Precise Bandwidth Allocation Scheme in Broadband Wireless Multimedia Networks

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Abstract—**Bandwidth is extremely valuable resource in wireless networks, in which the occurrence of handoff increases. Therefore, an effective bandwidth allocation is urgent. Recently, the dynamic method using stochastic control is found to be preferred. But the dynamic control for multi-services is still a problem. The main challenges come from variety of requirements of bandwidth, traffic characteristics, QoS guarantee and handoff rate. Moreover, the computational complexity is another challenge. In this paper, we set up a novel bandwidth allocation model. We consider optimal revenue instead of maximal bandwidth utility, the boundary conditions and the variety of channel occupation. In addition, we use a fast numerical method to reduce complexity. As a result, we get a precise multi-services dynamic bandwidth allocation scheme called MDBA to adapt for multiple types of services in broadband 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 high channel utility.**

Keywords—bandwidth allocation; QoS guarantee; stochastic control policy; wireless multimedia networks.

I. INTRODUCTION

The call handoff, occurring more and more frequently, challenges resource allocation for valuable bandwidth in wireless networks. Therefore, an effective bandwidth allocation policy is urgent. The traditional guard channel scheme (GC) and its numerous variants cannot adapt to changes in traffic pattern due to their static nature. Recently, the dynamic method using stochastic control is found to be preferred. But the dynamic control for multi-services is a problem. The main challenges with multiple types of traffic are that each has its own requirements of bandwidth, QoS guarantee, traffic characteristic and handoff rate. In addition, the computational complexity is another problem to be considered. This paper mainly deals with these challenges by a masterly stochastic model.

The well-known *guard channel* (GC) scheme and its numerous variations [1], [4], [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 bandwidth allocation scheme [2], [8], [14], [16]. But the dynamic control for multi-services is still a problem [8]. The main challenges with multiple types of traffic are that each has its own requirements of bandwidth, QoS guarantee and handoff rate. Meanwhile, the computational complexity is another challenge, especially in broadband environment.

In this paper, we set up a fictitious stochastic model to study the actual system so as to avoid coping with complex multiple dimensions stochastic problems. Unlike our research before [3], [7], we consider optimal revenue instead of maximal bandwidth utility, the boundary conditions and the variety of channel occupation. In addition, we have found a fast numerical method that can decrease the computation complexity greatly. As a result, we get an effective multi-services dynamic bandwidth allocation scheme called MDBA to adapt for multiple types of services in mobile wireless networks.

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 scheme with others simulations. We present the conclusion in Section IV.

II. THE ANALYTICAL MODEL

A. Bandwidth Allocation General Assumptions

In our analytical model, we are dealing with multiple kinds of service such as data, voice, and video, with the following assumptions.

1) A homogeneous cellular network consisting of closely packed hexagonal cells, with the same capacity of N channels, is considered.
2) The number of all call types is $\hat{n}$.
3) The new calls of the different traffics in cell i arrive according to Poisson distribution with rate of $\lambda_i^{(m)}$, $m = 1,2,...,\hat{n}$ respectively.
4) Call duration time for the call type m is exponentially distributed with the average call duration time $1/\mu^{(m)}$, $m = 1,2,...,\hat{n}$ (i.e., connected calls terminate at a rate of $\mu^{(m)}$).
5) For the call type m ($m = 1,2,...,\hat{n}$), channel holding time is exponentially distributed with $h_{ik}^{(m)}$, being the rate of handoff from cell k to a neighboring cell i.

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6) The maximal number of channel required by each call of type m is $c^{(m)}, m = 1,2,...,\hat{n}$
7) The revenue from using one channel for type m is $revenue^{(m)}, m = 1,2,...,\hat{n}$
8) $P_{QoS}^{(m)}$ is the predefined threshold of maximum call dropping probability required by the QoS of the call type m, $m = 1,2,...,\hat{n}$.
9) $f_{ik}^{(m)}(t)$ is the *single-call transition probability* that an ongoing call of type m, ($m = 1,2,...,\hat{n}$) in cell k at the beginning of the control period (t=0) is located in cell i at time t.
10) The *acceptance ratio vector* $(a_i^{(1)}, a_i^{(2)},..., a_i^{(\hat{n})})$ is the probability vector of new calls to be accepted.

