

OPTIMAL CHANNEL ALLOCATION IN CELLULAR SYSTEMS

M. Jain*, Kriti Priya** and Rakhee***

*Institute of Basic Science, Dr. B.R. Ambedkar University, Khandari,
Agra-282005, India*

*Email: * madhujain@sancharnet.in, **chaya_rakhee@yahoo.com,
***priyakriti@yahoo.com*

ABSTRACT

We address the problem of determining the optimal number of reserved and unreserved channels in cellular networks with integrated voice/data traffic. Four prioritized channel assignment schemes are considered for which the optimal number of channels for different traffic is determined. In scheme 1 (CAS 1), a fixed number of channels are reserved especially to serve hand-off calls. Scheme 2 (CAS 2) provides a buffer to the hand-off voice calls so that they could be served when the channel gets free. In scheme 3 (CAS 3), the new calls are allowed to use the reserved channels also, if they are available. In order to cope with the heavy traffic conditions, the reserved channels are subrated to accommodate more voice users in scheme 4 (CAS 4). The optimal number of channels to be allocated to each cell in all the schemes is calculated using an iterative algorithm, which minimizes the overall blocking probability of the handoff calls by solving a non-linear integer-programming problem. All the schemes are compared in terms of blocking probabilities of hand-off calls and new calls, overall blocking probability and carried load by using numerical illustrations.

Keywords: wireless communication, optimal channel allocation, subrating, prioritized channel assignment.

1.0 INTRODUCTION

In the past few years, there has been a tremendous growth in the demand for wireless communication services. Cellular technology has provided a strong backbone for dealing with this increasing demand. The service area in the cellular systems is divided into small cells, each of which is allocated a particular set of frequency channels. These frequency channels are reused many times to make efficient use of the limited bandwidth. Usually, we deal with two types of calls while studying cellular systems i.e., new calls and hand-off calls. The hand-off calls are the ones, which are already ongoing but have moved onto a new cell and need to connect to a new base station. The blocking probability of the hand-off calls is an important GoS (Grade of Service) metric of mobility management in cellular systems (cf. Rappaport, 1992). The main issue in cellular systems is to decide the number of frequency channels that should be assigned to each cell so that a pre-specified level of GoS can be achieved. Many researchers have addressed the problem of channel assignment. Most of the channel allocation schemes, which were proposed in the earlier days by several researchers (cf. Anderson, 1973; Eklundh, 1986; Karlsson and Eklundh, 1989), were aimed at improving the channel utilization. However, prioritized channel assignment schemes which took hand-off calls into consideration were also considered by Oh and Tcha (1992), Hong and Rappaport (1989), Purzynski and Rapport (1995), Ortigoza-Guerrero and Aghvami (1999). Jain (2000) discussed the prioritized channel schemes in mixed cellular radio systems. Jain and Rakhee (2002) suggested priority based channel assignment schemes for PCS with integrated traffic. These schemes were based on reserving a fixed number of frequency channels for the hand-off calls.

With the fast growing applications of multimedia, it has become desirable for wireless cellular networks to deliver broadband services for integrated traffic, which includes voice calls, data calls and images. To support this traffic scenario, cell sizes are reduced. This has resulted in an increase in the number of hand-offs and the forced termination probability. Recently, a new scheme has been reported in the literature in which a new channel is created for a hand-off attempt by subrating an existing cell. Lin et al. (1995) proposed a subrating channel assignment strategy where an occupied full rate channel is divided into two half-rate channels; one to serve the existing call and the other one to serve the hand-off request. Li and Alfa (1999) proposed that only the reserved channels could be splitted into two different rate channels. Jain and Rakhi (2001) suggested subrated channel assignment schemes for integrated traffic.

To implement any prioritized channel allocation scheme in real time systems, it is necessary to know the optimal number of channels which should be reserved exclusively for the hand-off calls, or the optimal number of channels which should be subrated. The determination of the number of channels for prioritized channel assignment schemes is an important issue, which has also attracted the attention of researchers. Davoli and Maryni (2000) suggested a two level approximation for admission control and bandwidth allocation. Lin and Lin (2001) provided a method for calculating the optimal number of channels for GPRS, using neural networks. They used the backpropagation algorithm for computing the optimal number of channels to be allocated to various users.

A cluster of cells is considered for analyzing the performance of the cellular system instead of a single cell. Our aim in this investigation is to decide the number of reserved and unreserved channels to be allocated in each cell of the cellular cluster with integrated traffic. The novel feature of this investigation over the existing literature is the determination of the optimal number of reserved channels, which seems to be a major design goal in the cellular architecture of future generations. In earlier work (cf. Jain (2000), Jain and Rakhee (2001, 2002)), we have suggested various channel assignment schemes for reducing the blocking probabilities of the calls. In this paper, we develop an algorithm for computing the optimal number of channels, to be reserved for the handoff calls. The algorithm aims at minimizing the overall handoff blocking probability for various assignment policies, which results in lesser blocking of handoff voice calls. Special provision of subrating is made in an improved policy so as to give priority to handoff voice attempts. This results in reducing the loss of ongoing calls, but of course at the cost of new calls in case of heavy traffic.

We consider four prioritized channel assignment schemes for which the optimal channel allocation is done. In scheme 1, a fixed number of channels are reserved exclusively for the hand-off calls. In order to accommodate more and more hand-off voice call users and to reduce the blocking of these calls, there is a provision of finite buffer for hand-off voice attempts in scheme 2. In scheme 3, the channels reserved for handoff calls may also be accessed by the new calls if available, in case of low handoff traffic. Subrating of the reserved channels in order to accommodate more voice calls, is done in scheme 4. The rest of the paper is organized as follows. In section 2, we discuss the traffic model along with the assumptions and notations being used in the formulation of the mathematical model. Section 3 describes all the channel assignment schemes

with the expressions for respective blocking probabilities. An iterative algorithm for computing the optimal number of channels to be allocated in each cell of a cellular cluster is provided in section 4 by formulating a constrained non-linear integer-programming problem. Numerical illustrations are reported in section 5. Finally, conclusions are drawn in section 6.

