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Dynamic Base Station Selection for Personal Communication Systems with Distributed Control Schemes

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Abstract:

Distributed control schemes allow base stations to be placed at locations corresponding to high expected traffic. This flexible base station placement creates overlapping areas - a property which can be utilized to improve system performance[1]. A new dynamic base station selection technique for overlapping cell placement is considered. This base station selection scheme in overlapping areas affects system performance. The technique realizes robust traffic performance for personal communication systems in fluctuating and heavily tapered traffic. A mathematical analysis method based on a state transition model is used to evaluate a system which employs the proposed technique. The results indicate that the proposed technique improves blocking probability and carried traffic performance. Computer simulations are performed to confirm the results.

1. Introduction

A micro cell strategy with a distributed control scheme is useful for Personal Communication Systems (PCS) since it significantly enhances system capacity. This strategy realizes flexible base station placement and easy installation when base stations are newly placed. If new base stations are needed in an area to serve heavy traffic, a frequency reuse pattern should be considered to place the base stations if the system is controlled by a centralized station. However, this is very complicated and intricate when there is a large number of base stations in a micro cell layout. Therefore, distributed control schemes are favored. These allow flexible base station placement since each base station works autonomously. With the micro cell strategy base stations need only use a few channels simultaneously because the required coverage area is small. They can be placed corresponding to the expected traffic, without consideration of the frequency reuse pattern. In heavy traffic areas, base station density will be high. Accordingly, a cell corresponding to the coverage area of a base station is overlapped by a cell that is served by an adjacent base station. Without overlap, heavy traffic offered to a small cell can cause unacceptable blocking. With overlap, however, even if no channels are available at one base station, the adjacent base station may have some available channels that can provide service for calls that would otherwise be blocked. This selection is performed by considering offered traffic conditions to the base stations. We propose a base station selection procedure which affects the system blocking probability characteristics and carried traffic performance. A mathematical analysis method is presented to evaluate system performance. Analytical results predict significant improvement in blocking probabilities and carried traffic performance in comparison with a non-overlapping architecture. These results are confirmed by computer simulations as well.

2. System Model

2-1. Overlapped Cell in Heavy Traffic Area

Base stations are placed at appropriate points by considering their coverage and expected traffic. Figure 1 shows overlapping coverage of base stations in a congested area where base stations are concentrated to accommodate heavy traffic. To make or receive calls, mobile stations in an overlapped area will chose one of the base stations. This selection procedure is very important to improve system performance. This issue is discussed in Section 3-1.

A ring model is assumed as a counterpart for an unending one-dimensional cellular model as shown in Figure 2. This model is useful for calculation because only a limited number of cells must be taken into account. A part of each cell is overlapped. The overlapping ratio (*Ro*) is defined as:

$$Ro = \frac{\beta - \alpha}{\alpha} \tag{2.1}$$

where

$$\alpha=2\pi/N_b \tag{2.2}$$

and where N_b is the number of base stations in the circle. The angle β specifies the coverage area of a base station. If $R_0=1$ ($\beta=2\alpha$), all areas are overlapped by two adjacent base stations, $R_0=0$ ($\beta=\alpha$), no areas are overlapped. This system model is equivalent to an infinite one dimensional system that has hot spots at regular special intervals.

The layout is shown in Fig. 2. We call a coverage area of a base station a "*cell*." The angular coverage of a cell is (ξ-β/2, ξ+β/2) where ξ is the angular coverage of the base station. A region which is in (ξ-α/2, ξ+α/2) is called a "*zone*". Each distinct in Fig. 2 is called "*segment*".

For convenience, a service area is divided into $2N_b$ segments and numbered as 0, 1, 2, $\cdots$, $2N_b$-1, the numbering begins in the nonoverlapped segment where BS_0 is located. Thus, the segment covered by only BS_0 is called "segment 0", the adjacent sector covered by both BS_0 and BS_2 is named "segment 1" and so on. Base stations are located in segments which have an even segment number. Thus we label the base stations by BS_0, BS_2, BS_4, $\cdots$, BS_{2N_b-2}.

2-2. Traffic Model

When system performance is evaluated, a flat shaped traffic is commonly used. However, the flat traffic model alone is not sufficient for our purposes since overlapping architectures have interesting properties when offered traffic is not uniform. We consider two types of offered traffic models in this study.

A. Hot Spot Traffic Model

We assume a non-uniform distributed traffic model for this study. The offered traffic has a hot spot which is described in this section. Evaluations of the proposed system is performed by using this model as well as the flat (uniformly distributed) model.

A traffic model which consists of a hot spot traffic and uniformly distributed background traffic is assumed. The offered traffic density of this hot spot model is given as call arrival rate in unit area by

$$g(\theta) = \Lambda_T \left[\gamma k_1 \cdot + (1-\gamma) \frac{k_2}{\sqrt{2\pi}\,\sigma} \exp \frac{-(\theta-\theta_0)^2}{2\sigma^2} \right] \quad \text{[calls/sec/radian]} \qquad (2.3)$$

$$|\theta - \theta_0| \le \pi$$

where k_1, k_2, θ_0 and γ are parameters which shape the traffic model, Λ_T gives the total new call arrival rate which is described later of this section. The hot spot position is determined by θ_0, which is an offset of the hot spot from a boundary of the first zone and the last zone in the ring model assumed in this study.

Here k_1 determines a background amount of uniform traffic on all areas, k_2 is a parameter which affects hot spot traffic and γ is a weight of the background traffic to the tapered traffic. This model is consistent with a bell shaped traffic distribution which is observed in real systems[2].

To normalize the amount of traffic, we define

$$\int_{\theta_0-\pi}^{\theta_0+\pi} k_1 d\theta = 1 \tag{2.4}$$

$$\int_{\theta_0-\pi}^{\theta_0+\pi} \frac{k_2}{\sqrt{2\pi}\sigma} \exp\frac{-(\theta-\theta_0)^2}{2\sigma^2} d\theta = 1 \tag{2.5}$$

Namely,

$$k_1 = \frac{1}{2\pi} \tag{2.6}$$

$$k_2 = \frac{1}{erf\left(\frac{\pi}{\sqrt{2}\sigma}\right)} \tag{2.7}$$

where erf(x) is

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x \exp(-t^2) dt \tag{2.8}$$

Consequently, the total new call arrival rate offered to the whole system is

$$\begin{aligned} \Lambda &= \int_{\theta_0-\pi}^{\theta_0+\pi} g(\theta) d\theta \\ &= \Lambda_T[\gamma + (1-\gamma)] \\ &= \Lambda_T \end{aligned} \tag{2.9}$$

This rate is independent of the traffic shape parameters.

The amount of offered traffic to the whole system, A_H, is obtained by using average holding time T

$$A_H = \Lambda_T \cdot T \quad \text{[erlangs]} \tag{2.10}$$

B. Flat Traffic Model

This is a basic traffic model for an evaluation. The same amount of traffic is offered to each cell. The offered arrival rate density is found by setting γ of equation (2.3) to one as:

$$g(\theta)=\Lambda_T/2\pi \quad \text{[calls/sec/radian]} \tag{2.11}$$

where Λ_T is the call arrival rate to the whole system.

3. Dynamic Base Station Selection Procedure

3-1. Concept of Dynamic Base Station Selection

A coverage area of a base station is defined as the cell in which the base station both provides and receives sufficient signal strength to allow acceptable fidelity on both the uplink and the downlink. The coverage area may be overlapped to some extent. In the overlapped areas, the strongest signal strengths is usually used to select the serving base station even *acceptable* quality can be provided by a different base station. This is because the strongest base station will offer the best quality channel. It is not *necessary*, however, to choose the base station which sends the strongest signal. Traffic conditions at the base stations can also be used in the selection process. The base station that can provide adequate signal quality and which has the least number of occupied channels or least traffic can be used. This helps to distribute the traffic load more evenly among the base stations and generally improves blocking performance.

3-2. Algorithm of Base Station Selection

Offered traffic to a base station and the number of currently occupied channels are employed as metrics for base station selection in an overlapped area. As shown in Fig. 3, when a call arrives in an overlapped area, the base station that has more available channels is selected. Broadcasting the two metrics makes it possible to make this selection for a call that is generated by a mobile station. The same metrics can be used for routing in the network when a mobile station receives a call. Since base stations have only a few channels, it is not unlikely that the number of available channels is the same among the base stations that serve an overlapped segment. Two possible procedures to break such "ties" are considered here: definite selection and proportional selection.

A. Definite Selection

If the number of available channels at the service base stations are equal when a call is to be served, the base station with the lower offered traffic is definitely selected. This procedure is intuitively reasonable since it acts to balance traffic load. If there are no available channels among all base stations which cover the mobile station position, the call must be blocked. If the number of available channels at the service base stations are the same, and the base stations have the same offered traffic, one of the base stations is selected randomly since they have the same metrics. Thus, the base station selection probability, r_i when a new call is generated in segment i is defined as follows.

