Efficient Protection Scheme for SVC Content Based on Network Coding*

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Abstract—How to protect the video streaming for reasonable usage is a necessary technology in multimedia services over network. However, most the previous schemes are too complicated and time-consuming to apply in real multimedia content protection system. Network Coding (NC) is a new technology which codes the input information at intermediate nodes and can make the network information flow achieve the upper bound of max-flow min-cut theory. Random Linear Network Coding (RLNC) is a practical approach of NC with advantage of decentralized operation. In this paper, we proposed a novel scalable video streaming protection algorithm with an efficient packetization scheme and a distribution scheme according to authority levels of different users based on RLNC approach. The algorithm classified the packetized packets into different levels and employed three kinds of permission matrix (PM) to control the distribution of video streaming. The implementation of the proposed algorithm was described in detail to show the efficiency and low complexity of the method.

Keywords—RLNC; SVC; Protection; Packetization

I. INTRODUCTION

Recently, the demand of the video multicast communication over network increases tremendously. The distribution of video streaming over network has become one of the most important multimedia services. The protection of the security of video streaming must be taken into consideration. However, most of the previous schemes are very complicated and time-consuming that they are not efficient in real multimedia services system. A novel algorithm is proposed in this paper to solve the problem.

Network Coding (NC) proposed in [1-4] can make the network information flow achieve the upper bound of Shannon channel capacity. Random Linear Network Coding (RLNC) [5] is a practical approach of NC with the advantage of decentralized and low complexity operation. Because the distribution setting feature of RLNC scheme, the user can recover the file in receiving sequence with high probability (base field is large enough), when the maxflow between the server and the user is no less than the size of the file at unit time.

As a result, in this paper, based on RLNC, we propose a packetization algorithm with consideration of an unequal error protection scheme proposed in [6] and introduce a protection scheme with permission matrix (PM) to control the distribution of scalable video coding (SVC) [7-8] bit streams. The whole process of video protection algorithm is simplified into a linear operation. The novel algorithm can be applied to hierarchical video transmission over network with RLNC.

The rest of the paper is organized as follows. Section 2 introduces the packet transmission over network and describes proposed packetization algorithm. Section 3 proposes the protection algorithm for SVC content. Section 4 introduces a video protection system as an example, and shows the results of the proposed algorithm in the implementation. The conclusions are given in section 5.

II. PACKETIZATION ALGORITHM

The proposed protection scheme consists of two parts. One is the arrangement of packets. The other is the permission restriction to consumers. We discuss the packetization algorithm firstly, in the following section.

A. Packet delivery

In the network with RLNC, the local encoding kernel (Lk) is randomly generated on each link. The Lk of a link has to be sent out and participates in the following linear operation. As a result, the destination node can acquire the global encoding kernel (Gk) from the receiving packets. The basic transmission unit is the packets in the block, which contains two main parts of information: the Gk and the valid information Y. The block structure owning h packets with length n+h is illustrated in Fig. 1. Where Y=(1≤i≤h, 1≤j≤n)∈Y is the linear combination of source information X and the n dimension row vector X=(1≤i≤h)∈X stands for the original information.

For hierarchical video coding, the consecutive video frames called picture of group (GOP) is the essential unit in the scalable algorithm. Each GOP unit can be coded into bit streams including basic layer and enhancement (Enh) layers independently. The coding process of the SVC algorithm is shown in Fig. 2.

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obeys the following formula.

\[ X = G_k^{-1} \cdot Y \]  

(1)

In the video multicasting application using SVC algorithm over RLNC network, the video image with different distortion can be recovered from the different layered bit streams with a singular \( G_k \). Thus, the distribution of \( G_k \) and \( Y \) also can be restricted by arranging the packet reasonably.