2.0 THE TRAFFIC MODEL

We consider a cluster of K hexagonal cells of uniform size in a cellular network as shown in Fig. 1. The traffic in the network is non-uniform and is supposed to consist of two types of calls i.e., voice calls and data calls. The arrival rates of all the calls are assumed to be Poisson and the service times are distributed exponentially. Also, the mean call holding times, call degradation times and call residence times follow exponential distribution.

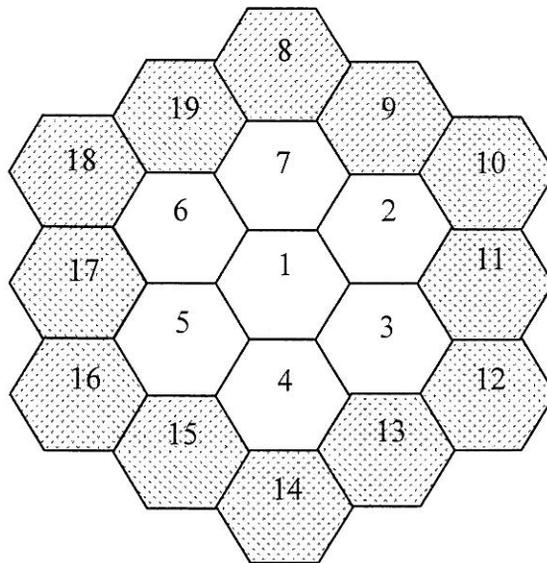


Fig 1: A Cluster of K Hexagonal Cells of Uniform Size in a Cellular Network

The following notations are used for formulating the mathematical model:

C	Number of channels allocated to a cell
TC	Number of channels allocated to the cluster
r	Number of channels reserved for handoff calls
s	Number of channels which serve both types of calls
N	Buffer size for handoff voice calls
$1/\mu_0$	Mean call-holding time
$1/\mu_\Delta$	Mean call-degradation time
$1/\eta$	Mean cell residence time of each portable
$\lambda_{\varphi, v\varpi} (\lambda_{\varphi, v\delta})$	Arrival rates for new voice (new data) calls in cell j, (j=1,2,...,K)
$\lambda_{\varphi, \eta\varpi} (\lambda_{\varphi, \eta\delta})$	Arrival rates for handoff voice (handoff data) calls in cell j, (j=1,2,...,K)
$\Lambda_{\varphi, v}$	Arrival rate of new calls so that $\Lambda_{\varphi, v} = \lambda_{\varphi, v\varpi} + \lambda_{\varphi, v\delta}$, (j=1,2,...,K)
$\Lambda_{\varphi, \eta}$	Arrival rate of handoff calls so that $\Lambda_{\varphi, \eta} = \lambda_{\varphi, \eta\varpi} + \lambda_{\varphi, \eta\delta}$, (j=1,2,...,K)
Λ_{φ}	Arrival rate of calls in each cell; $\Lambda_{\varphi} = \Lambda_{\varphi, v} + \Lambda_{\varphi, \eta}$, (j=1,2,...,K)
$P_{j,0}$	Steady state probability that there is no call in cell j
$P_{j,n}$	Steady state probability that there are n calls in cell j
$B_{j,n}$	Blocking probability of new calls in cell j, (j=1,2,...,K)
$B_{j,h}$	Blocking probability of handoff data calls in cell j, (j=1,2,...,K)
$B_{j,v}$	Blocking probability of handoff voice calls in cell j, (j=1,2,...,K)
B	Overall blocking probability
CL	Carried Load

**Note: For the sake of simplicity, we have dropped the suffix j in section 3.

3.0 CHANNEL ASSIGNMENT SCHEMES

In this section, we discuss all the four prioritized channel assignment schemes. The expressions for the steady state probabilities, blocking probabilities of new and hand-off calls and the carried load are provided for each scheme. The steady state diagrams for all the schemes are shown in Figures 2-5.

3.1 Channel Assignment Scheme 1 (CAS 1)

In cellular communication systems, it is important to give priority to the ongoing calls in comparison to the new calls. In this scheme, r channels among the total C channels are reserved for serving the hand-off calls only. The remaining $s=C-r$ channels serve both new and hand-off calls. The steady state probabilities for this scheme are given below:

$$P_n = \begin{cases} \frac{\Lambda^n}{n!(\mu_0 + \eta)^n} P_0, & 0 \leq n \leq s \\ \frac{\Lambda^s \Lambda_h^{n-s}}{n!(\mu_0 + \eta)^n} P_0, & s+1 \leq n \leq C \end{cases} \quad (1)$$

$$\text{where } P_0 = \left[\sum_{n=0}^s \frac{\Lambda^n}{n!(\mu_0 + \eta)^n} + \sum_{n=s+1}^C \frac{\Lambda^s \Lambda_h^{n-s}}{n!(\mu_0 + \eta)^n} \right]^{-1} \quad (2)$$

The blocking probabilities and carried load for this scheme are obtained as follows:

- Blocking probability of new calls is

$$B_n = \sum_{n=s}^C P_n \quad (3)$$

- Blocking probabilities of handoff data and voice calls are given by

$$B_{hd} = B_{hv} = B_h = P_C \quad (4)$$

- The overall blocking probability is calculated as

$$B = \frac{\Lambda_n B_n + \Lambda_h B_h}{\Lambda} \quad (5)$$

- The carried load is given by

$$CL = \frac{\Lambda_n (1 - B_n) + \Lambda_h (1 - B_h)}{\Lambda} \quad (6)$$

3.2 Channel Assignment Scheme 2 (CAS 2)

In this scheme, a finite buffer of size N is provided to the hand-off voice calls along with reserving r channels for the hand-off calls of both types. The hand-off voice calls wait in the buffer till the channel gets free. The data calls are not allowed to be stored in the buffer. The following are the steady state probabilities for CAS 2:

$$P_n = \begin{cases} \frac{\Lambda^n}{n!(\mu_0 + \eta)^n} P_0, & 0 \leq n \leq s \\ \frac{\Lambda^s \Lambda_h^{n-s}}{n!(\mu_0 + \eta)^n} P_0, & s+1 \leq n \leq C \\ \frac{\Lambda^s \Lambda_h^r \lambda_{hv}^{n-C}}{C!(\mu_0 + \eta)^C \prod_{j=0}^{n-C} [C(\mu_0 + \eta) + j(\mu_D + \eta)]} P_0, & C+1 \leq n \leq C+N \end{cases} \quad (7)$$

where

$$P_0 = \left[\sum_{n=1}^s \frac{\Lambda^n}{n!(\mu_0 + \eta)^n} + \sum_{n=s+1}^C \frac{\Lambda^s \Lambda_h^{n-s}}{n!(\mu_0 + \eta)^n} + \frac{\Lambda^s \Lambda_h^r}{C!(\mu_0 + \eta)^C} \sum_{n=C+1}^{C+N} \frac{\lambda_{hv}^{n-C}}{\prod_{j=0}^{n-C} [C(\mu_0 + \eta) + j(\mu_D + \eta)]} \right]^{-1} \quad (8)$$

Now, we obtain performance indices as follows:

- Blocking probability of new calls is given as

$$B_n = \sum_{n=s}^{C+N} P_n \quad (9)$$

- Blocking probability of handoff data calls is given by

$$B_{hd} = \sum_{n=C}^{C+N} P_n \quad (10)$$

- The blocking probability of handoff voice calls is

$$B_{hv} = P_{C+N} \quad (11)$$

- The overall blocking probability is calculated as

$$B = \frac{\Lambda_n B_n + \lambda_{hd} B_{hd} + \lambda_{hv} B_{hv}}{\Lambda} \quad (12)$$

- The carried load is given by

$$CL = \frac{\Lambda_n(1 - B_n) + \lambda_{hd}(1 - B_{hd}) + \lambda_{hv}(1 - B_{hv})}{\Lambda} \quad (13)$$

3.3 Channel Assignment Scheme 3 (CAS 3)

When there is heavy traffic on the network and it becomes difficult to deal with the overflowing traffic, then it becomes desirable to serve the new calls in a different manner. This can be done by using this scheme where the new calls can use the r reserved channels also if they are free, in case of light traffic of handover calls. For this purpose, the following reserve channel releasing function is used

$$f(i) = \frac{1}{2\sqrt{i}}, \text{ where } i = 1, 2, \dots, r.$$

which is a decreasing function of the chance of occupying reserved channels by new traffic load.

Now, we get

$$P_n = \begin{cases} \frac{\Lambda^n}{n!(\mu_0 + \eta)^n} P_0, & 0 \leq n \leq s \\ \frac{\Lambda^s \prod_{i=s+1}^n \{\Lambda_h + f(i-s)\Lambda_n\}}{n!(\mu_0 + \eta)^n} P_0, & s+1 \leq n \leq C \\ \frac{\Lambda^s \prod_{i=s+1}^C \{\Lambda_h + f(i-s)\Lambda_n\} \lambda_{hv}^{n-C}}{C!(\mu_0 + \eta)^C \prod_{j=0}^{n-C} [C(\mu_0 + \eta) + j(\mu_D + \eta)]} P_0, & C+1 \leq n \leq C+N \end{cases} \quad (14)$$

where

$$P_0 = \left[\sum_{n=1}^s \frac{\Lambda^n}{n!(\mu_0 + \eta)^n} + \sum_{n=s+1}^C \frac{\Lambda^s \prod_{i=s+1}^n \{\Lambda_h + f(i-s)\Lambda_n\}}{n!(\mu_0 + \eta)^n} + \frac{\Lambda^s \prod_{i=s+1}^C \{\Lambda_h + f(i-s)\Lambda_n\}}{C!(\mu_0 + \eta)^C} \sum_{C+1}^{C+N} \frac{\lambda_{hv}^{n-C}}{\prod_{j=0}^{n-C} [C(\mu_0 + \eta) + j(\mu_D + \eta)]} \right]^{-1} \quad (15)$$

Blocking probability of new calls is obtained by using

$$B_n = \sum_{n=s}^C P_n \{1 - f(n-s)\} + \sum_{n=C+1}^{C+N} P_n \quad (16)$$

Other performance measures are obtained by using the same formulae as given by equations (10)-(13) for scheme CAS 2.

3.4 Channel Assignment Scheme 4 (CAS 4)

The previous scheme (CAS 3) can be further improved by increasing its capacity to serve more hand-off voice attempts. Scheme CAS 4, is the result of incorporating subrating in scheme CAS 3. Here, a reserved channel is divided into two channels of equal frequency, thus creating a new channel, which serves the hand-off voice attempts at degraded but acceptable quality. The new channel is created only when all the C channels are busy and a new hand-off voice attempt is made.

$$P_n = \begin{cases} \frac{\Lambda^n}{n!(\mu_0 + \eta)^n} P_0, & 0 \leq n \leq s \\ \frac{\Lambda^s \prod_{i=s+1}^n \{\Lambda_h + f(i-s)\Lambda_n\}}{n!(\mu_0 + \eta)^n} P_0, & s+1 \leq n \leq C \\ \frac{\Lambda^s \prod_{i=s+1}^C \{\Lambda_h + f(i-s)\Lambda_n\} \prod_{l=C+1}^n \{\lambda_{hv} + f(l-C)\lambda_{nv}\}}{n!(\mu_0 + \eta)^n} P_0, & C+1 \leq n \leq C+r \\ \frac{\Lambda^s \prod_{i=s+1}^C \{\Lambda_h + f(i-s)\Lambda_n\} \prod_{l=C+1}^{C+r} \{\lambda_{hv} + f(l-C)\lambda_{nv}\} \lambda_{hv}^{n-C-r}}{(C+r)!(\mu_0 + \eta)^{(C+r)} \prod_{j=0}^{n-C} [(C+r)(\mu_0 + \eta) + j(\mu_D + \eta)]} P_0, & C+r+1 \leq n \leq C+r+N \end{cases} \quad (17)$$

where P_0 is calculated by using normalizing condition $\sum_{n=1}^{C+r+N} P_n = 1$.

In this scheme, we obtain various performance indices as follows:

- Blocking probability of new calls is given by
$$B_n = \sum_{n=s}^C P_n \{1 - f(n-s)\} + \sum_{n=C+1}^{C+r} P_n \{1 - f(n-C)\} + \sum_{n=C+r+1}^{C+r+N} P_n \quad (18)$$

- Blocking probability of handoff data calls is
$$B_{hd} = \sum_{n=C}^{C+r+N} P_n \quad (19)$$

- The blocking probability of handoff voice calls is given by
$$B_{hv} = P_{C+r+N} \quad (20)$$

- The overall blocking probability and carried load are determined using equations (12) and (13) as in CAS 2 scheme.

4.0 OPTIMAL CHANNEL ALLOCATION

We formulate a Non-linear Integer Programming Problem (NIPP) below for calculating the optimal number of channels in each cell. This will minimize the overall handoff call blocking probability as

NIPP:

$$\text{Minimize } BH = \sum_{j=1}^K \frac{\lambda_{j,hv}}{\Gamma} B_{j,hv}(s_j, r_j) + \sum_{j=1}^K \frac{\lambda_{j,hd}}{\Gamma} B_{j,hd}(s_j, r_j) \quad (21)$$

$$\text{subject to } B_{j,n}(s_j, r_j) \leq B_{\max}, \quad j=1, 2, \dots, K \quad (22)$$

$$\sum_{j=1}^K (s_j + r_j) \leq TC \quad (23)$$

$s_j, r_j \geq 0$, s_j, r_j ($j=1, 2, \dots, K$) being integers.

Here B_{\max} is the minimum level of grade of service (GoS) to be satisfied by both type of calls and $\Gamma = \sum_{j=1}^K \Lambda_{j,h}$. To solve NIPP we suggest the following algorithm:

Input : $\lambda_{j,nv}, \lambda_{j,nd}, \lambda_{j,hv}, \lambda_{j,hd}$ (for $j = 1, 2, \dots, K$), $\mu_0, \eta, \mu_D, TC, B_{\max}$.

Step 1 For $j = 1, 2, \dots, K$
 Step 1.1 set $k = 0$;
 Step 1.2 set $r_j^0 = 0$;

Step 2 For $j = 1, 2, \dots, K$
 find the smallest integer s_j^0 such that $B_{j,n}(s_j^0, 0) \leq B_{\max}$;

Step 3 Compute $Z = TC - \sum_{j=1}^K s_j^0$;
 Step 3.1 f ($Z > 0$)

- Step 3.1.1 set $(s_j^0, r_j^0) = (s_j^0, 0)$ for all j ;
 Step 3.1.2 go to step 4;
- Step 3.2 If $(Z = 0)$
 Step 3.2.1 set $s_j^* = s_j^0$ and $r_j^* = 0$ for all j ;
 Step 3.2.2 exit;
- Step 3.3 If $(Z < 0)$
 Step 3.3.1 problem NIPP is infeasible and the given channel set TC can not satisfy the pre-specified GoS.
 Step 3.3.2 exit;
- Step 4 For $j = 1, 2, \dots, K$
 Compute $B_{j,n}(s_j^k, r_j^k + 1)$ for all j ;
- Step 5 If $(B_{j,n}(s_j^k, r_j^k + 1) \leq B_{\max})$
 Step 5.1 set

$$\alpha_j^k = \frac{\lambda_{j,hv}}{\Gamma} \{B_{j,hv}(s_j^k, r_j^k) - B_{j,hv}(s_j^k, r_j^k + 1)\} + \frac{\lambda_{j,hd}}{\Gamma} \{B_{j,hd}(s_j^k, r_j^k) - B_{j,hd}(s_j^k, r_j^k + 1)\};$$
 Step 5.2 set $I_k(j) = 0$;
 else
 Step 5.3 set

$$\alpha_j^k = \frac{\lambda_{j,hv}}{\Gamma} \{B_{j,hv}(s_j^k, r_j^k) - B_{j,hv}(s_j^k + 1, r_j^k)\} + \frac{\lambda_{j,hd}}{\Gamma} \{B_{j,hd}(s_j^k, r_j^k) - B_{j,hd}(s_j^k + 1, r_j^k)\};$$
 Step 5.4 set $I_k(j) = 1$;
- Step 6 Find $l \in \{1, 2, \dots, K\}$ so that α_l^k is maximum;
 Step 6.1 If $(I_k(j) = 0)$
 set $\{(s_j^{k+1}, r_j^{k+1}) = (s_j^{k+1}, r_j^k + 1)\}$;
 Step 6.2 If $(I_k(j) = 1)$
 $\{(s_j^{k+1}, r_j^{k+1}) = (s_j^k + 1, r_j^k)\}$;

- Step 7 Set $k = k+1$;
 Step 7.1 If ($k = Z$)
 Step 7.1.1 set $s_j^* = s_j^{k+1}$ and $r_j^* = r_j^{k+1}$ for all j ;
 Step 7.1.2 exit;
 Step 7.2 If ($k < Z$)
 set $\alpha_j^k = \alpha_j^{k+1}$ for all j except l selected in step 6;
- Step 8 Compute $B_{l,n}(s_l^k, r_l^k + 1)$;
 Step 8.1 If ($B_{l,n}(s_l^k, r_l^k + 1) \leq B_{\max}$)
 Step 8.1.1 set

$$\alpha_j^k = \frac{\lambda_{j,sn}}{\Gamma} \{B_{j,m}(s_j^k, r_j^k) - B_{j,m}(s_j^k + 1, r_j^k)\} + \frac{\lambda_{j,hd}}{\Gamma} \{B_{j,hd}(s_j^k, r_j^k) - B_{j,hd}(s_j^k + 1, r_j^k)\}$$

 Step 8.1.2 set $I_k(j) = 0$;
 else
 Step 8.2.1 set

$$\alpha_j^k = \frac{\lambda_{j,m}}{\Gamma} \{B_{j,m}(s_j^k, r_j^k) - B_{j,m}(s_j^k + 1, r_j^k)\} + \frac{\lambda_{j,hd}}{\Gamma} \{B_{j,hd}(s_j^k, r_j^k) - B_{j,hd}(s_j^k + 1, r_j^k)\}$$

 Step 8.2.2 set $I_k(j) = 1$;
 Step 8.2.3 go to step 6;

Output: Optimal number of reserved channels r_j^* and optimal number of unreserved channels s_j^* for $j = 1, 2, \dots, K$.

5.0 NUMERICAL ILLUSTRATIONS

In this section, we compute the optimal number of reserved and unreserved channels in an individual cell of a cellular cluster. By taking numerical illustrations, the algorithm developed in the previous section is examined. We also compare all the schemes considered for optimal channel allocation, in terms of the respective blocking probabilities. The code for optimal channel allocation is written using C programming language, which takes about 4-5 seconds to run on a Pentium III. We consider a cellular cluster of seven cells i.e., $K=7$. The arrival rates of new calls in each cell are generated randomly and the arrival rates of hand-off calls are taken as 10% of that of the new ones. We

compute the blocking probability B_{hd} of hand-off data calls and B_{hv} of hand-off voice calls by taking $\mu_0 = \mu_\Delta = 0.5$, $\eta = 0.4$ and $N = 10$ (for CAS 2).

For various values of TC, Tables 1-4 provide the optimal number of channels (unreserved channels + reserved channels) to be allocated in each cell using the optimal allocation scheme for CAS 1-CAS 4 respectively by taking $B_{max}=2\%$. We observe that the optimal number of channels for each cell in the cluster can be determined, thereby minimizing the overall blocking of the handoff calls. The performance indices like blocking probability of new calls, blocking probability of hand-off calls, overall blocking probability and carried load in every cell for each of schemes are also tabulated. It is clear that the blocking of new calls is smaller in CAS 3 and CAS 4. This is quite obvious since in these schemes, the new calls are also allowed to use the reserved channels.

CAS 4 have lesser B_{hv} than CAS 1 and CAS 3 respectively. This implies that the provision of a finite buffer for hand-off voice calls in CAS 2, decreases the blocking probability to a desirable extent so as to facilitate low frequency channels. Also, by subrating a reserved channel for serving the hand-off voice calls, B_{hv} is decreased further significantly. This indicates that CAS 4 offers lesser blocking to hand voice attempts as compared to CAS 3. Moreover, it can be seen in each of the schemes that B_{hv} increases with the increase in the number of channels.

Fig. 4 illustrates the effect of TC on the blocking probability of hand-off data calls B_{hd} . We note that B_{hd} decreases as TC increases in all the four schemes CAS1-CAS 4. Furthermore, it can be seen that the curves for CAS 1 and CAS 2 coincide with each other. This is due to the reason that the hand-off data calls in CAS 2 are served in a similar manner as in CAS 1, and the buffer is provided to the hand-off voice calls only in CAS 2. Therefore, there is no change in the blocking of hand-off data attempts in CAS 2. We also observe that B_{hd} for a particular value of TC increases from CAS 1 (and CAS 2) to CAS 4 through CAS 3 i.e., at any particular value of TC, $B_{hd}(CAS\ 1) = B_{hd}(CAS\ 2) < B_{hd}(CAS\ 3) < B_{hd}(CAS\ 4)$. This is because in CAS 3, priority is given to hand-off voice calls by providing a finite buffer which decreases their blocking, and simultaneously increases the blocking of the hand-off data calls. This blocking is further increased in CAS 4 since in this scheme, the blocking of hand-off voice calls is decreased by subrating a reserved channel. This results in a noticeable increase in the blocking of hand-off data calls.

On the whole we conclude that

- The Optimal number of reserved channels can be determined in each cell of the cluster such that the overall blocking probability of the handoff calls could be minimized to a desirable extent.
- The prioritized channel assignment schemes considered for determining the optimal channel allocation offer lesser blocking to the handoff calls.
- The provision of the buffer for the handoff voice calls in CAS2 helps in accommodating more and more handoff voice calls. The users may suffer delay in service but they would not suffer from call losses.
- The subrating facility in CAS4 helps in dealing with heavy traffic of handoff voice call.

Figs. 2-4 show the effect of the total number of channels (TC) in the cluster on the blocking probabilities of hand-off voice and data attempts for the four schemes. In Fig. 2, logarithmic curves for B_{HV} are plotted for CAS 1 and CAS 2 by varying TC. In Fig. 3, B_{HV} is depicted against TC for CAS 3 and CAS 4. It can be noted that the blocking probability of hand-off voice calls is most prevalent in CAS 1 and has least value in CAS 4 for a particular value of TC. Further, CAS 2 and

6.0 CONCLUSION

We have presented an iterative algorithm for determining the optimal number of channels to be reserved for handoff calls in a cellular radio system. The optimal allocation of reserved and unreserved channels in a cell is done so as to minimize the overall blocking probability of the handoff calls in a cluster. For this purpose, four prioritized channel allocation schemes are considered. All the schemes can be successfully employed in a real time wireless system for providing a good quality of service to the hand-off calls, as all the schemes reserve a fixed number of channels to serve the hand-off attempts only. CAS 2 offers a finite buffer to the hand-off voice calls to avoid the forced termination of these calls. In CAS 4, the number of channels for serving these calls is increased by subrating the reserved channels. To deal with heavy traffic conditions, schemes CAS 3 and CAS 4 can be utilized, since here the new calls have the facility of using the reserved channels also. It is concluded that the scheme CAS 4 is the best among all the schemes as it can deal with both light as well as heavy traffic efficiently and can reduce the blocking of the hand-off calls of both types to a desirable extent.

Table 1: Optimal channel allocation and performance indices for CAS 1

TC	(s*,r*)	B _n	B _{hd} =B _{hv}	B	CL
170	(25,2)	0.01571	4.95E-05	0.01428	0.98572
	(26,2)	0.01866	6.27E-05	0.01697	0.98303
	(19,1)	0.01714	8.85E-04	0.01566	0.98434
	(22,2)	0.01770	5.28E-05	0.01609	0.98391
	(15,1)	0.01811	8.62E-04	0.01654	0.98346
	(25,1)	0.01472	8.14E-04	0.01346	0.98654
	(27,2)	0.01853	6.35E-05	0.01685	0.98315
180	(25,3)	0.01571	2.71E-06	0.01428	0.98572
	(26,3)	0.01866	3.56E-06	0.01697	0.98303
	(19,3)	0.01719	2.27E-06	0.01562	0.98438
	(22,3)	0.01770	2.79E-06	0.01609	0.98391
	(15,3)	0.01815	1.80E-06	0.01650	0.98350
	(25,3)	0.01477	2.50E-06	0.01343	0.98657
	(27,3)	0.01853	3.65E-06	0.01685	0.98315
190	(25,5)	0.01571	7.33E-09	0.01428	0.98572
	(26,5)	0.01867	1.03E-08	0.01697	0.98303
	(19,4)	0.01719	1.08E-07	0.01562	0.98438
	(22,4)	0.01770	1.42E-07	0.01609	0.98391
	(15,4)	0.01815	7.59E-08	0.01650	0.98350
	(25,4)	0.01477	1.31E-07	0.01343	0.98657
	(27,5)	0.01853	1.09E-08	0.01685	0.98315
200	(25,6)	0.01571	3.62E-10	0.01428	0.98572
	(26,6)	0.01867	5.31E-10	0.01697	0.98303
	(19,6)	0.01719	2.12E-10	0.01562	0.98438
	(22,6)	0.01770	3.29E-10	0.01609	0.98391
	(15,5)	0.01815	3.04E-09	0.01650	0.98350
	(25,6)	0.01477	3.26E-10	0.01343	0.98657
	(27,6)	0.01853	5.69E-10	0.01685	0.98315

Table 2: Optimal channel allocation and performance indices for CAS 2

TC	(s^*, r^*)	B_n	B_{hd}	B_{hv}	B	CL
170	(25,2)	0.01571	4.96E-05	8.09E-24	0.01428	0.98572
	(26,2)	0.01866	6.28E-05	8.19E-22	0.01697	0.98303
	(19,1)	0.01714	8.86E-04	2.26E-21	0.01562	0.98438
	(22,2)	0.01770	5.29E-05	6.25E-24	0.01609	0.98391
	(15,1)	0.01811	8.64E-04	4.69E-21	0.01649	0.98351
	(25,1)	0.01472	8.16E-04	4.70E-20	0.01341	0.98659
	(27,2)	0.01853	6.36E-05	3.25E-22	0.01685	0.98315
180	(25,3)	0.01571	2.71E-06	3.15E-25	0.01428	0.98572
	(26,3)	0.01867	3.56E-06	3.33E-23	0.01697	0.98303
	(19,3)	0.01719	2.27E-06	2.46E-24	0.01562	0.98438
	(22,3)	0.01770	2.80E-06	2.27E-25	0.01609	0.98391
	(15,3)	0.01815	1.81E-06	3.53E-24	0.01650	0.98350
	(25,3)	0.01477	2.50E-06	7.19E-23	0.01343	0.98658
	(27,3)	0.01853	3.65E-06	1.35E-23	0.01685	0.98315
190	(25,5)	0.01571	7.33E-09	4.43E-28	0.01428	0.98572
	(26,5)	0.01867	1.04E-08	5.14E-26	0.01697	0.98303
	(19,4)	0.01719	1.08E-07	7.76E-26	0.01562	0.98438
	(22,4)	0.01770	1.42E-07	8.01E-27	0.01609	0.98391
	(15,4)	0.01815	7.60E-08	9.22E-26	0.01650	0.98350
	(25,4)	0.01477	1.31E-07	2.71E-24	0.01343	0.98657
	(27,5)	0.01853	1.09E-08	2.18E-26	0.01685	0.98315
200	(25,6)	0.01571	3.63E-10	1.60E-29	0.01428	0.98572
	(26,6)	0.01867	5.32E-10	1.95E-27	0.01697	0.98303
	(19,6)	0.01719	2.13E-10	7.11E-29	0.01562	0.98438
	(22,6)	0.01770	3.29E-10	9.25E-30	0.01609	0.98391
	(15,5)	0.01815	3.04E-09	2.33E-27	0.01650	0.98350
	(25,6)	0.01477	3.27E-10	3.58E-27	0.01343	0.98657
	(27,6)	0.01853	5.70E-10	8.48E-28	0.01685	0.98315

Table 3: Optimal channel allocation and performance indices for CAS 3

TC	(s*,r*)	B _n	B _{hd}	B _{hv}	B	CL
170	(25,2)	0.01817	1.34E-03	2.19E-22	0.01659	0.98572
	(27,1)	0.00205	4.08E-03	5.33E-20	0.00202	0.98303
	(19,1)	0.00265	5.29E-03	1.35E-20	0.00263	0.98437
	(22,1)	0.00287	5.73E-03	1.00E-21	0.00293	0.98391
	(15,1)	0.00259	5.16E-03	2.80E-20	0.00252	0.98350
	(25,2)	0.00324	1.24E-03	5.04E-20	0.00298	0.98657
	(28,1)	0.00207	4.14E-03	2.11E-20	0.00207	0.98315
180	(25,3)	0.01837	2.85E-04	3.31E-23	0.01671	0.98572
	(27,2)	0.00272	1.05E-03	9.83E-21	0.00251	0.98303
	(19,2)	0.00344	1.24E-03	2.05E-21	0.00318	0.98438
	(23,2)	0.00225	8.26E-04	6.70E-23	0.00210	0.98391
	(16,2)	0.00167	5.34E-04	1.04E-21	0.00153	0.98350
	(25,3)	0.00342	2.63E-04	7.56E-21	0.00312	0.98657
	(28,3)	0.00292	2.32E-04	6.30E-22	0.00267	0.98315
190	(25,4)	0.01841	5.28E-05	4.39E-24	0.01673	0.98572
	(27,4)	0.00290	4.15E-05	2.06E-22	0.00264	0.98303
	(19,4)	0.00364	3.96E-05	2.85E-23	0.00331	0.98438
	(23,4)	0.00239	2.80E-05	1.11E-24	0.00217	0.98391
	(16,3)	0.00173	8.74E-05	1.06E-22	0.00158	0.98350
	(25,4)	0.00346	4.83E-05	9.98E-22	0.00314	0.98657
	(28,4)	0.00296	4.37E-05	8.75E-23	0.00269	0.98315
200	(25,6)	0.01841	1.31E-06	5.80E-26	0.01674	0.98572
	(27,5)	0.00291	6.90E-06	2.53E-23	0.00265	0.98303
	(19,5)	0.00365	5.82E-06	2.84E-24	0.00331	0.98438
	(23,5)	0.00239	4.27E-06	1.20E-25	0.00218	0.98391
	(16,4)	0.00174	1.22E-05	9.39E-24	0.00158	0.98351
	(25,6)	0.00346	1.18E-06	1.30E-23	0.00315	0.98659
	(28,6)	0.00296	1.14E-06	1.27E-24	0.00269	0.98315

