Performance Analysis of Trunk Network for CDMA Inter-MSC Soft Handoffs

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ABSTRACT

The soft handoffs between two adjacent MSC's should be employed to support the calls requesting handoffs to an MSC while minimizing the undesirable "ping pong" phenomenon of back-and-forth handoffs between two adjacent cells in conventional hard handoffs. In this paper, the soft handoff scheme between two MSC's is considered using the trunk between the packet routers for the two MSC's. The trunk network is proposed to support the inter-MSC soft handoff scheme in the service area with many MSC's. The probability that a soft handoff to an adjacent MSC will be blocked due to the shortage of the trunk capacity is derived

I. INTRODUCTION

Code division multiple access (CDMA) is a promising air interface technique for cellular systems. When a mobile station moves to an adjacent cell, the handoff between the serving cell and the target cell is needed. Compared with the hard handoffs, the soft handoffs between two CDMA channels with the identical frequency assignments and frame offsets can provide a better quality of service. [1-4] The soft handoffs between cells within an MSC (Mobile Switching Center)'s service area have been implemented in commercial CDMA cellular systems. The soft handoffs between two adjacent MSC's should be employed to support the calls requesting handoffs to a new MSC while minimizing the undesirable "ping pong" phenomenon of back-and-forth handoffs between two adjacent cells in conventional hard handoffs.

In this paper, the soft handoff scheme between two MSC's is considered using the trunk between the packet routers for the two MSC's. After a mobile station moves to a new MSC's service area, the old MSC will receive from and send to the mobile station the traffic data through the trunk between the packet routers for the two MSC's and the same vocoder in the old MSC will be used. The trunk network will be proposed to support the inter-MSC soft handoff scheme in the service area with many MSC's. The theoretical approach for the performance analysis of the trunk network will be developed to obtain the probability that a soft handoff to an adjacent MSC will be blocked due to the shortage of the trunk capacity. In the literature, the soft handoff scheme between two MSC's in [4] switches the vocoder in the old MSC to that in the new MSC for the mobile station moving to the new MSC's service area, and the performance of the trunk is investigated using computer simulation in [4]. But, by switching the vocoder for the inter-MSC soft handoff, a new connection for rerouting the call in progress of the mobile station through the new MSC should be established while maintaining the old connection through the old MSC. In addition to this implementation burden for the inter-MSC soft handoff, a new signaling scheme for switching the old call connection to the new one through the new MSC is needed. With the proposed scheme, the same call connection through the old MSC is maintained so the processing load for reestablishing the connection through the new MSC is not needed. The proposed scheme makes the inter-MSC soft

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handoff processing relatively simple and fast at the expense of reserving the trunk resource between MSC's. However, since the geographical coverages of MSC's are large compared with the size of cells within the coverage, it is expected that the traffic between MSC's due to the inter-MSC soft handoffs will be acceptably small and manageable by the trunk with a not large capacity.

The outline of this paper is as follows. In the next section, the soft handoff scheme between MSC's is described using the trunk between the packet routers. In Section 3, the trunk network for the soft handoffs between MSC's is proposed, and the parameters and random variables are defined to model the cellular system. For a given trunk capacity, an analytical approach is developed to calculate the probability that a soft handoff to an adjacent MSC will be blocked due to the shortage of the trunk capacity in Section 4. Numerical examples and conclusions are given in Section 5 and 6, respectively.

II. SOFT HANDOFF SCHEME BETWEEN MSC's

If a mobile station nears a cell boundary, the mobile station may detect the signal from at least two base stations. The area in which two or three base stations can be detected above a certain threshold of signal strength by the mobile station will be called the handoff area. The handoff area in which simultaneously 2 (or 3) adjacent base stations can serve the mobile station will be called 2 (or 3)-way handoff area. If the mobile station communicating with a base station moves to a new cell, the soft handoff allows both the original cell and the new cell to temporarily serve the call while it is located in the handoff area, as shown in Fig.1. Not only does this greatly minimize the probability of a dropped call, but it also makes the handoff virtually undetectable by the user. When the mobile station in service has entered the handoff area between two cells within an MSC's service area, the mobile station transmits a control message to its MSC and MSC initiates the soft handoff by establishing a link to the mobile station through the new cell while maintaining the old link. While the mobile station is located in a 2 (or 3)-way handoff area, two (or three) adjacent base stations serve the mobile station simultaneously and the MSC receives and sends two (or three) channel traffic data through two (or three) links to the mobile station.

