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A combined channel assignment mechanism for hierarchical cellular systems[☆]

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Abstract

This paper proposes a combined channel assignment (CCA) mechanism for hierarchical cellular systems with overlaying macrocells and overlaid microcells. The proposed CCA mechanism combines overflow, underflow, and reversible schemes, where new or handoff calls having no available channel to use in the overlaid microcell can *overflow* to use free channels in the overlaying macrocell, handoff calls from a neighboring macrocell can *underflow* to use free channels in the overlaid microcell, and handoff attempts from a macrocell-only region to an overlaid microcell can be *reversed* to use free channels in the microcell. We apply the CCA mechanism in two different hierarchical cellular systems of Strip type and Manhattan type and compare the CCA with the overflow channel assignment (OCA) scheme. Simulation results show that the CCA mechanism outperforms the OCA scheme by once in forced termination probability, by several times in new call blocking probability, and by 4.7% in system utilization for a hierarchical cellular system, and the CCA mechanism is more suitable for the Manhattan type than for the Strip type. © 1998 Elsevier Science B.V.

Keywords: Hierarchical cellular system; Channel assignment; Overflow; Underflow; Reversible

1. Introduction

Due to the increasing demands for wireless communication services, it seems essential to re-configure the existing cellular radio communication system into a hierarchical structure for enhancing the system capacity and improving the coverage. The hierarchical cellular system can provide overlaid microcells for high-teletraffic areas and overlaying macrocells for low-teletraffic regions [1–6].

In such a hierarchical cellular system, Rappaport and Hu proposed the *overflow channel assignment* (OCA) scheme that allows new and handoff calls which have no available channel in the overlaid microcell to overflow to use free channels in the overlaying macrocell [7,8]. The OCA scheme can reduce both the new-call blocking rate and the forced termination rate, and it is easy to implement because it needs no elaborate coordination between microcells. Beraldi et al. proposed a *reversible* hierarchical scheme [9], which allows the presence of handoff attempts from an overlaying macrocell to an overlaid microcell if there is any idle channel in the overlaid microcell. The reversible hierarchical scheme improves channel utilization in the microcells and decreases the blocking rate of both new calls and handoff calls in the whole system since microcells are designed to be capable of supporting high capacity and balancing the traffic load.

However, these schemes could be insufficient in the situation where there is a handoff call moving from an adjacent macrocell into an overlaid microcell of which the macrocell has no free channels but the overlaid microcell's channels are not fully occupied, and the handoff call is dropped by the system. In this paper we consider an *underflow* scheme to allow such a handoff call to get a free channel in the microcell. The underflow scheme could decrease the handoff blocking rate or the forced termination rate.

Therefore, we propose a new channel assignment mechanism that combines overflow, underflow, and reversible techniques for the hierarchical cellular system in the paper. The *combined channel assignment* (CCA) mechanism also adopts a buffering scheme in order to obtain a high total admitted traffic while guaranteeing the grade-of-service requirements. It is a complete-partition buffering scheme where buffers in the macrocell are separately provided for handoff calls from adjacent macrocells, overflowed handoff calls from overlaid microcells, new calls originating in the macrocell-only region, and overflowed new calls from microcells. Buffers in each microcell are

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separately provided for underflow handoff calls from adjacent macrocells, handoff calls from adjacent microcells, and new calls originating in microcells. The scheme is not necessary to support a buffer for the reversible handoff call. Furthermore, the CCA mechanism assumes a priority service discipline in that the handoff call is given more priority than the new call and the inter-macrocell handoff is more important than the inter-microcell handoff.

The objective of the proposed CCA mechanism is to increase the channel utilization for the whole system by balancing the overall traffic load between macrocell and microcell. To balance load among cells is the most effective way to increase channel utilization. In the CCA scheme, the load balancing is performed by comparing the queue length in the overlaying macrocell with that in the overlaid microcell as a call request occurs and all channels are busy; if the queue length in the macrocell (microcell) is larger than the queue length in the microcell (macrocell), it denotes that traffic load in the macrocell (microcell) is heavier than that in the microcell (macrocell), and the call will be assigned to the microcell (macrocell).

Simulation results show that the CCA mechanism can outperform the OCA scheme by once in forced termination probability, by several times in new call blocking probability, and by 4.7% in system utilization. In the simulations, we also consider two types of hierarchical cellular systems: Strip type and Manhattan type. In the Strip type, the macrocell overlaps many microcells which are put along highways like a strip. In the Manhattan type, the macrocell overlaps microcells which are put along city roads like Manhattan streets. It is found that the CCA scheme makes the traffic load more balanced in the Manhattan type than in the Strip type. This is because the Manhattan type has microcells that are better distributed than the Strip type.

The rest of the paper is organized as follows. In Section 2, the system model is described. The channel assignment strategy is presented in Section 3, and Section 4 gives the definitions of the performance measures and shows simulation results and discussions. Concluding remarks are presented in Section 5.

2. System model

The hierarchical cellular system contains a large geographical region tessellated by macrocells, each of which overlays several microcells. Fig. 1 depicts an architecture, where the overlaying macrocell is denoted by cell 0 and its overlaid microcells are denoted by cell 1,…,N. The coverage area of an overlaying macrocell is termed the macroarea. Within the macroarea, the area outside microcells is the region served only by the macrocell (cell 0). Hence, it is called the macrocell-only region. For cell i, $0 \leq i \leq N$, the system allocates a number of channels C_i of which C_{ri} are used as guard channels for handoff calls. Increasing C_{ri} provides more protection for handoff calls but sacrifices the admission possibility of new calls.

