An Unequal Error Protection Using Prioritized Network Coding for Scalable Video Streaming

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Abstract: - In order to improve the quality of video transmission over wireless relay system, some of the studies using Network Coding (NC) and Forward Error Correction (FEC) have been studied. In this paper, layered video streaming using scalable video coding (SVC) based on prioritized network coding is investigated. We propose a novel network coding scheme (prioritized-NC) in order to improve the quality of SVC layered video. The prioritized NC considers the dependency of SVC layered video data and provides Unequal Error Protection (UEP). This technique does not require additional redundancy, and improve overall video quality. Also we joint network coding and MIMO techniques in wireless relay-based cooperation system, in order to improve the video quality. Our simulation results indicate that the proposed prioritize-NC can efficiently increase the bit error rate and PSNR performances.

Key-Words: - Video streaming, Network coding, MIMO (Multi-input Multi-output), Relay Network, priority transmission

1 Introduction

Flexible and robust video delivery is one of the most important things in the wireless networks. There are lots of research to obtain the high quality video over wireless links. Layered video with scalable structure is a good candidate for video contents having a dependency. In order to use the information of enhancement layer (EL), we have to receive base layer (BL) information correctly. Then, reducing error by the order of importance among layers is useful for video quality. Based on this observation, this work investigates a prioritized network coding for layered video over Multi-input and multi-output (MIMO) relay systems.

By using network coding, we further increase the BL decoding probability. While forward error correction (FEC) requires additional network resources, the network coding can increase the BL decoding probability without additional resources. COPE [1], which is used at IP and MAC layers and adopts simple XOR operation, can reduce transmission number and get higher throughput than original relay communication. The case of Complex Field Network Coding (CFNC), which uses complex operation, can maximize transmission throughput [2]. Physical (PHY) layer network coding (PNC) is also introduced in [3]. Network coding can get much gain in broadcasting, but there is a performance degradation problem in fading channel. MIMO technology can reduce error rate and transmit more information by using diversity through Alamouti scheme [5] than single-input and single-output (SISO). MIMO technology can provide better performance by using multiplexing scheme of delay and quality than SISO transmission [4]. Therefore, if we combine network coding and MIMO, we can get a gain of throughput and can obtain better performance of capacity [6]. And hybrid scheme of diversity and multiplexing can provide much reliable and effective transmission at MIMO system. Some related research on improving performance of layered video and two-step relay network have been discussed. Other researches on improving of throughput using PNC have been discussed [3], but this method needs frequency-carrier synchronization. In [7], using rateless coding can improve frame error rate, however, this method did not consider the priority of layered video. Ref. [8] implemented a network priority encoding transmission (PET) [12] and random linear network coding (RLNC) [13] for differential error protection, but this method needs much redundancy. Ref. [9] obtained a performance gain by using an algorithm of measuring attenuation distortion and network coding, but this method did not consider priority of layered video. Ref. [10] proposed some network coding algorithm to maximize the video quality, but this method needed overhearing condition through retransmission process. An Unequal Error Protection (UEP) using network coding is provided for video data [11]. Data is mapping the global
encoding kernel (GEK) according to UEP level. By using this data can be controlled by priority. Ref. [14] compared forward error correction (FEC) and network coding. It focuses on additional data recovery using network coding and compares PSNR performance according to the packet loss rate. The most related papers do not consider data priority and dependency or they provide UEP by using additional redundancy. Our work can be differentiated to improve the quality of Scalable Video Coding (SVC) data using the network coding and MIMO scheme.

In this paper, we investigate a combination of MIMO, network coding and UEP for scalable video streaming. We consider relay-based wireless network using simple network coding operations (e.g., XOR). Through the simple network coding, we can improve the rate of decoding according to the priority of layered video. And we analyze the overall error probability of layered video having a priority by network coding. We compare the prioritized network coding scheme using different MIMO modes such as spatial multiplex (SM), Alamouti STBC, and Maximal Ratio Combining (MRC) techniques. As the result, we can get an improved layered video transmission.

