# Radio Link Performance of High-Speed Packet Transmission in HSDPA

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**Abstract** - This paper presents the achievable throughput performance employing key technologies such as adaptive modulation and channel coding (AMC), hybrid automatic repeat request (HARQ), fast cell selection (FCS), and fast packet scheduling to achieve high-speed packet transmission beyond 2 Mbps in a multipath-fading channel for high-speed downlink packet access (HSDPA) in the W-CDMA forward link. The throughput performance utilizing Chase combining and that of Incremental redundancy associated with AMC are first compared based on a link level simulation. The simulation results elucidate that although the achievable throughput with Incremental redundancy is almost identical to that with Chase combining in a slow mobility environment such as the average vehicular speed of 3 km/h, it is increased at the average vehicular speed of 30 km/h and 120 km/h, compared to that with Chase combining. Furthermore, the effect of FCS and a fast packet scheduling method is investigated based on system level simulations. The simulation results elucidate that the effect employing both inter-cell and inter-sector FCS is significant in improving the user throughput for accessing users with a lower received SINR near the cell edge, although the effect of inter-sector FCS only is small. Although the Maximum carrier-to-interference power ratio (CIR) method achieves a higher aggregated user throughput within a cell than that with the Proportional fairness (PF) and Round-robin (RR) methods, the PF method is more advantageous because it enhances the user throughput for a large number of accessing users near the cell edge, compared to the Maximum CIR method.

## 1. INTRODUCTION

While commercial wideband direct sequence code division multiple access (W-CDMA) [1] services were launched in Japan in 2001, high-speed downlink packet access called HSDPA is now under standardization in the 3rd generation partnership project (3GPP) in order to achieve much higher-rate data transmission than 2 Mbps employing a 5-MHz bandwidth in the W-CDMA forward link [2]. In HSDPA, high-speed packet transmission beyond 2 Mbps based on best-effort packet data services (i.e., guaranteeing minimum throughput according to the quality of service (QoS) requirement) are realized by several key technologies comprising adaptive data modulation and channel coding (AMC) [3] with fast link adaptation, hybrid automatic repeat request (HARQ) [4], a fast packet scheduling method, and fast cell selection (FCS). In most of discussions related to HSDPA [2], [5], [6], the evaluations were conducted assuming a single-path model (i.e., flat fading channel). However, these evaluations were not sufficient since severe multipaths are observed in a 5-MHz bandwidth in a real propagation channel based on the field experiments conducted near the Tokyo metropolitan area [7].

Therefore, this paper presents the achievable throughput performance employing the above-mentioned key technologies to achieve high-speed packet transmission beyond 2 Mbps in a multipath-fading channel for HSDPA in the W-CDMA forward link. In order to alleviate the influence of severe multipath interference (MPI) (note that this impact is especially profound for high-level data modulation such as 16QAM and 64QAM modulations), we apply in the paper the multipath interference canceller (MPIC), which exhibits throughput improvement in a multipath-fading channel [8]. In the paper, we first compare the throughput performance employing HARQ with packet combining, such as Type-I HARQ with packet combining [9] (simply Chase combining hereafter) and Type-II HARQ [10] (Incremental redundancy hereafter) associated with AMC. Then, we investigate the effect of fast packet scheduling algorithms such as Maximum carrier-to-interference power ratio (CIR), Proportional fairness (PF) [11], Round-robin (RR) schedulers, and the inter-sector or inter-cell FCS method for HSDPA.

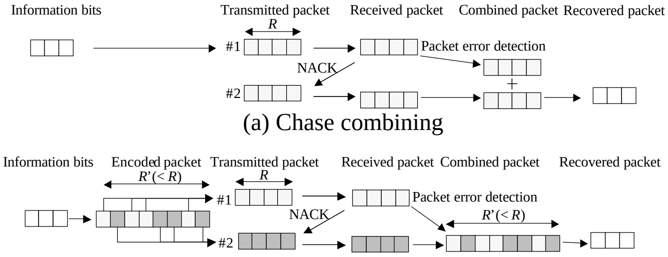



Fig. 1 Basic principle of HARQ

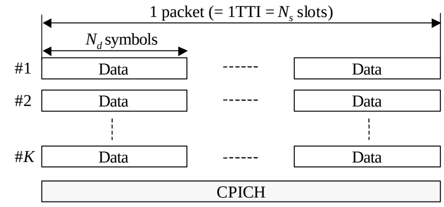



Fig. 2 Packet structure

## 2. HARQ THROUGHPUT COMPARISON COUPLED WITH AMC

### 2.1 HARQ Algorithm

HARQ is essential for high-quality packet transmission, since error-free transmission must be guaranteed for packet data services. HARQ complementarily works along with AMC because the packet errors caused by false selection of modulation and coding scheme (MCS) due to the estimation errors of radio link conditions are mitigated. In HARQ, by combining the Rake-combined signal before channel decoding of originally transmitted erroneous packets and that of subsequently retransmitted packets, the throughput performance is significantly improved thanks to the increasing signal-to-interference plus background noise power ratio (SINR) or to the increasing channel coding gain.

The basic principles of Chase combining and Incremental redundancy are illustrated in Figs. 1(a) and 1(b), where the original transmission and retransmission are represented as “#1” and “#2”, respectively. In Chase combining, the retransmitted packet, which is identical to the originally transmitted packet, is combined with the original packet. As a result, the throughput performance is improved owing to the increased SINR of the combined packet. Meanwhile, in Incremental redundancy, the puncturing pattern of retransmitted packets is typically not identical to that of the originally transmitted packets, i.e., the retransmitted packets carry additional redundancy information. This additional redundancy is combined with the previously received packets resulting in a more powerful forward error correction (FEC) code word with a lower coding rate. Therefore, the increase in the coding gain improves the throughput performance.

### 2.2 Simulation Results

We compared by link level simulations the throughput performance utilizing Chase combining and that of Incremental redundancy associated with AMC. The packet structure and simulation parameters are shown in Fig. 2 and Table 1, respectively. The base station (BS) selects the appropriate MCS from five MCSs (QPSK with $R$ = 1/2 and 3/4, 16QAM with $R$ = 1/2 and 3/4, and 64QAM with $R$ = 3/4) according to the measured instantaneous SINR us-

Table 1. Simulation Parameters in Link Level Simulations

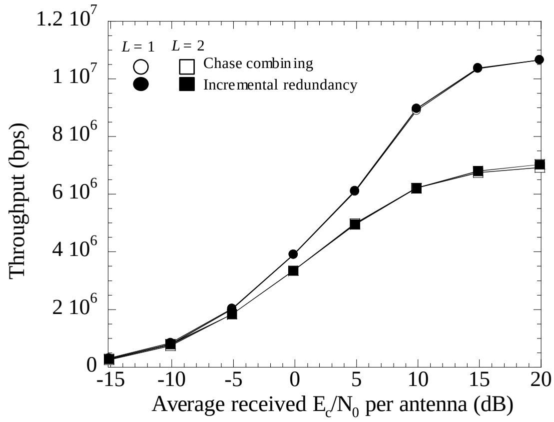
| | | |
|---|---|---|
| Chip rate | | 3.84 Mcps |
| Symbol rate | | 240 ksps |
| Spreading Factor (*SF*) | | 16 |
| Number of multicode (*K*) | | 10 codes |
| Packet length ($N_s$) | | $N_s$ = 3 slots (= 2 msec) |
| Spreading code | Channelization code | Tree-structured orthogonal sequences |
| | Scrambling code | Truncated Gold sequence (38,400 chips) |
| Modulation | Data | QPSK, 16QAM, 64QAM |
| | Pilot | QPSK |
| Power allocation | CPICH | 10 % |
| | Packet channel | 80 % |
| | Other channel | 10 % |
| Channel estimation | | 1-slot averaging |
| Channel coding / Decoding | | Turbo coding (*R* = 1/2, 3/4, *n* = 4) / Max-Log-MAP decoding (Iteration = 4) |
| Antenna diversity (*B*) | | 2 branches |
| Channel model | | Equal level *L*-path Rayleigh |

ing the common pilot channel (CPICH) reported from the mobile station (MS). In the simulations, we generated a table of the thresholds of MCS independently for the number of multipaths, *L*, the maximum Doppler frequency, $f_D$, and the HARQ algorithm as a function of the measured instantaneous SINR value. At the BS, the binary information data are encoded by turbo coding. The encoded sequence contains $N_s \times 160 \times m \times K$ bits, where $N_s$ is the number of slots in a transmission time interval (TTI) and *m* = 2, 4, and 6 for QPSK, 16QAM, and 64QAM data modulation, respectively. Every $(N_s \times 160 \times m)$ -bit sequence is block interleaved, and symbol-data modulation mapping is performed. The complex data modulated sequence is divided into *K* sequences, and each sequence is divided into $N_s$ = 3 slots and spread by the orthogonal variable spreading factor (OVSF) code with *SF* = 16. Finally, the spread *K* = 10 channels are code-multiplexed, and the CPICH with *SF* = 256 is also code-multiplexed as shown in Fig. 2.

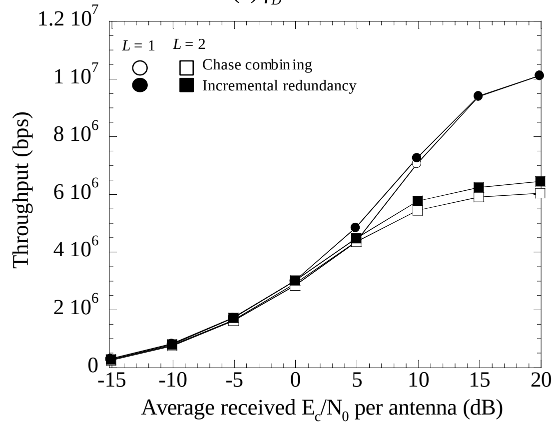
The transmitted packets are subjected to an average equal level *L*-path Rayleigh fading channel. At the receiver, two-branch antenna diversity reception is applied. The received signal sequence is embedded into the MPIC. In the MPIC, the MPI replica, which is generated from the channel estimate, tentative decision data after Rake combining, and estimation time delay of each path (note that we assumed ideal estimation of the time delay for each path) are subtracted from the received signal sequence in and after the second stage. Therefore, the SINR of each path is improved. The detailed operational principle is explained in [8]. The output sequence from MPIC is de-interleaved. In the case of a retransmitted packet, packet combining is performed with Chase combining and Incremental redundancy. At the decoder, each packet is turbo decoded (Max-Log-MAP decoding). Finally, a decoded packet is examined to determine whether or not it contained errors. When a packet is detected as erroneous, the soft decision sequence is stored in the receiver buffer, and the transmitter is requested to retransmit that packet. Otherwise, the transmitter transmits a new packet. In the HARQ evaluations, we assumed that the throughput is the actual information bit rate considering the redundancy of FEC and the insertion loss of the tail bits, cyclic redundancy check (CRC), in the correctly received packets normalized by the total number of transmitted packets.

The throughput performance employing Chase combining and Incremental redundancy is plotted in Fig. 3 as a function of the average received $E_c/N_0$ per antenna for *L* = 1 and 2. Figs. 3(a), 3(b), and 3(c) show the throughput for $f_D$ = 5.55, 55.5, and 222 Hz, corresponding to the vehicular speed of 3 km/h, 30 km/h, and 120 km/h, respectively, with the carrier frequency of 2 GHz. The round trip delay in HARQ was assumed to be a length of six slots. First, in Fig. 3(a), we cannot see a prominent difference between Chase combining and Incremental redundancy in a 2-path (1-path) channel. This is because the effectiveness of the higher coding gain in Incremental redundancy is minor since packet errors rarely occur due to the accurate tracking ability of AMC.

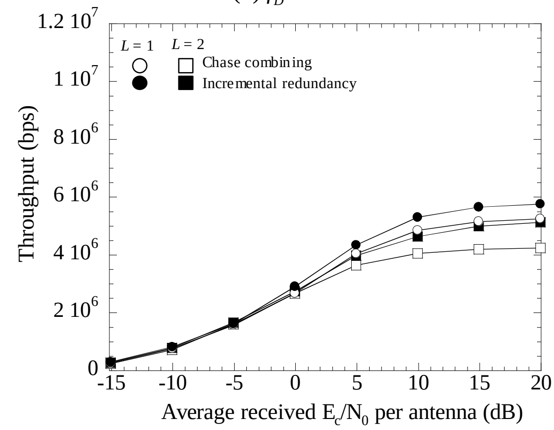
On the other hand, in Fig. 3(b), we find that the superiority of




(a) $f_D$ = 5.55Hz




(b) $f_D$ = 55.5Hz




(c) $f_D$ = 222 Hz

Fig. 3 Throughput performance

Incremental redundancy to Chase combining is evident when the average received $E_c/N_0$ is greater than 5 dB (approximately 0-10 dB) in a 2-path (1-path) channel, such that the throughput is improved about 300 kbps (500 kbps) when the average received $E_c/N_0$ is 10 (5) dB. This is because improving the coding gain in Incremental redundancy is more effective than improving the SINR in Chase combining to mitigate the packet error caused by the degraded tracking ability of AMC due to the increase of $f_D$. Then, we see in Fig. 3(c) that the advantage of Incremental redundancy is evident compared to Chase combining when the average received $E_c/N_0$ is greater than approximately 0 dB. Furthermore, Incremental redundancy exhibits superiority for the maximum throughput in Fig. 3(c); the throughput with Incremental redun-

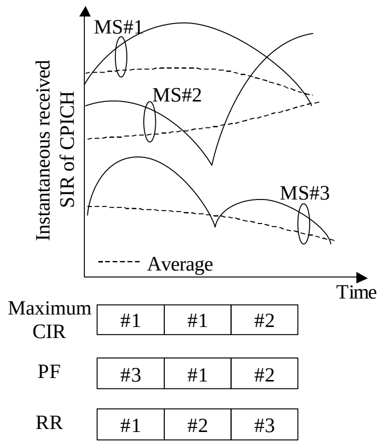



Fig.4 Simplified operating principle of packet scheduling algorithms

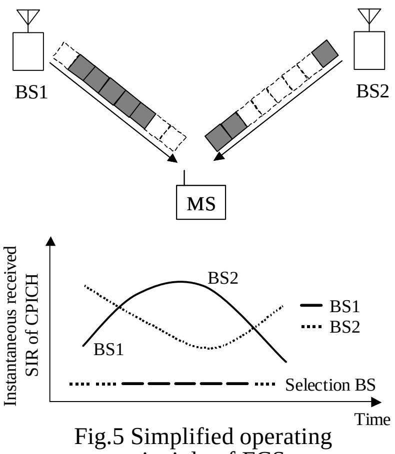



Fig.5 Simplified operating principle of FCS

Table 2. Simulation Parameters in System Simulation

| | | | |
|---|---|---|---|
| Cellular layout | | | 19 cells, 3 sectors/cell |
| Carrier frequency | | | 2000 MHz |
| Hybrid ARQ scheme | | | Incremental redundancy |
| Path loss exponent | | | 3.76 |
| Slow fading (Shadowing) | Standard deviation | | 8 dB |
| | Correlation | Between sectors | 1.0 |
| | | Between cell sites | 0.5 |
| Number of multipaths (*L*) | | | 1, 2 |
| Maximum number of active sets | | | 3 |
| Active set update interval | | | 1000 TTIs |
| HHO threshold | | | 3 dB |
| SHO add threshold | | | 4 dB |
| SHO drop threshold | | | 10 dB |
| Number of antenna branches at MS | | | 1 |

dancy in the 2-path (1-path) channel is increased by approximately 20 (10)% compared to that with Chase combining.

## 3. PACKET SCHEDULING AND FCS EVALUATIONS

The effect of three types of fast packet scheduling algorithms, i.e., the Maximum CIR, RR, and PF methods, under one-radio-link connection conditions in HSDPA was discussed in many articles (for instance, see [12]). Therefore, in the paper, we first clarify the effect of FCS in soft-handover mode employing PF method and then, investigate the features of three fast packet-scheduling algorithms associated with FCS.

### 3.1 Packet Scheduling and FCS Algorithms

Fig. 4 illustrates an example of packet assignment employing three fast packet scheduling algorithms. In the Maximum CIR method, the users with higher received SINRs are scheduled prior to those with lower received SINRs based on the measured received SINR values of all accessing users. Thus, the opportunities for packet transmission are scarcely provided to users with lower received SINRs. In contrast to this method, the packet transmission opportunities are equally assigned to all accessing users irrespective of the radio link conditions of each user in the RR method. However, the total system throughput with this method becomes much lower than that with the Maximum CIR due to its equal packet assignment feature. Meanwhile, the PF method assigns transmission packets based on criteria such as the power ratio between the instantaneous SINR and long-term averaged SINR value of each user. Thus, after maintaining the fairness of the packet assignment duration for each user, packet assignment based on priority is possible from the user having the highest relative received SINR.

Next, the simplified operating principle of FCS is illustrated in Fig. 5. The FCS algorithm assumed in the paper is as follows. A MS measured the instantaneous SINR over the FCS control interval of the CPICH from the sectors within an active set, which consists of sectors having a higher average received SINR value than the pre-determined threshold one. Then, the MS selects the sector with the maximum received SINR value and informs the target sector through the associated control channel so that the sector should transmit data through a high-speed downlink shared channel. The FCS control interval is set to 1 TTI. The sectors within an active set are updated every 1000 TTIs, that is, the MS measured the average received SINR over 1000 TTIs of the surrounding 19 x 3 sectors (assuming a 3-sector configuration), and adds (removes) the sectors when the power ratio between the measured SINRs and the maximum SINR is higher (lower) than the added (removed) threshold values. Meanwhile, in the hard handover mode, i.e., without FCS mode, when the power ratio between the average received SINR during the active set updating interval of the target sector with the maximum received SINR and that of the original sector is higher than the hard handover threshold, the MS connects a radio link to that target sector.

### 3.2 Simulation Results

We evaluated by system simulation the effect of FCS and thereby the fast packet scheduling algorithms associated with the FCS based on the achievable throughput performance, assuming key technologies such as AMC and HARQ evaluated in the previous section. A three-sectored 19-hexagonal cell model was used with the sector antenna beam pattern based on [2]. Table 2 gives the major simulation parameters. The location of each user was randomly assigned with a uniform distribution within each cell. The received SINR at each accessing user is measured (here interference from the 18 neighboring cells is considered). It was assumed that the distance-dependent path loss was constant during the throughput measurement period and shadowing and instantaneous fading variations were added (we employed the shadowing variation model in [13]). Furthermore, AMC based on the instantaneous received SINR measurement was used. The MCS updating interval and MCS control delay were set to 1 TTI and 3 TTIs, respectively. In the case of $L = 2$, MPIC is applied to remove the influence of severe multipath interference.

The modified ETSI WWW browsing model [2] was used as the traffic model. We evaluated the effect of FCS and packet scheduling algorithms by user throughput, which is defined as the average throughput during interval $T_{pc}(n)$ when an accessing user requests packet transmission (this is equal to the interval when the information bits to be transmitted exist in the BS buffer) as

$$\text{User throughput of user}\,\#n = \frac{D(n)}{T_{pc}(n)} \qquad (1)$$

where we define the number of received information bits of user #*n* as $D(n)$.

We first investigate the effect of FCS assuming the PF method. The cumulative distribution of the user throughput is shown in Fig. 6 when the number of accessing users per a cell is 100. It was assumed that $L = 1$ and 2, $f_D = 5.55$ Hz. Fig. 6 shows that at the cumulative distribution of 20%, which corresponds to the throughput of a user with a lower received SINR located in the handover area, the user throughput when both the inter-sector and inter-cell FCS are performed is improved by approximately 70% and 60% compared to that without FCS for $L = 1$ and 2 paths, respectively. However, we see that the user throughput when only inter-sector FCS is performed is almost identical to that without FCS. From Fig. 6, the improvement in the achievable throughput by FCS for $L = 2$ is decreased compared to that for $L = 1$. This is because the diversity effect for selecting an appropriate cell in FCS is reduced

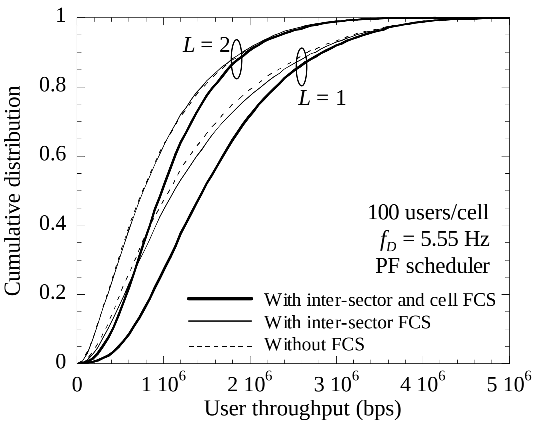



Fig.6 Effect of FCS

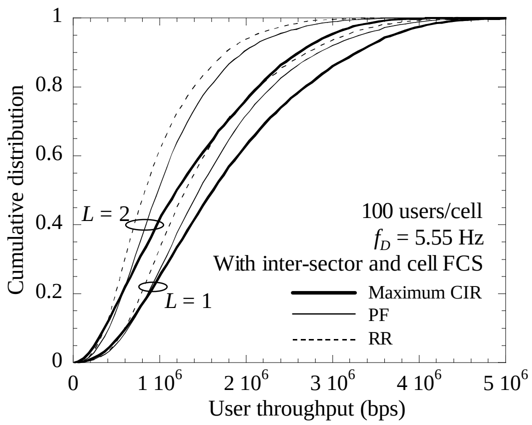



Fig.7 Effect of packet scheduling algorithm

since the instantaneous fluctuation of the received SINR is decreased by the increase in the paths.

Finally, the cumulative distributions of the user throughput of each accessing user employing three packet scheduling algorithms associated with both inter-sector and inter-cell FCS are plotted in Fig. 7 for $L$ = 1 and 2-path channels. It was assumed that the number of accessing users per cell of 100 and $f_D$ = 5.55 Hz. We find on the whole from Fig. 7 that the achievable throughput using RR is less that with the PF or Maximum CIR method. This is because packet-decoding errors frequently occur since the packet assignment is performed for the user suffering from poor radio link conditions, i.e., lower received SINR, which results in reduced AMC effectiveness. Meanwhile, by employing the Maximum CIR method, the packet transmission assignment to the user is performed with priority in decreasing order of the instantaneous received SINR from the highest. We find that the throughput for the user with a higher received SINR is improved. In contrast, the user throughput for the user with a lower received SINR becomes less since the opportunity for packet transmission is reduced for such a user. Furthermore, the PF method has merits such as the throughput for a user with a lower user throughput is improved compared to the other two methods, and still the overall user throughput is significantly increased compared to that with the RR method. By comparing the performance with $L$ = 1 and $L$ = 2, the tendency for $L$ = 2 is explicitly identical to that for $L$ = 1. Finally, from Fig. 7, we conclude that by applying the PF and Maximum CIR scheduling algorithm coupled with AMC, HARQ, and FCS, 28 (10)%, and 37 (24)% of accessing users within a cell can obtain a user throughput of more than 2 Mbps in a 1-path (2-path) channel.

## 4. CONCLUSIONS

This paper presented the achievable throughput performance employing key technologies such as AMC, HARQ, FCS, and fast packet scheduling to achieve high-speed packet transmission beyond 2 Mbps in a multipath-fading channel for HSDPA in the W-CDMA forward link. The throughput performance utilizing Chase combining and that of Incremental redundancy associated with AMC were first compared based on a link level simulation. The simulation results elucidated that although the achievable throughput with Incremental redundancy was almost identical to that with Chase combining in a slow mobility environment such as the average vehicular speed of 3 km/h, it was increased at the average vehicular speed of 30 km/h and 120 km/h, compared to that with Chase combining. Furthermore, the effect of FCS and a fast packet scheduling method was investigated based on system level simulations. The simulation results elucidated that the effect of employing both inter-cell and inter-sector FCS was significant in improving the user throughput for accessing users with a lower received SINR near the cell edge, although the effect of inter-sector FCS only was small. It was also clarified that although the Maximum CIR method achieved a higher aggregated user throughput within a cell than that with the PF and RR methods, the PF method was advantageous because it enhanced the user throughput for a large number of accessing users near the cell edge, compared to the Maximum CIR method. Finally, it was concluded that by applying the PF and Maximum CIR scheduling algorithm coupled with AMC, HARQ, and FCS, 28 (10)%, and 37 (24)% of accessing users within a cell can obtain a user throughput of more than 2 Mbps in a 1-path (2-path) channel assuming the modified ETSI WWW browsing model.

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