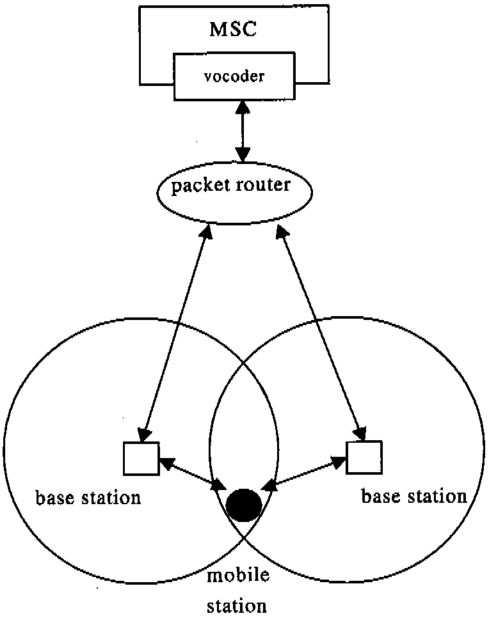

Fig. 1 soft handoff between two base stations

In Fig. 2, let a mobile station originate a call in an MSC 1's service area. When the mobile station requests a soft handoff from CELL 1 in MSC 1's service area to CELL 2 in MSC 2's service area, MSC 1 establishes a link to CELL 2 through the trunk between the packet routers of MSC 1 and MSC 2. In the handoff area, MSC 1 maintains two links to CELL 1 and CELL 2, and CELL 1 and CELL 2 serve the mobile station simultaneously. If the mobile station is located in the handoff area of MSC 1 and MSC 2 and one (or two) cells in MSC 2's service area have the mobile station in their service areas, MSC 1 receives and sends one (or two) channel traffic data through the trunk. After the mobile station moves out of the handoff area and the soft handoff is completed, the call of the mobile station will still be served by the vocoder in MSC 1 through the trunk while it is located in MSC 2's service area. While the mobile station is located in a 2 (or 3)-way handoff area in MSC 2's service area and two (or three) cells in MSC 2's service area serve the mobile station, MSC 1 receives and sends two (or three) channel traffic data through the trunk. If the mobile station moves to the service area of another new MSC, MSC 3, the trunk between the packet routers of MSC 1 and MSC 3 will be used to carry the traffic data from the mobile station to MSC 1 and vise versa. While the mobile station is located in a 2 (or 3)-way handoff area in MSC 3's service area, MSC 1 receives and sends two (or three) channel traffic data through the trunk between the packet routers of MSC 1 and MSC 3. For this soft handoff scheme between MSC's, the trunk capacity should be determined to satisfy the required blocking probability of the inter-MSC soft handoffs due to the shortage of the trunk capacity.

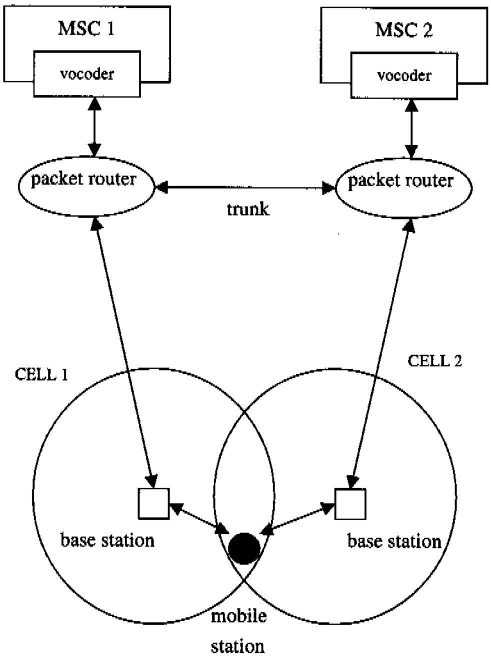

Fig. 2 soft handoff between two MSC's

Ⅲ. TRUNK NETWORK AND MODEL DESCRIPTION

As shown in Fig. 3, the whole service area is served by many MSC's and each rectangle represents the service area of an MSC. Usually the service area of an MSC will be large, so it can be assumed that a mobile station does not move to a distance of the length of a rectangle's side during a call. Then, when a mobile station originates a call in the service area of an MSC, during the call the mobile station will be located in the service areas of eight adjacent MSC's of the MSC after the inter-MSC soft handoff as shown in Fig. 3 (a). It is assumed that during a call a mobile station requests at most two inter-MSC soft handoffs and is located in the service areas of eight adjacent MSC's after the first inter-MSC soft handoff. (After the first inter-MSC soft handoff, the mobile station can return to the service area of the original MSC.) By the assumptions, for a given MSC we need to deploy totally eight trunks, each of which is between the given MSC and one of eight adjacent MSC's. The resulting trunk network for the inter-MSC soft handoffs is shown in Fig. 3 (b), where each solid

