Master's Thesis

Title

An Integrated Evaluation of Qualities of Wired and Wireless Channels with Consideration of Soft Handoff in CDMA Cellular Networks

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Abstract

In CDMA (Code Division Multiple Access) cellular networks, the soft handoff technique allows a mobile host to communicate with multiple base stations simultaneously, improving the transmission quality of the wireless channel and avoiding disconnection upon to base station switching. In this thesis, we define the soft handoff margin as the area in which the mobile host can use soft handoff and evaluate the influence of soft handoff on TCP (Transport Control Protocol) throughput in CDMA cellular networks through simulation. First,to simulate for changing the values of the soft handoff margin and mobile host density, we model the RLP (Radio Link Protocol) in the wireless channel in order to investigate the effect on TCP throughput for different positions of the mobile host between base stations, and identify the effective ranges for the soft handoff margin. Furthermore, we analyze the influence of avoiding disconnection on TCP throughput when the handoff is performed frequently by a moving mobile host.

Keywords

CDMA (Code Division Multiple Access)

TCP (transport control protocol)

RLP (Radio Link Protocol)

Hard/Soft Handoff

Soft Handoff Margin

Transient Performance

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1 Introduction

In recent years, the number of cellular phones has been explosive and their use has spread throughout the world. FDMA (Frequency Division Multiple Access) and TDMA (Time Division Multiple Access) are mobile data communications methods used in second generation mobile communication systems [1].

In FDMA, a different frequency band is assigned to each user, and the data of each user is transmitted using a narrow bandwidth. The shortcoming of FDMA is that other users cannot use the transmitting bandwidth of a user who is not transmitting any data. If there are many such users and the frequency bandwidth is limited, the use of bandwidth becomes inefficient. In TDMA, each user is assigned a different time slot, then the data of each user is transmitted intermittently and periodically using their assigned time slot. The shortcoming of TDMA is that the user occupies the assigned time slot even if there is no data to transmit, thus the time slot can be wasted.

The adopted standard of IMT-2000 is CDMA (Code Division Multiple Access) which is used in 3rd generation mobile communication systems [2]. CDMA assigns a pseudo-random code to each user, and the data of each user can be transmitted by spread-spectrum technology in a wide bandwidth. CDMA provides high security communication and is already used for military applications. Moreover, all frequencies and time slot are shared by all users, because if a different pseudo-random code is assigned to each user, multiple users can communicate simultaneously. CDMA is able to provide more users with service than TDMA or FDMA.

Generally, the typical CDMA cellular networks contain three elements: the BS (Base Station), MH (Mobile Host), and BSC (Base Station Control Center). Communication between MH and BS is wireless and the BSC is wired to two or more BSs. When a MH performs the communication, the BSC receives modulated data from the MH via a BS and then transmits it to a BS which is connected to the destination MH. In the CDMA cellular networks, the cell is defined as the zone in which the MH can communicate with a BS. In the case that the MH is moving, when the MH arrives at the boundary of a cell the communicating BS needs to be switched in order to maintain good communication quality.

Hard handoff and soft handoff are the techniques used to change the communicating BS to an adjacent BS. In hard handoff, when the MH arrives at the boundary of the cell, the present communication link is cut off and a new communication link is established between the MH and the adjacent BS if the power level of the adjacent BS is higher than that of the current BS for the threshold range. Soft handoff is different from hard handoff in that, before the MH arrives at the boundary of the cell, the MH has searched for the power levels of adjacent BSs and established a new communication link with another BS whose power level is the highest [3] (here, it is assumed the MH can only communicate with two BSs simultaneously when using soft handoff). Thus it does not cut off the present communication link during the handoff. This means that during soft handoff the MH communicates with two BSs simultaneously and at any space time it maintains at least one connection during soft handoff.

It is obvious that using soft handoff provide better performance than hard handoff as it can avoid interruptions and frequent switching. Nevertheless, when the number of MHs at the boundary of a cell increases, if the soft handoff is adopted, the number of connections to the BS also increases, and the wired channel resources will be consumed and the load on the wired channel will become heavier. Moreover, since one MH can communicate with two BSs simultaneously, if the area of soft handoff is too large, interference may be generated and obstruct the data transmission of other MHs in downlink. For these reason, optimal soft handoff control is required to enhance the system performance.

Over the past few years, most research has focused on evaluating the performance of voice communication in CDMA cellular networks. In [4], the authors varied the soft handoff margin, the network load and the number of MHs which communicated with one

BS, and made the assumption that each MH has to use one wired channel to communicate with one BS, to calculate the probability of blocking and handoff refused. But In an actual channel, data transmission is performed by packet switching. [5, 6] mentioned two kinds of RLP (Radio Link Protocol) of IS-95 in the wireless channel and, according to the adopted RLP, the effect on the system performance is evident. But in these studies, the influence of the soft handoff was not considered. When using soft handoff, the SIR (Signal to Interference Ratio) of some MHs which do not perform handoff is lower than in the case of hard handoff, thus it is necessary to evaluate and compare the influences of soft and hard handoff. [7] calculated the SIR based on the number of MHs in a cell, and showed that soft handoff causes an increment of SIR, which leads to the improvement of the quality of wireless channels. [8] introduced a better power control scheme that can decrease interference and thus improve the SIR. But these studies only evaluated the networks between BSC and MH. In IMT-2000, data transmission (the download of graphics or files from the Internet and so on) is supported. In a real system, the MH not only performs data transmission with a MH, it may also be a fixed host (FH). Then the evaluation should also consider the FH communicating via the Internet.

We expect that the using soft handoff can provide better communication quality than hard handoff. However, the amount of data transmission will increase and the system load on wired channels will be heavier. We can also expect that the packet loss and error will be higher than those in the case of hard handoff. Moreover, the interference will also increase due to the increasing number of MHs communicating with two BSs. On other hand, due to rapid technological advances in wireless communications and the Internet, the interconnections between wireless and wired networks have to be considered. TCP (Transport Control Protocol) is a reliable end-to-end transport protocol and can be tuned to perform well in wired networks. It has a congestion control option and can decrease TCP packet loss in the wired channel. However, in the wireless channel, because of the characteristic of high FER (Frame Error Rate), the performance of TCP is severely affected [9]. In [10] the authors proposed the variation of buffer size, initial congestion window size, MTU (Maximum Transmission Unit) size and the adoption of TCP SACK (selective ACK) to improve TCP performance. Nevertheless, this study also did not consider performance evaluation in the case of soft handoff.

The purpose of our research is to integrate the TCP performance in the wired and wireless channels over the CDMA cellular networks with soft handoff. On the basis of studies, the SIR is known to be an important factor that will affect the quality of the wireless channel, so we choose the parameters (soft handoff margin, the MH density in one cell and so on) that influence SIR in CDMA cellular networks. In this thesis, we propose a model for the simulation of the RLP of data link layer in wireless channel and the method to decide the transmission delay of a TCP packet from the upper layer in the wireless channel. We perform simulations based on the assumption mentioned above and according to the result it can be clarified which parameters have an influence on the TCP performance when soft handoff is used. First, we simulate the case when varying the soft handoff margin and the MH density, and investigate the relationship between the position of MH and the TCP performance. We then obtain the effective range of soft handoff margin. Furthermore, the use of soft handoff has the advantage it can avoid the cut off of communication during the handoff. We also simulate the case of a MH moving randomly with frequent handoff to investigate this effect.

The thesis is organized as follow. Section 2 describes the fundamental composition of CDMA cellular networks and the transmission of the TCP packet in the wireless channel. Section 3 explains our assumption. Section 4 shows the simulation result and expresses the examination. The conclusions are presented in the last section.

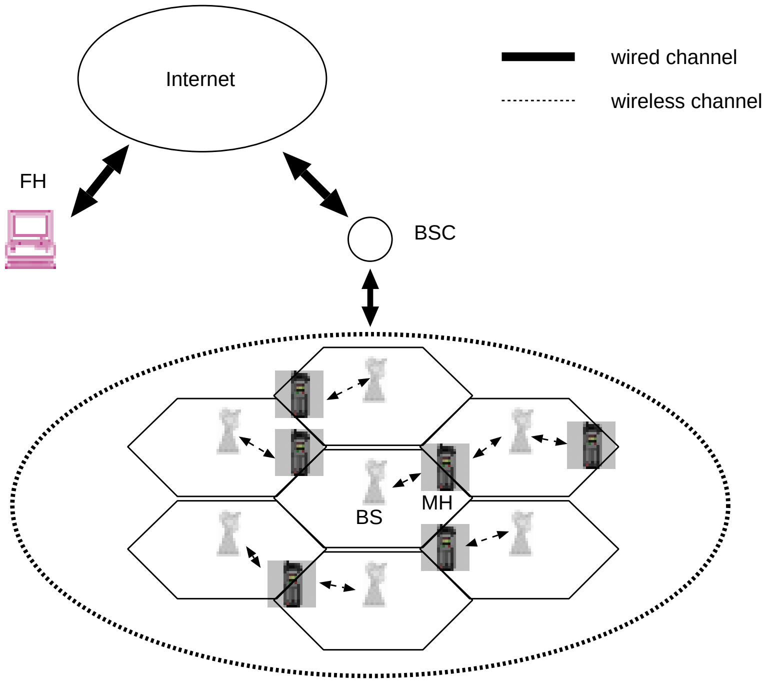


Figure 1: Network Configuration of CDMA cellular networks

2 The System Description of CDMA Cellular Networks

2.1 Network Configuration of CDMA Cellular Networks

The logical elements of typical CDMA cellular networks are a FH, a BSC, some BSs and a number of MHs. Communication between MH and BS is wireless and the BSC is wired to a FH and two or more BSs. The layout of the typical CDMA cellular networks is shown in Figure 1. When a MH performs the TCP transmission, the BSC receives the TCP packet from the FH via the Internet. The TCP packet is transmitted by RLP frames from the BSC to the BS which is connected to the destination MH, and the destination MH also receives the data as RLP frames from BS.

We mention the RLP scheme of the data link layer in Subsection 2.2. On the other hand, other MHs are also performing data transmission through the BS except the destination MH. Its transmission power causes the interference for the destination MH and the quality of communication in the wireless channel can be affected. In our thesis, we adopt

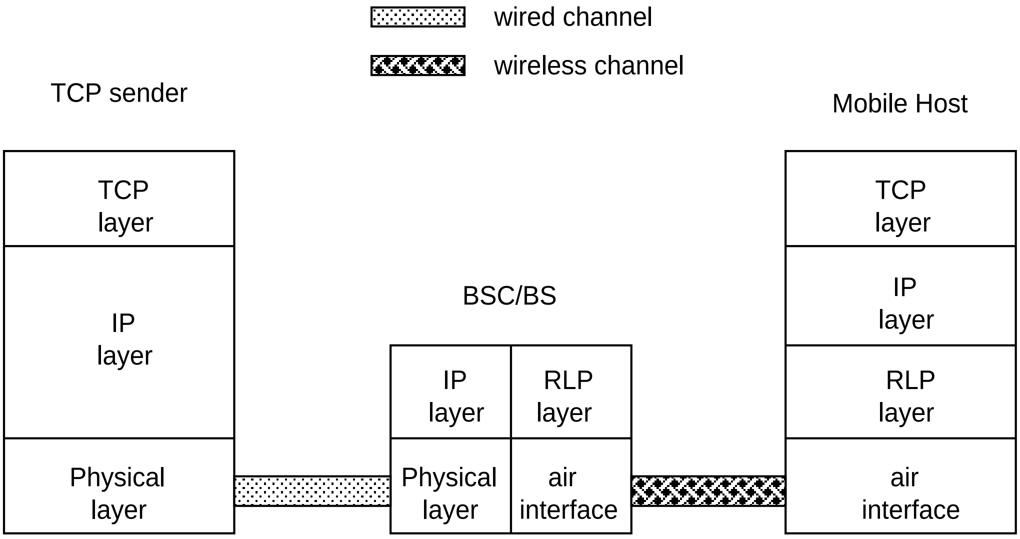


Figure 2: Protocol stack in CDMA cellular networks

SIR to decide the communication quality of physical layer in the wireless channel. In Subsection 2.3 we show the calculation stage of interference and how this result influences the SIR in the cases of considering the characteristics of both soft and hard handoff.

2.2 RLP (Radio Link Protocol)

Taking into consideration the TCP data packets transmission in the CDMA cellular networks, the simple protocol stack in this thesis is depicted in Figure 2. We assume that a FH in a wired part of network will transmit TCP packets to a MH in a wireless channel. In the FH side, the TCP layer passes the packets over to the IP layer and sends them to the BSC/BS via the physical layer. The BSC/BS takes over the packets and partitions the received packets into smaller sized frames in the RLP layer and then sends the frames to the destination MH. In other words, we can say that the TCP packets are sent as RLP frames in the wireless channel.