(a) i : even (an segment which has a base station)

$$r_i = 1 \tag{3.1}$$

(b) i : odd (an overlapped segment which has no base stations)

$$\begin{array}{ll} r_i = 1 & [v_i(s_c) < v_k(s_c)] \oplus [\{v_i(s_c) = v_k(s_c)\} \cap \{\lambda_i < \lambda_k\}] \\ r_i = 0.5 & [v_i(s_c) = v_k(s_c)] \otimes [\lambda_i = \lambda_k] \\ r_i = 0 & [v_i(s_c) > v_k(s_c)] \oplus [\{v_i(s_c) = v_k(s_c)\} \cap \{\lambda_i > \lambda_k\}] \end{array} \tag{3.2}$$

where λ_i is a call arrival rate which indicates the amount of offered traffic to the cell i. In this case, "i" is even number.

The call generation rates, λ_i is the total amount of call generation rate in the cell "i", that can be obtained by integration of $g(\theta)$.

$$\lambda_k = \int_{\left(\frac{k}{2}\right)\alpha}^{\left(\frac{k}{2}+1\right)\alpha} g(\theta)\, d\theta \qquad (k : even) \qquad [\text{calls/sec}] \tag{3.3}$$

B. Proportional Selection to Offered Traffic

If an segment is covered by two base stations, the selection probability of a base station is directly proportional to the offered traffic on the *other base station*. Consequently, a base station that has less offered traffic is more likely to be selected. A base station located in segment k (even) can be selected by mobile stations which are in segment k, $k+1$ and $k-1$. If the mobile stations are in a segment k which is covered by only one base station. It must be selected. In case a call arrives in an overlapped segment, selection probability of a base station, r_i for a new call which is in segment k is given by

(a) i : even

$$r_i = 1 \tag{3.4}$$

(b) i : odd

$$r_i = \frac{\lambda_{i-1}}{\lambda_{i-1} + \lambda_{i+1}} \qquad (i = k-1)$$

$$\tag{3.5}$$

$$r_i = \frac{\lambda_{i+1}}{\lambda_{i-1} + \lambda_{i+1}} \qquad (i = k+1)$$

The two selection procedures are described in Table 1. Performance of these two procedures is compared in the next section.

The call arrival rate (λ_k) used in equation (3.2) and (3.5) can be obtained by reporting a selected base station from a mobile station that knows which base station is closer and chosen. If a mobile station selects a lower signal strength base station, the mobile station reports to adjacent two base stations that it is in a cell of the farther base station. If a mobile station communicates to a higher signal strength base station, the mobile station reports to the adjacent two base stations that the mobile station selects the nearer base station.

4. System Performance Analysis

4-1. Identification of System States

The state of the system is characterized by a sequence of non-negative integers as $v_0, v_2, \cdots, v_{2N_b-2}$, where v_i denotes the number channels in use at a base station, BS_i. The number v_i, can be between zero and the number of channels, C that each base station can simultaneous use. The total number of possible system states N_s, is given by

$$N_s = (C+1)^{N_b} \tag{4.1}$$

Let the state index s ($s=0, 1, 2, \cdots, N_s-1$) denote the system state which is determined by the number of channels used in the base stations. An example of state index of a system which has three base stations is shown in Table 2. A state index of zero means that no channels are used in the all base stations. In this example, state index of one, two and three represent that one of base stations uses one channel. When all channels (two channels) in all base stations are in use, the state index is 26.

Let $w_k(s)$ denote the number of channels that are in use at base station k when the system is in state s.

The total number occupied channels in the system in state i is given by

$$w_k(i) = \sum_{j=0}^{N_b-1} v_{2j}(i) \tag{4.2}$$

4-2. State Transitions

The state of a system changes from a state $s_{\underline{n}}$ to another state s is driven by a new call arrival process. The transition rate $q(s,\ s_n)$ is determined by the traffic and the system conditions.

A necessary and sufficient condition for $s_{\underline{n}}$ to be a predecessor of s which is driven by new call arrivals that are served by BS_k is

$$\begin{aligned} &\mathrm{v}_k(\mathrm{s}_n)=\mathrm{v}_k(\mathrm{s})-1 \\ &\mathrm{v}_i(\mathrm{s}_n)=\mathrm{v}_i(\mathrm{s}) \qquad \text{for all } i \text{ except } \mathrm{i=k} \\ &\mathrm{v}_k(\mathrm{s})\ \mathrm{C} \end{aligned} \tag{4.3}$$

in which k=0, 2, 4, ···, N_{b-2}.

Obviously, state s=N_{S-1} has no successors which are driven by a new call arrival because all channels are occupied.

If there is no overlap, the state transition rate from s_n to s is equal to the call arrival rate in the interesting area. However, if there are overlapping segments, the transition rates depends on the base station selection probabilities, r_i. The base station selection probability depends on both the position of the mobile station which a new call arises, and traffic conditions of the possible serving base stations. The base station selection probability is described in section 3-2. An event that a base station serves a new call can be driven by three possible situations which corresponds to the mobile station position. Namely the mobile station can be in an segment which is served only by the base station k, or by either one of two overlapped segments which are also covered by the adjacent base stations (*k-2* or *k+2*). Thus, the transition rate from s_n to s is given by

$$q(s,s_n) = \sum_{k=i-1}^{i+1}(r_k \cdot \Lambda_k) \tag{4.4}$$

where Λ_k is the new call arrival rate in segment *k*.

A necessary and sufficient condition for s_c to be a predecessor of s if there is a call completion is

$$v_k(s_c)=v_k\ (s)+1$$

$$v_i(s_c)=v_i\ (s) \text{ for all i except for i=k} \tag{4.5}$$

$$v_k\ (s)\ 0$$

State s=0 cannot be a predecessor which is driven by a call completion because no calls are activated.

The system can change to another state by a call completion. If $v_k(s_c)$ calls are in progress, the transition rate driven by one call completion out of $v_k(s_c)$ calls is given by

$$q(s,s_c) = \frac{v_k(s_c)}{T} \tag{4.6}$$

if we assume that holding time of calls have a negative exponential distribution with the mean holding time of *T*.

Successor and predecessor in states, for any given states are shown in Table 2. As an example, state #4 is a predecessor for state #1, #2, #10, #11 and #13 and these states are also predecessors of state #4 as shown in Fig. 4. Transitions to #1 and #2 from #4 are caused by a call completion, transitions to #10, #11 and #13 are driven by a call arrival.

4-3. Flow Balance

The flow balance equations for the system can be used to obtain the statistical equilibrium state probabilities for the system[3,4].

$$\sum_{j=0}^{Ns-1} q(i,j)\cdot p(j)=0,\quad i=0,\ 1,\ 2,\ \cdots,\ N_S-1$$

$$\sum_{j=0}^{Ns-1} p(j)=1 \tag{4.7}$$

Equations (4.7) comprises a set of simultaneous equations, which can be solved for the unknown state probabilities, *p(s)*.

4-4. Performance Comparison

A. Blocking Probability

Generally, blocking probability performance of a system that employs a distributed control scheme is strongly influenced by the number of traffic channels that each base station has. If the frequency bandwidth of a system is not enough and blocking probability is dominated by the frequency resources, a base station placement strategy of the system should take the frequency reuse issue into account. It means that the advantage of the distributed control scheme is not utilized sufficiently. We assume that blocking probability performance is subject to the number of the traffic channels of a base station.

(a) Definition of Blocking Probability

Blocking probability is generally defined as a ratio of the number of blocked calls to the number of attempted calls. If a base station is in a state *s*, that has no channels available in an area, then a blocking event occurs if a new call is generated in the area. Namely, blocking event occurrence rate in this case is given by

$$r_b=\text{probability}(s=\{\text{No available channels in an area}\})\cdot\Lambda_k \tag{4.8}$$

where Λ_k is a call arrival rate in *segment k*. Blocking probability can be obtained as a ratio of r_b to the call arrival rate in the interesting segment. Thus a fraction of blocking probability in a state s in an segment k is given by

$$p_b = r_b/\Lambda_k$$

$$= \text{probability}(s=\{\text{No available channels in an segment}\}) \tag{4.9}$$

Consequently, average fraction of new calls that are blocked in an segment "*i*", which is equal to blocking probability of an segment "*i*" is given by

$$\begin{aligned} P_b(i) &= \sum_{i=0}^{N_s-1} p\left(s=\{v_i(s)=C\}\right) && i: even \\ P_b(i) &= \sum_{i=0}^{N_s-1} p\left(s=\left[\{v_{i-1}(s)=C\}\otimes\{v_{i+1}(s)=C\}\right]\right) && i: odd \end{aligned} \tag{4.10}$$

where *p(s)* is the state probability of state s that has no available channels in the interesting segment(s), C is the number of channels that each base station has. These are "segment blocking probabilities".

