Performance Analysis of Microcellisation with Channel Reservation, for Supporting Two Mobility Classes in Cellular Wireless Networks*

Shashi B. Tripathi† and Anurag Kumar
Dept. of Electrical Communication Engg.
Indian Institute of Science, Bangalore, 560012, INDIA
e-mail: shashi, anurag@ece.iisc.ernet.in

Abstract

We study a two layer cellular wireless network supporting two mobility classes, and with channel reservation for different types of calls in the two layers. Fast calls are always assigned a channel in the macrolayer; a slow call first attempts to get a channel in the microlayer and, if blocked there, overflows to the macrolayer. Channels are reserved for fast calls in the macrolayer, and for handoff calls in both the layers. Various approximate analyses of an isolated cell are used to iteratively compute the blocking and dropping probabilities, and are compared with simulations. Finally, using a combination of approximate analysis and simulation, we propose a method to design a cellular network with specified Grade of Service (GoS). Such an approach results in a huge saving of computation time.

1 Introduction

In cellular mobile wireless networks, decreasing the cell size yields more frequency reuse, but leads to more handoffs, and hence more signalling traffic, which in turn increases the load on the call processing system. Various techniques are used to overcome this problem. In [2], microcells are overlaid with macrocells which provide channels to accommodate those microcells that currently have no channels available for handover calls, thus reducing handover blocking. In [5], a two layer cellular system has been studied. The macrocells are further divided into microcells. The frequency spectrum is partitioned between micro and macro cells. To reduce the signalling traffic due to handovers, calls from fast mobiles are assigned a channel in a macrocell; calls from slow mobiles are assigned a channel in their microcell, and, if blocked in the microcell, overflow to the corresponding macrocell (see [9] for a technique for classifying vehicles as fast or slow). This approach leads to another problem of unequal grade of service (GoS) for the fast and slow calls, since slow calls are allowed to overflow from the micro to the macro layer. Hence a few channels need to be reserved for fast calls in the macrolayer. Channel reservation is also required to decrease the dropping probability. In [5], the microcellular system with channel reservation is studied only through simulation. Simulation of large cellular networks with a substantial degree of microcellisation is very time consuming; hence the use of simulation in an iterative design process is computationally prohibitive. In the present paper, using the basic model proposed in [5], we have studied analytical techniques for a cellular wireless network with channel reservation for new fast calls and handover fast calls in the macrolayer, and reservation for slow handoff calls in the microlayer.

Trunk reservation has been studied extensively in the context of conventional telephone networks. Our problem yields a multiclass reservation model with different holding times for each class; for this model, exact closed form results cannot be obtained. In [6], a state dependent resource allocation has been studied; they consider, however, equal service rate for all classes. Trunk reservation schemes for multirate services to reduce the disparity in the blocking has been studied in [7]. In [3], an approximation for blocking probabilities is given for multirate services with reservation, which is exact for equal service rates and performs badly as the difference in the service rates increases; one of our approximations is motivated by this work.

We assume fixed channel assignment in the macrolayer. The frequencies assigned to each macrocell are partitioned between the microcells and the original macrocell[1]. We also study a hybrid analysis and simulation method for obtaining an efficient channel partitioning between the microcells and the macrocell in a cell, in order to satisfy the specified GoS.

2 Model, Notation and Analysis Approach

New calls arrive into the macrocells as independent Poisson processes. The conversation time of a call, and a mobile's sojourn time in a cell are assumed to be exponentially distributed; the mean conversation time is $\mu^{-1} = 1$, i.e., time is normalised to this mean time. There are M macro-

*Work supported by the Department of Electronics (Govt. of India) funded ERNET project.

†This author is currently with Silicon Automation Systems, Bangalore, INDIA.

[1] Clearly, there are other more efficient channel allocation schemes, and our analysis approach applies to any static allocation scheme.

cells; cell i, $i \in \{1, 2, ...M\}$, has m_i microcells indexed by $j \in \{1, 2, ..., m_i\}$. There are N_i channels in the i^{th} macrocell; N_i^f (resp. $N_i^h (\leq N_i^f)$) is the number of channels reserved for new fast calls (resp. handoff fast calls). For the j^{th} microcell in the i^{th} macrocell, we define $n_{i,j}$ and $n_{i,j}^h$ as the total number of channels assigned, and the number of channels reserved for handoff calls. Λ_i is the total arrival rate of calls in the ith macrocell, ϕ_i the probability that a new arrival in the macrocell is a fast call, and $\omega_{i,j}$ the probability that a call originating in macrocell i is physically located in the microcell j. $\sigma_{i,j}^{-1}$ denotes the mean sojourn time of a slow call in microcell (i, j), and Σ_i^{-1} denotes that of a fast call in macrocell i. We denote by $r_{i,k}$ the probability that a call leaving macrocell i enters macrocell k, and by $r_{(i,j),(k,l)}$ the probability that a call leaving microcell (i, j) enters microcell (k, l).

