Fair Multi-Services Call Admission in Cellular Networks Using Stochastic Control

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Abstract - **With the handoff occurring more and more frequently in cellular networks, an effective call admission control is increasingly urgent for optimum utility of valuable bandwidth. Recently, the dynamic call admission mechanism using stochastic control was found to be more stable and precise. But, it is still hard to get an effective dynamic call admission mechanism for multi-services. The main challenges with multiple types of traffic are that each has its own requirements of bandwidth, QoS guarantee and handoff rate, especially for data call types. In addition, the computational complexity is another challenge. At present, most of the relative studies cope with this problem by setting up a multiple dimensions' stochastic model with high computational complexity [13], [14]. In this paper, we use a buffer to regulate the data type traffic and use the proposed single dimension stochastic model to compute the key parameters, such as call dropping probability and admission probability, considering fairness among multi-services. The result is decreased computational complexity. Numerical results of simulation show that the proposed scheme named FDCA (fair dynamic call admission scheme) steadily satisfies the hard constraints on call dropping probability for multi-services while maintaining a very high channel throughput.**

Keywords - Call admission control; QoS guarantee for multi-services; stochastic control; cellular networks.

I. Introduction

With the rapid development of wireless communication technology, multimedia traffic will be eventually carried for the new generation of wireless networks. This makes the QoS guarantee for multi-services very important.

One of the essential parameters of QoS is the call dropping probability. When a mobile station moves across the boundary of a cell, handoff dropping can occur, primarily caused by the unavailability of channels in the new cell. Dropping a call in progress is generally considered to have more negative impact from the users' perception than blocking a newly requested call [11]. Therefore, one of the key design goals is to minimize the handoff dropping probabilities required by multi-services' QoS. This, however, usually comes at the expense of potentially poor channel utilization by admitting fewer new calls. The main challenge in the design of an efficient admission control scheme is to balance these two conflicting requirements.

With the call handoff occurring more and more frequently in wireless networks, an effective call admission control is increasingly urgent for optimum utility of valuable bandwidth.

Meanwhile, there are a number of unique aspects in the next generation of multimedia enabled wireless cellular networks that the design of effective call admission control schemes need to take into account. To start with, smaller cells will be employed, thus, the number of handoffs during a call's lifetime is likely to be increased. Meanwhile, there is an increased influence from neighboring cells [2]. Secondly, possibly different *QoS* requirements for different traffic types, and potentially more stringent *QoS* requirements of individual calls require a highly precise admission control. Finally, diversified traffic load requires that call admission control have to be adaptive to the changing traffic pattern [6]. Therefore, a dynamic policy is preferred [7], [8].

A basic approach, to reduce handoff failure due to lack of resources in adjacent cells, is to reserve resources for handoffs in each cell. The well-known *guard channel* (GC) scheme and its numerous variations [1], [3], [5] reserve a fixed number of channels in each cell exclusively for handoffs in. All these policies cannot adapt to changes in traffic pattern due to the static nature. Recently, a number of proposals have made fine attempts to implement dynamic control in the call admission control scheme [7], [8], [10]. But, it is still hard to get an effective dynamic call admission mechanism for multi-services [8]. The main challenges with multiple types of traffic are that each has its own bandwidth requirements, QoS guarantee, and handoff rate. In [10], we set up a fictitious stochastic model to represent the actual system to avoid coping with the complex multiple dimensions stochastic problem and propose a *multi-services dynamic call admission* (*MDCA*) scheme to adapt for multiple types of services in broadband mobile wireless networks. But in a narrowband environment, the control precision is not satisfied. This paper proposes a fair call admission stochastic control mechanism for multi-services, named FDCA, in mobile wireless networks. Numerical results of simulation show that our scheme steadily satisfies the hard constraint on call dropping probability of multi-services while maintaining a very high channel throughput in either broadband or narrowband environment.

The rest of the paper is organized as follows. In Section II, we start from description of the analytical model, and then, study the control algorithm in a multi-services environment. Thereafter, in Section III, we study and compare the performance of our proposed call admission scheme with others through simulations. We present the conclusion in Section IV.

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II. THE ANALYTICAL MODEL

Multiple kinds of service such as data, voice, and video are considered in a homogeneous cellular network. This network consists of closely packed hexagonal cells, each with the same capacity of *N* channels.

Generally, the new and handoff calls, except data types, arrive according to Poisson distribution and that call duration time and channel holding time are exponentially distributed. But the data traffic types, such as e-mail, www and ftp, have self-similar characteristics. That is, the packet generating process of these classes is modeled by fractional Brownian motion process.

