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Blocking Performance Evaluation of Trunk Network for Soft Handoffs Between MSC's in CDMA Cellular Systems

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CDMA 이동통신 시스템에서 MSC 간 Soft Handoff를 위한 트렁크망의 성능분석

최우용

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.

1. 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(Cheung and Leung, 1997; Gilhousen *et al.*, 1991; Lee, 1991; Pickholtz et al., 1991). The soft handoffs between the cells within an MSC(Mobile Switching Center)'s service area have been implemented in commercial CDMA cellular systems without having calls switch vocoders(Generally, voices are encoded into 9.6 Kbps or 14.4 Kbps packet data. Vocoders are the converters from 9.6 Kbps or 14.4 Kbps voice packet data to 64 Kbps PCM (Pulse Code Modulation) data.). As wireless communication networks become ubiquitous, it is necessary to support the soft handoff service between MSC's 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 without switching vocoders is proposed using the trunk between the packet routers for the two MSC's (The packet routers of MSC's direct the packets from the base stations or MSC's to the appropriate destinations based on the destination addresses in the packet headers.).

While solutions for rerouting ATM/B-ISDN network connections between different MSC's have been proposed (Acampora and Naghshineh, 1994; Acampora and Naghshineh, 1994; Cheung and Leung, 1997; Lee and Sung, 1999; Wong *et al.*; Wong and Leung, 1999; Yu and Leung, 1996), the support of soft handoffs between adjacent MSC's has not received much consideration in the literature. The soft handoff scheme between two MSC's in(Cheung and Leung, 1997) 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 trunks for supporting the inter-MSC soft handoff is investigated using computer simulation in(Cheung and Leung, 1997). 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. While the mobile stations are located in the handoff area between MSC's, the voice traffics from the base stations connected to the MSC's should be carried to the MSC's and one "good" traffic should be chosen and carried to the corresponding user. Therefore, a new signaling scheme for switching the old call connection to the new one through the new MSC and choosing the "good" traffic for diversity combining is needed. For these reasons, most wireless communication systems known by us adopt the inter-MSC soft handoff scheme without switching vocoders.

In this paper, the soft handoff scheme between two MSC's without switching vocoders 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. 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 considered scheme makes the inter-MSC soft 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 acceptably small and manageable by the trunk with a not large capacity. 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. By numerical examples, the traffic loads generated by the soft handoff schemes with and without switching vocoders will be compared.

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 explained, 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.

2. Soft Handoff Scheme between MSC's

If a mobile station nears a cell boundary, the mobile station may detect the signals from two base stations. The area in which simultaneously two adjacent base stations can serve the mobile station with a sufficient signal strength will be called the handoff area. (In this paper, it is assumed that the area where three or more base stations can serve mobile stations simultaneously does not exist.) If the mobile station with a call 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 mobile station while it is located in the handoff area, which is shown as the shaded area between the cells in <Figure 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 enters the handoff area between two

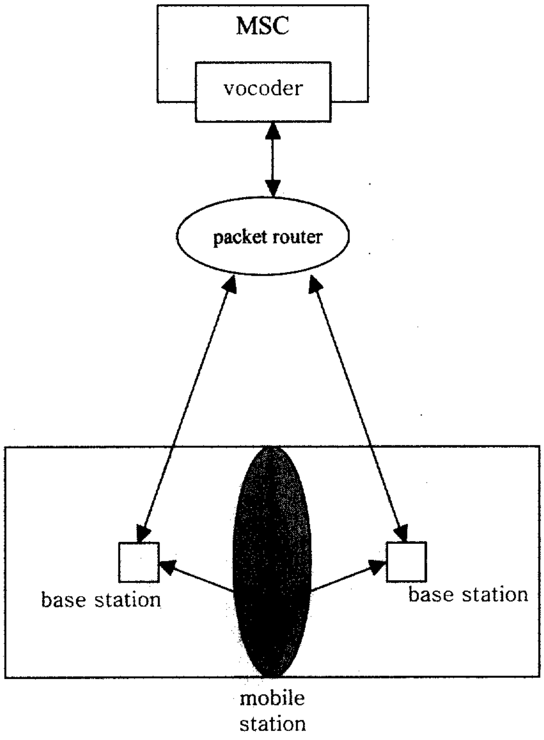


Figure 1. soft handoff between two base stations

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. When the mobile station moves out of the handoff area to the new cell, only the link through the new cell is maintained. While the mobile station is located in the handoff area, two adjacent base stations serve the mobile station simultaneously and two channel traffic data are received by and sent to the MSC through two links.