The remained part of this paper is organized as follows: Section 2 describes the MIMO-OFDM system and relay system. Section 3 proposes the prioritized network coding. In section 4, we analyze the video-aware network coding gain, throughput and PSNR with layered video transmission environment. Section 5 presents simulation results. Finally, conclusions are presented in section 6.

2 System Model

We consider a MIMO-OFDM system consisted with convolutional codes, Quadrature phase-shift keying (QPSK) and Gray-coded quadrature modulations (QAM). Fig. 1 shows the block diagram of MIMO-OFDM systems with multiple antennas. Information bits are encoded by convolutional codes, and coded bits are to be modulated symbols through the constellation mapper. The generated symbols are converted to OFDM symbols after inverse fast transform (IFFT) and adding cyclic prefix (CP). The OFDM symbols are ported each antenna and transmitted through the MIMO channel.

It is assumed that the wireless link is connected through 3GPP-LTE type 2 relay. Type 1 relay acts as a kind of base station and generates its own cell. Therefore type 1 relay can improve the cell coverage. Unlike type 1 relay, type 2 relay improves the UE throughput. The type 1 relay may be a solution for coverage extension, while the type 2 relay is more suitable for throughput enhancement [15].

3 Proposed Prioritized Network Coding

For relay network, in general, the source and relay nodes send the same data toward destination. And if BL video data from both source and relay are impossible to be decoded, EL can not be decoded even if EL is successfully transferred. We propose the method of BL decoding by sending the previous data with a video-source priority order using XOR operation at relay. If EL data and XOR-ed data are successfully transmitted, we can decode the BL data using both two data.

Prioritized Network Coding on the basic topology of this paper is shown in Fig 3. Source node (S) has message to transmit toward destination (D) through a relay node (R). The R transmits data using Galois Field Network Coding (GFNC). First, the S transmits data to the R and D nodes. The video data, that the S wants to send, is divided into three layers: (one Base Layer (BL) and two enhancement layers (EL1, EL2)). Then the R, receiving and decoding the three-layer packets, performs prioritized network coding as follows: BL, BL ⊕ EL1, and BL ⊕ EL1 ⊕ EL2. The BL, having the highest priority, is included in all packets which are generated by the R. The next important EL1 is included in the XOR-ed packets with next priority order. Thus, the more important data is involved into lot of packets at the relay, in order to increase the probability of decoding with the more number of transfers toward
the destination. Then, the $R$ node transmits the XOR-ed data to the $D$ node. Then the $D$ node decodes the data using received packets from the $R$ node, which is indicated by dotted lines in Fig 3. Decoding process uses simple XOR operation. In the case of Fig 3(b), the wireless system has two relay nodes to apply maximal ratio combining (MRC) scheme. The $S$ node transmits data to the nodes of $R_1$, $R_2$ and $D$. and both of $R_1$ and $R_2$ do network coding and transmit the network coded packet toward $D$. The other thing is that the nodes of $S$, $R$ and $D$ have two transceiver antennas. So, all of the data transmission process can be seen 2X2 MIMO system. Source node $S$ is independent of other nodes placed at different place. It is assumed the relay node is located in the middle of source and destination nodes. These multi-antennas in relay node system are capable of robust and fast transmission.

4 Performance Analysis

4.1 Prioritized Network Coding Gain

The proposed network coding scheme for layered video data is that an important data is included in the data with more frequency. As the result, the more important data will increase the frequency of sending data. Bit error rate (BER) gain obtained by the proposed network coding can be expressed as follows.

In the case of BL, the BER gain through proposal is obtained by additional decoding probability. We can get additional decoding when all BL data in the event of error, using $BL \oplus EL1$ and $BL \oplus EL1 \oplus EL2$, we can decode BL data with higher probability. In non-coded case, the decoding probability of BL data is shown as $1 - \tilde{p}_BL P_{BL}$, where $\tilde{p}_BL$ and $P_{BL}$ are the error probability of BL data from source node and from relay node, respectively. These $\tilde{p}$ and $p$ notations are applicable to following equations also. When using network coding, the decoding probability of BL data, $Pr(BL)$, is shown as:

$$Pr(BL) = 1 - \tilde{p}_BL P_{BL} + \tilde{p}_BL P_{BL} (1 - \tilde{p}_{EL1}) \times [(1 - p_{BL/BL1/EL1}) + (1 - \tilde{p}_{EL2})(1 - p_{BL/BL1/EL1/EL2} - \tilde{p}_{EL2} p_{BL/BL1/EL1/EL2})] + (1 - \tilde{p}_{EL2})(1 - p_{BL/BL1/EL1/EL2}) \tilde{p}_{EL1}$$

