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The Impact of Varying Traffic Intensities on an Optimized Resource Reservation Model for Handover in Mobile Networks

[1]Ezeja Obinna M., [2]Ahaneku Mamilus A., [3]Chijindu Vincent C., [4]Eneh Joy N., [5]Ozue Izuchukwu T.

[1]Ph.D. Student & Lecturer
[1, 2, 3, 4, 5]Department of Electronic Engineering, University of Nigeria, Nsukka, 410001, Enugu State, Nigeria.

[1]ORCID: 0000-0001-8116-547X , [2]ORCID: 0000-0001-9427-6937

Abstract

The importance of handover functionality in any cellular system cannot be overemphasized as it is central to the effectiveness or otherwise of the network. Therefore, the choice of its parameters, and the appropriate setting of same to ensure tolerable call drop probability is very critical. These parameters are normally chosen depending on network performance and traffic load patterns, among other criteria. In this work, the best analytical expression for a Resource Reservation Model (RRM) earlier developed is determined. The three approaches tested were from logarithmic representation, Gaussian elimination technique and linear regression analysis of the optimized template. The expression from Gaussian elimination was found to best represent the system model experimental results. Also, the impacts of various traffic intensities of the combined new and handover connection requests, α, as well as the traffic intensities of handover requests alone, β, on call drop probabilities and call blocking probabilities were investigated. The results show that as traffic intensities increased and reservations were made for handover calls, the call drop probabilities were reduced significantly while call blocking probabilities increased.

Keywords: Call drop probability, Networks, Handover, Traffic Intensities, Resource Reservation.

I. INTRODUCTION

The importance and usefulness of wireless communication cannot be over-emphasized as it has a wide range of applications which tremendously improve the life of users. This is due to the capabilities and services it provides while offering flexibility and mobility. Mobility features in wireless communication ensure seamless connection of mobile terminals on transit. Currently, it is estimated that there are more than 3.2 billion users of wireless communication devices [1], which naturally results in huge increase in traffic. This in itself is a challenge in wireless communications, as it creates competitions for scarce radio resources.

The Global Systems for Mobile communication, GSM, is one of the most successful and most deployed cellular technologies which handles mobility effectively. There are broadly two scenarios for management of mobility for cellular networks. The first is when the Mobile System, MS is in the idle mode, which implies that there is no call in progress or it is switched off. In this case the network keeps track of the MS by a means of location management [3]. Secondly, there is a scenario in which an active mobile terminal moves within the coverage area of a wireless network [2]. This would possibly result in a situation where the MS leaves the coverage area of a single cell in the course of its movement, making it necessary to transfer the ongoing connection to the next cell with available channel, in order to maintain the connection. This functionality of mobile communication networks is referred to as handover [12], and is responsible for the retention of connection to networks.
Handover is one of the basic features of a cellular communication network system. Managing the process is critical in mobile networks particularly as the density of cells and users continue to rise [16]. It can be categorized into two:

- Horizontal handover where it is carried out in one type of network, with the same radio access technology (as in GSM to GSM), and
- Vertical Handover in which transfer of call is implemented between different networks or between different radio access technologies (e.g. 3G to LTE) [2].

Moreover, the horizontal handover also has two categories: a hard handover where at any given time the call is handled by only one connection. This is the type used in GSM, and the default in LTE. The second type is the soft handover, where the MS is connected to more than one cell at the same time during the handover process [1]. Handover failure is one of the main issues in mobility, and it can be avoided by adjusting handover control parameters (HCPs) [4].

Prior to the occurrence of handover, there are certain critical conditions that must be met. Such conditions may include issues of the radio environment, like the received signal strength, and speech quality. It could also be related to a network criterion, like cell traffic load. An active MS thus continuously sends measurement reports to its serving cell, the need for a handover is then decided only after consideration of the prevailing radio situations [5]. Reservation of Resources for handover calls results in the depreciation of the Quality of Service, QoS for fresh calls while improving the QoS for ongoing handover calls [11]. It is pertinent to note that the upcoming next generation wireless networks is expected to among other things, provide mobility in a continuous and seamless way to subscribers [15].

