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육각형의 셀배치를 가지는 CDMA 이동통신 시스템에서 MSC 간의 소프트 핸드오프를 위한 성능분석

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Performance Analysis for CDMA Soft Handoffs between MSC's under Hexagonal Configuration

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CDMA (Code Division Multiple Access) is a promising air interface technique for digital cellular systems. The soft handoff between base stations is one of many important features of CDMA for the mobile stations crossing the cell boundaries. The service areas of MSC's (Mobile Switching Centers) are defined as the unions of the service areas of the base stations connected to MSC's and are assumed to have hexagonal shapes. An analytical approach to the performance analysis of the link between MSC's for supporting the inter-MSC soft handoff scheme will be developed to obtain the probability that a soft handoff to an adjacent MSC will be blocked due to the shortage of the link capacity. Also, the rate of new connection establishments that are requested by the mobile stations moving to the service area of an MSC according to the inter-MSC soft handoff scheme will be obtained.

Keywords: blocking probability, erlang loss, soft handoff

1. Introduction

CDMA (Code Division Multiple Access) is a promising air interface technique for digital cellular systems. The soft handoff between base stations is one of many important features of CDMA for the mobile stations crossing the cell boundaries. When a mobile station during a call moves to a new cell, the base stations serve the mobile station in the handoff zone simultaneously. This minimizes the undesirable "ping-pong" phenomenon of back-and-forth handoffs between adjacent cells in conventional hard handoffs. (Cheung and Leung (1997))

In the literature, the soft handoff schemes between MSC's (Mobile Switching Centers) were proposed in Cheung and Leung (1997) and Choi (2000B) to provide the seamless services to the mobile stations crossing the boundaries between the service areas of MSC's. Cheung and Leung (1997) proposed the soft handoff scheme which switches the vocoders in the old MSC to those in the new MSC for the mobile stations moving to the service area of the new MSC, and investigated the performance of the link for supporting the inter-MSC soft handoffs using computer simulation. By switching the vocoders for the inter-MSC soft handoffs, new connections for rerouting the calls in progress of the mobile stations through the new MSC should be established while maintaining the old connections through the old MSC. In Choi (2000B), the soft handoff scheme without switching

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vocoders was proposed using the link between MSC's and the performance of the link between MSC's was analyzed to derive the soft handoff blocking probability due to the shortage of the link capacity. According to the inter-MSC soft handoff scheme proposed in Choi (2000B), 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 link between the MSC's and the same vocoder in the old MSC will be used.

In this paper, the service areas of MSC's are defined as the unions of the service areas of the base stations connected to MSC's and are assumed to have hexagonal shapes. An analytical approach to the performance analysis of the link between MSC's for supporting the inter-MSC soft handoff scheme as in Cheung and Leung (1997) will be developed to obtain the probability that a soft handoff to an adjacent MSC will be blocked due to the shortage of the link capacity. Also, the rate of new connection establishments that are requested by the mobile stations moving to the service area of an MSC according to the inter-MSC soft handoff scheme will be obtained. The occurrence rate of new connection establishments can be used to design the processing capacity of the processor for rerouting calls.

This paper is organized as follows. Following this introduction, the soft handoff scheme between MSC's, which is slightly different from the one in Cheung and Leung (1997), will be described in the next section. Section 3 proposes an analytical approach to obtaining the blocking probability of soft handoff between MSC's. Numerical examples and conclusions are presented in Sections 4 and 5, respectively.

2. Soft Handoffs between MSC's

Suppose that a mobile station during a call moves from an old cell in the service area of an old MSC (MSC A) to a new one in the service area of a new MSC (MSC B) and requests the inter-MSC soft handoff to the new MSC. While the mobile station is located in the handoff zone between the service areas of the MSC's, the vocoder in the old MSC receives from and sends to the mobile station traffic data through the base stations having the mobile station in their service areas and the diversity selection is performed at the old MSC and the mobile station. The link between the packet routers of the MSC's will be used to carry the traffic from the mobile station to the old MSC and vise versa through the new base station and the same vocoder in the old MSC will be employed. As shown in <Figure 1>, while the mobile station is located in the overlapping service area of MSC A and MSC B, two connection links between MSC A and the mobile station are maintained through the base stations. At the time when the mobile station moves out of the handoff zone between the service areas of the MSC's into the service area of MSC B, the new connection establishment and the seamless handoff of network connections (e.g., using the protocols in Yu and Leung (1996)) is requested to reroute the call in progress so that the call connection is set up through the MSC B. After this, the link between the packet routers of the MSC's will be occupied to carry the traffic from the mobile station to MSC A and vise versa while it is located in the service area of MSC B until the new connection is established and the call service through the new connection is in full operation. When the new connection is established and the call service through the new connection is in full operation, the inter-MSC soft handoff is completed, the old connection through MSC A and the link between the packet routers of the MSC's is dropped and the MSC B will serve the mobile station while the mobile station is located in the service area of MSC B.