(1)

For EL1 using network coding, the overall decoding probability is shown as:

$$Pr(EL1) = (1 - \tilde{p}_{EL1}) + (1 - \tilde{p}_BL P_{BL}) \times [\tilde{p}_{EL1}(1 + p_{BL/BL1/EL1/EL2} - \tilde{p}_{EL2} p_{BL/BL1/EL1/EL2})] + (1 - \tilde{p}_{EL1})(1 - p_{BL/BL1/EL1/EL2}) \tilde{p}_{EL2}$$

(2)

Through the network decoding, we can decode the EL1 data even if error occurs in EL1 transmitted from source node. Similarly, the overall decoding probability of the EL2 using network coding can be shown as:

$$Pr(EL2) = (1 - \tilde{p}_{EL2}) + (1 - p_{BL/BL1/EL1/EL2}) \times \{[1 - \tilde{p}_BL P_{BL} (1 - \tilde{p}_{EL1}) \tilde{p}_{EL2} P_{BL/BL1/EL1/EL2}] + (1 - P_{BL/BL1/EL1/EL2}) \tilde{p}_{EL1}\}$$

(3)

4.2 Throughput and PSNR Performance

After layered video decoding, we obtain the throughput using packet error rate (PER) that is obtained from the packet length and BER. Packet transmission success probability is given by:

$$q(\gamma_i, M_i) = (1 - p_e(\gamma_i, M_i))^{\frac{K}{\log_2 M}}$$

(4)

where $p_e(\gamma_i, M_i)$ is the symbol error probability. The expected throughput for the transmission of a coded packet is obtained as [16]:

$$r(\tilde{\gamma}) = \frac{1}{KT} (\log_2 M)q(\gamma_i, M_i)$$

(5)

where $K$ is the length of packet, $T$ is duration of symbol, $\gamma_i$ is the SNR, and $M$ is modulation order. The PSNR is most commonly used as a measure of quality of reconstruction of lossy compression codecs. Therefore, we analyze PSNR performance.
to measure video quality. PSNR is most easily defined via the mean squared error (MSE).

\[ \text{MSE} = q_{BL} \cdot \text{MAX}^2_i + (1-q_{BL})q_{BL} \cdot D_{BL} + (1-q_{BL})(1-q_{EL})q_{EL} \cdot D_{EL} + (1-q_{BL})(1-q_{EL})(1-q_{EL})q_{EL} \cdot D_{EL} \]  

(6)

where \( \text{MAX}_i \) is the maximum possible pixel value of the image, \( D_i \) is distortion of \( L \) layer and \( q \) is packet success probability of layers (i.e., \( q_{BL} \) is packet success probability of base layer). Using Eq. (6), the PSNR of video packet is calculated as:

\[ \text{PSNR} = 10 \log_{10} \left( \frac{\text{MAX}^2_i}{\text{MSE}} \right) \]  

(7)

Then, average PSNR of total video sequence is obtained as:

\[ \text{avgPSNR} = \frac{1}{G} \sum_{i=0}^{G-1} \text{PSNR}_i \]  

(8)

where \( G \) is total GOP size of video sequence.

### 5 Simulation Results

In this section, we evaluate the performance of proposed video-aware network coding. The BER and PSNR performance over different MIMO techniques are used for evaluation.

We compare performance of BER and PSNR in cases of multiplexing scheme and diversity schemes. We assume Rayleigh flat fading channel and OFDM system. We use a test video sequence named as Football. It is assumed as the size of \( K \) from encoding data and the duration of a symbol, \( T \) as \( 1/K \) sec, (i.e., we set \( KT = 1 \)). All nodes have two antennas for the transmission and receiving processes. Alamouti STBC scheme, in comparison with the SM scheme, needs twice as much time. Therefore Alamouti STBC scheme can be seen in terms of transport efficiency is not good. So for a fair comparison, Alamouti STBC scheme uses 16QAM modulation scheme, spatial multiplexing uses QPSK modulation scheme. Simulation environment is illustrated at Table 1.

