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Robust FMO algorithm and adaptive redundant slice allocation for wireless video transmission

Feng Zhu · Weiming Zhang · Nenghai Yu · Xianfeng Zhao

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Abstract Visual quality of compressed video may suffer great degradation when transmitted over lossy wireless networks. Flexible macro-block ordering (FMO) is a new error resilient tool adopted by H.264/AVC. It has a good performance of error resilience by changing the coding order of macro-blocks in the frame. redundant slice (RS) is another tool which adds redundant copy of slices into the stream to take precautions against packet loss. However, we shouldn't only care about peak signal to noise ratio (PSNR) of the video; the robustness of video streams to burst packet loss of wireless channel is also worth considering. In applications, such as real-time video transmission services, degradation of video quality may be tolerable, but collapse of decoder due to burst packet loss will greatly lower user's quality of experience. This paper proposes a robust FMO (RFMO) algorithm which takes gradient feature of frames into consideration to enhance robustness of video streams, and the adaptive RS allocation (ARSA) helps to increase the PSNR with only a little increase in bit rate. Experiment results show that the RFMO algorithm can significantly reduce the collapse times of decoder with invisible decrease in visual quality, and the ARSA can still guarantee a high PSNR in the case of high packet loss rate.

Keywords Error resilient coding · H.264/AVC · Robust FMO · Adaptive redundant slice allocation

1 Introduction

With the widely use of smart phones, tablet computers and many other mobile terminals, there has been an increasing demand for transmitting compressed video streams over wireless channel, such as video telephony, video on demand service and so on. However, Visual quality of compressed video may suffer great degradation when transmitted over error-prone wireless channel, due to packet loss and bit error. Figure 1 shows that there are serious regional blur and blocking artifacts in the frame when some packets are lost. So, it is necessary to take some measures to prevent the degradation.

There are a lot of error-resilient tools for wireless video transmission, such as data hiding [1–3], reference frame selection (RFS), adaptive intra refreshment [4], forward error correction (FEC) [5] and so on. H.264/AVC has introduced some new error-resilient tools to enable reliable video communication. Two of those tools are flexible macro-block ordering (FMO) [6] and redundant slice (RS). FMO allows encoder to define the coding order of MBs freely, and obtains impressive performance of error resilience. RS places one or more coded representations of a MB or slice into the bit stream to protect the particular MB or slice.

There are 7 FMO Types in H.264/AVC, which define different types of Macro-block Allocation map (MBAmap) and different coding orders of MBs. FMO Type 0–Type 5 are fixed patterns, for example, Type 0 distributes MBs to slice groups in raster scan order within a picture and each slice

F. Zhu · W. Zhang · N. Yu (✉)
Department of Electronic Engineering and Information Science,
University of Science and Technology of China,
Hefei, Anhui, China
e-mail: ynh@ustc.edu.cn

F. Zhu
e-mail: zhufengx@mail.ustc.edu.cn

W. Zhang
e-mail: weimingzhang@yahoo.cn

X. Zhao
State Key Laboratory of Information Security (SKLOIS),
Institute of Information Engineering, CAS, Beijing, China
e-mail: zhaoxianfeng@iie.ac.cn

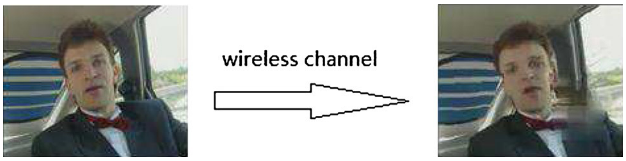


Fig. 1 Video transmission over wireless error-prone channel

0	1	2	3	0	1	2	3	0	1	2
2	3	0	1	2	3	0	1	2	3	0
0	1	2	3	0	1	2	3	0	1	2
2	3	0	1	2	3	0	1	2	3	0
0	1	2	3	0	1	2	3	0	1	2
2	3	0	1	2	3	0	1	2	3	0
0	1	2	3	0	1	2	3	0	1	2
2	3	0	1	2	3	0	1	2	3	0
0	1	2	3	0	1	2	3	0	1	2

Fig. 2 FMO Type 1 (176*144, 4 slice groups)

group has a maximum number of MBs that it can contain, while in case of Type 1, MBs in a slice group are separated from each other as far as possible, so that FMO Type 1 is also known as the Chessboard pattern. An example of MBAmap generated by FMO Type 1 is shown in Fig. 2, and numbers 0–3 are the labels of the slice group which the current MB belongs to. FMO Type 6 is called Explicit, and it is the most flexible type of all. Usually, Type 1 has the greatest performance in PSNR among Type 0–Type 5 because the special pattern is helpful for error concealment at the decoder side. While using FMO Type 6, the entire MBAmap should be transmitted to the decoder in PPS (picture parameter set), which may decrease the coding efficiency.