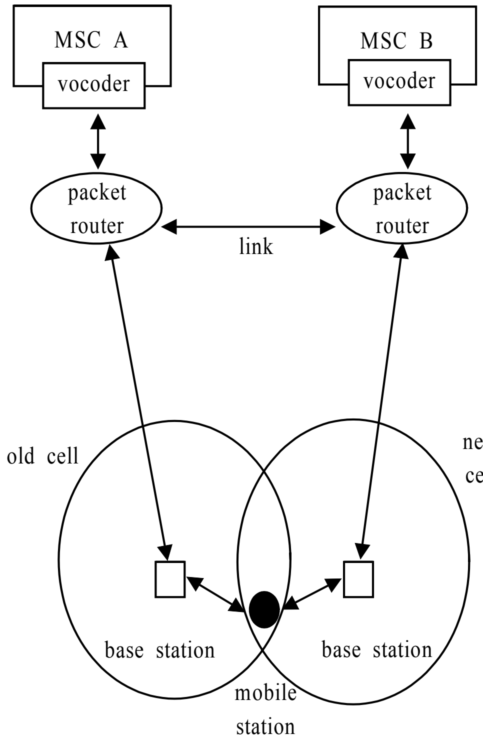


Figure 1. Soft handoff between MSC's.

According to the soft handoff scheme between MSC's in Cheung and Leung (1997), the new connection establishment and the call rerouting can be requested while the mobile station is located in the handoff zone between the MSC's or can be delayed until the mobile station moves further to the service area of a cell of MSC B that is not located at the boundary between the service areas of the MSC's. By delaying the new connection establishment and the call rerouting, possible oscillations between the connections due to the mobile station moving back and forth across the boundary between the service areas of the MSC's can be reduced. In this paper, the new connection establishment is requested at the time when the mobile station moves out of the handoff zone between the service areas of the MSC's. The handoff zone between the service areas of MSC's can be designed to be large enough to avoid the frequent oscillations between the connections since the old connection is used while the mobile station is located in the handoff zone.

3. Blocking Probability

The whole service area is assumed to be covered by the array of hexagonal cells as shown in <Figure 2>. Each circle represents the service area of a base station where two way communication between mobile stations and the base station is possible. The service area of MSC B is defined as the union of the service areas of the base stations connected to MSC's. In <Figure 2>, the center cell of the service area of MSC B is labeled by 0, and the numbers indicated in the cells represent the distances between the cells and the center cell of the service area of MSC B. L will denote the number of rings of cells in the service area of each MSC where the cells at the same distance from the center cell of the service area of each MSC compose a ring of cells.

The handoff zone is the overlapping region of the circles in <Figure 2>. The overlapping service area in which 2 (or 3) base stations can serve the mobile station simultaneously will be called 2 (or 3)-way handoff zone. 2 (or 3)-way handoff zone is referred to as Q_2 (or Q_3) in Srivastava and Rappaport (1991). We assume that the call holding time is exponentially distributed with the average of $1/\mu$. r_2 and r_3 will denote the ratios of the 2- and 3-way handoff zones to the whole service area, respectively. r_2 and r_3 can be calculated from the radius of a circle and the size of a hexagonal cell. (Refer to <Figure 1 (c)> and the equations, (3a), (3b), (3c), (3d), (3e), (3f), (3g), (3h), (3i), and (3j) in Srivastava and Rappaport (1991)) Let us denote by s (>1) the ratio of the area of a circle to that of a hexagonal cell. (In <Figure 1 (c)> in Srivastava and Rappaport (1991), the circle and the hexagonal cell are depicted as those of radius, d and radius, R, respectively.) Then, from <Figure 2>, the ratios of the areas of the 2- and 3-way handoff zones in a circle to the area of the circle, which will be denoted by u_2 and u_3, respectively, can be obtained as follows.

$$u_2 = 2r_2/s\ ,\ u_3 = 3r_3/s \qquad (1)$$

So, the areas of the 2- and 3-way handoff zones in a circle are two and three times as large as those of the 2- and 3-way handoff zones in a hexagonal cell, respectively.