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

B. *Bandwidth Allocation Policy*

Our dynamic scheme is distributed. The status information including the channel occupancies and the new call arrival rates is periodically exchanged between neighboring cells. Each cell updates its control policy.

The BA scheduler determines the probability of new calls to be accepted in the coming control period, at the beginning of the control period of duration. If a new call is not accepted, it has another chance to be accepted by testing the surplus channel pool capacity whether there are surplus channels, which come from the ongoing calls, such as voice and video.

For the handoff calls, it will be accepted only if there are enough channels to hold it. Figure 1 shows the detail.

Therefore, the key is to derive the acceptance ratios for all call types of new handoff calls in a cell periodically.

C. *The Arrival and Departure Rates*

At first, we consider the arrival (including new calls) and departure (including termination calls) rates for all call types in a cell.

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.

Similar to [3], they can be gained by.

$$\begin{cases} \Lambda_i^{(m)} - \mathrm{M}_i^{(m)} = \dfrac{\langle n_i^{(m)}(t) \rangle - n_{i0}^{(m)}}{t} \\ \Lambda_i^{(m)} + \mathrm{M}_i^{(m)} = \dfrac{\sigma_i^{(m)}(t)^2}{t} \end{cases} \quad (1)$$

where $\langle n_i^{(m)}(t) \rangle$ is the mean of the distribution of active calls of type m in cell i at time t

$$\langle n_i^{(m)}(t) \rangle = \sum_k f_{ik}^{(m)}(t) n_{k\bullet}^{(m)} + \sum_k g_{ik}^{(m)}(t) a_k^{(m)} \lambda_k^{(m)} \quad (2)$$

and $\sigma_i^{(m)}(t)^2$ is the variance.

$$\sigma_i^{(m)}(t)^2 = \sum_k f_{ik}^{(m)}[1 - f_{ik}^{(m)}(t)] n_{k\bullet}^{(m)} + \sum_k g_{ik}^{(m)} a_k^{(m)} \lambda_k^{(m)} \quad (3)$$

where $$g_{ik}^{(m)} = \int_0^t f_{ik}^{(m)}(t-u)du \quad (4)$$

Since our control period is short, the long-range cell hopping can be neglected and the summation beyond third nearest neighboring cells can be truncated.

D. *Channel Occupation Model*

To start with, we consider the overall channel occupation process, which is not a pure Poisson process but a sum of Poisson processes with bulk arrivals. The type m call new admission or incoming-handoff process would occupy resource to the system at the rate of $\Lambda_i^{(m)}$, with bulk arrival $c^{(m)}$. A conventional Poisson process at the rate $\Lambda_i^{(m)} c^{(m)}$ can be constructed from a given bulk arrival Poisson process with rate $\Lambda_i^{(m)}$ and bulk size $c^{(m)}$ by using 'shaper beforehand', which distribute exponentially the bulk arriving channels in advance in time, as shown in Fig. 1.

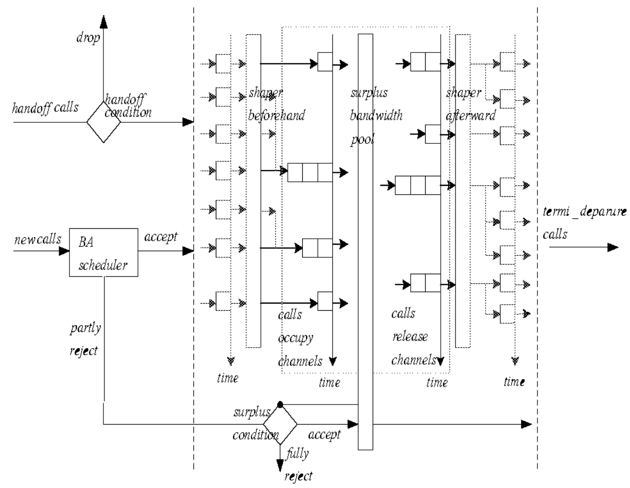

Figure1. Bandwidth Allocation and Channel Occupation Model

The correspondent state transition graph of an example is illustrated in Fig.2. Note that, multiple steps of state transition for channel occupying process become single step, which is a necessary condition for ideal birth-death processes.

