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Connection admission control in micro-cellular multi-service mobile networks

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Connection Admission Control in Micro-cellular Multi-service Mobile Networks

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Abstract

This paper investigates the use of fixed bandwidth reservation for Multi-service mobile networks. In particular it extends previous fixed Multi-service network results to the mobile scenario and presents analytical and simulation results for new and handover call blocking probabilities. It also investigates the performance sensitivity to different traffic load ratios as well as the cell dwell time distribution.

1. Introduction

Multiservice networks are expected to be the next generation in Personal Communications networks, taking over from currently successful services such as GSM. Indeed, many problems need to be solved before this is realised, one of these problems is Connection Admission Control (CAC). CAC is the network function that determines whether a particular call is accepted into the network based on a predefined criterion. Traditionally, this criterion has been the availability of bandwidth, but user mobility and multi-rate calls add more constraints to the problem of CAC.¹

The problem of CAC in fixed multi-service networks is a complex problem that has been studied extensively [1]. Another level of complexity is added to the problem when the network supports user mobility. This complexity manifests itself in the addition of another variable to the system: The cell dwell time. In fixed multi-rate networks, each class has a particular arrival rate and holding time, while in mobile multi-rate networks, the amount of time each mobile host spends in the cell has to be also considered. The cell dwell time has been shown to follow a generalised gamma distribution [9], but could be approximated with an exponential distribution [2][3]. The cell dwell time affects the average call holding time for each class as well as the handover rate, and these in turn

affect the overall behaviour of the network. In mobile networks, call termination due to handover blocking is highly undesirable from a subscribers' point of view, while new call blocking is tolerable [10]. Hence the network must insure that handover blocking is much lower than new call blocking for all classes. New call blocking probability of 0.01 and a handover call blocking probability of 0.001 are widely accepted in the literature [3].

One solution that results in achieving lower blocking probabilities for handover calls than new calls is bandwidth reservation. Bandwidth reservation works by putting aside a portion of the bandwidth available in each cell specifically for handover calls. This reserved bandwidth can be shared between all classes of handover traffic or can be partitioned on a per class basis. This reservation could be fixed (pre-allocated in the network design stage) or dynamic.

Fixed bandwidth reservation has the advantage of being the simplest approach. Dynamic bandwidth reservation has many variations, some are measurement based schemes taking into account the handover rate into the cell [3], while others use the motion of the user to pre-allocate bandwidth in ahead cells [11]. The major advantage of dynamic bandwidth reservation is its ability to handle dynamically changing traffic loads. This comes at the cost of extra complexity as a great body of information has to be collected and processed in order to determine the amount of bandwidth to reserve. This paper only considers the fixed reservation case.

Although other studies have looked at similar problems, the solutions presented in the literature have been computationally intensive (especially when network size is large and many classes are considered) [7], or the network topologies being considered are not general enough [8]. The solutions presented in this paper build up on previous work originally intended for fixed multirate-networks [5] and present an approximate and fast method for calculating new and handover call blocking probabilities. A simple rule for optimising utilisation while maintaining new and handover call blocking constraints is also presented.

¹ Eryk Dutkiewicz is now with Motorola Australia Research Labs.

Section 2 of this paper describes the network model presents the simulation and analytical results, Section 5 presents a study of utilisation, Section 6 presents a sensitivity study, it considers the effect of the ratio of traffic loads on performance and the effect of changing the cell dwell time distribution on the blocking probabilities, while Section 7 presents the conclusion.

2. Multiservice Mobile Network Model and Analysis

An ideal (typical) 2 dimensional mobile network model is considered. Edge conditions are satisfied by the cells rapping around to form a toroidal structure [12]. Each cell has capacity C and supports K different service classes, while each class requires bandwidth c_i . The assumption is made that classes requiring less bandwidth are subsets of classes that require more bandwidth. Hence a call requiring 10 kb/sec is a subset of calls that require 100 kb/sec. The admission control policy is defined as follows: A new call is admitted to the cell if

$$c_i + \sum_l^K n_l c_l \leq \theta_i \quad (1)$$

where n_i is the number of ongoing class i calls and θ_i is the allowable bandwidth that can be used for a particular class within a cell. For example if the total available bandwidth is 1000 kb/sec, and 10% of bandwidth is reserved for handover calls, θ_i for new calls is set to 900 kb/sec. A handover call is admitted to the cell if

$$c_i + \sum_l^K n_l c_l \leq C \quad (2)$$

Hence a handover call of any class has access to the full capacity of the cell, while a new call has access to a portion of the channel capacity.

