Cross-Layer Packet Prioritization for Error-Resilient Transmission of IPTV System over Wireless Network

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ABSTRACT
This paper proposes a novel cross-layer packet prioritization scheme that overcomes the limitations of conventional video prioritization schemes for IPTV system. In the conventional schemes, the Extend profile or frame unit is used for prioritization and these incur limited uses of the video prioritization schemes or unreliable transmission of the P-frame and B-frame headers. In order to overcome these limitations, the proposed scheme uses the MPEG-2 system information and the H.264/AVC NAL header information to prioritize the important video packets including the P-frame and B-frame headers. The experimental results using a testbed demonstrated that the proposed scheme has a significant performance enhancement over the conventional video prioritization schemes in terms of packet utilization ratio for video streaming, direct frame loss ratio, and PSNR.

Categories and Subject Descriptors
H.5.1 [Information interfaces and presentation]: Multimedia Information Systems – *Multimedia streaming*

General Terms
Performance, Reliability, Algorithms

Keywords
IPTV system, error-resilient video streaming, per-packet prioritization algorithm

1. INTRODUCTION
The tremendous growth of mobile devices in recent years has dramatically increased the Internet traffic over IEEE 802.11 wireless networks. This phenomenon is primarily due to the increase in the amount of real-time multimedia services, such as YouTube and online broadcasting [1, 2]. However, the available bandwidth of the current IEEE 802.11 wireless networks is not sufficient to satisfy the bandwidth consumption of these multimedia services [3], which results in connection losses and frame freezes during video streaming. In particular, video quality degradation during streaming is a significant problem that the current real-time multimedia service technologies need to overcome.

In order to solve this problem, various approaches have been proposed. The notable approaches include the data partition prioritization schemes based on the H.264/AVC Extended profile [4-9]. In these schemes, the H.264/AVC network abstraction layer (NAL) header information, such as Nal_Ref_Idc (NRI), is mapped to the IEEE 802.11e access categories (ACs) in order to provide highly error-resilient transmission of video. Other notable approaches are the frame prioritization schemes that manage the transmission rates and the delays of video streaming [10-15]. In these schemes, the video frames are prioritized according to their importance, and lower priority frames are selectively dropped when network conditions deteriorate.

However, a number of limitations remain in the existing prioritization schemes. First, the existing data partition prioritization schemes only work in the Extended profile [5], which is a profile that is rarely used in practice. Second, the existing schemes focus primarily on the granularity of the data partitions [4-9] or video frames [10-15] of H.264/AVC. In order to enhance the quality of the video streaming, the stream should be processed on a per-packet basis. Lastly, despite the extensive use of H.264/AVC over the MPEG-2 transport stream (TS) framework in real-time multimedia services such as Internet protocol television (IPTV) system [16], most previous research on video prioritization has been conducted using H.264/AVC video streaming without the consideration of MPEG-2 TS. Therefore, the feasibility of a new video prioritization scheme should be studied over the legacy MPEG-2 TS.

Therefore, this paper proposes a novel cross-layer packet prioritization scheme called the PackEt Prioritization Scheme (PEPS) to overcome these limitations. The PEPS manages the IPTV video streaming on a per-packet basis using the MPEG-2 system information and H.264/AVC NAL header information. As a result, the IP packets containing important video information, such as the IDR frame, sequence parameter set (SPS), picture parameter set (PPS), and the P-frame and B-frame headers, are assigned the highest priority.

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In order to demonstrate the practicality of the PEPS, a performance evaluation is conducted between the PEPS and the conventional frame prioritization in terms of the packet utilization ratio for video streaming (PURV), direct frame loss ratio, and peak signal-to-noise ratio (PSNR). The PURV is a new evaluation metric that estimates the impact of the video data losses by dividing the amount of decoded video data by the amount of successfully delivered video data during transmission. The direct frame loss ratio is a metric that estimates the difference between the number of video frames after encoding and the number of decoded video frames after reception [17]. Lastly, the PSNR is the most commonly used evaluation metric and it estimates the difference between the sent and received video clips. In this study, the evaluation on a testbed demonstrates that the proposed PEPS has better performance than that of the conventional frame prioritization scheme in all three aspects.

