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An adaptive bandwidth reservation scheme for 4G cellular networks using flexible 2-tier cell structure

Chenn-Jung Huang [a,*], Hung-Yen Shen [a], Yi-Ta Chuang [b]

[a] Department of Computer Science and Information Engineering, National Dong Hwa University, Hualien 970, Taiwan
[b] Department of Computer Science and Information Engineering, National Chiao Tung University, Hsinchu 300, Taiwan

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ABSTRACT

Many mechanisms based on bandwidth reservation have been proposed in the literature to decrease connection dropping probability for handoffs in cellular communications. The handoff events occur at a much higher rate in packet-switched fourth generation mobile communication networks than in traditional cellular systems. An efficient bandwidth reservation mechanism for the neighboring cells is therefore critical in the process of handoff during the connection of multimedia calls to avoid the unwillingly forced termination and waste of limited bandwidth in fourth generation mobile communication networks, particularly when the handoff traffic is heavy. In this paper, an adaptive two-tier scheme, which employs grey prediction theory and swarm intelligence techniques, is proposed to reduce the forced termination probability of multimedia handoffs. The simulation results show that the proposed scheme can achieve superior performance than the representative bandwidth-reserving schemes in the literature when performance metrics are measured in terms of the forced termination probability for the handoffs, the call blocking probability for the new connections and bandwidth utilization.

1. Introduction

With the increasing demand for the provision of multimedia applications, such as Video on Demand (VoD), videoconference, and many WWW-based applications, a great deal of attention is being paid to resource allocation for providing seamless multimedia access in fourth generation (4G) mobile communication networks (Huber, 2004; Hui & Yeung, 2003; Jiang & Zhuang, 2004; Schollmeier & Winkler, 2004; Zahariadis, 2003). Since the multimedia applications are very sensitive to the available bandwidth, jitters or delays in the networks, some sorts of service quality guarantees are desperately needed.

There are two important Quality-of-Service (QoS) parameters considered in wireless networks, namely the handoff call dropping probability (CDP) and new call blocking probability (CBP). Handoff is a mechanism that a mobile host (MH) is transferred from one base station (BS) to another during an ongoing call and the desired bandwidth should be allocated in the new cell in order to provide QoS guarantee for multimedia traffic. The CDP denotes the likelihood that an ongoing call is forced to terminate during a handoff process when the allocated resources in the new cell are degenerated to an unacceptable level, while the CBP represents the possibility that a new connection request is denied admission into the cellular networks. Accordingly, one of the most important QoS issues in providing multimedia traffic in wireless networks is to reduce handoff drops caused by lack of available bandwidth in the new cell while maintaining high bandwidth utilization and low new call blocking rate. In traditional handoffs only signal strength and channel availability are considered, while the following new metrics have been proposed for use in conjunction with signal strength measurements in the envisioned 4G system (McNair & Fang, 2004), such as class of traffic, monetary cost, network conditions, include traffic, available bandwidth, network latency, and congestion (packet loss), and mobile node conditions, such as velocity, moving pattern, moving histories, and location information. The use of the above metrics further increases the complexity of the handoff process and makes the 4G handoff decision more ambiguous.

In recent years, a variety of resource reservation algorithms have been proposed to process handoff in traditional cellular networks (Boumerdassi & Beylot, 1999; Ei-Kadi, Olariu, & Abdel-Wahab, 2002; Kuo, Ko, & Kuo, 2001; Lee, Jung, Yoon, Youm, & Kang, 2000; Lee, Wang, & Tseng, 2001; Levine, Akyildiz, & Naghshineh, 1997; Liu, Bahl, & Chlamtac, 1998; Malla, El-Kadi, & Todorova, 2001; Oliveira, Kim, & Suda, 1998; Wu, Yeung, & Hu, 2000). Among them, Oliviera et al. suggested reserving some bandwidth in the target cells and the neighboring cells at the same time. However, their scheme was unable to adapt to the abrupt oscillation of bandwidth requirement and bandwidth utilization was deteriorated as well (Oliveira et al., 1998). Levine et al. presented a shadow cluster

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[*] Corresponding author. Tel.: +886 38633503.
E-mail address: cjhuang@mail.ndhu.edu.tw (C.-J. Huang).