This problem definition is very similar to Trunk Reservation in ATM networks [5], with some small differences. In Trunk Reservation, particular classes are restricted to using a portion of the total bandwidth, hence these classes suffer from more call blocking than classes that are able to use the total bandwidth. In the mobile scenario, new calls (class 1 and class 2) are restricted to using a portion of the total cell bandwidth, while handover calls (class 1 and class2) have access to all the bandwidth. Hence for the mobile multi-rate network, any new class i has a corresponding class for handover, which has full access to all the cell bandwidth.

The equations in [5] can be used to describe the mobile network with some changes. These changes are in the offered load from each class, $(\lambda_i/\mu_i) = \rho_i$. In each cell the

and analysis, Section 3 describes the simulation, Section 4 effective call holding time $(1/\mu_i)$ will be less than the users' call holding time $(1/t_i)$ due to handovers [14]. The effective call holding time in each cell is a function of the cell dwell time $(1/d_i)$ and the call holding time $(1/t_i)$. As previously stated, the cell dwell time is the time that a call spends in a cell and it can be modeled with an exponential distribution [2]. The effective call holding time is given by [13]:

$$\frac{1}{\mu_i} = \frac{1}{t_i + d_i} \quad (3)$$

and the handover probability is given by

$$p_h = \frac{d_i}{t_i + d_i} \quad (4)$$

Hence the handover rate λ_h is given by

$$\lambda_h = \lambda_n p_h (1 - b_i) \quad (5)$$

where λ_n is the arrival rate of new calls for a particular class and b_i is the new call blocking probability for that particular class. Hence the handover rate is a function of the new call blocking probability. In this paper we make the assumption that the reduction in λ_h due to new call blocking is small and can be ignored for now.

The following analysis extends the results in [5] into the mobile network environment. Define M the total number of effective bandwidth units as

$$M = C/\Delta c \quad (6)$$

where Δc is the greatest common divider of all the bandwidth requirements of the different service classes and C is the total bandwidth in the cell. Now define m_i to be the number of effective bandwidth units required per class,

$$m_i = c_i/\Delta c \quad (7)$$

The unnormalised probabilities of being in each state are given by,

$$\tilde{p}^*(m) = \begin{cases} 1 & : m = 0 \\ 0 & : m < 0 \\ \frac{1}{m} \sum_{i=1}^N \tilde{p}^*(m - m_i) m_i (m) (\lambda_i/\mu_i) & : 0 < m \leq M \end{cases} \quad (8)$$

where $m_i(m)$ is given by,

$$m_i(m) = \begin{cases} m_i & : m\Delta c \leq \theta_i + c_i \\ 0 & : m\Delta c > \theta_i + c_i \end{cases} \quad (9)$$

One can then obtain the normalising factor G by summing across all the steady state probabilities,

$$G = \sum_{m=0}^M \tilde{p}^*(m) \quad (10)$$

The normalized probabilities are given by

$$p^*(m) = \frac{\tilde{p}^*(m)}{G} \quad (11)$$

The blocking probability b_i for each class is given by

$$b_i = \sum_{m=\min\{M-m_i, \theta_i/\Delta c\}+1}^M p^*(m) \quad (12)$$

Hence we have approximate single dimensional equations (which are quickly solved recursively) that represent this ideal system.

3. Simulation Model

A simulation was performed to validate the analytical solution of Section 2 to the problem of determining call blocking probabilities for a multi-rate mobile network. The simulation uses a network of 64 cells (8x8), with cells rapped around at the edges forming a toroidal shape. This makes dealing with edge conditions easier, while only having a very slight impact on results [6]. Two traffic classes were considered; low and high bandwidth (e.g. voice sources and video sources), with class 2 needing 10 times more bandwidth than class 1 (10 kb/sec and 100 kb/sec). The capacities in each cell are equal with each having a total capacity of 1000 kb/sec. The call holding time is set to 100 sec [15], while cell dwell time is set to 1000 sec. The cell dwell time corresponds to a cell with an approximate diameter of 1 km. New call arrivals follow a Poisson distribution while call holding times and cell dwell times are exponentially distributed. The handover probabilities of each cell to any other cell are equal (i.e. 1/6).