We here propose a new channel assignment mechanism that combines overflow, underflow, and reversible schemes in the system. Details of the CCA mechanism will be described in the next section. The system also adopts a buffering scheme for new and handoff calls. As shown in Fig. 2, the system provides several buffers in the microcell i, among which a buffer with capacity N_{hui} is for underflowed handoff calls from the overlaying macrocell, a buffer with capacity N_{hi} is for handoff calls from adjacent microcells, and a buffer with capacity N_{ni} is for new call originations. The system also supports buffers in the macrocell, among which a buffer with capacity N_{ha} is for handoff calls from adjacent macrocells, a buffer with capacity N_{ho} for overflowed handoff calls from overlaid microcells, a buffer with capacity N_{na} is for new calls originating in the macrocell-only region, and a buffer with capacity N_{no} is for overflowed new calls from overlaid microcells. Reneging of

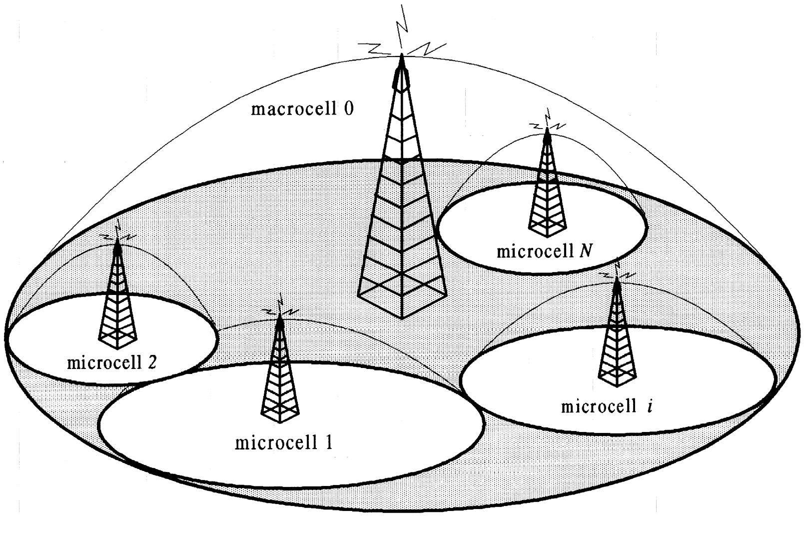


Fig. 1. Hierarchical cellular system.

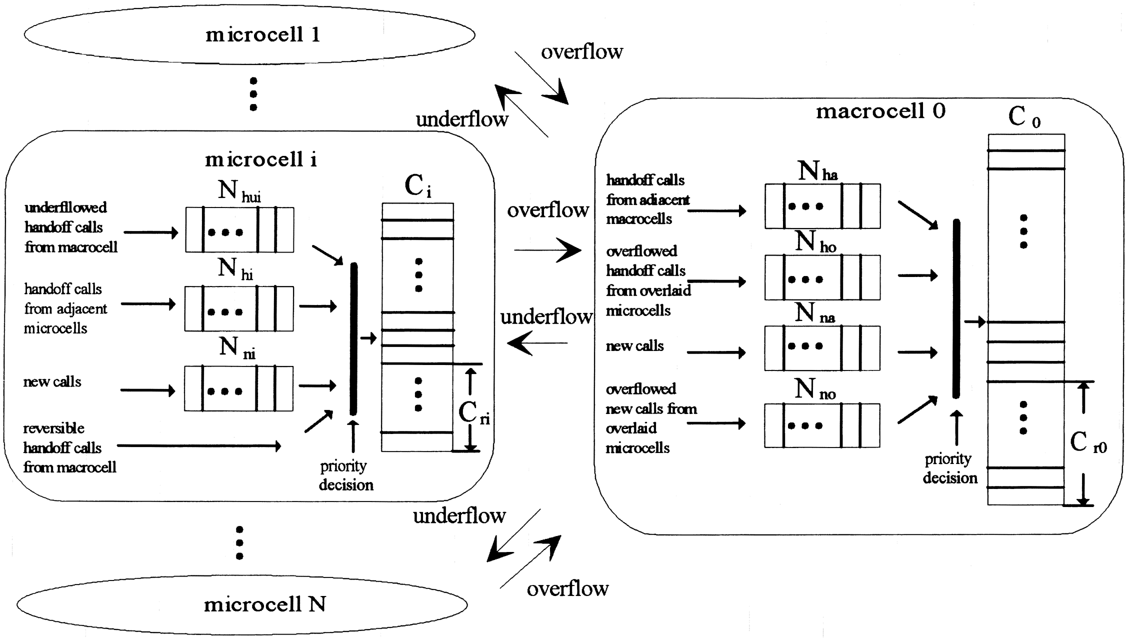


Fig. 2. System model for the hierarchical cellular system.

waiting new calls and dropping of waiting handoff calls are considered because of the impatience of new calls and handoff calls moving out of the handoff area.

For convenience, the system is assumed to be homogeneous, i.e. macrocells are statistically the same. Further assumptions are made in the following.

1. The new-call arrival process in a cell follows a Poisson process with calling rate per mobile station (user) λ.
2. The handoff behavior of the user is characterized by a teletraffic flow matrix [7], defined as

$$A=\begin{vmatrix} a_{00} & a_{01} & a_{02} & \cdots & a_{0N} & a_{0d} \\ a_{10} & a_{11} & a_{12} & \cdots & a_{1N} & a_{1d} \\ a_{20} & a_{21} & a_{22} & \cdots & a_{2N} & a_{2d} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{N0} & a_{N1} & a_{N2} & \cdots & a_{NN} & a_{Nd} \end{vmatrix}$$

where a_{ij}, $i \neq j$, represents the probability of a handoff call originated in cell i and directed to cell j, $1 \leq j \leq N$, and a_{id} denotes the probability of this handoff call directed to the adjacent macrocell. a_{ii} would be zero and $\sum_{\forall j} a_{ij} = 1$ for $0 \leq i \leq N$.

3. The dwell time of a mobile station in the cell i is assumed to have a negative exponential probability density function $0 \leq i \leq N$ [4,10]. Its mean depends on many factors such as cell radius, mobility, the path a mobile station follows, etc.
4. The unencumbered session duration of a call is a random variable having a negative exponential probability density function.
5. The reneging (dropping) process for queued new (handoff) calls is also assumed to be with a truncated exponential distribution.
6. The overflowed new-call arrival process to macrocell 0, the overflowed (underflowed) handoff call arrival process in the overlaying macrocell (overlaid microcell i), and the reversible handoff call arrival process from overlaying macrocell 0 to overlaid microcell i depend on the combined channel assignment mechanism.

3. CCA mechanism

The CCA mechanism for hierarchical cellular systems adopts an overflow scheme for blocked calls in microcells, a underflow scheme for blocked handoff calls in macrocells, and a reversible scheme, besides the guard channel protection scheme for handoffs in each cell.

Fig. 3 shows the flowchart of the CCA mechanism. If a new call is originated in the macrocell-only region, as shown in Fig. 3(a), it will be immediately served by the macrocell (a macrocell channel is assigned) if the number of idle channels I_0 in the macrocell 0 is larger than C_{r0}; otherwise, it will be put in the new-call buffer of the macrocell. The new call will be blocked if the buffer is full. The queued new call may renege from the buffer unless it can be successfully served within its patience time. The assigned channel will be released if the ongoing call is terminated due to call completion, handoffs to a neighboring cell, or reverses to an overlaid microcell. If a new call is originated in the microcell i, as shown in Fig. 3(b), it will be immediately served by microcell i (a microcell i channel is

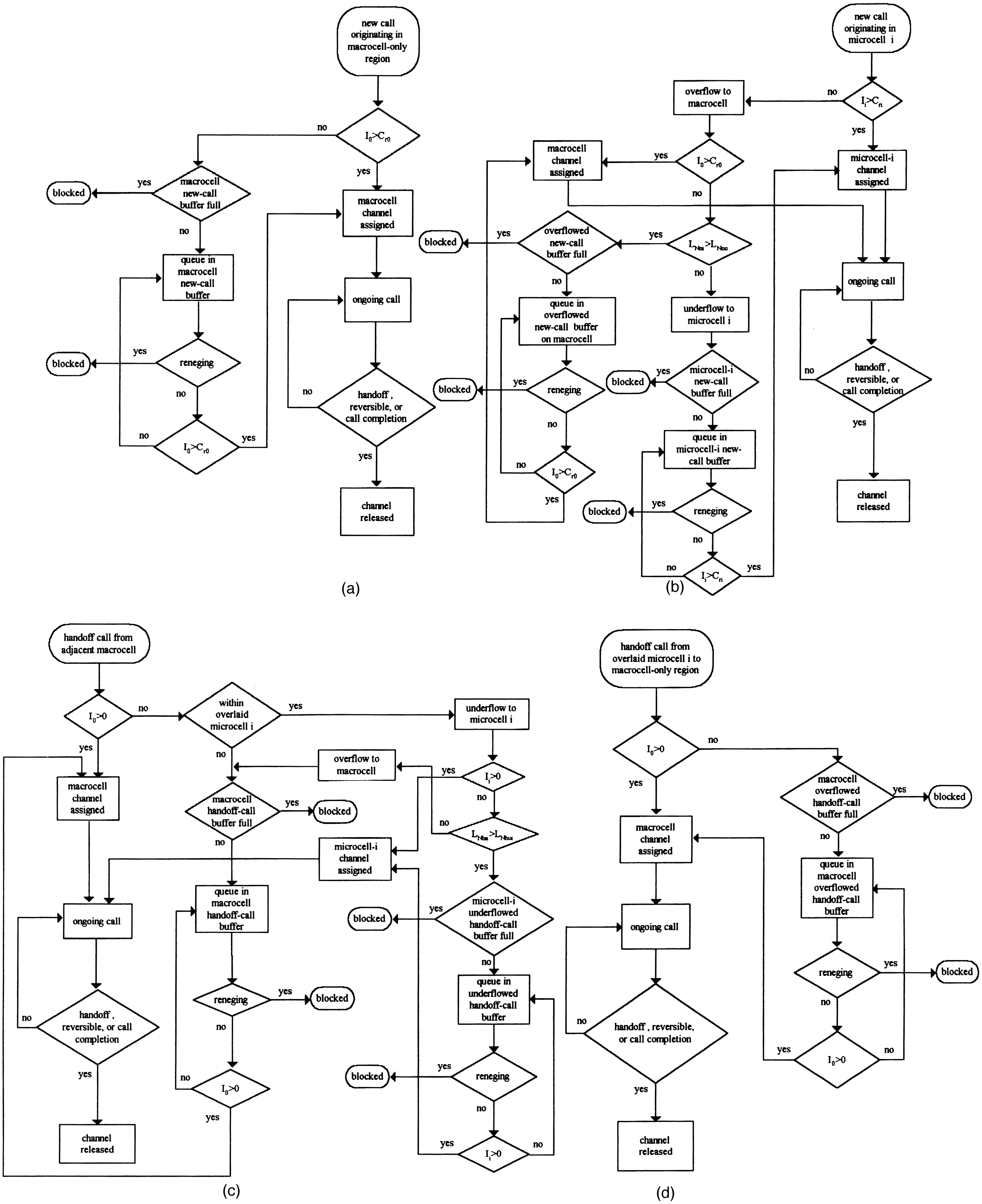
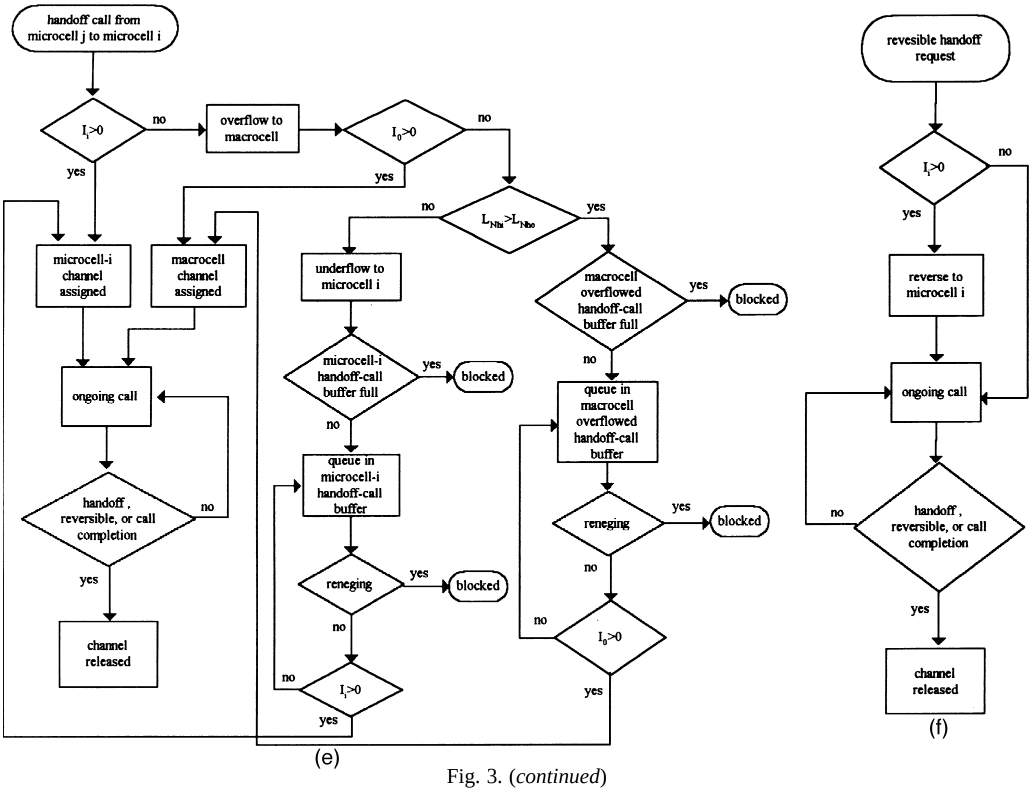


Fig. 3. Combined channel assignment mechanism for (a) new calls originating in the macrocell-only region, (b) new calls originating in the microcell *i*, (c) handoff calls from adjacent macrocell, (d) handoff calls from microcell *i* to macrocell-only region, (e) handoff calls from microcell *j* to microcell *i*, and (f) reversible handoff.



(e)

(f)

Fig. 3. (*continued*)

assigned) if the number of free channels I_i is larger than C_{ri}, otherwise it will overflow to the overlaying macrocell. The overflowed new call will be immediately served by the macrocell if the number of idle channels I_0 in the macrocell 0 is larger than C_{r0}; otherwise it will choose an overflowed new-call buffer in macrocell or microcell i new-call buffer to queue according to their respective buffer length. The overflowed new call is underflowed to microcell i (kept in macrocell) and put in the new-call buffer (the overflowed new-call buffer) of microcell i (macrocell), if the length of the new-call queue $L_{N_{ni}}$ (the overflowed new-call queue $L_{N_{no}}$) in microcell i (macrocell) is not larger (smaller) than the overflowed new-call queue length in the macrocell $L_{N_{no}}$ (the new-call queue length in the microcell $L_{N_{ni}}$). The call will be blocked if both buffers are full. The queued new call may renege from the buffer unless it can be successfully served within its patience time. The assigned channel will be released if the ongoing call is terminated due to call completion, handoffs to a neighboring cell, or reverses to an overlaid microcell.

If the handoff call is from adjacent macrocells, as shown in Fig. 3(c), the call will be immediately served by the macrocell if there is any idle channel in the macrocell 0 ($I_0 > 0$); otherwise, it will be put in the handoff-call queue of macrocell 0 if the handoff call is not within overlaid microcell i, or be blocked due to a full buffer. If the handoff area is within the overlaid microcell i, the handoff call will underflow to microcell i and be immediately served by the microcell i if there is any idle channel in microcell i ($I_i > 0$); otherwise, it will be put in the handoff buffer of macrocell 0 or the underflowed handoff buffer of microcell i according to their respective queue length. The handoff call will be buffered in the underflowed handoff-call queue (handoff-call queue) of microcell i (macrocell 0) if there are no free channels available in both macrocell 0 and microcell i and the underflowed handoff-call queue length $L_{N_{hui}}$ (the handoff-call queue length $L_{N_{ha}}$) in microcell i (macrocell 0) is smaller (not larger) than the handoff-call queue length $L_{N_{ha}}$ (underflowed handoff-call queue length $L_{N_{hui}}$) in macrocell 0 (micro cell i). The handoff call will be blocked if both buffers are full.

If a handoff call is from microcell i to the macrocell-only region, as shown in Fig. 3(d), it will be immediately served if there is any idle channel in macrocell 0; otherwise it will be put in the overflowed handoff-call buffer of macrocell 0 if the buffer is available or be blocked if the buffer is full.

If the handoff call arrives at microcell i from adjacent microcell j, as shown in Fig. 3(e), it will be immediately served by microcell i if there is any idle channel in the microcell i; otherwise it will overflow to the overlaying macrocell. The overflowed handoff call will be immediately served by macrocell 0 if there is any idle channel in the macrocell 0; otherwise it will be put in handoff-call queue (overflowed handoff-call queue) of microcell i (macrocell) if the handoff-call queue length $L_{N_{hi}}$ (overflowed handoff-call queue length $L_{N_{h0}}$) in the microcell i (macrocell 0) is not larger than the overflowed handoff-call queue length $L_{N_{h0}}$ (handoff-call queue length $L_{N_{hi}}$) in macrocell 0 (microcell i). The call is blocked if both buffers are full.

All the queued handoff calls may be dropped by the

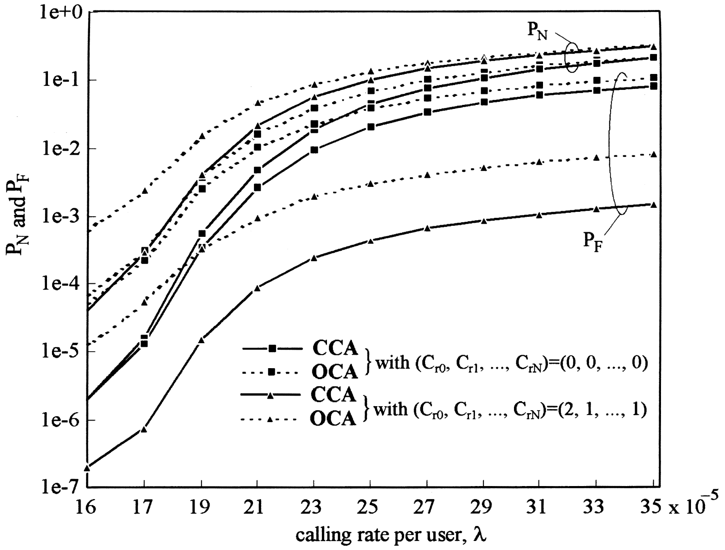


Fig. 4. P_N and P_F for CCA and OCA mechanisms in the Strip type.

system as it moves out of the handoff area. The occupied channel is released if the call is terminated due to call completion, handoffs to a neighboring cell, or reverses to microcell.

Fig. 3(f) shows the flow chart of the CCA mechanism for the reversible handoff. For the handoff call from macrocell-only region to microcell *i*, the channel of the macrocell for this handoff call can be reversible to a channel in microcell *i* if there is an available channel in microcell *i*, otherwise the call will continue to use the channel of macrocell 0.

4. Simulation results and discussion

Four performance measures are considered: the new-call blocking probability, the forced termination probability, the cost function, and the channel utilization. The new call blocking probability, denoted by P_N, is defined as the average fraction of new calls, originating in the macrocell-only region or microcell *i*, that cannot be served by macrocell 0 or microcell *i* finally. It includes the reneging waiting calls that hand on the set before being served by the system. P_N is given by

$$P_N = \frac{\sum_{i=0}^{n} (B_i + R_i)}{\sum_{i=0}^{n} N_i} \qquad (1)$$

where B_i (R_i) is the number of blocked (reneging) new calls in cell *i*, and N_i (N_0) is the number of new calls originating in microcell *i* (macrocell-only region).

A forced termination occurs if a call is interrupted during its conversation time due to a handoff failure. The handoff failure means that the handoff call fails to gain a channel or is dropped out of the queue. The forced termination probability, denoted by P_F, is the average fraction of

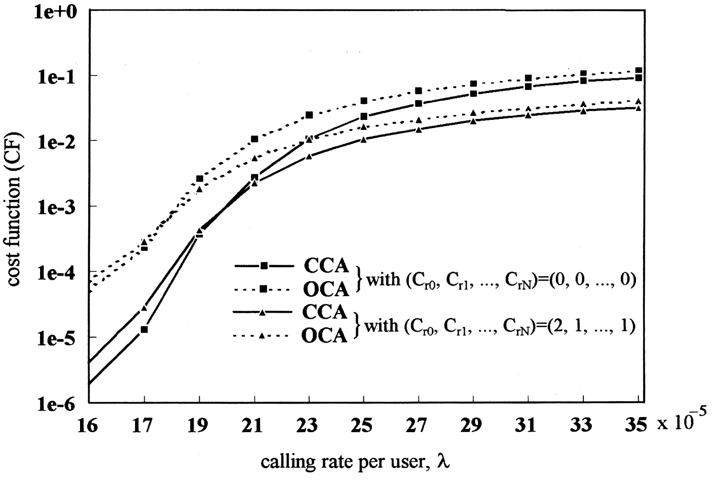


Fig. 5. Cost function with $\alpha = 0.1$ for CCA and OCA mechanisms in the Strip type.

prematurely terminated calls, which is defined as the ratio of handoff failure to the total successfully initiated calls. P_F is given by

$$P_F = \frac{\sum_{i=0}^{n} (H_i + HR_i)}{\sum_{i=0}^{n} S_i} \tag{2}$$

where H_i (HR_i) is the number of blocked (dropped) handoff calls in cell i, and S_i is the number of successful new calls.

The cost function is defined as

$$\mathrm{CF} = \alpha P_N + (1-\alpha) P_F \tag{3}$$

where α is the weighting factor between P_N and P_F. It is an overall blocking probability of the system.

The channel utilization of macrocells (microcells), denoted by U_0 (U_i), is given by

$$U_0 = \frac{K_0}{C_0} \left(U_i = \frac{\sum_{i=1}^{n} K_i}{\sum_{i=1}^{n} C_i} \right) \tag{4}$$

where K_0 (K_i) is the average number of busy channels in macrocell 0 (microcell i) and C_0 (C_i) is the allocated channels for macrocell 0 (microcell i). We further define the channel utilization of the whole system, denoted by U, as

$$U = \frac{K_0 + \sum_{i=1}^{n} K_i}{C_0 + \sum_{i=1}^{n} C_i} \tag{5}$$

where K_0 (K_i) and C_0 (C_i) are as defined above.

In the simulations, two types of microcell arrangement in a hierarchical cellular system are investigated. The first type is a Strip type, in which $N = 9$ microcells that are put in order along a highway like a strip. The second type is the Manhattan type, where $N = 9$ microcells are constructed like Manhattan streets. A total of 150 channels are fixedly allocated to the macrocell and microcells with a pattern of $(C_0, C_1, \ldots, C_N) = (42, 12, \ldots, 12)$ and $(C_{r0}, C_{r1}, \ldots, C_{rN}) = (2, 1, \ldots, 1)$. The number of mobile stations in each cell is assumed to be 550. The mean unencumbered session duration is 100 s. The mean dwell times in the macrocell and microcells are 225 and 150 s, respectively. The patience (dwell) time for queued new (handoff) calls is assumed to be in the range 5–20 s. Since the reneging (dropping) process is considered, it is not necessary to provide a large queue size for new (handoff) calls [11]. In these examples, all queue sizes in both the macrocell and microcells are assumed to be 1.

4.1. Strip type

In this type, the teletraffic matrix is assumed to be

$$A = \begin{vmatrix}
0.0 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 \\
0.1 & 0.0 & 0.45 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.45 \\
0.1 & 0.45 & 0.0 & 0.45 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\
0.1 & 0.0 & 0.45 & 0.0 & 0.45 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\
0.1 & 0.0 & 0.0 & 0.45 & 0.0 & 0.45 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\
0.1 & 0.0 & 0.0 & 0.0 & 0.45 & 0.0 & 0.45 & 0.0 & 0.0 & 0.0 & 0.0 \\
0.1 & 0.0 & 0.0 & 0.0 & 0.0 & 0.45 & 0.0 & 0.45 & 0.0 & 0.0 & 0.0 \\
0.1 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.45 & 0.0 & 0.45 & 0.0 & 0.0 \\
0.1 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.45 & 0.0 & 0.45 & 0.0 \\
0.1 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.45 & 0.0 & 0.45
\end{vmatrix}$$

Fig. 4 shows P_N and P_F versus new-call arrival rate per user λ for CCA and OCA mechanisms. We found that CCA can have a significant improvement over OCA in both P_N and P_F for all call rates. Take a case of $\lambda = 21 \times 10^{-5}$ and $(C_{r0}, C_{r1}, \ldots, C_{rN}) = (2, 1, \ldots, 1)$ for instance. The improvement of P_N for the CCA mechanism over the OCA mechanism is 2.2 times, and the improvement of P_F is 11 times. This is because the CCA mechanism combines overflow, underflow, and reversible schemes, and provides buffers for new and handoff calls. Fig. 5 shows the cost function CF with $\alpha = 0.1$ versus the calling rate λ for the CCA and OCA mechanisms. We observe that CF of CCA is smaller

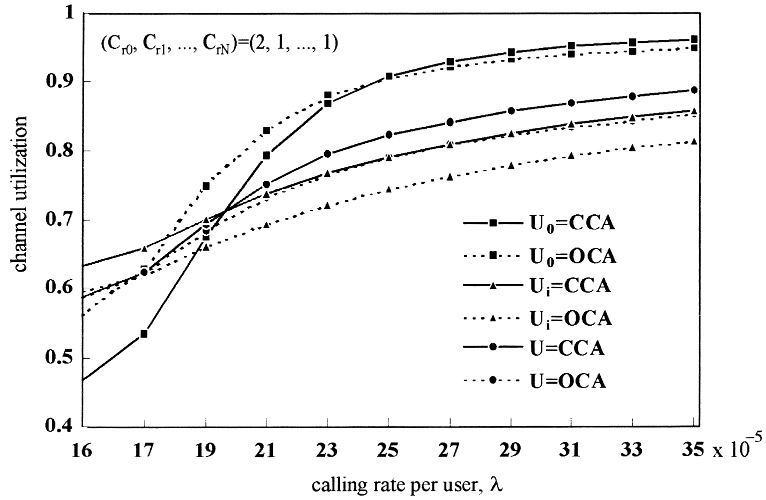


Fig. 6. Channel utilization for CCA and OCA mechanisms in the Strip type.

than that of OCA. For the same case as above, CF of CCA is reduced 3.85 times under OCA. And the guard-channel protection scheme becomes more effective as the traffic load is increasing.

4.2. Manhattan type

The teletraffic matrix in this type is assumed to be

$$A=\begin{vmatrix}
0.0 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 \\
0.1 & 0.0 & 0.3 & 0.0 & 0.3 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.3 \\
0.1 & 0.2 & 0.0 & 0.2 & 0.0 & 0.2 & 0.0 & 0.0 & 0.0 & 0.0 & 0.3 \\
0.1 & 0.0 & 0.3 & 0.0 & 0.0 & 0.0 & 0.3 & 0.0 & 0.0 & 0.0 & 0.3 \\
0.1 & 0.2 & 0.0 & 0.0 & 0.0 & 0.2 & 0.0 & 0.2 & 0.0 & 0.0 & 0.3 \\
0.0 & 0.0 & 0.25 & 0.0 & 0.25 & 0.0 & 0.25 & 0.0 & 0.25 & 0.0 & 0.0 \\
0.1 & 0.0 & 0.0 & 0.2 & 0.0 & 0.2 & 0.0 & 0.0 & 0.0 & 0.2 & 0.3 \\
0.1 & 0.0 & 0.0 & 0.0 & 0.3 & 0.0 & 0.0 & 0.0 & 0.3 & 0.0 & 0.3 \\
0.1 & 0.0 & 0.0 & 0.0 & 0.0 & 0.2 & 0.0 & 0.2 & 0.0 & 0.2 & 0.3 \\
0.1 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.3 & 0.0 & 0.3 & 0.0 & 0.3
\end{vmatrix}$$

Fig. 6 shows channel utilization U, U_0, and U_i versus the calling rate per user λ. The channel utilization U of CCA is superior to OCA. To take a range of λ from 23×10^{-5} to 35×10^{-5} for instance, the channel utilization U of CCA is superior to OCA by 4%. This is because our scheme combines overflow, underflow, and reversible schemes, and provides buffers for new and handoff calls. The channel utilization, U_0 and U_i, of CCA is almost surrounded by OCA in the heavy traffic, denoting the system traffic load is distributed in a more balanced manner in CCA than in OCA. This is because the microcells in the CCA mechanism with buffer provisioning absorb some traffic load from the overlaying macrocell; hence, U_i increases at heavy traffic load.

Fig. 7 shows P_N and P_F versus calling rate per user λ for the CCA and OCA mechanisms. We find that CCA can significantly improve P_N and P_F over OCA. For example, when $\lambda = 21 \times 10^{-5}$ and $(C_r0, C_r1, \ldots, C_rN) = (2, 1, \ldots, 1)$, the CCA mechanism can improve 2.1 times in P_N and 29.24 times in P_F over OCA. Comparing the Manhattan type with the Strip type, P_F in the CCA mechanism for the Manhattan type obtains more improvement than that for the Strip type. For example, at $\lambda = 21 \times 10^{-5}$ in the Manhattan type, the CCA with $(C_{r0}, C_{r1}, \ldots, C_{rN}) = (0,0,\ldots,0)$ can improve by 11 times and the CCA with $(C_{r0}, C_{r1}, \ldots, C_{rN}) = (2,1,\ldots,1)$ can improve 29 times in P_F over OCA, while in the Strip type, the CCA with $(C_{r0}, C_{r1}, \ldots, C_{rN}) = (0,0,\ldots,0)$ can improve 3.9 times and the CCA with $(C_{r0}, C_{r1}, \ldots, C_{rN}) = (2,1,\ldots,1)$

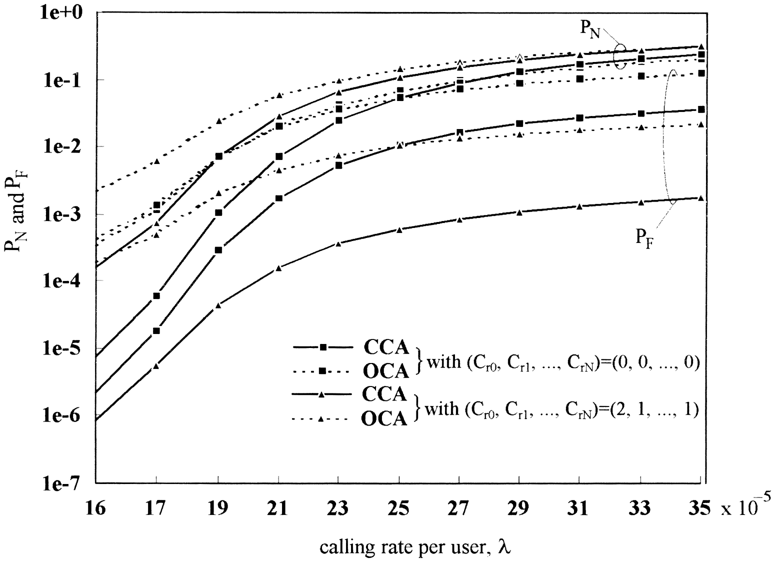


Fig. 7. P_N and P_F for CCA and OCA mechanisms in the Manhattan type.

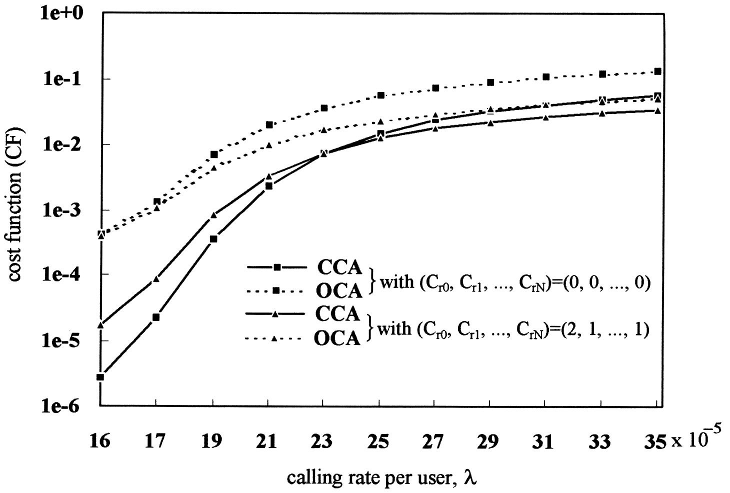


Fig. 8. Cost function with $\alpha = 0.1$ for CCA and OCA mechanisms in the Manhattan type.

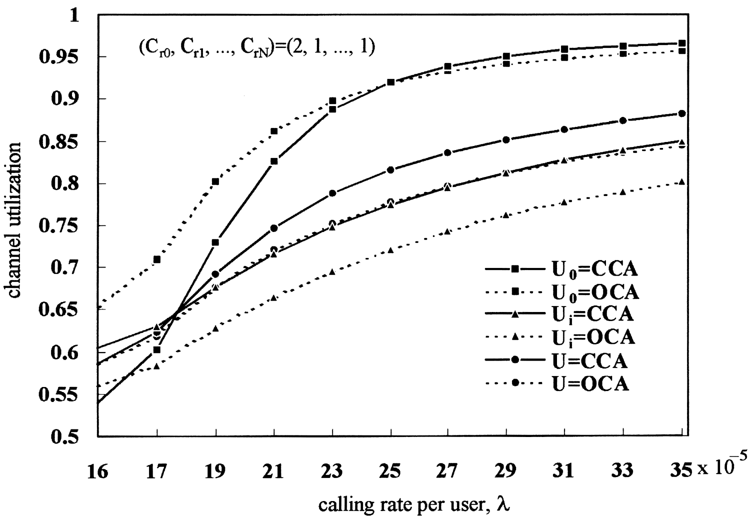


Fig. 9. Channel utilization for CCA and OCA mechanisms in the Manhattan type.

can improve 11 times in P_F over OCA. This is because microcells in the Manhattan type are closer to adjacent macrocells than those in the Strip type; also, microcells are so well distributed in the Manhattan type. The successful handoff probability in the Manhattan type is larger than that in the Strip type. Thus, CCA is more suitable in the Manhattan type than in the Strip type.

Fig. 8 shows the cost function CF with $\alpha = 0.1$ versus the calling rate λ. We observe that CF of CCA is smaller than that of OCA. In the example of $\lambda = 21 \times 10^{-5}$, CF is reduced from 0.0198 for OCA to 0.00226 for CCA.

Fig. 9 shows channel utilization U, U_0, and Ui versus the calling rate λ. The channel utilization U of CCA is superior to OCA. In examples of λ from 23×10^{-5} to 35×10^{-5}, the channel utilization U of CCA is superior to OCA by 4.7%. This is because the CCA mechanism combines overflow, underflow, and reversible schemes, and provides buffers for new and handoff calls. U_i of the CCA mechanism is higher than U_i of OCA. The reason is that microcells can support traffic from the overlaying macrocell. U_0 of CCA is higher than U_0 of OCA with heavy traffic; this is due to the buffer effect. The CCA mechanism provides buffers to accommodate the calls which are not available channel to use in temporary, thus implying higher channel utilization. Again, U_i and U_0 of CCA are almost surrounded by those of OCA, indicating the load balancing of CCA is better than that of OCA.

5. Concluding remarks

A combined channel assignment mechanism for a hierarchical cellular system is proposed in this paper. In this scheme the system not only provides overflow channels in an overlaying macrocell for new and handoff calls having no available channel to use in the overlaid microcell, but also allows handoff calls from a neighboring macrocell to underflow to use the free channel in the microcell. Meanwhile, the handoff attempts from the overlaying macrocell to overlaid microcell can reverse to use free channels in the microcell if there are idle channels in the microcell. The simulation results show that the CCA mechanism can significantly decrease new call blocking probability and forced termination probability. Also it can achieve the balance of load between macrocell and microcells, implying that the overall channel utilization is improved. We also investigate the two cases of Strip type and Manhattan type for the hierarchical cellular system, and it can be concluded that the CCA mechanism is more applicable in the Manhattan type than in the Strip type.

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