In a wireless channel, because of the fading effect and the characteristics of the spectrum, the probability of data miss and error is higher than in a wired channel. To provide

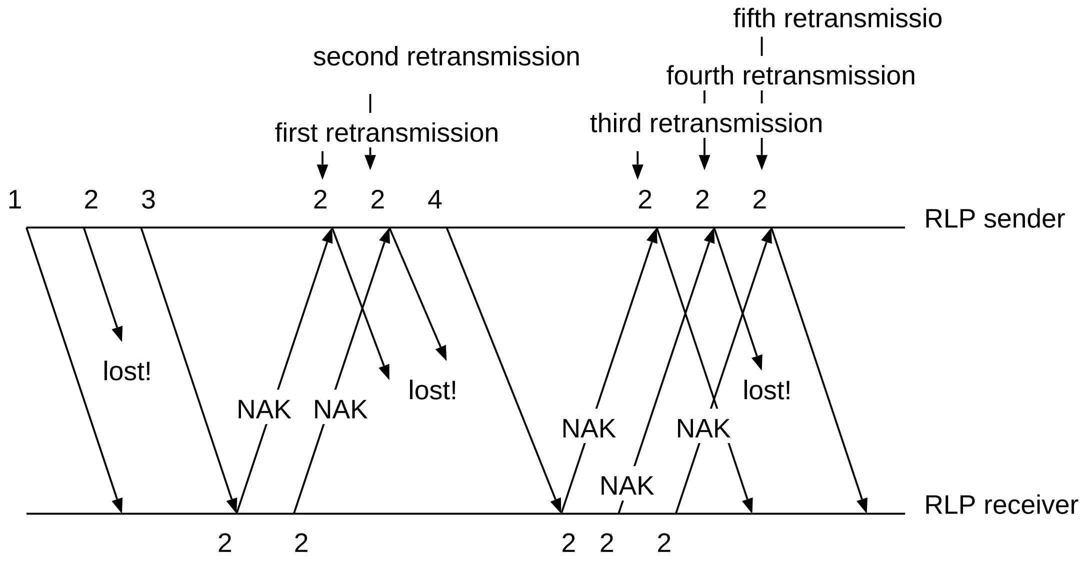


Figure 3: Example of a RLP3 scheme

shielding from receiving error frames, the use of NAK (Negative Acknowledgment) based RLP in CDMA cellular networks has been proposed. With NAK based RLP, whenever the RLP receiver detects a missing frame, the NAK frame that has the same specified sequence number as the missing frame is sent back to RLP sender. When the RLP sender receives the NAK frame, the missing frame is retransmitted.

The RLP3 [5] specifies that the RLP sender can have two rounds of retransmission with 2 and 3 NAKs in the first and second rounds, respectively. This means that the RLP sender can attempt to retransmit the missing RLP frame up to five times. In the RLP sender, the retransmission is performed as shown in Figure 3 with the NAK scheme specified by RLP3.

Firstly let us assume that four frames are sent by a RLP sender and the sequence number of frames is 1, 2, 3, and 4. In the case of frame 2 being lost for the duration of the transmission, the RLP receiver concludes that frame 2 is missing when frame 3 arrives, and requests the RLP sender to retransmission with two NAKs in the first round. The RLP sender receives each NAK and retransmits the frame which has the same sequence number as the received NAK. In first round, we can expect that two retransmissions of the missing frame, frame 2, will be performed if the sender has received two NAKs from the RLP receiver. Assuming that both of the retransmissions of the missing frame are lost again, the received in the RLP receiver time will expire. In the second round, the RLP receiver will request the retransmission of frame 2 with three NAKs and trigger the abort time counter. As in round one, the RLP sender receives the three NAKs and performs the retransmission of frame 2 for each NAK. The abort time will expire if the RLP receiver does not receive the missing frame. In this case, the RLP receiver passes over the received data to the upper layer, whether the missing frame, frame 2, arrives or not.

2.3 Calculation of SIR in Physical Layer

Due to the fact that a MH can communicate with plural BSs in the soft handoff, the calculation of SIR in the soft handoff state is different from that in the hard handoff state. We explain this in the following.

2.3.1 SIR in the Case of Hard Handoff

In a wireless channel, the interference power is the main factor influencing the connection quality of CDMA cellular networks. Interference power is when a MH that is connecting with a BS generates power and the power level obstructs the communication of other MHs. The parameter in the control scheme and the pointer of communication quality on CDMA cellular networks always uses the SIR (signal to interference ratio). The signal level attenuates due to distance or shadow fading, such as when the radio passes though buildings, mountains or other obstructions. Taking this into consideration, the propagation attenuation of the downlink link in the CDMA cellular networks can be written as;

$$L_{j,i} = d_{j,i}^{-\mu} 10^{\zeta/10} \tag{1}$$

where $d_{j,i}$ is the distance between BS$_j$ and MH$_i$ μ is the path loss exponent, and $10^{\zeta/10}$ expresses the shadow fading with log-normal distribution.

Ignoring the thermal noise, the total interference power of the CDMA cellular networks can be said to include both the intra and inter interference power. The intra-cell interference power is the power with which a BS transmits data to each MH in the cell except for the reference MH. Similarly, aside from the BS which communicates with the reference MH, other BSs also transmit data to each MH in the cell, and the total of its transmission power can be defined as inter interference to the reference MH. Taking into account the path attenuation and the influence of total interference power, the calculation of SIR can be shown as Eq. (2) [11];

$$\frac{S}{I} = \frac{W}{v_i R_i} \frac{P_{j,i} L_{j,i}}{(P_{total,j} - P_{j,i})\alpha L_{j,i} + \sum_{k=1}^{m} P_{total,k} L_{k,i}} \tag{2}$$

where W is the bandwidth R_i is the service bit rate of MH$_i$ and v_i is the data activity factor $P_{j,i}$ is the transmission power allocated from BS$_j$ to reference MH$_i$ and $P_{total,j}$ expresses the total transmission power from BS$_j$ to each MH of BS$_j$. α is the downlink orthogonality factor which has perfect orthogonality with value 0 and non-orthogonality with value 1. m expresses the number of cells of the range with consideration to the inter-cell interference. Let $P_{j,i}$,$L_{j,i}$ be the received power C_i, $\frac{W}{R_i}$ be the process gain G_i, $(P_{total,j} - P_{j,i})\alpha L_{j,i}$ be the interference power from other MHs in the cell $I_{intra,i}$ (intra-cell interference) and $\sum_{k=1}^{m} P_{total,k} L_{k,i}$ be the interference power of other BSs $I_{inter,i}$ (inter-cell interference) for MH$_i$, Eq. (2) can be simplified

$$SIR = \frac{G_i}{v_i} \left(\frac{I_{intra,i}}{C_i} + \frac{I_{inter,i}}{C_i}\right)^{-1} \tag{3}$$

Supposing the transmission power from the BS to each MH is equal, we can obtain the $\frac{I_{intra,i}}{C_i}$ and $\frac{I_{inter,i}}{C_i}$ as follows;

$$\frac{I_{intra,i}}{C_i} = \frac{\alpha \sum_{v=1, v \neq i}^{n} P_{j,v} L_{j,i}}{P_{j,i} L_{j,i}} = \alpha(n-1) \qquad P_{j,v} = P_{j,i}, v = 1..n \tag{4}$$

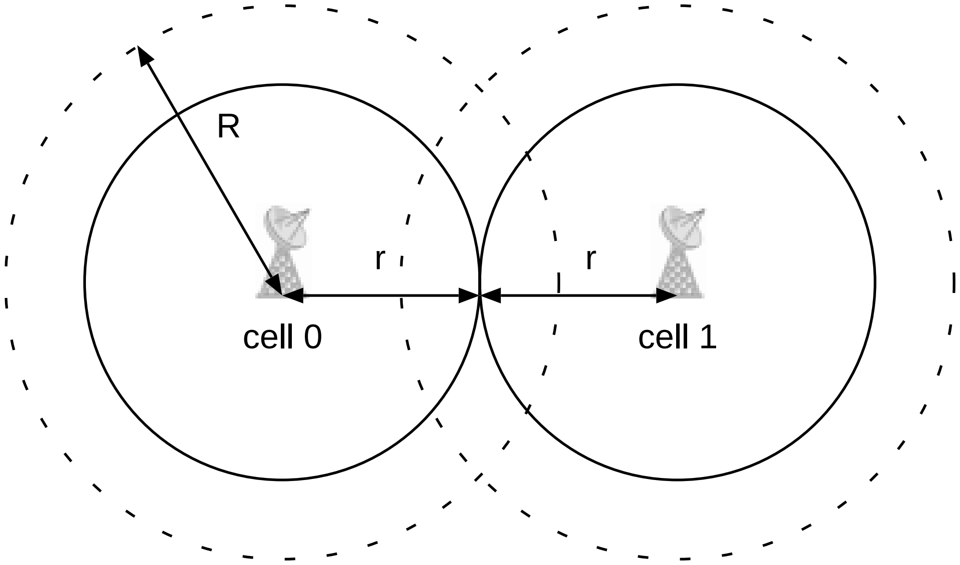


Figure 4: Definition of the Soft handoff margin

$$\frac{I_{inter,i}}{C_i} = \frac{\sum_{k=1}^{m} P_{total,k} L_{k,i}}{P_{j,i} L_{j,i}} = \frac{\sum_{k=1}^{m} \sum_{v=1}^{n} P_{k,v} L_{k,i}}{P_{j,i} L_{j,i}} = n \sum_{k=1}^{m} \frac{L_{k,i}}{L_{j,i}} \tag{5}$$

2.3.2 SIR in the Case of Soft Handoff

The soft handoff margin is an important parameter in adopting the soft handoff. It expresses the area size that the MH is able to communicate with the plural BSs. The definition of the soft handoff margin is shown in Figure 4 and can be calculated by

$$M_{sh} = 10 \mu log \frac{R}{r} \tag{6}$$

where R is the cell coverage radius with the soft handoff, r is the cell coverage radius with the hard handoff and μ is the path loss slope. To obtain the intra-cell interference power of MH$_i$, we have to know how many MHs are communicating with one BS. As shown in Figure 5, for the soft handoff the MHs that are communicating with BS$_0$ must consider other MHs in the adjacent BS$_1$ because of some MHs communicating with nearest two BSs, (BS$_0$ and BS$_1$) in the soft handoff region. Considering that the number of MHs in a cell in the hard handoff state is ρ, P_{r0} and P_{r1} are the powers that MH$_i$ receives from BS$_0$

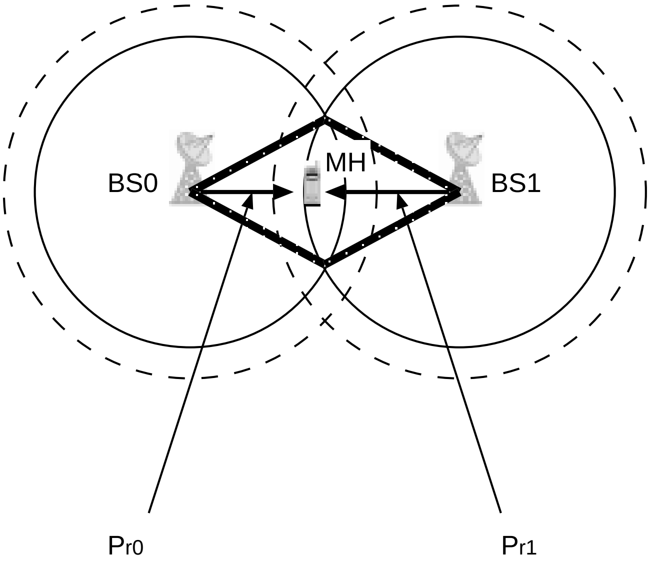


Figure 5: Relationship between the two nearest BSs with which a MH communicates

and BS_1, respectively. The number of MHs that communicate with BS_0 is calculated by

$$N = 6\int\int \rho P_r(P_{r0} > P_{r1} - M_{sh})dA \tag{7}$$

here, the integral range is the diamond shaped area in Fig. 5.