Calls that arise in an overlapped segment should be taken into account by the two base stations that shape the overlap in one-dimensional ring model shown in Fig. 2. Thus, we define a blocking probability of a base station (cell blocking probability) by using $p_b(i)$ as

$$p_b(BS_i) = \sum_{j=i-1}^{i+1} \frac{\Lambda_j}{\Lambda_{T_i}} p_b(j) \tag{4.11}$$

where i is an segment number which is even number, Λ_{T_i} is the total new call arrival rate in the coverage of BS_i. In the equation (4.11), Λ_{T_i} is given by

$$\Lambda_{T_i} = \sum_{j=i-1}^{i+1} \Lambda_j \tag{4.12}$$

where Λ_i is a call generation rate in an segment "i" described as

$$\begin{aligned} \Lambda_k &= \int_{\frac{(k-1)\alpha+\beta}{2}}^{\frac{(k+3)\alpha-\beta}{2}} g(\theta)d\theta \qquad (no - overlap\ area) \\ \Lambda_k &= \int_{\frac{(k+3)\alpha-\beta}{2}}^{\frac{(k+1)\alpha+\beta}{2}} g(\theta)d\theta \qquad (overlap\ area) \end{aligned} \tag{4.13}$$

Blocking probability of a whole system can be calculated by using following formula

$$P_b(sys) = \sum_{i=0}^{2N_b-1} \frac{\Lambda_i}{\Lambda_T} p_b(i) \tag{4.14}$$

The sum of Λ_i is equal to the total amount of traffic.

$$\Lambda_T = \sum_{i=0}^{2N_b-1} \Lambda_i \tag{4.15}$$

(b) Numerical Results

- Blocking Probability Performance of the Whole System

Figure 5 shows blocking probability improvement of a system by the proposed base station selection scheme for the case that a tapered traffic is offered to the system. A hot spot is located at a base station placement position, namely $\theta_0=(2n-1)\cdot\alpha/2$ $(n=1, 2, \cdots, N_b)$. These results are obtained by calculating the equation (4.14). The blocking probability of the system is improved by overlapping. With 100% overlap ($R_0=1$) and the definite selection procedure, the system can be offered 2.8 times the traffic that can be offered without overlap at the blocking probability of 2%.

The definite selection procedure allows more traffic load than the proportional selection procedure. This difference increases as overlap increases.

- Blocking Probability Performance of Each Base Station

The blocking probability of a heavy traffic offered cell (hot spot) is improved significantly by definite base station selection and it is close to the blocking probability of the adjacent cell as shown in Fig. 6. Highly tapered traffic (75% of the offered traffic is tapered traffic and 25% of traffic is the background traffic) is assumed in these calculations. These results indicate that the heavy traffic is pushed away to the adjacent cell by the proposed scheme. Note that blocking characteristics of cells that are adjacent to the hot spot are also improved (in spite of the traffic that has been "pushed" into them). This is because base stations that are adjacent to the hot spot (i.e. "first adjacent base stations") also have base stations adjacent to them (on the other sides, i.e. "second adjacent base stations") that have less offered traffic. Thus call arrivals in the coverage areas of the first adjacent cells are likely to be accommodated in the second adjacent base stations. Blocking probability performance of a system which employs the proportional selection is also shown in Fig. 7. For the system using proportional selection, blocking probability in each cell is worse than that of the corresponding cell for the system using definite selection except for blocking probability performance of the furthest cell. System blocking probability with the definite selection is better than that with the proportional selection as mentioned above.

- Blocking Probability Improvement by Overlap

This improvement depends on the overlapping ratio. As increasing the ratio of overlap, the blocking probability performance is improved more as shown in Fig. 8. The blocking probability of the hot spot cell is improved more than that of the adjacent cells. Blocking probability performances of the hot spot cell and the adjacent cells that employ the definite selection are better than those which employs the proportional selection. However, the blocking probability of the farthest cell for the definite selection is worse than for the proportional selection. It means that more traffic is pushed to the farthest cell from the hot spot area by the definite selection than by the proportional selection. In the case that heavy traffic is offered, channels of a base station in the hottest spot should be kept for the expected calls as many as possible.

The blocking probability of no-overlapping is the same results as that calculated by Erlang-B formula.

- Hot Spot Position

All of the above numerical results are obtained with an assumption that the hot spot traffic is centered on the same point as a base station locations. This corresponds to θ_0 of π/N_b. If six base station is assumed in the ring model, θ_0 is equal to $\pi/6$. Fig. 9 shows effects of the hot spot position on blocking probability. These characteristics are obtained with the condition of θ_0 between zero and $\pi/6$. The characteristics with a condition of $\pi/6<\theta_0<\pi/3$ is line symmetrical with respect to the θ_0 of $\pi/6$. The characteristics with a condition of θ_0 between zero and $\pi/3$ appears at regular special intervals for larger θ_0. As being closer of the hot spot point to the base station position, blocking probability of the hot spot cell is slightly degraded. Because more traffic is offered to the hot spot base station if the hot spot is close to the base station position. On the other hand, blocking probability of the farthest cell is decreased a little due to going away of the hot spot. Totally, the system blocking probability is insensitive to the hot spot position.

- Weight of Background Traffic and Tapered Traffic

In a mobile radio system, the subscribers of the system will move and heavily tapered traffic can arise. This situation corresponds to decreasing of the background traffic weight of γ. Fig. 10 shows blocking probability degradation due to tapered traffic with a constant amount traffic of six erlangs in the whole system. Performance of the proposed scheme is always superior to the no overlap system. Real systems must be designed by taking this situation into account.

- Standard Deviation of Tapered Traffic

A small standard deviation shapes a highly tapered traffic and it degrades blocking probability of the hot spot cell and its adjacent cells as shown in Fig. 11. However, the performance difference between cells are relatively small for the variance of $3\pi/4$ or larger. Note that in case of large standard deviation, namely lowly tapered traffic, blocking probability of the farthest cell is worse than that of the hot spot cell. This is because much traffic is pushed away in spite of small traffic difference. The definition of the offered traffic which is the metric of definite selection is location of mobile stations. This definition causes this inversion.

B. Carried Traffic

Carried traffic of BS_i is calculated by using the state probabilities as

$$C(i) = \sum_{j=0}^{N_s-1} \{ v_{2i}(j) \cdot p(j) \} \tag{4.16}$$

where $v_{2i}(j)$ is the number of occupied channels of a state "j" in segment "$2i$". Total carried traffic in the whole system is given by

$$C_T = \sum_{i=0}^{N_b-1} C(2i) \quad = \sum_{i=0}^{N_s-1} \{ w_T(i) \cdot p(i) \} \tag{4.17}$$

Fig. 12 is an example of carried traffic performance comparison calculated by the equation (4.16). Carried traffic of a hot spot is decreased by the proposed schemes with increasing the overlapped coverage segments. This is because the heavy traffic is pushed away and blocking probability of the hot spot is improved. On the other hand, carried traffic of the base stations that are adjacent to the hot spot are increased. A noticeable result is that carried traffic of the adjacent cells are higher than that of the hot spot if overlapping ratio of 0.85 or higher. The carried traffic performance that employs the proportional selection is decreased as well. However, the carried traffic of the hot spot is higher than that of the adjacent cells if the proportional selection scheme is used. The carried traffic of the farthest cell which is using the definite selection is more increased than which is using the proportional selection. This result proves that the tapered traffic is equalized more by the definite selection than the proportional selection.

4-5. Comprehensive Evaluation

The most important performance measures from a system viewpoint is the system blocking probability versus the system carried traffic. Larger carried traffic at a blocking probability implies more efficient usage of the frequency resource. Even if more traffic can be carried with a high blocking probability, the system performance is not regarded as good. Fig. 13 shows a comparison of trade off among no-overlapping, 50% of overlapping and 100% overlapping. The performance of definite selection achieves the best performance.

4-6. Computer Simulation

To make the results reliable and firm, computer simulations are performed.

A. Simulation Procedure

The computer simulation based on the Monte Calro simulation. Events are observed in a short period discretely. A number of calls in the short period is generated as a Poisson distribution by using random numbers, if the number of calls in the period is not zero, holding time is generated with the negative exponential distribution for each generated call.

The period should be short enough to avoid errors. One second is used for heavy traffic conditions and five second is used for light traffic conditions. Average holding time of one hundred seconds is assumed in the simulation, the period is relatively short enough. When a call arises at a mobile station, it chooses a base station follows the two types of procedure if it is in an overlapped segment. The selected base station serves the call if it has an available channel. If there is no available base station, the call is counted as a blocked call. This procedure is performed in each segment. In the short period, some events in some base station can be occurred. The blocked calls may depend on the order of the events. The order of segment in which events are observed is also generated as random numbers to avoid bias of blocking probabilities. In a period, events in segment 1 is observed earlier than events in segment 2, however, the order may be inverted in another period.