We denote the new call **blocking probabilities** by B_{fast} and B_{slow}; typical values are 1% – 2%. **The handoff blocking probability** for a call class (H_{fast} and H_{slow}) is the probability that a handover of that class fails due to non-availability of a channel. **The dropping probability** for a call class is defined as the probability that a call of that class is forced to terminate prematurely due to handover failure; denoted by D_{slow} and D_{fast}; typical values are 0.1% – 0.2%.

As usual, **dynamic** (rather than static) **channel reservation** is considered. Thus, if k channels are reserved for an attempt type (e.g., new fast calls, or handovers) in a group of channels, then if the number of free channels in that group is $\leq k$ only call attempts of that type are accepted.

2.1 The Analysis Approach

At time t, let $X^{(i)}(t)$ and $Y^{(i)}(t)$ be the number of fast and slow calls in the macrolayer of cell i. Let $Y_j^{(i)}(t)$ = the number of slow calls in the macrolayer of cell i that are located in the microcell (i, j); (thus, $Y^{(i)}(t) = \sum_{j=1}^{j=m_i} Y_j^{(i)}(t)$). Let $Z_j^{(i)}(t)$ = the number of slow calls in the microlayer that are located in microcell (i, j). Let $\xi^{(i)}(t) = (X^{(i)}(t), ((Y_j^{(i)}(t), Z_j^{(i)}(t)), 1 \leq j \leq m_i))$.

As usual (see, for example, [1, 4]), the process $\{\xi^{(i)}(t)\}$ is analysed in isolation, assuming that the arrival process of handoffs from the neighbouring cells is Poisson. Then, using the intercell routing probabilities, handoff rates between various cells are obtained. The isolated cell analysis is iterated with these new handoff rates. If this iterative calculation converges (as it does for all the cases we have studied) then the limiting probability distribution of the i^{th} cell is taken to be the stationary distribution of the i^{th} marginal of the process $\{\xi^{(i)}(t), 1 \leq i \leq M\}$. Since the new call arrivals are Poisson and handover arrivals are assumed to be Poisson, this yields an approximation for the new call blocking probabilities and handoff blocking probabilities, which in turn can be used to compute the dropping probabilities.

We carry out the above procedure for the special case of a homogeneous cellular network, i.e., all cells are identical, having the same number of microcells, arrival rates, mean call holding times, sojourn times and number of channels in the macrolayer and the microlayer. Further uniform routing is assumed between the cells. This homogeneous analysis is expected to apply well to the central cells of a large array of identical cells. This is verified by comparing the analysis results with the simulation results from the central 19 cells of a 64 macrocell (8 × 8) network. For the homogeneous model, we denote the stationary marginal random variable for $\{X^{(i)}(t)\}$ by X, for $\{Y_j^{(i)}(t)\}$ by Y_j, for $\{Y^{(i)}(t)\}$ by Y and that for $\{Z_j^{(i)}(t)\}$ by Z_j.

For a macrocell, let λ_o = the arrival rate of new fast calls (thus $\lambda_o = \phi\Lambda$), λ_h = arrival rate of fast call handoffs, and $\lambda_f = \lambda_o + \lambda_h$. We also define ψ_o, ψ_h to be, respectively, the arrival rate of new slow calls in a microcell, that of slow handoff calls in a microcell. Hence $\psi_o = (\Lambda(1-\phi))/m$, and we let $\psi = \psi_o + \psi_h$. The rates λ_h and ψ_h are *a priori* unknown and are calculated iteratively after assuming an initial value for them. The definitions of the random variables X, Y and Z easily yield: $\lambda_h = E(X)\Sigma$ and $\psi_h = (E(Z) + (E(Y)/m))\sigma$. $E(X), E(Y)$ and $E(Z)$ are again functions of the arrival and service rates of fast and slow calls in a cell. Hence, λ_h and ψ_h can be computed iteratively.

