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A Dynamic Channel Assignment Approach to Reuse Partitioning Systems Using Rearrangement Method

Kazuhiko SHIMADA†, **Takeshi WATANABE**††, **Masakazu SENGOKU**†† *and* **Takeo ABE**†, *Members*

SUMMARY The applicability of Dynamic Channel Assignment methods to a Reuse Partitioning system in cellular radio systems is investigated in this paper. The investigations indicate that such a system has a tendency to increase the difference between blocking probability for the partitioning two coverage areas in comparison with the conventional Reuse Partitioning system employing Fixed Channel Assignment method. Two schemes using new Channel Rearrangement algorithms are also proposed in order to alleviate the difference as a disadvantage which gives unequal service to the system. The simulation results show that the proposed schemes are able to reduce the difference significantly while increasing the carried traffic by 10% as compared with the conventional system.

key words: *cellular radio systems, dynamic channel assignment, reuse partitioning system, channel rearrangement*

1. Introduction

The demand for mobile communication services is rapidly increasing. In cellular radio systems, frequency management involving Channel Assignment methods and cell planning techniques is an important factor to increase spectrum efficiency. In Channel Assignment methods, it is known that Dynamic Channel Assignment (DCA) methods [2]–[4] offer a potential advantage for the flexibility to traffic fluctuations and to the increment of the radio network (e.g. , additional Base Stations based on cell splitting or underlaid-overlaid arrangement [1]) in comparison with Fixed Channel Assignment (FCA) method.

Reuse Partitioning (RP), by which a cell in an original system is typically divided into two concentric cells (inner and outer cell), is a cell planning technique to provide more efficient channel reuse while maintaining the interference constraint in the existing system [5]–[7]. There are two different reuse patterns (with smaller and larger reuse distance) for the respective inner and the outer cells systems in a RP system, as detailed in Ref. [5]. It has been also considered that RP systems can be required as a stage toward a future system with small cells structure [1], [5]. RP systems employing FCA method have been studied so far. However, it is to be considered that DCA methods with the flexibility as an advantage are more suitable for such a RP system because the variance of traffic distributions becomes greater in the smaller cells structure in a future system.

Also, in a previous study on the conventional RP systems employing FCA method, it has been indicated that a substantial increase of carried traffic can be accomplished at the expense of unbalanced blocking probability for two coverage areas based on the inner and the outer cells, resulting from the two different reuse patterns [6]. And then it has been mentioned that this inequality on blocking probability is a great disadvantage of the RP approach because it would not only give the system the different grade of service but also create a problem with handoffs of calls between the outer and the inner cells.

In this paper, the applicability of DCA methods to a RP system is investigated and discussed for the first time as far as authors know. We indicate that the RP systems employing DCA methods have a tendency to increase the inequality on blocking probability in comparison with the conventional RP system. In order to alleviate the inequality, we also propose two schemes using new Channel Rearrangement algorithms which are given by modifying *the First-Level Rearrangement method* [4], [8]. These RP systems employing two schemes use all channels in a shared pool to accommodate offered traffic in the same way as the DCA systems without RP. The simulation results show that the proposed schemes are able to rectify the inequality significantly while increasing the carried traffic by 10% as compared with the conventional RP system. Section 2 describes an application of DCA to a RP system as a simple approach, and the examinations then indicate the problem that the blocking probability for the outer cells is always much higher than for the inner cells. Section 3 describes two schemes as the alternative approaches and presents the effects of them from the simulation results for both of homogeneous and inhomogeneous traffic distribution models.

2. An Application of DCA to a RP System

A simple approach to apply DCA methods to a RP

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system can be implemented by dividing the whole channels into two groups. This is the same way as the conventional RP systems employing FCA method. The divided two groups of channels are given to the outer cells and the inner cells systems, respectively. In the conventional RP systems, there is "*overflow procedure*" which is used in order to enhance the efficiency of channel utilization and to reduce the sensitivity to changes in the distribution of traffic load given to an outer and inner cell [5]-[7]. This is the procedure which can allow a call in an inner cell coverage to *overflow* into the outer cell in order to assign a channel given to the outer cell to the call. This procedure can be also installed in these DCA systems by defining the interference cells for each of an outer and an inner cell. And then, it is required to maintain the interference constraint based on the interference cells in the inner cells system, when the inner cells system borrows a channel from the outer cells system. In the conventional system, however, it is not required that such a matter is taken into consideration because the outer cell coverage inherently includes the inner one and an available channel to be allocated fixedly in an outer cell can be used in the inner cell. In the DCA system, the respective structures of the interference cells is given from each reuse pattern for the outer and the inner cells systems, which makes DCA with "*overflow procedure*" in the RP systems possible.

