme II) based on data collected from the MSC in Uyo LGA..**

Network Traffic, Call activity and Statistical Multiplexer Parameters		
S/N	**Parameter Title**	**Value**
1	Calibration Talk Activity Factor	0.5
2	Maximum Statistical Gain	2
3	Calibration Effective Statistical Gain	1.2
4	Cognitive Radio Gain Factor	0.6
5	Operating Talk Activity Factor	0.48
6	Effective Talk Activity Factor	0.8
7	Handoff Statistical Gain	1.393315536
8	New Call Statistical Gain	1.12244898
9	Effective Statistical Gain	1.25
10	Handoff Arrival Rate (Calls/sec)	0.336546
11	New Call Arrival Rate (Calls/sec)	0.378141
12	Call Arrival Rate (Calls/sec)	0.714687
13	Handoff Service Rate (Calls/sec)	0.0057284
14	New Call Service Rate (Calls/sec)	0.0028642
15	Call Service Rate (Calls/sec)	0.0085926
16	Traffic Intensity (Erlang)	83.17471
17	Number of Channels	98
18	Number of Shared Channels	88

A. the Effect of Reserved Channels on Handoff Dropping Probability and New call Blocking Probability

The part I of the comparison of the effect of reserved channels on handoff dropping probability and new call blocking probability for the SGCPHS (scheme I) and the SGCPHICB (scheme II) based on the empirical data collected from the MSC in Uyo LGA is shown in Figure 11. In the three parts comparison of blocking and dropping probabilities, the parameters are such that New Call Statistical Gain = 1.12244898, Handoff Statistical Gain = 1.25 and Effective Statistical Gain = 1.393315536.

In the part I, the comparison is based on the measured handoff dropping probability and new call blocking probability. According to the results in Figure 11, the SGCPHICB scheme reduced both handoff dropping probability and new call blocking probability by more than 99.9 %.

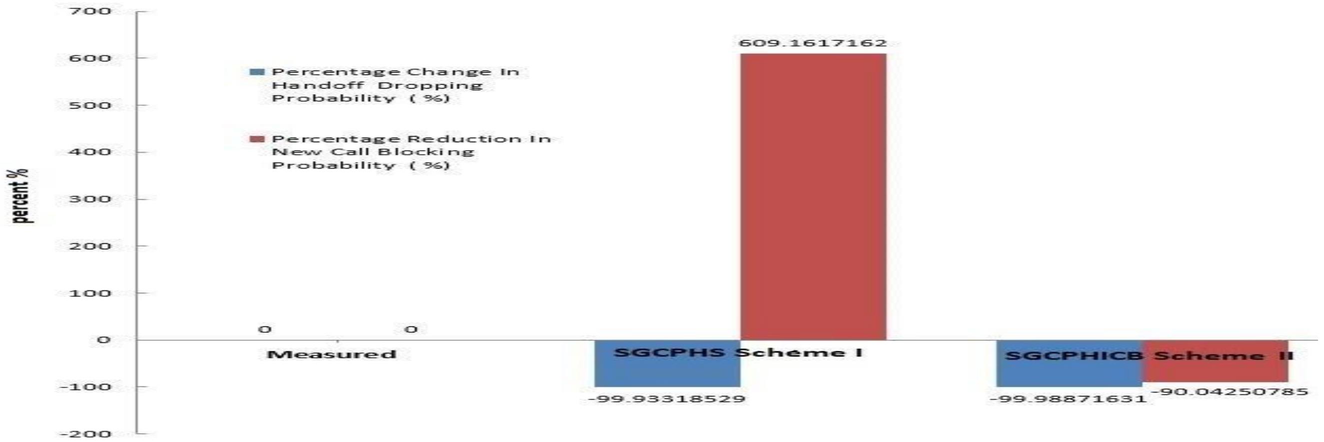

Figure 11: Part I of the comparison of the effect of reserved channels on handoff dropping probability and new call blocking probability for the SGCPHS (scheme I) and the SGCPHICB (scheme II) based on the empirical data collected from the MSC in Uyo LGA.