2.2 Calculating $B_{fast}, B_{slow}, D_{fast}, D_{slow}$

The Poisson arrival assumption for handoff calls implies that we use the following approximations: $B_{fast} = P(X + Y \geq N - N^h)$; $B_{slow} = P(Z \geq n - n^h, X + Y \geq N - N^f)$; $H_{fast} = P(X + Y = N)$; $H_{slow} = P(Z = n, X + Y \geq N - N^f)$. Using the exponential model for call holding times, and cell sojourn times, and the Poisson arrival assumption for handover calls, we obtain

$$D_{fast} = \Sigma H_{fast}/(\mu + \Sigma H_{fast}) \qquad (1)$$

A slow call (new or handover) can be accepted either in a microcell or in a macrocell. We define $A_s = P(Z < n - n^h)/(1 - B_{slow})$ and $A_s^h = P(Z < n)/(1 - H_{slow})$, i.e., A_s (resp. A_s^h) is the probability that a new (resp. handed-off) slow call is accepted in a microcell given that it is accepted. Once a slow call is accepted in a *macrocell* (since we do not consider slow call repacking as in [5]) it can only be dropped when it crosses a macrocell boundary. Hence (noting that $\sigma/\sqrt(m)$ is the sojourn time parameter for a slow call in a macrocell) we get

$$D_{slow} = \left(A_s \frac{\sigma}{\sigma + \mu} + (1 - A_s) \frac{\sigma/\sqrt(m)}{(\sigma/\sqrt(m)) + \mu} \right) \times (H_{slow} + (1 - H_{slow}) D_{slow}^h) \qquad (2)$$

where D_{slow}^h is the probability that a slow call that is handed off once is eventually dropped. It is easily seen that

$$D_{slow}^h = \left(A_s^h \frac{\sigma}{\sigma + \mu} + (1 - A_s^h) \frac{\sigma/\sqrt(m)}{(\sigma/\sqrt(m)) + \mu} \right) \times (H_{slow} + (1 - H_{slow}) D_{slow}^h)$$

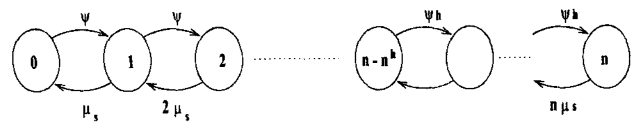


Figure 1: The transition diagram for the process $\{Z(t)\}$ in a microcell. The last n_h channels are reserved for slow handoff calls

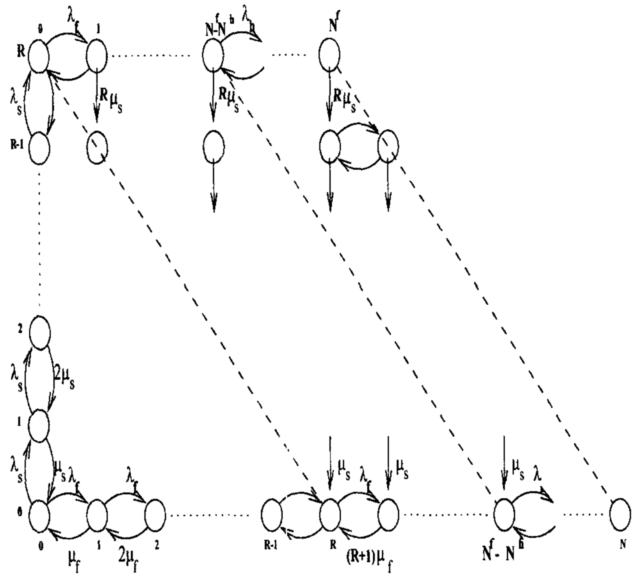


Figure 2: Transition diagram for the Markov chain approximating $\{X(t), Y(t)\}$; $(R = N - N^f)$.

from which it follows that

$$D^h_{slow} = \frac{H_{slow}\left(\frac{\sigma}{\sigma+\mu}A^h_s + \frac{\frac{\sigma}{\sqrt{(m)}}}{\frac{\sigma}{\sqrt{(m)}}+\mu}(1 - A^h_s)\right)}{1-(1-H_{slow})\left(\frac{\sigma}{\sigma+\mu}A^h_s + \frac{\frac{\sigma}{\sqrt{(m)}}}{\frac{\sigma}{\sqrt{(m)}}+\mu}(1 - A^h_s)\right)} \tag{3}$$

Observe that $\left(\frac{\sigma}{\sigma+\mu}A_s + \frac{\sigma/\sqrt{(m)}}{(\sigma/\sqrt{(m)})+\mu}(1 - A_s)\right)$ is the probability that an accepted slow call experiences a handoff; the same expression with A^h_s instead of A_s is the probability that an accepted handed-off slow call experiences a handoff.