To investigate the performance of this DCA approach for RP system, we consider that a RP system is constructed by a combination of the outer (or original) cells system with a reuse pattern of 7 cells cluster and the inner cells system with a reuse pattern of 3 cells cluster, as presented in Ref. [5]. The inner cells system is formed by noncontiguous circle-shaped cells, as represented in Fig. 1 including the representation of the respective traffic coverage areas. And then, the coverage area of the inner cell should be smaller than half of the original cell area, resulting from the interference constraint in the original system with a reuse pattern of 7 cells cluster. We hereon consider the condition that the ratio of the traffic coverage area of the outer cell to one of the inner cell is 1 : 1. The structure of the interference cells for each of an outer and an inner cell is then given as shown in Fig. 1. And, for such a RP system, well-known the First-Available method (**FA**) [2]-[4] and the First-Level Rearrangement method (**FLR**) [8] are performed. In the DCA system without RP, **FLR** is implemented in order to attempt weeding a call congestion produced by **FA**, in which the efficiency of channel utilization can be improved [4], [8]. In order to apply **FLR** algorithm to this DCA system with RP, we carry out some minor modifications. For making mention of the modified **FLR** algorithm, let $\boldsymbol{U}_k$ be the set of cells (outer and inner cells) to which the channel k is assigned, and a set $\boldsymbol{H}_k(z_i)$ is as follows:

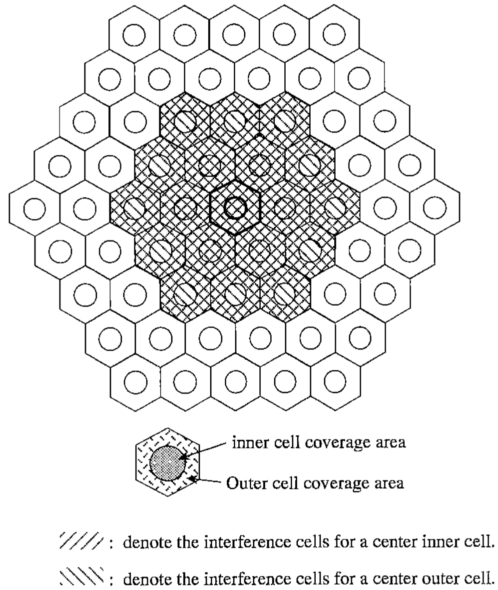


Fig. 1 Illustration of a Reuse Partitioning system and representation of the structures of the interference cells.

$$\boldsymbol{H}_k(z_i) = \boldsymbol{U}_k \cap \boldsymbol{B}(z_i),$$

where $\boldsymbol{B}(z_i)$ is the set of the interference cells for a cell i (: z_i). It is then given as follows:

step 0. If a new call originates in an outer or an inner cell z_{new}, go to step 1 or step 2, respectively.

step 1. Select a channel k belonging to the outer cells system, which is not selected yet, as a candidate. Block a new call in the outer cell z_{new} if all channels belonging to the outer cells system are already selected. Go to step 4.

step 2. Select a channel k belonging to the inner cells system, which is not selected yet, as a candidate. Go to step 3 if all channels belonging to the inner system are already selected. Go to step 4.

step 3. Select a channel k belonging to the outer cells system, which is not selected yet. Block a new call in the inner cell z_{new} if all channels are already selected.

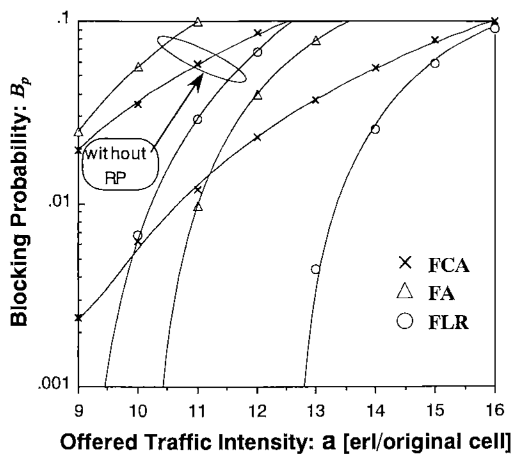
step 4. If the channel k is already assigned to z_{new}, return to step 0.

step 5. Find an available channel in any cell $z \in \boldsymbol{H}_k(z_{new})$. If each cell of $\boldsymbol{H}_k(z_{new})$ does not have an available channel except channel k, return to step 0.