State probability is obtained by this simulation procedure. Blocking probability of each cell is obtained by this state probability as the analysis. System blocking probability is also calculated by the state probability that is obtained this computer simulation as well as counting the number of blocked and generated calls. The system blocking probability obtained computer simulations by two ways (using state probability and counting numbers) show the same results.

B. Results

Computer simulation results are plotted in Figure 5, 6, 7 and 12. These results meet well with the numerical calculation results. In low blocking probabilities, errors between analysis and simulation results are slightly large since the number of blocked call events is small. The call generation is reiterated till the number of blocked call events reaches one hundred. Errors of blocking probability obtained by the computer simulations are larger than errors of carried traffic since the absolute value of blocking probability is smaller.

C. Expansion to a Two Dimensional Model

The proposed analytical method can be extended to a two dimensional special layout. The difference between one and two dimensional analysis is the flow rate $q(i,j)$. This difference is caused by the number of surrounded base stations. However, this approach leads to an overwhelming number of states even for small systems.

5. Discussion

5-1. Improvement by Overlapping Cell and Base station Dynamic Selection

A mobile station that initiates a call selects one of available base stations if it is in an overlapped segment. It is obvious that blocking probability performance is improved because there are two candidate base stations that may be able to serve the call. In the case of heavy traffic offered to a cell, some amount of the traffic is pushed away to the adjacent base stations. The adjacent base stations handle more traffic than they have originally (the amount of traffic to the cell), and some of the traffic offered on the adjacent cell is pushed away to next adjacent cell as well. Consequently, carried traffic at the base stations is increased except for the hot spot base station. Corresponding to the increase of carried traffic, one may be afraid that blocking probability characteristic of the adjacent cells degrades. However, all base stations get this benefit brought by the proposed method.
In two dimensional model, more significant improvement is expected since some of overlapped segments can be covered by three or more base stations.

5-2. Carried Traffic of the Adjacent Cells

Carried traffic of a base station that is in the hot spot area is lower than that in the adjacent to hot spot area with definite selection scheme. In case there are the same number of available channels in the adjacent base station as in the hot-spot base station, the adjacent cell is definitely selected to serve the call. This procedure increases the carried traffic of the adjacent cell to the hot spot as shown in Figure 3. This also means that the hot spot base station can prepare for new call arrivals with some available channels. Thus, carried traffic is decreased but blocking probability is improved in the hot spot. On the other hand, the adjacent base station channels are often used because of the idleness of the hot spot base station. Overall, the system's carried traffic performance is also improved.

5-3. Scattering of Hot Spot Traffic

According to Fig. 6 and 7, blocking probability of the hot spot is worse than that of the adjacent cells in spite of smaller carried traffic since available channels are intended to be used as many as possible by the definite selection. This implies that channels in the adjacent base stations is utilized very efficiently. The carried traffic of the adjacent cells are more than the offered traffic when no-overlapping is applied. The carried traffic of the farthest cell is also increased by overlapping and the proposed scheme. This indicates that the hot spot traffic is pushed away to the farther cells by the dynamic base station selection scheme.

5-4. Selection Procedure Comparison

Two types of call handling methods are evaluated above. The difference of these procedures is not significant, however, this difference impacts on the system performance. By using the definite selection, calls generated in the overlapped segment are handled by the base station that has smaller traffic if there are available channels. Only in the case that there is no available traffic channels in the base station that is offered lighter traffic, the other base station that is in a higher traffic segment serves the calls. That brings lower carried traffic in the hot spot area as shown in Fig. 12. Proportional selection seems to be appropriate scheme for a system that has tapered traffic because a base station is selected by the rate that is defined proportionally to the offered traffic ratio. However, we can say that channels of a base station in hotter area should be remained as many as possible.

Judging from the results shown in Fig. 6, 7 and 12, the definite selection pushes more traffic away from the hot spot. As a result, carried traffic of the hot spot is less than that of the adjacent cell to the hot spot. Few carried traffic increase in the farthest cell is found if the proportional selection scheme is applied.

5-5. Inversion of Blocking Probability Performance for Slightly Tapered Traffic

As shown in Fig. 11, blocking probability of the farthest cell is worse than that of the hot spot cell. However, blocking probability of this condition is tolerably small. By tolerating this inversion, blocking probability in case of highly tapered traffic which can be occurred because of a mobile system is improved.

5-6. Traffic Shape

System average blocking probability performance is degraded if the subscribers move to a spot. This degradation due to non-uniform traffic can be improved by the dynamic base station selection because there are three possible service base station for the hot spot. If the hot spot variance is smaller than the cell area (angle of α in the model), a base station which is placed at the hot spot relieves the dense traffic. A system that each base station has only a few traffic channels can be robust for congested traffic due to moving of subscribers.

This hot spot traffic model should be taken into account when a system is designed.

6. Conclusions

We proposed a dynamic base station selection scheme. Its performance has been analyzed by using a state transition model. Analytical results were confirmed by computer simulations. The proposed scheme, dynamic base station selection in overlapping areas improves blocking probability and carried traffic performance significantly. This is especially effective to the cells that are loaded highly tapered traffic, which commonly occurs in PCS systems. Tapered traffic is equalized and adjacent base stations to the hot spot carry more traffic than the traffic generated in the cell. The definite selection scheme in case of the same channels are in use shows the better performance than the proportional selection scheme. The dynamic base station selection technique enhances robustness of a system for congested traffic due to moving of the subscribers even if each base station has a few channels.

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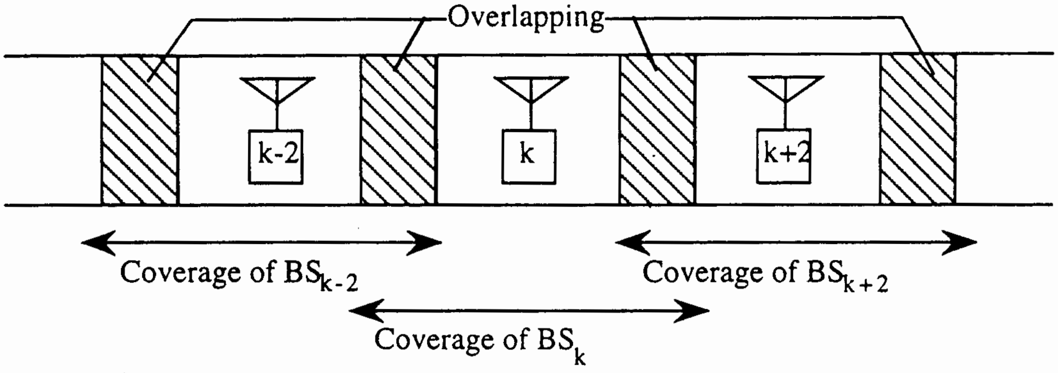