The conditions are set for a moderate load with both classes of traffic assumed to be exerting equal load. The total effective cell utilisation γ is 0.6. The effective cell utilisation γ is the total load offered (new and handover calls from both classes) divided by the bandwidth available. The effective cell utilisation is given by

$$\gamma = \frac{1}{M} \sum_{i=1}^N \left(\frac{\lambda_{n,i}}{\mu_{n,i}} + \frac{\lambda_{h,i}}{\mu_{h,i}} \right) \quad (13)$$

where n and h subscripts stand for new and handover arrival and service rates respectively.

4. Analytical and Simulation Results

Figure 1 shows the blocking probabilities for both classes of traffic for new and handover calls as the amount

of bandwidth reserved for handover traffic is increased in each cell.

Figure 1 shows that handover blocking probability decreases as more bandwidth is reserved in each cell for both classes of traffic. The figure also shows that bandwidth reservation is most effective if bandwidth is reserved in multiples of class bandwidth requirements. For example, a dramatic improvement is obtained for class 1 handover blocking if enough bandwidth for a single class 1 call is reserved, while 10% (100 kb/sec) of the cell bandwidth needs to be reserved (corresponds to one class 2 call) for a significant improvement in class 2 handover blocking probability.

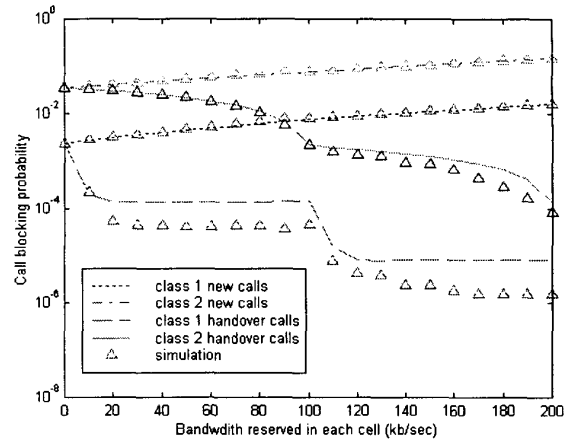


Figure 1. Blocking probabilities of both classes of traffic for new and handover calls as the bandwidth reserved is increased.

In some cases there is a discrepancy between the simulated and the analytical results. This is most apparent for class 1 handover calls. This difference is due to the fact that the total load into the cell (for the particular class) is over estimated. The total load into the cell is a function of the new call blocking probability and the handover blocking probability, but the load is in turn part of the equations for the calculations of these values. Hence the actual load will be smaller than the predicted load which is only calculated using the effective call holding time. The equations in this case provide worst case performance, but it should be stated that the equations are accurate for the required region of interest (blocking probabilities between 0.001 and 0.05).

It is interesting to note that Figure 1 shows a kind of non-linear behaviour. This is clearly evident for class 1 and 2 handover calls, where the non-linearities occur on multiples of class 2 traffic bandwidth reservations. As stated earlier a significant improvement in performance is obtained when 1% of bandwidth is reserved (enough for one class 1 call, 10kb/sec), but this quickly saturates and by the time 10% of the bandwidth is reserved

(corresponding to one class 2 call) the performance is slightly worse. This is due to the fact that class 2 calls are blocked most of the time when only a small amount of bandwidth is reserved, but as more and more bandwidth is reserved, more class 2 calls are accepted. Finally when enough bandwidth is reserved for a single class 2 call, class 2 is competing 'fairly' with class 1 traffic. At this point if one class 2 call is accepted into the reserved bandwidth it has the potential of blocking 10 class 1 calls, hence the slight reversal of direction in the curve.

Similar non-linear behaviour exists for new class 1 and 2 blocking probabilities. The effect is not prominent due to the fact that relatively speaking only a small amount of bandwidth is being "taken away" from the total amount of available bandwidth, while for the handover case the reserved bandwidth forms the majority of bandwidth that handover traffic competes for.

5. Effective Channel Utilisation

In wireless mobile networks, an important objective is to optimise network resources (including the total cell bandwidth) while maintaining the required performance objectives (in terms of new and handover call blocking probabilities). The optimum bandwidth utilisation was investigated while maintaining the performance constraints. Again the case of two classes was investigated, class 1 requires 10 kb/sec of bandwidth and class 2 requires 100 kb/sec, while the total capacity of each cell is 1 Mb/sec. New call blocking probabilities for both classes of traffic were set to 0.01 while handover blocking probabilities for both classes were set to 0.001. The load from both classes is equal.