Here, we use a buffer to regulate the burst data traffic to regular Poisson generating process. So the channels' occupation process is a normal Poisson process. The key point is how to regular the parameter of the Poisson process out of buffer. For a too small one, the delay for data type calls will beyond the QoS requirement. For a too large one, the buffer lost it function and made the CDP of other type calls beyond their QoS requirements. We regulate the parameter periodically by computing statistical average value for arrival rate during last control period and the queue length. Suppose the first one is A, and the delay requirement and the queue length can decide the maximum of arrival rate, suppose it is B, we let the parameter equal to max{A, B}. Note that the parameter is invariable during next control period.

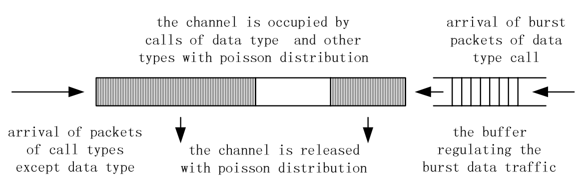

Figure. 1. The buffer regulating the burst data traffic

Main Notations

$P_{QoS}^{(m)}$	The predefined threshold of maximum call dropping probability required by the QoS of the call type m
$f_{ik}^{(m)}(t)$	The *single-call transition probability* that an ongoing call of type m in cell *k* at the beginning of the control period (t=0) is located in cell i at time t.
$(a_i^{(1)}, a_i^{(2)}, ..., a_i^{(\hat{n})})$	The probability vector of new calls to be accepted
$c^{(m)}$	The number of channel required by each call of type m
$\mu^{(m)}$	The terminate rate of connected calls of type m
$h_{ik}^{(m)}$	The rate of handoff from cell *k* to a neighboring cell *i*
$\hat{n}$	The number of all call types

where $m = 1, 2, ..., \hat{n}$.

Note that, for data call types, the notations denote statistical average value.

The objective of our scheme is to maximize channel utilization, that is, minimize the new call blocking probability subject to a hard constraint that the handoff dropping probability should be maintained below $P_{QoS}^{(m)}$.

A. *The Overall Channel Occupying Probability*

First, we consider the overall channel occupancy probability $p_{n_i}(t)$ in cell i. At the beginning of a control period, the number of channel occupied is $n_0 = \sum_m c^{(m)} n_{i0}^{(m)}$. Our objective is to compute the probability of the number of channel occupied equal to n at time t, i.e., $p_n(t)$, when $n = N, N-1, ..., N-(c^{(m)}-1)$.

We can assume that all calls dropping probabilities equal to 0 for an effective control. So we have the evolution equation for the call type m:

$$\begin{cases} \dfrac{df_{ik}^{(m)}(t)}{dt} = -\sum J_{ij}^{(m)} f_{jk}^{(m)}(t) \\ f_{ij}^{(m)}(0) = \delta_{ik} \end{cases} \quad (1)$$

The solution of (1) is: $f_{ik}^{(m)}(t) = [\exp(-J^{(m)}t)]_{ik}$ (2)

At *t*=0, there are $n_{k0}^{(m)}$ calls of type m in cell *k* initially. The number of active calls in cell *i* at time *t* is then a variables with mean : $\sum_k f_{ik}^{(m)} n_{k0}^{(m)}$, and

variance: $\sum_k f_{ik}^{(m)}(t)[1-f_{ik}^{(m)}(t)] n_{k0}^{(m)}$.

For the new calls of type *m* arriving in cell *k* at time u, the probability of finding them in cell i at time *t* is $f_{ik}^{(m)}(t-u)$. Since they are evenly distributed over time, the number of new calls in cell *i* at time t obeys a Poisson distribution with mean of $\sum_k g_{ik}^{(m)}(t) a_k^{(m)} \lambda_k^{(m)}$, where $g_{ik}^{(m)}(t)$ is the integrated transition probability given by

$$g_{ik}^{(m)} = \int_0^t f_{ik}^{(m)}(t-u) du \quad (3)$$

Thus the mean of the distribution of active calls of type *m* in cell i at time *t* is

$$\langle n_i^{(m)}(t) \rangle = \sum_k f_{ik}^{(m)}(t) n_{k0}^{(m)} + \sum_k g_{ik}^{(m)}(t) a_k^{(m)} \lambda_k^{(m)} \quad (4)$$

and the variance is given by

$$\sigma_i^{(m)}(t)^2 = \sum_k f_{ik}^{(m)}[1-f_{ik}^{(m)}(t)] n_{k0}^{(m)} + \sum_k g_{ik}^{(m)} a_k^{(m)} \lambda_k^{(m)} \quad (5)$$

For a large capacity system, the distribution of the number of active calls of type m evolves into a Gaussian distribution with mean $\langle n_i^{(m)}(t) \rangle$ and variance $\sigma_i^{(m)}(t)^2$. However, the limited capacity of cells modifies the distribution to non-Gaussian, especially for nearly full channel occupancy, which is the key region in estimating the dropping probability.