It is assumed that there are N traffic channels in each base station. When a mobile station is located in the handoff zone,

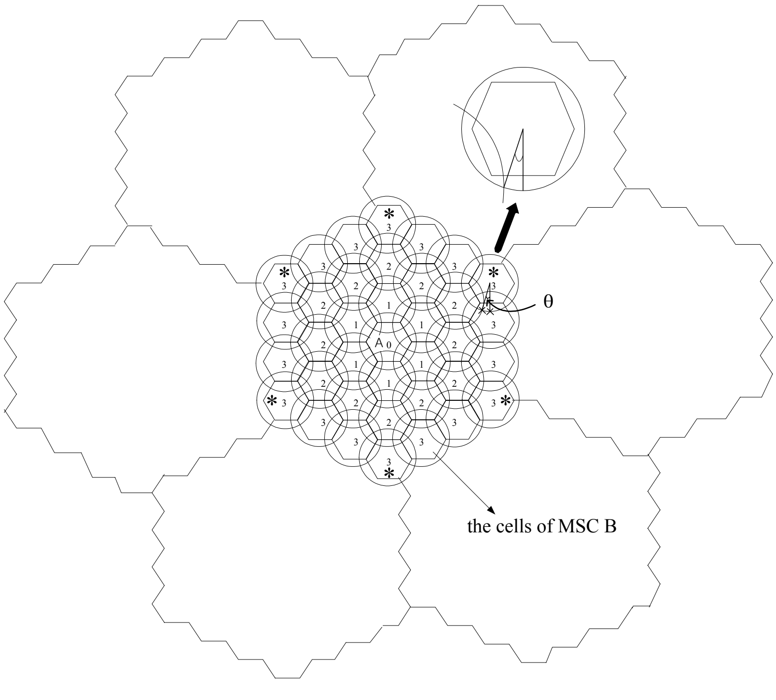


Figure 2. Hexagonal shape configuration of service areas of MSC B and six adjacent MSC's of MSC B when L = 3.

we will say that the mobile station is in the soft handoff transition between base stations. When a mobile station is located in the overlapping region of the service areas of MSC's, the mobile station will be said to be in the inter-MSC soft handoff transition.

In <Figure 2>, the handoff mobile stations to MSC B are defined as the mobile stations during calls that are in the soft handoff transitions from the six adjacent MSC's or remain in the service area of MSC B without the call terminations after the inter-MSC soft handoffs and are served by the old connections through the adjacent MSC's. Then, the six links between MSC B and the adjacent six MSC's will support the inter-MSC soft handoffs of the handoff mobile stations to MSC B. Suppose that the traffic channels in the base stations and the capacity of the links, etc. are unlimited so that no call is lost or dropped. Then, with this unlimited resource assumption, the traffic load on the six links by the inter-MSC soft handoffs from the six adjacent MSC's to MSC B can be defined as the total mean number of traffic channels in the base stations in the service area of MSC B occupied by the handoff mobile stations to MSC B. Let us denote this traffic load by T. Then, considering the inter-MSC soft handoffs from MSC B to the six adjacent MSC's, by symmetry the total traffic load on the six links will be $2T$. Therefore, the traffic load on a single link by the inter-MSC soft handoffs is

$$\Omega = 2T/6 = T/3. \tag{2}$$

The handoff mobile stations to MSC B can be divided into two types of mobile stations:

1) the handoff mobile stations to MSC B that are in the inter-MSC handoff transitions to MSC B, and
2) the handoff mobile stations to MSC B that are located in the service area of MSC B after the inter-MSC soft handoffs to MSC B, and are served by the old connections through the adjacent MSC's until the new connections are established and the seamless handoffs are completed.

Let us denote the traffic loads on the six links by the former and latter types of handoff mobile stations to MSC B by T_1 and T_2 respectively. T_1 and T_2 will be obtained in the rest of this section.