In <Figure 2>, let a mobile station originate a call in the service area of MSC 1. When the mobile station requests a soft handoff from CELL 1 in the service area of MSC 1 to CELL 2 in the service area of MSC 2, 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 between MSC 1 and MSC 2, MSC 1 receives from and sends to CELL 2 one channel traffic data through the trunk. After the mobile station moves out of the handoff area and the inter-MSC soft handoff is completed, the call of the mobile station will still be served by the vocoder of MSC 1 through the trunk while it is located in the service area of MSC 2. While the mobile station is located in the handoff area within the service area of MSC 2 and two cells in the service area of MSC 2 serve the mobile station simultaneously, MSC 1 receives and sends two 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 the handoff area within the service area of MSC 3, MSC 1 receives and sends two 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 reserved to satisfy the required blocking probability of the inter-MSC soft handoffs due to the shortage of the trunk capacity.

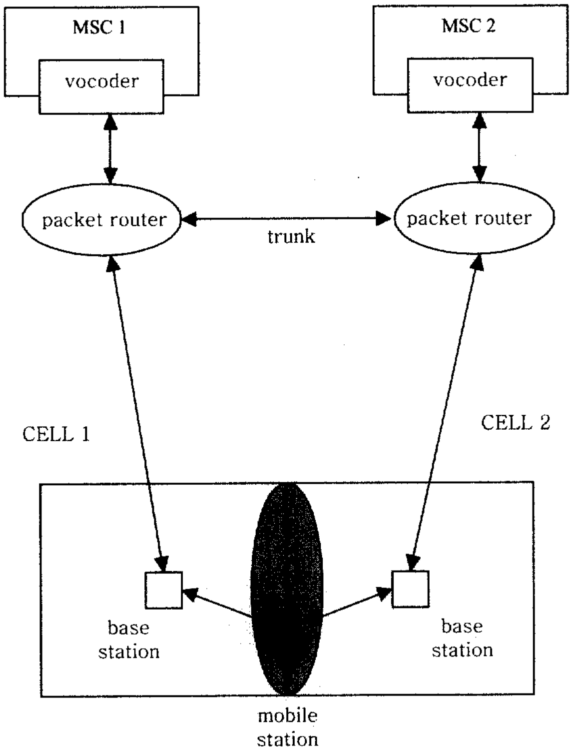
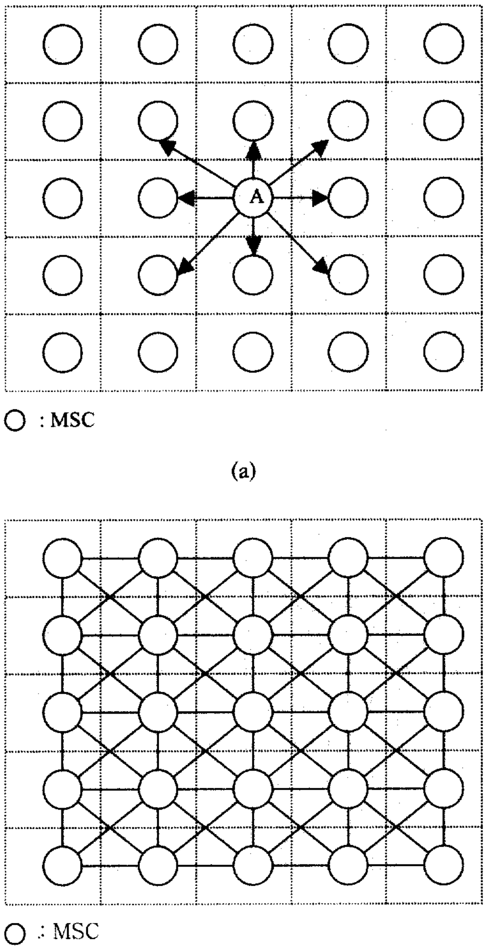


Figure 2. soft handoff between two MSC's.