Figure 2(a) shows that the optimum effective utilisation is obtained when 90 kb/sec is reserved for handover calls. The cell dwell time is 1000 seconds (corresponding to a slow moving mobile in a 1 Km cell), while call holding time is 100 seconds. This value is close to the bandwidth that is required by a single class 2 call (100 kb/sec). The optimum utilisation is a compromise between the handover blocking probability of class 2 calls and new class 2 call blocking probability. As more bandwidth is reserved, the utilisation increases, until a point where the constraint on new call blocking comes into effect and starts reducing the utilisation.

Figure 2(b) shows the effective utilisation for different cell dwell times. The graph shows that reserving bandwidth is effective for larger cells while for small cells, the advantage gained by bandwidth reservation is minimal. This is because a large proportion of the total load seen by the cell will be handover traffic and not new call traffic (due to many handovers), and when only a fraction of the total bandwidth is reserved, this will not be sufficient to significantly reduce the handover blocking probability. Significant improvement is only gained after a large

portion of bandwidth is reserved, but this adversely affects the new call blocking probability.

The previous case study looked at a traffic mix of two classes with one class requiring 10 times more bandwidth. While keeping the bandwidth requirement for class 1 constant at 10 kb/sec, the requirement for class 2 traffic was varied between 10 kb/sec (hence one class is formed) to 240 kb/sec and the cell dwell time was maintained at 1000 seconds. Figure 3 shows the required amount of reserved bandwidth in each cell that results in obtaining the maximum effective utilisation.

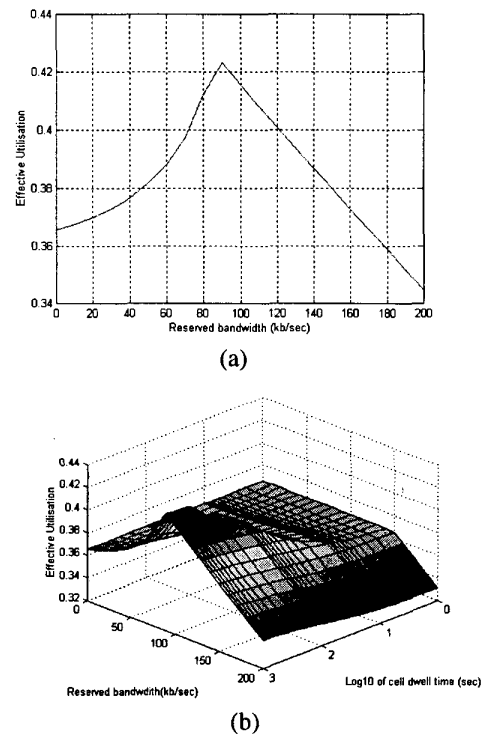


Figure 2. Effective channel utilisation against reserved bandwidth for cell dwell time of 1000 seconds (a), and for a range of cell dwell times (b).

When capacity is set at 1 Mb/sec, the line displays non-linear behaviour, but when the capacity is increased to 10 Mb/sec, the behaviour becomes more linear and indeed approaches the line where class 2 bandwidth requirement equals reserved bandwidth. The non-linear behaviour is due to the fact that the ratio of capacity to traffic requirement is decreasing and hence the effects of certain combinations of traffic size and reservation are much more pronounced. When the ratio of capacity to traffic bandwidth requirement is increased, the effects of these combinations are not prominent.

Hence class two has the major effect on the cell bandwidth utilisation since it is the largest class and

dictates the blocking probability constraints. As class 1 is a subset of class 2 traffic, its blocking probability is always less than the class 2 blocking probability. The conclusion can be made that the optimum effective utilisation is affected by the class 2 bandwidth requirement. This can be extended further to say that the class with the highest bandwidth requirement will dictate the amount of reserved bandwidth (as all other classes are subsets of the highest class and hence have lower blocking probabilities).

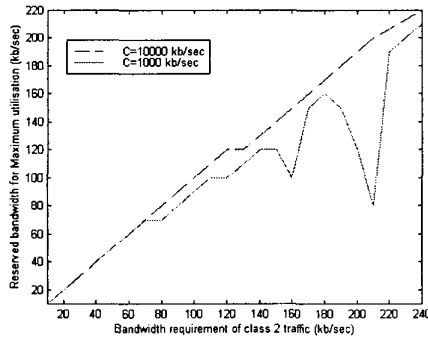


Figure 3. Bandwidth reserved against the bandwidth requirement of class 2 that result in the maximum effective bandwidth utilisation.