Under heavy traffic, N traffic channels in each base station can be assumed to be occupied by mobile stations. Assuming that mobile stations are uniformly distributed throughout the service area, on the average $N(u_2+u_3)$ out of N traffic channels in each base station are occupied by the mobile stations in the handoff zones. When a mobile station is located in the overlapping region of the service areas of adjacent two (or three) base stations, the mobile station can be assumed to move to each of two (or three) service areas with the equal probability. Therefore, on the average $N(u_2/2+u_3/3)$ traffic channels are occupied by the mobile stations that are in the soft handoff transitions to the service area of each base station. The mean number of traffic channels occupied by the mobile stations that are in the soft handoff transitions to the service area of each base station through a side of a hexagonal cell is

$$\tau = \mathrm{N}(\mathrm{u}_2/2+\mathrm{u}_3/3)/6. \tag{3}$$

The number of boundary cells of MSC B is $6L$. From <Figure 2>, we can see that six hexagonal cells out of $6L$ boundary cells of MSC B, which are indicated by *, have three sides between the service areas of MSC B and the adjacent MSC's, and the remaining $6L$-6 boundary cells have two sides between the service areas of MSC B and the adjacent MSC's. Therefore, $12L + 6$ (=6 3+2($6L$-6)) sides can be the passages for the mobile stations that are in the inter-MSC handoff transitions from the adjacent MSC's of MSC B to MSC B. Then, the mean number of traffic channels in the base stations in the service area of MSC B occupied by the handoff mobile stations to MSC B that are in the inter-MSC soft handoff transitions to MSC B can be obtained as

$$\mathrm{T}_1 = (12\mathrm{L}+6)\,\tau. \tag{4}$$

Assuming that mobile stations are uniformly distributed in the service area of a base station, the mean amount of time for which a mobile station will remain continuously in the service area, $1/\varphi$, the probability that a mobile station during a call crosses the boundary of the service area without the call termination, η, and the mean amount of time for which a mobile station during a call remains continuously in the service area without the call termination, $1/\rho$ can be obtained as follows(Refer to Jabbari and Fuhrmann (1997)).

$$1/\varphi = \pi\mathrm{R}/2\mathrm{V} \tag{5}$$

$$\eta = \varphi/(\mu+\varphi) \tag{6}$$

$$1/\rho = 1/(\mu+\varphi) \tag{7}$$

In (5), R denotes the radius of the service area of a base station and V the mean speed of mobile stations.

Under heavy traffic, the mean number of the mobile stations being served by a base station can be assumed to be N. So, by Little's law, the departure rate of the calls out of the service of a base station due to the call completions or the handoffs will be $\gamma = N\rho$. The departure rate of the mobile stations during calls crossing the boundary out of the service area of a base station is

$$\delta = \gamma\eta = \mathrm{N}\varphi \tag{8}$$

Using the angle, θ in <Figure 2>, when a mobile station moves out of the service area of a base station, the probability that the mobile station will be located in the non-handoff zones of the service areas of the adjacent base stations, which is represented by Q_1 in <Figure 1 (c)> in Srivastava and Rappaport (1991), is

$$\mathrm{p} = 12\theta/2\pi = 16\theta/\pi \tag{9}$$

(Using the results in Srivastava and Rappaport (1991), the angle, θ can be obtained as $\theta = \cos^{-1}[(\sqrt{3}/q)[1+\sqrt{1-4(10-q^2)}]]$ where $q = \sqrt{1.5\sqrt{3}s/\pi.}$) Therefore, the arrival rate of the mobile stations during calls to the non-handoff zone of the service area of a base station from the service area of an adjacent base station through a side of a hexagonal cell should be equal to $p\delta/6$ .12L+6 (=6 3+2(6L-6)) sides can be the passages from the service areas of the adjacent MSC's to the service area of MSC B. Therefore, the total arrival rate of the mobile stations during calls to the non-handoff service area of MSC B from the service areas of the adjacent MSC's can be obtained as

$$\psi = \mathrm{p}\delta(12\mathrm{L}+6)/6 = \mathrm{p}\delta(2\mathrm{L}+1) \tag{10}$$

which equals to the rate of new connection establishments that are requested by the mobile stations moving to the service area of MSC B according to the soft handoff scheme in the previous section. The mobile stations that entered the non-handoff service area of MSC B from the service areas of the six adjacent MSC's use the old connections through the adjacent MSC's of MSC B until the new connections are established through MSC B and the seamless handoffs to the new network connections are completed. Therefore, the mean number of traffic channels in the base stations of MSC B occupied by the handoff mobile stations to MSC B that entered the non-handoff service area of MSC B from the service areas of the six adjacent MSC's is obtained as

$$\mathrm{T}_2 = \psi\Delta\mathrm{t} \tag{11}$$

where Δt is the amount of time taken to establish a new connection through MSC B and complete the seamless handoff to the new network connection.