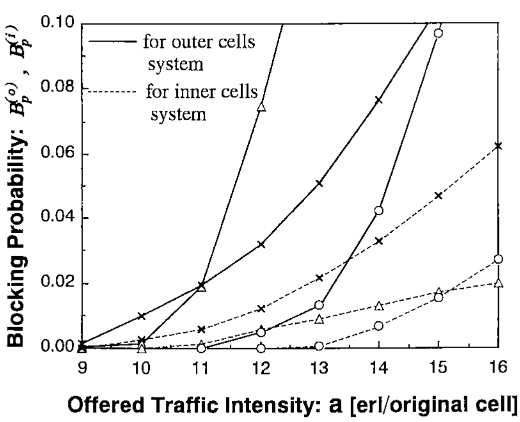
step 6. Assign the respective available channels to the cells of $\boldsymbol{H}_k(z_{new})$ instead of the channel k, and assign the channel k to a new call in z_{new}.

The difference between the conventional **FLR** algorithm and this one is a point that the whole channels can not be selected as the candidate to be assigned to a new call if the new call originates in the distinguished traffic coverage of an outer cell, while it can be done for a new call in an inner cell because of using "overflow procedure." In the conventional **FLR** algorithm used in the systems without RP, the whole channels can be selected as the candidate for all new calls.

Figure 2(a) shows blocking probability (:B_p) as a function of traffic intensity offered for an original cell (: a) on the whole of the system, including the performance of DCA and FCA systems without RP. The data, which show the characteristics of blocking probability in the outer cells system (: $\boldsymbol{B}_p^{(o)}$) and the inner cells system (: $\boldsymbol{B}_p^{(i)}$), are plotted in Fig. 2(b). Simulations are performed along the cell structure model (61 cells) shown in Fig. 1. The statistics are taken from the central 7 original cells. The traffic simulation model is assumed that the arrival of request for the service forms a Poisson process, the mean holding time is 1.5 minutes, the traffic distribution is uniform over all cells, and the mobility of mobile stations is ignored. The number of system channels is 105. In these DCA systems and the conventional FCA system with RP, it



(a) blocking probability in the whole of the system: B_p



(b) blocking probability in the outer cells system: $B_p^{(o)}$ and in the inner cells system: $B_p^{(i)}$

Fig. 2 Characteristics of blocking probability versus offered traffic intensity (using the DCA rule with the channel division of 84 : 21 channels for the outer : the inner cells system).

is then selected that the channel division is the ratio of 21 channels for the inner cells system to 84 channels for the outer cells system, because the difference between blocking probability for the inner and the outer cells systems becomes comparatively smaller with more carried traffic by this selection. It is shown in Fig. 2(a) that each of the systems with RP can carry about 30% more traffic at B_p=3% than the respective systems without RP, in which the performance by **FLR** is always better than others. In Fig. 2(b), the differences between $\boldsymbol{B}_p^{(o)}$ and $\boldsymbol{B}_p^{(i)}$ in both systems by **FA** and **FLR** are over 4.5% at B_p=3% in Fig. 2(a) and become remarkably larger under such a condition as over load above B_p=3%, whereas the difference in the conventional FCA system is 2.5% at B_p=3% and is comparatively smaller under the condition. At the same time, $\boldsymbol{B}_p^{(o)}$ in **FA** and **FLR** systems are over 5.0% at B_p=3%, while $\boldsymbol{B}_p^{(o)}$ in the conventional FCA system is 4.1%. Particularly in these DCA systems, it is considered that these results arise from both of the difference of the efficiency of channel utilization resulting from the difference of the reuse distance and *overflow procedure*.

In particular, this inequality on blocking probability in RP systems creates a problem with handoffs of calls. It implies that, with higher blocking probability in the outer cells system, the forced call terminations would become more when calls pass from the inner cells to outer cells. However, the handoff to reassign the channel is not required in the reverse process. Therefore, we consider that it is necessary for the DCA systems with RP to keep smaller difference between $\boldsymbol{B}_p^{(o)}$ and $\boldsymbol{B}_p^{(i)}$ to a large extent than the conventional FCA system, while improving the efficiency of channel utilization.