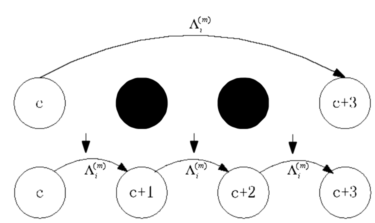

Figure2. The state transition graph with bulk arrival ($c^{(m)} = 3$)

Now, we construct all that of the bulk arrival channel occupying processes of the cell to be exponentially shaped to conventional Poisson processes, the overall channel occupying process of the fictitious model is a sum of Poisson processes. Consequently, the overall channel occupying process of the fictitious model is a well-characterized Poisson process with rate given as follows:

$$\Lambda = \Lambda_i = \sum_m \Lambda_i^{(m)} c^{(m)} \quad (5)$$

Similarly, the overall channel releasing process of the fictitious model is a well-characterized Poisson process by using 'shaper afterwards' with rate given as follows:

$$\mathrm{M} = \mathrm{M}_i = \sum_m \mathrm{M}_i^{(m)} c^{(m)} \quad (6)$$

Similar to [12], our model distributes the bulk to construct conventional Poisson processes. However, in our model, the direction to distribute on time is different for arrival or departure events, as shown in the figure 1. Suppose the overall channel occupancy probability in the fictitious model is $\overline{p_{n_i}(t)}$. Let $n_i = \widetilde{N}$ denotes n_i is near to N, when the call dropping might happen. We want to infer $p_{\widetilde{N}}(t)$ by $\overline{p_{\widetilde{N}}(t)}$. In [3], we prove that only by bulk-direction-distribution can we have $p_{\widetilde{N}}(t) \le \overline{p_{\widetilde{N}}(t)}$ and $p_{\widetilde{N}}(t) \approx \overline{p_{\widetilde{N}}(t)}$.

At the beginning of a control period, the number of channel occupied is $n_\bullet = \sum_m c^{(m)} n_{i\bullet}^{(m)}$. Our objective is to compute the probability of the number of channel occupied equal to n at time t, i.e., $\overline{p_{n_0 n}(t)}$, when $n = N, N-1, \ldots, N-(c^{(m)}-1)$.

The following focuses on discussing the solution with boundary condition. Suppose $c^{(1)}=1, c^{(2)}=2, c^{(3)}=3$, considering both the low traffic boundary condition (ignored by [3], [7], [8]), which concerns the computational precision of the call dropping probability in narrowband environment, and the high traffic boundary condition (ignored by [3], [7]), which is the main boundary condition that concerns the computational precision of the call dropping probability in all instances, the state transition graph the of the fictitious model compared with the actual system is shown in Fig. 3.

Generally, the arrival and departure rates are

$$\begin{cases} \Lambda = 1*\Lambda_i^{(1)} + 2*\Lambda_i^{(2)} + 3*\Lambda_i^{(3)} \\ \mathrm{M} = 1*\mathrm{M}_i^{(1)} + 2*\mathrm{M}_i^{(2)} + 3*\mathrm{M}_i^{(3)} \end{cases} \quad (7)$$

At the boundary,

$$\begin{cases} \Lambda' = 1*\Lambda_i^{(1)} + 1*\Lambda_i^{(2)} + 1*\Lambda_i^{(3)} \\ \mathrm{M}' = 1*\mathrm{M}_i^{(1)} + 1*\mathrm{M}_i^{(2)} + 1*\mathrm{M}_i^{(3)} \\ \Lambda'' = 1*\Lambda_i^{(1)} + 2*\Lambda_i^{(2)} + 2*\Lambda_i^{(3)} \\ \mathrm{M}'' = 1*\mathrm{M}_i^{(1)} + 2*\mathrm{M}_i^{(2)} + 2*\mathrm{M}_i^{(3)} \end{cases} \quad (8)$$