The traffic load on the six links by the handoff mobile stations to MSC B is $T = T_1 + T_2$ Using (2), the total traffic load on a single link by the inter-MSC soft handoffs can be obtained as

$$\Omega = (\mathrm{T}_1+\mathrm{T}_2)/3 \tag{12}$$

The capacity of the link is assumed to be M duplex channels. That is, through the link M simultaneous channel traffic data can be sent and received. Using Erlang loss formula, the blocking probability of an inter-MSC soft handoff due to the shortage of the link capacity between MSC's can be obtained by as follows.

$$\mathrm{P}_b = \frac{\frac{\Omega^M}{M!}}{\sum_{i=0}^{M}\frac{\Omega^i}{i!}} \tag{13}$$

4. Numerical Examples

In this section, numerical results for sample cases of cellular systems are presented. The mobility of mobile stations is considered with V, the mean speed of mobile stations. As V is larger, the mobility becomes higher and the traffic load, Ω and the rate of new connection establishments, ψ are expected to become larger. This expectation is verified by <Figure 3>, <Figures 4, 5 and 6>, where the traffic load, Ω, the link capacity, M required for satisfying the blocking probability, P_b = 0.001 or 0.005 due to the shortage of the link capacity and the rate of new connection establishments, ψ are plotted versus V. In <Figures 3 (a), 4 (a), 5 (a)> and <Figure 6 (a)>, the dotted lines with triangles represent Ω when N = 78, the solid lines with triangles Ω when N = 156, the dotted lines with rectangles M when N = 78 and P_b = 0.005, the dotted lines with circles M when N = 78 and P_b =0.001, the solid lines with rectangles M when N = 156 and P_b = 0.005, and the solid lines with circles M when N = 156 and P_b= 0.001. In <Figures 3 (b), 4 (b), 5 (b) and 6 (b)>, the dotted lines represent ψ when N = 78, and the solid lines ψ when N = 156. The required link capacity can be obtained using (13).

In <Figure 3>, s = 1.86, r_2 = 0.46, r_3=0.2, L = 10, N = 78 or 156, R = 1.5 km, Δt = 2.3 seconds and V is ranged from 0 km/h (that is, the case of stationary mobile stations) to 100 km/h. Using the formulae in Srivastava and Rappaport (1991), s = 1.86 was selected to result in r_2 = 0.46 and r_3 = 0.2. When s = 1.86, the angle θ in <Figure 2> is 0.25 radians or 14.3 degrees. When the frequency bandwidth is 1.25 MHz in CDMA cellular systems, N = 78 maximum voice calls per base station can be served(Refer to Choi (2000A). N = 156 is the case where the double call capacity is assumed in CDMA cellular systems of the future. According to the equations in the previous section, μ has no effect on the traffic load, Ω, the link capacity, M and the rate of new connection establishments, ψ. So, the value of μ is not specified here. According to ETRI (1993), the traffic capacity of TDX-10 is about 27,000 Erlang. Therefore, we can infer that TDX-10 can support about 346 (= 27,000 / 78) base stations and the corresponding L is about 10 because the total number of base stations in the service area of an MSC is $1 + 6 + 2 \cdot 6 + ... + 6L = 3L^2 + 3L + 1$. $\Delta t = 2.3$ seconds is the worst case call setup time based on the architecture without personal number translations (Refer to Giordano and Chan (1994)). For the other cases of (L, R) = (10, 3 km), (15, 1.5 km) and (15, 3 km) with the same values of the other parameters except (L, R), the results are respectively plotted versus V in <Figure 4, 5 and 6>. ($L = 15$ corresponds to the case where the number of the base stations of an MSC is about two times as large as that of the case of $L = 10$.)