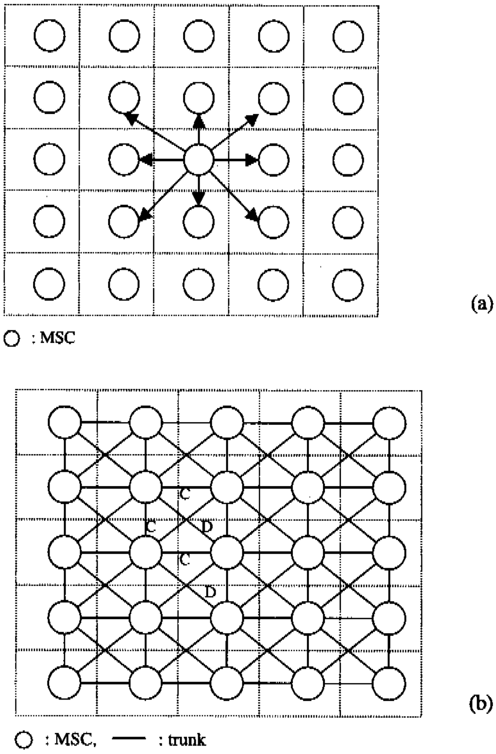

Fig. 3 eight adjacent MSC's of an MSC and the trunk network in the service area with many MSC's (a) eight adjacent MSC's (b) trunk network line represents the trunk between two MSC's. The trunk between the packet routers of MSC I and MSC J will be denoted by $T_{I,J}$.

It is assumed that the homogeneous service areas of MSC's are covered by the array of disjoint homogeneous hexagonal cells. When a mobile station moves from the service area of MSC 1 to that of MSC 2 in Fig. 4, we consider the soft handoff scheme in Section II using the trunk between the packet routers for the two MSC's. In Fig. 4, L denotes the number of cells in each of the service areas of MSC 1 and MSC 2 which are located at the boundary between the service areas of MSC 1 and MSC 2. And the service area of MSC 2 is covered by L(>1) cell layers, each of which has L cells. Let λ be the originating call arrival rate in each cell, and call holding time T_{call} be distributed with the distribution function $F_{call}(.)$ with the mean $1/\mu$.

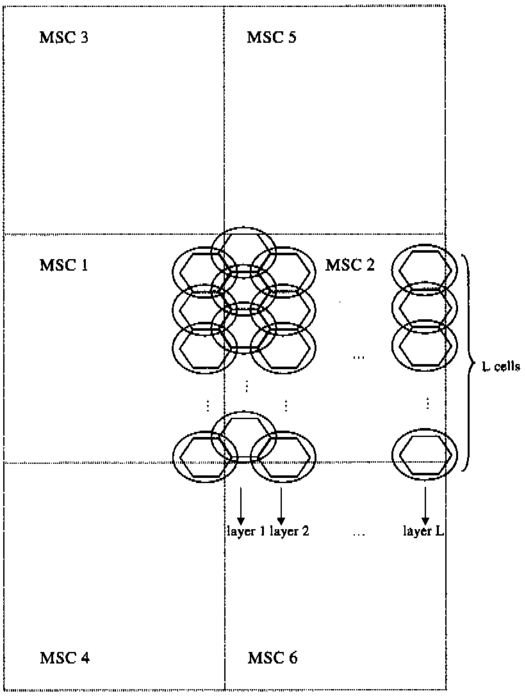

Fig. 4 cellular model for performance analysis

In Fig. 4, the handoff area is the overlapping region of the circles of the hexagonal cells. Each circle represents the service area of a cell. When a mobile station initiates a call, the mobile station will be said to *belong* to the cell of the nearest base station. The mobile station will belong to the cell while it is located in the service area of the cell. It is assumed that the base stations are located at the centers of cells. Suppose that the mobile station moves out of the service area of the cell. At the time that the mobile station moves out of the service area of the cell, the mobile station will be said to *belong* to the cell of the nearest base station from the current location of the mobile station. And the mobile station will be said to *belong* to the cell while it is located in the service area of the cell. For example, when a mobile station at the point p1 moves from CELL 1 to CELL 2 crossing the point p2 as shown in Fig. 5, the mobile station belongs to CELL 1 at the line between p1 and p2. At the point p2, the nearest base station is that of CELL 2. While it is located in the service area of CELL 2 after then, it belongs to CELL 2. r_2 and r_3 will denote the ratios to the whole service area of the 2-way and 3-way handoff areas, respectively. r_2 and r_3 can be calculated from the radius of the service area of a cell and the size of a hexagonal cell. [5] It is assumed that there is no overlapping region of the service areas of more than three cells. When a mobile station is located in a handoff area, we will say that the mobile station is in the handoff transition. Similarly, when a mobile station is in the overlapping region of the service areas of adjacent MSC's, the mobile station will be said to be in the inter-MSC soft handoff transition. The service area of an MSC is defined as the union of the service areas of the base stations of the MSC.