Suppose $\Lambda_i^{(m)}$ and $\mathrm{M}_i^{(m)}$ are the arrival and departure rates for calls of type m in cell *i*. Their dependence on *n* and *t* is assumed to be negligible. They can be gained by.

$$\begin{cases} \Lambda_i^{(m)} - \mathrm{M}_i^{(m)} = \dfrac{\langle n_i^{(m)}(t) \rangle - n_{i0}^{(m)}}{t} \\ \Lambda_i^{(m)} + \mathrm{M}_i^{(m)} = \dfrac{\sigma_i^{(m)}(t)^2}{t} \end{cases} \quad (6)$$

Unlike other models such as [7], [12], our model considers short-term instantaneous PDF instead of long-term balanced PDF. Therefore, our scheme is much more precise. But the computation is accordingly complex. Fortunately, the number of the state of channel occupied is finite, equal to N+1, where N is the channel number in a cell. This makes the rank of transition matrix not a terrible large number and the probability problem computable for normal computer. For example, suppose $c^{(1)}=1$, $c^{(2)}=2$, $c^{(3)}=3$, considering the boundary condition, the state transition graph of the actual system is shown in Fig. 2.

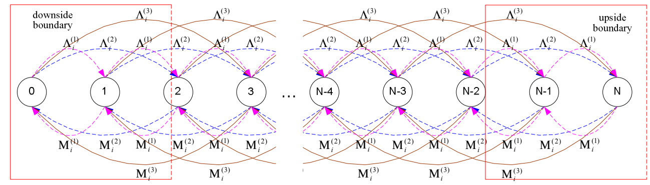

Figure 2. Single dimension stochastic model with $c^{(1)}=1$, $c^{(2)}=2$, $c^{(3)}=3$,

The transition matrix of the actual system is

$$Q=\begin{bmatrix}
\Gamma(0,3) & \Lambda_i^{(1)} & \Lambda_i^{(2)} & \Lambda_i^{(3)} & 0 & 0 & \cdots & \cdots & \cdots & \cdots & 0\\
\mathrm{M}_i^{(1)} & \Gamma(1,3) & \Lambda_i^{(1)} & \Lambda_i^{(2)} & \Lambda_i^{(3)} & 0 & \cdots & \cdots & \cdots & \cdots & 0\\
\mathrm{M}_i^{(2)} & \mathrm{M}_i^{(1)} & \Gamma(2,3) & \Lambda_i^{(1)} & \Lambda_i^{(2)} & \Lambda_i^{(3)} & 0 & \cdots & \cdots & \cdots & 0\\
\mathrm{M}_i^{(3)} & \mathrm{M}_i^{(2)} & \mathrm{M}_i^{(1)} & \Gamma(3,3) & \Lambda_i^{(1)} & \Lambda_i^{(2)} & \Lambda_i^{(3)} & 0 & \cdots & \cdots & 0\\
0 & \mathrm{M}_i^{(3)} & \mathrm{M}_i^{(2)} & \mathrm{M}_i^{(1)} & \Gamma(3,3) & \Lambda_i^{(1)} & \Lambda_i^{(2)} & \Lambda_i^{(3)} & 0 & \cdots & 0\\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots\\
0 & \cdots & \cdots & \mathrm{M}_i^{(3)} & \mathrm{M}_i^{(2)} & \mathrm{M}_i^{(1)} & \Gamma(3,3) & \Lambda_i^{(1)} & \Lambda_i^{(2)} & \Lambda_i^{(3)} & 0\\
0 & \cdots & \cdots & 0 & \mathrm{M}_i^{(3)} & \mathrm{M}_i^{(2)} & \mathrm{M}_i^{(1)} & \Gamma(3,3) & \Lambda_i^{(1)} & \Lambda_i^{(2)} & \Lambda_i^{(3)}\\
0 & \cdots & \cdots & 0 & 0 & \mathrm{M}_i^{(3)} & \mathrm{M}_i^{(2)} & \mathrm{M}_i^{(1)} & \Gamma(3,2) & \Lambda_i^{(1)} & \Lambda_i^{(2)}\\
0 & \cdots & \cdots & 0 & 0 & 0 & \mathrm{M}_i^{(3)} & \mathrm{M}_i^{(2)} & \mathrm{M}_i^{(1)} & \Gamma(3,1) & \Lambda_i^{(1)}\\
0 & \cdots & \cdots & 0 & 0 & 0 & 0 & \mathrm{M}_i^{(3)} & \mathrm{M}_i^{(2)} & \mathrm{M}_i^{(1)} & \Gamma(3,0)
\end{bmatrix}_{(N+1)*(N+1)} \quad (7)$$