3. Alternative DCA Approach to a RP System

3.1 DCA Rule

For the purpose of retrenching the bothersome job of the decision how to divide the whole system channels into two groups, we propose the DCA rule that all channels are used in a shared pool. It is expected that this way would produce more flexible Channel Assignments to accommodate inhomogeneous traffic distributions (e.g., resulting from particularly the spatial distribution over the service area or the difference between the outer and the inner cell coverage area), because this rule is similar way to popular DCA systems without RP and so can sufficiently bring the advantage of DCA systems. This rule can be implemented by defining the structures of the interference cells, and each of structures of the interference cells as shown in Fig. 1 can be used for this DCA rule, also. However, it may be deduced that by this DCA rule $\boldsymbol{B}_p^{(i)}$ in the inner cells system would be lower than $\boldsymbol{B}_p^{(o)}$ in the outer cells because the channel assignments in the inner cells with smaller number of the interference cells are easier than in the outer cells with larger number of them. It is also expected that the matter would become greater for the system employing **FA** classified as call-by-call type. Therefore, we consider that the Rearrangement technique should be utilized in order to alleviate the inequality on blocking probability, and then two schemes using this DCA rule without the channel division are proposed as follows.

3.2 New Channel Rearrangement Algorithms

For the purpose of coping with the undesirable difference between $\boldsymbol{B}_p^{(o)}$ and $\boldsymbol{B}_p^{(i)}$ while maintaining higher efficiency of channel utilization as much as possible, two schemes, as new Channel Rearrangement algorithms, are given by modifying **FLR** algorithm. That is, we consider to impose restrictions on Channel Assignments by Rearrangement only to the new calls in the inner cells.

The first scheme is an algorithm that the Rearrangement is not executed if a new call belongs to an inner cell and if an element of $\boldsymbol{H}_k(z_{new})$ in step 6 of **FLR** algorithm as described above is "an inner cell." We then call this one "**RFLRI**" algorithm in this paper and this algorithm is given as follows:

step 1. Select a channel k, which is not selected yet, as a candidate. Block a new call in a cell z_{new} if all channels are already selected.

step 2. If the channel k is already assigned to z_{new}, return to step 1. If z_{new} is an inner or an outer cell, go to step 3 or step 4, respectively.

step 3. If a cell $z \in \boldsymbol{H}_k(z_{new})$ is "an inner cell," return to step 1. Find an available channel in any cell $z \in \boldsymbol{H}_k(z_{new})$ except channel k. If each cell of $\boldsymbol{H}_k(z_{new})$ does not have an available channel, return to step 1. Go to step 5.

step 4. Find an available channel in any cell $z \in \boldsymbol{H}_k(z_{new})$ except channel k. If each cell of $\boldsymbol{H}_k(z_{new})$ does not have an available channel, return to step 1.

step 5. Assign the respective available channels to the cells of $\boldsymbol{H}_k(z_{new})$ instead of the channel k, and assign the channel k to a new call in z_{new}.

The second scheme can be given by replacing "an inner cell" in step 3 of "**RFLRI**" algorithm with "an outher cell," and we then call this one "**RFLRO**" algorithm in this paper.