II. RELATED WORKS

There are a number of mobility management schemes developed to handle handover issues such as the use of reserved channel schemes (RCS), probabilistic channel reservation (PCR), queuing priority schemes (QPS), preemptive and non-preemptive channel borrowing handover scheme and the intelligent channel reservation (ICR) scheme [6, 7, 8, 9, 10, 14]. Nonetheless, there are shortcomings associated with these schemes known in literature. Reserving guard channels for handover connections requires careful considerations and critical decision making. For instance, insufficient reservation would result in handover calls competing for free channels with new connections and consequently lead to a higher handover call drop rate. On the other hand, prodigal reservation might increase the number of idle channels in a system. A channel is classified as an idle channel if it is reserved but has not been assigned to any connections. Obviously, new-connection blocking rate increases with the number of the idle channels. Thus, determining an appropriate number of guard channels for handover connections is an essential issue for handover management. Handover algorithms in GSM are operational algorithms designed to perform according to the specifications stated in [13].

III. METHOD

This work adopted a design and simulation approach. The diagram in figure 1 shows the system model used in this research.

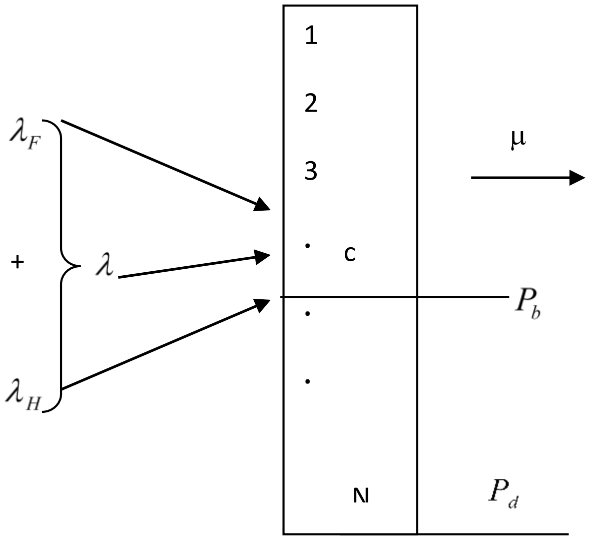

Figure 1: The System Model

Model Parameters defined:

- λ_F is the arrival rate of the fresh calls (ie calls requesting for new connections and are also known as originating or new calls);
- λ_H or λ' is the arrival rate of handover calls (ie calls which are already served but require to handover to a new channel in the same cell due to weak signal or to a new channel in another cell due to its mobility as it crosses the cell boundary;
- $\lambda = \lambda' + \lambda_F$ (ie the combined arrival rate of both fresh calls and handover calls.
- k (= N – c) is the number of resources reserved for handover calls;
- c is the number of resources that can serve both originating and handover calls beyond which fresh calls can no longer be served, as handover calls are prioritized by provision of k reserved channels;
- μ is the service rate;
- $\alpha = \lambda/\mu$ is the traffic intensity of both new and handover calls;
- $\beta = \lambda'/\mu$ = traffic intensity of handover calls.

To develop the model, the state (fluid-flow) equations for the corresponding Markov chain representation are:

$$S_0:\ \lambda P_0 = \mu P_1 \ or\ P_1 = \frac{\lambda}{\mu} P_0 \qquad (1)$$

$$S_1:\ \lambda P_1 + \mu P_1 = \lambda P_0 + 2\mu P_2 \qquad (2)$$

$$\vdots$$

$$S_{c-1}:\ \lambda P_{c-2} + c\mu P_c = \lambda P_{c-1} + (c-1)\mu P_{c-1} \qquad (3)$$

$$S_c:\ \lambda' P_c + c\mu P_c = \lambda P_{c-1} + (c+1)\mu P_{c+1} \qquad (4)$$

$$S_{c+1}:\ \lambda' P_{c+1} + (c+1)\mu P_{c+1} = \lambda' P_c + (c+2)\mu P_{c+2} \qquad (5)$$