There has been a lot of research on error resilient tools based on FMO [7,8]. Combine FMO and the concept of region of interest (ROI). [7] proposes the ESI algorithm which uses both FMO Type 1 and Type 3 to allocate MBs into 2 slice groups, and each slice group is divided into several slices. The central part of every frame is constantly set to be ROI, which ignores the diversity of frames. Though a minor increase (less than 0.2 dB in all cases) of PSNR is achieved, it may not lead to visible improvement in visual quality [8] detects ROI in every frame when compressing the video stream, so that the efficiency of compression and the accuracy of ROI detection need to be advanced. In [9–11], the importance of each MB is defined first, and then the MBAmap is generated according to the order of importance. This method ignores position information of MBs, so the neighboring MBs may be allocated to the same slice group, which is detrimental to error concealment. Gradient information is used for importance estimate of MBs in [12], but the approach can only apply to 2 slice groups, which is not enough for wireless video transmission. The number of slice groups is adaptive in [13]. When the channel is good, only 4 slice groups are used, otherwise, four more groups will be generated. In this paper, the proposed algorithm can be easily adapted to different number of slice groups. Some other methods focus on protection of slice groups while using FMO. There are several choices for the protection of important slices, such as FEC [14,15], RS and so on. FEC is aimed at correcting bit error so that it doesnt work well in packet loss situation, while RS could ensure a relatively high PSNR in both packet loss and high bit error environment.

In some applications, such as real-time video transmission services, degradation of video quality may be tolerable, but collapse of decoder due to burst packet loss will greatly lower user's quality of experience (QoE). That is, when too many continuous packets are lost, the decoder may crash. This paper will propose a robust FMO (RFMO) algorithm and adaptive RS allocation (ARSA). The RFMO takes both position information and texture complexity of MBs into consideration, and reduces crash times of decoder greatly. The ARSA generates redundant slices into video streams according to the situation of wireless channel, and improves the PSNR with only a little increase in bit rate.

The rest of this paper is organized as follows. Section 2 describes the robust FMO algorithm. The adaptive redundant slice allocation is presented in Sect. 3. Section 4 shows the experiment results and analysis, and a brief conclusion based on these results is given in Sect. 5.

2 Robust FMO algorithm

In order to enhance the robustness of video streams to burst packet loss, we should consider both the position and texture of MBs. Since FMO Type 1 has a good performance in separating MBs in the same slice group from each other, we will take the Chessboard pattern as a part of our algorithm.

At the decoder side, the decoder will apply error concealment tools to conceal the lost slices. Error concealment is classified into spatial concealment and temporal concealment. The spatial concealment is to conceal the lost MBs using adjacent pixels in the same frame, while the temporal concealment takes similar MBs in the previous frame to conceal MBs in the current frame. No matter which error concealment tool is used, the concealment of MBs with great texture complexity is still a problem. So, it is necessary to select MBs with complex texture from the flat ones. We take gradient value as the measure of MB's texture. The MB with large gradient value is considered to be an important MB, or it is an unimportant one.

The robust FMO algorithm—RFMO is as follows :

(1) Calculate the gradient image of a frame using templates in Fig. 3;

0	1	0
1	-4	1
0	1	0

(a)

1	1	1
1	-8	1
1	1	1

(b)

0	-1	0
-1	4	-1
0	-1	0

(c)

-1	-1	-1
-1	8	-1
-1	-1	-1

(d)

Fig. 3 Templates for gradient calculation

(2) Calculate the average gradient value of every MB—*MbAveGrad*, and the average gradient of the whole frame—*FraAveGrad*. If *MbAveGrad* > *FraAveGrad*, the MB is thought to be important, otherwise it is an unimportant one;

(3) Allocate the MBs into 4 slice groups using the following formula [6]:

$$K = ((i \bmod W) + ((i/W) \times n)/2) \bmod n \tag{1}$$

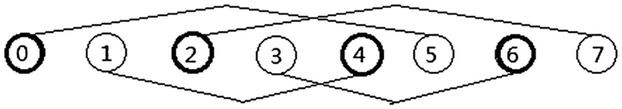
Where, i denotes the number of a MB, W is the width of the frame in terms of MB, and n is the total number of slice groups;