Fig. 1 Overlapped Cell in One Dimentional Model

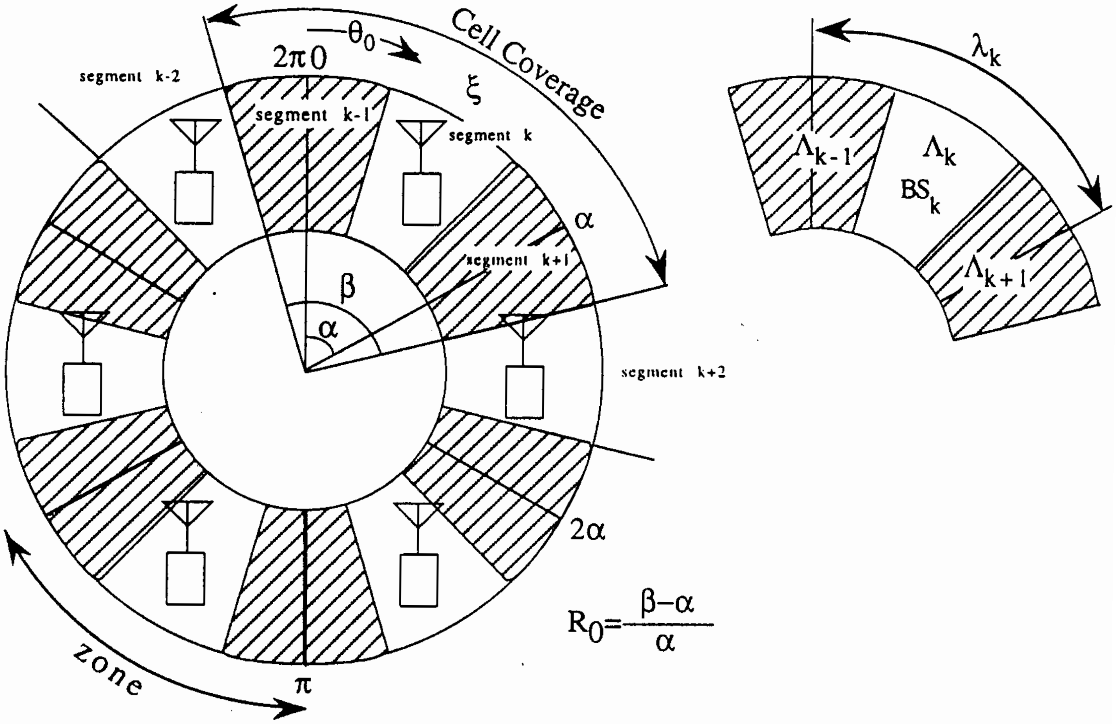

Fig. 2 Ring System Model, Overlapping Ratio and Offered Traffic

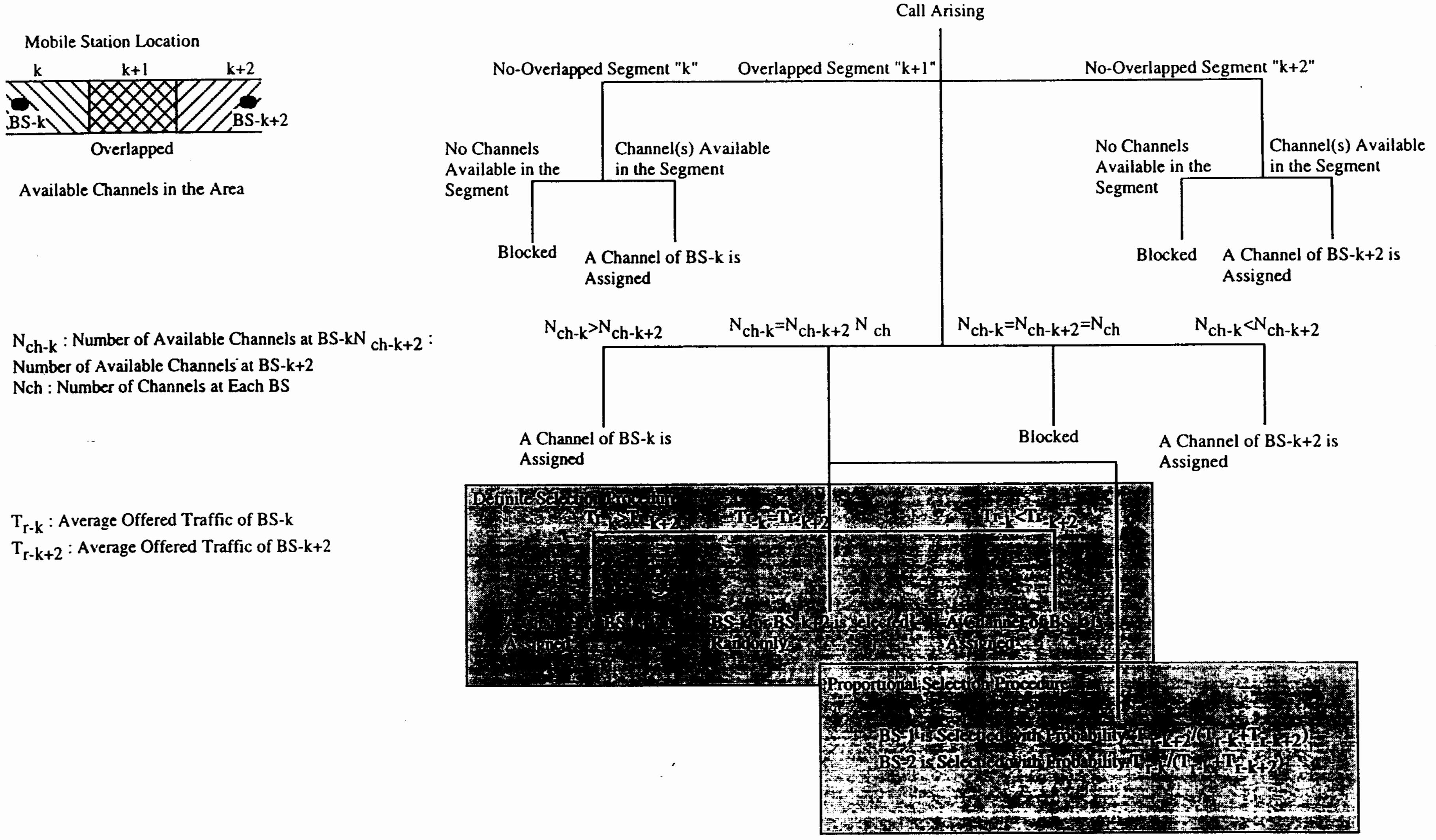

Fig. 3 Call Handling for the Proposed Schemes

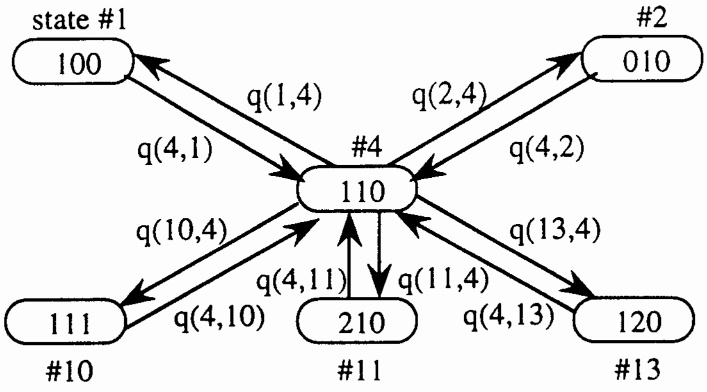

Fig. 4 State Transition Example : Shows current state #4 having state variables(1,1,0) with predecessor and successor states, and state transition rates, q(i,j).

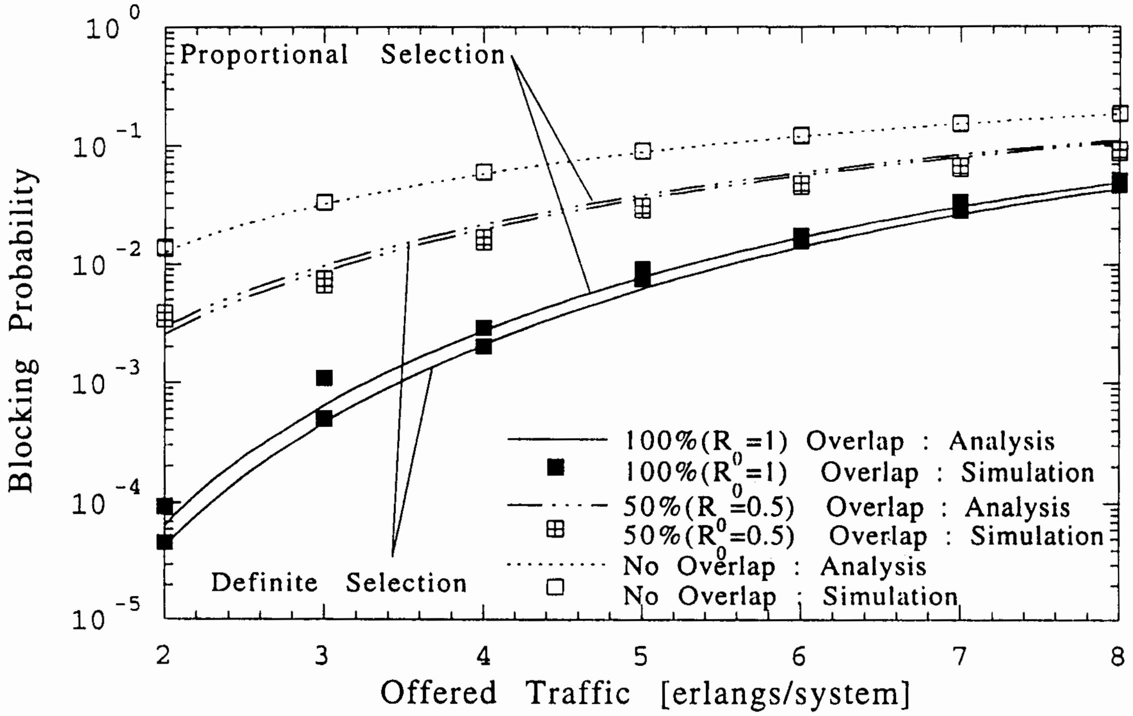

Fig. 5 System Blocking Probability Performance

Standard Deviation (σ)=$\pi/3$, Background Traffic/Tapered Trafic($\gamma/(1-\gamma)$)=0.25/0.75
Hot Spot Possition (θ_0)=$\pi/6$, 6 Base Stations, 3 Channels in each Base Station