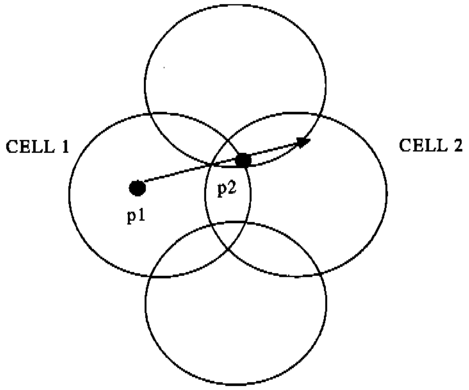

Fig. 5 the time when the mobile station belongs to a new cell

We need to define two random variables concerning the mobility of the mobile stations. When a mobile station originates a call in a hexagonal cell, T_{new} will denote the time interval between the call initiation and the time when the mobile station will move out of the service area of the cell. When a mobile station moves into a new cell out of the service area of an old cell to belong to the new cell, T_{old} will denote the time interval between the time when the mobile station moves out of the service area of the old cell and the time when the mobile station will move out of the service area of the new cell again. Let the distribution functions of T_{new} and T_{old} be $F_{new}(.)$ and $F_{old}(.)$, respectively. $1/\nu$ and $1/\pi$ will denote the means of T_{new} and T_{old}, respectively.

In Fig. 4, assume that during a call a mobile station requests the soft handoff from MSC 1 to MSC 2. Then, by the assumptions at the beginning of this section the original MSC in whose service area the call in progress is originated can be MSC 1, MSC 2, MSC 3 or MSC 4. If the original MSC is MSC 1, the traffic data will be carried through the trunk, T_{12} while the mobile station is located in the service area of MSC 2. If the original MSC is MSC 3 or MSC 4, T_{23} or T_{24} will be used to carry the traffic data while the mobile station is located in the service area of MSC 2. (If the original MSC is MSC 2, the trunk between MSC's is not used while the mobile station is located in the service area of MSC 2.) Generally speaking, when MSC I and MSC J are adjacent, the trunk $T_{I,J}$ is reserved for the soft handoffs to MSC I or MSC J when the calls in progress were originated in the service area of MSC I or MSC J.

The capacity of the trunk between horizontally or vertically adjacent MSC's like MSC 1 and MSC 2 or MSC 3 and MSC 1 in Fig. 4 is assumed to be C duplex channels. That is, through the trunk up to C simultaneous channel traffic data can be received from and sent to the mobile stations. The capacity of the trunk between diagonally adjacent MSC's like MSC 2 and MSC 3 in Fig. 4 is assumed to be D duplex channels. The capacities of the trunks of the trunk network are shown in Fig. 3 (b). Assuming the equal probabilities of the directions of the movement of the mobile station, it will be sufficient to analyze the performance of the trunks, T_{12} and T_{23} for the performance analysis of the trunk network in Fig. 3.

Concerning Fig. 4, the following two terms will be defined. The mobile stations that are in the soft handoff transition from MSC 1 to MSC 2 or remain in the service area of MSC 2 without the call termination after the soft handoff from MSC 1 to MSC 2 and the current calls of which were initiated in the service areas of MSC 1, MSC 3 and MSC 4 will be called *the handoff mobile stations from MSC (1, 3, 4) to MSC 2*. Note that the handoff mobile stations from MSC (1, 3, 4) to MSC 2 are in the handoff transition from MSC 1 to MSC2 or experienced the handoff from MSC 1 to MSC 2. Especially, the handoff mobile stations from MSC (1, 3, 4) to MSC 2 the current calls of which were initiated in the service area of MSC 3 will be also called *the handoff mobile stations from MSC 3 to MSC 2*. Note that the handoff mobile stations from MSC 3 to MSC 2 experienced the handoff from MSC 3 to MSC 1 and are in the handoff transition from MSC 1 to MSC2 or experienced the handoff from MSC 1 to MSC 2.

Each handoff mobile station from MSC (1, 3, 4) to MSC 2 is served by at least one base stations of MSC 2 and at least one channel traffic data is carried through one of three trunks, T_{12}, T_{23} and T_{24} in Fig. 4. While the handoff mobile station from MSC (1, 3, 4) to MSC 2 is located in the overlapping region of the service areas of two (or three) base stations of MSC 2, two (or three) traffic channels may be occupied on the trunk and in the base stations of MSC 2. Assume that the capacity of the trunks, the traffic channels in the base stations, etc. are unlimited and no call is lost or dropped. With this unlimited resource assumption, Λ_A is defined as the mean number of traffic channels in the base stations of MSC 2 occupied by the handoff mobile stations from MSC (1, 3, 4) to MSC 2. And Λ_B is defined as the mean number of traffic channels in the base stations of MSC 2 occupied by the handoff mobile stations from MSC 3 to MSC 2. Λ_A includes the mean number of traffic channels occupied by the mobile stations from the service areas of MSC 3 and MSC 4, which equals to 2 Δ_B. So, the mean number of traffic channels occupied by the handoff mobile stations from MSC (1, 3, 4) to MSC 2 with the calls initiated in the service area of MSC 1 is Δ_A - 2 Δ_B. Considering the mobile stations requesting the soft handoffs from MSC 2 to MSC 1, by symmetry the total input traffic load on T_{12} is

$$L_{12} = 2(\Delta_A - 2\Delta_B) \qquad (1)$$

When a call is initiated in the service area of MSC 2 or MSC 3, T_{23} supports the following four kinds of inter-MSC handoffs.

the handoff from MSC 1 to MSC 2 of the calls originated in the service area of MSC 3
the handoff from MSC 1 to MSC 3 of the calls originated in the service area of MSC 2
the handoff from MSC 5 to MSC 2 of the calls originated in the service area of MSC 3
the handoff from MSC 5 to MSC 3 of the calls originated in the service area of MSC 2

The traffic load on the trunk by each kind of inter-MSC soft handoff is Δ_B. So, the total traffic load on T_{23} is

$$L_{23} = 4\Delta_B. \qquad (2)$$

In the next section, Δ_A and Δ_B are calculated and the probabilities that an inter-MSC soft handoff request will be blocked due to the shortage of the capacities of T_{12} and T_{23} will be derived, respectively.

VI. BLOCKING PROBABILITY

We need to calculate Δ_A and Δ_B to obtain the traffic loads L_{12} and L_{23} using (1) and (2). Erlang loss formula will be used to obtain the blocking probabilities of the inter-MSC soft handoffs due to the shortage of the capacities of T_{12} and T_{23}, respectively.

A. Calculation of Δ_A

According to Section III, the sets of the mobile stations belonging to different cells are disjoint. So, the input traffic load to a cell by the mobile stations belonging to the cell is $\Delta = \lambda / \mu$, which equals to the input traffic load of the originating calls of each cell. With the unlimited resource assumption, the traffic load to a cell is defined as the mean number of traffic channels in the base station of the cell occupied by the mobile stations. Suppose that at a given time a mobile station belongs to a cell. When the mobile station is located in a 2 (or 3)-way handoff area, two (or three) base stations including the base station to which the mobile station belongs serve the mobile station simultaneously. Then, excluding the base station to which the mobile station belongs, the mean number of the additional base stations by which the mobile station is served is $N_h = r_2 + 2r_3$. So, the input traffic load to a cell by the mobile stations not belonging to the cell is $N_h \Delta$. It was assumed that the mobile stations are uniformly distributed throughout the service area. The amount of time for which a new call will continue in the service area of a cell is $Y = \mathrm{Min}(T_{call}, T_{new})$. So, the input traffic load to each cell by the new calls is $\lambda E[Y]$. Assuming that T_{call} and T_{new} are independent, E[Y] can be calculated by

$$E[Y] = \int_0^\infty (1 - F_{call}(t))(1 - F_{new}(t))dt.$$

When T_{call} and T_{new} are exponentially distributed, $E[Y] = 1/(\mu + \nu)$.

Subtracting the input traffic load to a cell by the new calls from that by the mobile stations belonging to the cell, the input traffic load to the cell by the mobile stations that have experienced at least one handoff and belong to the cell can be obtained by $\Omega_1 = \Delta - \lambda E[Y] = \lambda/\mu - \lambda E[Y]$. In this paper, when a mobile station belonging to a cell moves out of the service area of the cell to belong to another cell, we say that the mobile station experiences one handoff. Suppose that call duration is exponentially distributed. Then, by the memoryless property the arrival rate to a cell of the mobile stations that have experienced one handoff and belong to the cell is $\lambda_1 = \mu \Omega_1 = \lambda - \lambda\mu E[Y]$. By a similar method, the input traffic load to a cell by the mobile stations that have experienced at least two handoffs and belong to the cell can be derived as $\Omega_2 = \lambda_1/\mu - \lambda_1 E[Z]$, where Z is the amount of time for which an old call that experienced one handoff will continue in the service area of the current cell, which can be obtained as Z=Min(T_{call}, T_{old}) using the memoryless property of the exponential distribution, and E[Z] is given by

$$E[Z] = \int_0^{\infty} (1 - F_{call}(t))(1 - F_{old}(t))dt.$$

When T_{call} and T_{old} are exponentially distributed, $E[Z] = 1/(\mu + p)$. (Y and Z represent the continuous cell residence times of the new call and the old call that experienced at least one handoffs, respectively.) If we denote by Ω_k the input traffic load to a cell by the mobile stations that have experienced at least k handoffs and belong to the cell, Ω_k can be derived as follows.