Therefore, the birth-death matrix is

$$Q = \begin{bmatrix} -\Lambda' & \Lambda' & \bullet & \bullet & \bullet & \cdots & \cdots & \cdots & \bullet \\ \mathrm{M}' & -(\mathrm{M}'+\Lambda'') & \Lambda'' & \bullet & \bullet & \cdots & \cdots & \cdots & \bullet \\ \bullet & \mathrm{M}'' & -(\mathrm{M}''+\Lambda) & \Lambda & \bullet & \cdots & \cdots & \cdots & \bullet \\ \bullet & \bullet & \mathrm{M} & -(\mathrm{M}+\Lambda) & \Lambda & \bullet & \cdots & \cdots & \bullet \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \bullet & \cdots & \cdots & \bullet & \mathrm{M} & -(\mathrm{M}+\Lambda) & \Lambda & \bullet & \bullet \\ \bullet & \cdots & \cdots & \cdots & \bullet & \mathrm{M} & -(\mathrm{M}+\Lambda'') & \Lambda'' & \bullet \\ \bullet & \cdots & \cdots & \cdots & \bullet & \bullet & \mathrm{M}' & -(\mathrm{M}'+\Lambda') & \Lambda' \\ \bullet & \cdots & \cdots & \cdots & \bullet & \bullet & \bullet & \mathrm{M}' & -\mathrm{M}' \end{bmatrix}_{(N+1)*(N+1)} \quad (9)$$

Then, the correspondent differential equations is

$$P'(t) = P(t)Q \quad (10)$$

Obviously, the probability of the channel occupation state changes with no time is 0. So we have the initial condition:

$$\overline{p_{n_0,n}(0)} = \delta_{n_0 n} \quad (11)$$

An iterative method is given in [9]. However, the computational complexity of this method is very high and various with traffic change. Here, we use another effective numerical method.

Let $p = \begin{bmatrix} \overline{p_{n_0,0}} \\ \overline{p_{n_0,1}} \\ \vdots \\ \overline{p_{n_0,N}} \end{bmatrix}$, $f = \begin{bmatrix} f_0 \\ f_1 \\ \vdots \\ f_N \end{bmatrix}$, $\delta = \begin{bmatrix} \delta_{n_0 0} \\ \delta_{n_0 1} \\ \vdots \\ \delta_{n_\bullet N} \end{bmatrix}$

Then (10) can be denoted as

$$\begin{cases} p' = f(t,p)(\bullet \le t \le T) \\ p(\bullet) = \delta \end{cases} \quad (12)$$

The vector formula using classical Runge-Kutta method to solve (12) is

$$\begin{cases} p^{(i+1)} = p^{(i)} + \dfrac{h}{6}(k_1 + 2k_2 + 2k_3 + k_4) \\ k_1 = f(t^{(i)}, p^{(i)}) \\ k_2 = f(t^{(i)} + \dfrac{h}{2}, p^{(i)} + \dfrac{h}{2}k_1) \\ k_3 = f(t^{(i)} + \dfrac{h}{2}, p^{(i)} + \dfrac{h}{2}k_2) \\ k_4 = f(t^{(i)} + h, p^{(i)} + hk_3) \end{cases} \quad (13)$$

where i is the times of iteration, $t^{(i)} = ih, (i = 0,1,\ldots,S)$, $h = \dfrac{T}{S}$ is the step in [0, T], S is a predefined integer used to control the precision.

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

$$D_i^{(m)}(t) = \sum_{\xi=\bullet}^{c^{(m)}-1} p_{N-\xi}(t) \approx \sum_{\xi=\bullet}^{c^{(m)}-1} \overline{p_{N-\xi}(t)} \quad (14)$$

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

$$\overline{D_i^{(m)}} = \frac{1}{T}\int_0^T D_i^{(m)}(t)dt \approx \frac{1}{T}\int_0^T \sum_{\xi=0}^{c^{(m)}-1} \overline{P_{N-\xi}(t)}dt = \frac{1}{T}\sum_{\xi=0}^{c^{(m)}-1} \int_0^T \overline{P_{N-\xi}(t)}dt \quad (15)$$

which can be directly gained by the Composite Simpson integral formula, making use of solutions in the midst of the iterative procedure in the computation of (13).

