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Call Connection Control in CDMA-Based Mobile Networks with Multiple Frequency Assignments

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Abstract

CDMA-based mobile networks with multiple FAs (Frequency Assignments) can inherently provide soft handoff as well as hard handoff. Then, there naturally arises a trade-off between soft handoff and hard handoff. To deal with this problem, this paper proposes an efficient call connection control scheme that is capable of handling the handoff requests in a flexible way. The performance of the proposed scheme is analyzed using the Markov chain and some numerical results are provided.

Keywords

Handoff, CDMA, Mobile Networks, Connection Control, Wireless ATM

Performance of Information and Communication Systems U. Körner & A. Nilsson (Eds.)

1 INTRODUCTION

Mobile communication systems eventually aim at providing mobile end users (stations) with seamless multimedia service. To this end, wireless ATM (Asynchronous Transfer Mode) is being considered as one of the most promising technologies that enable mobile stations to communicate in a high-speed asynchronous mode [1]. However, it seems practically impossible to adopt ATM on the air interface in the current PCS (Personal Communication System) or the upcoming IMT-2000 (International Mobile Telecommunications for the 2000's). The IMT-2000 system shall be deployed in conjunction with ATM, but its wireless access still relies on the wide-band CDMA (Code Division Multiple Access) which extends the transmission bandwidth of the existing CDMA. Thus, for the time being, the CDMA is expected to play an important role in the operation of mobile communication systems.

The main advantage of CDMA is that the so-called soft handoff is allowed during the mobile's handoff. Compared with the hard handoff, the soft handoff inherently offers mobile stations the better QoS (Quality of Service) by providing the seamless communication service. From the system's point of view, it also provides the better performance in terms of cell coverage area and reverse link capacity [2]. Soft handoff can be supported only when the same FAs (Frequency Assignment) are available between two adjacent cells. Let us suppose that base stations are equipped with multiple FAs. If the target base station can provide the same FA as the one currently used by the mobile station, soft handoff can be activated. Otherwise, the handoff request must be rejected or can still be accepted as being the hard handoff. Rather than rejecting the handoff request, it may be desirable to switch it to hard handoff.

From the above statements, we see that there exists a trade-off between soft handoff and hard handoff. If soft handoff is emphasized, the QoS of the individual connection will be improved. However, the handoff blocking probability will increase due to the low utilization of wireless channels. On the contrary, if hard handoff is emphasized, the handoff blocking probability will be lowered at the expense of the QoS of each connection. Thus, by carefully controlling the amount of hard handoff, the overall network performance may be improved. For this purpose, this paper proposes an efficient call connection control scheme for the CDMA-based mobile networks where multiple FAs are available at base stations. The main purpose of the proposed scheme is to obtain the satisfied network performance by adjusting the ratio of soft handoff and hard handoff.

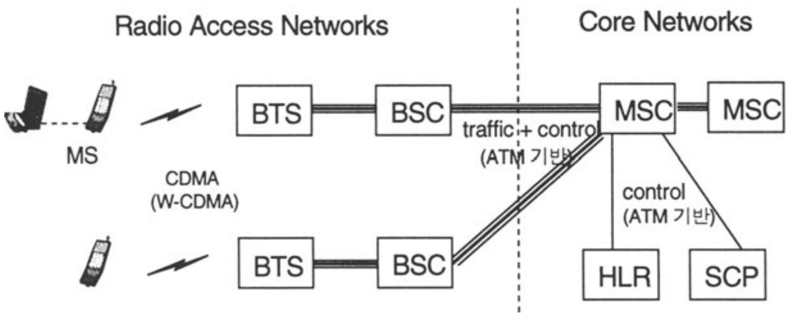
This paper is organized as follows. Section 2 introduces an example of the CDMA-based mobile networks with their wireless FAs. In Section 3, we review the general handoff procedure of the mobile system. In Section 3, the proposed call connection control scheme is also described. In Section 4, the performance of the proposed scheme is analyzed using the Markov chain and some numerical results are provided. Finally, we conclude this paper in Section 5.

2 SYSTEM MODEL

2.1 Network architecture

The general architecture of the CDMA-based networks for IMT-2000 is shown in Figure 1. The whole network is hierarchically constructed and consists of two parts: the core network and the radio access network.

As shown in the Figure 1, switching entities such as MSC (Mobile Switching Center) are physically interconnected with each other on a point-to-point link and comprises a core network. A series of BSCs (Base Station Controllers) and BTSs (Base Transceiver Systems) are connected to the MSCs through the radio access networks. Both user traffics and control information are exchanged between MSC and BTS/BSC using the ATM-based transport layer. On the other hand, only control information is transferred between the HLR (Home Location Register) and SCP (Service Control Point) based on the ATM. HLR and SCP manage the location information of mobile stations and the control information of intelligent service, respectively.



MS : Mobile Station BTS : Base Transceiver System BSC : Base Station Controller
MSC : Mobile Switching Center HLR : Home Location Register SCP : Service Control Point

Figure 1 Example architecture of IMT-2000 network.

The wide-band CDMA is being considered for wireless access protocol of the IMT-2000 systems. In the IMT-2000, the base stations would support a various sizes of cell (e.g. macro cells, micro cells, and pico cells) depending on traffic conditions. The size of cells tends to be smaller to attain higher capacity in emerging wireless mobile networks. With the smaller size of cells, handoff would occur more frequently than ever and must be carefully handled to avoid the performance degradation due to itself. Moreover, the QoS required by some multimedia connections may put more strict restrictions on the performance of handoff process.

2.2 Wireless channels

The 2 GHz (1.885~2.025 GHz, 2.110~2.200 GHz) frequency bands are assigned for the IMT-2000. In the IMT-2000, the maximum transmission speed may vary from a few hundred kbps to Mbps (pico cell: 2 Mbps, micro cell: 384 Kbps, macro cell: 144 Kbps) depending on the current situation of mobile stations (e.g., location, moving speed, type of service, etc.). To cope with these varieties, the system will be implemented with several different frequency bands (1.25/5/20 MHz). As of this writing, the detailed layout of frequency allocations for the IMT-2000 has not been available. Instead, we show the channel structure of CDMA-based PCS that are already implemented in Korea. Basically, one FA is allocated to each cell. However, in an urban area, multiple FAs (e.g. 2FA, 3FA) can be given to accommodate high volumes of user traffics.

Down-link channels of PCS can be divided into two: broadcast channels for control information and traffic channels for user information. The broadcast channel is composed of pilot channel, sync channel, and paging channel. Since the system is based on the CDMA, mobile stations are able to differentiate between logical channels with the unique code assigned to each channel. These codes are known as the Walsh code and have orthogonal properties among themselves.

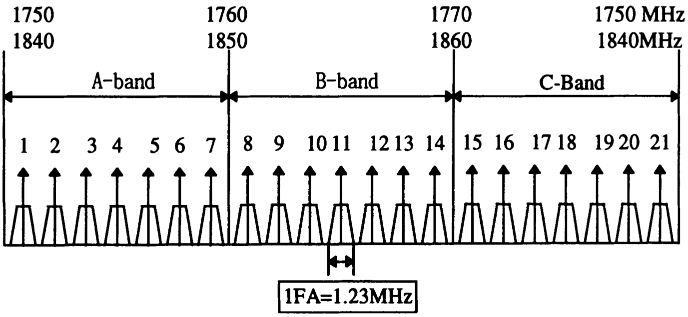


Figure 2 Frequency assignment of PCS in Korea.

2.3 Handoff process

The conventional handoff requires the mobile station to break the ongoing connection with the currently communicating base station before establishing a new connection with the target base station (break before make). This hard handoff is widely used in the existing analog/digital cellular systems. On the other hand, with the soft handoff, the mobile station can commence its communication with the target base station without interrupting the ongoing connection (make before break).

In the CDMA-based mobile networks with multiple FAs, soft handoff as well as hard handoff may exist to enhance the utilization of wireless access channels. The generalized inter-BTS handoff process can be summarized as follows;

1) If a mobile station detects the strength of the pilot signal received from the

adjacent base station beyond a certain threshold while communicating, it notifies this information to BSC via BTS.

2) The BSC then sends to the target BTS the soft handoff request that the same FAs be assigned as the one used by the origin BTS.
3) The target BTS makes the reservation of the requested FA and acknowledges the soft handoff requests back to the BSC. If the channel in the same FA is not available, hard handoff is invoked by reserving a channel on the different FA.
4) The BSC sends back the results to the mobile station and the mobile station takes a proper action according to this response. That is, for the soft handoff, the mobile station adds another wireless channel with the target BTS and communicates simultaneously with the two BTSs. For the hard handoff, the mobile station disconnects the current connection and establishes a new connection with the target BTS.

3 CALL CONNECTION CONTROL

From the step (3) of the handoff process described in the previous section, we know that the soft handoff is preferably invoked over hard handoff. The handoff request is switched to hard handoff only when there are no available channels on the requested FA. Suppose that only soft handoffs are allowed to exist. Then, the handoff blocking probability will be adversely affected due to the asymmetrical occupancy of calls on different FAs. On the other hand, if the hard handoff is allowed, the corresponding connection must be disconnected and the retransmission of data is unavoidable. In this case, the handoff blocking probability can be smaller at the expense of the deteriorated QoS of individual connection.

To deal with the above-mentioned trade-off between soft handoff and hard handoff, this paper proposes a new call connection control scheme that provides more flexible handling of the handoff process. The main purpose of the proposed scheme is to let the system fully exploit the advantages of soft handoff while retaining the occurrence of hard handoff within the acceptable level. To do this, the proposed scheme keeps the occupancy of each FAs balanced among themselves by maintaining the difference of ongoing calls among the FAs below the given threshold. Of course, this threshold directly affects the system performance (e.g. handoff blocking probability and call blocking probability etc.) and should be carefully chosen.

For the sake of convenience, we restrict our focus on the case that there are only two FAs available for each base station. In addition, two different cases can be considered depending on the existence of handoff queues: with queues and without queues. Figure 3 illustrates the proposed scheme using pseudo code. In the Figure 3, n_1 and n_2 represent the number of active calls in each FA, respectively, and q_1 and q_2 the number of waiting handoff calls in each FA's queue, respectively. T is the threshold that determines the execution of hard handoff and is called the hard handoff threshold hereafter.

```
/* Handoff without Queue */

if (NEW CALL) then
    if (n1<n2)
            admit call to FA1
    else if(n1>n2)
            admit call to FA2
    else
            admit call randomly to FA1 or FA2

else if (HANDOFF CALL)
    if (|n1-n2|<T)
            soft handoff
    else
            hard handoff


/* Handoff with Queue */

if (NEW CALL) then
    if (Empty Queue)
            if (n1<n2)
                    admit call to FA1
            else if (n1>n2)
                    admit call to FA2
            else
                    admit call randomly to FA1 or FA2
    else
            reject call

else if (HANDOFF CALL)
    if (|q1-q2| < T)
            soft handoff
    else
            hard handoff
```

Figure 3 Call connection control scheme.

4 PERFORMANCE ANALYSIS

4.1 Queuing model

We investigate the performance of the proposed call connection control scheme. Here, we only describe an analysis for the one with handoff queues. To simplify our analysis, we assume that the mobile network operates under the homogeneous traffic conditions [3]. That is, all cells have the same total number of channels. Each mobile station in the network has the same new call rate, handoff rate, and call holding time, all of which are independent each other. The new call arrivals follow an independent Poisson process with the mean rate λ in each cell. The handoff call arrivals also follow an independent Poisson process with the mean rate Γ in each FA. The call holding time is distributed exponentially with the mean $1/\mu$. The sojourn time of every mobile station in a cell is also assumed to be exponentially distributed with mean $1/\gamma$. Note that γ represents the handoff rate of each mobile station.

Based on the above assumptions, the proposed call control scheme can be modeled as a queuing system as shown in Figure 4. All the servers in the system are partitioned into two groups according to the number of FAs and handoff queues are provided for each FA.

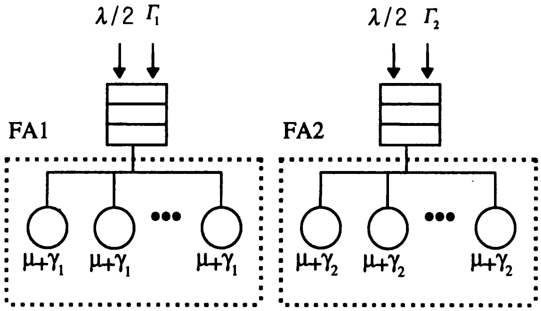
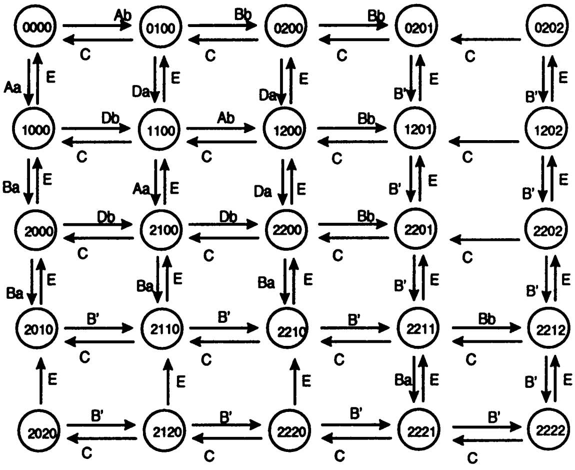


Figure 4 System model with queue.

Now we start our analysis with the birth-death process. Then channel occupancy of each FA can be described in a 4-dimensional space as follows;

$$S = (n_1, n_2, q_1, q_2), 0 \le n_1, n_2 \le c,\ 0 \le q_1, q_2 \le b$$

where c is the total number of wireless channels in each cell, b is the size of queue in each FA, n_1 is the number of occupied channels in FA1, n_2 is the number of occupied channels in FA2, q_1 is the number of handoff requests waiting in FA1's queue, and q_2 is the number of handoff requests waiting in FA2's queue. However, making use of the operational relationships between wireless channels and handoff queues, the above 4-dimensional state space can be reduced to the 2-dimensional one.



$Aa = \lambda/2 + \Gamma_1$ $Ba = \Gamma_1$ $Da = \lambda + \Gamma_1$ $E = j(\mu + \gamma_1)$ $B' = \Gamma_1 + \Gamma_2$

$Ab = \lambda/2 + \Gamma_2$ $Bb = \Gamma_2$ $Db = \lambda + \Gamma_2$ $C = i(\mu + \gamma_2)$

Figure 5 A Markov chain for a particular cell

Figure 5 describes an example of state transition diagram in a particular cell with T=1, c=2, and b=2. Let $\pi(n_1, n_2, q_1, q_2)$ denote the steady-state probability of the state (n_1, n_2, q_1, q_2) in the Markov chain. Then there exists a flow equilibrium equation for each state. In words, the total rate of flowing into a state will be equal to that of flowing out from it. Since the total number of states is $(b+c+1)^2$, we obtain $(b+c+1)^2 - 1$ linearly independent flow equations. By solving the above 2-dimensional birth-death process from the chosen linearly independent equations combined with the normalization condition (the sum of all steady state probabilities must be equal to one), the steady state probabilities can be obtained.

After finding the steady-state probabilities, we can determine some important parameters that affect the network performance: new call blocking probability P_N, handoff blocking probability P_H, and hard handoff probability P_{HD}.

$$P_N = \sum_{n_1 = n_2 = c} \pi(n_1, n_2, q_1, q_2)$$

$$P_H = \sum_{\{q_1 < b \cap q_2 = b \cap |q_1 - q_2| < T\}} \pi(n_1, n_2, q_1, q_2)/2 + \sum_{\{q_2 < b \cap q_1 = b \cap |q_1 - q_2| < T\}} \pi(n_1, n_2, q_1, q_2)/2 + \pi(c, c, b, b)$$

$$P_{HD} = \sum_{\{q_1 < q_2 = b \cap |q_1 - q_2| \geq T\}} \pi(n_1, n_2, q_1, q_2)/2 + \sum_{\{q_1 > q_2 = b \cap |q_1 - q_2| \geq T\}} \pi(n_1, n_2, q_1, q_2)/2$$

4.2 Numerical examples

Some numerical examples are provided in this subsection. Throughout the analysis, we assume that c=5, λ=60 [calls/min], $\Gamma_1 = \Gamma_2$=10 [calls/min], μ=0.2 [calls/min], and $\gamma_1 = \gamma_2$=10 [calls/min].

Figure 6 plots new call blocking probability, handoff call blocking probability, and hard handoff probability against various values of hard handoff threshold. No handoff queues are assumed here. From the Figure 6, it is observed that, as the hard handoff threshold increases, the new call blocking probability and the handoff call blocking probability do not show any remarkable changes while the hard handoff probability decreases drastically.

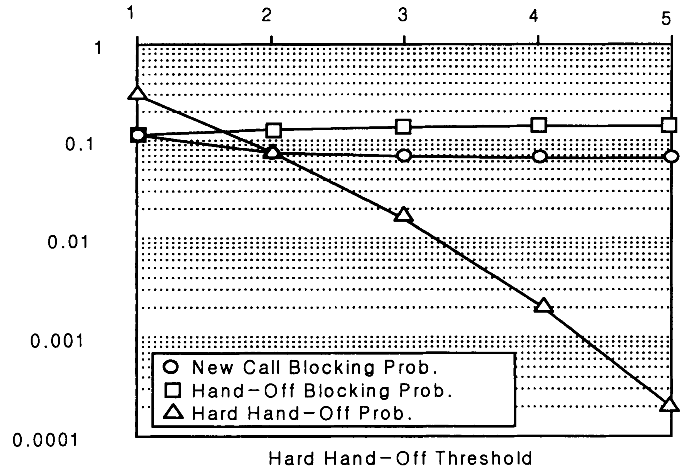


Figure 6 Call blocking and hard handoff probabilities vs. hard handoff threshold (without handoff queue).

In Figure 7, the same probabilities as in the Figure 6 are shown, but handoff queues are provided. Compared with the previous results with no handoff queues, the new call blocking probability is slightly increased due to the effects of handoff queueing. On the contrary, the handoff blocking probability and the hard handoff probability are prominently decreased. Moreover, we notice that, as the hard handoff threshold increases, the handoff blocking probability increases while hard handoff probability decreases. Compared to the results in the Figure 6, it can be said that the handoff blocking probability is more affected by the hard handoff threshold when there are handoff queues.

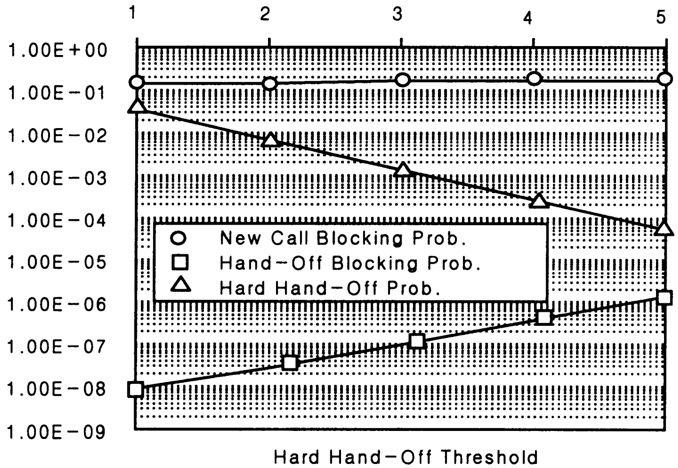


Figure 7 Call blocking probabilities vs. hard handoff threshold (with handoff queue).

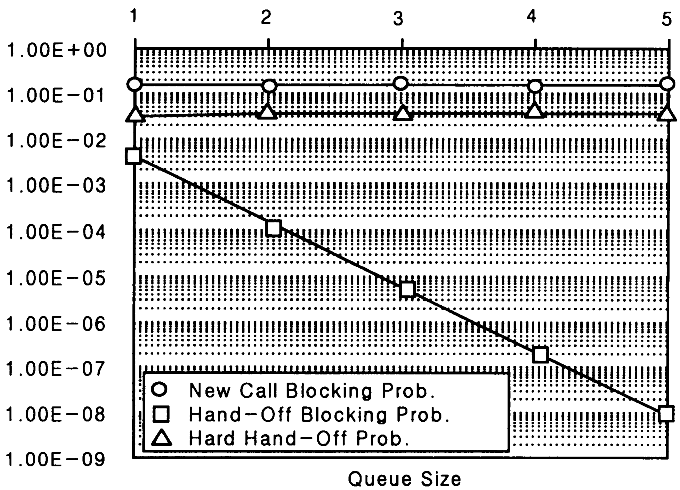


Figure 8 The performance evaluation probability versus queue size

Figure 8 plots the same probabilities again, but against various queue sizes. Handoff queues are provided and the hard handoff threshold is given T=1. As seen from the Figure 8, the handoff blocking probability considerably decreases as the size of queue increases. Hence, we believe that the waiting queues are very helpful for the efficient handoff process. On the other hand, we also observe that the size of handoff queues does not affect noticeably both the handoff blocking probability and the hard handoff probability.

5 CONCLUSION

We proposed the call connection control scheme for more efficient handoff in the CDMA-based mobile networks where multiple FAs exist in each base station. Based on the assumptions of homogeneous traffic conditions, the performance of the proposed scheme has been investigated using the Markov chain for the two cases: with queue and without queue. For the performance measures, three different kinds of probabilities are chosen: new call blocking, handoff call blocking, and hard handoff. From the analysis, we obtained the following conclusions.

- When no handoff queues are used, the hard handoff threshold affects directly the hard handoff probability. Thus, it is desirable to have larger value of hard handoff threshold to reduce the occurrence of hard handoff.
- When handoff queues are used, the hard handoff threshold affects both handoff blocking probability and hard handoff probability. Thus, proper trade-off between them is necessary to guarantee a certain level of QoS.
- As long as the hard handoff threshold is fixed, the size of handoff queues mainly affects the handoff blocking probability without affecting the other two probabilities. Thus, larger size of queues is preferred to obtain the lower handoff blocking probability.

6 REFERENCE

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