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scheme to reserve resources with neighboring cells by exchanging information related to the movement pattern and position (Levine et al., 1997). However, the scheme introduces too many communication overheads among the BSs of the cellular system. In Malla et al. (2001), a scheme based on max-min fairness protocol to provide QoS guarantees in wireless multimedia network is proposed. In spite of potentially improving both the CBP and the CDP in this scheme, the users might be subjected to significant bandwidth fluctuations. Lee et al. presented a handoff management scheme using simultaneous multiple bindings that reduces packet loss and generates negligible delays due to handoff in IP-based third-generation cellular systems (Lee et al., 2000). The CDP is probably reduced whereas the bandwidth levels of ongoing multimedia traffic are also degraded. Kuo et al. took use of the knowledge of staying time, available time, and the class of the MH to develop a resource semi-reservation scenario and it turns out to be idealistic since the speed of the MH is difficult to detect accurately (Kuo et al., 2001). In Wu et al. (2000), the traffic in a wireless system is first divided into two classes, which are voice calls and video calls, respectively. Then a channel borrowing scheme is proposed to allow voice calls to borrow channels from those pre-allocated to video calls temporarily. Although the CBP for the voice calls is reduced, the issue of improving the CDP during the handoff is not addressed. The work proposed by Ei-Kadi et al. borrowed bandwidth from multimedia connections for supporting the new calls or handoff connections because multimedia connections can tolerate and gracefully adapt themselves to transient fluctuations in QoS (Ei-Kadi et al., 2002). The borrowed bandwidth is returned to the original connections as soon as possible to satisfy the QoS requirements. There is 15% of bandwidth reserved exclusively for multimedia handoff connections. Thus, if a new call or handoff requests for bandwidth, the scheme in Ei-Kadi et al. (2002) tries to borrow bandwidth from other existing connections first. If the borrowed bandwidth is insufficient for the request, the connection will try to use the bandwidth in the reservation pool. If there is no enough bandwidth, the connection will be dropped.

Although the above-mentioned resource reservation algorithms more or less decrease the handoff dropping probability, the issue of unfairness is still unresolved. This is unacceptable in the 4G system since some new metrics, such as class of traffic, monetary cost, should be considered in 4G handoff process (McNair & Fang, 2004).

The handoff process in the packet-switched 4G system is apparently a more critical challenge task than in traditional wireless networks due to the existence of more bandwidth intensive multimedia applications, client mobility and other new metrics such as monetary cost. In Choi, Kim, Kim, and Kim (2001), Choi proposed a two-tier cell structure which reserved the bandwidth for class 1 traffic only when the MH located in "Tier-2" as shown in Fig 1, and the boundary for the two-tier structure is half of the radius of base station. However, the fixed boundary used for the two-tier structure does not fit the volatile behavior of wireless mobile networks. We thus employ two renowned machine learning techniques in this work, i.e., grey prediction theory and particle swarm optimization (PSO), to decide the dynamic boundary of the two-tier structure that suits each individual mobile host and the expected amount of bandwidth used in the neighboring cells for the handoff calls, respectively, in the packet-switched 4G system so that the CDP of handoff calls can be effectively lowered and the resource can be reserved more efficiently. The motivation of choosing the grey prediction theory and PSO to implement dynamic two-tier structure and bandwidth reservation scheme in this work is that the grey prediction theory and swarm intelligence have been successfully applied in many areas, such as time series prediction (Chi et al., 1999; Sheu and Wu, 2000; Wen, Lee, & Cho, 2005; Wen et al., 2001), Internet traffic prediction (Hasegawa, Wu, & Mizuno, 2001), decentralized-based routing (Mavromoustakis & Karatza, 2004), cell assignment in personal communication services networks (Shyu, Lin, & Hsiao, 2004), and earning prediction in the investment decision (Ko & Lin, 2004).

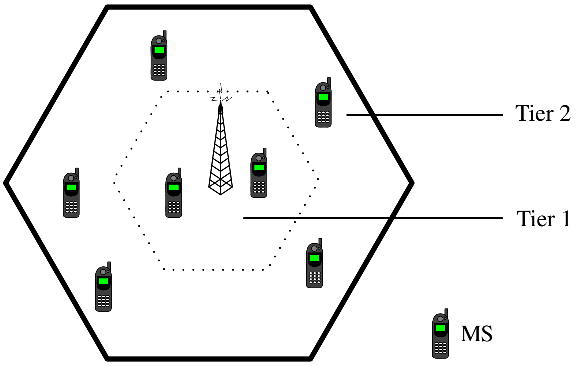

Fig. 1. Two-tier cell structure.

The proposed approaches are compared with the representative bandwidth reservation schemes in the literature, such as Fixed Reservation scheme (FR) and Rate-Based Borrowing scheme (RBB) (Ei-Kadi et al., 2002). The experimental results reveal that our approaches can achieve better performance than that of other bandwidth reservation schemes in terms of CDP and CBP.

The remainder of the paper is organized as follows. A primitive bandwidth reservation scheme for 4G system is introduced in Section 2. In Section 3 we state how to use grey prediction theory to compute the dynamic boundary of two-tier structure. Then in Section 4 we state how to incorporate the particle swarm optimization techniques into the bandwidth-reserving estimator given in Section 2 for better performance achievement. Section 5 is the simulation results, which compare the proposed approach with FR and RBB schemes. Conclusions are given in Section 6.