At first, 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.

$$\overline{D_i^{(m)}} \le P_{\bullet\bullet S}^{(m)} \quad (16)$$

Secondly, to maximize the channel utilization, the average sum of revenue from the channels occupied by all type calls to be accepted should be maximized. It can be obtained by

$$c_{sum} = \sum_{m=1}^{\hat{n}} a_i^{(m)} c^{(m)} revenue^{(m)} \quad (17)$$

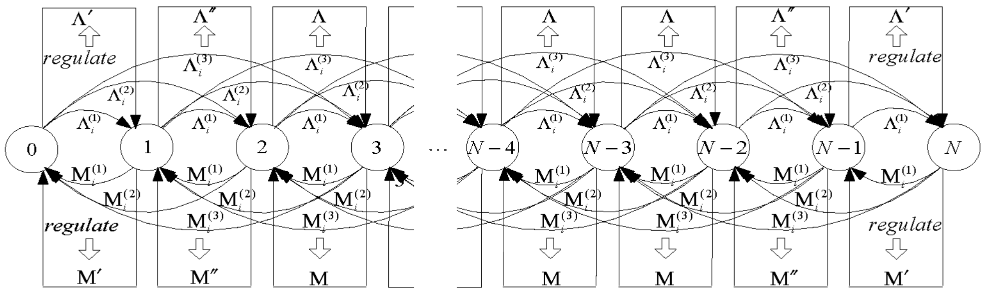

Figure3. The state transition graph with $c^{(1)} = 1, c^{(2)} = 2, c^{(3)} = 3,$

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

$$0 \le a_i^{(m)} \le 1 \tag{18}$$

Note that only the acceptance ratio $a_i^{(m)}, m = 1,2,...,\hat{n},$, are unknown in (16)(17)(18), so we just 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 (16) and (18).

All cells adjust the acceptance ratio vector $\left(a_i^{(1)}, a_i^{(2)},..., a_i^{(\hat{n})}\right)$, by exchanging their status information including the channel occupancies and the new call arrival rates at the beginning of a control period. During the control period, every new call is accepted by the acceptance ratio of the corresponding call type. Obviously, the overhead is not more than that of other schemes. 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 exist in (16). Since we use Runge-Kutta method, the computation is decreased greatly. As for (15), it is enough to use the composite Simpson formula to get satisfactory precision.

III. NUMERICAL RESULTS

The simulation scenario is a hexagonal system with three rings of radio cell clusters, with total 19 cells. We investigated a multi-service scenario with three call types. The information transmitted by cell i includes its cell occupancy $n_{i●}^{(m)}$, (m=1, 2, 3) at that instant and the number of admitted new calls $d_i^{(m)}$ in the previous period.

The transition probabilities are computed in the local approximation for paths up to 3 hops. $N = 150$, T=20s. These parameters are then used to compute the admission ratio in cell i. Other parameters of the three call types are shown in Table 1. Note that, all types of calls have various motion and traffic characteristics, and the narrowband call has more stringent QoS requirements than the wideband call.

In Figs. 4–6, call dropping probability (CDP) and new call blocking probability (CBP) are compared for our MDBA, OSCA (proposed in [13]) and 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 as well as call blocking probability under light or mild load condition.

When the wireless network starts to get over-loaded, the CDP of GC scheme soars. However, the MDBA and OSCA scheme can well maintain the CDP of each cal type below its target level. Meanwhile, a tradeoff occurs, the CBP of them is a little higher than that of the GC. Our scheme gain a higher channel throughput, shown in Fig.6, than the OSCA and almost close to the GC subject to meeting QoS requirements for CDP.

Obviously, our scheme is more precise than OSCA and GC. So it shows outstanding advantages on both precision and computability in broadband environment.