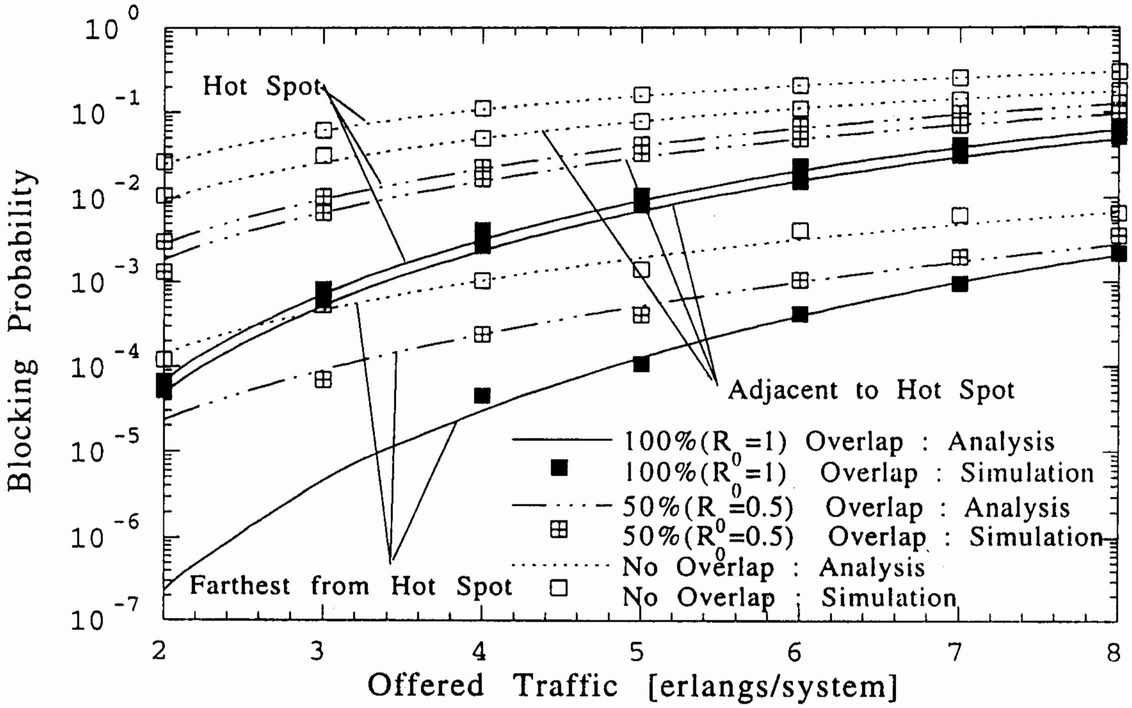

Fig. 6 Blocking Probability Performance Difference between Base Stations

Standard Diviation (σ_θ)=$\pi/3$, Background Traffic/Tapered Trafic($\gamma/(1-\gamma)$)=0.25/0.75
Hot Spot Possition (θ_0)=$\pi/6$, BS Selection Procedure : Definite
6 Base Stations, 3 Channels in each Base Station

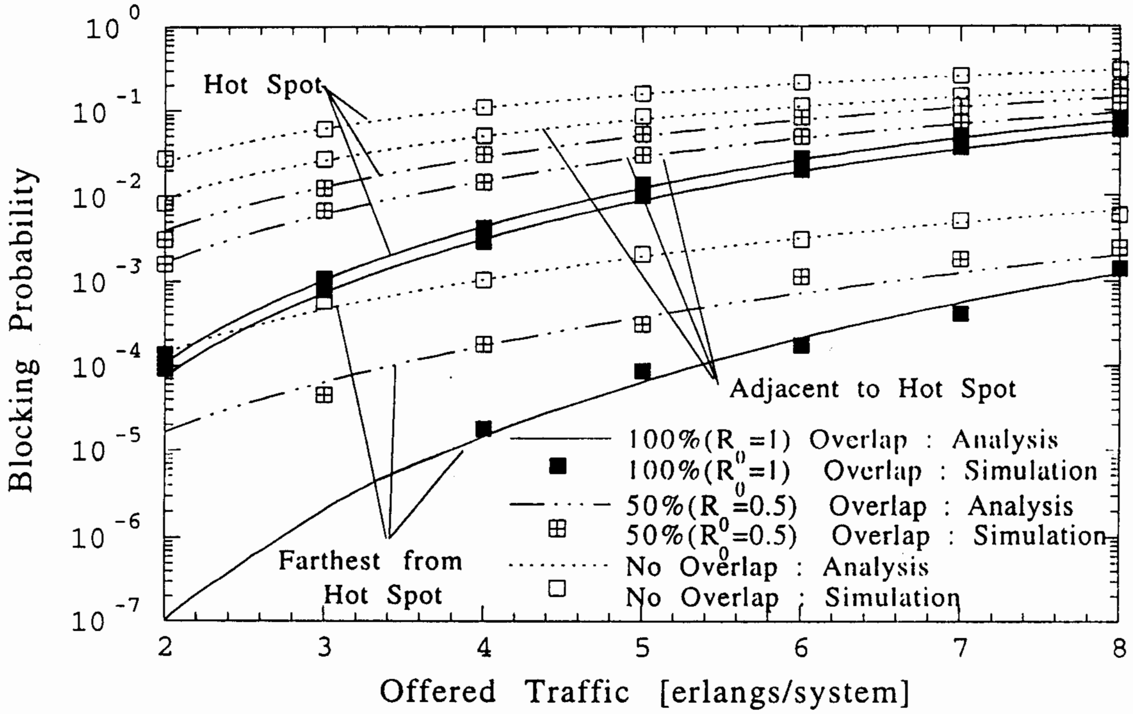

Fig. 7 Blocking Probability Performance Difference between Base Stations

Standard Diviation $(\sigma_0)=\pi/3$, Background Traffic/Tapered Trafic$(\gamma/(1-\gamma))=0.25/0.75$
Hot Spot Possition $(\theta_0)=\pi/6$, BS Selection Procedure : Proportional
6 Base Stations, 3 Channels in each Base Station

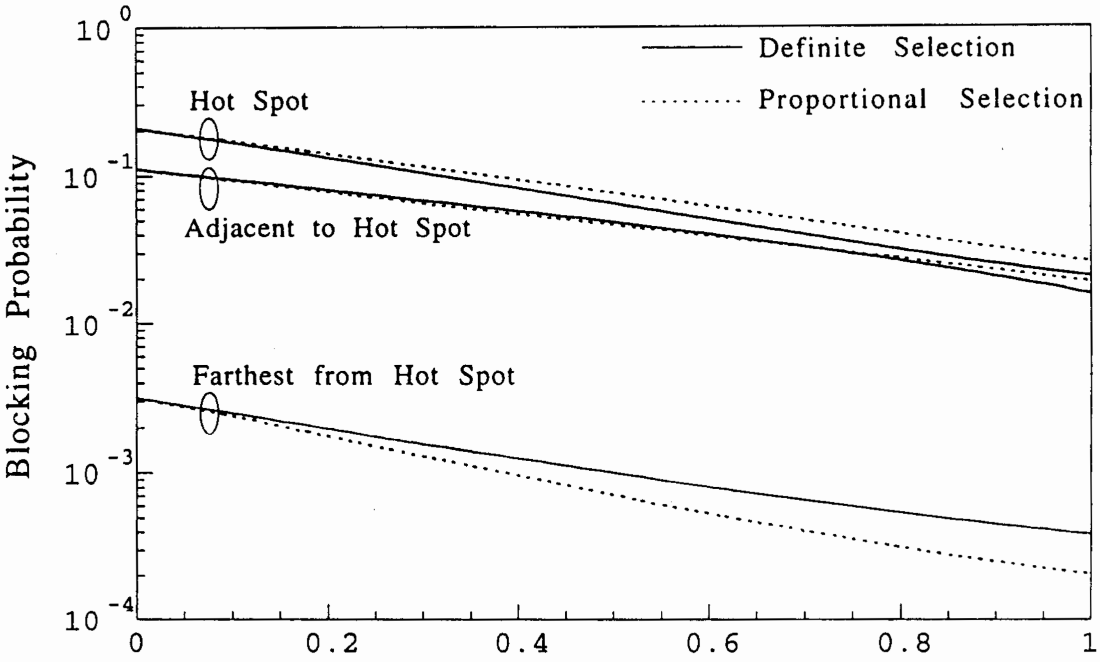

Fig. 8 Blocking Probability Improvement by Overlapping

Standard Diviation (σ)=π/3, Background Traffic/Tapered Trafic($\gamma/(1-\gamma)$)=0.25/0.75
Hot Spot Possition (θ_0)=π/6, 6 Base Stations, 3 Channels in each Base Station
Offered Traffic=6 [erlangs/system]