3 Approximate Analysis

Stationary Analysis of the Microlayer: For a cell in isolation, with Poisson arrival of new and handover slow calls, $\{Z(t)\}$ is a Markov chain on $\{0, 1, ...n\}$ as shown in Figure 1, where $\mu_s = \mu + \sigma$. The stationary distribution $P(Z = k), 0 \leq k \leq n$, is easily obtained, and then, using Little 's theorem, we get

$$E(Z) = \psi_o(1 - P(Z \geq n - n^h)) + \psi_h(1 - P(Z = n))/(\mu + \sigma) \tag{4}$$

Stationary Analysis of the Macrolayer: Slow calls blocked in microcells (new or handed off) arrive into the macrolayer. Hence in the isolated cell model, the process $\{(X(t), Y(t))\}$ depends on the process $\{Z(t)\}$. If the number of microcells in a macrocell is large, then we can expect that the dependence of the macrolayer process on any particular microcell will be small, and also the microcells will be weakly dependent among themselves. With this in mind, we ignore this dependence and use the stationary probabilities obtained for $\{Z(t)\}$. Hence the rate of arrival of overflow slow calls to the macrolayer (:=λ_s) is approximated as $\lambda_s = m(\psi_o P(Z \geq n - n^h) + \psi_h P(Z = n))$. Thus $\{X(t), Y(t)\}$ is approximated as a continuous time Markov chain (CTMC) on the finite state space $S = \{n_f, n_s : n_f \geq 0, 0 \leq n_s \leq (N - N^f), n_f + n_s \leq N\}$ with the transition diagram shown in Figure 2, where $R := (N - N^f), \mu_f = \mu + \Sigma$, and $\mu_s = \mu + \sigma$. Let the stationary distribution of this Markov chain be denoted by $\pi(n_f, n_s)$.

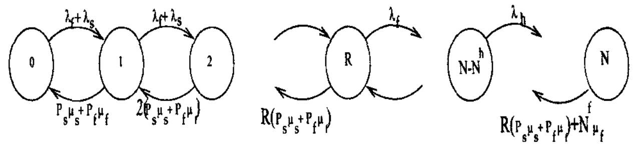


Figure 3: Transition diagram of the Markov chain approximating $\{X(t) + Y(t)\}$ in the one dimensional approximation

3.1 Various approximations to compute $\pi(n_f, n_s)$

A closed form solution is not available for the stationary distribution since $\mu_f \neq \mu_s$. Observe that to get the blocking and dropping probabilities only the sums of the stationary probabilities along the diagonals $n_f + n_s = R, R + 1, \ldots$ are sufficient.

One dimensional approximation: In [5], the case without reservation has been studied. Defining $\rho_f = \lambda_f/\mu_f$, and $\rho_s = \lambda_s/\mu_s$, the stationary distribution in this case is given by the product form

$$\pi(n_f, n_s) = G\rho_s^{n_s}\rho_f^{n_f}/(n_s!n_f!) \tag{5}$$

where, G is the normalization constant. Let $\pi(i) := \sum_{n_f+n_s=i}\pi(n_f, n_s)$. For the no-reservation case, consider the conditional probability

$$\frac{\pi(n_f, n_s)}{\pi(i)} = \frac{i!}{n_s!n_f!}\left(\frac{\rho_s}{\rho_s+\rho_f}\right)^{n_s}\left(\frac{\rho_f}{\rho_s+\rho_f}\right)^{n_f} \tag{6}$$

Thus in the no-reservation case, the probability that a call in the system is fast (:=P_f), is $\frac{\rho_f}{\rho_s+\rho_f}$ and that it is slow (:=P_s), is $\frac{\rho_s}{\rho_s+\rho_f}$. We use this as an approximation in the reservation case, i.e., we assume that with probability P_s a call in the system is slow and with probability P_f the call is fast. We then approximate the process $\{X(t) + Y(t)\}$ by the one dimensional Markov chain shown in Figure 3. The stationary distribution of this chain is easily found. This approximation is exact for $\mu_f = \mu_s$, and tends to perform badly as the difference between these two increases.