TABLE I. PARAMETER F●R THREE TYPES ●F CALLS

Call Parameters	Type1 (m=1)	Type2 (m=2)	Type3 (m=3)
$c^{(m)}$	1	2	3
$\mu^{(m)}$	●.●●4(s^{-1})	●.●●3(s^{-1})	●.●●2(s^{-1})
$h^{(m)}$	●.●2(s^{-1})	●.●3(s^{-1})	●.●1(s^{-1})
$P_{QoS}^{(m)}$	●.●1	●.●15	●.●2
$revenew^{(m)}$	●.1654	●.1244	●.1321

IV. CONCLUSION

In this paper, we have proposed a novel distributed and dynamic bandwidth allocation scheme, known as MDBA, to support multiple connection-level QoS for handoff calls of different types and maximize the bandwidth utilization in mobile wireless networks via stochastic control. We have set up a novel model and taken into account the boundary conditions, the effects of limited channel capacity and time dependence on the call dropping probability, and the influences from nearest and next-nearest neighboring cells, which greatly improve the control precision. Moreover, the computational complexity is so low that the complex problem can be practically computable in real time, which owes to setting up the effective fictitious stochastic model and the effective computational method. All these make the MDBA scheme extremely stable, precise and computable for practical application, especially for broadband environment.

We are currently studying more practical broad sense birth-death processes model and its computational complexity in order to get an optimal control subject to computability in all environments.

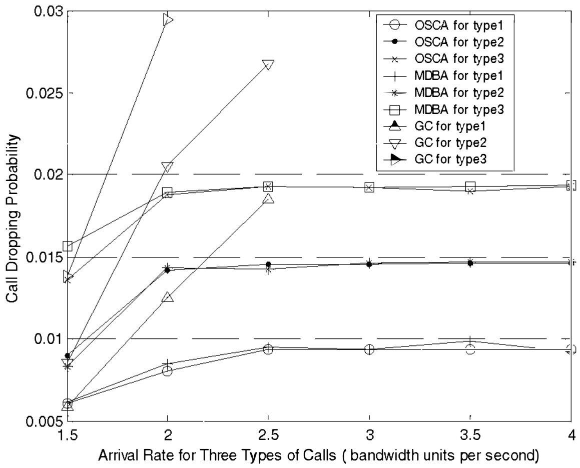

Figure. 4. Dropping probabilities comparison

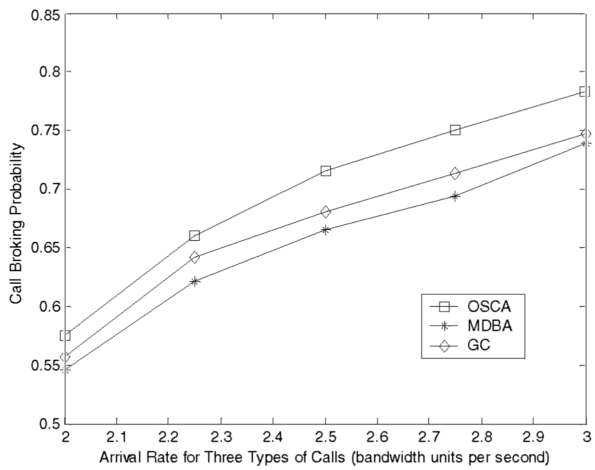

Figure. 5. Blocking probabilities for all call types traffic combined

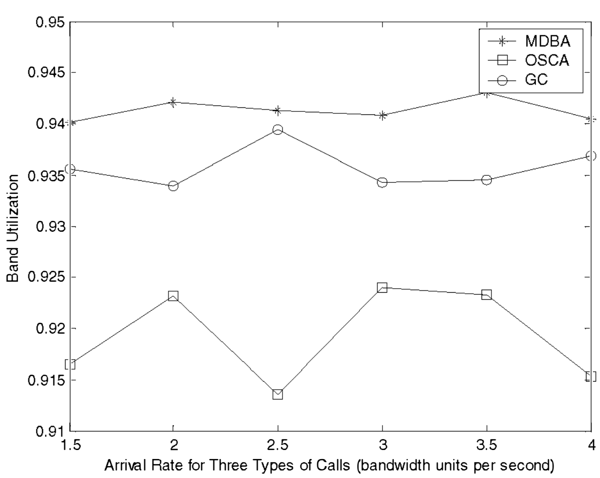

Figure. 6. Bandwidth utilizations for all call types traffic combined.

