Impact of Soft Handoff on TCP Throughput over CDMA Wireless Cellular Networks

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***Abstract*— In CDMA 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 paper, we evaluate the influence of soft handoff on TCP (Transport Control Protocol) throughput in CDMA cellular networks through simulation experiments. 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.**

I. Introduction

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. 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 (Mobile Hosts) at the boundary of a cell increases, if the soft handoff is adopted, the number of connections to the BS (Base Station) 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, however, most research has focused on evaluating the performance of voice communication in CDMA cellular networks

On the 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 (Transmission Control Protocol) is a reliable end-to-end transport protocol and can be tuned to perform well in wired networks. However, in the wireless channel, because of the characteristic of high FER (Frame Error Rate), the performance of TCP is severely affected [1].

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. It is because soft handoff affects both the wired portion of a network, and the wireless portion. In this paper, we propose a model for the simulation of the RLP (Radio Link Protocol) of data link layer in wireless channel and the method to decide the transmission delay of a packet from TCP layer. We perform simulation experiments and according to the result it can be clarified which parameters have an influence on the TCP performance when soft handoff is adopted. 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.

This paper is organized as follows. Section II describes the fundamental composition of CDMA cellular networks and the transmission of the TCP packet in the wireless channel. Section III explains our simulation model. Section IV shows the results of our evaluation by simulation, and Section V presents our conclusions.

II. System Description

A. Network configuration

The logical elements of typical CDMA cellular networks are a FH (Fixed Host), a BSC (Base Station Controller), 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. 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.

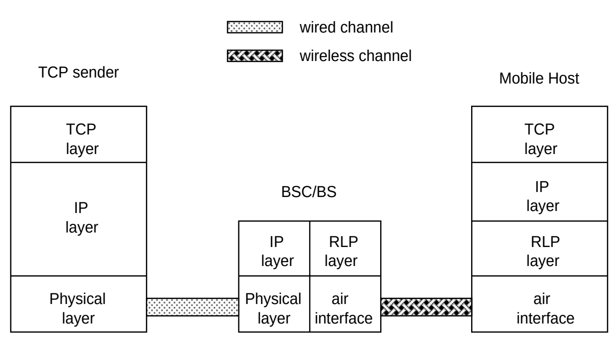


Fig. 1. Protocol stack in CDMA cellular networks

Taking into consideration the TCP data packets transmission in the CDMA cellular networks, the simple protocol stack is depicted in Figure 1. 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.

B. Calculation of SIR

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 through buildings, mountains or other obstructions. Taking this into consideration, the propagation attenuation of the downlink 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 component, 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 is tha 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 power, the calculation of SIR can be shown as Eq. (2) [2]:

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

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

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

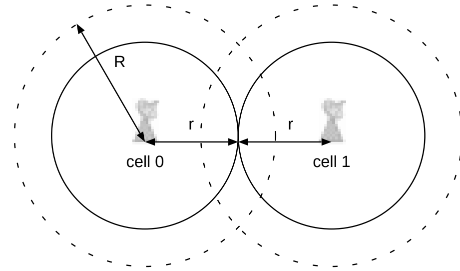


Fig. 2. Definition of the Soft handoff margin

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;

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

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

2) 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 2 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 3, 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 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. 3.

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.

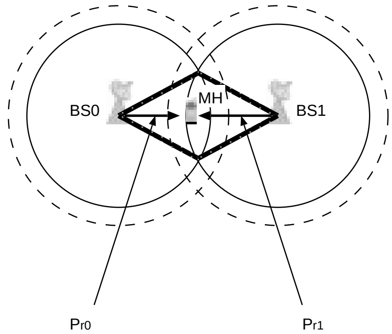


Fig. 3. Relationship between the two nearest BSs with which a MH communicates

(8), (9) and (10) when the MH_i communicates with BS_0, BS_1 or both of them.

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

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

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

Then, we can obtain the SIR of MH_i in soft handoff state as

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

More details on SIR calculation in the soft handoff state are given in [3].

C. RLP (Radio Link Protocol)

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 [4] and in the downlink the data modulation method uses QPSK (Quadrature Phase Shift Keying) [5]. The bit error rate B_e for using QPSK [6] in a wireless channel can be expressed as

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

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

$$F_n = 10 \times 10^{-3} r_i \quad (13)$$

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

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

In a wireless channel, because of the fading effect and the characteristics of the spectrum, the probability of transmission error is higher than in a wired channel. To provide shielding from receiving error frames, the use of NAK (Negative Acknowledgment) based RLP in CDMA cellular networks has been proposed [7], [8]. 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.