The partial product form approximation: When there is no reservation for fast calls in the macrolayer, the resulting Markov chain has a product form for the stationary distribution. Typically, the number of channels reserved for fast calls is small as compared to the total number of channels in the macrolayer. Hence we approximate the stationary distribution of the states $\{(n_f, n_s) : 0 \le n_f \le R, 0 \le n_s \le R\}$ by the product form given by Equation 5. Now, from the balance equation for the state (N^f,R) (see Figure 2), we get $\pi(N^f - 1, R) = \pi(N^f, R)N^f\mu_f/(\lambda_h)$. The idea is to write all the states (i,R), $0 \le i \le N^f$, in terms of $\pi(N^f, R)$, then substitute these values into the balance equation for the state $\pi(0, R)$, and thus find the value of $\pi(N^f, R)$. Once $\pi(N^f, R)$ is known the values of $\pi(i, R)$, $0 \le i \le N^f$ can be computed recursively from the equations obtained.

Now the same procedure can be applied to compute the values of the $\pi(i,j), R < (i+j) \le N$, by first finding the value of $\pi(i,j)$, $i + j = N$, and then computing the values of the other states recursively. Observe that to compute the stationary probability of any state we have to start at the state $(N^f + i,(R\text{-}i))$ $0 \le i \le R$, and then recursively compute the values for the states $(n_f, R-i), i < n_f < (N_f+i)$. Thus, with the product-form approximation having been made for some of the states, the stationary probabilities of all the states can be approximated.

The power method: For comparison, "exact" results for the 2-dimensional Markov chain in the macrolayer are obtained from this iterative method that is asymptotically exact (see [7]). In this method the stationary probability of the embedded Markov chain is obtained by taking increasing powers of its transition probability matrix (aperiodicity is assured by adding a "self-loop", with the same probability, to every state). The stationary probability vector of the CTMC is obtained by suitably renormalising the probability vector of the embedded Markov chain.

4 Validation of the Analyses

Each of the two approximations may work very well for certain parameters and not so well for others. In [8] a detailed study of this is done, by comparing results for the macrocell analysis from the approximations with those obtained from the power method; a rule-of-thumb is developed for choosing the appropriate approximation for given input parameters. In summary, if the difference $| \mu_f - \mu_s |$ is small (less than 0.6), or the ratio of the number of reserved channels to the total number of channels in the macrocell is small (less than 10%), then the one-dimensional approximation is better; otherwise the partial product-form approximation is better. If the rule-of-thumb is followed, the difference between results from the approximation and the power method is less than 5%. It should be noted that this only assures that each iteration of the overall iterative analysis is accurate; there are inherent errors in the iterative analysis for the cellular system, owing to the Poisson and independence assumptions.

Load (Erlangs)	Analysis B_{fast}	Analysis D_{fast}	Simulation B_{fast}	Simulation D_{fast}
85	0.5906	0.0445	0.7883	0.1255
90	1.3311	0.1087	1.4074	0.2072
95	2.4915	0.2172	2.2961	0.3463
100	4.0331	0.3708	3.2729	0.5255
105	5.8609	0.5624	4.5635	0.7519