$$\vdots$$

$$S_{c+(k-1)}:\ \lambda' P_{c+(k-1)} + (c+(k-1))\mu P_{c+(k-1)} = \lambda' P_{c+(k-2)} + (c+k)\mu P_{c+k} \qquad (6)$$

$$S_{c+k}:\ \lambda' P_{c+(k-1)} = (c+k)\mu P_{c+k} \qquad (7)$$

Solving recursively, we can establish that:

$$P_i = \frac{1}{i!}\left(\frac{\lambda}{\mu}\right)^i P_0 \qquad (8)$$

Hence

$$P_c = \frac{1}{c!}\left(\frac{\lambda}{\mu}\right)^c P_0 \qquad (9)$$

Beyond state S_c, a new arrival rate λ', is defined representing arrival rate of handover calls only, which can be served by k reserved resources. Hence at that point, the state equations are:

$$S_c:\ \lambda' P_c + c\mu P_c = \lambda P_{c-1} + (c+1)\mu P_{c+1} \qquad (10)$$

Substitution of terms as previously defined, leads to:

$$P_{c+1} = \frac{1}{(c+1)\mu}\lambda\, P_c \qquad (11)$$

Hence generally,

$$P_{c+k} = \prod_{n=1}^{k}\left(\frac{1}{c+k}\right)\left(\frac{\lambda'}{\mu}\right)^k P_c = \frac{c!}{(c+k)!}\left(\frac{\lambda'}{\mu}\right)^k P_c \qquad (12)$$

Recalling the boundary condition:

$$\sum_{i=0}^{\infty} P_i = 1 \tag{13}$$

and carrying out further analysis, we obtain:

$$P_0 = \left[\sum_{i=0}^{c} \frac{\beta}{i!} + \sum_{n=1}^{k} \frac{c!}{(c+n)!} (\beta)^n \frac{\alpha^c}{c!}\right]^{-1}$$

Therefore, the call blocking probability for originating/new calls, P_b is obtained by substituting this value into equation (9) is:

$$P_b = \frac{\beta}{c!}\left[\sum_{i=0}^{c} \frac{\beta}{i!} + \sum_{n=1}^{k} \frac{c!}{(c+n)!} (\beta)^n \frac{\alpha^c}{c!}\right]^{-1} \tag{15}$$

Also, the call dropping probability for handover calls, P_d is obtained by substituting P_b into equation (12) as:

$$\begin{aligned} P_d = \frac{c!}{(c+k)!} (\beta)^k \frac{\alpha^c}{c!} \Bigg[& \sum_{i=0}^{c} \frac{\beta}{i!} \\ & + \sum_{n=1}^{k} \frac{c!}{(c+n)!} (\beta)^n \frac{\alpha^c}{c!}\Bigg]^{-1} \end{aligned} \tag{16}$$

IV. RESULTS

The Microsoft Excel Worksheet was used to simulate, observe and record the behaviour (that is, change in the call blocking probabilities, P_b, for the fresh calls and change in call drop probabilities, P_d, for handover calls using the developed analytical expressions for P_b and P_d) of the model for varying number of reserved resources, k in systems with different number of resources, N. The traffic intensities α and β as previously defined were assigned values of 0.9 and 0.7 respectively. The behavior of the model was then noted and recorded for number of resources, N = 10, 15, 20, 25, and 30 respectively.

1. Determination of the Optimum Reservations, R in a system

The optimum number of resources, R to be reserved for handover calls in any system with number of available resources, N can be estimated by taking a close look at the results obtained and carrying out a mathematical analysis. The method adopted was that the points in the graphs of P_b and P_d versus k, for each system capacity, N (see that of N = 10 in Figure 2) where the call blocking probability, P_b begins to rise sharply due to reservation of resources for handover is noted as the optimum for that system.