(4) After the above 3 steps of the algorithm, each MB is assigned with a slice group number and a label (important or not), and each slice group has both important and unimportant MBs. We propose 2 ways to generate the final MBAmap:

RFMO-1 for MBs in slice group 0 and 2, the unimportant MBs are moved to slice group 5 and 7, and the important MBs in slice group 1 and 3 are moved to slice group 4 and 6, as Fig. 4a shows;

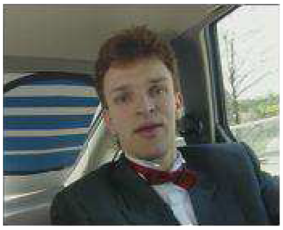
RFMO-2 for slice group x ($x = 0, 1, 2, 3$), the important MBs are distributed into slice group x and $x + 4$ evenly, so are the unimportant ones.

Figure 4 shows the RFMO-1. It is obvious that in Fig. 4a, slice group 0, 2, 4, 6 are important, while the others are not so important. The important slice groups are dispersed, so that it can avoid consecutive loss of important packets. An example of MBAmap using RFMO-1 is shown in Fig. 4b. Since we don't limit the number of MBs which a slice groups can contain in RFMO-1, size of slice groups may be very different from each other, and that's why we introduce RFMO-2. In Sect. 4, we will measure performance of these two methods.



(a)

5	1	7	3	5	1	7	3	0	1	7
7	3	5	1	7	3	5	1	2	3	5
0	1	7	3	5	1	2	3	0	4	7
2	6	0	4	7	3	0	1	2	6	5
0	4	2	6	5	1	2	3	0	4	2
2	6	0	4	7	3	5	4	2	6	5
0	4	2	6	0	4	2	6	5	1	2
2	3	0	1	7	3	0	1	7	3	5
5	1	7	3	5	1	7	6	5	1	7



(b)

Fig. 4 RFMO-1: **a** RFMO-1 (0–7 are the labels of slice groups, and the *bold* ones are slice groups of important MBs; **b** MBAmap generated by RFMO-1 (0–7 are the labels of slice groups)

3 Adaptive redundant slice allocation

The error resilient effect of FMO is limited because it just changes the coding order of MBs and the packaging strategy of coded bit streams. Since Sect. 2 has classified MBs into important and unimportant ones, unequal protection can be taken for different slice groups using redundant slice. Though the wireless channel is error-prone, the quality of video transmission is acceptable in most of the time. So, redundant slices can be generated just when the channel situation is terrible.

Considering that the random packet loss model cannot describe burst packet loss well, it takes the two-state Markov model [16] to simulate the wireless channel in this paper. Figure 5 shows the Markov model, which can be uniquely specified by average burst length (BL) and packet loss rate (PLR) using formula (2) and (3).

$$p_{10} = 1/BL \tag{2}$$

$$p_{01} = p_{10} \times PLR/(1 - PLR) \tag{3}$$

The Two-state Markov model has only two states, "Good" or "Bad", so it is naturally to code one redundant slice into

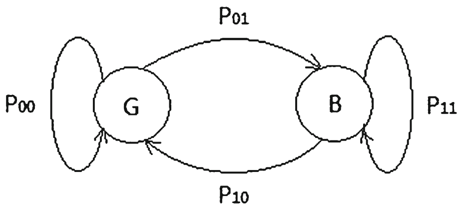


Fig. 5 Two-state Markov model

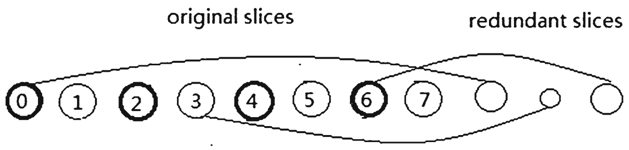


Fig. 6 Position of redundant slices (0–7 are the labels of slice groups, and the *bold* ones are slice groups of important MBs)

the bit stream when the channel state is “Bad”. After coding an original slice, the encoder will check the channel state, and then determine if the redundancy coding will be conducted adaptively.