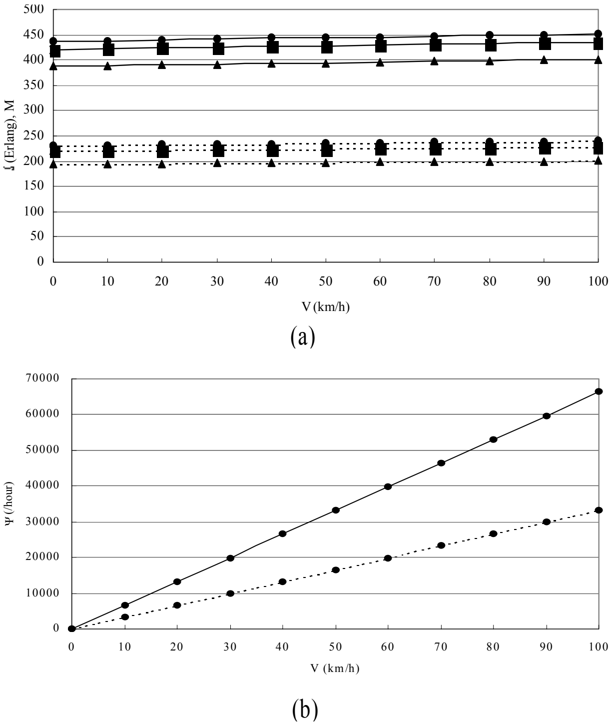
As can be seen in <Figures 3, 4, 5 and 6>, the traffic load, Ω and the rate of new connection establishments, ψ linearly increase as V is larger. Using (1), (2), ..., (12), the total traffic load, Ω on a single link by the inter-MSC soft handoffs and the rate of new connection establishments, ψ can be derived as

$$\Omega = \frac{T_1 + T_2}{3}$$

$$= \frac{T_1}{3} + \frac{(8L+4)N\theta\Delta t}{\pi^2 R}V, \qquad (14)$$

$$\psi = \frac{(24L+12)N\theta}{\pi^2 R}\mathrm{V} \qquad (15)$$

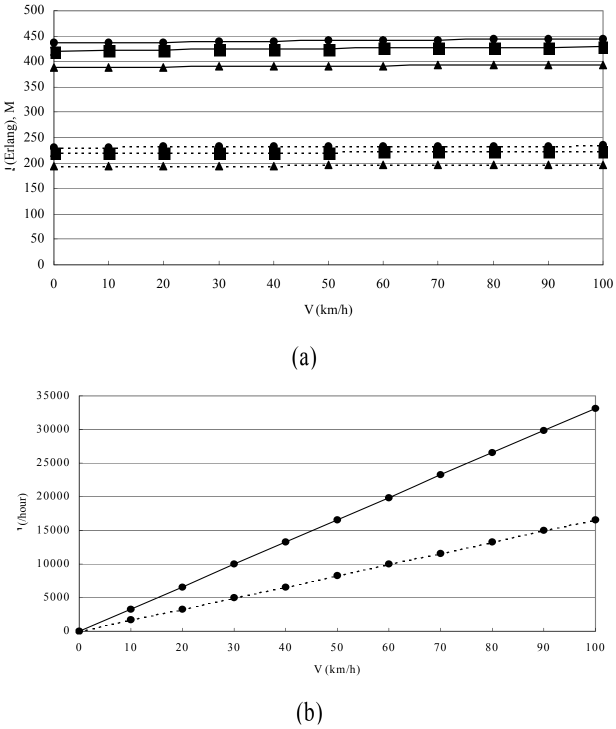
where T_1 is constant with respect to V. Therefore, the slope of the plot of the traffic load, Ω with respect to V is $((8L+4)N\theta\Delta t) / (\pi^2 R)$, which is relatively small in <Figure 3, 4, 5 and 6> because the small value of $\Delta t = 2.3$ seconds was used. Comparing the results of the four cases of *(L, R)*, the traffic load, Ω and the rate of new connection establishments, ψ are largest for the case of *(L, R)* = (15, 1.5 km) among the four cases of *(L, R)*. Generally, the traffic load, Ω and the rate of new connection establishments, ψ will be larger as L is larger and R is smaller. This implies that the larger boundary area between the service areas of MSC's and the smaller service areas of base stations will result in the larger traffic load on the link between MSC's and the larger rate of new connection establishements (The number of cells of an MSC at the boundary between the service areas of the MSC and the adjacent MSC's of the MSC is $6L$). We can also see that $N = 156$ leads to the double traffic load, Ω, and the double rate of new connection establishments, ψ, compared with those obtained when $N = 78$, and the larger link capacity, M is required when $P_b = 0.001$ than is required when $P_b = 0.005$.