REFERENCES

[1] M. Fang, I. Chlamtac, and Y.-B. Lin, "Channel occupancy times and handoff rate for mobile computing and PCS networks," IEEE Trans. Comput., vol. 47, pp. 679–692, 1998.

[2] A. Acampora and M. Naghshineh, "Control and quality-of-service provisioning in high speed micro-cellular networks," IEEE Pers. Commun.,vol. 1, pp. 36–43, 2nd quarter 1994.

[3] G. Liu, G. Zhu and W. Wu, "An Adaptive Call Admission Policy for Broadband Wireless Multimedia Networks Using Stochastic Control" IEEE WCNC, Atlanta, Georgia USA, March 2004.

[4] C. Oliveira, J. B. Kim, and T. Suda, "An adaptive bandwidth reservation scheme for high-speed multimedia wireless networks," IEEE J. Select. Areas Commun., vol. 16, pp. 858–874, Aug. 1998

[5] E. Posner and R. Guerin, "Traffic policies in cellular radio that minimize blocking of handoff calls," in Proc. ITC-11, Kyoto, 1985, pp. 294–298.

[6] B. Li, C. Lin, and S. Chanson, "Analysis of a hybrid cutoff priority scheme for multiple classes of traffic in multimedia wireless networks," ACM/Baltzer J. Wireless Networks, vol. 4, pp. 279–290, Aug. 1998.

[7] G. Liu, G. Zhu, W. Wu, Z. Hu and Y. Liu "An Effective Call Admission Policy for Multi-Services Wireless Networks Using Stochastic Control," IEEE 59th VTC, May, 2004.

[8] S. Wu, K. Y. M. Wong, and B. Li, "A new, distributed dynamic call admission policy for mobile wireless networks with QoS guarantee," IEEE/ACM Trans. Networking, pp. 257–271, Apr. 2002

[9] Wang Zikun, Yang Xiangqun. "Birth and Death Processes and Markov Chains," Berlin: Springer-Verlag, Beijing: Science Press, 1992, pp. 220-237.

[10] "3GPP, 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects QoS Concept," 3GPP, 3G TR 23.907 Version 1.2.0, 1999.

[11] T. S. Rappaport, "Wireless Communications: Principles and Practice". second edition, Prentice Hall, NJ, 2002.

[12] X.-Y Luo, B. Li, I. L.-J Thng, Y.-B Lin, and I. Chlamtac, "An Adaptive Measured-Based Preassignment Scheme With Connection-Level QoS Support for Mobile Networks" IEEE Trans. Wireless Commun, vol. 1, pp.512-529, July 2002.

[13] G. Liu, Y. Ruan, W. Wu, W. Lang, and G. Zhu, "Optimal Stochastic Control for Multi-Services Call Admission in Mobile Wireless Networks" Proceeding of 4th International Conference on Computer and Information Technology, Wuhan, China, September 2004.

[14] S. Anand, A. Sridharan, and K. N. Sivarajan, "Performance Analysis of Channelized Cellular Systems With Dynamic Channel Allocation" IEEE Trans. Vehicular Technology. vol. 52, pp.847-859, July. 2003

[15] Y.-C. Lai and Y. –D. Lin, "A Novel Admission Control for Fairly Admitting Wideband and Narrowband Calls" IEEE Commun. Letters.vol.7,,pp186-188, April 2003.

[16] S. G. Choi and K. R. Cho "Traffic Control Schemes and Performance Analysis of Multimedia Service in Cellular Systems" IEEE Trans. Vehicular Technology. vol. 52, pp.1594-1602, Nov. 2003