On the other hand, for the calculation of inter-cell interference power, the SIR must be considered under three circumstances. When the MH_i communicates with BS_0, BS_1 or both of them together, assuming that SIR_0, SIR_1 and $SIR_{0,1}$ are when MH_i communicates with BS_0, BS_1 or both together, respectively. In addition to the consideration of the soft handoff margin, SIR_0, SIR_1 and $SIR_{0,1}$ can be calculated by Eqs. (3), (4), and (5) respectively. It is also essential to calculate the probability P_0, P_1 and $P_{0,1}$ as Eqs. (8), (9) and (10) when the MH_i communicates with BS_0, BS_1 or both of them.

$$P_0 = P_r(P_{r0} > P_{r1} + M_{sh}) \tag{8}$$

$$P_1 = P_r(P_{r1} > P_{r0} + M_{sh}) \tag{9}$$

$$P_{0,1} = P_r(P_{r1} - M_{sh} < P_{r0} < P_{r1} + M_{sh}) \tag{10}$$

Then, we can obtain the SIR of MH$_i$ in soft handoff state as

$$SIR = SIR_0 P_0 + SIR_{0,1} P_{0,1} + SIR_1 P_1 \tag{11}$$

More details on SIR calculation in the soft handoff state are given in [7].

3 Simulation Model

We propose that the topology of evaluation consists of FH, BSC, BS$_0$, BS$_1$, and many MHs as shown in Figure 6. If it is assumed that the multiple communication of a MH is with two BSs at most by soft handoff, it can be divided into three zones: the single communication zone of BS$_0$, the single communication zone of BS$_1$ and the multiple communication zone in which the MH communicates with both of them. Among all of MHs, we assume that some are in the single communication area (communicate with BS$_0$ or BS$_1$) and others are in the multiple communication area (communicate with BS$_0$ and BS$_1$ simultaneously) as in a real CDMA cellular networks environment. In addition to these, there is also a MH which is analyzed by performance measures according to the MH state. In this thesis, we used the ns-2 [12] for simulation. However, there were no utilizable CDMA modules available for RLP on the data link layer in ns-2, so we make the RLP modules and use some assumptions to support this thesis. A detailed account of the scheme is given below.

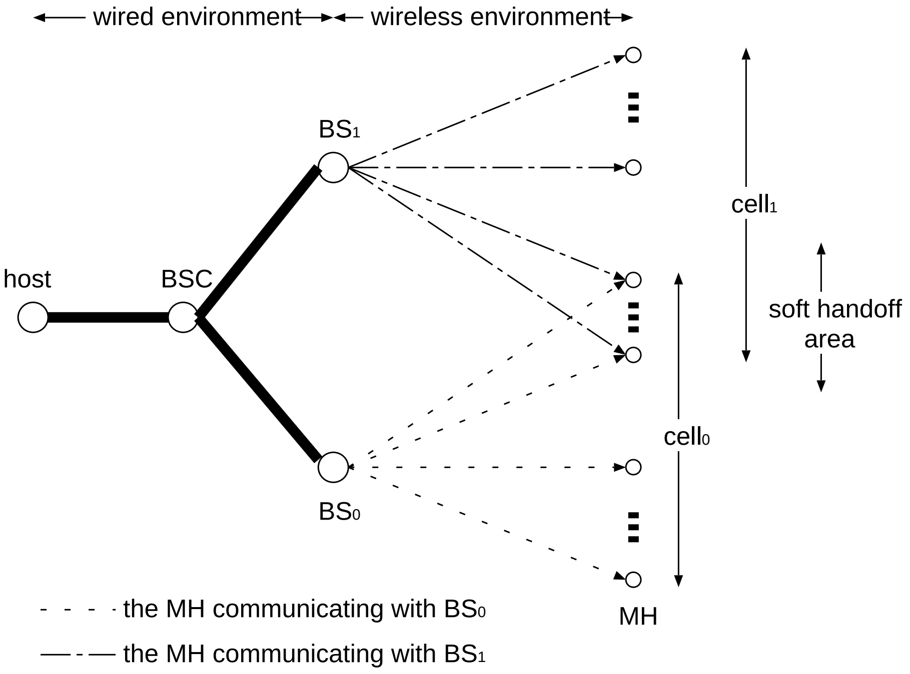


Figure 6: Simulation model

3.1 The Derivation of FER (Frame Error Rate) from SIR

To evaluate the performance of CDMA cellular networks, we must consider the state of transmission data error in both wired and wireless channels. In the wired channel the transmission data error occurs due to traffic congestion, but in the wireless channel it occurs because of the shadow fading effect of the spectrum or huge interference power in the channel. To show the transmission data error of the wireless channel in simulation we use the FER to obtain the state of the wireless channel and to view the TCP packets loss from the TCP layer.

Packets transmission in the WCDMA (Wideband CDMA) is on a common channel or on a dedicated channel depending on the character of packet data traffic (medium or large data amounts). The soft handoff technique can be adopted in a dedicated channel [13] and in the downlink the data modulation method uses QPSK (Quadrature Phase Shift Keying) [14]. The bit error rate B_e for using QPSK [15] in a wireless channel can be expressed as

$$B_e = \frac{1}{2} erfc\sqrt{(SIR)} \tag{12}$$

where, the SIR is the signal to interference ratio that was explained in 2.3.

Assuming r_i is the service bit rate and taking into account that the transmission time of each frame is specified to 10 ms in the WCDMA, the number of bits per frame F_n can be shown as

$$F_n = 10 \times 10^{-3} r_i \tag{13}$$

Based on Eqs.(12) and (13), we can obtain the FER as

$$FER = 1 - (1 - B_e)^{F_n} \tag{14}$$

3.2 The Assumption of RLP in the Simulation

As we discussed in Subsection 2.2, in order to transmit a TCP packet in a radio channel, it is divided into plural frames. Here we make the assumption that one TCP packet is divided into four frames and the sequence number of frames is 1, 2, 3 and 4. The probability of retransmission for each frame can calculated by FER which is introduced in Subsection 3.1.

$$R_{jn} = (1 - FER) \times FER^n \tag{15}$$

where, we use R_{jn} to define the probability of frame j with n retransmissions.

We noted earlier on that the TCP packets are transmitted by RLP frames in wireless channel, so the transmission delay of TCP packet in the wireless channel must be considered with the retransmission of each frame in a TCP packet. As a description of RLP3, the first and second retransmissions can be performed in the first round, and the third, fourth and fifth retransmissions can be performed in the second round. This means that a frame can be retransmitted five times at most when the frame has an error or is missing. In the wireless channel we use the FER to judge how many times the retransmission of the missing frame will be performed, and classify two cases in order to calculate the transmission delay of a frame based on the retransmission of the first round or second round. Assuming $f_{jndelay}$ is the transmission delay of frame j with n retransmissions, f_t is the transmission time of one frame with no errors and $RTT_{wireless}$ is the round trip time between BSC and MH. The transmission delay of a frame can be obtained as follows.

- Case 1: the retransmission of first round

  In the first round, the first and second retransmissions are performed when a frame is dismissed or has an error. The first and second retransmission of the missing frame is performed as shown in Figure 7. We can calculate the transmission delay of a frame performing the first or second retransmission by using Eq. (16)

  $$f_{jndelay} = (j+1) \times f_t + \frac{3}{2} RTT_{wireless} \qquad j = 1, 2, 3, 4 \qquad n = 1, 2 \tag{16}$$

- Case 2: the retransmission of second round

  In the second round, the third, fourth and fifth retransmission are performed if all of

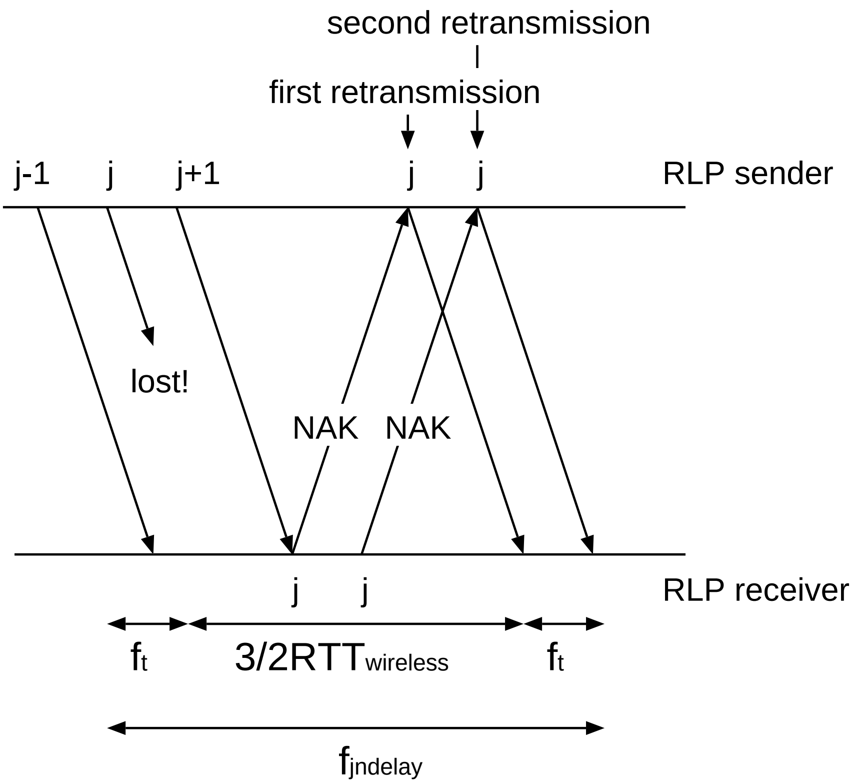


Figure 7: First and second retransmissions in first round

the retransmissions of the missing frame fail in the first round. The retransmission of second round is performed as shown in Figure 8. By using Eq. (17), the transmission delay of the frame that performs the third, fourth or fifth retransmission in the second round can be obtained.

$$f_{jndelay} = (j+4) \times f_t + \frac{5}{2} RTT_{wireless} \qquad j = 1,2,3,4 \qquad n = 3,4,5 \qquad (17)$$

Finally, the transmission delay of a TCP packet can be given with the maximal $f_{jndelay}$ of four frames in the wireless channel.

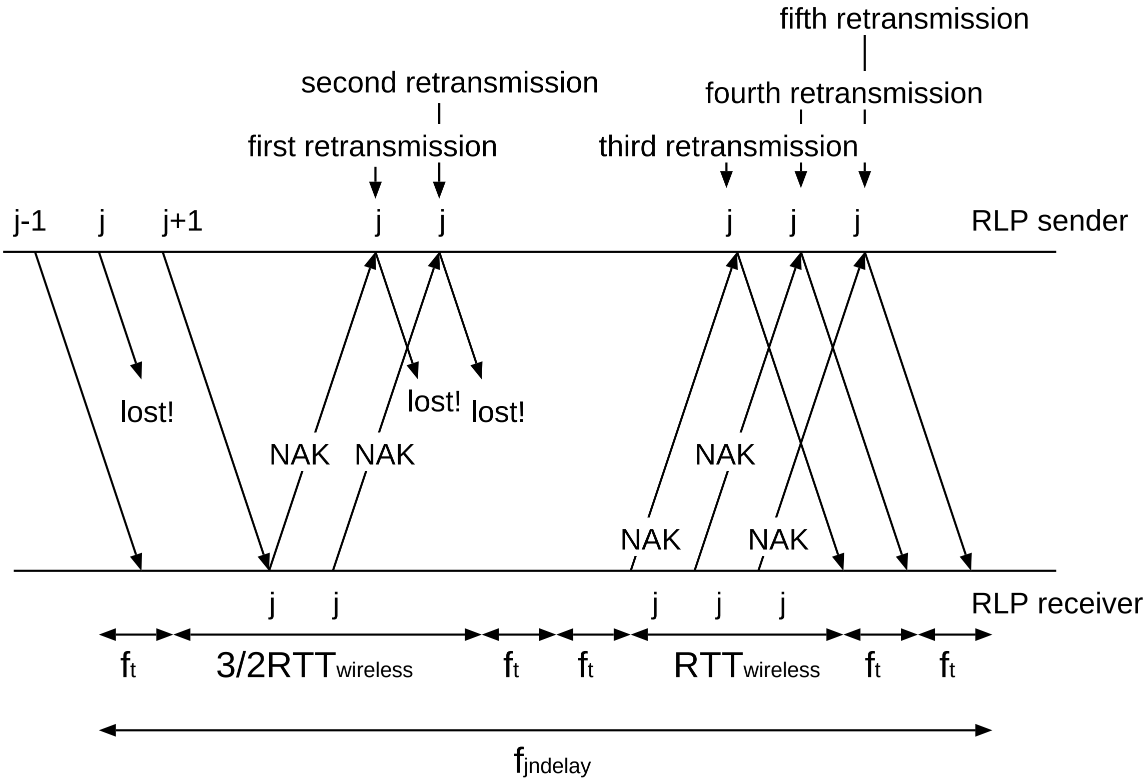


Figure 8: Third, fourth and fifth retransmissions in second round

4 Simulation Results and Discussions

In this section, we show our proposal for evaluating CDMA cellular networks. We assume that the MH state can be divided into the MH in the stationary state and the MH in the moving state during the transmission time. When a MH is in the stationary state, we analyze its TCP performance under the variation of a number of parameters (soft handoff margin, the MH position, MH density and so on). Moreover, we investigate the influence on TCP performance in soft or hard handoff when MH is in the moving state. We will describe the detail of evaluation criterion and present our examination through the simulation results as follows.