3. Trunk Network and Model Description

As shown in <Figure 3(a)>, the service area is served by many MSC's and the rectangles represent the service areas of the MSC's. Suppose that a mobile station originates a call in the service area of MSC A. Usually the service areas of the MSC's will be large, so it can be assumed that during the call the mobile station requests at most two inter-MSC soft handoffs and is located in the service areas of MSC A and the eight adjacent MSC's as shown in <Figure 3(a)>. (After the first inter-MSC soft handoff, the mobile station can return to the service area of MSC A.) By the assumptions, for a given MSC we need 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 <Figure 3(b)>, where each solid line represents the trunk between two MSC's. The trunk between 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 rectangular cells. In <Figure 4>, L2 cells comprise each of the service areas of the MSC's. (i, j) for $i=1, 2, \cdots, L$ and $j=1, 2, \cdots$, L represent the L^2 cells(In this paper, L is assumed to be an even number greater than 4 for convenience. But, when L is an odd number or an even number less than or equal to 4, an analytical method similar to that in this paper can be also developed). Let λ be the



(a)

(b)

Figure 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.

Poisson originating call arrival rate in each cell, and call holding time $T_{\rm call}$ be exponentially distributed with the mean $1/\mu$. 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 <Figure 4> is assumed to be M duplex channels. That is, through the trunk up to M simultaneous channel traffic data can be transmitted. The capacity of the trunk between diagonally adjacent MSC's like MSC 2 and MSC 3 in <Figure 4> is assumed to be N duplex channels. Assuming the statistically homogeneous mobility patters for all mobile stations, 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 <Figure 3>.

The service coverage of the base station of a cell is the area where mobile stations can establish a link with acceptable signal quality with that base station, and is overlapped with those of four adjacent cells from which mobile stations can move to the cell crossing the cell boundary lines between cells. The handoff area is the overlapping region of the service coverages of cells and r will denote the ratio of the handoff area to the whole service area. The cell residence times of mobile stations are assumed to be independent and each cell residence time $T_{\rm cell}$ is exponentially distributed with mean $1/\nu$.

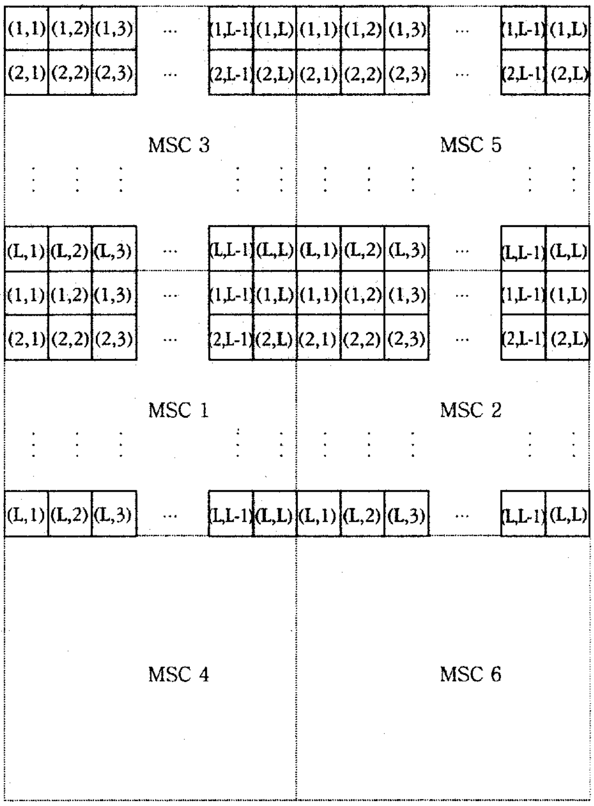


Figure 4. cellular model for performance analysis.

4. Blocking Probability

In this section, 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.

4.1 Definition of Terms

From the assumption at the beginning of Section 3 that the mobile stations request at most two inter-MSC soft handoffs, we can infer the following two facts concerning <Figure 4>). 1) The calls corresponding to the traffic data carried on the trunk T_{12} for supporting the soft handoffs from MSC 1 to MSC 2 was initiated in the service area of MSC 1 and have continued in that of MSC 1 and MSC 2. 2) The calls corresponding to the traffic data carried on the trunk T_{23} for supporting the soft handoffs from MSC 1 to MSC 2 was initiated in the service area of MSC 3 and have continued in that of MSC 1, MSC 2 and MSC 3. Two kinds of mobile stations corresponding to the facts are defined. The mobile stations the current calls of which were initiated in the service area of MSC 1 and have continued in the service area of MSC 1 and MSC 2 will be called *the handoff mobile stations of type A*. And the mobile stations the current calls of which were initiated in the service area of MSC 3 and have continued in the service area of MSC 1, MSC 2 and MSC 3 will be called *the handoff mobile stations of type B*. Let us denote the probabilities that the mobile station during a call located in the cell (i, j) of MSC 2, for $i = 1, 2, \cdots, L$ and $j = 1, 2, \cdots, L$, is the handoff mobile stations of type A and B by $P^A_{i,j}$ and $P^B_{i,j}$, respectively. And let us denote the probabilities that the mobile station during a call located in the cell (i, L) of MSC 1, for $i = 1, 2, \cdots, L$, is the handoff mobile stations of type A and B by Q^A_i and Q^B_i, respectively.