$$where\ \Gamma(s,t)=-(\sum_{k=1}^{s}\mathrm{M}_i^{(k)}+\sum_{k=1}^{t}\Lambda_i^{(k)})$$

Considering the low traffic boundary, which concerns the computation of the call dropping probability in narrowband case, and the high traffic boundary condition, which concerns the computation of the call dropping probability in any case, the differential equations can be gained by:

$$\left(\frac{dp_0(t)}{dt},\frac{dp_1(t)}{dt},...,\frac{dp_N(t)}{dt}\right)=\left(p_0(t),p_1(t),...,p_N(t)\right)Q \quad (8)$$

Its solution can be gained by the following iterative equations, according to [9]:

$$\begin{cases} {}_0p_{n_0n}(t)=\delta_{n_0n}e^{-q_{n_0n_0}t} \\ {}_{n_s+1}p_{n_0n}(t)=\sum_{k\neq n_0}\int_0^t {}_{n_s}p_{n_0k}(s)q_{kn}e^{-q_{nn}(t-s)}ds,(n_s\geq 0) \end{cases} \quad (9)$$

where $\delta_{n_0n}=0(n\neq n_0),\delta_{n_0n}=1(n=n_0)$, $p_{n_0n}(t)$ denotes the probability of transition from the state n_0 to n during time t and ${}_{n_s}p_{n_0n}(t)$ denotes the probability of transition from the state n_0 to n by n_s steps during time t. Then the solution of (8) can be gained by

$$P_n(t)=p_{n_0n}(t)\sum_{n_s=0}^{\infty}{}_{n_s}p_{n_0n}(t) \quad (10)$$

Note that, supposing n_s' is the upper boundary of the total of call generation and termination, arrival and departure in the next control period, it can be estimated at the beginning of the control period by parametric statistics, therefore, when $n_s>n_s'$, ${}_{n_s}p_{n_0n}(t)=0$. So we have:

$$P_n(t)=\sum_{n_s=0}^{\infty}{}_{n_s}p_{n_0n}(t)=\sum_{n_s=0}^{n_s}{}_{n_s}p_{n_0n}(t) \quad (11)$$

For an active call of type m, the dropping probability $D_i^{(m)}(t)$ is the probability of the new cell, into which the call will enter, has not enough channels to support its handoff. That is to say, the number of the new cell's occupied channels is more than N-$c^{(m)}$. So the dropping probability of the type m call is given by

$$D_i^{(m)}(t)=\sum_{\xi=0}^{c^{(m)}-1}P_{N-\xi}(t) \quad (12)$$

When the call handoff into new cell *i*, the average dropping probability during the control period T equal to

$$\overline{D_i^{(m)}}=\frac{1}{T}\int_0^T D_i^{(m)}(t)dt=\frac{1}{T}\int_0^T\sum_{\xi=0}^{c^{(m)}-1}P_{N-\xi}(t)dt=\frac{1}{T}\sum_{\xi=0}^{c^{(m)}-1}\int_0^T P_{N-\xi}(t)dt \quad (13)$$

On one hand, to satisfy QoS requirement of multi-services, the average dropping probability of each call type should not be more than the predefined threshold of maximum call dropping probability required by the QoS of each one.

$$\overline{D_i^{(m)}}\leq P_{QoS}^{(m)} \quad (14)$$

On the other hand, to minimize the call blocking probability as well as to maximize the channel utilization, the average sum of channel occupied by all type calls to be accepted should be maximized. The average sum of channel occupied by all type calls to be accepted can be obtained by

$$c_{sum}=\sum_{m=1}^{\hat{n}}a_i^{(m)}c^{(m)} \quad (15)$$

At last, for the acceptance ratio $a_i^{(m)}$

$$0\leq a_i^{(m)}\leq 1 \quad (16)$$

In this paper, we let fairness parameter

$$F = \max\left\{\min\{1, \frac{a_i}{a_j}\}\right\}_{i,j=1,2,...,\hat{n}, and, i\neq j} \qquad (17)$$

And let the downside boundary is B_{fair} .