As we have mentioned before, the characteristics of the MH signal level become weaker when the MH moves away from a BS for a distance in the CDMA cellular networks and this makes the FER higher. For this reason, our evaluation plan is to increase the interval of equal distance between BS_0 and BS_1 to the MH position every time and to observe the influence of the communicating MH on the TCP throughput by varying the soft handoff margin and the density of MH in each position as shown in Figure 9. Generally, the cell radius in the CDMA cellular networks is 0.5km in the dense urban areas and 20km in the countryside or rural areas. Here, we set the cell at a radius of 2km, therefore the distance between BSs is 4km and the interval of distance between BSs is 0.4km.

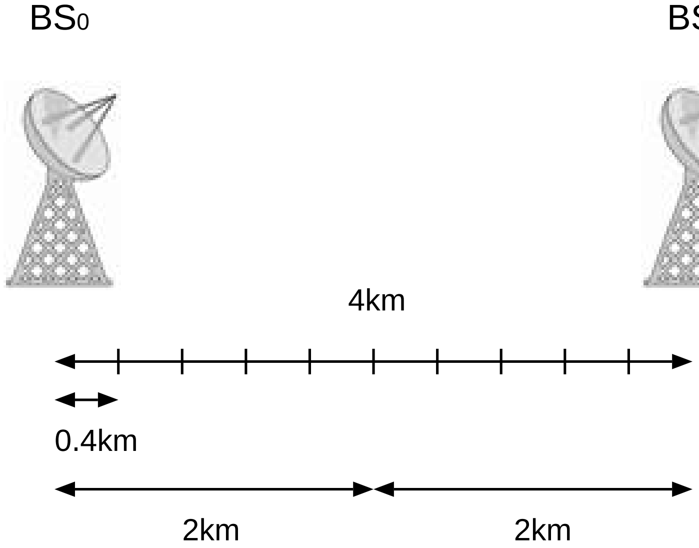


Figure 9: Distance between BSs

Parameters used for the numerical examples are summarized in Table 1. We clarify about the effect of soft handoff under various conditions by changing some parameters. We first give the definition of the following parameters and explain their effect on the TCP performance.

1. MH Position

   In the CDMA cellular networks, since the signal level of MH from BS becomes weaker when MH moves away from the communicating BS, the FER increases. In this case, it can be expected that the RLP frames loss and error occur and the retransmission

Table 1: Parameter Settings

Cell Radius	2 km
MH Speed	2, 20 m/s
MH Position	0.1-0.9
Soft Handoff Margin	0, 2, 4, 8 dB
MH Density	50, 60, 70, 80 MHs par cell
Bandwidth in Wireless Channel	192 kbps
Bandwidth in Wired Channel	10, 1000 Mbps
Propagation Delay in Wireless Channel	50, 100 ms
Propagation Delay in Wired Channel	100, 200 ms
Buffer Size of BSC	10, 1000
TCP Maximum Congestion Window Size	4, 16, 32, 64

of lost frames is requested frequently. This means that it takes more time to transmit a packet, degrading system performance. Here, we define the position of the MH as the ratio of the actual position of the MH to the distance between the BSs. Assuming BS_0 and BS_1 are in the CDMA cellular networks, the MH is in the same position as BS_0 if the position of the MH is equal to 0, and in the same position as BS_1 if the MH position is equal to 1. Similarly, when the MH position is equal to 0.5, this indicates that the MH is in the center, between BS_0 and BS_1.

2. Soft Handoff Margin

The soft handoff margin has a close relationship with the number of MHs which can communicate with plural BSs (we set the maximum number of BSs with which a MH can communicate with to two simultaneously). By the soft handoff , since the MH can not only communicate with the communicated BS but also with another BS of which the signal level is the strongest among the adjacent BSs, the FER can be improved more than by using the hard handoff. However, for a fixed number of MHs per unit area, increase of the soft handoff margin also increases the number of MHs which communicates with one BS. For this reason, the load on the wired channel will increase, the effect of the soft handoff will be suppressed and the TCP performance may deteriorate.

3. MH Density

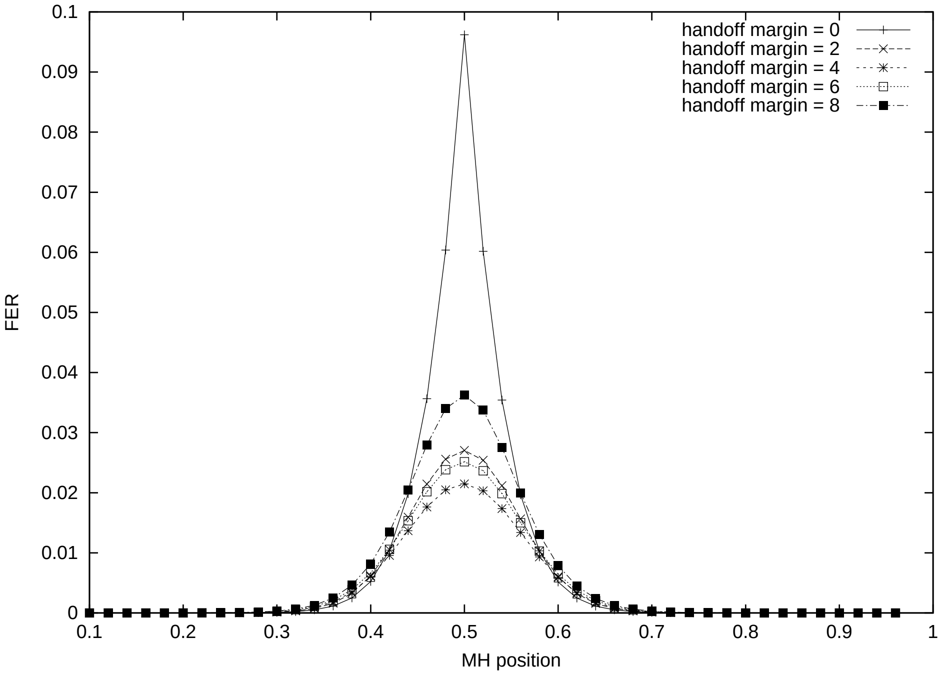
   We define the MH density as the number of MHs per unit area (of one cell). If we increase the MH density, the number of MHs which communicate with a BS also becomes greater. This can also increase the possibility of congestion in the wired channel, degrading the TCP performance.

4.1 The Effect of the Soft Handoff under Various Parameter Conditions

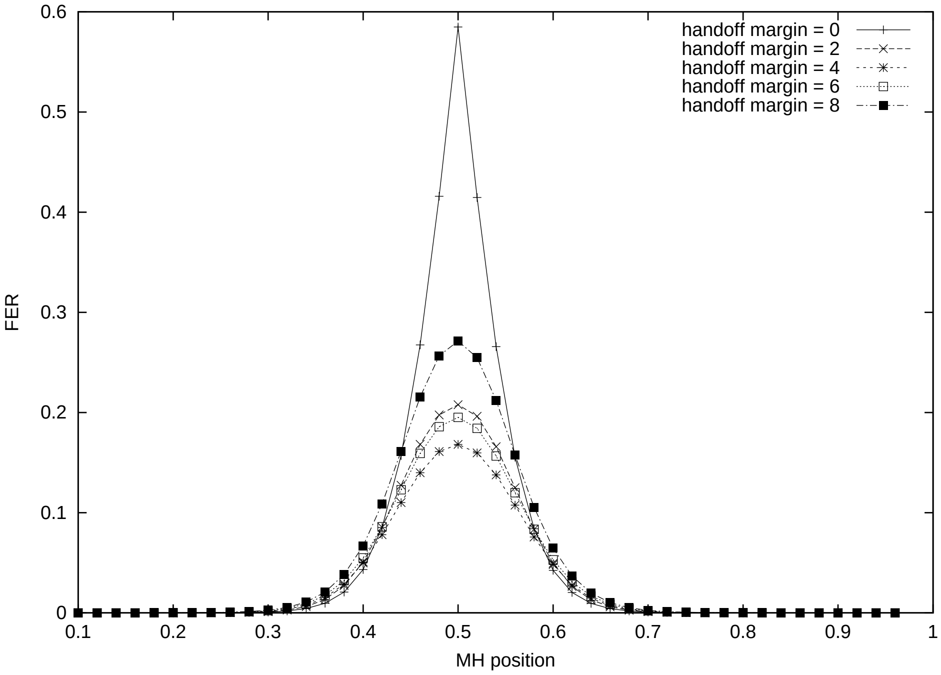
4.1.1 The Capacity of the Wireless Channel

For varying the values of the soft handoff margin, the relations between FER and the MH position are investigated for the cases of the MH densities equal to 50 and 80 as shown in Figure 10(a) and 10(b), respectively. The influence on FER due to the variation of MH MH density is shown in Figure 11.

Figures 10(a) and 10(b) indicate that when the MH is in the boundary area of cell_0 or cell_1 (MH position from about 0.4 to 0.6), the FER of using soft handoff is better than using hard handoff. If the MH density is increased further, the difference in FER between the cases of soft handoff and hard handoff also becomes greater as shown in Figure 11. However, although the FER is better when the soft handoff margin is increased from 2 dB to 4 dB, FER becomes much worse when the soft handoff margin is further increased to 8 dB. When the soft handoff margin was set to 8 dB, it caused the number of MHs communicating with one BS to increase too much. This generates huge interference and the effect of the soft handoff is suppressed.



(a) Density = 50



(b) Density = 80

Figure 10: Relationship between FER and MH position

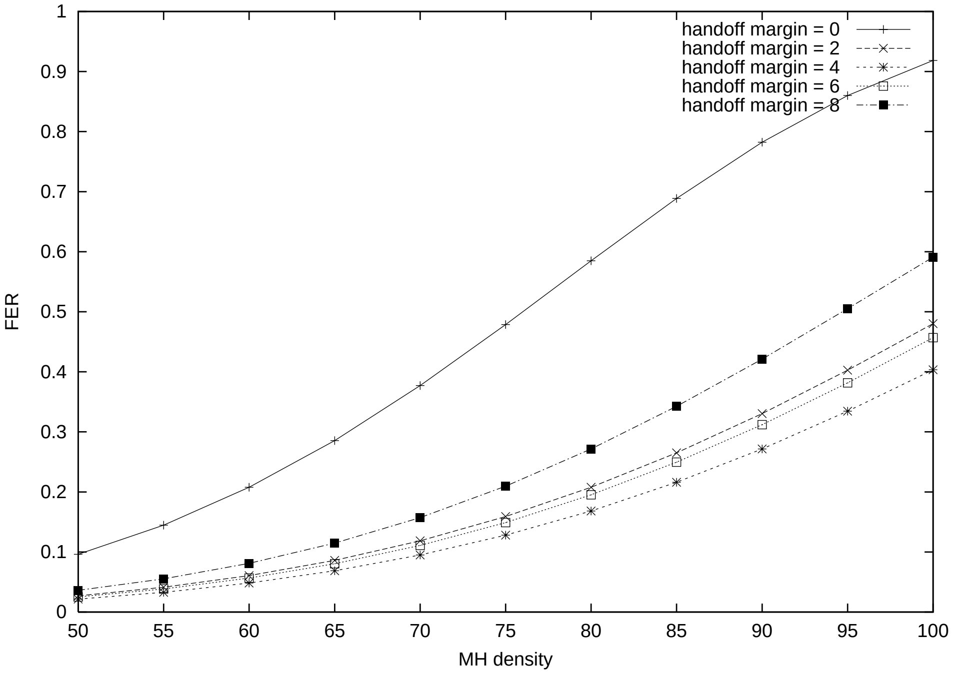
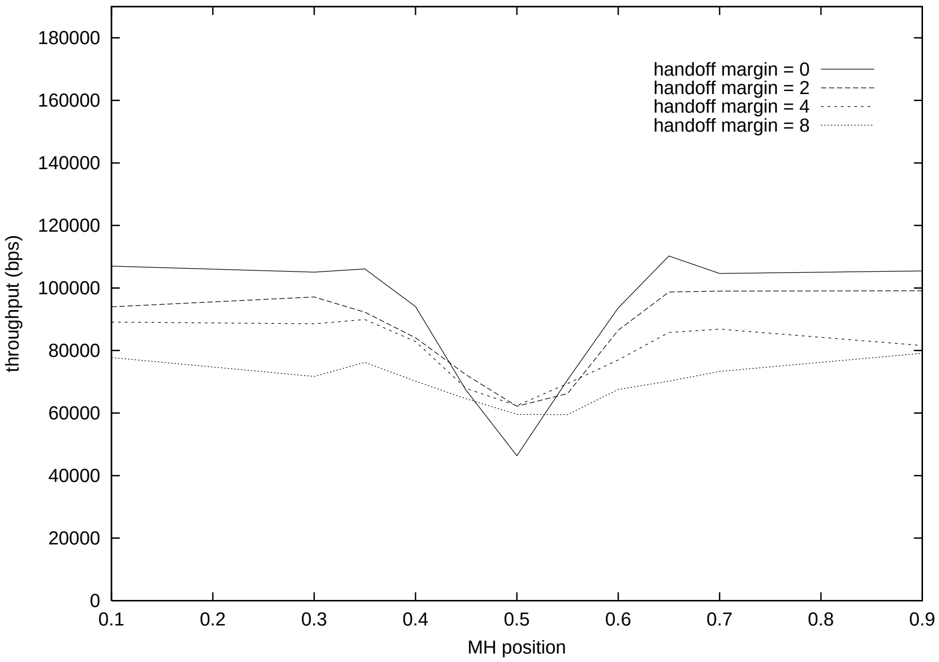


