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Improving Handover Quality in 4G Mobile Systems*

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SUMMARY In this paper, we propose a new handover algorithm to guarantee handover quality in 4G mobile systems. The proposed algorithm limits the handover interruption time by improving the HARQ retransmission latency of the first packet transmitted from new serving cell. Through the simulations, we proved that our algorithm meets the requirement of handover interruption time for TCP services with high rate.

key words: *handover, hybrid ARQ, 4G mobile systems, wireless QoS*

1. Introduction

Fourth generation (4G) mobile systems aim at achieving the provision of data transmission at rates of 1 Gbps for stationary users and 100 Mbps for mobile users on top of all IP-based networks. The speed of stationary user is up to 60 km/h and that of mobile users is up to 250 km/h. To support high data rates in multi-path propagation environment, orthogonal frequency division multiplexing (OFDM) will be adopted as the physical layer technology in the systems. OFDM modulation meets the requirement for high data rates of multimedia services by mitigating inter-symbol interference (ISI) due to larger delay spread than symbol period. In the 4G mobile systems, high speed communications should be supported with minimal or no degradation during handover to guarantee high quality of real-time and TCP-based services. The packet transmission delay fluctuations due to handover execution should be within 30 ms to ensure real-time streams including VoIP [1]. For TCP-based services, the handover interruption time should be below 50 ms to obtain robust TCP throughput performance [2].

The 4G mobile systems transmit user packets using link adaption and hybrid automatic repeat request (HARQ) techniques. The mapping design for link adaptation between the modulation and coding scheme (MCS) and channel quality feedback would determine the success probability of transmissions and packet delay. Besides, HARQ operation, which adopts fast retransmissions at layer 1, effectively compensates adaptation errors incurred in an instantaneous channel link. However, in the cell edge area, the user who just performed handover would still experience bad channel conditions. In this situation, the HARQ delay of the first packet from new serving cell can be prolonged. Moreover, if the packet delay at the IP layer becomes longer than the required interruption time, the service quality is seriously degraded. Therefore, an effective handover algorithm that makes the HARQ operation complete successfully within the specified number of transmissions is needed to satisfy the required handover interruption time.

2. System Model and Problem Definition

We consider a 4G system based on time division duplex (TDD) mode. In the 4G system, the base station (BS) managing the Internet connectivity is called the anchor BS and the handover mechanism exploits the break-before-make (BBM) operation as illustrated in Fig. 1. In case of BBM handover, the serving BS sends the last MAC packet to the MS after it receives context transfer complete message from the target BS. Therefore, the delay due to data forwarding is only included in the interruption time among the delays caused by procedures using transport network. Following condition describes the requirement of handover interruption time:

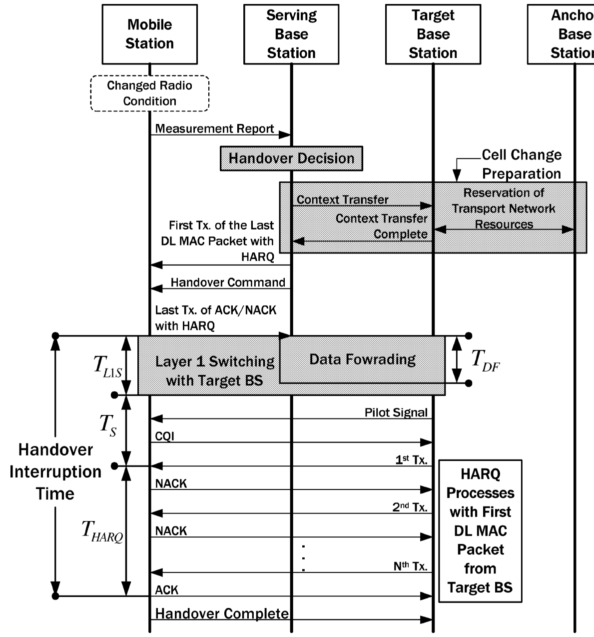

Fig. 1 Handover procedure.