2. A primitive adaptive resource reservation scheme

The traffic in cellular networks is usually categorized into the following two classes in the literature (Oliveira et al., 1998). Class I traffic denotes real-time multimedia traffic, such as interactive audio and video, while Class II is non-real-time data traffic, such as images and text. The representative bandwidth reservation schemes in the literature (Ei-Kadi et al., 2002; Kuo et al., 2001; Lee et al., 2000; Levine et al., 1997; Malla et al., 2001; Oliveira et al., 1998; Wu et al., 2000) anticipate that a Class I connection request will make a handoff into one of its neighboring cells in the future and thus try to reserve some bandwidth in surrounding cells before the connection request is admitted. The Class I connection is forced to dropped during handoff if its minimum acceptable bandwidth requirement cannot be satisfied in the entering cell. As for Class II traffic, a handoff is always accepted as long as there is any free bandwidth available. Although the above-mentioned bandwidth reservation schemes can effectively lower the CDP in traditional macrocell wireless networks, whether they fit the requirement of the new metrics defined for processing 4G multimedia handoff is doubtful. We thus propose a primitive resource reservation scheme in this section to aim at reducing overheads among the BSs and reserving bandwidth in an effective manner, effectively decreasing the CDP for the 4G multimedia handoffs, while keeping bandwidth utilization at a reasonable level.

The amount of the reserved bandwidth is determined by the following three factors:

- The probability that the MH will move to a neighboring cell will be larger if the neighboring cell is a hot cell.

- The current reserved bandwidth for the six neighboring cells. The probability of moving to a neighboring cell is proportional to the bandwidth that the neighboring cell reserves.
- The distance of the MH's position to the neighboring cells. There are more chances that the MH will move to the neighboring cell that the MH is closer to.

Based upon the above considerations, the bandwidth reserved in cell B for the MH located at cell A when the new connection is accepted as shown in Fig. 2, can be derived as follows:

$$BR_B = C \cdot P_B \cdot BW_{\mathrm{MH}} \cdot \frac{1}{D_B}, \tag{1}$$

where C is a constant, BW_{MH} denotes the minimum bandwidth requested by a MH at cell A, P_B represents the probability that the MH moves to cell B, and D_B stands for the distance of the MH's position to cell B. Notably, The parameters BW_{MH} and P_B can be obtained easily by a simple computation in the base station, and D_B can be acquired based on the location management implemented in the 4G system (Saha, Mukherjee, Misra, Chakraborty, & Subhash, 2004; Zahariadis, 2003).

3. Adaptive two-tier structure using grey prediction theory

Grey theory was initiated by J.L. Deng in 1982 (Chen, Lin, Hsu, Ku, & Liu, 2003; Deng, 1989; Fan et al., 2004; Gudmuundson, 1991; Zhao, 2004). Here we call the system "white system" if all the information of a system is known. On the other hand, if we do not have any information about a system, the system is called "black system". Therefore, a grey system is a system which we have only a few information about it. Grey theory points at the system with uncertain information and provides the relation analysis and model construction. It has been widely applied to various fields including control system, random variable problem. In the grey theory, the grey prediction model is mostly used to predict the behavior of a Grey system. Through the prediction, we can make a decision with the grey system. Since the processing only need a few data to get predictive value with high accuracy, it is very suitable for system with a real-time requirement.

In this work, we adopt the following mobility profile of the MH:

- The speed of the MH.
- The distance between the MH and the radius of base station.
- Probability to neighbor cell is larger if it is a hot cell.

Since the above-mentioned metrics are all time series, we can use them as the parameters of the grey system, and apply the predictive values of these parameters as the inputs to the following equation so that the boundary for each individual MH can be decided as shown in Fig. 3:

$$Bounadary = Radius \times Ratio \times Speed \times Direction, \tag{2}$$

where $Radius$ is the radius of the base station, $Ratio$ denotes the distance between the MH and the radius of base station, $Speed$ represents the speed of the MH, and $Direction$ stands for the probability to the neighbor cells.

The grey system can be briefly reviewed two import methods: (i) GM (1, 1) Model Construction and (ii) Rolling checking.

3.1. GM (1, 1) Model Construction

Grey prediction based on grey model (GM) has three basic operations. They are the accumulated generating operation (AGO), inverse accumulated generating operation (IAGO) and grey modeling. The GM(1, l) model is the most commonly used model. According to the Grey Theory, an irregular raw data can be transformed to the regular data by using AGO (Gudmuundson, 1991). Being processed through AGO, the generated data can be used to construct system model in grey differential equation. GM(1, l) model construction procedure is as described as follow:

Suppose there is one parameter of the system that is intended to be predicted, and the non-negative data sequence are denoted as

$$x^{(0)} = (x^{(0)}(1), x^{(0)}(2), x^{(0)}(3), \ldots, x^{(0)}(n)), \quad \forall n \geq 4 \tag{3}$$

and the GM(1, l) model is

$$x^{(0)}(k) + aZ^{(1)}(k) = b, \quad k = 1, 2, 3, \ldots, n, \tag{4}$$

where a is named as "develop parameter", and b is the "grey input".