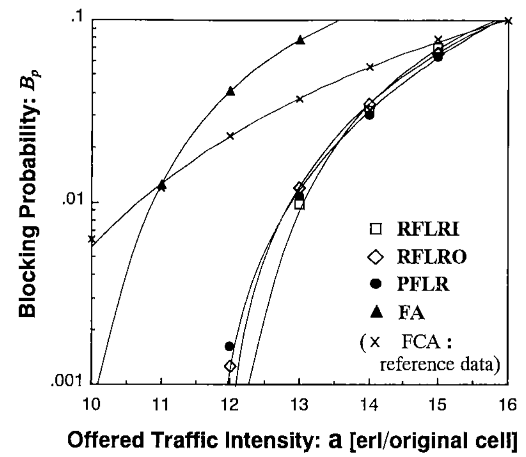
An important one of the differences between both of these algorithms and the **FLR** algorithm as described in Sect. 2 is whether the whole channels can be selected as the candidate to be assigned to a new call in an outer cell or not. In both of **RFLRI** and **RFLRO** algorithms, the whole channels can be selected, resulting in increasing such a potentiality as more Channel Assignments by Rearrangement to the new calls in the outer cells may be successful. In two algorithms, it is also expected that imposing restrictions on Channel Assignments to the new calls in "the inner cells" is able to make the Channel Assignments in the outer cells system be relatively easier. Consequently, it is surmised that $\boldsymbol{B}_p^{(o)}$ may become lower with increasing $\boldsymbol{B}_p^{(i)}$ in **RFLRI** and **RFLRO** systems as compared as the **FLR** system using the DCA rule with the channel division. On the other hand, making a comparison between **RFLRI** and **RFLRO** algorithms, **RFLRI** system may have higher $\boldsymbol{B}_p^{(i)}$ than **RFLRO** system because Rearrangement to accept the new calls in "the inner cells" by **RFLRI** does not outperform it by **RFLRO**. That is, in step 3 in each of two algorithms, it means that finding an available channel in any outer cell $z \in \boldsymbol{H}_k(z_{new})$ *by* **RFLRI** is more difficult than finding an available channel in any inner cell $z \in \boldsymbol{H}_k(z_{new})$ by **RFLRO** because of having larger number of the interference cells for an outer cell. It is also surmised that $\boldsymbol{B}_p^{(o)}$ may become lower with increasing $\boldsymbol{B}_p^{(i)}$ in **RFLRI** system as compared as **RFLRO** system.

In respect of the restriction on the Rearrangement, if a strong restriction which forbids accepting all new calls in the inner cells by the Rearrangement technique was imposed, it is considered that the carried traffic in the whole of the system might decrease with reducing the number of Channel Assignments by the successful Rearrangement.

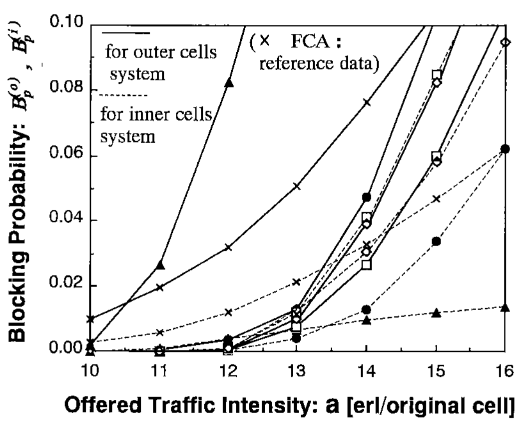
In the following section, the performance by each of two schemes is also compared with it by "pure **FLR** algorithm," i.e., this is a scheme without imposing restrictions on the Channel Assignments to the new calls in the inner cells and is the same algorithm as used in the DCA system without RP. We then call the pure **FLR** algorithm **PFLR** algorithm in this paper.

3.3 Simulation Results and Discussion

Under the same assumptions as described in Sect. 2, simulations are performed to evaluate the performance by **RFLRI**, **RFLRO**, **PFLR** and **FA** using the DCA rule without the channel division. The simulation results are shown in Fig. 3, in which the data by the conventional FCA system obtained in Sect. 2 are also plotted as reference data. It is shown in Fig. 3(a) that there is no difference between the performance of **RFLRI**, **RFLRO** and **PFLR**, and that at $B_p=3\%$ each of three systems by **RFLRI**, **RFLRO** and **PFLR** can carry about 10% more traffic than the conventional FCA system. It is also seen that the **FLR** system using the DCA rule with the channel division in Fig. 2(a) carries about 2% more traffic at $B_p=3\%$ than these systems. And it is obvious that lower $\boldsymbol{B}_p^{(i)}$ in the **FLR** system as compared with $\boldsymbol{B}_p^{(i)}$ in **RFLRI**, **RFLRO** and **PFLR** systems results in reducing blocking probability in the while of the system. In Fig. 3(b), the differences between $\boldsymbol{B}_p^{(o)}$ and $\boldsymbol{B}_p^{(i)}$ in **RFLRI** and **RFLRO** systems at $B_p=3\%$ in Fig. 3(a) are only 1.5% at most and are much smaller than in the conventional FCA system,



(a) blocking probability in the whole of the system: B_p



(b) blocking probability in the outer cells systec: $B_p^{(o)}$ and in the inner cells system: $B_p^{(i)}$

Fig. 3 Characteristics of blocking probability versus offered traffic intensity (using the DCA rule without the channel division).