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$$\max(T_{DF}, T_{L1S}) + T_S + T_{HARQ} < \delta \tag{1}$$

where T_{DF} is the delay due to data forwarding between serving and target cells. T_{L1S} is the delay due to layer 1 switching. T_S is the time that new serving cell obtains the channel quality information from handover user (CQI feedback delay) and selects the users scheduled in the current transmission time interval (TTI). T_{HARQ} is the HARQ retransmission latency of the first MAC packet. δ takes different values according to the type of services, for example, 30 ms for real-time services and 50 ms for TCP-based services.

In (1), T_S and T_{HARQ} are the parts contributing to the handover interruption time generated in the MAC layer. The T_S is constant when the CQI feedback delay is constant and the new serving cell gives the highest priority to the user who just performed handover in the scheduling discipline. Therefore, T_{HARQ} is the most important factor to determine the interruption time generated in the MAC layer.

3. Proposed Algorithm

As we discussed earlier, the handover interruption time is the sum of $\max(T_{DF}, T_{L1S})$, T_S, and T_{HARQ}. The T_{DF} is reasonably low because the forwarding operation is performed through the transport network connecting cells. In this paper, this delay is set to 10 ms taken from [4]. The T_{L1S} is determined by how fast the handover user is able to switch layer 1 parameters. It is set to 20 ms taken from [2]. The T_S is also constant and set to 3 TTIs. Lastly, The T_{HARQ} is HARQ retransmission latency of the first MAC packet transmitted from new serving cell. In the synchronous HARQ, the retransmissions have priority over the new transmissions and they happen 3 TTIs after the previous transmission with the three interlace structure. Then, this delay is defined by

$$T_{HARQ} = N \cdot v \tag{2}$$

where, N is the number of transmissions and v is the latency of one HARQ process. The v is constant with the synchronous HARQ scheme. Therefore, we have to determine T_{HARQ} by finding the appropriate number of transmissions with the HARQ operation.

First, we propose the scheme that determines the number of transmissions N in (2). It is defined as follows:

$$N = \left\lfloor \frac{\delta - T_{L1S} - T_S}{v} \right\rfloor \tag{3}$$

where δ is the required handover interruption time of each services. If the result from (3) is lower than 1, N is set to 1.

Second, we propose the MCS selection scheme which makes the HARQ operation complete successfully within the number of transmissions N obtained from (3). In our system, the channel quality feedback carries SINR and the mapping only depends on the instantaneous channel SINR rather then channel statistics. Each user decodes packets with Chase combining based HARQ mechanism and the MCS level used in retransmissions is the same as that in the original transmission. With these conditions, the proposed MCS selection scheme is defined as follows:

$$MCS_k(t) = \arg\max_{i \in M} \left\{ R_i \,\middle|\, \prod_{n=1}^{N} F_{i,k}(n \cdot \gamma_t) < \xi \right\} \tag{4}$$

where t is the current TTI, R_i is the data rate of MCS i, and N is the number of transmissions obtained with (3). $F_{i,k}(\cdot)$ is the associated FER derived from MCS i and SINR$(\cdot)$ of packet k. γ_t is the SINR used to select MCS level at the TTI t. With Chase combing, the user will decode the packet with the increased SINR, $n \cdot \gamma_t$ at the nth transmission. ξ is the required error rate. Finally, we can obtain the MCS levels which satisfy the conditions given in (4). Among these levels, the proposed algorithm selects the best MCS for maximizing the data rate.

4. Performance Evaluation

For the system-level simulations, we used the MATLAB simulator. The parameters for the simulations are listed in Table 1 [3]. We compared the proposed algorithm with the conventional algorithms. The conventional algorithms select the MCS level for maximizing the instantaneous data rate while maintaining a give FER constraint. The algorithms are expressed as

$$MCS_{FER_x}(t) = \arg\max_{i \in M} \{ R_i | F_{i,k}(\gamma_t) < x \} \tag{5}$$

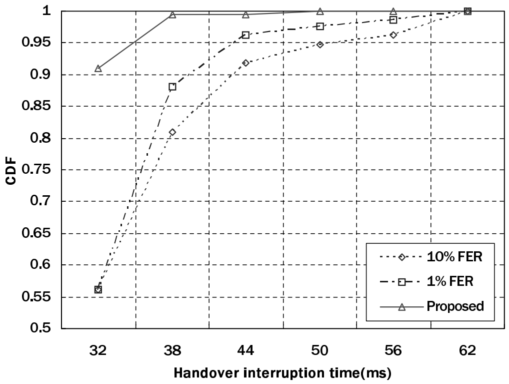
where x is the maximum allowable FER. For the conventional algorithms, 10% and 1% of FER are employed in the simulations. Table 2 lists the SINR thresholds in dB associated with different values of FER for 6 MCS set [5]. The

Table 1 System-level simulation parameters.