Fig. 4 illustrates the BER performance of relay-based cooperative MIMO system which considers the dependency of video data. We compare BER between non-coding and network coding for layered video. Fig. 4 (a) shows the overall BER of each video layer when SM multiplexing scheme is applied, and Fig. 4 (b) is for Alamouti STBC case. In Fig. 4 (c), we show the MRC case of SM scheme, and Fig. 4 shows the MRC case of Alamouti STBC scheme. In Fig. 4 (a)-(d), we can find that both two MIMO schemes with network coding techniques have superior performance over the other case without network coding. The network coded data has an average performance gain of 1.5dB in SM and Alamouti STBC Base Layer data. Using MRC scheme, we can improve the BER performance.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video sequence</td>
<td>Football</td>
</tr>
<tr>
<td>Codec</td>
<td>H.264 SVC – JSVM v.9.19.7</td>
</tr>
<tr>
<td>GOP</td>
<td>16</td>
</tr>
<tr>
<td>Resolution</td>
<td>352x288 (CIF)</td>
</tr>
<tr>
<td>Layer</td>
<td>BL: QP = 38, FR = 30; EL1: QP = 34, FR = 30; EL2: QP = 30, FR = 30</td>
</tr>
<tr>
<td>Channel</td>
<td>Rayleigh fading</td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK, 16QAM</td>
</tr>
<tr>
<td>Channel Coding</td>
<td>Convolutional coding (Code rate = 1/2)</td>
</tr>
<tr>
<td>FFT size</td>
<td>64</td>
</tr>
<tr>
<td>Cyclic prefix</td>
<td>7</td>
</tr>
<tr>
<td>Decoder</td>
<td>Viterbi</td>
</tr>
<tr>
<td>MIMO</td>
<td>Spatial Multiplexing (SM) or Alamouti STBC with/without MRC</td>
</tr>
<tr>
<td>S-D:S-R:R-D</td>
<td></td>
</tr>
<tr>
<td>Link Distance ratio</td>
<td>( \sqrt{2} : 1 : 1 )</td>
</tr>
</tbody>
</table>

Using the above BER performance and Eq. (4), PER performance can be achieved. Corresponding throughput can be obtained by the PER and Eq. (5). Throughput performance of layered video dependency is also considered.

![BER Comparison](image_url)

(a) BER comparison of Spatial Multiplex (SM)
Next, the PSNR performance over each scheme is calculated based on Eq. (6) through (8). Fig. 5 shows that PSNR also gives the same trend as throughput. The case of using network coding has better performance than non-coded case in both two MIMO schemes and MRC scheme. In Fig. 5, ‘network coded DIV’ means the case of network coding with Alamouti STBC scheme and ‘non-coded MUX’ means the case of non-network coding with SM scheme. And ‘network coded DIV MRC’ and ‘non-coded DIV MRC’ means using two relays with both Alamouti STBC and MRC schemes. In SM case, PSNR performance gains can be found in the channel SNR range of 5–15dB. In particular, SNR 8–12dB region shows an average PSNR gain of 7. In Alamouti STBC case, PSNR performance gains can be found in the SNR range of 1–10dB as lower communication channel quality. In the case using MRC scheme, we can found that almost 5 dB performance gain in Alamouti STBC scheme and 12 dB performance gain in SM scheme. From the Fig. 5, the SM can provide much larger network coding gain.

**Fig. 5** PSNR comparison overall MIMO schemes

### 6 Conclusion

In this paper, we propose a novel prioritized network coding technique for layered video based on H.264 SVC. The prioritized network coding minimizes the error probability of higher important layer and provides better performance than non-coded case in terms of BER and PSNR. The result comes from the dependency of layered video and relay-based wireless network characteristics. Also different MIMO modes are evaluated. MRC scheme has very good performance when especially poor channel state. And we provide a performance analysis of prioritized network coding gain. A practical guidance of combined scheme using network coding and MIMO can be derived in our performance analysis.
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References: