Determining the Optimum Threshold Values of MCS Levels for Retransmission Packets in HARQ Schemes

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Abstract – **We analyze the optimum threshold value used in determining the modulation and coding scheme (MCS) level of retransmission packets in HARQ schemes. In HARQ schemes, although the first packet is erroneous, it has a considerable energy that can enhance the system performance such as packet error rate (PER) and throughput. Using the existing energy of the first transmission packet, we can save the power for retransmission while satisfying the given target PER. The saved power can be used to adjust the MCS level for retransmitted packets or increase the data rate of other users. The proposed algorithm which adjust the transmit power at the retransmission can be applied to all types of HARQ schemes including Chase combining, partial incremental redundancy (IR), and full IR. Especially in the IR scheme, retransmitted packets convey inherent coding gain as well as energy because they contain additional redundant information for the first failed attempt. Using this inherent coding gain, we can save more energy compared to the simplest HARQ form, the Chase combining scheme. The result shows that the saved energy can enhance the throughput of the overall system. In addition, the proposed scheme yields robustness about feedback information errors.**

I. INTRODUCTION

Recently, the high speed downlink packet access (HSDPA) technology has been developed in order to accommodate the demand for very high data rate packet services. The main purpose of HSDPA is to provide peak data rates of 8~10 Mbps in downlink. In order to achieve the high data rate transmission, many schemes have been proposed including adaptive modulation and coding (AMC), hybrid automatic repeat request (HARQ), fast cell selection (FCS), and multiple input multiple output (MIMO) antenna processing [1].

The AMC scheme plays a major role in supporting high data rate services of HSDPA. The basic idea of AMC is to adaptively change the modulation and coding scheme (MCS) level according to the downlink channel condition. The MCS level is determined based on the channel-quality feedback reported by user equipment (UE), the transmit power of a related dedicated physical channel (DPCH), or other methods. If a UE has a good channel quality, it typically uses a high MCS level, that is, high order modulation and high code rate. In a system with link adaptation schemes like AMC, interference variation can be reduced by changing the MCS levels instead of transmit power.

HARQ is another link adaptation technique in HSDPA. While AMC selects a modulation and coding format based on explicit C/I measurements, HARQ uses ACK/NACK signaling for determining retransmission. There are three types of HARQ in HSDPA. The first type of HARQ is a Chase combing scheme that retransmits the same packet as that of the first attempt [2]. The second type of HARQ is a partial incremental redundancy (IR) scheme that retransmits a partially different packet from the first one. However, each packet transmitted in the partial IR scheme is self-decodable because it has the systematic bits of turbo codes. The last type is full IR scheme that retransmits a fully different packet from the first one. In the full IR scheme, retransmission packets are not self-decodable. IR usually yields better performance compared to the Chase combining scheme. However, it requires more implementation complexity and may not result in good performance unless the link adaptation errors are very large. On the other hand, the Chase combining scheme yields reasonable performance with lower implementation complexity and cost [3]. Fig. 1 shows three types of HARQ schemes in HSDPA.

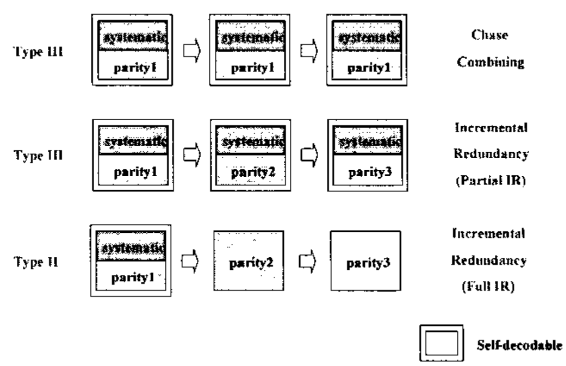

Fig. 1. Three types of HARQ schemes in HSDPA

Recently, many improved versions of HARQ systems have been proposed, including various retransmission techniques for bandwidth efficient HARQ [4], adaptive HARQ [5, 6], HARQ using space-time codes [7], and HARQ with rate compatible punctured turbo codes [8].

Even though the first packet experiences a transmission error, it has considerable energy that can improve system performance such as packet error rate (PER) and throughput.

In conventional systems a retransmission packet has the same power as that of the first attempt. In other words, they do not fully utilize the energy of the first packet, even though the UE has already obtained it. We will show the minimum power level of the retransmission packet while satisfying the target PER utilizing the energy of the first attempt. This power saving can contribute to increasing system capacity. Furthermore, the effect of this power saving will be evaluated for all types of HARQ schemes in HSDPA.

In this paper, we analyze the optimum threshold values used in determining the MCS levels of retransmission packets in HARQ schemes. The rest of the paper is organized as follows: In Section II, we explain conventional retransmission schemes in HSDPA and the proposed retransmission schemes utilizing the energy of the first failed packets. The proposed scheme is evaluated by simulation in Section III. Conclusions are given in Section IV.

II. SYSTEM MODEL

Fig. 2 shows the block diagram of the proposed HARQ system. Information bits are encoded using Turbo code with a mother code rate of 1/3 at the Node B of HSDPA. The scheme of combination of trellis coded modulation (TCM) and turbo code can be applied to HARQ system, but we use the gray mapping for high data rate transmission in this paper.

After channel coding, encoded bits enter the rate matching block. The rate matching block requires sufficient memory for puncturing and retransmission. When the Node B receives a NACK for the previously transmitted packet, it should retransmit the packet according to the given HARQ strategy. If we select the Chase combining scheme for HARQ, the same packet is retransmitted. However, if we select the IR scheme, the packet with different redundant symbols should be retransmitted. When we use the IR scheme, we need more memory and computational complexity in the Node B because it requires different data from the first packet. In the IR scheme, the Node B should store the whole encoded block of each transmitted packet until an ACK signal arrives from the UE. If the Node B receives the ACK signal, the encoded data stored at the memory is erased, but if the Node B receives a NACK signal, the Node B chooses another redundant version of the failed packet and sends it in the next transmission time according to the HARQ schemes such as the partial IR or the full IR.

AMC control signal from the receiver includes the required transmit power to satisfy a given target packet error rate (PER). This power varies according to the type of HARQ. At the UE, the channel quality and SINR estimation is performed and the channel quality information is used to compensate for fading and to perform a combining scheme when the previous packet is retransmitted. In conventional schemes, if the packet contains errors, the UE just feedbacks a NACK and channel quality information. Therefore, the Node B repeats the same packet transmission as that of the first attempt. However, in the proposed system, even if the first packet has errors, the UE feedbacks a NACK and the quantity of energy for satisfying the given target PER in the next transmission in accordance with the HARQ type.

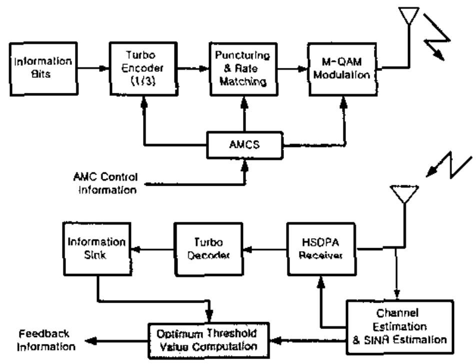

Fig. 2. Structure of the proposed scheme

The HARQ schemes in HSDPA include the Chase combining, the partial IR, and the full IR. According to the HARQ schemes used in the Node B, the required energy levels for the target PER are different. As we expect, the IR scheme can save more power than the Chase combining because it conveys additional coding gain as well as energy. Therefore, when we use the IR schemes as a HARQ scheme, we need to apply different energy thresholds, compared with those of the Chase combining. Furthermore, in real systems, the Node B already knows the channel condition and the required energy for the target PER at the first attempt. In this situation, a failed packet already has sufficient energy for the target PER though it has some errors, and thus we can save more energy.

In fact, the feedback signal from the UE about channel condition and received SINR may be possibly incorrect. The Node B may misread the additional energy for the target PER. If the feedback information is incorrect, the optimized scheme may lose its effects. However, the proposed scheme has robustness about channel estimation error or incorrect SINR due to the special characteristics of turbo codes. We compare the error-free feedback situation with the incorrect feedback situation.

MCS	Modulation	Code Rate
4	16QAM	3/4
3	16QAM	1/2
2	QPSK	3/4
1	QPSK	1/2

Table 1. Frame format of 4 MCS levels

III. SIMULATION RESULTS AND DISCUSSIONS

Four MCS levels are considered in simulation. The detailed information about the MCS levels is specified in Table 1. An MCS level is applied for 2ms TTI (3 time slots). Turbo codes are used for channel coding and a MAP algorithm is adopted for iterative decoding. Decoding is performed per TTI and the maximum number of iterations is 8. As for the selection of decoding algorithm, even though log-MAP, Max-log-MAP, or soft output Viterbi algorithm (SOVA) algorithm can be applied to decoder for simplicity and low cost, but the MAP algorithm is the best in terms of error performance. All simulations are performed in an AWGN channel because the channel is assumed to be constant during the transmission time. Furthermore, we assume the feedback information from the UE is error-free and use it for retransmission decision. In this paper, we also assume that the target packet error rate is 0.01 and the MCS level for the retransmitted packets is not changed during retransmission.

Fig. 3 shows the basic performance of the Chase combining and the performance of the proposed scheme in AWGN channels. The curves represent the required Eb/No for a target PER of 0.01 for varying the MCS levels. If we assume the Node B has no feedback information of downlink channel quality, we use the upper 2 curves for a retransmission power criterion. The solid line in the figure shows the performance of the first attempt and the dotted line indicates the performance after combining with the same Eb/No. The Chase combining scheme yields a 3dB energy gain. For example, when the Node B uses the fourth MCS level and the received Eb/No is 4dB, PER of the first attempt is nearly 1 because the fourth MCS level requires an Eb/No of 6.5dB for a target PER of 0.01. However, after the first trial, if the retransmitted packet arrives at the UE with the same Eb/No of 4dB, the PER of the second attempt is 0.01.

In real systems, a Node B knows the transmit power to meet a target PER. Therefore, the first transmitted packet has considerable energy regardless of the errors in the packet. In this case, we can save more power for retransmission packets because the original packet has sufficient energy for successful transmission. In this case, we use the lowest curve in the figure for the retransmission power criterion. In the first attempt, the packet is transmitted with a power level that can satisfy the 1 % PER for each MCS level. We assume that the feedback information for the second transmission is accurate. If the first attempt fails, we retransmit the packet with the minimum power for the target PER, as shown in Fig. 3. For example, when we transmit the first packet with an Eb/No of 4.5dB for the third MCS level, we can achieve the target PER by transmitting the retransmitted packet with an Eb/No of 0dB. If we save the transmit power for the retransmitted packet, the saved power can be used for another user in HSDPA. If we want to use the same transmit power for retransmission, we can change the MCS level toward higher rate using the reference data shown in Fig. 3.

However, the lowest curve in Fig. 3 does not have results for MCS levels 2 and 4. In fact, when we use packets with different reliability levels at UE, we need a proper combining method. The first failed packet still has sufficient energy to satisfy the target PER in the proposed scheme because the Node B knows the energy level to meet the target PER at the UE. In this situation, the failed packet requires additional coding gain as well as energy to improve the PER performance. Especially, the MCS levels 2 and 4 have a code rate of 3/4, that is, one parity bit per three systematic bits. Therefore, they need more parity bits to obtain coding gain for better performance. It means that the first erroneous packet may contain critically bad data sequences for the specific turbo code, and thus, the error cannot be easily removed only by applying additional energy. If we use the Chase combining as a HARQ scheme, we send the same format of packet as the first packet, and then, there is a performance limit for MCS levels 2 and 4 because they have not sufficient coding gain compared to MCS levels 1 and 3.

Fig. 4 shows the PER performance of the proposed scheme using the Chase combining. MCS levels 2 and 4 have error floors. MCS levels 2 and 4 require coding gain as well as the energy for the target PER. The graph of the second trial of MCS levels 1 and 3 with a code rate of 1/2 shows smooth slopes like the graph of the first trial because they have sufficient coding gain for the target PER. From this result, the combination of different packets with different reliability levels is complex and requires a proper combining scheme. Furthermore, if we use the energy of the first packet in the proposed scheme, additional gain can be obtained in the existence of sufficient parity bits for the coding gain (MCS levels 1 and 3). It is not helpful that only the energy is added for the target PER if the code rate is too high to compensate for the noise effects at UE.

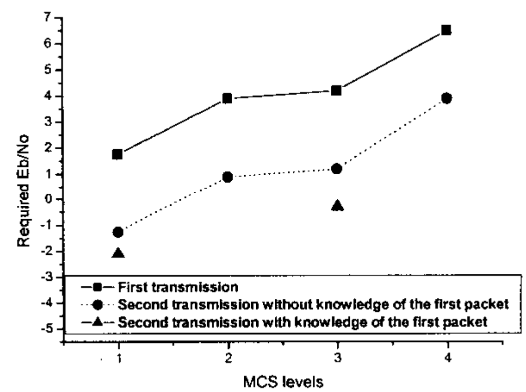

Fig. 3. Required Eb/No to satisfy a target PER of 0.01 in the Chase combining scheme

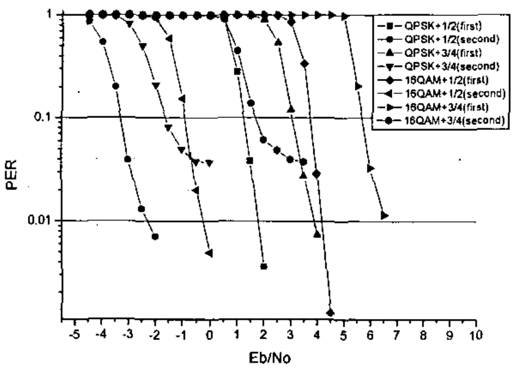

Fig. 4. PER performance of the Chase combining scheme with knowledge of channel conditions

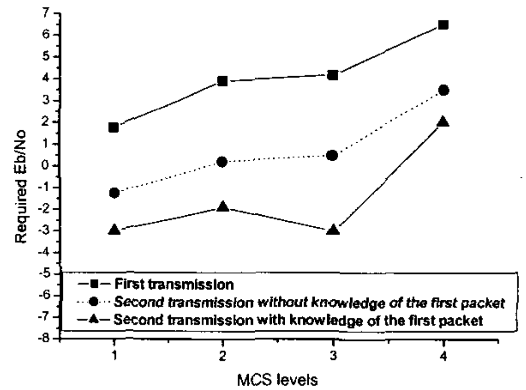

Fig. 5. Required Eb/No to satisfy a target PER of 0.01 in the Partial IR scheme

Fig. 5 illustrates the required Eb/No for a target PER of 0.01 in the first attempt and retransmission in the partial IR scheme. The required Eb/No of the first attempt is the same as that of the Chase combining scheme. The dotted line indicates the performance after combining based on the partial IR scheme with the same Eb/No. The performance of the second transmission without knowledge of the first packet is better than for the Chase combining due to the inherent coding gain of the IR scheme. As noted before, the second packet in the IR schemes conveys coding gain as well as energy, and if we use the IR scheme, we can save more power at the Node B. However, the decoding complexity and cost increase at the UE. In the partial IR schemes the systematic bits are combined by the maximum likelihood (ML) method and incremental redundant bits are added to the received packet. Since the Chase combining method and the incremental redundant method are used together in the partial IR scheme the performance of the partial IR scheme is estimated between those of the Chase combining scheme and the full IR scheme. Note that the performance of MCS level 3 has a power gain of 7.5dB in retransmission. MCS levels 1 and 3 have a code rate of 1/2 and the redundant bits are fully transmitted in the second transmission. Furthermore, if we use 16QAM modulation, 4-coded bits are sent in a symbol. Turbo codes have better performance if the decoding unit is long. MCS level 3 has a code rate of 1/2 and uses 16QAM. If we use the MCS levels 2 and 4, three systematic bits are combined by an ML manner and one redundant bit is added for decoding. Therefore, the partial IR scheme yields strong characteristics of the Chase combining scheme. However, the MCS levels 1 and 3 have the same number of bits between systematic bits and redundant bits, and more redundant bits added for decoding result in better performance.

Fig. 6 shows the required Eb/No for a target PER of 0.01 in the first attempt and retransmission in the full IR scheme. In the second transmission of the full IR scheme, no systematic bit is transmitted, but a sufficient number of redundant bits are transmitted instead. However, MCS levels 1 and 3 have a code rate of 1/2, and if the same MCS level is used for a retransmission, there is too much room which does not convey any information in retransmitted packets. Therefore, we only use the MCS levels 2 and 4 with a code rate of 3/4 in this simulation. As we expected before, the full IR scheme yields the best performance among the three schemes in the second transmission without knowledge of the first packet. The full IR scheme requires the most complex design. However, the performance is the best among the three HARQ schemes in terms of PER. In the proposed scheme, the MCS level 4 needs more energy than that of conventional scheme which is a required method of equal Eb/No combining because the first failed packet contains bad data sequence. An additional reason of this phenomenon stems from the combining method used at the UE. For the MCS level 4 in the proposed scheme, the first packet has sufficient energy and the second packet adds coding gain for better performance. However, if parity bits are padded at the first packet, the parity bits of the second packet have a different reliability level from the coded bits of the first packet and they may cause an unstable decoding process in turbo decoder.

If we use a16QAM modulation and combining method of packets with different reliability levels, a proper combining method is required for better performance in the proposed schemes. Furthermore, performance, complexity, delay requirement, and memory should be considered properly for the selection of HARQ type.

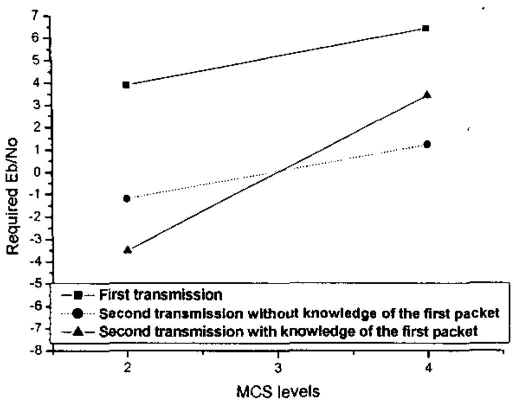

Fig. 6. Required Eb/No to satisfy a target PER of 0.01 in the full IR scheme

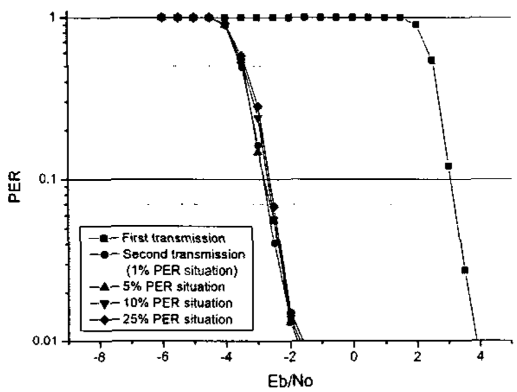

Fig 7. PER performance of the proposed scheme in the presence of the feedback information errors

Thus far, we assumed the feedback information contains no error but the feedback information about the first packet may be incorrect. In this case, the proposed scheme should be robust about the feedback information errors. Fig. 7 shows the effect of the incorrect information in the proposed scheme based on the partial IR strategy and MCS level 2. If the first transmission has energy of 4dB, the first attempt has a PER value of 0.01, and then, we can use the minimum power at the second transmission, as shown in Fig. 5. The second transmission is performed for an erroneous packets in Eb/No of 1%, 5%, 10%, or 25% PER for the first transmission. The proposed scheme is still effective in case of incorrect channel quality feedback information because the second transmission needs almost the same Eb/No regardless of PER for the fist transmission. Therefore, we expect that it is enough for a UE to feed back a NACK without additional information for a small change in Eb/No. From the Fig. 7, the results of Fig. 5 can be used at the presence of feedback information errors. Therefore, the proposed scheme using the energy of the first packet can be used in the presence of feedback errors without modification of threshold values.

IV. CONCLUSIONS

In HARQ schemes, although the first packet is erroneous, it has a considerable energy that can enhance the system performance such as PER and throughput. Using the existing energy of the first transmission packet, we can save the power for retransmission while satisfying the given target PER. The proposed algorithm is evaluated for the three of HARQ schemes: the Chase combining, the partial IR, and the full IR schemes. The result shows that the saved energy can enhance the system throughput. Furthermore, the proposed scheme has robustness about feedback information errors. The proposed algorithm can be used to adjust the MCS level for retransmitted packets and to increase the data rate of other users, by utilizing the saved power. We will study further about these topics. In addition, robustness about feedback information errors should be carefully examined in further studies.

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