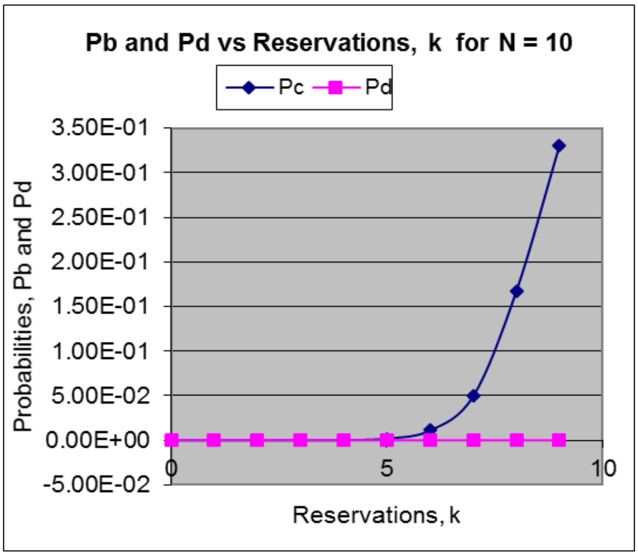

Figure 2: Probabilities, Pb and Pd versus Reservations, k (N = 10).

It is worthy of note that the following were observed:

- When there is no reservation of resources for handover calls (that is k = 0), the two types of calls arriving the system, that is the fresh calls and the handover calls, compete for channels with equal chances of being served. The implication is that the values of P_b and P_d are observed to be equal. This is expected because with no priority given to handover calls, the call blocking probability should be the same for both classes of calls.
- There was a gradual but steady increase in P_b and a gradual but steady decrease in P_d as reserved channels were progressively provided (from k = 1 to k = 9) in the system for handover calls. However beyond the point where reserved resources, k = 4, a sharp and significant increase in P_b is observed. Thus this point is noted as optimum number of reservations for system with N = 10, beyond which the new call blocking probability P_b becomes intolerable.
- Similar analysis were carried out for N = 15, 20, 25, and 30 and the optimum reservations R, found to be at the point k = 9, 13, 18, and 24 respectively.

2. The Analytical Expression for Optimum Reservations, R.

Three methods were used to find an expression that relates the optimum reservations, R to different number of resources, N in a system.

1. The logarithmic expression representing the behavior of the graph of system capacities N, versus the respective optimum reservations, R for each system (determined by the optimum k as explained above) was noted and is given as :
   $$R = 17.5 \ln N - 37.61 \tag{17}$$
2. Using the data set obtained, that is, the system capacities, N, and the corresponding points of optimum reservations as determined above, the Gaussian Elimination process was used to generate a function that shows the relationship between N and R, adopting the power series
   $$R = a_0 + a_1 N + a_2 N^2 + a_3 N^3 + \dots \tag{18}$$

where a_0, a_1, a_2, etc are coefficients to be determined. Using the experimental data results from the model, R values for the respective N values, formed a set of five equations representing the five data points and were solved simultaneously using matrices. The resultant equation is given as:

$$R = 0.01N^2 + 0.6N - 3 \tag{19}$$

3. Also, we found through linear regression analysis, the function that relates the system capacity, N to the optimum reservations, R using the Generalized Power Law given by:

   $$R = aN^b \tag{20}$$

   The details of the analysis is given in [11]. The analysis shows that the reservation expression can be given as:

   $$R = 0.1068\,N^{1.6} \tag{21}$$

Table 1 shows the evaluation of R from the three expressions (17), (19), and (21) above, compared with the experimental results for N = 10, 15, 20, 25, and 30.

Table 1: Evaluation of the Analytical Expressions relating R to N.

N	k by Experiment	k by Regression	k by Gaussian Elimination	k by Logarithm
10	4	4.2518	4.0000	2.6852
15	9	8.1343	8.2500	9.7809
20	13	12.8890	13.0000	14.8153
25	18	18.4194	18.2500	18.7203
30	24	24.6584	24.0000	21.9110

The evaluation outcomes of the three analytical templates were plotted and the R^2 values found as shown in Figure 3.

Table 2: Simulation Parameters

Parameter	Value
System Capacity, N	25, 50, 75, and 100
Reservations, k	From 0 to (N – 1)
Combined Traffic Intensity, α	0.5, 1.0, 1.5, 2.0, 2.5,and 3.0 (simulated with β = 0.5)
Handover Traffic Intensity, β	0.2, 0.4, 0.6, 0.8, and 0.9 (simulated with α = 0.9)
Quality of Service parameters to be determined	Call blocking probability, P_b and Call drop probability, P_d

From the graph of Figure 3, the Gaussian Elimination method gave the closest performance, with R^2 value of 0.9981 which is the closest to unity. Thus equation (19) best represents the System Model.

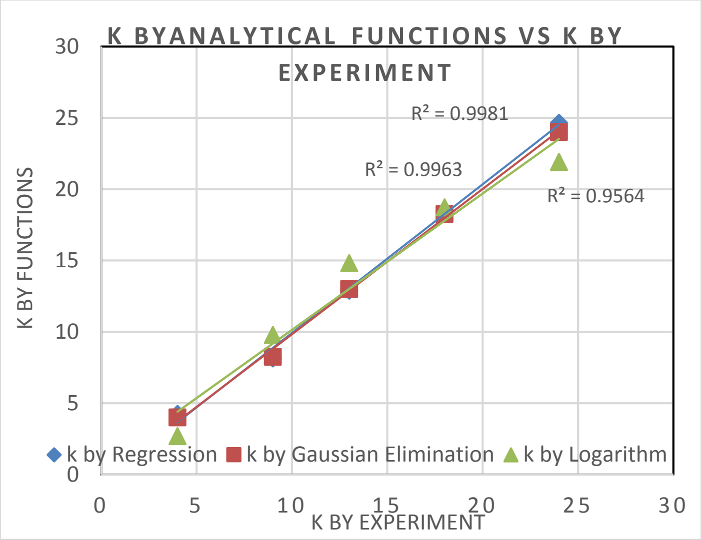

Figure 3: Evaluation of the Analytical Expressions for R Compared with System Values

V. THE IMPACT OF VARYING α AND β ON CALL BLOCKING PROBABILITY, P_b AND CALL DROP PROBABILITY, P_d.

Given the derived equations (15) and (16) for new call blocking probability and handover call drop probability respectively, the previous analysis in Section IV used randomly picked values for the traffic intensities α and β, namely 0.9 and 0.7 respectively, to evaluate the behavior of the developed models. However, since in real life, the traffic intensities vary continuously, it is imperative to study the effect of such variations in traffic levels, α and β on the reservation model.

PYTHON program codes were therefore written and run to enable the researchers investigate not only the effect of varying traffic loads, but also the behavior of the model in larger system capacities, N. This makes the simulation easier. The various system capacities N considered were N = 25, 50, 75, and 100.

Simulation Results

The program code in Python was run for different values of the parameters shown in Table 2. The behavior of the model was observed to be of the same pattern for N = 25, 50, 75 and 100. Hence we present and discuss the result of one of them, namely N = 25. The simulations were run by keeping α constant at 0.9 and then varying β from 0.2 to 0.8 in steps of 0.2, in addition to running the simulation when α = β = 0.9. The P_b and P_d values were noted. Also, β was kept constant at 0.5, and α varied from 0.5 to 3.0 in steps of 0.5. This of course includes when α = β = 0.5. The values of P_b and P_d were also noted. Graphs of the outcomes were plotted as shown in Figures 4 to 7.