The key advantages of PEPS are as follows: (1) highly error-resilient transmission of important video data including the P-frame and B-frame headers, which have not been considered in conventional error-resilient and frame prioritization schemes for H.264/AVC video streaming; (2) PEPS manages H.264/AVC video streaming for IPTV system on a per-packet basis, which is a more fine-grained unit than the data partition and video frame; (3) PEPS is not constrained to a specific H.264/AVC profile; and (4) the implementation of PEPS does not incur significant CPU consumption and can be installed in all devices without requiring significant changes in the existing network infrastructure.

The remainder of this paper is organized as follows. Section 2 introduces the techniques that are related to the error-resilient transmission for real-time video streaming services. Section 3 specifies the limitations of the previous work and discusses the problem definition. Section 4 presents the PEPS as a solution to overcome the existing problem. Section 5 introduces the new metric PURV and compares the performance of PEPS and the conventional frame prioritization. Finally, Section 6 concludes the paper and discusses the possible future work.

2. RELATED WORKS

The error-resilient transmission of H.264/AVC video streaming for IPTV system is a technique that combines video coding and prioritized transmission techniques. Therefore, it is necessary to understand the related techniques such as H.264/AVC error-resilient schemes, video prioritization schemes, and real-time multimedia service technologies. This section briefly introduces the current techniques and discusses their limitations.

The H.264/AVC standard has a number of error-resilient schemes to manage the loss of video data during transmission, which can be classified using error detection and localization, resynchronization, data recovery, and error concealment [18]. The H.264/AVC decoder can reduce the negative effects of video data loss and partially recover the lost video data using these techniques. However, the error-resilient schemes primarily work on the video coding layer (VCL) of the H.264/AVC [19]. Therefore, only schemes based on redundant transmission are effective in preventing the losses of video data during transmission, such as redundant transmission of the parameter sets [19] and redundant pictures [20]. However, the existing solutions cannot be applied in managing the losses of the frame headers for I-frames, P-frames, or B-frames despite their importance for decoding [2, 22]. Therefore, the probability of successful transmission of the frame headers should be increased using other solutions such as video prioritization.

Table 1. Priority assignment of the conventional frame prioritization.

Priority	Video Data
High	SPS, PPS, PAT, PMT, I-frame header, I-frame data
Low	P-frame header, P-frame data, B-frame header, B-frame data

The prior work on video prioritization can be classified into two types: data partition prioritization and frame prioritization schemes. A number of previous data partition prioritization schemes have focused on the cross-layer design in order to enhance the quality of the video streaming [4-9]. For example, Ksentini et al. demonstrated that a cross-layer design between the H.264/AVC NAL and IEEE 802.11e could offer highly error-resilient transmission of the H.264/AVC data partitions [4]. However, these schemes have an obvious limitation that only the Extended profile of the H.264/AVC is applicable. Since this profile does not support certain types of video compression methods, such as context-adaptive binary arithmetic coding (CABAC) [21], the size of the encoded video file is larger than that of the video file encoded with the High or Main profiles. Therefore, the Extended profile is not typically used in real-time multimedia applications.

Alternatively, frame prioritization schemes have been proposed that manage the transmission rates and delays in video streaming [10-15]. Due to the conventional wisdom that packet prioritization requires high CPU consumption [10], the application of these schemes has been constrained to the unit of the frame, even though a packet is a more fine-grained unit of video transmission. Therefore, these schemes cannot provide highly error-resilient transmission of the P-frame and B-frame headers. The transmission of the P-frame and B-frame headers, which have a significant impact on the video quality, should be given higher priority in order to enhance the quality of the video streaming [2, 22]. An effective solution for the packet prioritization problem remains an open issue [10]. Therefore, this paper proposes the PEPS in order to achieve the per-packet prioritization of video streaming.

Finally, a per-packet basis prioritization is a significant enhancement in a new MPEG standard, which is called MPEG media transport (MMT). However, even though the legacy MPEG-2 TS is the most popular packetizing method for real-time multimedia services, such as IPTV system [16] and HTTP live streaming (HLS) [23], the existing video prioritization schemes are only based on a per-frame prioritization [14, 15]. Thus, the video prioritization on a per-packet basis has not yet been addressed using the legacy MPEG-2 TS. In order to achieve highly error-resilient transmission of IPTV system over the legacy MPEG-2 TS, it is necessary to develop a new prioritization scheme based on packets.