However, the SGCPHS scheme reduced only the handoff dropping probability by about 90 % but it increased the new call blocking probability by over 609%. This is the disadvantage of the SGCPHS scheme, in a bid to improve (reduce) the handoff dropping probability it greatly increases the new call blocking probability. On the other hand, the SGCPHICB scheme can greatly improve both handoff dropping probability and new call blocking probability at the same time.

B. Effect of Reserved Channels on Effective Arrival Rate of Handoff Call and New call for the SGCPHS scheme I and the SGCPHICB scheme II

The comparison of the effect of reserved channels on effective arrival rate of handoff call and new call for the SGCPHS scheme and the SGCPHICB scheme based on the empirical data collected from the MSC in Uyo LGA is shown in Figure 12. The comparisons is made with respect to the measured effective handoff arrival rate and effective new call arrival rate.

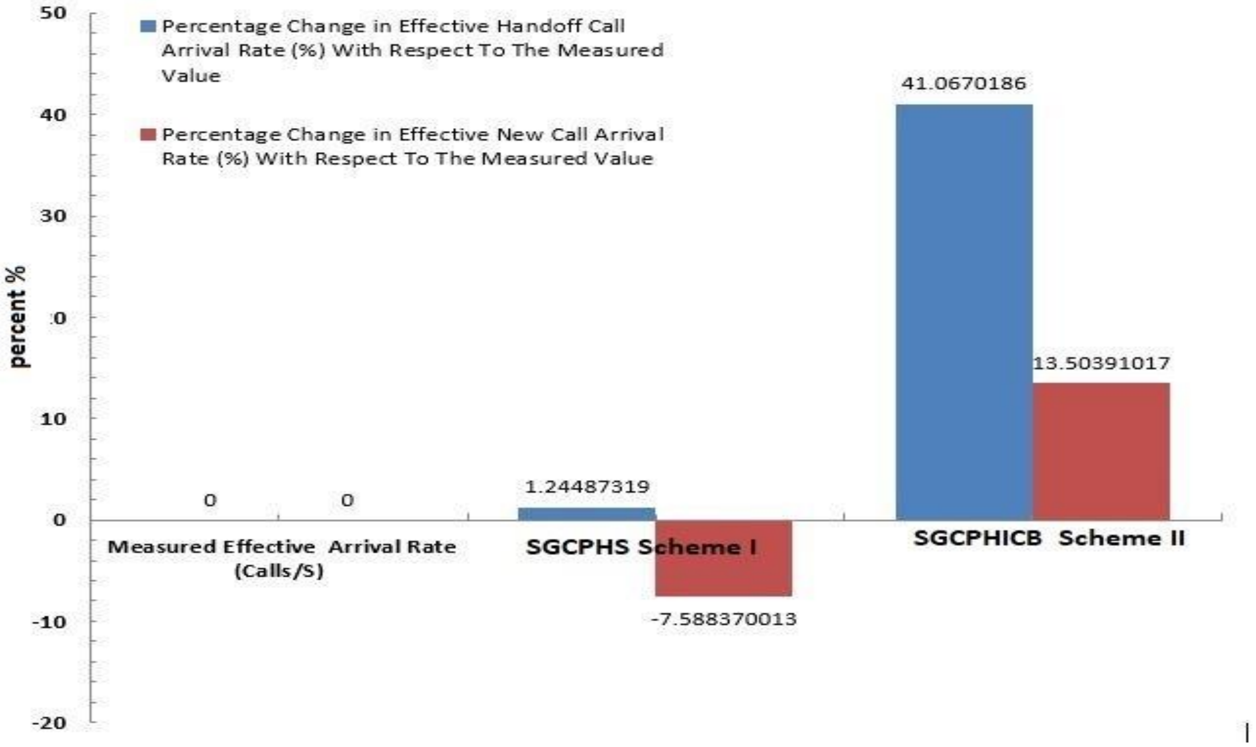

Figure 12: The comparison of the effect of reserved channels on effective arrival rate of handoff call and new call for the SGCPHS scheme I and the SGCPHICB scheme II based on the empirical data collected from the MSC in Uyo LGA (comparisons made with respect to the measured effective handoff call arrival rate (calls/s).

In the comparison, the parameters are such that New Call Statistical Gain = 1.12244898, Handoff Statistical gain = 1.25 and Effective Statistical Gain = 1.393315536. According to the results in Figure 11, the SGCPHICB scheme increased effective handoff arrival rate by about 41 % and also increased effective new call arrival rate by about 13 %. However, the SGCPHS scheme increased effective handoff arrival rate by just 1.2 % and at the same time it reduced the effective new call arrival rate by about 7.5 %.

C. Effect of Reserved Channels on Effective Traffic Intensity of Handoff Call and New call for the SGCPHS scheme I and the SGCPHICB scheme II

The comparison of the effect of reserved channels on effective traffic intensity of handoff call and new call for the SGCPHS scheme and the SGCPHICB scheme based on the empirical data collected from the MSC in Uyo LGA is shown in Figure 13. The comparisons is made with respect to the measured effective handoff traffic intensity and effective new call traffic intensity. In the comparison, the parameters are such that New Call Statistical Gain = 1.12244898, Handoff Statistical gain = 1.25 and Effective Statistical Gain = 1.393315536. According to the results in Figure 13, the SGCPHICB scheme increased effective handoff traffic intensity by about 41 % and also increased effective new call traffic intensity by about 13 %. However, the SGCPHS scheme increased effective handoff traffic intensity by just 1.2 % and at the same time it reduced the effective new call traffic intensity by about 7.5 %

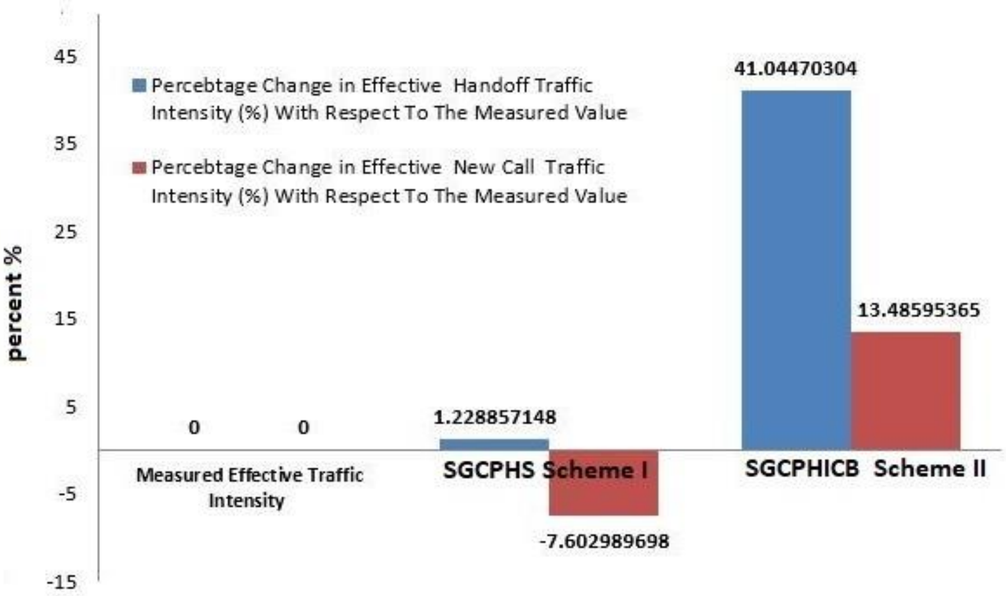

Figure 13: The comparison of the effect of reserved channels on effective traffic intensity of handoff call and new call for the SGCPHS scheme and the SGCPHICB scheme based on the empirical data collected from the MSC in Uyo LGA (the comparisons are made with respect to the measured effective handoff call arrival rate (calls/s).

D. Effect of Reserved Channels on Server Utilization for the SGCPHS scheme I and the SGCPHICB scheme II

The comparison of the effect of reserved channels on server utilization server utilization for the SGCPHS scheme and the SGCPHICB scheme based on the empirical data collected from the MSC in Uyo LGA is shown in Figure 14. The comparisons is made with respect to the measured server utilization. In the comparison, the parameters are such that new call statistical gain = 1.12244898, handoff statistical gain = 1.25 and effective statistical gain = 1.393315536. According to the results in Figure 14, the SGCPHICB scheme increased server utilization by about 51 %. However, the SGCPHS scheme decreased server utilization by about 3%.