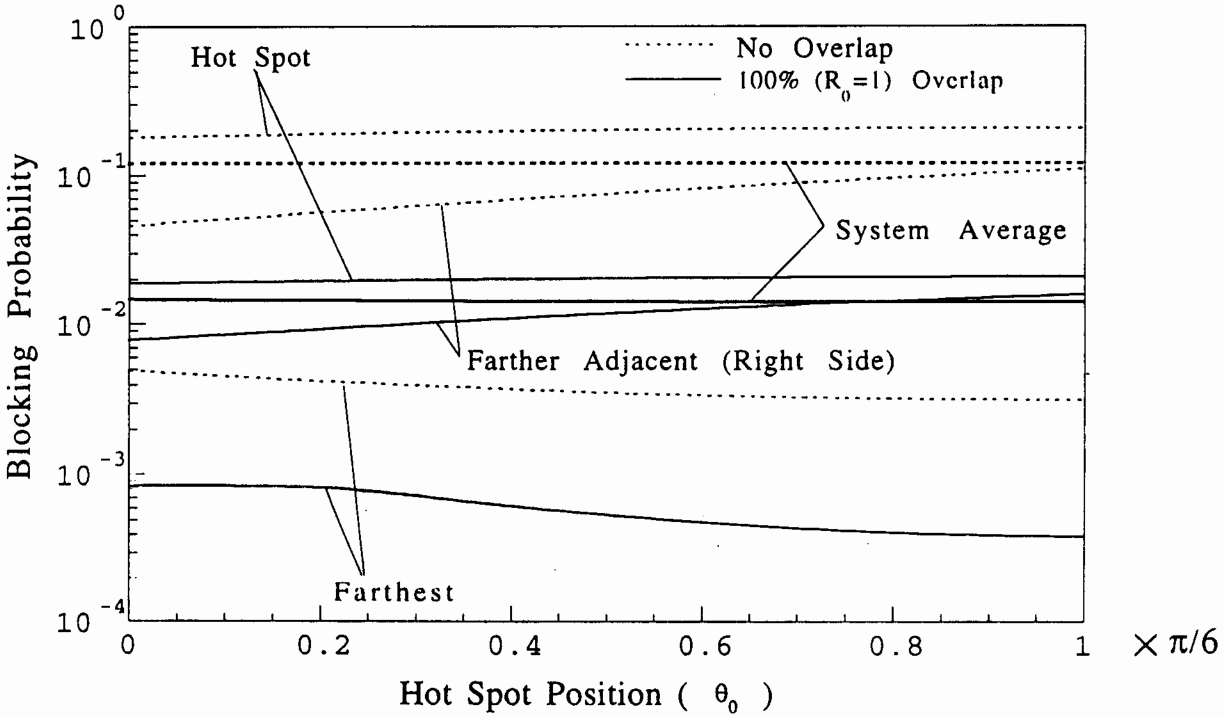

Fig. 9 Insensitive Blocking Probability Performance to Hot Spot Position

Standard Diviation (σ)=π/3, Background Traffic/Tapered Trafic($\gamma/(1-\gamma)$)=0.25/0.75
Offered Traffic=6 [erlangs/system], 6 Base Stations, 3 Channels in each Base Station
Selection Procedure : Definite

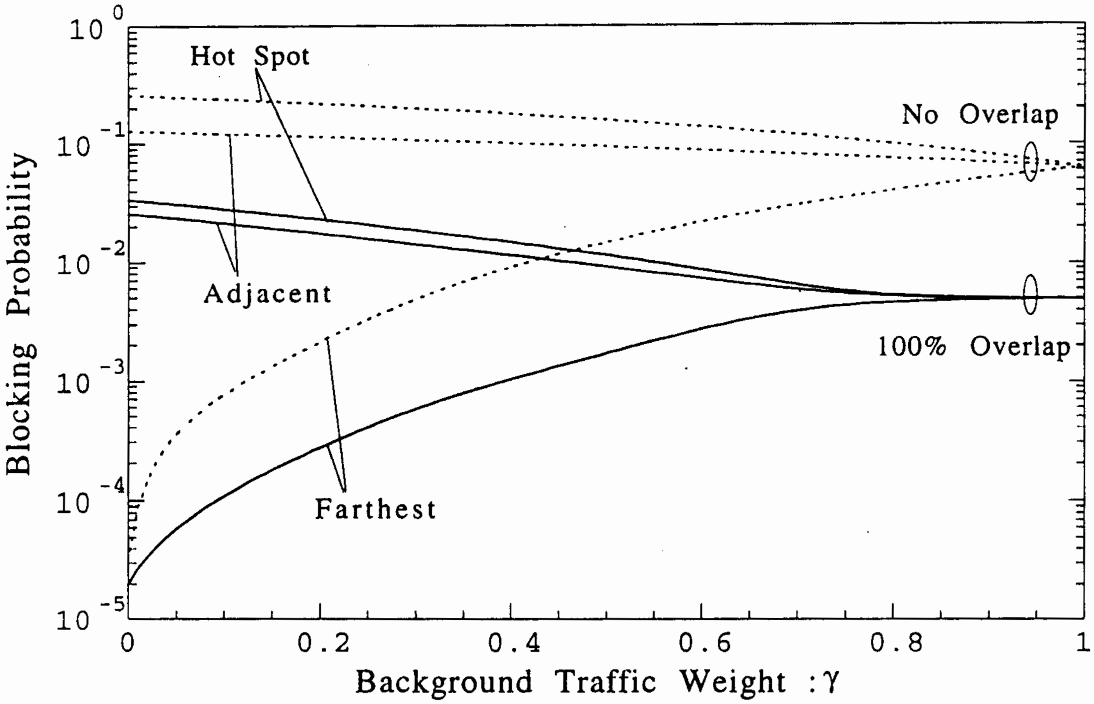

Fig. 10 Blocking Probability Degradation due to Tapered Traffic

Standard Diviation (σ)=$\pi/3$, 6 Base Stations, 3 Channels in each Base Station
Hot Spot Possition (θ_0)=$\pi/6$, Selection Procedure : Definite
Offered Traffic=6 [erlangs/system]

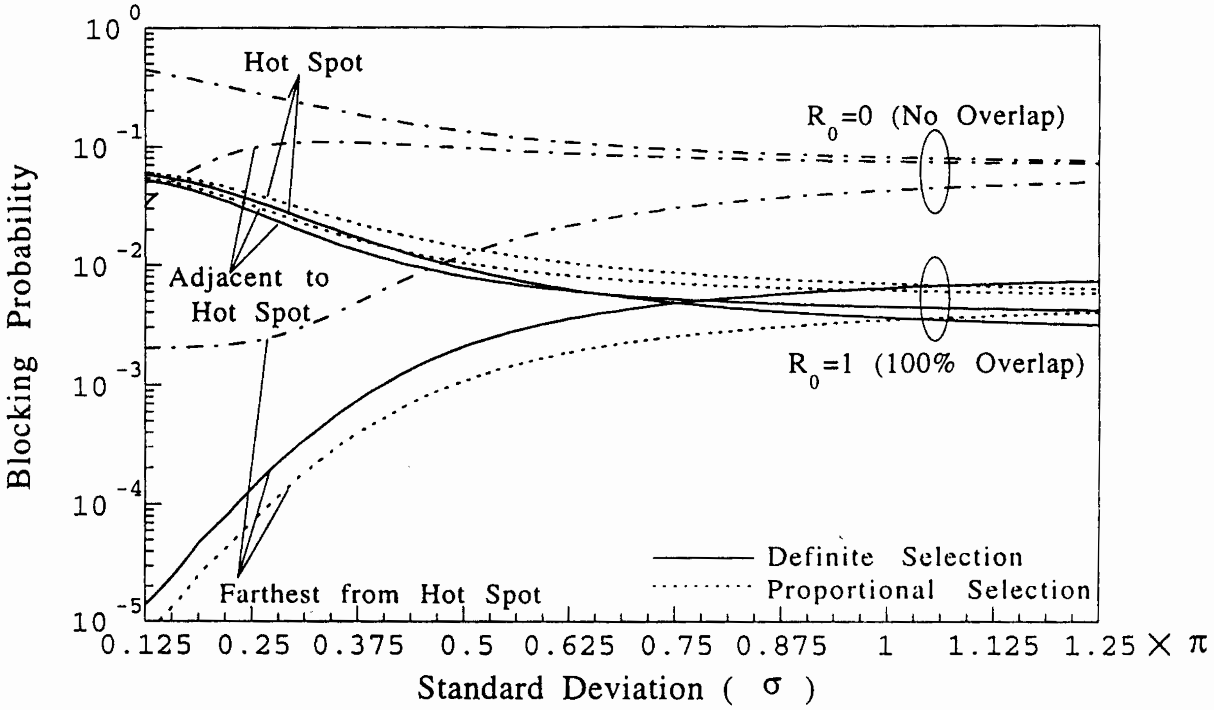

Fig. 11 Effects of Tapered Traffic Shape on Blocking Probability Performance

Hot Spot Possition (θ_0)=π/6, Background Traffic/Tapered Trafic($\gamma/(1-\gamma)$)=0.25/0.75
Offered Traffic=6 [erlangs/system], 6 Base Stations, 3 Channels in each Base Station