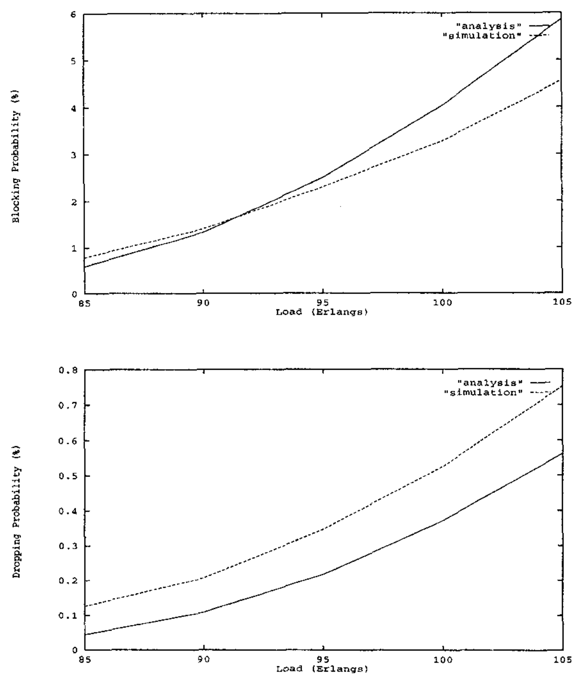


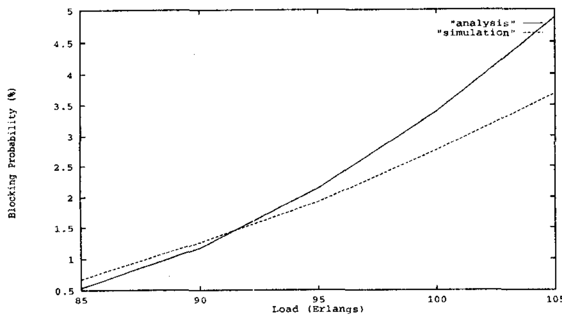
Figure 4: Comparison of analysis and simulation for various loads. The plots show the blocking and dropping probabilities of fast calls (%) for the input parameters: $\phi = 0.4, N = 52, n = 7, \Sigma = 1.0, m = 16, N^f = 7, N^h = 2, n^h = 1$.

In terms of computation times, the one-dimensional approximation takes a fraction of a second, the partial product-form approximation takes a few seconds, whereas the power method takes several minutes.

We shall compare the approximate iterative analysis results with the simulation results for the central 19 cells of a 64 cell network. The number of channels allocated to each macrocell is 80. A reuse factor of 4 is assumed in the microlayer; i.e., $N + 4n = 80$. We assume that fast mobiles travel 5 times as fast as the mobiles. Thus we have the relation $\sigma = \Sigma\sqrt{m}/5$.

Figures 4 and 5 give the numerical values and plots for the fast and slow calls for $\Sigma = 1.0$. Similar results are obtained for other values of Σ also (see [8]). The one-dimensional approximation is used for all these results. Observe that the approximation works well in the range of probabilities of interest (near the desired GoS) except for the slow call dropping probability, for which the errors are large.

Load (Erlangs)	Analysis B_{slow}	Analysis D_{slow}	Simulation B_{slow}	Simulation D_{slow}
85	0.5340	0.0680	0.6731	0.2629
90	1.1693	0.1542	1.2590	0.5136
95	2.1386	0.2906	1.9184	0.7872
100	3.4016	0.4747	2.7644	1.1498
105	4.8799	0.6965	3.6870	1.5056



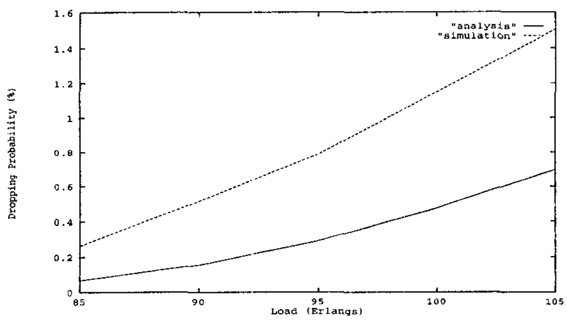


Figure 5: Comparison of analysis and simulation for various loads. The plots show the blocking and dropping probabilities of slow calls (%) for the same input parameters as in Figure 4.

There are several effects present in the simulation that the approximation does not capture: (a) overflow processes are bursty (not Poisson), (b) handover processes are also bursty (not Poisson), (c) the cellular system has a boundary from which there are not handover arrivals.

5 System Design for Given GoS

We consider the GoS: $B_{fast} = B_{slow} = 2\%, D_{fast} = D_{slow} = 0.1\%$. Given the total number of channels per macrocell (taken to be 80), M, N, m, ϕ, and Σ, and the reuse factor in the microlayer (taken to be 4), for the given GoS, we wish to find the the maximum offered load, Λ, and the corresponding (n, N^f, N^h, n^h).