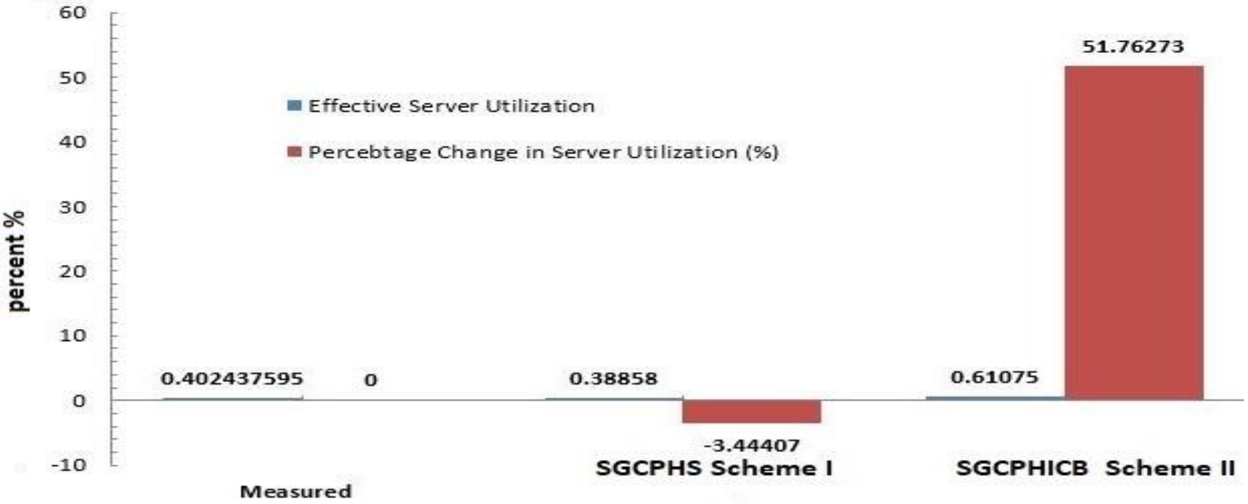

Figure 14: The comparison of the effect of reserved channels on server utilization for the SGCPHS scheme and the SGCPHICB scheme based on the empirical data collected from the MSC in Uyo LGA (the comparison is made with respect to the measured server utilization).

E. Effect of Reserved Channels on Number of Active Calls in the System for the SGCPHS scheme and the SGCPHICB scheme

The comparison of the effect of reserved channels on number of active calls in the system for the SGCPHS scheme and the SGCPHICB scheme based on the empirical data collected from the MSC in Uyo LGA is shown in Figure 15. The comparisons is made with respect to the measured number of active calls in the system. In the comparison, the parameters are such that new call statistical gain = 1.12244898, handoff statistical gain = 1.25 and effective statistical gain = 1.393315536. According to the results in Figure 15, the SGCPHICB scheme increased the number of active calls in the system by about 25 %. However, the SGCPHS scheme decreased the number of active calls in the system by about 3%.