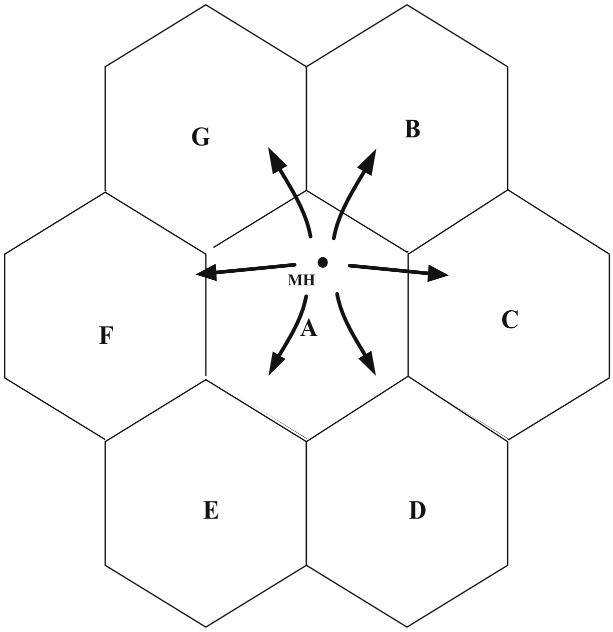

Fig. 2. Hexagonal cellular architecture with a cluster size equal to seven.

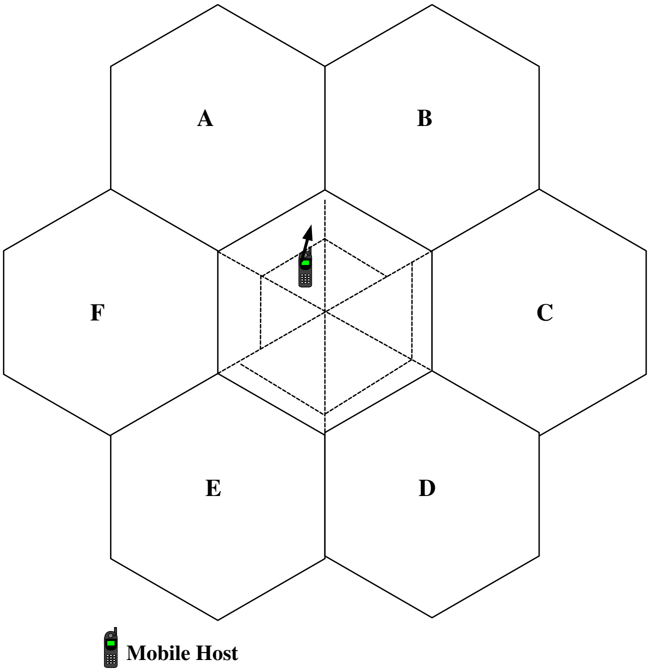

Fig. 3. Adaptive two-tier structure.

Step I: We can get the first order AGO sequence by taking AGO on $x(0)$ and denoted as

$$x^{(1)}(k) = \mathrm{AGO}(x^{(0)}(k)) = \sum_{i=0}^{k} x^{(0)}(i) \tag{5}$$

and the rth order AGO is defined as

$$x^{(r)}(k) = \sum_{m=1}^{k} x^{(r-1)(m)}, \quad k = 1, 2, 3, \ldots, n, \tag{6}$$

$$x^{(r)}(k) = x^{(r)}(k-1) + x^{(r-1)}(k). \tag{7}$$

Step II: Find $Z^{(1)}(k)$

$$Z^{(1)}(k) = 0.5[x^{(1)}(k) + x^{(1)}(k-1)]. \tag{8}$$

Step III: Use "Least Square Method" to find matrix B and vector y_n,

$$B = \begin{bmatrix} -Z^{(1)}(2) & 1 \\ -Z^{(1)}(3) & 1 \\ . & . \\ . & . \\ -Z^{(1)}(k) & 1 \end{bmatrix}, \tag{9}$$

$$y_n = [x^{(0)}(2), x^{(0)}(3), x^{(0)}(4), \ldots, x^{(0)}(n)]. \tag{10}$$

Step IV: The parameters a and b can be derived through follow operation:

$$\hat{a} = [a, b]^T = (B^T B)^{-1} B^T y_n, \tag{11}$$

where

$$a = \frac{\sum_{k=2}^{n} z^1(k) \sum_{k=2}^{n} x^{(0)}(k) - (n-1) \sum_{k=2}^{n} z^{(1)}(k) x^{(0)}(k)}{(n-1) \sum_{k=2}^{n} [z^{(1)}(k)]^2 - \left[\sum_{k=2}^{n} z^{(1)}(k)\right]^2}, \tag{12}$$

$$b = \frac{\sum_{k=2}^{n} [z^1(k)]^2 \sum_{k=2}^{n} x^{(0)}(k) - \sum_{k=2}^{n} z^{(1)}(k) \sum_{k=2}^{n} z^{(1)}(k) x^{(0)}(k)}{(n-1) \sum_{k=2}^{n} [z^{(1)}(k)]^2 - \left[\sum_{k=2}^{n} z^{(1)}(k)\right]^2}. \tag{13}$$

Step V: The response equation can be expressed by:

$$x^{(1)}(k+1) = \left[x^{(0)}(1) - \frac{b}{a}\right] e^{-ak} + \frac{b}{a}. \tag{14}$$

Step VI: $x^{(0)}(k+1)$ is obtained by

$$x^{(0)}(k+1) = (1 - e^{a}) \left[x^{(0)}(1) - \frac{b}{a}\right] e^{-ak}. \tag{15}$$

3.2. Rolling checking

Rolling checking method is mostly used to check the precision of the grey model. The procedure is described as follow:

Initially, use the first n data to construct a prediction model, then use the prediction model to predict the value of the (n+1)th data and compare the predicted data to the original (n+1)th data. After that, use the next n original data (from *2* to n+1) to construct another model to predict the (n+2)th data and compare it to the original (n+2)th data. Continue the operation until all the data are predicted. There is an error check equation in the grey system theory. When $i = 1$, $k = 4, 5, 6, \ldots, n-1$, the traditional error equation is

$$e(k+1) = \frac{x^{(0)}(k+1) - \hat{x}^{(0)}(k+1)}{x^{(0)}(k+1)} \times 100\%, \tag{16}$$

where $e(k+1)$ is the error of the $(k+1)$ instant of GM(1, l) model, and $k+1 \leqslant n$. The rolling checking average error (RCAE) of GM(1, l); is defined as:

$$e = \frac{1}{n-4} \sum_{k=4}^{n} \| e(k+1) \| \times 100\%. \tag{17}$$

Therefore, the rolling checking average precision of GM(1, l) is defined as

$$\sigma \equiv (1 - e) \times 100\%. \tag{18}$$

4. Bandwidth reservation mechanism using particle swarm optimization

Particle swarm optimization (PSO) is a computational intelligence approach to optimization that is based in the behavior of swarming or flocking animals, such as birds or fish. In the PSO, every individual moves from a given point to a new one which is a weighted combination of the individual's best position ever found, and of the group's best position. The PSO algorithm itself is simple and involves adjusting a few parameters. With little modification, it can be applied to a wide range of applications. Because of this, PSO has received growing interest from researchers in various fields.

In this work, we assume that each base station executes its individual PSO algorithm, and each swarm consists of seven particles (cells) as shown in Fig. 1. Recall that a simple relationship between the expected reserved bandwidth and the three input parameters was derived as shown in Eq. (1) in Section 2. To improve the accuracy of this equation, we assume the input/output parameters have the following nonlinear relationship:

$$\mathrm{BR}_B(t) = C \cdot (P_B(t))^{x_1} \cdot (\mathrm{BW}_{\mathrm{MH}}(t))^{x_2} \cdot \frac{1}{(D_B(t))^{x_3}}, \tag{19}$$

where the value of x_1, x_2 and x_3 is expected to be determined by the PSO technique. Meanwhile, the fitness function used in the PSO is the handoff call dropping probability (CDP) for multimedia class (Class I) traffic, since the achievement of the low CDP is the main goal of this work.

A summary of the PSO algorithm used in this work is given below:

(1) Initialize the swarm of the particles such that the position $\vec{x}_{ij}(t=0)$ of each particle is random within the hyperspace, where $j = 1, 2, 3$, denote the values of the three exponent parameters as given in Eq. (19), respectively.

(2) Compare the fitness function of each particle, $F(\vec{x}_{ij}(t))$, which is the CDP of Class I traffic of each individual during current time period, to its best performance thus far, $pbest_{ij}$;
if $F(\vec{x}_{ij}(t)) < pbest_{ij}$ then

$$\text{(i)} \quad pbest_{ij} = F(\vec{x}_{ij}(t)), \tag{20}$$

$$\text{(ii)} \quad \vec{x}_{pbest_{ij}} = \vec{x}_{ij}(t). \tag{21}$$

(3) Compare $F(\vec{x}_{ij}(t))$ to the global best particle, $gbest_j$
if $F(\vec{x}_{ij}(t)) < gbest_j$ then

$$\text{(i)} \quad gbest_j = F(\vec{x}_{ij}(t)), \tag{22}$$

$$\text{(ii)} \quad \vec{x}_{gbest_j} = \vec{x}_{ij}(t). \tag{23}$$

(4) Revise the velocity for each particle:

$$\vec{v}_{ij}(t) = \vec{v}_{ij}(t-1) + c_1 \cdot r_1 \cdot (\vec{x}_{pbest_{ij}}(t) - \vec{x}_{ij}(t)) + c_2 \cdot r_2 \cdot (\vec{x}_{gbet_j}(t) - \vec{x}_{ij}(t)), \qquad (24)$$

where r_1 and r_2 are random numbers between 0 and 1, and c_1 and c_2 are positive acceleration constants, which should satisfy $c_1 + c_2 \leqslant 4$ as reported in Kennedy (1998).

(5) Move each particle to a new position:

$$\text{(i)} \quad \vec{x}_{ij}(t) = \vec{x}_{ij}(t-1) + \vec{v}_{ij}(t), \qquad (25)$$

$$\text{(ii)} \quad t = t + 1. \qquad (26)$$

(6) Repeat steps (2)–(6) until convergence.

5. Simulation results

A series of simulations are conducted to compare the proposed bandwidth reservation scheme (DTBR) schemes, with the fixed reservation scheme (FR), and the scheme without bandwidth reservation (NR). Meanwhile, the rate-based borrowing scheme (RBB) Ei-Kadi et al. (2002) is also compared with the proposed work because it was reported in Ei-Kadi et al. (2002) that the RBB scheme achieves better performance than other representative bandwidth allocation and reservation schemes in the literature, such as the well-known bandwidth reservation scheme presented in Oliveira et al. (1998). The RBB scheme not only allows the new calls and handoff connections to borrow bandwidth form existing multimedia connections, but also reserves 15% of bandwidth exclusively for Class I handoff connections.

In the NR scheme, no bandwidth is reserved for handoff connections in each cell. If there is no bandwidth available when the MH moves to the new coverage area, the handoff call is disconnected and a forced termination occurs. As for the FR approach, a set of channels called guard channels are preserved in each cell to provide a way of prioritizing handing off calls on new call originations by setting aside a fixed bandwidth to support handing off users. New call originations cannot be assigned bandwidth from the guard channel pool. The guard channels are set to 20% of the whole bandwidth for the FR scheme in our simulations. Meanwhile, the acceleration constants c_1 and c_2 are both set to two in the PSO scheme.

The connections in the simulations are divided into two classes. A Class I traffic, which is a multimedia connection, is allowed to move to a neighboring cell only when the unallocated bandwidth in the target cell exceeds the requested bandwidth. A data connection of Class II traffic can be granted to switch to a neighboring cell as long as the target cell possesses any unused bandwidth. Additionally, a new connection of Class I real-time traffic is allowed to borrow bandwidth from Class II non real-time connections in the same cell if the unallocated bandwidth in the current cell is smaller than the minimum bandwidth that the new Class I traffic requests in the proposed scheme. Similar approach was taken in Wu et al. (2000) and Ei-Kadi et al. (2002) to effectively reduce the new call blocking probability of real-time traffic.

There are 36 cells included in the simulation environment as shown in Fig. 4. A total of 30 Mbps bandwidth is allocated in each cell. Both classes of the connections are listed in Table 1. The bandwidth requirement for each connection is randomly selected within the range of the maximum and the minimum bandwidth requirement listed in Table 1. Both the class and the location of each MH are randomly selected at the initial state. Each MH is given a speed characteristic, which decides the time spent in a cell, in order to simulate handoffs. If a hot cell neighbors with the cell that a MH is located at, then the MH has a probability of 0.5 to move to the neighboring hot cell, and a probability of 0.1 to one of other neighboring cells. On the other hand, each MH will move to one of the six neighboring cells with equal probability if no neighboring hot cell exists.

Table 1
Multimedia traffic used in the simulations.

Traffic class	Bandwidth requirement	Average call duration (min)	Example
Class I	30 Kbps	3	Voice service
Class I	256 Kbps	5	Video-phone
Class I	1–4 Mbps	10	Video service
Class II	5–20 Kbps	0.5	E-mail, paging
Class II	64–512 Kbps	3	Remote login & Data on demand
Class II	1–5 Mbps	2	Ftp

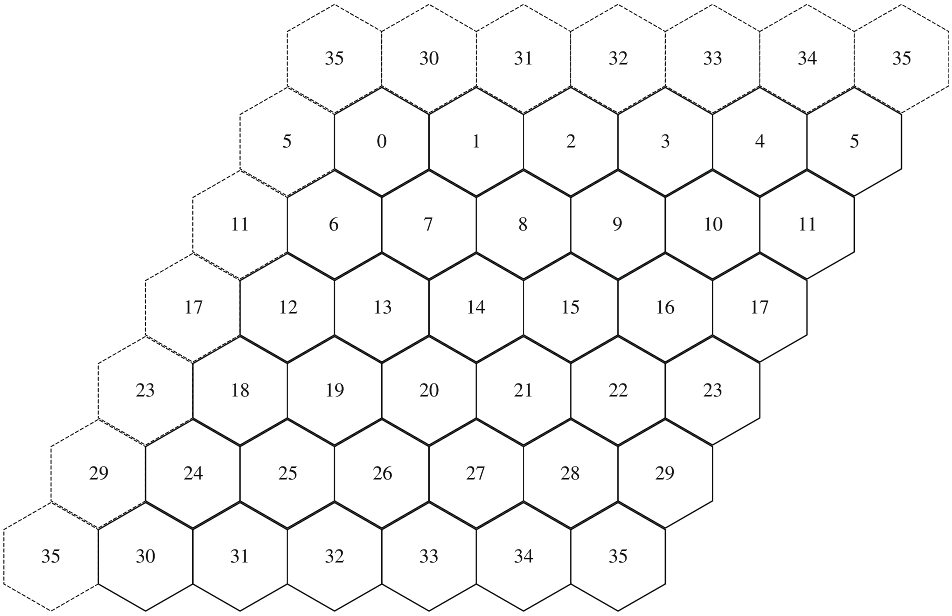

Fig. 4. Cellular topology with 36 cells in the simulations.

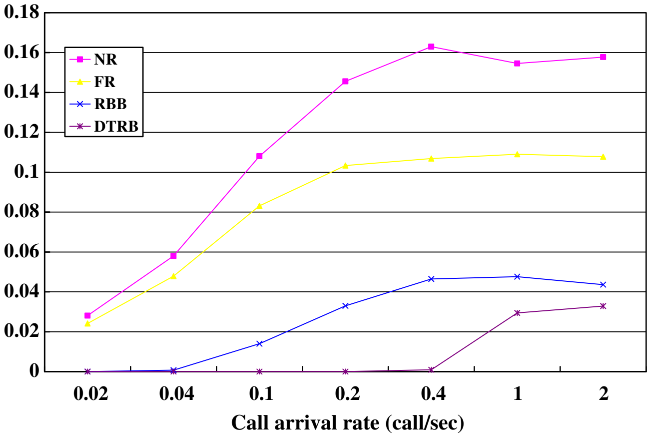

Fig. 5. Call dropping probability for Class I traffic in the four schemes.

Fig. 5 shows the comparison of call dropping probability (CDP) for multimedia handoffs (Class I), and Fig. 5 illustrates the CDP for combined Class I and II traffic. We can see from Fig. 5 that the CDP for multimedia handoffs is the lowest for the proposed scheme (DTBR). Besides, the CDP for combined Class I and II traffic in proposed scheme is still lower than the other three schemes as shown in Fig. 6. The NR has the worst performance as expected since it does not reserve bandwidth for the handoffs at all. As for the RBB scheme, although it uses bandwidth borrowing technique to lower down the CDP for handoffs, its fixed bandwidth reservation mechanism is still inferior to the approach of adaptive bandwidth reservation based on the dynamic change of mobile node conditions as taken in this work.

Fig. 7 shows the CBP for the new multimedia connections in the four schemes, and Fig. 8 illustrates the CBP for combined Class I and II traffic. The call blocking probability for the new connections in the PSOBR and the RBB schemes is apparently improved by means of the channel borrowing technique. Meanwhile, the effectiveness of adaptive bandwidth reservation contributes to the better performance achieved in the proposed scheme as illustrated in Figs. 7 and 8. The FR scheme has the highest CBP for new connections because it reserves fixed bandwidth for multimedia handoff connections and results in lessened bandwidth available for new connections.

The bandwidth utilization of various mechanisms is given in Fig. 9. Note that the bandwidth utilization is defined as:

$$\text{Bandwidth Utilization} = \frac{\sum_{\text{for each cell}} \text{Used bandwidth of each cell}}{\sum_{\text{for each cell}} \text{Maximum bandwidth of each cell}}. \qquad (27)$$

The proposed scheme achieves better performance than the other three schemes in bandwidth utilization due to the efficient usage of adaptive bandwidth reservation mechanism. The RBB scheme uses bandwidth borrowing technique to achieve higher bandwidth utilization than the NR and FR schemes. Bandwidth utilization is the

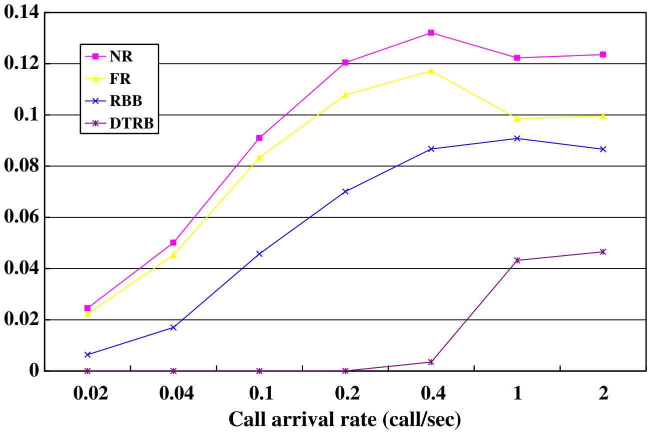

Fig. 6. Call dropping probability for combined Class I and II handoffs in the four schemes.

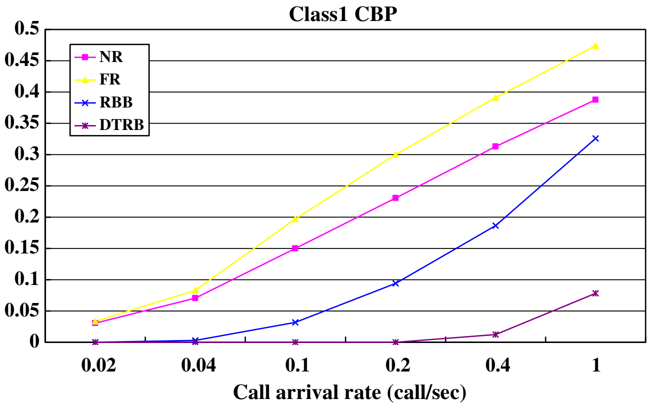

Fig. 7. Call blocking probability for Class I traffic in four schemes.

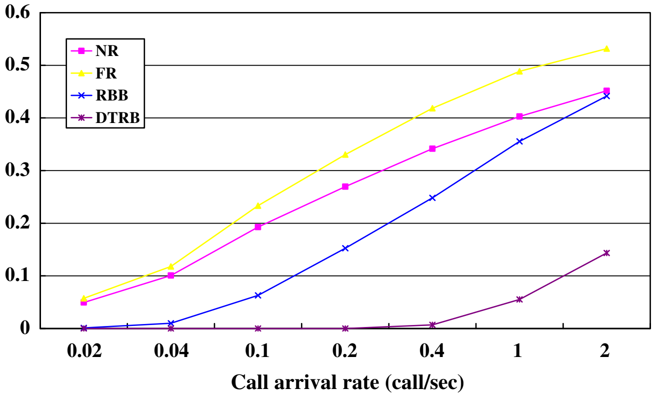

Fig. 8. Call blocking probability for combined class I and II traffics in the four schemes.

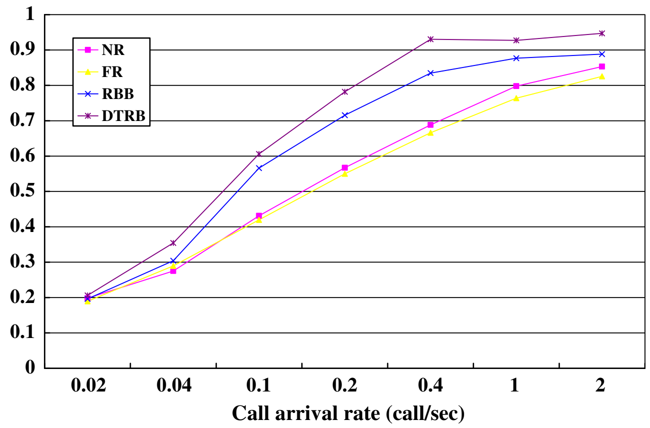

Fig. 9. Bandwidth utilization for the four schemes.

poorest in the FR scheme since it always reserves fixed bandwidth in each cell which is not necessarily used by the handoffs.

6. Conclusion

In this paper, an adaptive bandwidth reservation scheme is proposed to reduce forced termination of multimedia handoffs in the packet-switched 4G systems. Grey prediction theory and particle swarm optimization techniques are employed to compute the dynamic boundary of a two-tier structure and the amount of reserved bandwidth for the handoffs in the candidate target cells. This work also tries to decrease the call blocking probability of new connections by using a channel borrowing technique. The simulation results show that the proposed scheme performs better then the fixed reservation (FR) scheme, the scheme without reservation (NR), and the rate-based borrowing scheme (RBB) when call blocking probability for new connections, call dropping probability for the handoffs, and bandwidth utilization are compared. The proposed scheme is proved to be a good choice for the bandwidth reservation scheme used for processing multimedia handoffs in 4G systems where the increasing amounts of multimedia connections are expected and the QoS requirements of multimedia traffic need to be maintained persistently during connection time. Subsequent research will investigate the feasibility of applying other intelligent tools such as neuro-fuzzy and genetic algorithms into the proposed scheme to improve the accuracy of the motion prediction for the MH.

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