Here we make the assumption that one TCP packet is divided into four frames and the sequence number of four frames is 1, 2, 3 and 4. The probability of retransmission for each frame can calculated by FER.

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

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

We noted earlier on that th TCP packets are transmitted by RLP frames in wireless channel, so the transmission delay on 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 retransmission 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 fjn 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 retransmission are performed when a frame is dismissed or has an error. The first and second retransmission if the missing frame is performed as shown if Figure 4(a). We can calculate the transmission delay of a frame performing the first or second retransmission by using Eq. (16).

$$f_{jn} = (j+1)f_t + \frac{3}{2}RTT_{wireless} \quad j = 1, \ldots, 4; \quad n = 1, 2 \quad (16)$$

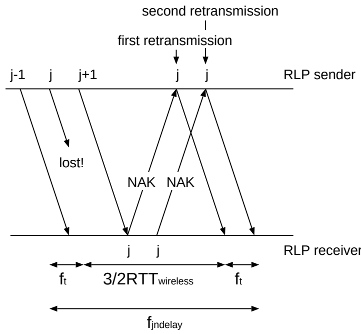
Case 2: the retransmission of second round

In the second round, the third, fourth and fifth retransmissions are performed if all of the retransmission of the missing frame fail in the first round. The retransmission of second round is performed as shown in Figure 4(b). 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.

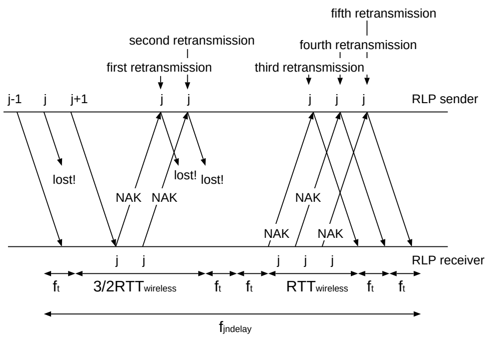
$$f_{jn} = (j+4)f_t + \frac{5}{2}RTT_{wireless} \quad j = 1, \ldots, 4; \quad n = 3, 4, 5 \quad (17)$$

III. Simulation Model

We propose that the topology of evaluation consists of FH, BSC, BS_0, BS_1, and many MHs. 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



(a) First and second retransmission



(b) Third, fourth and fifth retransmission

Fig. 4. Retransmission of missing frames in RLP

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 this paper, we used the ns-2 [9] 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 introduce some assumptions to derive the packet delay.

In this simulation, we derive the frame error rate of RLP according to SIR. Here we make the assumption that one TCP packet is divided into four RLP frames. The probability of retransmission for each frame can be calculated by FER. 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. Then we calculate the transmission delay of a frame based on the retransmission of the first round or second round. Due to lack of space we do not present the formulation of analysis.

IV. Simulation Results and Discussions

In this section, we show our proposal for evaluating CDMA cellular networks. Here, we define the position of the MH

TABLE I

Parameter Settings

Cell Radius	2 km
Bandwidth in Wireless Channel	192 kbps
Bandwidth in Wired Channel	1000 Mbps
Propagation Delay in Wireless Channel	50 ms
Propagation Delay in Wired Channel	100 ms

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. We also define the MH density as the number of MHs per unit area (of one cell). Parameters used for the numerical examples are summarized in Table I.

We first show the effect of soft handoff margin on FER at the terminal located in the border of a cell in Figure 6. We can see the FER is better when the soft handoff margin is increased from 2 dB to 4 dB. However, 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.

Figure 7 expresses the throughput by the position of a MT for every soft handoff margin. In this figure, it turns out that the case where a soft handoff margin is 4dB is the optimum at the MT located near the border of a cell (MH position = 0.45 and 0.5). However, it is shown in the terminal near the center of a cell that it is almost uninfluential. Figure 8 shows the relation between the position of a terminal and TCP throughput for every hand off margin. It became clear from this result that a throughput improves by performing a suitable soft hand off near the circumference of a cell.