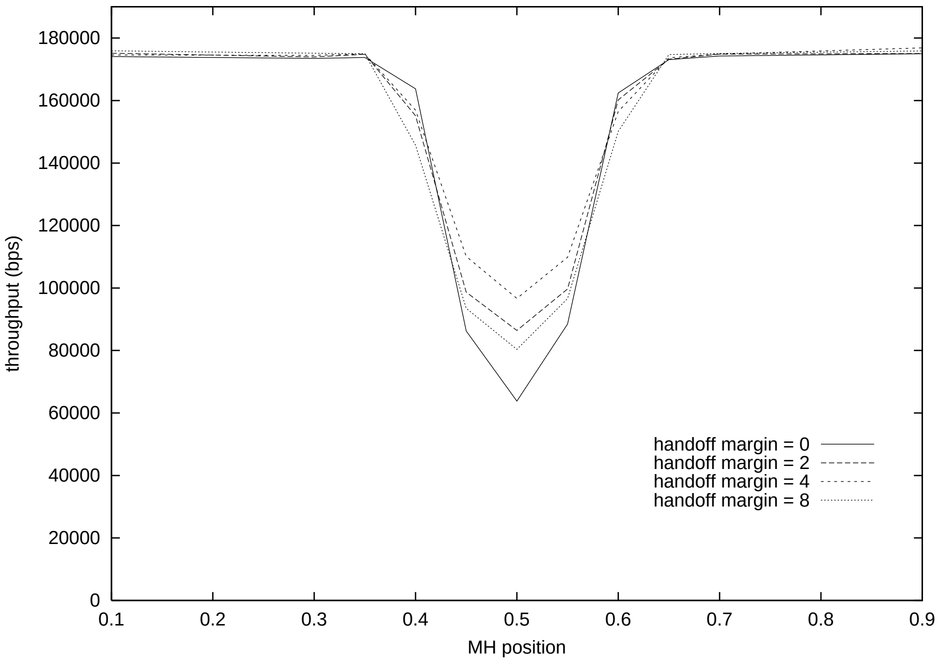
Figure 11: Relationship between FER and MH density for MH position equal to 0.5

4.1.2 In the Case of Variation of Bandwidth in the Wired Channel

If the wired channel bandwidth is insufficient, congestion occurs in the wired channel and it can be expected that the performance of the wireless channel can be affected. Figure 12(a) to 13(b) show that the influence on TCP performance in the cases of adopting the soft and hard handoff depends on the variation of bandwidth in the wired channel. We can observe from Figure 13(a) to 13(b) that the optimal range of soft handoff margin is about 4 dB. Moreover, using the soft handoff can also provide a better quality of communication than using the hard handoff when MH is in the boundary area of the cell (MH position from 0.45 to 0.55). The maximum quantity of throughput that can be improved is about 20kbps when the bandwidth of wired channel was set to 10Mbps as shown in Figure 12(a) and 40kbps when it is set to 1000Mbps as shown in Figure 12(b). Nevertheless, when the wired bandwidth is set to 10Mbps, the quality of communication is worse than that using the hard handoff for MH positions from 0.1 to 0.4 and from 0.6 to 0.9 as shown in Figure 12(a). This is because when the soft handoff margin was increased, the wired channel did not have sufficient bandwidth, and congestion in the wired channel occurs frequently due to the increase in number of MHs communicating with one BS. In this case, although only about half of the capacity of bandwidth in the wireless channel had been utilized and the FER is very low, the bandwidth cannot support the packet transmission of each MH in the wired channel, so the packet error rate becomes higher than that when using the hard handoff. When bandwidth is set to 1000Mbps, this state can be improved because it provides sufficient bandwidth as shown in Figure 12(b).

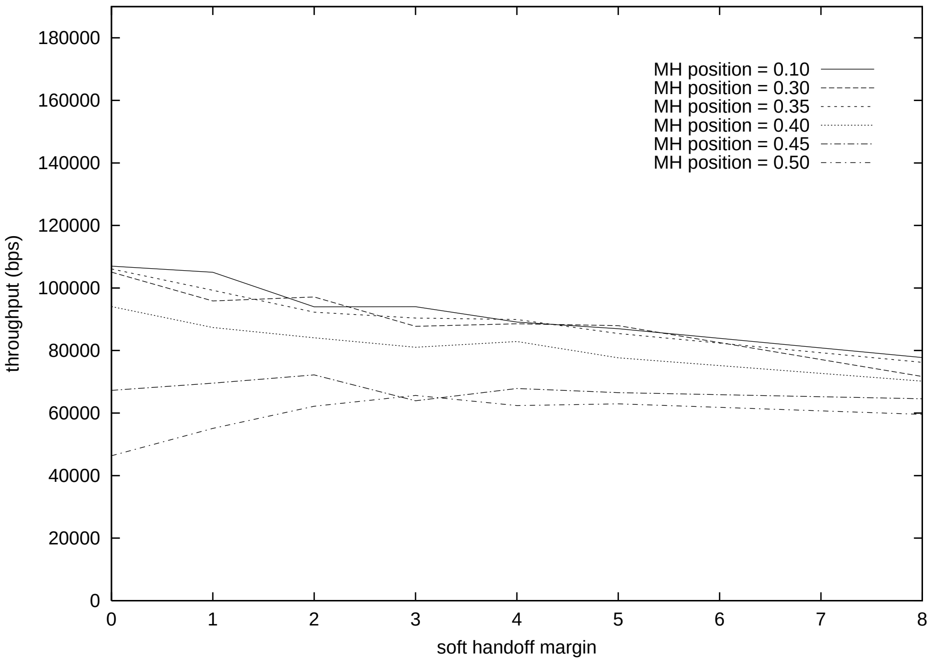


(a) Wired bandwidth=10Mbps

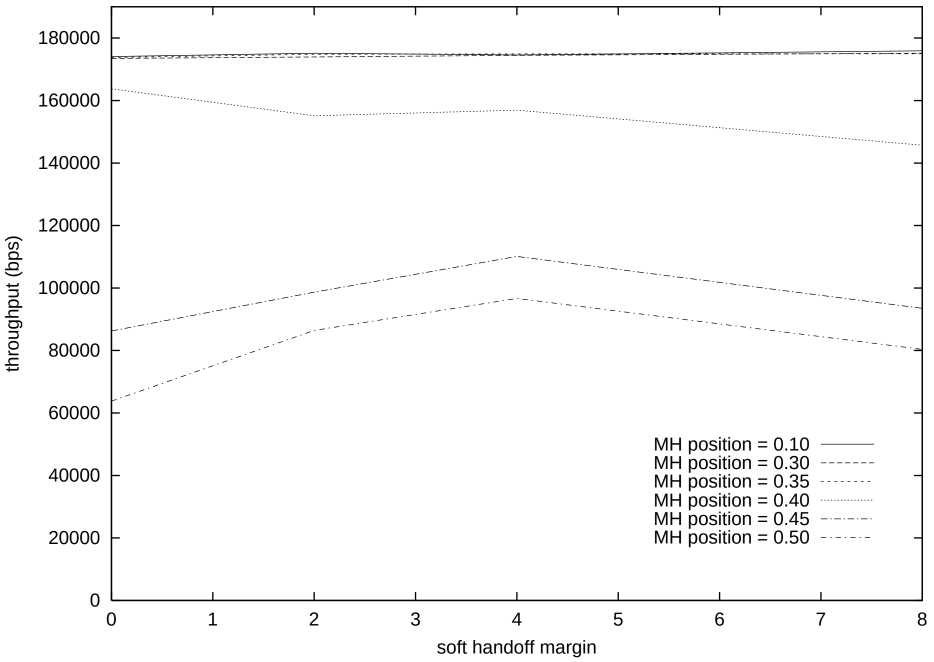


(b) Wired bandwidth=1000Mbps

Figure 12: Effect of wired bandwidth (MH density = 50)



(a) Wired badwidth = 10Mbps



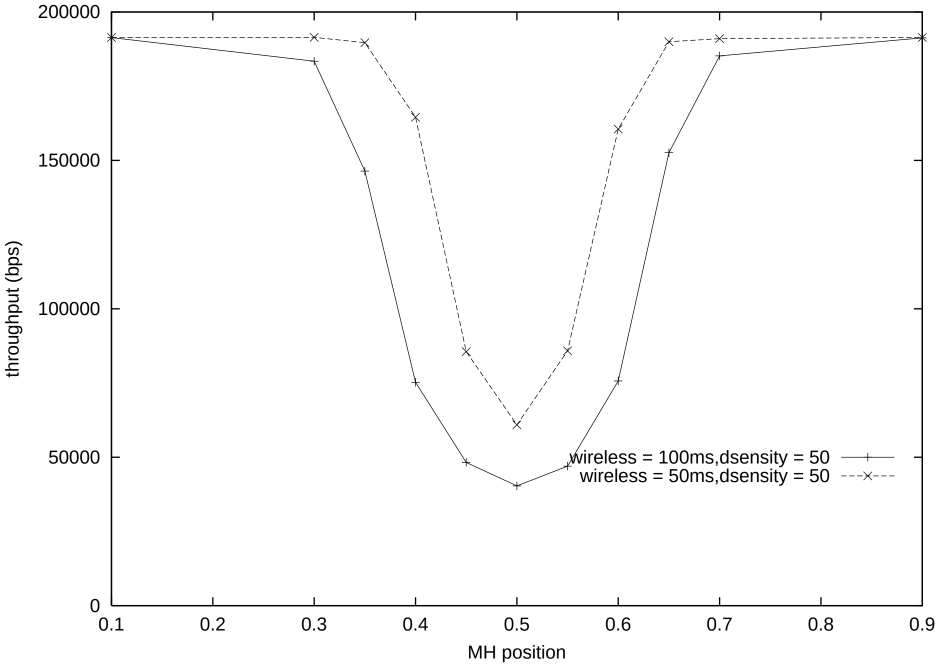
(b) Wired badwidth = 1000Mbps

Figure 13: Effect of Soft handoff margin (MH density = 50)

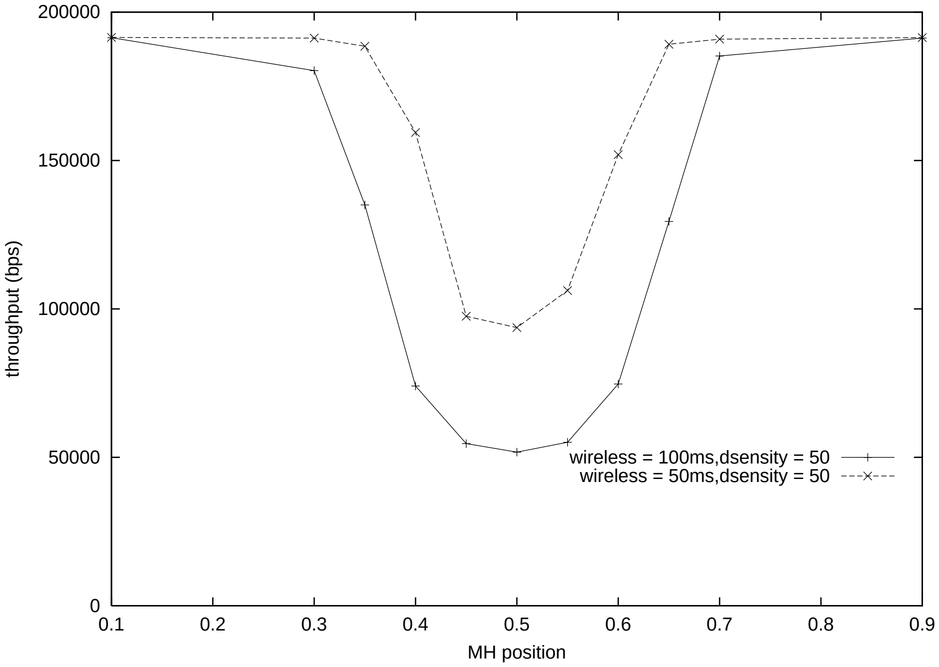
4.1.3 In the Case of Variation of Propagation Delay in the Wireless Channel

When the communication quality between MH and BS is good, in RLP frame transmission, loss or error in RLP frames seldom occurs in the wireless channel, and the influence of propagation delay in the wireless channel is small. However, when the communication quality is poor (high FER), RLP frames error and drop occur and frequent retransmission of RLP frames becomes necessary in the wireless channel. Therefore, the transmission delay of one RLP frame becomes longer. For the upper layer, this means that the transmission delay of a TCP packet also increases.