B. Packetization algorithm

With fully consideration of both the practical video multicasting system and the scalable feature of the video content, a hybrid block structure, including program, GOP and quality, is introduced here. The arrangement of the block obeys the following formula.

\[ \text{Rate}(P_{num}, G_{size}, L_{quality}) \leq B_{\text{bandwidth}} \]  

(2)

Where \( P_{num} \) is the number of programs, \( G_{size} \) is the size of GOP, \( L_{quality} \) is the number of layers of bit streams, and the \( B_{\text{bandwidth}} \) is the bandwidth of network. The formula (2) indicates that the rate of the bit streams should be less than the bandwidth of network. Due to the variation of the bandwidth of network, we propose a hybrid GOPs block structure.

We assume that the \( H \) layers of bit streams in \( S \) GOPs contains \( Q \) programs, and define the symbol \( G_{i,j}^h \) (1 \( \leq i \leq S \), 1 \( \leq j \leq Q \), 1 \( \leq h \leq H \)) as the \( h \)th layer bit streams of the \( i \)th GOP in the \( j \)th program, and \( X_{i,j}^h \) (1 \( \leq j \leq m_k \)) denotes a byte in that bit streams. According to the formula (2) and the GOP structure, a hierarchical block structure with UEP of filling ‘0’ achieves the design objectives with the constraint:

\[ m_{i,j}^h \cdot (H + S \cdot Q \cdot \sum_{h=1}^{H} k_h) \leq B_{\text{bandwidth}} \]  

(3)

It organizes the same layered bit streams in a GOP of different programs together. The formula (3) deduced from formula (2) illuminates the designation of SVC streaming rate. The Fig. 3 describes the proposed block structure.

How to assign the replicated number of the packets in packet format is the key technique to design the block structure. We omit the details here for the limit length of the paper. In conclusion, the main idea of the packetization algorithm is to reasonable arrange the SVC bit streams in the block according to their importance. So it can increase the decoding success probability of the lower layers in the SVC bit streams, and has the advantages of low transmission delay and high robustness of video service.

III. PERMISSION PROTECTION

The video content should be divided into different quality levels, and the distribution of each level is controlled by the Key. For the packetization algorithm discussed above, we proposed three kinds of the protection scheme of video streaming. There are access control, program control and quality control scheme respectively. Fig. 4 shows the proposed protection algorithm.

1) Access scheme. This scheme can restrict the user only access authorized parts of the video content. If video bit streams get \( S \) GOPs \( \{G_1, G_2, \ldots, G_S\} \) in a GOP group (GG). Then we define an \( S \)-dimension unit matrix named Section Permission Matrix (A-KEY, S-PM) with a diagonal element \( e_i^j \) (1 \( \leq i \leq S \)). It represents the validity of \( G_i \). Hence, the user
can retrieve video with non-zero $e_i$. Especially, a random integer $g_{valid}$ is defined to divide $S$ GOPs into two parts. Let $e_i^G = 1 (1 \leq i \leq g_{valid})$ in each part, and then the user can browse the video image with the absence of some frames.

2) Program scheme. In the multi-program with $Q$ programs $\{P_1, P_2, ..., P_Q\}$ broadcasting network, some programs are restrained to the users. A Program-PM (P-KEY, P-PM) with a diagonal element $e_i^P (1 \leq i \leq Q)$ stands for the validity of $P_i$, which is presented here to control the program restriction.

3) Quality scheme. The enhancement layers in SVC bit stream include temporal layers, spatial layers, and quality layers. The three kinds of layers offer video quality with different frame rate, resolution, and SNR scalability. For the bit streams of $H$ layers $\{L_1, L_2, ..., L_H\}$, we introduce a Layer-PM (Q-KEY, L-PM) with a diagonal element $e_i^L (1 \leq i \leq H)$ denoting the validity of $L_i$. Then the bit stream layers can be decoded selectively.