To protect the fairness among multi-services, we let

$$B_{fair} \le F \le 1 \qquad (18)$$

Note that only the acceptance ratio $a_i^{(m)}, m = 1,2,..., \hat{n},$ are unknown in (14)(15)(16)(18), so we need to determine the acceptance ratio vector $\left(a_i^{(1)}, a_i^{(2)}, ..., a_i^{(\hat{n})}\right)$, which can make the c_{sum} maximum subject to (14), (16)and (18).

Fig. 3 shows the solution of the example when n=2 and $c^{(1)} = 1, c^{(2)} = 2$, Supposing the solution of (14) equal to the space labeled S and considering the fairness among multi-services, then the acceptance ratio vector $\left(a_i^{(1)}, a_i^{(2)}\right)$, is the point P's coordinates.

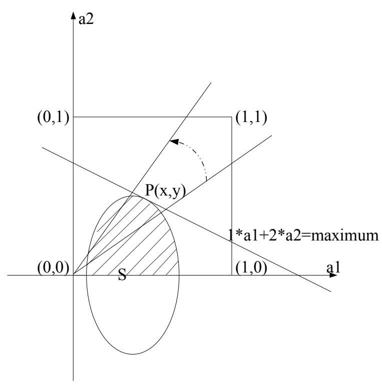

Figure. 3. Solutions that make $\sum_{m=1}^{\hat{n}} a_i^{(m)} c^{(m)}$ maximum.

B. *The computational complexity*

Most of the computational complexity of the control policy comes from calculating the acceptance ratio vector for the average dropping probability on-line by solving the equations that exist in (14). Since the number of integrals in (9) is N. The upper boundary of the sum of integrals in (11) is N* n_s'. Since the control is stochastic, a coarse-grain integration of the average dropping probability is already sufficient. Therefore it is enough to use the Compound Simpson numerical integral formula to get satisfactory precision in the computation of integrals in (9) and (13). Normally, N, i.e. the bandwidth in a cell, is not a large number. Therefore, this scheme is suitable for the general environment, especially for the narrowband environment, for which the scheme MDCA in [4] and [10] are not suitable. Compared with this scheme, MDCA is less computationally complex and more suitable for the broadband environment. In practice, these two schemes can be combined.

The call transition probabilities, for constant handoff rates, can be precalculated off-line, either by local approximation or precise matrix calculation. For evolving handoff rates, they can be easily calculated on-line by local approximation.

III. NUMERICAL RESULTS

The simulation scenario consists of closely packed hexagonal cells, each with the same capacity of *N* channels. We investigated a multi-services scenario with three call types, including the data call type. By using the buffer, the call lifetime and channel holding time follow exponential distribution.

The information transmitted by cell i includes its cell occupancy $n_{i0}^{(m)} (m = 1,2,3)$ at that instant and the number of admitted new calls $a_i^{(m)}$ in the previous period.

The transition probabilities are computed in the local approximation for paths up to 3 hops, $N = 150$, T=20s, and $B_{fair} = 0.85$. Other parameters of the call types are shown in Table 1. Not that, for the data call type, the parameter is statistic average value. These parameters are used to compute the admission ratio vector in cell i . Note that the narrowband call (i.e., type 1 call) has more stringent QoS requirements than the wideband call and the three types of calls have different motion characteristics. In Figs. 4-5, call dropping probability (CDP) and new call blocking probability (CBP) are compared for our FDCA scheme, the MDCA scheme in [10] and the GC scheme with resource complete sharing. We present the results of the GC scheme with 10 guard channels for comparison, as they achieve comparable performance in terms of call dropping probability and call blocking probability under light or mild load condition.