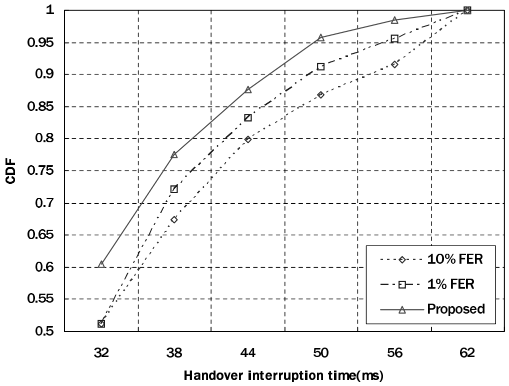
Parameter	Expalanation
Network topology	Hexagonal grid, 19 cells with wrap around
Site-to-site distance	1 km (urban area)
Carrier frequency	2 GHz
Channel bandwidth	5 MHz
BS total Tx Power	44 dBm
Propagation model	L=128.1+37.6$Log_{10}(R)$ R in kilometers
Standard deviation of Log-normal shadowing	8 dB
Correlation between sites	0.5
Correlation distance	5 m
User velocity	3 km/h
Fast fading model	Jakes spectrum (ITU Ped-B 3 km/h)
TTI duration	2 ms
Traffic model	BE (e.g., full queue)
Required error rate(ξ)	10^{-12}
Layer 1 switching time	20 ms
CQI feedback delay	3 TTIs
Maximum # of retransmissions used in 10% and 1% FER scheme	5
Filtering duration	100 ms [4]
Handover hysteresis	2 dB
# of symbols allocated in one physical channel	480

Table 2 SINR thresholds in dB associated with different FERs for 6 MCS set.

FER	QPSK1/6	QPSK1/4	QPSK1/3	16QAM1/3	16QAM1/2	16QAM2/3
1%	−8.74	−6.99	−5.37	−2.49	−0.08	2.01
10%	−9.02	−7.27	−5.65	−2.77	−0.36	1.73
50%	−9.34	−7.59	−5.97	−3.09	−0.68	1.41
90%	−9.52	−7.77	−6.15	−3.27	−0.86	1.23



(a) When CQI feedback delay is ignored.



(b) When CQI feedback delay is 3 TTIs.

Fig. 2 CDF versus handover interruption time.

proposed and conventional algorithms dynamically change the MCS level depending on channel conditions. These dynamic MCS level selection algorithms are a little more complicated than the fixed MCS level selection algorithms. However, the dynamic MCS algorithms have better performance than the fixed MCS algorithms. Therefore, we did not evaluate the fixed MCS algorithms in this paper.

Figure 2 shows the cumulative distribution function (CDF) of handover interruption time. Figure 2(a) and Fig. 2(b) show the results when the delay of CQI feedback is not considered and is considered as 3 TTIs, respectively. In the simulations of these results, the total number of transmissions with HARQ is 6 times and the layer 1 switching time is assumed to be 20 ms. With these parameters, all three considered algorithms successfully did handovers within 62 ms. As shown in Fig. 2(a), our algorithm guarantees the required handover interruption time of the TCP-based services, 50 ms with almost 100% satisfaction. The 1% FER algorithm, which does not consider the HARQ operation, does not meet the required time margin, so that the handover user experiences TCP throughput degradation. In Fig. 2(b), even through our algorithm shows some decreased improvement due to the MCS selection errors from the channel variations, the proposed algorithm shows better results than the conventional algorithms (10.3% improvement over 10% FER algorithm and 5% improvement over 1% FER algorithm at 50 ms).

5. Conclusion

In this paper, we have proposed a new handover algorithm for limiting the interruption time caused by intra-system handover in 4G mobile systems. Our algorithm is based on the constant channel condition during retransmissions and Chase combining based HARQ mechanism. We will enhance our algorithm to efficiently deal with the variable channel conditions and incremental redundancy (IR) based HARQ mechanism as the further works.

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