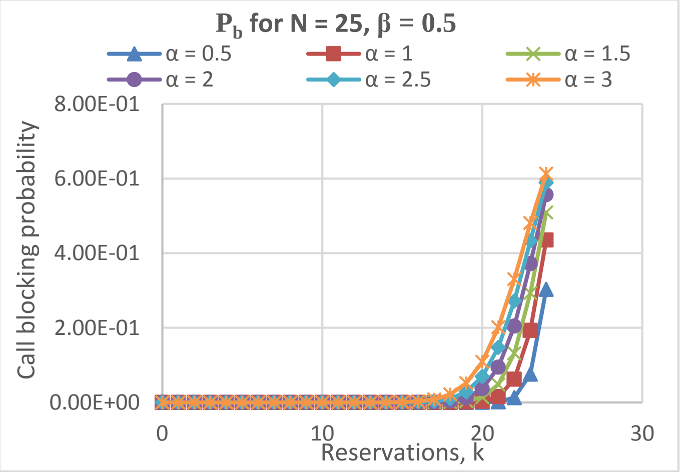

Figure 4: Call blocking probability, P_b for N = 25, β = 0.5

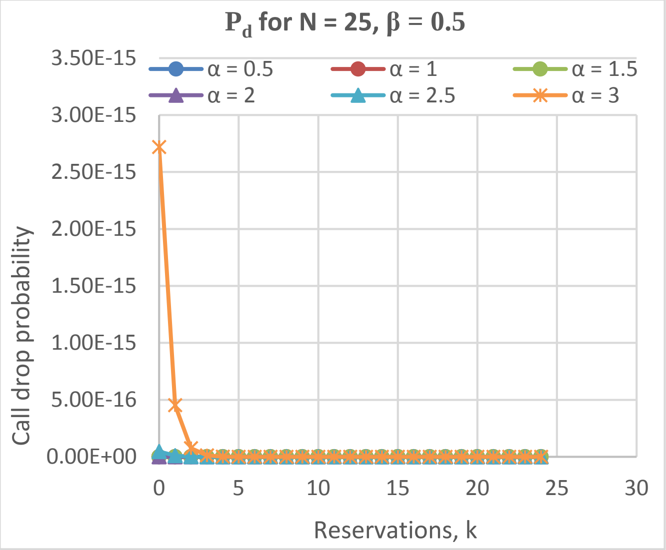

Figure 5: Call drop probability, P_d for N = 25, β = 0.5

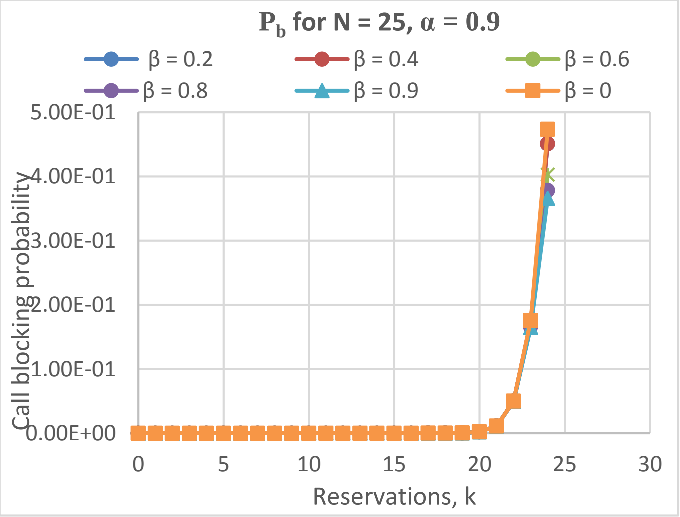

Figure 6: Call blocking probability, P_b for N = 25, α = 0.9

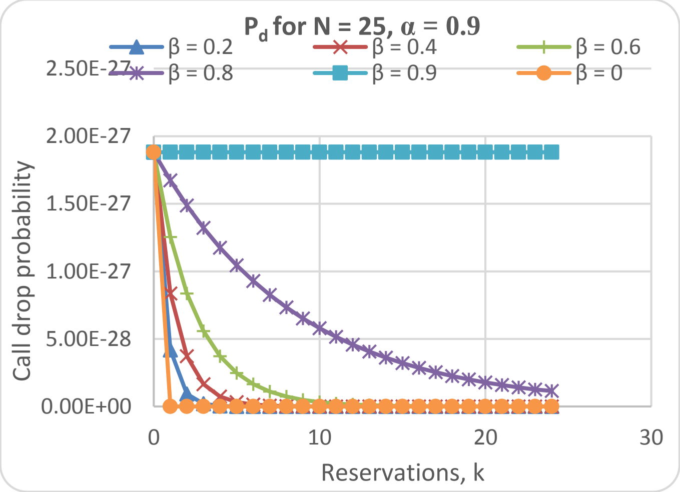

Figure 7: Call drop probability, P_d for N = 25, α = 0.9

VI. DISCUSSION OF RESULTS

Figure 4 shows the call blocking probability, P_b for a system with capacity, N = 25, and β = 0.5. The P_b increased from 1.17E-33 to 0.303265, as number of reservations, k increased from 0 to 24. This was observed when combined traffic intensity of both new and handover calls, α = 0.5 and the handover call traffic intensity, β is also 0.5. This is due to the fact that progressively, handover calls are prioritized with the increasing reservations. However, as α was set at 1.0, 1.5, 2.0, 2.5, and 3.0, while maintaining β at 0.5, the call blocking probability, P_b increased progressively across α values. This is because as the combined traffic of both new and handover, α increased while the handover traffic, β is fixed, it implies that more new calls arrive with reduced chance of being served as resources are reserved for β. However, it is observed that the variation in P_b became pronounced only from k = 16 and beyond.

Figure 5 shows the call drop probability, P_d for a system with capacity, N = 25, β = 0.5. The P_d was seen to be constant at 1.17E-33, as number of reservations, k increased from 0 to 24, when combined traffic intensity of both new and handover calls, α = 0.5 and the handover call traffic intensity is also 0.5. This is due to the fact that the value of α = β = 0.5, which implies that the total traffic was that of handover calls. However, as α was set at 1.0, 1.5, 2.0, 2.5, and 3.0, while maintaining β at 0.5, the call drop probability, P_d increased progressively *across* α values. This is because new call arrival increased progressively in the system. For all α values, as k increases, the P_d decreased progressively. It is also observed from the graph, that the impact of the k on P_d is highest at the highest level of α, (ie α = 3) as this means that the small percentage of handover calls have the highest level of prioritization from k.