6. Sensitivity Study

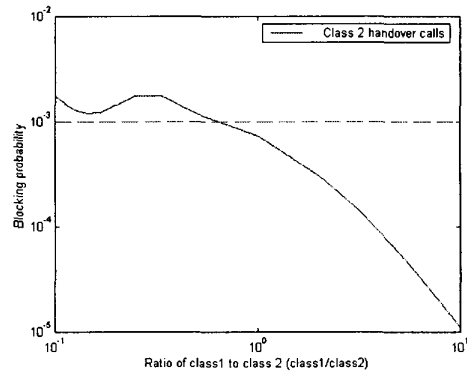
An important aspect of any network is how well it will behave if there was some change to its input conditions. Two of these conditions are the traffic ratio (proportion of each traffic class to the overall load) and the cell dwell time, both of which will impact on the call blocking probabilities of all classes. Two sensitivity studies were performed, one dealing with the effects of a changing traffic ratio, while the other studies the effect of changing the cell dwell time distribution on the new and handover blocking performance for the two classes of traffic.

6.1. Traffic Ratio Study

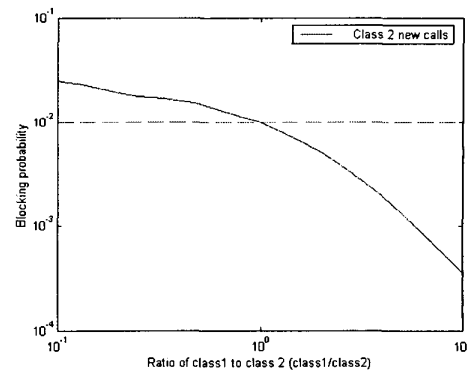
A sensitivity study was performed to test the performance of fixed bandwidth reservation when loads from each class differ from the loads used to design the network (In this case the effective loads from each class were assumed to be equal). 90 kb/sec of bandwidth was reserved and a 42.5% (total) load applied (this is the load that met the design conditions of new call blocking of 0.01 and handover blocking of 0.001, when the loads from both classes of traffic are equal and utilization is optimum). The total load was kept constant, while the ratio of the two classes was varied. Figure 4(a) shows that as class 1 load increases with respect to class 2 (moving towards the right from the center, with the center of the graph being the point when the loads from both classes are equal and have

a ratio of 1:1), the handover blocking probability of class 2 is reduced dramatically. Hence bandwidth is under utilised at this stage. As the load from class 2 increases with respect to class 1 load, the handover blocking probability increases moderately, but it is still well below the blocking constraint of new calls (blocking probability of 0.01).

Figure 4(b) shows similar behaviour to Figure 4(a), with a reduction in blocking as the class 1 load is increased and an increase when the class 2 load is increased. One observation is that even if class 2 to class 1 load ratio is 10:1, the effect on the call blocking probability is not dramatic.



(a)



(b)

Figure 4. New (a) and Handover (b) Call blocking probabilities for class 2 as the ratio of class 1 to class 2 is varied with the total load kept on the optimal value.

Class 1 new and handover call blocking sensitivity showed similar behaviour and their performance constraints are always met as long as the requirements of class 2 are met because class 1 is a subset of class 2.

6.2. Cell Dwell Time Sensitivity

An accurate description of the cell dwell time is a critical part of analyzing the problem of Multi-service Mobile

Networks. Thus far the cell dwell time has been assumed to follow a negative exponential distribution. Zonoozi [9] has described the cell dwell time by using a generalised gamma distribution, while Fang [17] proposes the use of a hyper-Erlang distribution. Traffic studies have shown that the call holding times for current cellular networks follow a lognormal distribution [16]. All of the for-mentioned distributions can have a squared coefficient of variation higher than 1 except the exponential distribution which has a coefficient of 1. The squared coefficient of variation provides an important measure of the variability of the distribution and is defined by

$$c^2 = \frac{\sigma^2}{\mu^2} \quad (14)$$

where σ^2 and μ are the variance and mean respectively.

The simulation (in section 3) was used to obtain the blocking probabilities with 3 different distributions for the cell dwell time. These were the exponential, gamma and lognormal distributions. Figure 5 shows the different blocking probabilities of classes 1 and 2 for a mean cell dwell time of 1000 seconds, while Figure 6 shows the blocking probabilities for a cell dwell time of 100 seconds.