$$\Omega_k = \Omega_2 (1 - \mu E[Z])^{k-2} \quad \text{for } k \geq 2 \tag{3}$$

Then, by the memoryless property the arrival rate to a cell of the mobile stations that have experienced k handoffs and belong to the cell is obtained by

$$\lambda_k = \mu \Omega_k. \tag{4}$$

Suppose that a mobile station belonging to CELL 1 moves into CELL 2 out of the service area of CELL 1. Then, using (3) and (4), the probability that the mobile station had experienced at least one handoff except the handoff from CELL 1 to CELL 2 can be calculated by

$$\alpha = 1 - \frac{\lambda_1}{\sum_{k=1}^{\infty} \lambda_k} = 1 - \frac{\Omega_1}{\Omega_1 + \dfrac{\Omega_2}{\mu E[Z]}} \tag{5}$$

In Fig.4, L cell layers, each of which has L cells, cover the service area of MSC 2. The handoff mobile stations from MSC (1, 3, 4) to MSC 2 consist of two kinds of mobile stations. First, the mobile stations that are in the soft handoff transition from MSC 1 to MSC 2 and do not belong to the cells in the service area of MSC 2 occupy the traffic channels in the base stations of MSC 2. Second, the mobile stations that are located in the service area of MSC 2 after the soft handoffs from MSC 1 to MSC 2 and belong to the cells in the service area of MSC 2 occupy the traffic channels in the base stations of MSC 2. The input traffic load to the first layer cell of MSC 2 by the mobile stations in the soft handoff transition to the cell is $N_h \Delta$. Assuming that the mobile station is from each of the six adjacent cells with the equal probability 1/6, from Fig. 4 we can see that 1/3 of the mobile stations in the soft handoff transition are from the service area of MSC 1 ignoring two cells at the two ends of the first layer. The probability that the mobile station in the soft handoff transition from MSC 1 to MSC 2 initiated the current call in the service area of MSC 2 so is not the handoff mobile station from MSC (1, 3, 4) to MSC 2 can be estimated as $\sigma = \Omega_1/(3\Delta)$, where Ω_1/Δ is the probability that the mobile station has experienced at least one soft handoff between cells and 1/3 is the probability that the previous cell is in the service area of MSC 2. So, the mean number of traffic channels in the base stations of MSC 2 occupied by the first kind of handoff mobile stations from MSC (1, 3, 4) to MSC 2 is

$$T_1 = (1 - \sigma) L N_h \Delta / 3. \tag{6}$$

Suppose that a mobile station belongs to one of the k-th layer cells for k=1, 2, ..., L and has experienced at least one handoff. Let P_k be the probability that the mobile station is the handoff mobile station from MSC (1, 3, 4) to MSC 2. Ignoring two cells at the two ends of the first layer, each of the first layer cells has two adjacent cells in the service area of MSC 1, two of the first layer and two of the second layer. Assuming the equal probabilities with which the mobile station is from the adjacent cells, the following equation can be derived.

$$P_1 = (1 - \sigma)/3 + \alpha P_1/3 + \alpha P_2/3 \tag{7}$$

In the preceding equation, the first term $(1-\sigma)/3$ is the probability that the mobile station, which moved to one of the first layer cells to belong to the cell, is directly from the service area of MSC 1 and the current call was not initiated in the service area of MSC 2. Given that the mobile station is from one of two adjacent first layer cells, αP_1 is the probability that the mobile station is the handoff mobile station from MSC (1, 3, 4) to MSC 2. αP_2 is the probability that the mobile station is the handoff mobile station from MSC (1, 3, 4) to MSC 2 given that the mobile station is from one of two adjacent second layer cells. Note that generally αP_k is the probability that a mobile station is the handoff mobile station from MSC (1, 3, 4) to MSC 2 given the mobile station moved into a cell out of the service area of one of the k-th layer cells. It was assumed that given $T_{new} > T_{call}$ or $T_{old} > T_{call}$ for a mobile station initiating a new call in a cell or moving into a cell out of the service area of an old cell, the mobile station moves into six adjacent cells of the cell with the equal probabilities. In the similar manner, the following equations can be also derived.

$$P_k = \alpha P_{k-1}/3 + \alpha P_k/3 + \alpha P_{k+1}/3, \text{ for } k = 2, 3, .., L\text{-}1$$
$$P_L = \alpha P_{L-1}/3 + \alpha P_L/3 \tag{8}$$

In the preceding equations, the last one is from the fact that ignoring two cells at the two ends, the L-th layer cell has two adjacent cells which cannot be the passages directly from MSC 1 and only four adjacent cells in the (L-1)-th and L-th layers can be the passages.

By the definition of P_k, the traffic load to the k-th layer cell by the handoff mobile stations from MSC (1, 3, 4) to MSC 2 that belong to the k-th layer cell is $P_k\Omega_1$. Suppose that a mobile station is located in the service area of MSC 2 after the soft handoff from MSC 1 to MSC 2. The mobile station occupies one traffic channel in the base station of the cell to which it belongs. While the mobile station is located in a 2 (or 3)-way handoff area, the mobile station will occupy one (or two) additional ones in the base stations of the cells to which the mobile station does not belong. Obtaining P_k for k=1, 2, ..., L by solving the equations in (7) and (8), the mean number of total traffic channels in the base stations of MSC 2 occupied by the handoff mobile stations from MSC (1, 3, 4) to MSC 2 that belong to the cells in the service area of MSC 2 is obtained by

$$T_2 = L\sum_{k=1}^{L}\left((1+r_2+2r_3)\right)P_k\Omega_1 = L(1+N_h)\Omega_1\sum_{k=1}^{L}P_k. \tag{9}$$

Summing T_1 and T_2 in (6) and (9), Δ_A can be obtained by $\Delta_A = T_1 + T_2$. The handoff mobile stations from MSC (1, 3, 4) to MSC 2 are in the overlapping region of the service areas of MSC 1 and MSC 2 or otherwise belong to the cells in the service area of MSC 2. The ratio of the mean number of traffic channels in the base stations of MSC 2 occupied by the former handoff mobile stations from MSC (1, 3, 4) to MSC 2 to that by the latter handoff mobile stations, which will be called *the inter-MSC handoff area traffic ratio*, is $\beta = T_1/T_2$.

B. Calculation of Δ_B

In Fig. 4, suppose that a mobile station has experienced at least one handoff between base stations and belongs to one of L cells of MSC 1 at the boundary between the service areas of MSC 1 and MSC 2. Then, the probability that the mobile station is from the service area of MSC 3 will be

$$Q = \frac{\sum_{k=1}^{L} P_k}{L}$$

where P_k can be obtained by solving the equations in (7) and (8). Consider a mobile station that has experienced at least one handoff between base stations and belongs to the k-th layer cells in the service area of MSC 2. Let the probability that the mobile station is from the service area of MSC 3, that is, the mobile station experienced the soft handoffs from MSC 3 to MSC 1 and from MSC 1 to MSC 2 be Q_k for k=1, 2, ..., L. Similarly to (7) and (8), the equations for Q_k can be derived as follows.

$$Q_1 = \alpha Q/3 + \alpha Q_1/3 + \alpha Q_2/3$$
$$Q_k = \alpha Q_{k-1}/3 + \alpha Q_k/3 + \alpha Q_{k+1}/3, \text{ for } k = 2, 3, .., L\text{-}1$$
$$Q_L = \alpha Q_{L-1}/3 + \alpha Q_L/3 \tag{10}$$

In the first equation of (10), αQ is the probability that the mobile station, which moved from the service area of MSC 1 to that of MSC 2 and belongs to one of the first layer cells of MSC 2, is from the service area of MSC 3. Similarly to (9), the mean number of total traffic channels in the base stations of MSC 2 occupied by the handoff mobile stations from MSC 3 to MSC 2 that belong to the cells in the service area of MSC 2 is obtained by

$$U_2 = L\sum_{k=1}^{L}((1+r_2+2r_3)Q_k\Omega_1 = L(1+N_h)\Omega_1\sum_{k=1}^{L}Q_k. \tag{11}$$

The handoff mobile stations from MSC 3 to MSC 2 belong to the cells in the service area of MSC 2 or otherwise are in the soft handoff transition from MSC 1 to MSC 2. Assume that the inter-MSC handoff area traffic ratios are equal for the handoff mobile stations from MSC (1, 3, 4) to MSC 2 and from MSC 3 to MSC 2. Then, the mean number of total traffic channels in the base stations of MSC 2 occupied by the latter handoff mobile stations from MSC 3 to MSC 2 can be obtained by $U_1 = \beta U_2$. And, $\Delta_B = U_1 + U_2 = (1+\beta)U_2$.

C. Blocking Probabilities by Erlang Loss Formula

Using (1) and (2), the total input traffic loads on the trunks, T_{12} and T_{23} can be obtained from Δ_A and Δ_B, respectively. Using Erlang Loss Formula, the probabilities that an inter-MSC soft handoff request will be blocked due to the shortage of the capacities of the trunks, T_{12} and T_{23} can be derived as follows, respectively.

$$P_{12} = \frac{\frac{(L_{12})^C}{C!}}{\sum_{i=0}^{C}\frac{(L_{12})^i}{i!}}, P_{23} = \frac{\frac{(L_{23})^D}{D!}}{\sum_{i=0}^{D}\frac{(L_{23})^i}{i!}} \tag{12}$$

V. NUMERICAL EXAMPLES

In this section, numerical results for a sample case of a cellular system are presented. The mobility of mobile stations is considered with v and π. As v and π are larger, the mobility becomes higher and the traffic loads, L_{12} and L_{23} are expected to become larger. This expectation is verified by Fig. 6, where both the analytical and simulation results of L_{12} and L_{23} are plotted versus v. The simulation results were obtained by estimating the probabilities that the mobile stations located in the service area of MSC 2 initiated the current calls in the service areas of MSC 1, MSC 3 and MSC 4. In Fig. 6, λ = 40 calls/min., $\pi = 2v$, $r_2 = 0.4$, $r_3 = 0.2$, L = 16, T_{new}, T_{old}, and call holding time T_{call} are exponentially distributed, μ = 1/1.5 min., and v is ranged from 0.2 to 5/min.. (When the frequency bandwidth is 1.25 MHz in CDMA cellular systems, 78 maximum voice calls per base station can be served. [6] λ and m are selected to result in the traffic load $\Delta = 60$ for which the blocking probability is 0.5 %. According to [7], the traffic capacity of TDX-10 is about 27,000 Erlang. Therefore, we can infer that TDX-10 can support about 250 base stations and the corresponding L is about 16 when the total traffic load per base station is $\Delta(1+N_h)$ = 108. The cell dwell times, T_{new} and T_{old} can be modeled by the exponential distributions with reasonable accuracy. [8, 9])

From Fig. 6, we can see that the analytical and simulation results of L_{12} match very closely, but the analytical results of L_{23} give the upper bounds of the simulation results. More accurate analytical approach for L_{23} should be investigated in the further research. For accurate analysis of L_{23}, the individual cell states should be considered to derive the traffic load imposed on T_{23} while this paper considers only the states of L cell layers for the derivations of the traffic loads by the inter-MSC handoffs. It can be seen that the traffic load on the trunk T_{12}, L_{12}, is larger than that on the trunk T_{23}, L_{23}. With the blocking probability of 0.5%, the required channel capacities of the trunks, T_{12} and T_{23} can be obtained using (12) and are also plotted versus n in Fig. 6. According to Fig. 6, the trunk T_{12} should have the larger capacity than the trunk T_{23}.

VI. CONCLUSIONS

This paper considers the soft handoff scheme

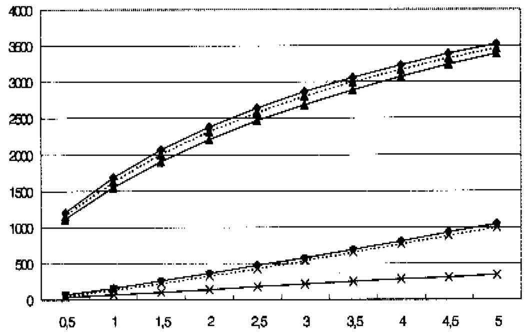

Fig. 6 the effect of the mobility of the mobile stations on the traffic loads, L_{12} and L_{23} and the required trunk capacity (solid line with ◆: required capacity (C), dashed line with ▲: analytical result of L_{12}, solid line with ▲: simulation result of L_{12}, solid line with ●: required capacity (D), dashed line with ×: analytical result of L_{23}, solid line with ×: simulation result of L_{23})

between two MSC's using the trunk between the packet routers for the two MSC's. The trunk network is proposed to support the inter-MSC soft handoff scheme in the service area with many MSC's. Taking into account the mobility of the mobile stations, an analytical approach is developed to obtain the traffic load imposed on the trunk by the inter-MSC soft handoff. The probability that a soft handoff to an adjacent MSC will be blocked due to the shortage of the trunk capacity is derived using Erlang loss formula.

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