3. PROBLEM DEFINITION

Since the limitation of the conventional data partition prioritization is clear as described in Section 2, this section

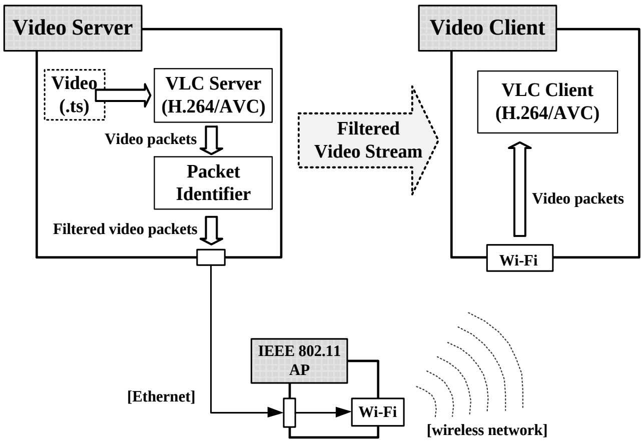


Figure 1. The testbed environment.

Table 2. Six test scenarios with the conventional frame prioritization.

No	Scenario	Delivered (O) / Filtered Out (-)						Is it playable?
		PPS, SPS, PAT, PMT	I-frame	P-frame		B-frame		
				Hdr	Data	Hdr	Data	
1	General case	O	O	O	O	O	O	Good
2	P-frames are omitted	O	O	-	-	O	O	Able to play, but significant freezes
3	B-frames are omitted	O	O	O	O	-	-	Few distortions, but able to play
4	P- and B-frames are omitted	O	O	-	-	-	-	Not able to play
4-1	Only P- and B-header are omitted	O	O	-	O	-	O	Not able to play
4-2	Only P- and B-data are omitted	O	O	O	-	O	-	Able to play I-frames

focuses on the limitation of the conventional frame prioritization for H.264/AVC video streaming. In the conventional frame prioritization schemes [10-15], the important video data such as SPS, PPS, and I-frame are typically assigned a higher priority than P-frame and B-frame, as shown in Table 1.

However, assigning lower priorities to the P-frame and B-frame headers increases the probability that they will be lost, which causes a significant degradation in the video. In order to analyze the extent of the degradation in detail, a testbed using the legacy MPEG-2 TS was setup as shown in Figure 1. As can be seen in the figure, a typical home network environment consists of an IEEE 802.11g access point (AP) and a VideoLAN Client (VLC) multimedia framework [24]. An open source H.264/AVC codec, i.e. the x264 codec [25], was used to encode the test videos with various profiles, such as High, Main, and Baseline profiles, at the video server. During the experiment, the encoded videos were streamed from the video server to the video client in real-time. Finally, a packet identifier program that filters the TS packets in the stream was developed.

Table 2 presents the six test scenarios that were used to demonstrate the limitations of the priority assignment for the

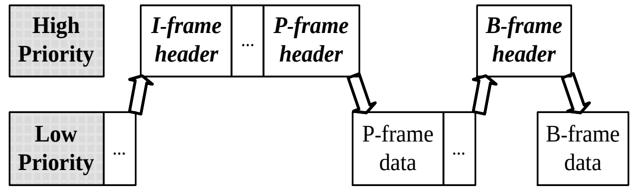


Figure 2. Error-resilient transmission for H.264/AVC.

conventional frame prioritization. In Scenario 1, all video packets are streamed from the VLC server to the VLC client without packet losses. Thus, the received video can be played without quality degradation. In Scenarios 2 and 3, the P-frames and B-frames are omitted, respectively. As a result of the omission, the frame freezes and distortions increase in the received video but the videos remain playable. In Scenario 4, both the P-frames and B-frames are omitted. Because the decoder does not receive a sufficient number of video frames to construct a group of pictures (GOP), the VLC client cannot play the received video in real time, even if all I-frames are successfully delivered [14].