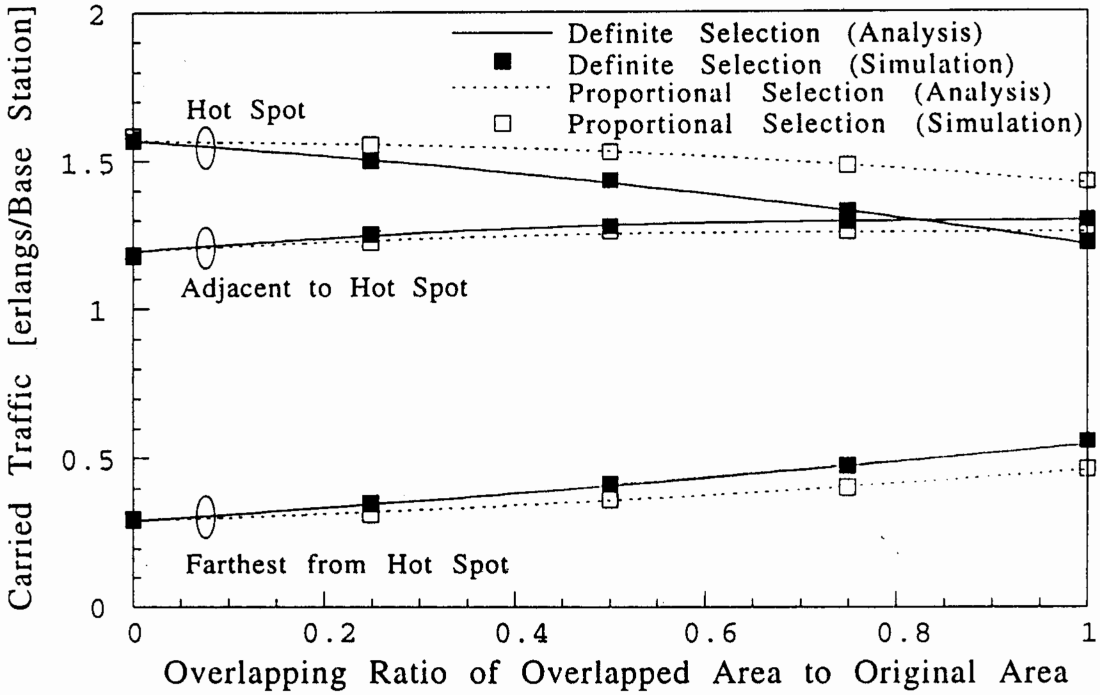

Fig. 12 Smoothing of Tapered Traffic by Overlapping with Dynamic Base Station Selection

Standard Diviation (σ)=$\pi/3$, Background Traffic/Tapered Trafic($\gamma/(1-\gamma)$)=0.25/0.75
Hot Spot Possition (θ_0)=$\pi/6$, Offered Traffic : 6 [erlangs/system]
6 Base Stations, 3 Channels in each Base Station

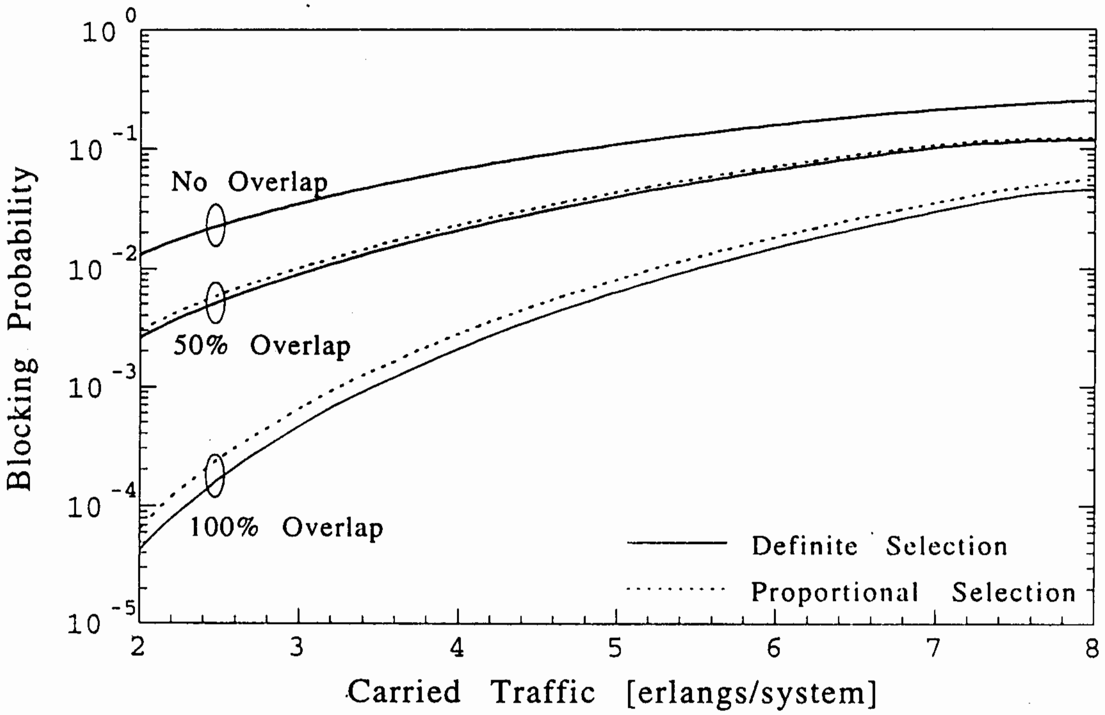

Fig. 13 Trade off of Blocking Probability and Carried Traffic (System Average)

Standard Diviation (σ)=$\pi/3$, Background Traffic/Tapered Trafic($\gamma/(1-\gamma)$)=0.25/0.75
Hot Spot Possition (θ_0)=$\pi/6$, 6 Base Stations, 3 Channels in each Base Station

Table 1 Base-station Selection Conditions

System Conditions		Selection	
Offered Traffic λ_k, λ_{k+2}	**Number of Occupied Channels** O_k, O_{k+2}	**Definite Selection**	**Proportional Selection**
$\lambda_k > \lambda_{k+2}$	$O_k > O_{k+2}$	k +2	k+2
$\lambda_k > \lambda_{k+2}$	$O_k < O_{k+2}$	k	k
$\lambda_k = \lambda_{k+2}$	$O_k > O_{k+2}$	k+2	k+2
$\lambda_k = \lambda_{k+2}$	$O_k < O_{k+2}$	k	k
$\lambda_k < \lambda_{k+2}$	$O_k > O_{k+2}$	k+2	k+2
$\lambda_k < \lambda_{k+2}$	$O_k < O_{k+2}$	k	k
$\lambda_k > \lambda_{k+2}$	$O_k = O_{k+2}$	k+2	$\lambda_{k+2}/(\lambda_k+\lambda_{k+2})$ for k $\lambda_k/(\lambda_k+\lambda_{k+2})$ for k+2
$\lambda_k < \lambda_{k+2}$	$O_k = O_{k+2}$	k	$\lambda_{k+2}/(\lambda_k+\lambda_{k+2})$ for k $\lambda_k/(\lambda_k+\lambda_{k+2})$ for k+2
$\lambda_k = \lambda_{k+2}$	$O_k = O_{k+2}$	0.5/0.5	$\lambda_{k+2}/(\lambda_k+\lambda_{k+2})$ for k $\lambda_k/(\lambda_k+\lambda_{k+2})$ for k+2

Table 2 A System State and its Transition Example

state index s	$v_0v_2v_4$	Number of Occupied Channels	Successors/Predecessors (denoted by state index number)	Blocking Possible Areas
0	000	0	1,2,3	-
1	100	1	0,4,5,7	-
2	010	1	0,4,6,8	-
3	001	1	0,5,6,9	-
4	110	2	1,2,10,11,13	-
5	101	2	1,3,10,12,14	-
6	011	2	2,3,10,15,16	-
7	200	2	1,11,12	k
8	020	2	2,13,15	k+2
9	002	2	3,14,16	k-2
10	111	3	4,5,6,17,18,19	-
11	210	3	4,7,17,20	k
12	201	3	5,7,17,21	k
13	120	3	4,8,18,20	k+2
14	102	3	5,9,19,21	k-2
15	021	3	6,8,18,22	k+2
16	012	3	6,9,19,22	k-2
17	211	3	10,11,12,23,24	k
18	121	4	10,13,15,23,25	k+2
19	112	4	10,14,16,24,25	k-2
20	220	4	11,13,23	k,k+1,k+2
21	202	4	12,14,24	k-2,k-1,k
22	022	4	15,16,25	k+2,k+3,k-2
23	221	5	17,18,20,26	k,k+1,k+2
24	212	5	17,19,21,26	k-2,k-1,k
25	122	5	18,19,22,26	k+2,k+3,k-2
26	222	6	23,24,25	k,k+1,k+2,k+3,k-2,k-1