Figure 6 shows the call blocking probability, P_b for a system with capacity, N = 25, α = 0.9. The P_b was seen to increase from 1.17E-33 to 0.303265, as number of reservations, k increased from 0 to 24 when combined traffic intensity of both new and handover calls, α = 0.5 and the handover call traffic intensity is also 0.5. This is due to the fact that progressively, handover calls are prioritized with the increasing reservations. However, as β was set at 0.2, 0.4, 0.6, 0.8, and 0.9, while maintaining α at 0.9, the call blocking probability, P_b increased progressively across β values. This was as expected because the increased arrival of handover increased the service deprivation for the new calls.

Figure 7 shows the call drop probability, P_d for a system with capacity, N = 25, α = 0.9. The P_d was seen to be constant at 1.88E-27, at k = 0, regardless of the varying β (β = 0.2, 0.4, 0.6, 0.8, 0.9). This is because no reservation is made for handover at this instant. Also, at β = α = 0.9, the P_d remained constant at 1.88E-27, regardless of increasing reservations, k. Even with increasing reservations, the P_d will remain at 1.88E-27 since the entire traffic is that of handover requests at that instant. Another interesting observation was that at β = 0, and k = 1 to 24, the P_d = 0, since there is no handover request at all. The entire traffic is thus that of new calls only.

VII. CONCLUSION

In this paper, the best performing expression out of three developed from a model, for the optimum number of resources to be reserved, R for handover call connections in a GSM network of a given system capacity N, was determined. It was found that the Gaussian Elimination yielded the best equation that represents the system model used. Also, PYTHON program code was written to simulate the model with a view to investigating the impact of varying traffic intensities (α and β), on the call blocking and call drop probabilities, P_b and P_d respectively. It was found that P_b increased from 1.17E-33 to 0.303265, as number of reservations, k increased from 0 to 24, provided β is constant at 0.5. Also, P_d was seen to be constant at 1.17E-33, as number of reservations, k increased from 0 to 24, when α = β = 0. For all α values, as k increases, the P_d decreased progressively, with β = 0.5.

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