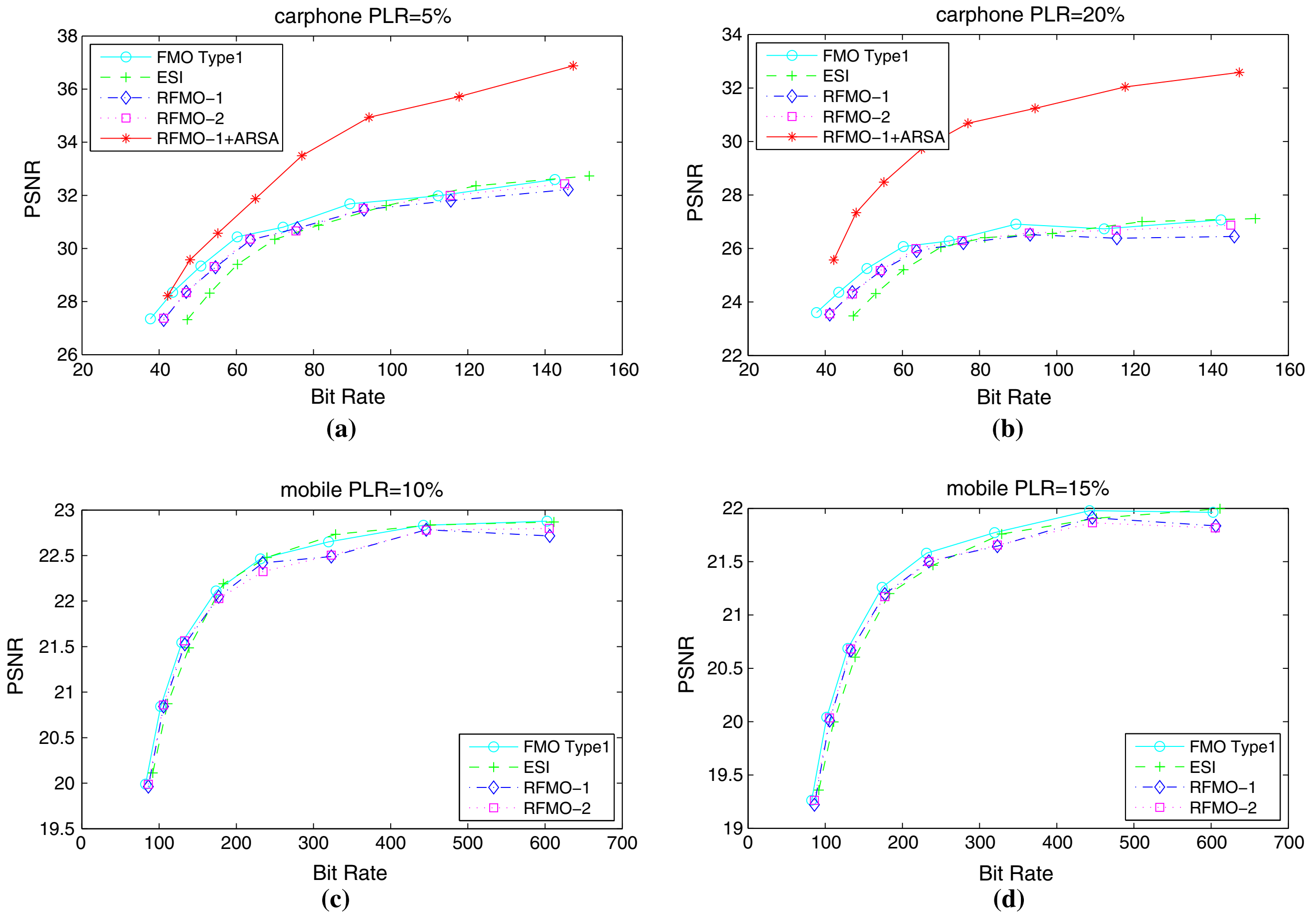
It’s important to note that the redundant slice is not a simple copy of the original one. Indeed, a redundant slice is usually coded using different settings, for example, a high QP (low quality). In this paper, we choose a high QP when coding a redundant slice for important slice groups, while the other redundancy is coded with a higher QP.

The position of redundant slices in the bit stream is also a problem worth considering. If the redundant slice is too close to the original one, the two packets may be lost at the same time in one burst packet loss. To handle this problem, we can encode the redundant slices of a frame only when all the original slices are coded, as shown in Fig. 6.