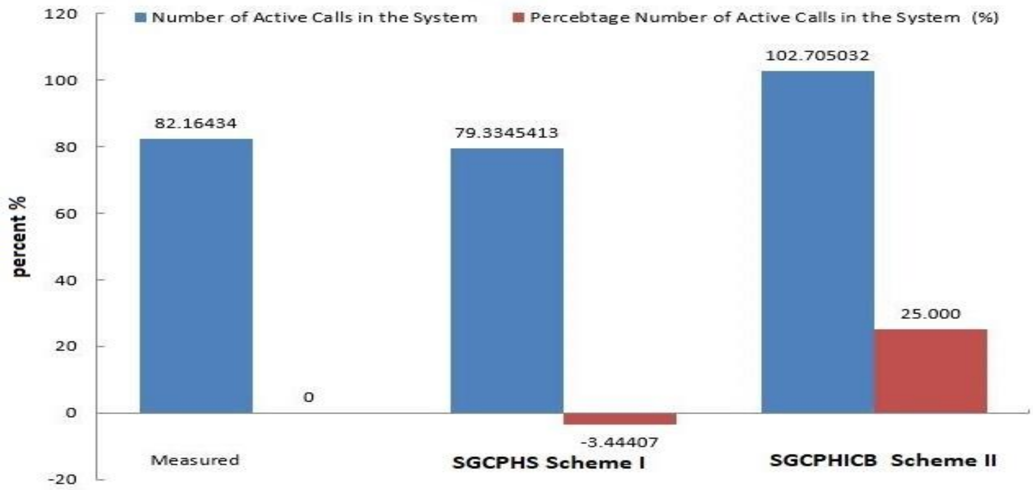

Figure 15: The comparison of the effect of reserved channels on number of active calls in the system for the SGCPHS scheme and the SGCPHICB scheme based on the empirical data collected from the MSC in Uyo LGA (the comparison is made with respect to the measured number of active calls in the system).

F. Shared Channels and Statistical Gains for the handoff and new calls

The shared channels and statistical gains for the handoff and new calls are shown in Figure 16. . According to Figure 16, the new call statistical gain increases as the number of shared channels increases whereas the handoff statistical gain decreases as the number of shared channels increases. Also, the ratio of number of available channels to number of shared channels increases as the number of shared channels increases. In any case, the effective statistical gain remains constant at 1.25. It can be seen that reduction in the number of shared channels can make the handoff statistical gain to rise to 1.5223 which is far above the effective statistical gain of 1.25.

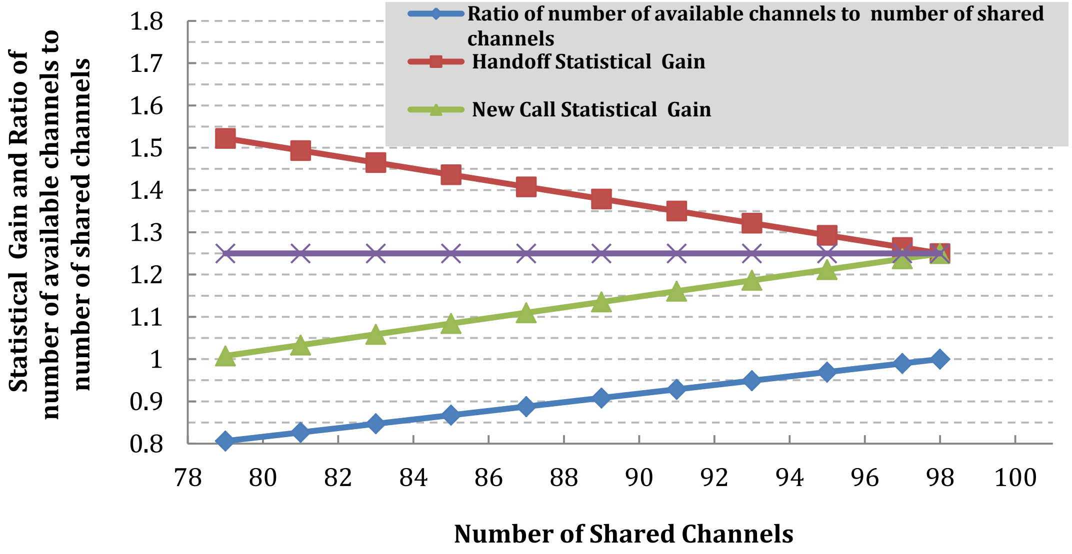

Figure 16: Shared channels and statistical gains for the handoff and new calls.
Source: Formulated by the researcher (2019).

V. CONCLUSION

In cellular networks, there is always a need for more efficient methods of channel utilization in each cell. Also, a good handoff scheme has to balance the call blocking and call dropping in order to provide the desired Quality of Service (QoS) requirements. The main objective of this study therefore was to develop a guard channel-based prioritized handoff scheme with idle channel borrowing mechanism for cellular networks. In other to achieve this, network and traffic datasets were obtained from the case study cellular network in Uyo metropolis. An already existing guard channel-based prioritized handoff scheme without idle channel borrowing mechanism was modelled and compared with the newly developed guard channel-based prioritized handoff scheme with idle channel borrowing mechanism. Analytical model was developed for call activity ratio and statistical multiplexer gain for the channel borrowing mechanism in the newly developed handoff model. The mechanism was simulated using the MATLAB software and a comparative analysis of the performance of the already existing handoff scheme without idle channel borrowing mechanism and the newly developed handoff scheme with idle channel borrowing mechanism was carried out based on the simulation results. Thus, channel utilization was improved by borrowing the idle channel which increased the effective call service time, thereby making sure that at any time a handoff request is initiated, there is always an available channel to handle the request without noticeable network interference to new calls or degradation of the standard QoS. The improvement realised through the guard channel borrowing was demonstrated with the numerical results that shows that the handoff scheme with idle channel borrowing mechanism gave lower probability of call blocking and call dropping in all cases when compared with the existing handoff scheme without idle channel borrowing mechanism.