We start the procedure with initial values of Λ, N and $n, N + 4n = 80$. Initially, we take $N^f = N^h = n^h = 1$. Then Λ, N^f, N^h, n^h are adjusted such that the approximate analysis shows the GoS to be achieved. This procedure gives the maximum traffic that can be carried by the network for the chosen values of N and n. We repeat the procedure for one more or one less channel in the microlayer (i.e. 4 more or 4 less channels in the macrolayer). If the value of the maximum load is more than that obtained in the previous step, the procedure is continued until the new break-up does not give any improvement in Λ. There are many iterations involved in carrying out this procedure. Finally, with the obtained design parameters as input, the 64 macrocell simulation program is run to get the exact blocking and dropping probabilities. Thus we use the approximate analysis to get a rough design that is fine-tuned by simulation. Significant computation time savings are achieved this way.

$\Lambda = 107, N = 48, n = 8, N^f = 4, N^h = 2, n^h = 2$				
	B_{fast}	B_{slow}	D_{fast}	D_{slow}
Anal.	2.0288	2.1376	0.1187	0.0883
Simul.	1.3615	1.5658	0.1335	0.1892

$\Lambda = 102, N = 44, n = 9, N^f = 5, N^h = 3, n^h = 3$				
	B_{fast}	B_{slow}	D_{fast}	D_{slow}
Anal.	3.2116	2.7735	0.0575	0.0244
Simul.	2.1856	1.9829	0.0648	0.0578

Table 1: Blocking and dropping probabilities (%) from analysis and simulation in the last two iterations. The input parameters are $\phi = 0.25, \Sigma = 1.0, m = 16$. Λ is the offerred load in Erlangs.

Table 1 shows the results from an example with 80 channels, $M = 64, m = 16, \phi = 0.25, \Sigma = 1$. The top part of the table shows the design obtained in the final iteration of the analysis, the GoS from the analysis, and the exact grade of service from simulation. Since the analysis tends to underestimate the dropping probabilities, observe that the simulation shows that, whereas blocking is close to 2%, the dropping probabilities are about 0.2%. The analytical iteration was continued to obtain lower dropping probabilities. The bottom part of the table shows the result (after a few more iterations) of increasing n to 9 and increasing each of N^f, N^h, n^h by 1. Now the simulation shows that the dropping probabilities are lower than desired, and the maximum carried load is smaller by 5 Erlangs.

The one-dimensional approximation was used, and each iteration of the analysis took about 0.25 seconds, whereas each iteration with the simulation took about 3.5 hours! Since many iterations are typically required, clearly a purely simulation based approach would be computationally very expensive. In the above example only 2 simulation runs were needed.

References

[1] Daehyoung Hong and Stephen S. Rappaport, "Traffic Model and Performance Analysis for Cellular Mobile Radio Telephone Systems with Prioritized and Nonprioritized Handoff Procedures", *IEEE Transactions on Vehicular Technology*, Vol VT-35, August 1986.

[2] M. Inoue, H. Morikawa, and M. Mizumachi "Performance Analysis of Microcellular Mobile Communication Systems", *IEEE 44th Vehicular*

Technology Conf., Stockholm, June 1994.

[3] K. Lindberger "Blocking for Multi-Slot Heterogenous Traffic Streams Offered to a Trunk Group with Reservation" *Proc. of 5th Int. Teletraffic Congress* , 1987.

[4] David Macmillan, "Traffic Modelling and Analysis for Cellular Mobile Networks", *International Teletraffic Congress, ITC-13*, pp 627-632, 1991.

[5] K. Maheshwari and A. Kumar "Performance Analysis of Microcellisation for supporting two mobility classes in cellular wireless networks", *National Communication Conference*, IIT Madras, March 1997.

[6] D. Mitra and I. Ziedins "Virtual Partitioning by Dynamic Priorities: Fair and Efficient Resource-Sharing by Several Services" *International Zurich Seminar on Digital Communications*, Feb. 1996, Springer, Lecture Notes in Computer Sciences.

[7] M. I. Reiman and J. A. Schmitt "Performance models of multirate traffic in various networks inplementations" *Proc. 14th Int. Teletraffic Congress*, 1994.

[8] Shashi B. Tripathi, "Performance Analysis of Microcellisation with Channel Reservation in Cellular Wireless Networks" *Master of Engineering thesis, Dept. of Elec. Communication Engg., I.I.Sc., Bangalore.*, June 1997.

[9] K.L. Yeung and S. Nanda, "Optimal Mobile-Determined Micro-Macro Cell Selection", *IEEE International symposium on Personal, Indoor, and Mobile Radio Communication (PIMRC)*, pp. 294-299, 1995.