4 Experiment and analysis

The experiments are conducted based on the joint model (JM) version 8.6 of H.264/AVC. The paper compares the performance among FMO Type 1, ESI in [7], the proposed RFMO-1, RFMO-2 and RFMO-1 with ARSA. Each frame is divided into 8 slice groups ($n = 8$) while using FMO Type 1, and each slice group has only one slice. In ESI, MBs are allocated into two slice groups, and each slice group is organized into 4 slices. RFMO-1 and RFMO-2 generate 8 slice groups for every frame, with one slice for each slice group. All slices are organized in packets for transmission, where each slice is packed in one packet. So, every frame is transmitted in 8 packets while using the tested 4 algorithms.

Four QCIF (176*144) video sequences (“carphone”, “foreman”, “mobile” and “akiyo”) are tested, and 100 frames of each sequence are encoded with the frame rate of 30 frames per second. The frame GOP structure is set as IPPPP..., thus

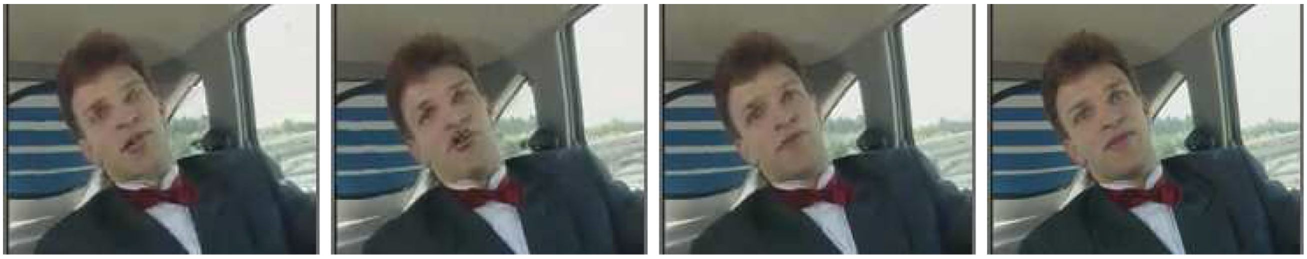


(a) **(b)** **(c)** **(d)**

Fig. 7 PSNR as a function of bit rate: **a** carphone PLR = 5 %, **b** carphone PLR = 20 %, **c** mobilePLR = 10 %, **d** mobile PLR = 15 %

(**a**) FMO Type 1 (**b**) ESI (**c**) RFMO-1 (**d**) RFMO-2

(**e**) RFMO-1+ARSA (**f**) error-free (**g**) FMO Type 1 (**h**) ESI



(**i**) RFMO-1 (**j**) RFMO-2 (**k**) RFMO-1+ARSA (**l**) error-free

Fig. 8 Visual quality of "foreman" and "carphone": The 100th frame with QP = 28, PLR = 5 %, **a** and **g**: FMO Type 1, (**b**) and (**h**): ESI, (**c**) and (**i**) RFMO-1, (**d**) and (**j**): RFMO-2, (**e**) and (**k**) RFMO-1 + ARSA, (**f**) and (**l**) error-free

only the first frame is intra-frame and the others are all inter-frame. The original slices are encoded with QP = 26, 28, 30, 32, 34, 36, 38 and 40, while the redundant slices of important slice groups are encoded using $QP' =$ QP+6. The quantization parameter for other redundancy is QP + 12. As for the Two-State Markov Model, average burst length (BL) is set to be 2, and packet loss rate (PLR) ranges from 5 to 20 %, with an interval of 5 %. The experiment with same settings is conducted 50 times for average.

Figure 7 shows the the PSNR of decoded video streams as a function of bit rate. The results in different sequences and different packet loss rate indicate that the PSNR of decoded videos using FMO Type 1, ESI, RFMO-1 and RFMO-2 are similar to each other. FMO Type 1 and ESI are a little higher in PSNR than the proposed robust FMO algorithm, but the difference is less than 0.5 dB, which may not lead to significant superiority in visual quality of videos. RFMO-2 distributes MBs into slice groups evenly, and obtains a minor improvement in PSNR than RFMO-1. When applied the proposed ARSA, PSNR is improved greatly as is shown in Fig. 7a, b.

The visual quality of "foreman" and "carphone" are shown in Fig. 8. The tested 4 algorithms seem to have the same performance of error resilience because frames (a)–(d) to (g)– (j) are not much different in visual quality. (e) and (k) are much better than those frames coded using algorithms without redundant slices. The edges in the frame are sharp and the lines are smooth in (e) and (k).