REFERENCES

1. Chu, James. "The Whats, Hows, and Whys of Wireless Networking [Book\/Software Reviews]." *IEEE Microwave Magazine* 20.3 (2019): 91-92.
2. Sarraf, Saman. "5G Emerging Technology and Affected Industries: Quick Survey." *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)* 55.1 (2019): 75-82.
3. Majid G. and Raouf B. (2006). *IEEE Published in Journal IEEE Transactions on Mobile Computing archive*, 5(3): 193-207
4. Akpan, U., Kalu, C., Ozuomba, S., and Obot, A. (2013). Development of improved scheme for minimising handoff failure due to poor signal quality. *International Journal of Engineering Research and Technology*, 2(10): 31- 34
5. Ekiz N. , Tara S., Sibel K. and Kemal F.,(2006).An overview of handoff techniques in cellular networks. *International Journal of Information Technology*. 2(2)
6. Sheluhin, O. I., Atayero, A. A., and Eyinagho, M. O. (2011). Markov models of statistical multiplexing of telephone dialogue with packet switching. *IEEE ITS Telecommunications (ITST), 11th International Conference.* : 768-772
7. Atayero, A. A. (2000). Estimation of the quality of digitally transmitted analogue signals over corporate VSAT networks. Ph.DThesis. handoff for cellular networks. *IEEE Transactions on Vehicular Technology*, 57(1): 502-510.
8. Sun, Y., Ahmad, I., Li, D., and Zhang, Y. Q. (2006). Region-based rate control and bit allocation for wireless video transmission. *IEEE Transactions on Multimedia*, 8(1): 1-10.
9. Sangwan, A. et. (2002). High Speed Networks and Multimedia Communications. IEEE 5th International Conference. pp. 46-50
10. Jeong, W., Kavehred, M., and Yun, J. (2004). Spectral efficiency of dynamic time-division system for asymmetric and dynamic multimedia traffic. *International Journal of Wireless Information Networks.*
11. Zhuang, W. *et al.* (2000). Adaptive quality of service handoff priority scheme for mobile multimedia networks. *IEEE Transactions on Vehicular Technology*, 49(2): 494-505.
12. Alagu, S., and Meyyappan, T. (2012). *Efficient utilization of channels using dynamic guard channel allocation with channel borrowing strategy in handoffs*. arXiv preprint arXiv:1206.3375.
13. Shah A. and Krishan L. K.. (2011). Digital speech interpolation advantage of statistical time division multiplexer . *PJETS*, 1(1): 9-13
14. Enderes, T., Khoo S.C., Somerville C.A., and Samaras, K. (2002). Impact of statistical multiplexing on voice quality in cellular networks. *Mobile Networks and Applications, 7:* 153-161.
15. Zabanoot, Zaid Ahmed Said. *Modelling and Analysis of Resource Management Schemes in Wireless Networks. Analytical Models and Performance Evaluation of Handoff Schemes and Resource Re-Allocation in Homogeneous and Heterogeneous Wireless Cellular Networks*. Diss. University of Bradford, 2012.
16. Battulga, D., and Sato, T. (2013). Analyzing the handoff call blocking probability in wireless network with mobile base station. *Japan Society for Simulation Technology*
17. Goswami, V., and Swain, P. K. (2012). Analytical modeling for handling poor signal quality calls in cellular network. *International Journal of Networks and Communications*, 2(4): 47-54.
18. Ujarari, C. S., and Kumar, A. (2015). Handoff schemes and its performance analysis of priority within a particular channel in wireless systems.