We next show the simulation result in the case of a MH moving at random between cells and repeating handoff many times. We set up the initial MH position to be random and the average time of MH stay in a cell is 100 second. The influence on TCP performance of using the hard and soft handoff can be shown as Figure 9. We can observe the effect of prevention of disconnection by the soft handoff has the largest case where a soft handoff margin is 2dB. That is, even if it performs a soft

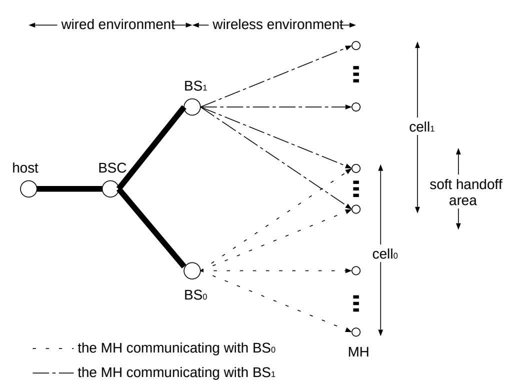


Fig. 5. Simulation model

handoff more than it, a throughput deteriorates by the increase of interference or the load of wired portion.

V. Conclusion

In this paper, 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, we 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. Moreover, 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.

Acknowledgments

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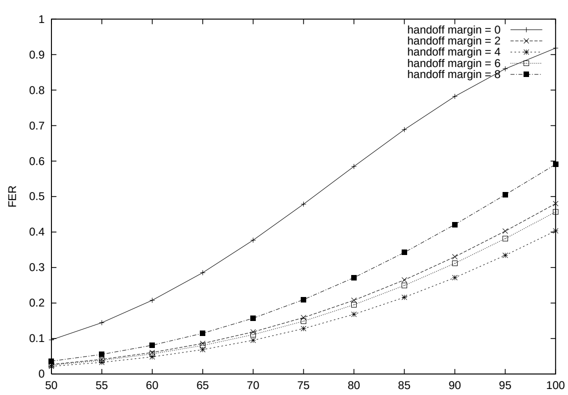

Fig. 6. Relationship between FER and MH density

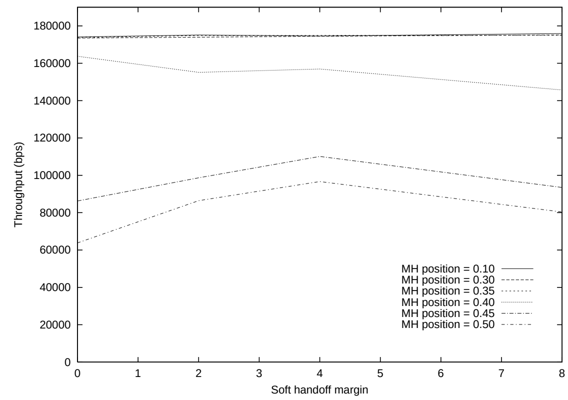

Fig. 7. Effect of soft handoff margin (MH density = 50)

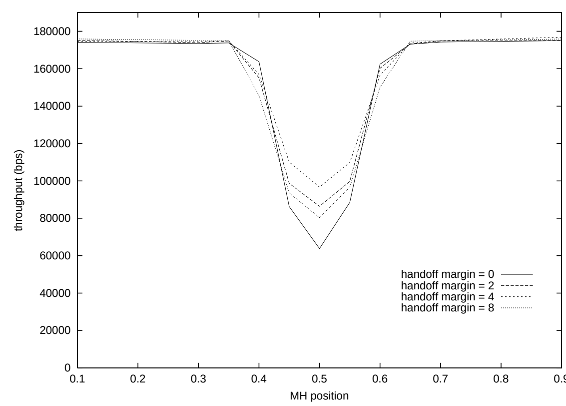

Fig. 8. Variation of the TCP throughput by the position of a terminal (MH density = 50)

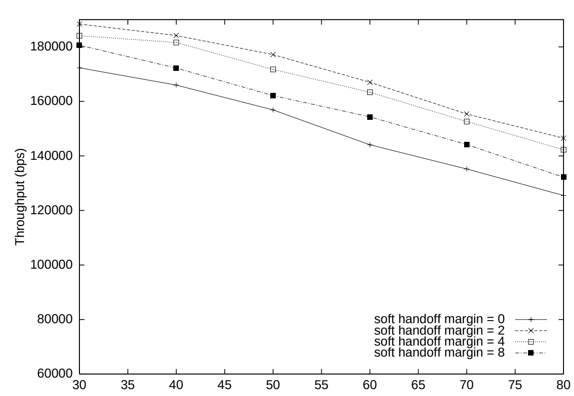

Fig. 9. Average Throughput in case of MH moving randomly