The valid GOPs are firstly chosen from entire GOPs in the bit streams according to value of $e_i^G$ in the $S$-PM, and then the available programs and layers are selected depending on $P$-PM and $L$-PM respectively. The following formula defines the valid bit streams $I$ in a GG.

$$I(G, P, L) = GG \cdot \sum_{i=1}^{S \cdot H} e_i^G \cdot \sum_{j=1}^{G} e_j^P \cdot \sum_{k=1}^{H} e_k^L \quad (3)$$

The procedure is simply illustrated in Fig. 5 and explained in the following steps.

a) Step1. Choose $S = 10$ and $g_{valid}=1$. Then the $e_i^G$ in $S$-PM is calculated as follow, $e_i^G = 1$ when $1 \leq (i \mod Q \cdot H \cdot S) \leq g_{valid}$.

b) Step2. Choose $m = 2$. Then the $e_i^P$ in $P$-PM equals to 1, when $(i \mod H \cdot Q) = m$.

c) Step3. Choose $h = 2$. Then $e_i^L = 1$, if $i \leq h$

The objective of the algorithm is to protect the SVC bit streams over RLNC network. The distribution algorithm introduces simple linear calculations as shown in (3) with $G$-PM, $P$-PM and $L$-PM permission matrices. The authorization of PMs (Keyes) is not concern with the packets. The video content protection system can be implemented by the packetization algorithm and distribution scheme.

IV. IMPLEMENTATION

We design a simple video protection system in this section. The system consists of two main parts, the packet processing unit that deals with the metadata into block formatted information, and the license processing unit that distributes the PMs. The video protection system is shown in Fig. 6. The source video data coded at the server is sent into network. The user gets the PMs from the license center and retrieves the authorized content.

The pseudo-code of the algorithm is illustrated in Fig. 7. The parameters are defined as follows. $H$ denotes the total layer numbers of SVC bit streams. $G_{size}$ is the amount of images included in a GOP. $Q$ stands for the number of program(s). $g_{valid}$ denotes the valid GOP numbers in a GOP groups. $m$ is the number of the chosen program. $h$ is the valid layers of SVC bit streams.

#Packet processing

for (i=1;program_num)

Bit stream(i)=SVC_encode($H, G_{size}$)

Block_structure = Packetization(Bit Stream(i), m)

($Y,G_k$) = RLNC(Block_structure,$L_k$)

#License processing

G=A_Permission($Y,S$-$PM$($g_{valid},S$))

P=P_Permission($G,P$-$PM$($m$))

L=Q_Permission($P,L$-$PM$($h$))

Video=SVC_decode($L,G_k$)

The pseudo-code of the algorithm

We implement the protection system with the parameters of PMs. The PMs’ parameters of users are different from each others. For three users owning different authority A, B, and C, their PMs’ parameters are shown in table 1.

<table>
<thead>
<tr>
<th>User</th>
<th>$g_{valid}$</th>
<th>$S$</th>
<th>$m$</th>
<th>$h$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>
We assume that the server sends a *multi-program* block with $Q$ of 3 and $H$ of 5. The SVC bit streams have five layers. A and B get all GOPs in program 1 and 2 respectively, while B can retrieve the video from the former three layers bit streams. The user C can only get one GOP in every five GOPs of program and browse the video recovering from the base layer. As the feature of SVC, A shares the entire video content in a program with best quality and largest definition. But C owns only limited segments in a program, and it has worst quality of video. The frames retrieved by the three different users are shown in Fig. 8.

The algorithm manages the video content by distributing different parameters in $P_M$s. As discussed above, the user A and C take the highest and lowest authority level respectively. Generally, the proposed video protection system can realize various levels with the selection of different parameters in $P_M$s.

![User A](image1.png) ![User B](image2.png) ![User C](image3.png)

**Figure 8.** The recovered frames

V. CONCLUSION

In this paper, we introduced the packetization algorithm based on GOP. It is bandwidth-adaptive and suitable to be used in multicasting the scalable video over the network with RLNC. A video streaming distribution algorithm with three types of permission matrixes was proposed. The algorithm has low complexity and is easy to be implemented. It can be applied to the protection system of hierarchical data streaming over the network.

REFERENCES


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