4.2 Traffic Loads on Trunks

When call loss and forced termination probabilities are small, the mean number of mobile stations during arbitrary calls located in a cell will be able to be accurately approximated by $\Lambda = \lambda / \mu$. Suppose that a mobile station during a call is located in a cell E. The number of adjacent cells having the service coverages overlapped with that of the cell E is four. Since the probability that the mobile station is located in the handoff area is r, the mean total number of base stations serving each mobile station is $1 + r$ if we assume that all mobile stations are uniformly distributed throughout the service area. And, the mean number of adjacent base stations serving the mobile station is r.

The number of simultaneous channels of traffic data of the handoff mobile station of type A carried on the trunk T_{12} equals to the total number of base stations of MSC 2 serving the mobile station. The mean number of base stations of MSC 2 serving the handoff mobile station of type A located in the service area of MSC 2 is $1 + r$ when the mobile station is located in a cell the service coverage of which overlaps with those of four adjacent cells of MSC 2. But, as shown in <Figure 4>, the cells of MSC 2 at the boundaries of the service area of MSC 2, the number of which is 4L-4, have less than four such adjacent cells of MSC 2 so the mean number of adjacent base stations of MSC 2 serving the mobile station located in these boundary cells is expected to be less than r. Assuming that L is sufficiently large, this effect will be able to be ignored and we can approximately say that all L^2 cells of MSC 2 have four such adjacent cells of MSC 2. For the analytical simplicity, we want to approximate the mean number of simultaneous channels of traffic data of the handoff mobile stations of type A in the service area of MSC 2 carried on the trunk T_{12} by

$$\varLambda_A = \varLambda \sum_{i=1}^{L} \sum_{j=1}^{L} P^A_{i,j}(1 + r)$$

Each of L cells of MSC 1, (i, L), for $i = 1, 2, \cdots, L$ is overlapped with the service coverage of one adjacent cell of MSC 2. Therefore, the mean number of base stations of MSC 2 serving the handoff mobile station of type A located in the L cells will be able to be approximated by $r/4$ because r is the total mean number of adjacent base stations serving the mobile station. We can obtain the mean number of simultaneous channels of traffic data of the handoff mobile stations of type A in the L cells carried on the trunk T_{12} by

$$\varPi_A = \varLambda \sum_{i=1}^{L} Q^A_i (r/4)$$

Summing the traffic loads on the trunk T_{12} by the handoff mobile stations of type A in the L cells of MSC 1 and the service area of MSC 2 and considering the inter-MSC soft handoff from MSC 2 to MSC 1, by symmetry the total traffic load on the trunk T_{12}, which is defined as the mean number of simultaneous channels of traffic data carried on the trunk T_{12}, can be obtained as

$$L_{12} = 2(\varLambda_A + \varPi_A)$$

In a similar manner, the mean numbers of simultaneous channels of the traffic data of the handoff mobile stations of type B in the service areas of MSC 1 and MSC 2 carried on the trunk T_{23}, which will be denoted by $\varLambda_B$ and $\varPi_B$, can be obtained as follows.

$$\varLambda_B = \varLambda \sum_{i=1}^{L} \sum_{j=1}^{L} P^B_{i,j}(1 + r), \quad \varPi_B = \varLambda \sum_{i=1}^{L} Q^B_i (r/4)$$

Suppose that a call is initiated in the service area of MSC 2 or MSC 3. T_{23} supports the inter-MSC soft handoff of the call from MSC 1 or MSC 5 to MSC 2 or MSC 3. The traffic load on the trunk by each kind of inter-MSC soft handoff is $\Lambda_B + \Pi_B$. So, the total traffic load on T_{23} is

$$L_{23} = 4(\Lambda_B + \Pi_B)$$

We need to obtain $P^A_{i,j}$, $P^B_{i,j}$, Q^A_i and Q^B_i to calculate the traffic loads L_{12} and L_{23} using the preceding equations in this subsection.

4.3 Balance Equations

The mean amount of time for which a new call will continue in a cell is $E[\mathrm{Min}(T_{\mathrm{call}}, T_{\mathrm{cell}})] = 1/(\mu + \nu)$. Therefore, the mean number of the mobile stations the current calls of which have continued in a cell can be approximated by $\Lambda_{\mathrm{new}} = \lambda/(\mu + \nu)$. And the probability that the current call of a mobile station have experienced at least one inter-cell movements can be obtained by $P_h = 1 - \Lambda_{\mathrm{new}}/\Lambda = \nu(\mu + \nu)$.

Let us denote by $R^1_{i,j}$ the conditional probability that a mobile station during a call located in the cell (i, j) of MSC 1, for $i = 1, 2, \cdots, L$ and $j = 1, 2, \cdots, L$, is the handoff mobile station of type A given that the mobile station have experienced at least one inter-cell movements during the current call. And the corresponding conditional probability of the cell (i, j) of MSC 2, for $i = 1, 2, \cdots, L$ and $j = 1, 2, \cdots, L$, will be denoted by $R^2_{i,j}$. We want to derive the balance equations for $R^1_{i,j}$ and $R^2_{i,j}$, for $i = 1, 2, \cdots, L$ and $j = 1, 2, \cdots, L$. For example, consider the mobile station that has moved to the cell (1, 1) of MSC 2 from one of four adjacent cells including (1, L) of MSC 1 and (1, 2) and (2, 1) of MSC 2. Given the previous cell is (1, L) of MSC 1, the conditional probability that the mobile station is the handoff mobile station of type A is $(1 - P_h) + P_h R^1_{1,L}$, where $(1 - P_h)$ is the probability that the call in progress had continued in the cell (1, L) of MSC 1 before it has moved to the current cell and $P_h R^1_{1,L}$ is the probability that the call had experienced at least one inter-cell movements before it has moved to the current cell and the mobile station is the handoff mobile station of type A. And, given the previous cell is (1, 2) and (2, 1) of MSC 2, the conditional probabilities that the mobile station is the handoff mobile station of type A are just $P_h R^1_{1,L}$ and $P_h R^2_{2,1}$, respectively because the current call of the mobile station should be initiated in the service area of MSC 1 for the mobile station to be the handoff mobile station of type A. The previous cell cannot be the other adjacent cell for the mobile station to be the handoff mobile station of type A. Therefore, assuming the equal probabilities with which the mobile station is from four adjacent cells, the balance equation for the cell (1, 1) of MSC 2 can be derived as follows.

$$\begin{aligned} R^2_{1,1} &= (1 - P_h + P_h R^1_{1,L})\frac{1}{4} + P_h R^2_{1,2}\frac{1}{4} + P_h R^2_{2,1}\frac{1}{4} \\ &= \frac{1 - P_h}{4} + P_h \frac{R^1_{1,L} + R^2_{1,2} + R^2_{2,1}}{4} \end{aligned}$$

In this manner, the balance equations for all the cells of MSC 1 and MSC 2 can be derived. Since the service areas of MSC's are square-shaped and the statistically homogeneous mobility patterns of all mobile stations are assumed, the following symmetrical property holds.

$$R^1_{i,j} = R^1_{L-i,j} \text{ and } R^2_{i,j} = R^2_{L-i,j},$$
$$\text{for } i = 1, 2, \ldots, L/2 \text{ and } j = 1, 2, \ldots, L$$

Therefore, we can reduce the number of unknown $R^1_{i,j}$'s and $R^2_{i,j}$'s to half of that and the resulting balance equations are shown in <Figure 5>.

$$R^1_{i,j} = 1 - P_h + P_h \frac{R^1_{i+1,j} + R^1_{i,j+1} + R^1_{i-1,j} + R^1_{i,j-1}}{4} \text{ for } i = 2, 3, \ldots, L/2 - 1 \text{ and } j = 2, 3, \ldots, L - 1$$

$$R^2_{i,j} = P_h \frac{R^2_{i+1,j} + R^2_{i,j+1} + R^2_{i-1,j} + R^2_{i,j-1}}{4} \text{ for } i = 2, 3, \ldots, L/2 - 1 \text{ and } j = 2, 3, \ldots, L - 1$$

$$R^1_{1,j} = \frac{3(1 - P_h)}{4} + P_h \frac{R^1_{2,j} + R^1_{1,j+1} + R^1_{1,j-1}}{4} \text{ for } j = 2, 3, \ldots, L - 1$$

$$R^2_{1,j} = P_h \frac{R^2_{2,j} + R^2_{1,j+1} + R^2_{1,j-1}}{4} \text{ for } j = 2, 3, \ldots, L - 1$$

$$R^1_{L/2,j} = 1 - P_h + P_h \frac{R^1_{L/2,j} + R^1_{L/2,j+1} + R^1_{L/2-1,j} + R^1_{L/2,j-1}}{4} \text{ for } j = 2, 3, \ldots, L - 1$$

$$R^2_{L/2,j} = P_h \frac{R^2_{L/2,j} + R^2_{L/2,j+1} + R^2_{L/2-1,j} + R^2_{L/2,j-1}}{4} \text{ for } j = 2, 3, \ldots, L - 1$$

$$R^1_{i,1} = \frac{3(1 - P_h)}{4} + P_h \frac{R^1_{i+1,1} + R^1_{i,2} + R^1_{i-1,1}}{4} \text{ for } i = 2, 3, \ldots, L/2 - 1$$

$$R^2_{i,L} = P_h \frac{R^2_{i+1,L} + R^2_{i,L-1} + R^2_{i-1,L}}{4} \text{ for } i = 2, 3, \ldots, L/2 - 1$$

$$R^1_{i,L} = \frac{3(1 - P_h)}{4} + P_h \frac{R^1_{i+1,L} + R^2_{i,1} + R^1_{i,L-1} + R^1_{i-1,L}}{4} \text{ for } i = 2, 3, \ldots, L/2 - 1$$

$$R^2_{i,1} = \frac{1 - P_h}{4} + P_h \frac{R^2_{i+1,1} + R^2_{i,2} + R^1_{i,L} + R^2_{i-1,1}}{4} \text{ for } i = 2, 3, \ldots, L/2 - 1$$

$$R^1_{1,1} = \frac{1 - P_h}{2} + P_h \frac{R^1_{1,2} + R^1_{2,1}}{4}, R^1_{L/2,1} = \frac{3(1 - P_h)}{4} + P_h \frac{R^1_{L/2,1} + R^1_{L/2,2} + R^1_{L/2-1,1}}{4}$$

$$R^2_{1,L} = P_h \frac{R^2_{2,L} + R^2_{1,L-1}}{4}, R^2_{L/2,L} = P_h \frac{R^2_{L/2,L} + R^2_{L/2-1,L} + R^2_{L/2,L-1}}{4}$$

$$R^1_{1,L} = \frac{1 - P_h}{2} + P_h \frac{R^1_{2,L} + R^2_{1,1} + R^1_{1,L-1}}{4}$$

$$R^1_{L/2,L} = \frac{3(1 - P_h)}{4} + P_h \frac{R^1_{L/2,L} + R^2_{L/2,1} + R^1_{L/2-1,L} + R^1_{L/2,L-1}}{4}$$

$$R^2_{1,1} = \frac{1 - P_h}{4} + P_h \frac{R^2_{2,1} + R^2_{1,2} + R^1_{1,L}}{4}$$

$$R^2_{L/2,1} = \frac{1 - P_h}{4} + P_h \frac{R^2_{L/2,1} + R^2_{L/2,2} + R^2_{L/2-1,1} + R^1_{L/2,L}}{4}$$

Figure 5. balance equations for $R^1_{i,j}$ and $R^2_{i,j}$.

By solving the balance equations in <Fig 5>, we can obtain $R^1_{i,j}$ and $R^2_{i,j}$ for $i=1, 2, \cdots, L$ and $j=1, 2, \cdots, L$. From $R^1_{i,j}$ and $R^2_{i,j}$, we can derive $P^A_{i,j}$ and Q^A_i as follows.

$$P^A_{i,j} = P_h R^2_{i,j} \text{ for } i = 1, 2, \ldots, L \text{ and } j = 1, 2, \ldots, L$$

$$Q^A_i = P_h R^1_{i,L} + (1 - P_h) \text{ for } i = 1, 2, \ldots, L$$

Moreover, if we think of MSC 3 and MSC 1 as MSC 1 and MSC 2, respectively, we can derive Q^B_i from $R^2_{1,i}$ as follows.

$$Q^B_i = P_h R^2_{1,i} \text{ for } i = 1, 2, \ldots, L$$

Let us denote by $S_{i,j}$ the conditional probability that a mobile station during a call located in the cell (i, j) of MSC 2, for $i=1, 2, \cdots, L$ and $j=1, 2, \cdots, L$, is the handoff mobile station of type B given that the mobile station have experienced at least one inter-cell movements during the current call. We want to derive the balance equations for $S_{i,j}$, for $i=1, 2, \cdots, L$ and $j=1, 2, \cdots, L$. For example, consider the mobile station that has moved to the cell (1, 1) of MSC 2 from one of four adjacent cells including (1, L) of MSC 1 and (1, 2) and (2, 1) of MSC 2. Given the previous cell is (1, L) of MSC 1, the conditional probability that the mobile station is the handoff mobile station of type B is Q^B_1. And, given the previous cell is (1, 2) and (2, 1) of MSC 2, the conditional probabilities that the mobile station is the handoff mobile station of type B are $P_h S_{1,2}$ and $P_h S_{2,1}$, respectively. The previous cell cannot be the other adjacent cell for the mobile station to be the handoff mobile station of type B. Therefore, assuming the equal probabilities with which the mobile station is from four adjacent cells, the balance equation for the cell (1, 1) of MSC 2 can be derived as follows.

$$S_{1,1} = Q^B_1 \frac{1}{4} + P_h S_{1,2} \frac{1}{4} + P_h S_{2,1} \frac{1}{4}$$

In this manner, the balance equations for all the cells of MSC 2 can be derived as shown in <Figure 6>.

From $S_{i,j}$, we can derive $P^B_{i,j}$ as follows.

$$P^B_{i,j} = P_h S_{i,j} \text{ for } i = 1, 2, \ldots, L \text{ and } j = 1, 2, \ldots, L$$

Based on the probabilities obtained in this subsection, we can calculate the traffic loads, L_{12} and L_{23} using the equations in the previous subsection.

$$S_{i,j} = P_h \frac{S_{i+1,j} + S_{i,j+1} + S_{i-1,j} + S_{i,j-1}}{4} \text{ for } i = 2, 3, \ldots, L-1,\ j = 2, 3, \ldots, L-1$$

$$S_{i,1} = P_h \frac{S_{i+1,1} + S_{i,2} + S_{i-1,1} + Q^B_i / P_h}{4} \text{ for } i = 2, 3, \ldots, L-1$$

$$S_{i,L} = P_h \frac{S_{i+1,L} + S_{i-1,L} + S_{i,L-1}}{4} \text{ for } i = 2, 3, \ldots, L-1$$

$$S_{1,j} = P_h \frac{S_{2,j} + S_{1,j+1} + S_{1,j-1}}{4} \text{ for } j = 2, 3, \ldots, L-1$$

$$S_{L,j} = P_h \frac{S_{L,j+1} + S_{L-1,j} + S_{L,j-1}}{4} \text{ for } j = 2, 3, \ldots, L-1$$

$$S_{1,1} = P_h \frac{S_{2,1} + S_{1,2} + Q^B_1 / P_h}{4}, S_{L,1} = P_h \frac{S_{L,2} + S_{L-1,1} + Q^B_L / P_h}{4}$$

$$S_{1,L} = P_h \frac{S_{2,L} + S_{1,L-1}}{4}, S_{L,L} = P_h \frac{S_{L-1,L} + S_{L,L-1}}{4}$$

Figure 6. balance equations for $S_{i,j}$.

4.4 Blocking Probabilities

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} will be able to be obtained as follows, respectively.

$$U_1 = \frac{\frac{(L_{12})^M}{M!}}{\sum_{i=0}^{M} \frac{(L_{12})^i}{i!}}, \quad U_2 = \frac{\frac{(L_{23})^N}{N!}}{\sum_{i=0}^{N} \frac{(L_{23})^i}{i!}}$$

5. Numberical Examples

In this section, numerical results for a sample case of a cellular system are presented. The mobility of mobile stations is considered with ν. As ν is larger, the mobility becomes higher and the traffic loads, L_{12} and L_{23} are expected to become larger. This expectation is verified by <Figure 7>, which plots L_{12} and L_{23} versus ν. In <Figure 7>, $\lambda = 15$ calls/min., $r = 0.3$, $L = 10$, $\mu = 1/1.5$ min., and ν is ranged from 0.5 to 5/min. From <Figure 7>, we can see that the traffic load on the trunk T_{12}, L_{12}, is more than 10 times as large as that on the trunk T_{23}, L_{23}. With the blocking probability of 0.1%, the required channel capacities of the trunks, T_{12} and T_{23} can be obtained using the Erlang Loss formula and are also plotted versus ν in <Figure 7>. According to <Figure 7>, the trunk T_{12} should have the much larger capacity than the trunk T_{23}.

Under the soft handoff scheme between MSC's that has calls switch vocoders, when the mobile stations request the soft handoffs between two MSC's, the traffic data of the mobile stations are

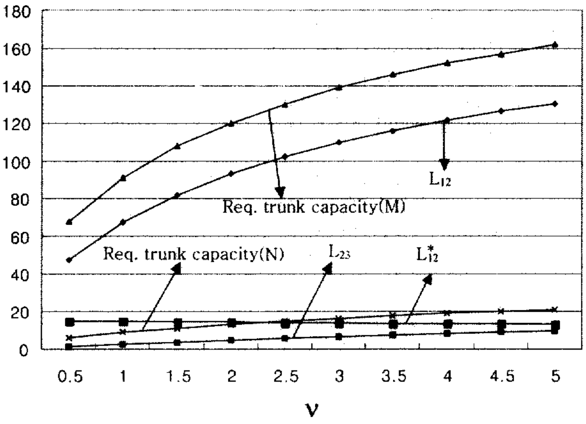


Figure 7. The effect of the mobility of the mobile stations on the traffic loads, L_{12}, L_{23} and L^*_{12} and the required trunk capacity.

carried through the trunk between the MSC's only when the mobile stations are located in the overlapping service region of the MSC's(Cheung and Leung, 1997). The diagonal trunks in <Figure 3(b)> are not needed for the inter-MSC soft handoff scheme that has calls switch vocoders because the overlapping service region between diagonally adjacent MSC's does not exist. The current calls of the mobile stations that are located in the overlapping service area between MSC 1 and MSC 2 can be from the service areas of MSC 1, MSC 3, MSC 4, MSC 2, MSC 5 and MSC 6 in <Figure 4>. The mean numbers of the handoff mobile stations of type A and B in the L cells, (i, L) of MSC 1 for $i=1, 2, \cdots, L$, can be obtained by Π_A and Π_B, respectively. And, the mean numbers of the handoff mobile stations of type A and B in the L cells, $(i, 1)$ of MSC 2 for $i=1, 2, \cdots, L$, can be obtained by $\Theta_A = \Lambda \sum_{i=1}^{L} P^A_{i,1}(r/4)$ and $\Theta_B = \Lambda \sum_{i=1}^{L} P^B_{i,1}(r/4)$, respectively. Therefore, the mean numbers of mobile stations in the overlapping service area of MSC 1 and MSC 2 of which the current calls are from the service areas of MSC 1 and MSC 3 can be obtained by $\Pi_A + \Theta_A$ and $\Pi_B + \Theta_B$, respectively. By symmetry, we can obtain the mean total number of mobile stations in the overlapping service area of MSC 1 and MSC 2 of which the current calls are from the service areas of MSC 1, MSC 3, MSC 4, MSC 2, MSC 5 and MSC 6 by $L^*_{12} = 2(\Pi_A + \Theta_A) + 4(\Pi_B + \Theta_B)$, which equals to the traffic load on the trunk, T_{12} because each mobile station sends and receives one channel traffic data through T_{12}. L^*_{12} is also plotted in <Figure 7> for the comparison between the traffic loads on T_{12} by the inter-MSC soft handoff schemes with and without switching vocoders. We can see that L^*_{12} is far less than L_{12} and insensitive to the mobility of the mobile stations, ν. But, using the call rerouting schemes(Wong and Leung), the additional traffic load should be carried through the backbone network. With the inter-MSC soft handoff scheme without switching vocoders described in this paper, the path rerouting is done using the trunk between MSC's and no additional traffic load is carried through the backbone network. Considering this additional traffic load carried through the backbone network, the traffic load generated by the soft handoff scheme with switching vocoders is expected to have a behavior similar to L_{12} in <Figure 7>. The rigorous treatment of the comparisons of the traffic loads generated by the inter-MSC soft handoff schemes with and without switching vocoders should be done in the future research.

6. Conclusions

This paper considers the soft handoff scheme 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 method is derived 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 also derived using Erlang loss formula.

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