(a)

(b)

Figure 3. The traffic load, Ω, the link capacity, M and the rate of new connection establishments, ψ versus the mean speed of mobile stations, V when (L, R) = (10, 1.5 km)
(a) Ω and M versus V (b) ψ versus V.

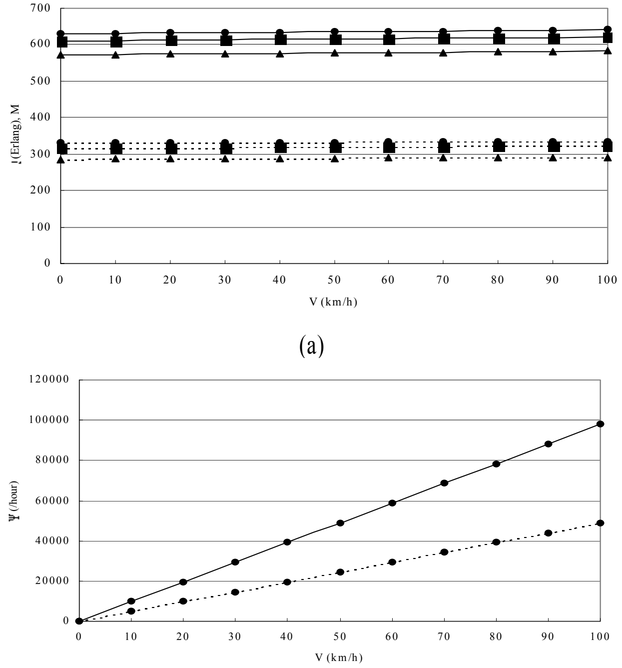


(a)

(b)

Figure 4. The traffic load, Ω, the link capacity, M and the rate of new connection establishments, ψ versus the mean speed of mobile stations, V when (L, R)

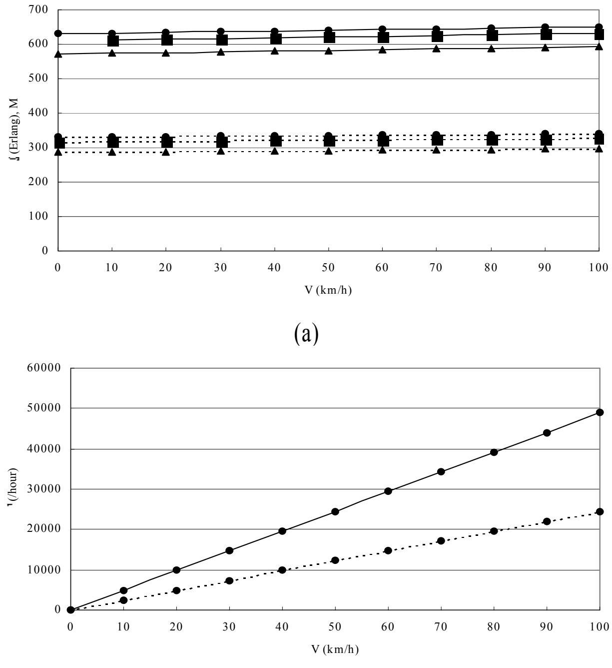
= (10, 3 km) (a) Ω and *M* versus *V* (b) ψ versus *V*.



(a)

(b)

Figure 5. The traffic load, Ω, the link capacity, *M* and the rate of new connection establishments, ψ versus the mean speed of mobile stations, *V* when *(L, R)* = (15, 1.5 km) (a) Ω and *M* versus *V* (b) ψ versus *V*.



(a)

(b)

Figure 6. The traffic load, Ω, the link capacity, *M* and the rate of new connection establishments, ψ versus the mean speed of mobile stations, *V* when *(L, R)*

= (15, 3 km) (a) Ω and *M* versus *V* (b) ψ versus *V*.

5. Conclusions

In this paper, an analytical approach to the performance evaluation of the link between MSC's was developed to support the soft handoffs between MSC's. Taking into account the mobility of mobile stations, the traffic load imposed on the link between MSC's and the rate of new network connection establishments requested by the soft handoffs between MSC's were derived. The probability that a soft handoff request to an adjacent MSC will be blocked due to the shortage of the link capacity was obtained using Erlang loss formula. Numerical examples were also presented to see the effects of the mobility of mobile stations, the size of the boundary area between the service areas of MSC's and the size of the service areas of base stations on the traffic load on the link between MSC's and the rate of new connection establishments requested by the soft handoffs between MSC's.

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