Figures 14(a) to 14(b) indicate the influence on TCP performance when the wireless propagation delay is set to 100ms. Because the RTT (Round Trip Time) from FH to MH is longer than when the wireless propagation delay is set to 50ms, the throughput becomes slightly smaller. On the other hand, since the MH is in the boundary area of $cell_0$ or $cell_1$, the FER will be higher than in other positions. If the frame error or drop occurs, the retransmission of the frame will be carried out five times at most. In this case, the transmission time of one RLP frame will become longer than when the wireless propagation delay is set to 50ms, so the effect of the soft handoff will be weak.



(a) Hard handoff (Soft handoff margin = 0dB)



(b) Soft handoff (Soft handoff margin = 4dB)

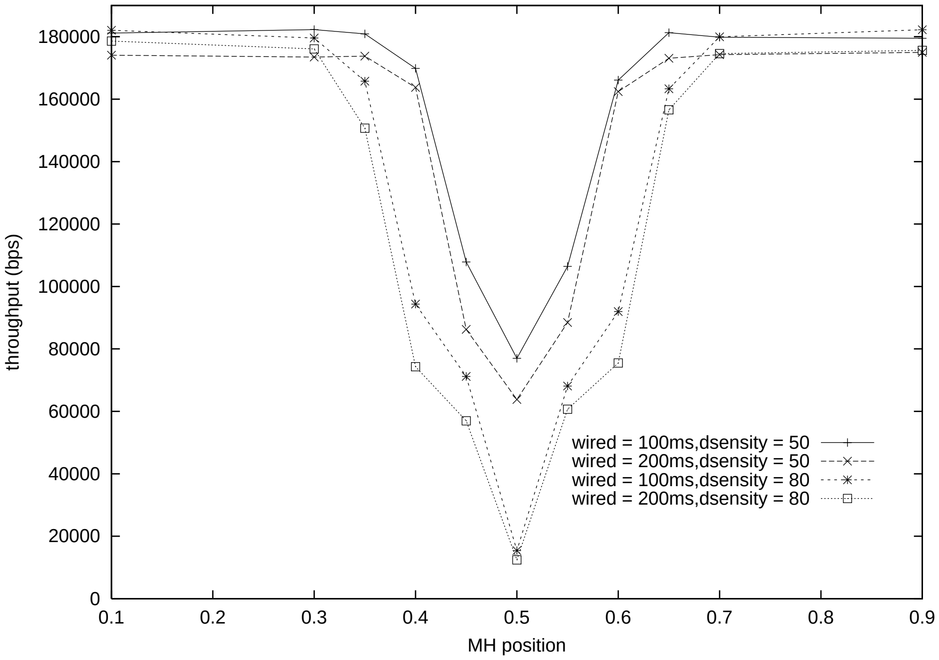
Figure 14: Effect of propagation delay in wireless channel

4.1.4 In the Case of Variation of Propagation Delay in the Wired Channel

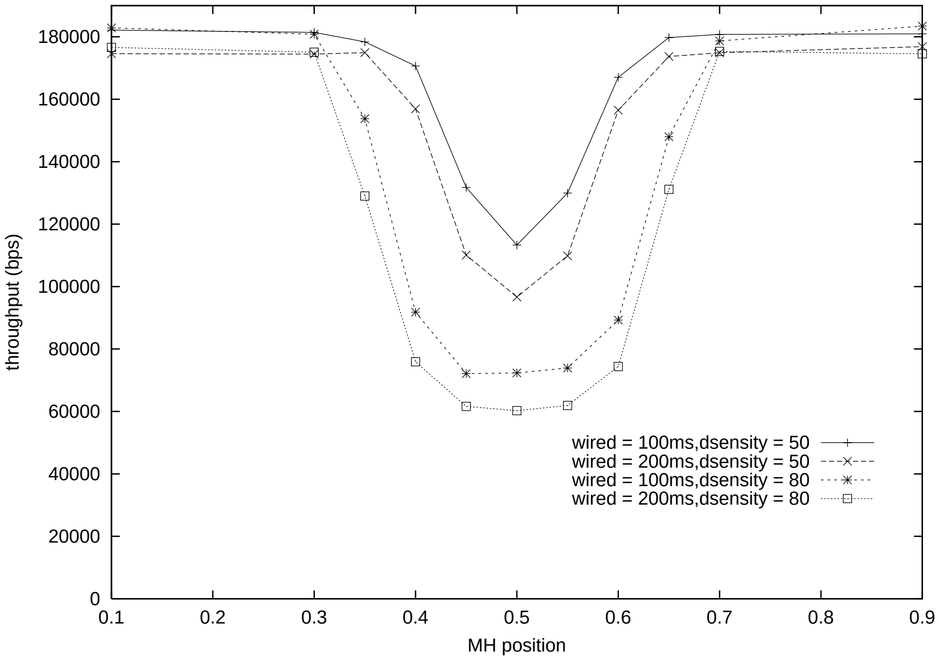
The system throughput can be calculated by Eq. 18

$$\frac{(number \quad of \quad transmitted \quad TCP \quad packet)\times(TCP \quad packet \quad size)}{(total \quad transmission \quad time)} \tag{18}$$

If the propagation delay in the wired channel increases, since the total transmission time of one packet will also become longer, the system throughput will deteriorate. According to Eq.(18), the transmissible number of TCP packets is increased if the propagation delay of the wired channel decreases during the same transmission time, so the throughput will be high. This phenomenon also occurs in the case of wireless channels. Figure 15(a) to 15(b) show that the throughput can be increased by about 10kbps when the propagation delay in the wired channel is changed to 100ms from 200ms.



(a) Hard handoff (Soft handoff margin = 0dB)



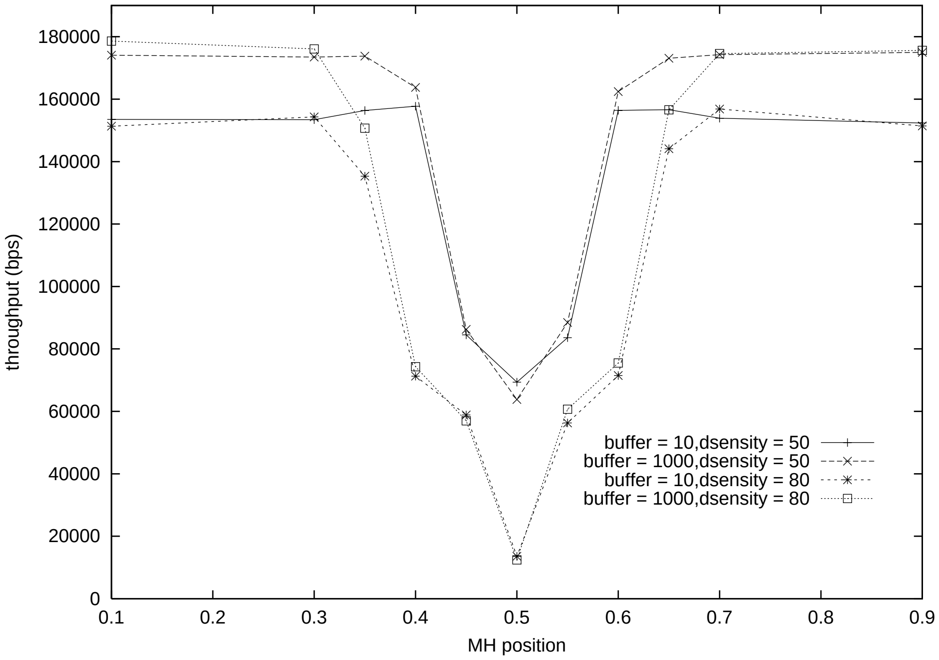
(b) Soft handoff (Soft handoff margin = 4dB)

Figure 15: TCP Performance with variation of propagation delay in wired channel

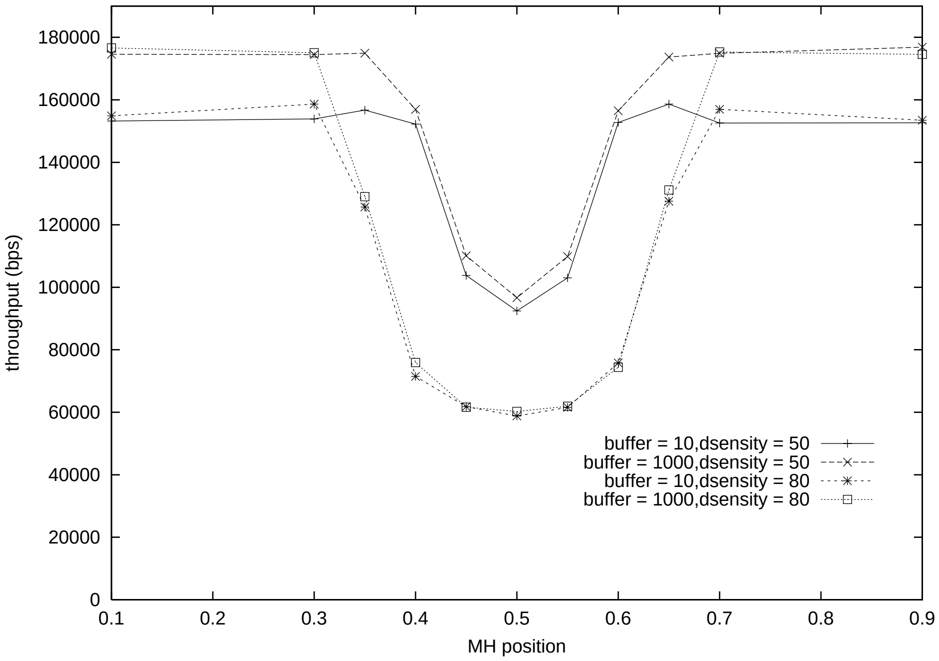
4.1.5 Effect of Buffer Size of BSC

Generally, in the CDMA cellular networks, the wired channel bandwidth is larger than the wireless channel bandwidth. When congestion happens in the radio channel, RLP frame drop and error cause the retransmission of lost RLP frames in the wireless channel. In this circumstance the TCP packet send from FH accumulates in the buffer of the BSC. If the buffer size of BSC is not sufficiently large, the BSC will drop the TCP packet, affecting the system throughput.

Figure 16(a) to 16(b) reveal that the characteristics of the TCP congestion window size cannot be enhanced due to the insufficient buffer size of BSC. Moreover, the retransmission of the RLP frame will be carried out frequently in a wireless channel when FER is high. This causes the transmission time for one TCP packet to be longer. The subsequent packet from FH will be accumulated in the buffer of BSC and if the buffer size of BSC is insufficient, the throughput will decrease due to the drop in the number of TCP packets.



