TCP Performance-aware HARQ with AMC Scheme

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Abstract— This paper proposes a TCP performance-aware hybrid automatic repeat request (HARQ) with adaptive modulation and coding (AMC). The conventional scheme adapts the target packet error rate (PER) to improve the spectral efficiency at the expense of the average packet error rate when a packet is retransmitted. Unfortunately, this can cause the deterioration of TCP throughput. A TCP segment consists of several HARQ packets, thus the increase of error probability of a HARQ packet can exponentially increase the error probability of a TCP segment. For this reason, the conventional scheme may be inadequate from the TCP perspective. To solve this problem, this paper proposes the cross-layer MCS level selection method while referring to the TCP throughput. Compared with the conventional scheme, the proposed method improves the TCP throughput up to 89% over the poor signal quality.

Keywords-component: MCS level, HARQ, End-to-end performance

I. INTRODUCTION (HEADING 1)

In wireless communication systems, the variation of the wireless channel is one of the most important considerations to improve the reliability and the spectral efficiency. Unfortunately, there is a tradeoff relation between these two objectives. To solve this problem, the adaptive modulation and coding (AMC) scheme has been studied [1-2]. The AMC scheme dynamically changes the modulation and coding rate according to the channel conditions. However, an error can be generated due to channel deep fading, although the AMC scheme is applied. To recover the packet experienced an error, several retransmission schemes have been taken into account [3-4].

There have been two different retransmission schemes, automatic repeat request (ARQ) and hybrid automatic repeat request (HARQ), which are defined at the medium access control (MAC) layer and physical (PHY) layer, respectively. The ARQ has an advantage that the implementation is relatively simple. However, the ARQ can lead to the increase of the access delay because of the processing time and the round trip delay. In the case of real-time service, the increased access delay may seriously affect to the quality of service. Therefore, the HARQ has been investigated for the fast feedback in PHY layer [3].

In [5], [6], authors have proposed and analyzed the retransmission schemes (e.g. ARQ and HARQ) combined with AMC for improving bandwidth efficiency and reliability over wireless channel. The proposed schemes exploit the QoS requirements and target packet error rate (PER) to determine the maximum number of retransmissions and modulation and coding scheme (MCS) level, respectively. The authors have also presented an analytical model. The analytical results described in these papers have shown that the proposed schemes can enhance the spectral efficiency. Especially, the HARQ with AMC can achieve the maximum spectral efficiency [5].

However, this scheme can deteriorate the transmission control protocol (TCP) performance. In the HARQ with AMC scheme, the target PER is selected at every retransmission by using the estimated signal-to-noise ratio (SNR) including the gain of the soft combining. This can increase the average spectral efficiency, whereas this can also increase the average PER of HARQ packet. Since a TCP segment generally consist of several HARQ packets, the increase of the average PER of a HARQ packet can exponentially increase the average PER of a TCP segment. This can have a serious impact on the TCP throughput. Consequently, this paper newly proposes the cross-layer MCS level selection method while considering the TCP throughput.

The remainder of this paper is organized as follows. In Section II, system architecture and channel model are described, and in Section III, we introduce the MCS level selection method in the conventional method. In Section IV, we describe the proposed MCS level selection method to improve the end-to-end performance of wireless communication system. The performance evaluation results are shown in Section V. Finally, the conclusions are discussed in Section V.

II. SYSTEM MODEL

A. System architecture

In this paper, we assume the cross-layer architecture of the system as shown in Fig. 1. We consider AMC and HARQ scheme (Type II) at the PHY layer and TCP Reno at the transport layer. For simplifying end-to-end performance analysis, we assume that one MAC protocol data unit (PDU) corresponds to one HARQ packet. We also assume that HARQ scheme operates as a stop-and-wait protocol.


When a packet is retransmitted, the BER of retransmitted packet is not independent from the initially transmitted packet. Thus, the analysis of the BER after i-th retransmission is difficult, because the previously transmitted packets corresponding to the retransmitted packets are considered for decoding. Therefore, we use a PER upper bound under an assumption that the convolutional code with hard-decision Viterbi decoding is used [7]. The PER upper bound after the i-th retransmission is written as

\[ P_{\text{upper}} = 1 - \left(1 - P_{a}^{(i)}\right)^L \geq \text{PER}^{(i)}, \]  

where \( P_{a}^{(i)} \) is the PER and \( P_{a}^{(i)} \) is the union bound of the first-event error probability after decoding of the i-th retransmitted packet. \( P_{a}^{(i)} \) is obtained by using free distance of convolutional code and total number of error events with weight. If we let \( \text{PER}^{(i)} = P_{\text{target}} \), we can obtain the target BER for retransmission as

\[ \text{BER}_{\text{target}}^{(i)} = \left[ 1 - \left(1 - P_{\text{target}}\right)^{1/L} \right]^{1/2d_f^{(i)}}, \]  

where \( a_d \) is the total number of error events with weight \( d \) and \( d_f \) is the free distance of the convolutional code [5].

Also, the SNR value for MCS level selection in the conventional method can be obtained from (6) by using target BER as

\[ \gamma_{s}^{(i)} = \frac{1}{b_d} \ln \left( \frac{a_d}{\text{BER}_{\text{target}}^{(i)}} \right), \]  

where \( \gamma_{s}^{(i)} \) is the SNR boundary for the i-th transmission attempt when using MCS level \( n \), and \( a_d, b_d \) are MCS level dependent constants and they can be obtained by fitting the experimental BER values of MCS level n to exponential function. In the conventional method, the SNR values for the MCS level selection are derived from (6). In this method, the selection probability of higher MCS level increases under the same channel condition when the packet is retransmitted. Thus, the average PER of retransmitted HARQ packets can be increased up to the target PER due to the combining gain. Although the average PER of retransmitted HARQ packets satisfy the target PER, this MCS level selection method can increase the packet loss rate (PLR) of HARQ packets. The increment of the PLR of HARQ packets may cause the increment of the PER of TCP packets. Thus, the conventional MCS level selection method can reduce the end-to-end performance of wireless communication system, because the conventional MCS level selection method only considers the target BER of HARQ packet for the packet transmission, but conventional MCS selection method does not consider the end-to-end performance for MCS level selection. For this reason, a modified MCS level selection method is in need for the enhanced end-to-end performance. In this work, we propose the modified MCS level selection method which has increased the end-to-end performance in compare with the conventional method.
TABLE I. PSEUDO CODE OF PROPOSED MCS LEVEL SELECTION METHOD

Algorithm 1 The proposed MCS level selection method

1: if the packet is transmitted initially then
2:     Select a MCS level by using the target BER and the received SNR
3: else
4:     Obtain intersection points by using transport layer throughput
5:     Select a SNR region which includes the received SNR
6:     if the estimated BER at the SNR value for intersection point < target BER then
7:         Select a MCS level corresponding to selected SNR region
8:     else
9:         Select a MCS level by using the target BER and the received SNR
10: end if
11: Transmit a packet using selected MCS level
12: end if

V. PERFORMANCE EVALUATION

For the performance evaluation of the proposed MCS level selection method, we use system model introduced in section II and consider WiMAX system as wireless access system. Table II represents system parameters as referred in [5], [8], [9]. Also, we adopt several assumptions in this paper. First, wireless channel resource is allocated to a particular device per PHY packet unit. Second, the transmission delay on backbone network is 100 msec [10]. On these conditions, table III represents the SNR values for MCS level selection as an intersection point in the proposed method.

TABLE II. SYSTEM PARAMETERS

<table>
<thead>
<tr>
<th>System Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing delay (intra-layer)</td>
<td>1 msec</td>
</tr>
<tr>
<td>Processing delay (inter-layer)</td>
<td>3 msec</td>
</tr>
<tr>
<td>Transmission Time Interval (TTI)</td>
<td>5 msec</td>
</tr>
<tr>
<td>TCP Packet size</td>
<td>1500 bytes</td>
</tr>
<tr>
<td>PHY Packet size</td>
<td>250 bytes</td>
</tr>
<tr>
<td>$b$</td>
<td>2</td>
</tr>
<tr>
<td>$a_d^{(2)}$, $a_d^{(5)}$</td>
<td>2, 5</td>
</tr>
<tr>
<td>$d_f^{(7)}$, $d_f^{(12)}$</td>
<td>7, 12</td>
</tr>
</tbody>
</table>

| Level l (BPSK, 1/2) | 1.1367, 7.5556 |
| Level 2 (QPSK, 1/2) | 0.3351, 3.2543 |
| Level 3 (QPSK, 3/4) | 0.2197, 1.5244 |
| Level 4 (16QAM, 9/16)| 0.2081, 0.6250 |
| Level 5 (16QAM, 3/4) | 0.1936, 0.3484 |
| Level 6 (64QAM, 3/4) | 0.1887, 0.0871 |

TABLE III. INTERSECTION POINT OF TRANSPORT LAYER THROUGHPUT

<table>
<thead>
<tr>
<th>SNR value (dB)</th>
<th>1 and 2</th>
<th>2 and 3</th>
<th>3 and 4</th>
<th>4 and 5</th>
<th>5 and 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>5.1</td>
<td></td>
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</tr>
<tr>
<td>9.2</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>12.2</td>
<td></td>
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</tr>
<tr>
<td>17.8</td>
<td></td>
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</tbody>
</table>
Fig. 3 represents the MCS level selection probability for the second transmission of a packet. In Fig. 3, the dashed line represents the probability of the conventional method and the solid line represents the probability of the proposed method and only three kinds of MCS level are shown for simplicity. As shown in Fig. 3, we observe that the selection probability of each MCS level in the proposed method has shifted to higher SNR region as compared with the conventional method. In other word, the proposed method needs higher average SNR to select each MCS level than the conventional method. Thus, the proposed method selects the lower MCS level at a given average SNR in comparison with the conventional method. The reason is that the conventional method sets the higher target BER for each retransmission and the system selects the higher MCS level when the packet is retransmitted. It may cause an increase in PER of TCP packet as shown in Fig. 4. In contrast to the conventional scheme that allows a BER to be a target BER, the proposed method reduces effect of soft combining gain so that the error rate of a TCP packet will be decreased. As a result, the enhancement of transport layer throughput can be achieved through the proposed one.

Fig. 5 represents the comparison of the spectral efficiency between the conventional method and the proposed method. As shown in Fig. 5, the spectral efficiency is increased according to the total transmission number of a packet in conventional method. In the other hand, the spectral efficiency is not increased after second transmission in proposed method, because the proposed method uses the fixed SNR values for MCS level selection when the packet is retransmitted. Consequently, the proposed method has smaller spectral efficiency than conventional method.
Fig. 6 depicts the comparison of the throughput performance between the conventional method and the proposed method. As shown in Fig. 6, the proposed method improves the throughput performance when the average SNR is lower than 14dB. Significantly, the throughput is improved by up to maximum 89% at 0dB. The reason is that TCP packet error rate when using the proposed method is lower than the conventional method, because the proposed method prevents unnecessary increase of target BER and selects the MCS level where the maximum throughput can be achieved to improve the end-to-end performance. Thus, the end-to-end transmission delay of packet can be reduced as TCP packet error rate decreases. For this reason, though the spectral efficiency of HARQ type-II may decrease, but the efficiency of end-to-end packet transmission increases in the proposed method.

VI. CONCLUSION

This paper proposes the cross-layer retransmission architecture and the modified MCS level selection method to improve the transport layer throughput. The proposed method selects the MCS level based on the two conditions. First, the average SNR is smaller than the SNR value for each intersection point of transport layer throughput. Second, the BER at the SNR value of the intersection point is lower than target BER. The simulation result shows that the proposed method outperforms the conventional method in throughput performance up to 89% especially when the average SNR is less than 14dB. Therefore, the proposed method can provide enhanced end-to-end performance which will allow users to experience better service.

REFERENCES