As mentioned before, we should not only care about PSNR of videos in wireless environment, the robustness of streams to burst packet loss is also worth considering. In the experiment, when too many continuous packets are lost, the decoder will crash. If the collapse occurs in applications such as real-time services, it will lower user's Quality of Experience (QoE) greatly, which is more difficult to tolerate than just degradation of visual quality. Table 1 shows the crash times of decoder while using the 4 tested algorithms in the experiment.

It is shown that the ESI algorithm has the highest crash times of 1124, while crash times of RFMO-1 is only 63. Though the number of RFMO-2 is higher than RFMO-1, it is still much less than that of FMO Type 1 and ESI. Consid-

Table 1 Crash times of decoder, **a** FMO Type 1, **b** ESI, **c** RFMO-1, **d** RFMO-2

Seq.\PLR	5 %	10%	15 %	20 %	Total
(a)					
Carphone	0	17	20	92	129
Foreman	4	64	69	266	403
Mobile	6	47	68	193	314
Akiyo	0	0	0	0	0
Total	0	128	157	551	**846**
(b)					
Carphone	0	64	59	153	276
Foreman	4	82	83	233	402
Mobile	5	88	99	254	446
Akiyo	0	0	0	0	0
Total	0	234	241	640	**1,124**
(c)					
Carphone	0	0	0	0	0
Foreman	0	21	21	21	63
Mobile	0	0	0	0	0
Akiyo	0	0	0	0	0
Total	0	21	21	21	**63**
(d)					
Carphone	5	22	22	41	90
Foreman	0	32	32	64	128
Mobile	0	3	29	46	78
Akiyo	0	0	0	0	0
Total	0	57	83	151	**296**

ering that we have conducted 6,400 experiments for every algorithm in total, the crash percentages of the 4 methods are 13.22, 17.56, 0.98 and 4.63 % respectively. While using the proposed robust FMO algorithm (RFMO-1 and RFMO-2), the crash times of decoder are much reduced compared with FMO Type 1 and ESI, but the visual quality is not much influenced.

5 Conclusion

FMO and redundant slice are two useful error resilient tools in H.264/AVC. This paper first introduces a robust FMO algorithm called RFMO, which takes both the texture and position information of MBs into consideration. Then, an adaptive Redundant Slice allocation scheme is proposed. In this coding scheme, redundant slices are generated according to the channel states. Experiment results show that the RFMO can achieve almost the same PSNR as FMO Type 1 and ESI mentioned in [7], but the robusfig:4tness of video streams to burst packet loss is significantly enhanced. The adaptive Redundant Slice allocation can improve the PSNR of videos by introducing only a little increase in bit rate.

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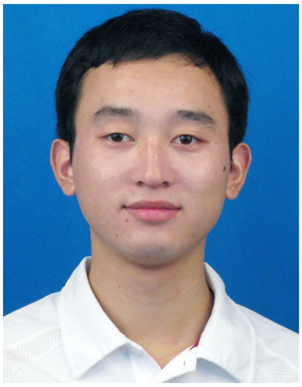

Feng Zhu received his B.S. degree in 2011 from Department of Electronic Engineering and Information Science, University of Science and Technology of China, Hefei, China. Currently, he is a Ph.D. student at University of Science and Technology of China. His research interests include video processing and information hiding.

Weiming Zhang received his M.S. degree and PH.D. degree in 2002 and 2005 respectively from the Zhengzhou Information Science and Technology Institute, Zhengzhou, China. Currently, he is an associate professor with the School of Information Science and Technology, University of Science and Technology of China. His research interests include information hiding and cryptography.

Nenghai Yu received his B.S. degree in 1987 from Nanjing University of Posts and Telecommunications, M.E. degree in 1992 from Tsinghua University and Ph.D. degree in 2004 from University of Science and Technology of China, where he is currently a professor. His research interests include multimedia security, multimedia information retrieval, video processing and information hiding.

Xianfeng Zhao received the Ph.D. degree in computer science from Shanghai Jiao Tong University, Shanghai, China, in August 2003. From October 2003 to November 2005, he worked as a postdoctoral fellow with the Data Assurance and Communication Security Center (DCS Center), Chinese Academy of Sciences (CAS), Beijing. In December 2005, he joined the State Key Laboratory of Information Security (SKLOIS), Institute of Software, CAS, Beijing. Now, he is an associate professor at SKLOIS, which has been moved to Institute of Information Engineering, CAS, Beijing. Dr. Zhao is a member of IEEE, ACM, China Computer Federation (CCF), and Chinese Association for Cryptologic Research (CACR). Dr. Zhao's research interests include information hiding and its application.