(a) Hard handoff (Soft handoff margin = 0dB)

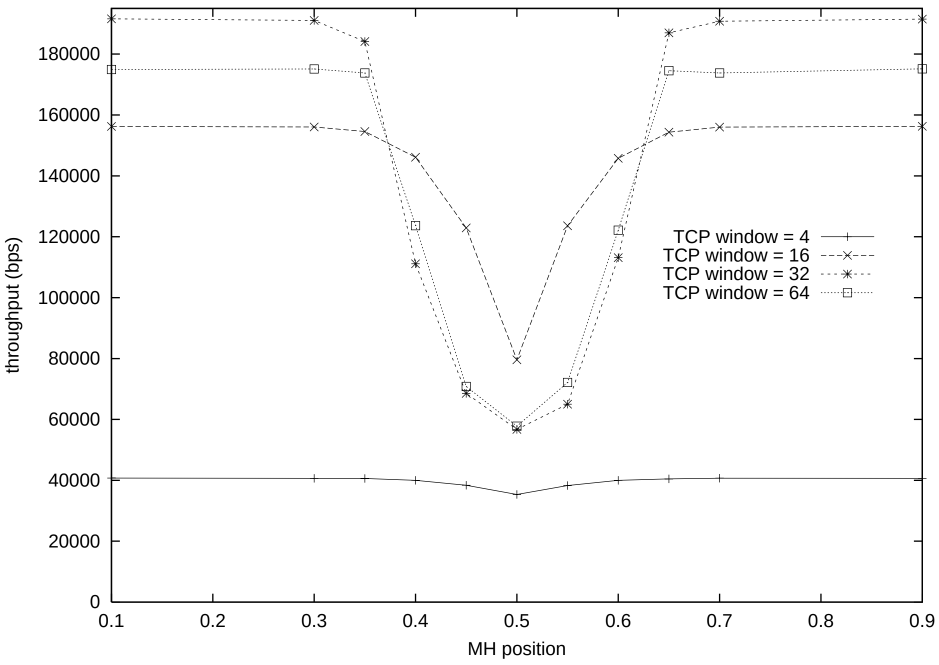


(b) Soft handoff (Soft handoff margin = 4dB)

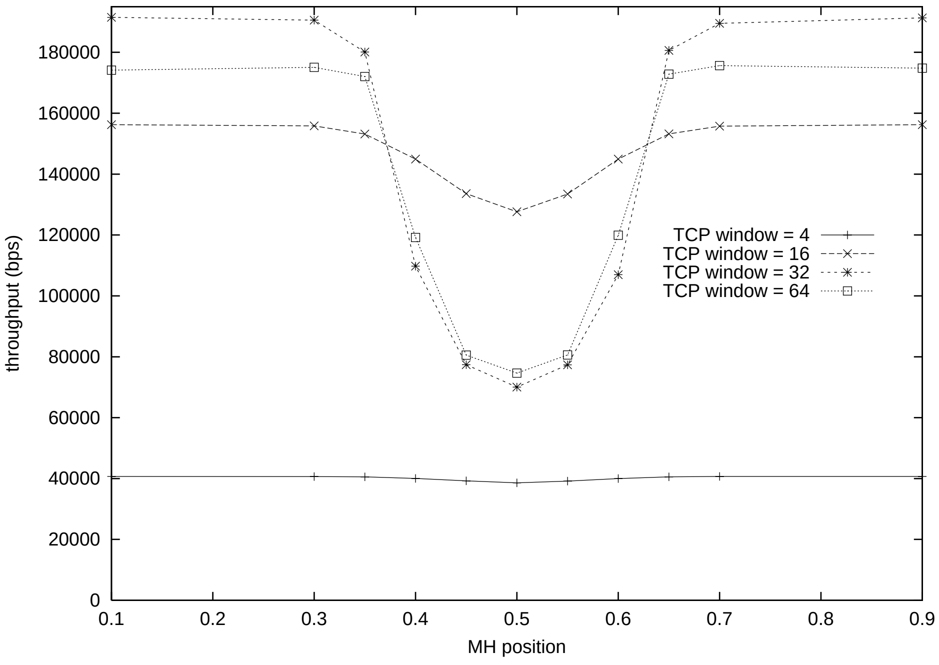
Figure 16: TCP Performance with variation of buffer size of BSC

4.1.6 TCP Maximum Congestion Window Size

In the case that the wired channel has sufficient bandwidth, we can increase system throughput by enlarging the TCP maximum congestion window size. As has been shown before the effect of wireless bandwidth can be utilized completely under the condition of sufficient bandwidth in the wired channel. From Figure17(a) to 18(b), we present the results for the influence on TCP performance for the TCP maximum congestion window sizes of 4, 16, 32 and 64. It can be proven that when the TCP maximum window sizes are set larger, the throughput is also higher. However, when the TCP maximum window size is set to 64, the throughput is lower than that when it was set to 32. The main reason is that the TCP maximum congestion window size could not be kept when it is set to 64. Under this circumstance, the average value of the TCP congestion window size is below 32 due to the drop of TCP packets. On the other hand, when the MH position is between 0.4 and 0.6, the retransmission of the RLP frame is carried out frequently because of the higher FER and the transmission time for a frame also became longer. If the TCP maximum congestion window size is not large, the buffer of BSC can accommodate the subsequent TCP packet from FH. Conversely, if the TCP maximum congestion window size is very large, the throughput will deteriorate because the buffer of BSC cannot accommodate the subsequent TCP packet from FH. Furthermore, it would deteriorate severely if the MH density increases.

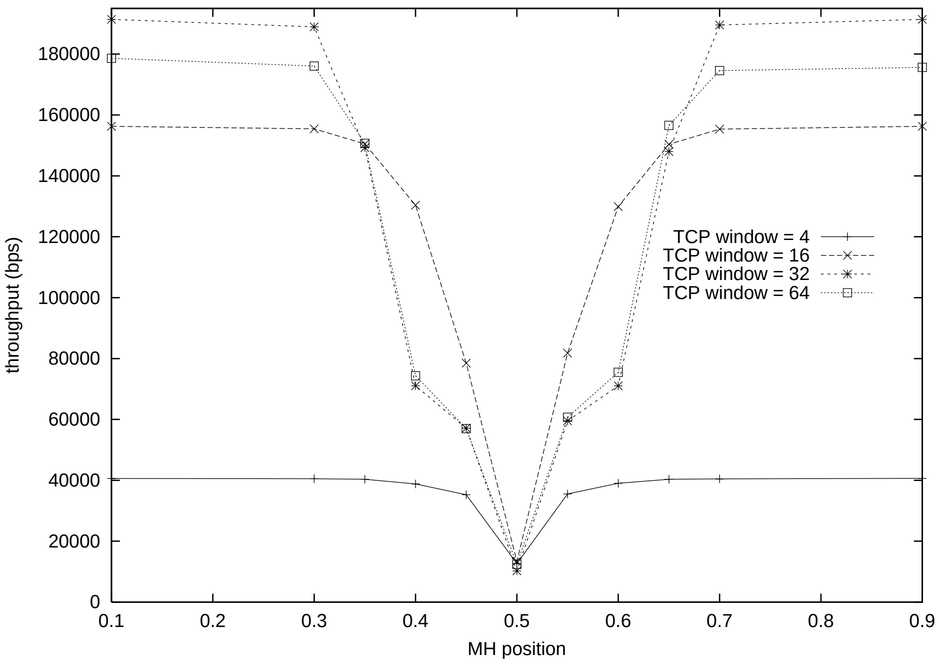


(a) Hard handoff (Soft handoff margin = 0dB)

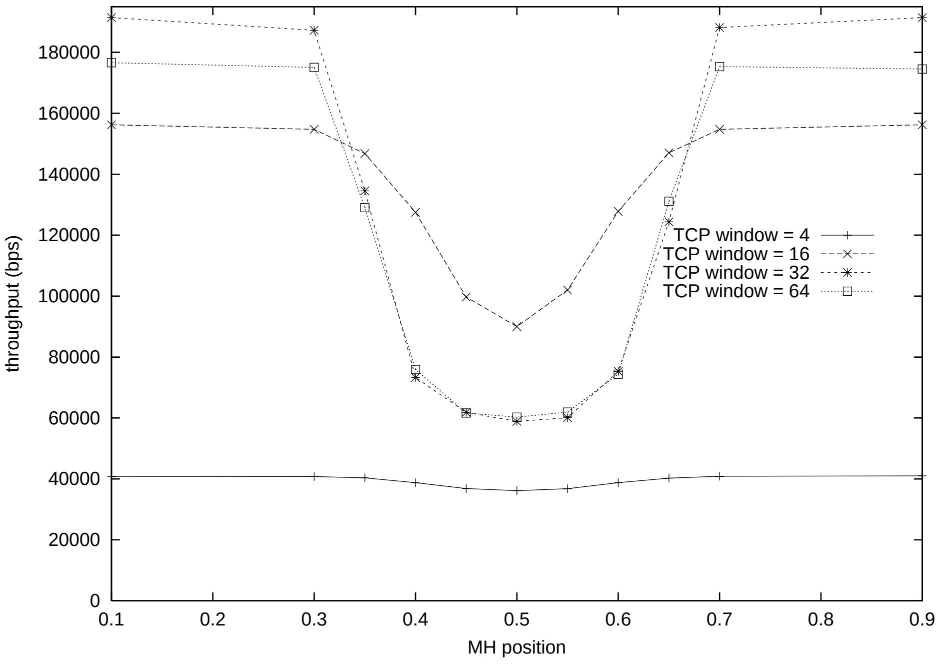


(b) Soft handoff (Soft handoff margin = 4dB)

Figure 17: TCP Performance with variation of TCP maximum congestion window (MH density = 60)



(a) Hard handoff (Soft handoff margin = 0dB)



(b) Soft handoff (Soft handoff margin = 4dB)

Figure 18: TCP Performance with variation of TCP maximum congestion window (MH density = 80)

4.2 The Influence to the TCP Throughput of Communicating MH when the MH is Moving

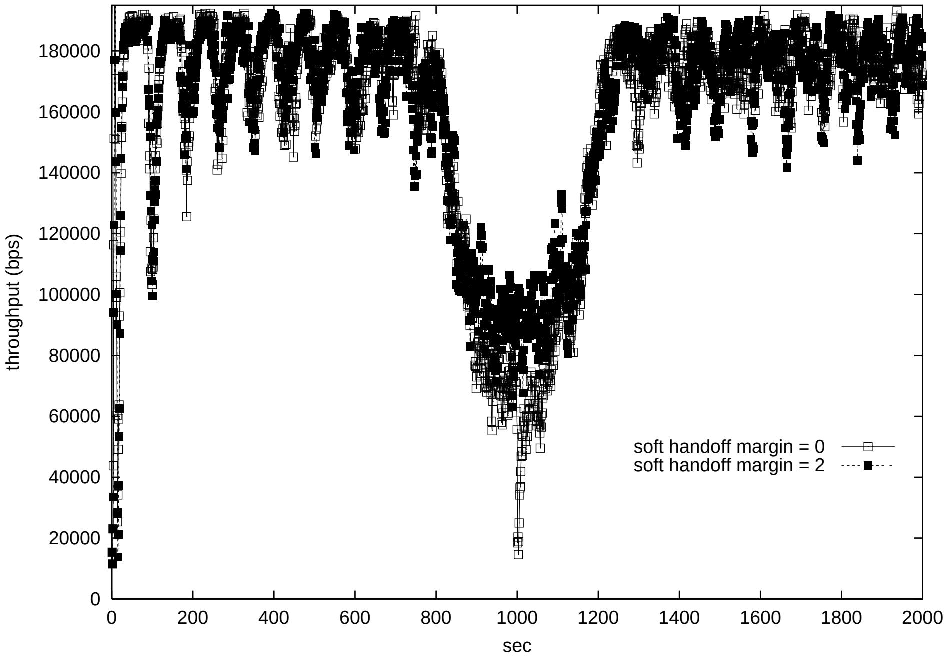
When the MH moves over the boundary of BS_0, the handoff which achieves the change in communication from BS_0 to BS_1 is carried out by the hard handoff . If it is evident from the TCP layer that the TCP connection is cut off once the MH communicates with BS_1, and the connection will be recovered again. Due to this the data transmission stops during the handoff and the throughput of the communicating MH deteriorates. Conversely, since the MH has already entered into a multiple communication zone before it moves over the boundary of BS_0 by the soft handoff, another link which communicates with BS_1 is also established in addition to the link which communicates with BS_0. From then the handoff is carried out with two links. When MH enters into the single communication zone of BS_1, the link which communicates with BS_0 is cut off leaving the link which communicates with BS_1. In this case, the TCP connection will not be cut off when handoff is carried out. We hypothesized that the TCP throughput of the communicating MH is better than in the case of hard handoff.

The optimal parameter can be decided on the basis of the result of the simulation performed when the MH is in a stationary state. Here, we propose two kinds of simulations for the moving MH and both of them are performed using the optimal parameter. We think that the characteristics of hard handoff and soft handoff can be compared through the result of this simulation.