TABLE I. PARAMETER FOR TWO TYPES OF CALLS

Call Parameters	Type1 (m=1)	Type2 (m=2)	Type3 (m=3)
$c^{(m)}$	1	2	3
$h^{(m)}$	$0.0135 (s^{-1})$	$0.015 (s^{-1})$	$0.012 (s^{-1})$
$\mu^{(m)}$	$0.0045 (s^{-1})$	$0.003 (s^{-1})$	$0.0025 (s^{-1})$
$P_{QoS}^{(m)}$	0.01	0.015	0.02

When the traffic of the network starts to get over-loaded, the CDP of all call types of GC scheme soars. However, the FDCA scheme can well maintain the CDP of each call type below its target level. Fig.5 shows the CBP of FDCA is a little higher than that of the GC, but is a little lower than that of the MDCA. Fig.6 shows a higher channel throughput in FDCA is maintained than MDCA, and very close to GC, although a little lower than GC, this come from the tradeoff for fairness requirements.

IV. CONCLUSION

In this paper, we have presented a fair distributed and dynamic call admission control scheme, known as FDCA, to support multiple call-level QoS for handoff calls of multiple types and maximize the bandwidth utilization in mobile wireless networks via stochastic control. We have taken into account the effects of limited capacity and time dependence on the call dropping probability, the probability of multiple hops from distant cells for longer control periods to improve the accuracy of the control mechanism. In addition, we have computed and adjusted the acceptance ratio vector instead of the admission threshold as in a guard channel scheme, in order to spread the new calls uniformly over the control period, by stochastically accepting each new call with probability. This avoids a sudden overload of the network at the beginning of the control period during congestion, leading to more stable control. All these make the FDCA scheme stable and precise. The most prominent feature of the FDCA is its optimal probability precision under reasonable fairness. We use the proposed single dimension stochastic model instead of multiple dimensions one, so the computational complexity is greatly decreased. Compared with EMDCA, which use a more novel model, the computation complex of FDCA is still higher, but the precision is higher too, especially for narrowband environment. In practice, it can be combined with EMDCA, which are especially suitable for broadband environment, detailed in [2].

We are currently managing to further decrease the computation complex in the FDCA scheme and set up a more effective model to adapt for the increasingly complex wireless environments.

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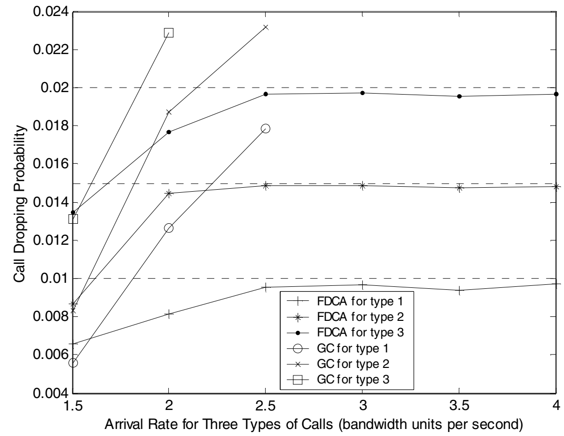

Figure. 4. Dropping probabilities for three call types.

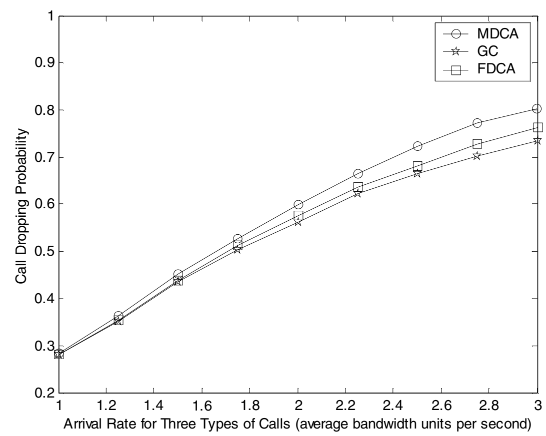

Figure. 5. Blocking probabilities for combined traffic.

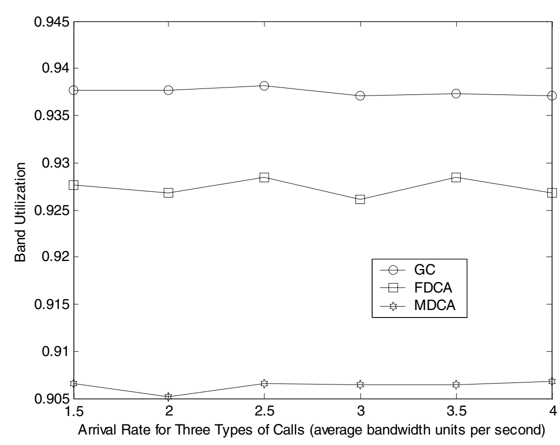

Figure. 6. Bandwidth utilizations for combined traffic.