while the difference in **PFLR** system is 3.5%. It is also seen that at $B_p=3\%$ $B_p^{(i)}$ is higher than $B_p^{(o)}$ in the **RFLRI** system and $B_p^{(o)}$ is higher than $B_p^{(i)}$ in the **RFLRO** system. And then $B_p^{(i)}$ and $B_p^{(o)}$ in **RFLRI** and **RFLRO** systems, respectively, is about 3.7% at $B_p=3\%$, while $B_p^{(o)}$ in **PFLR** system is 4.3% and $B_p^{(o)}$ in the conventional FCA system is 4.1% as shown in Fig. 2 (b). And it is also seen that the differences in both of **RFLRI** and **RFLRO** systems are considerably smaller under the condition of over load above $B_p=3\%$ than in the conventional FCA system. It is moreover seen that $B_p^{(o)}$ in each of **RFLRI** and **RFLRO** systems is lower as compared with $B_p^{(o)}$ in both of **PFLR** and **FLR** systems, and also that there is a noticeable result in the **RFLRI** system in which $B_p^{(i)}$ is always higher than $B_p^{(o)}$. It is considered that these characteristics on the performance result from the effect as mentioned in Sect. 3. 2. These results indicate that the systems by **RFLRI** and **RFLRO** significantly outperform the conventional RP

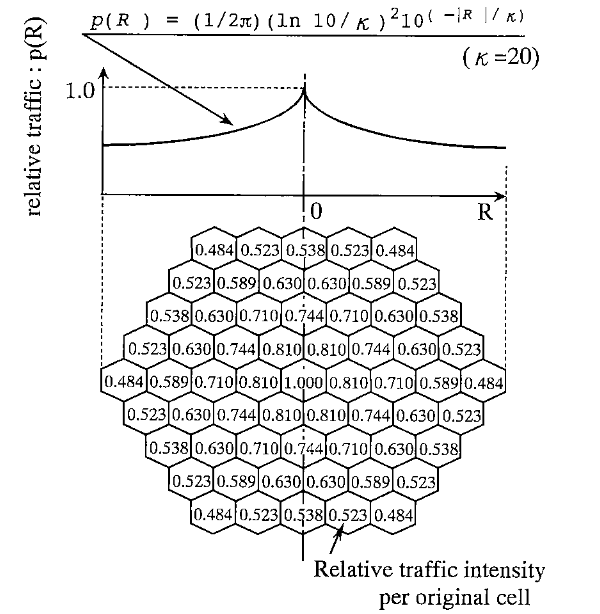


Fig. 4 The model of inhomogeneous traffic distribution.

system employing FCA.

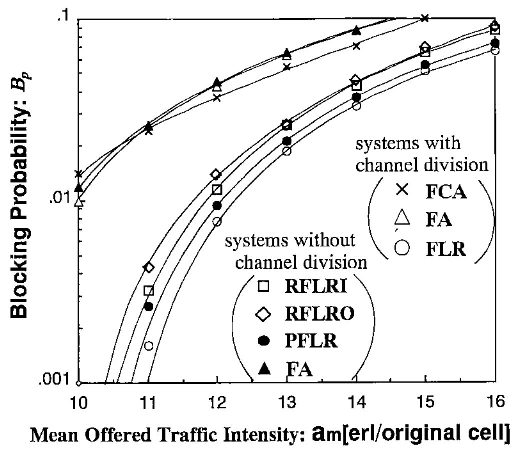
Next simulations are performed for a model of the inhomogeneous traffic distribution. The model as presented in Ref. [9] is used, in which the traffic distribution function, as a function of the distance from the center of the service area (: R), has been presented by:

$$p(R)=(1/2\pi)\{(\ln 10)/\varkappa\}^2 10^{(-R/\varkappa)},$$

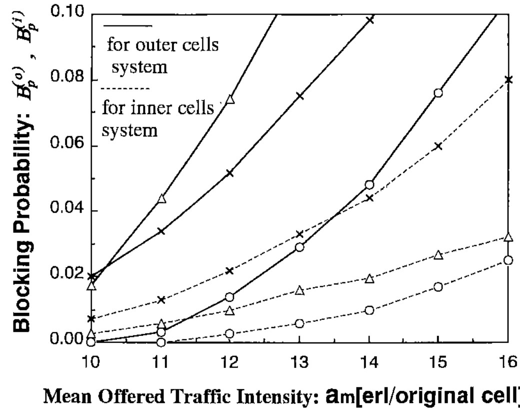
where the constant $\varkappa$ represents the steepness of traffic distribution curve and $\varkappa=20$ in the Tokyo metropolitan area. We assume that $\varkappa=20$, the radius of an original cell is 1 km, and the traffic distribution in an original cell is uniform. And the relative traffic intensity for any original cell in Fig. 1 is then obtained as represented in Fig. 4.