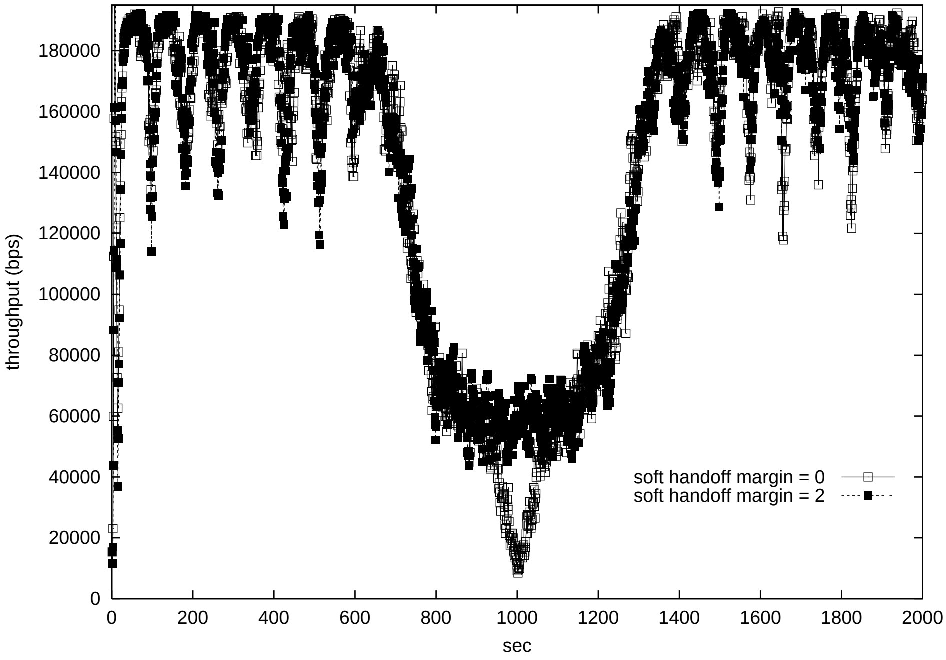
4.2.1 Throughput in Case of the MH Moving at Fixed Speed

In the case of having the same MH density, the number of MHs which communicate with a BS by the soft handoff is greater than the number communicating by the hard handoff . For this reason, when adopting the soft handoff, the FER is slightly worse than with hard handoff before the MH enters into the multiple communication zone. Moreover, adopting the soft handoff causes a greater number of MHs to communicate with a BS, and it can be foreseen that the state of the wired channel also be more congested and the throughput will become lower than when adopting the hard handoff. If the MH density continues to increase, the difference in throughput between adopting the soft handoff and adopting the hard handoff also becomes larger. The analytic target pays attention to the variation of throughput of a moving MH adopting the soft handoff or the hard handoff, depending on whether the wired channel has sufficient bandwidth or does not have sufficient bandwidth respectively.

In this simulation, we assume that the MH moves between BSs at 2 meters per second(about the speed of a person walking) and it takes 2000 seconds to move from the position of BS_0 to the position of BS_1. Moreover, we also set the propagation delays of the wired and wireless channels with the typical transmission environment of the CDMA cellular networks and assume that it has a sufficient bandwidth in the wired channel as shown in Figure 19(a) to 20(b). According to the simulation results, it can be understood that the TCP performance can also be improved when the MH is in the boundary of cell_0 or cell_1 (simulation time from about 900 to 1100 seconds) in using the soft handoff. The optimal soft handoff margin is about 4dB when the MH density is between 50 and 80.

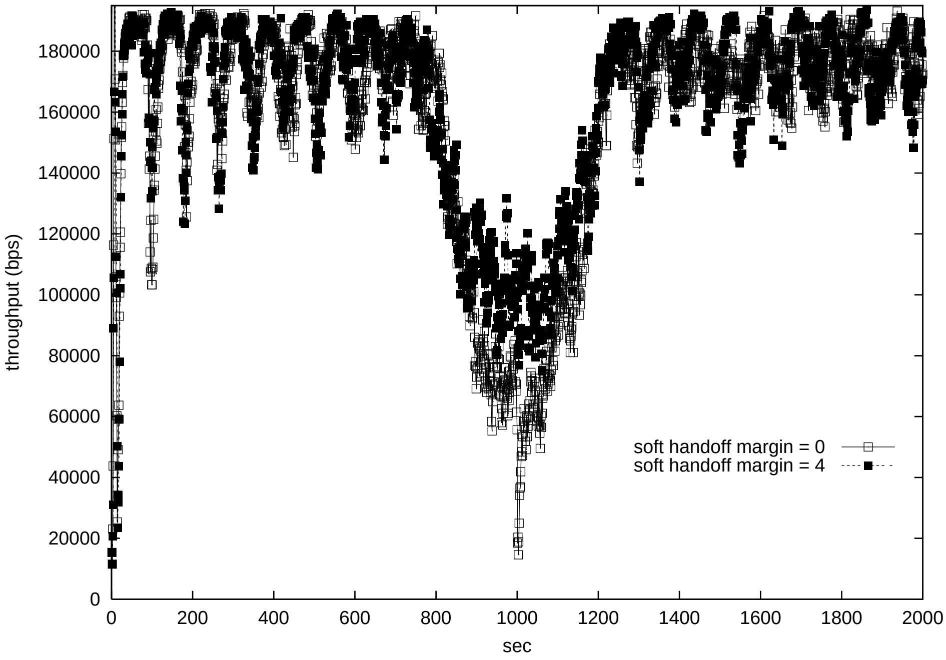


(a) MH density = 50

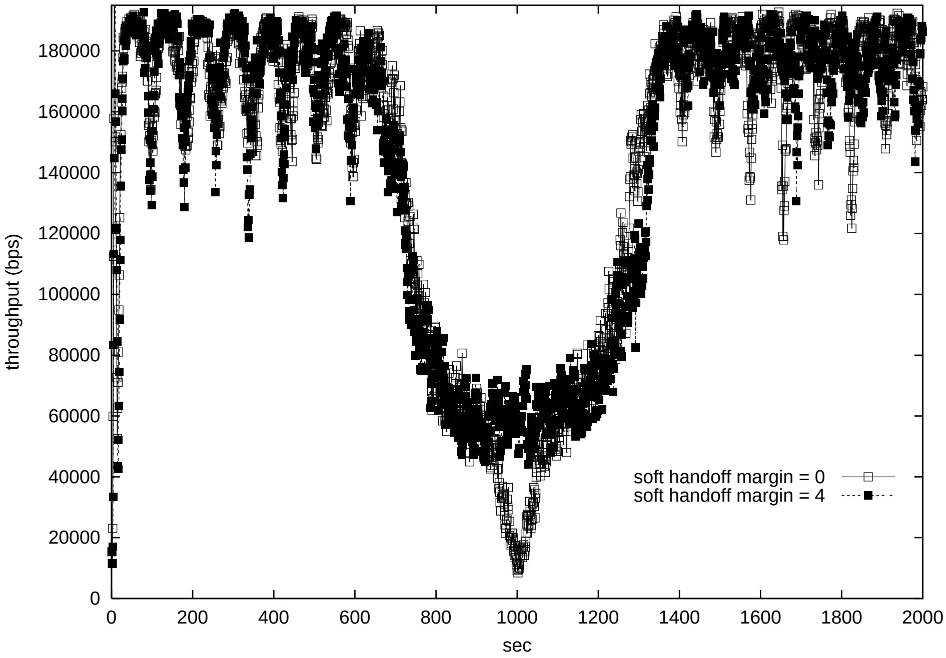


(b) MH density = 80

Figure 19: Relationship between the Hard and Soft handoff when the MH moving (1)



(a) MH density = 50



(b) MH density = 80

Figure 20: Relationship between the Hard and Soft handoff when the MH moving (2)

4.2.2 The Case of the MH Moving Randomly

We consider that MH always executes irregular movement between BSs in the actual state of CDMA cellular networks. In the simulation, we set up the initial MH position to be random and in order to carry out handoff many times, many destinations for movement are also set up. In the soft handoff the TCP connection is not cut off when the communicating MH carries out the handoff many times. We consider that this simulation shows that the merits of the soft handoff outweigh those of the hard handoff.

Supposing that the MHs are distributed over the cell and the MH moves between BSs for a long period of time, the influence on TCP performance of using the hard and soft handoff can be shown as Figure 21. Here, in order to make the MH perform handoff many times, we set the occurring probability of handoff as 0.01. This means that the average time of MH stay in a cell is about 100 second. We can observe the merit of using soft handoff, as it prevents the connection from being cut off and decreases the FER in the case that the MH is the boundary area of a cell.

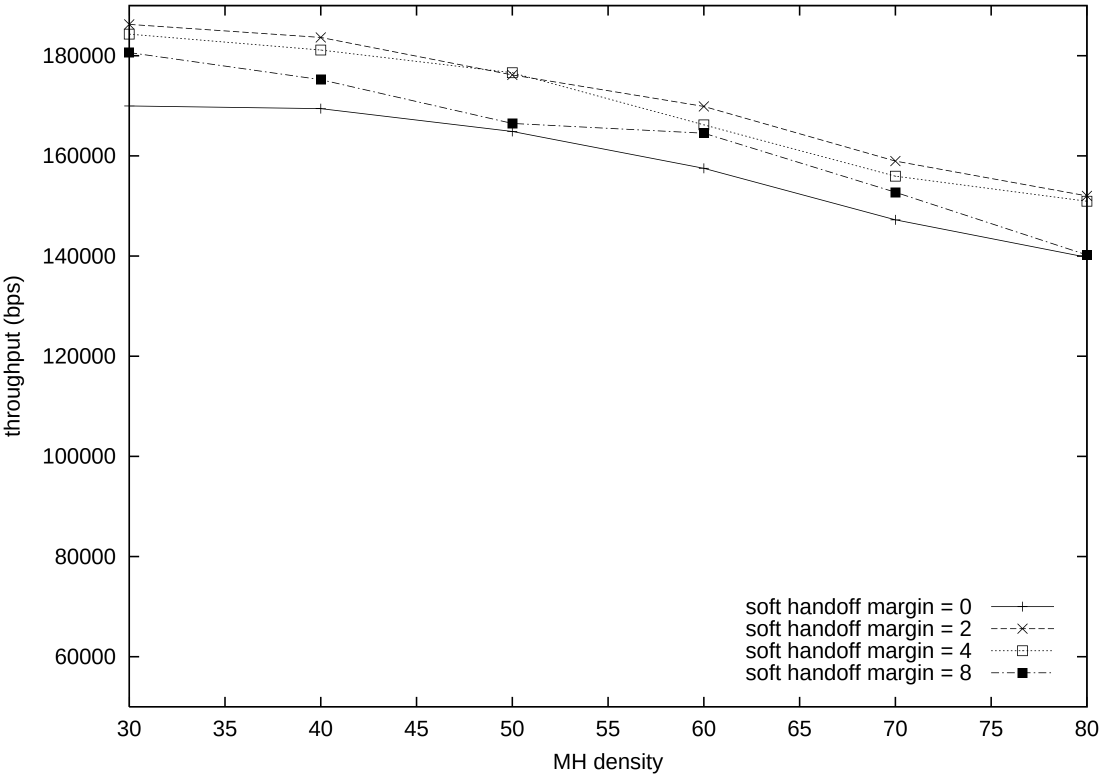


Figure 21: Average Throughput in case of MH moving randomly

5 Conclusion

In this thesis, we offered a method of simulate the MH in the soft and hard handoff states and compared the influence on TCP performance based on a consideration of the integrated evaluation of both wired and wireless channels for system design. We analyzed the FER based on RLP with the use of both soft and hard handoff and using the result we evaluated the TCP performance with varying the CDMA cellular networks environment.

According to our simulation result, the optimal soft handoff margin had little variation it is about 4dB. We also found that the TCP throughput deteriorated with the increase of soft handoff margin when the MH in the single communication zone and it could be improved by achieving sufficient bandwidth in a wired channel. On the other hand, when variation of the propagation delay is in a wireless or wired channel, the transmission time of one TCP packet is also changed, which will affect TCP performance in using soft handoff. Moreover If the buffer size of BSC is not sufficient large or the TCP maximum congestion window is too large, the BSC will drop TCP packet, affecting the system throughput when using the soft handoff.

Finally, we showed the merit of using soft handoff, as it prevents the connection from being cut off and decreases the FER to enhance the TCP performance in the case of MH moving around the boundary area of cell.

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