Table 4: Optimal channel allocation and performance indices for CAS 4

TC	(s^*, r^*)	B_n	B_{hd}	B_{hv}	B	CL
170	(25,2)	0.01826	1.52E-03	1.30E-24	0.01669	0.98572
	(27,1)	0.00244	4.87E-03	7.47E-21	0.00240	0.98303
	(19,1)	0.00309	6.17E-03	1.47E-21	0.00306	0.98438
	(22,1)	0.00323	6.46E-03	8.66E-23	0.00330	0.98391
	(16,0)	0.00002	9.42E-03	5.11E-20	0.00032	0.98350
	(25,2)	0.00340	1.56E-03	9.00E-22	0.00313	0.98658
	(28,1)	0.00243	4.86E-03	2.72E-21	0.00243	0.98315
180	(25,3)	0.01839	3.23E-04	1.01E-26	0.01673	0.98572
	(27,2)	0.00283	1.27E-03	1.36E-22	0.00262	0.98303
	(19,2)	0.00356	1.46E-03	1.67E-23	0.00329	0.98438
	(23,2)	0.00231	9.31E-04	3.31E-25	0.00215	0.98391
	(16,2)	0.00172	6.32E-04	8.01E-24	0.00158	0.98350
	(25,3)	0.00345	3.28E-04	1.21E-23	0.00315	0.98657
	(28,3)	0.00295	2.76E-04	5.37E-25	0.00269	0.98315
190	(25,4)	0.01841	5.95E-05	5.81E-29	0.01674	0.98572
	(27,4)	0.01447	5.01E-05	3.61E-25	0.01315	0.98303
	(19,4)	0.00365	4.61E-05	6.83E-28	0.00332	0.98438
	(23,4)	0.00239	3.13E-05	1.00E-29	0.00218	0.98391
	(16,3)	0.00174	1.03E-04	4.63E-26	0.00158	0.98350
	(25,4)	0.00346	5.98E-05	1.20E-25	0.00315	0.98657
	(28,4)	0.01455	5.87E-05	3.31E-24	0.01323	0.98315
200	(25,6)	0.01841	1.48E-06	3.85E-29	0.01674	0.98572
	(27,5)	0.01447	1.44E-05	4.31E-24	0.01316	0.98303
	(19,6)	0.00365	8.85E-07	9.75E-33	0.00332	0.98438
	(23,5)	0.00239	4.76E-06	3.69E-32	0.00218	0.98391
	(16,5)	0.00174	1.75E-06	6.21E-31	0.00158	0.98350
	(25,6)	0.01729	1.60E-06	2.36E-25	0.01572	0.98657
	(28,4)	0.01455	5.87E-05	3.31E-24	0.01323	0.98315

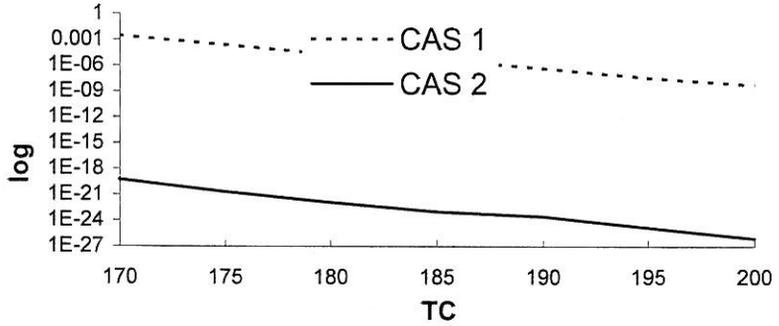


Fig. 6: Comparison of hand-off voice blocking by varying total number of channel for CAS 1 and CAS 2

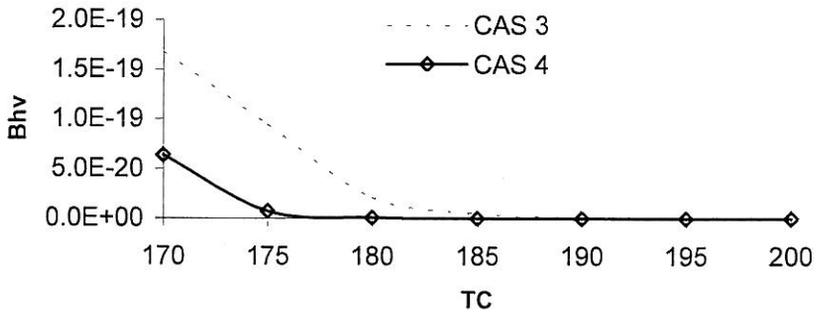


Fig. 7: Comparison of hand-off voice blocking by varying total number of channels for CAS 3 and CAS 4

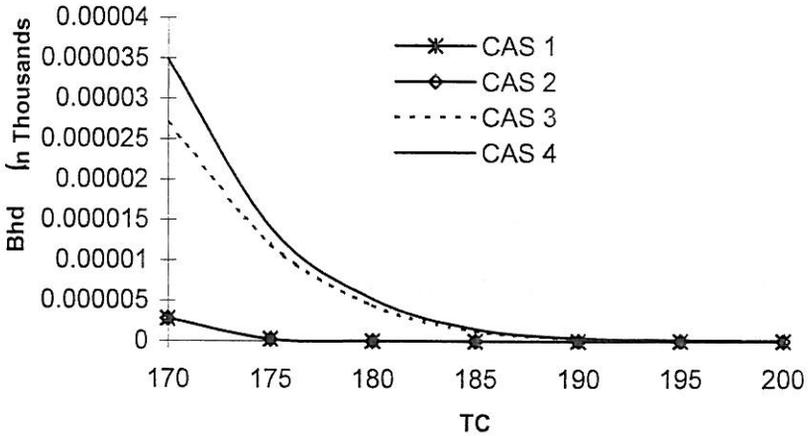


Fig. 8: Comparison of hand-off data blocking by varying total number of channels for various schemes

The suggested algorithm for calculating the optimal number of channels to be allocated to each cell in a cellular cluster provides results for all the schemes in equally good manner and can be employed in any wireless communication system. Though we have determined the optimal channel allocation for the total handoff calls i.e., inclusive of voice and data calls, our work can be further extended to find the optimal number of channels to be reserved for the handoff voice and handoff data calls separately.

REFERENCES

- Anderson, L.G. (1973). A simulation study of some dynamic channel assignment in a high capacity mobile telecommunications system. *IEEE Trans. Commun.*, 21, 1294-1301.
- Davoli, F. & Maryni, P. (2000). A two-level stochastic approximation for admission control and bandwidth allocation. *IEEE Jour. Selec. Areas Commun.*, 18(2), 222-233.

- Eklundh, B. (1986). Channel utilization and blocking probability in a cellular mobile telephone system and directed retry. *IEEE Trans. Commun.*, 34, 329-337.
- Hong, D. & Rappaport, S. S. (1989). Priority oriented channel access for cellular system serving vehicular and portable radio telephones. *IEEE Proc. Part 1*, 136(5), 339-346.
- Jain, M., & Rakhee (2002). Priority based channel assignment schemes for PCS with integrated traffic. In *Proceeding of Emerging Convergent Technologies and Systems (SECTAS-2002)*, (pp. 79-84). Allied Publishers Ltd., New Delhi, India.
- Jain, M., & Rakhee (2001). Queueing analysis for PCS with integrated traffic and sub-rating channel assignment scheme. *Journal of CSI*, 31(2), 1-8.
- Jain, M. (2000). Prioritized channel assignment in mixed media cellular radio system. *IETE Journal of Research*, 46(4), 187-192.
- Karlsson, J., & Eklundh, B. (1989). A cellular mobile telephone system with load sharing-an enhancement of directed retry. *IEEE Trans. Commun.*, 37, 530-535.
- Li, W. & Alfa, A. S. (1999). A PCS network with correlated arrival processes and splitted rating channels. *IEEE Jour. Selec. Areas Commun.*, 17(7), 1318-1325.
- Lin, P., & Lin, Y. B. (2001). Channel allocation for GPRS. *IEEE Trans. Veh. Tech.*, 50(2), 375-387.
- Lin, Y. B., Noerpel, A. R., & Harasty, D. J. (1995). The subrating channel assignment strategy for PCS hand-off. *IEEE Trans. Veh. Tech.*, 45(1), 122-130.
- Oh, S. H., & Tcha, D. W. (1992). Prioritized channel assignment in a cellular radio network. *IEEE Trans. Commun.*, 40(7), 1259-1269.
- Ortigoza-Guerrero, L., & Aghvami, A. H. (1999). A prioritized handoff dynamic channel allocation strategy for PCS. *IEEE Trans. Veh. Tech.*, 48(4), 1203-1215.

- Purzynski, C., & Rappaport, S. S. (1995). Multiple call hand-off problem with queued hand-off and mixed platform types. *IEEE Proc. Commun.*, 142(1), 31-39.
- Rappaport, S. S. (1992). Models for call handoff schemes in cellular communication networks. In *Proceeding of 3rd WINLAB Workshop: Third Generation Wireless Information Networks: Workshop Rec.*

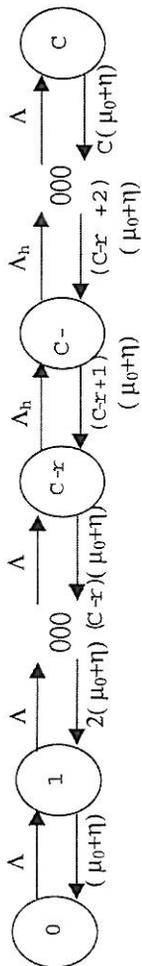


Fig. 2 Transition state diagram for CAS 1

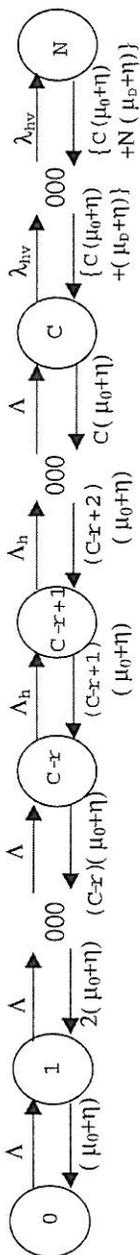


Fig. 3 Transition state diagram for CAS 2

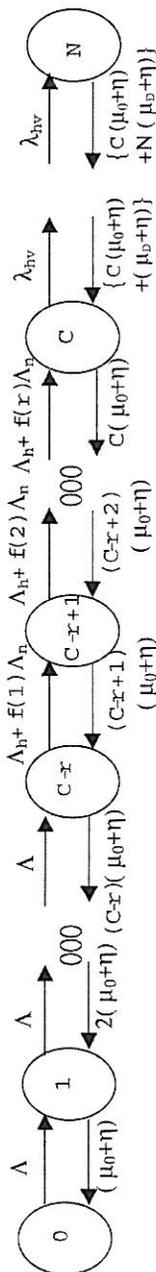


Fig. 4 Transition state diagram for CAS 3

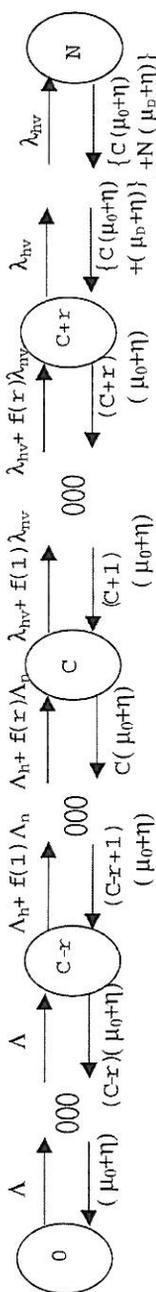


Fig. 5 Transition state diagram for CAS 4