Figures 5 (a), (b), and (c) show the simulation results, in which each of the performance by four DCA systems without the channel division, two DCA systems with the channel division and the conventional FCA system is evaluated. The statistics are then taken from the whole of the outer and inner cells. And mean offered traffic intensity (: a_m) in Fig. 5 denotes the mean value of the offered traffic intensity per original cell. It is shown in Fig. 5 that the relative merits on each of the performance by seven schemes are similar to the results obtained for the homogeneous traffic distribution.

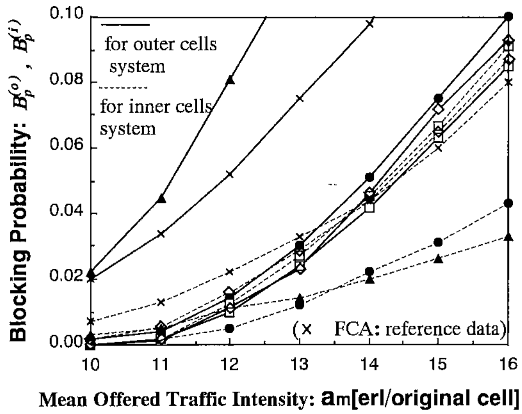
From these results, it is considered that **RFLRI** and **RFLRO** schemes are effective to cope with the undesirable difference between $B_p^{(o)}$ and $B_p^{(i)}$ while maintaining higher efficiency of channel utilization. Particularly in **FA** systems, compared with the conventional FCA system, there is the intolerable inequality on blocking probability and the efficiency of channel



(a) blocking probability in the whole of the system: B_p



(b) blocking probability in the outer cells system: $B_p^{(o)}$ and in the inner cells system: $B_p^{(i)}$ for using the DCA rule with the channel division.



(c) blocking probability in the outer cells system: $B_p^{(o)}$ and in the inner cells system: $B_p^{(i)}$ for using the DCA rule without the channel division.

Fig. 5 Characteristics of blocking probability versus offered traffic intensity for the model of inhomogeneous traffic distribution.

utilization is lower also. Therefore, it is to be considered that the **FA** system is unsuitable for the RP systems.

A consideration with respect to the difference between $\boldsymbol{B}_p^{(o)}$ and $\boldsymbol{B}_p^{(i)}$ affords a plan that **RFLRI** with $\boldsymbol{B}_p^{(o)} < \boldsymbol{B}_p^{(i)}$ may be superior to **RFLRO** with $\boldsymbol{B}_p^{(i)} < \boldsymbol{B}_p^{(o)}$, because handoffs are required only for the movement of the calls from the inner cell to the outer cell in RP systems.

4. Conclusion

The applicability of the First-Available method and the First-Level Rearrangement method, as popular DCA methods, to a RP system is investigated and discussed. We indicate that the RP systems employing these methods have a great tendency to increase the inequality on blocking probability in the partitioned two systems as compared with the conventional RP system employing FCA method. The investigations particularly show that the First-Available method is unsuitable for RP systems. In order to rectify the undesirable inequality while maintaining higher efficiency of channel utilization in comparison with the conventional system, we also propose two schemes called RFLRI and RFLRO algorithms which are presented by modifying the First-Level Rearrangement method.

The simulation results show that the proposed schemes are able to rectify the inequality significantly while increasing the efficiency of channel utilization by 10% as compared with the conventional RP system. Consequently, it is considered that the proposed RFLRI and RFLRO algorithms are quite valuable approaches for RP systems.

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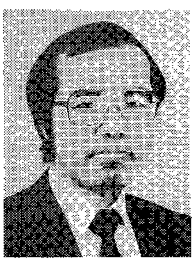

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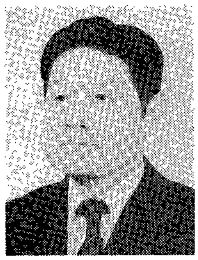

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