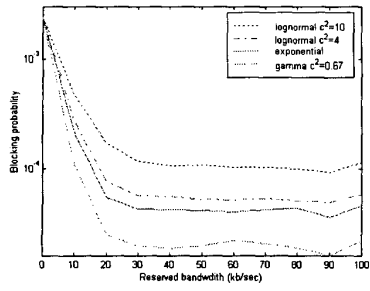
Both figures show that as the c^2 is increased (increasing the variance), the blocking probabilities increase. This is most apparent in Figures 5(a) and 6(a), where the difference in performance is large. The graphs also show that the difference gets larger as more bandwidth is reserved.

7. Conclusion

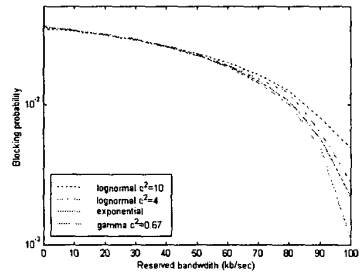
In this paper the problem of Connection Admission Control was investigated with fixed bandwidth reservation. Analytical approximations were shown to agree with simulation results for an ideal multi-rate cellular network. It was concluded that fixed bandwidth reservation is effective if the cell dwell time is relatively large compared to the call holding time and it was observed that the use of fixed bandwidth reservation where the cell dwell time is comparable to the call holding time is not effective. To obtain maximum utilisation, it was observed that enough bandwidth should be reserved for the dominant class (the class with highest bandwidth requirement) if all class loads are equal. This observation holds when the total cell capacity is large compared to the dominant class, but when the dominant class bandwidth requirement approaches the total capacity of the cell, the equations have to be used to obtain the maximum value of effective utilisation. Also, a sensitivity study was carried out to show the impact of changing the ratio of class loads on the blocking probabilities. It was also observed that the cell dwell time distribution has an impact on call blocking performance.

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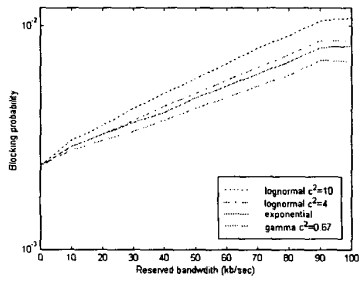
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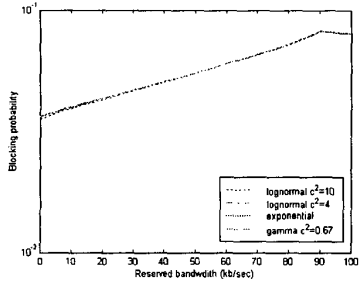
(a)



(b)

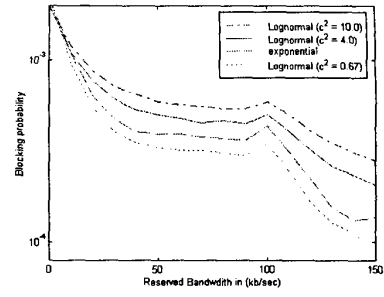


(c)

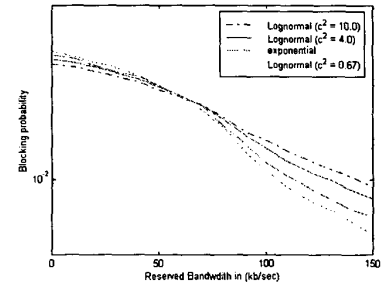


(d)

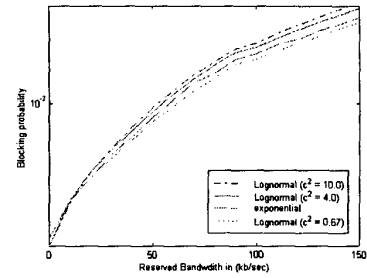
Figure 5. Blocking probabilities against reserved bandwidth for a mean cell dwell time of 1000 seconds, (a) class 1 handover calls, (b) class 2 handover calls, (c) class 1 new calls and (d) class 2 new calls.



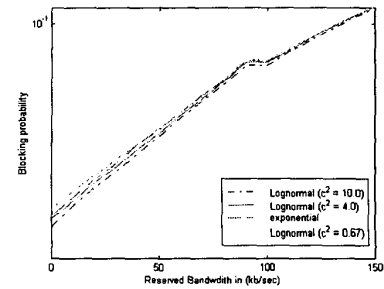
(a)



(b)



(c)



(d)

Figure 6. Blocking probabilities against the reserved bandwidth for a mean cell dwell time of 100 seconds., (a) class 1 handover calls, (b) class 2 handover calls, (c) class 1 new calls and (d) class 2 new calls.