The last two scenarios expand Scenario 4 in order to provide more detailed scenarios. In Scenario 4-1, all P-frame and B-frame headers are omitted. In this case, the decoder is not able to recognize the P-frames and B-frames in the stream, and thus it cannot play the streamed video even if the I-frames are successfully delivered. However, in Scenario 4-2, only the P-frame and B-frame headers are delivered to the VLC client. In this case, the decoder can determine whether or not the P-frames and B-frames are received, even if all subsequent P-frame and B-frame data are missing. As a result, the VLC client can configure the GOPs using the incomplete P-frames and B-frames and can play the streamed video in real time.

The results based on these scenarios demonstrate that the loss of the P-frame and B-frame headers has a significant impact on the quality of the H.264/AVC video streaming. In addition, the results also demonstrate that the conventional error-resilient and frame prioritization schemes for H.264/AVC video streaming do not appropriately manage the P-frame and B-frame headers in order to prevent their loss. Therefore, it is necessary to provide highly error-resilient transmission of the P-frame and B-frame headers using a different prioritization scheme. Figure 2 presents an appropriate priority assignment that can provide highly error-resilient transmission of the H.264/AVC video. Since the I-frames are referenced in multiple video frames, all I-frame packets including the header and data are assigned the highest priority during the transmission. In addition, due to the negative impact of the P-frame and B-frame header losses, these should also be assigned to the high priority.

In summary, an effective and flexible video prioritization scheme for IPTV system should satisfy the following four criteria; it should:

- provide highly error-resilient transmission of important video data including the P-frame and B-frame headers;
- not be constrained to a specific H.264/AVC profile;
- be applicable to H.264/AVC video streams packetized using MPEG-2 TS; and,
- have a negligible amount of CPU overhead that is incurred by the scheme.

Table 3. Priority assignment of the PEPS.

Priority	Video Data
High	SPS, PPS, PAT, PMT, I-frame header, I-frame data, P-frame header, B-frame header
Low	P-frame data, B-frame data

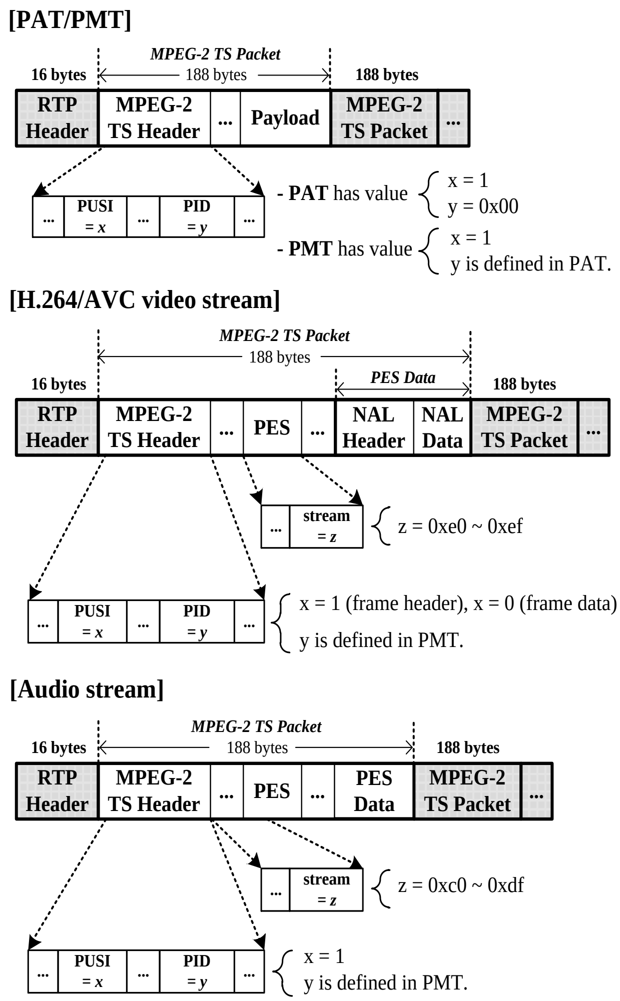


Figure 3. MPEG-2 TS packet structure.

In the next section, the PEPS is proposed as a scheme that satisfies the above requirements. This entails a significant paradigm shift from the conventional video prioritization schemes to a packet prioritization scheme for IPTV system.

4. PACKET PRIORITIZATION SCHEME FOR IPTV SYSTEM

The proposed PEPS classifies the priorities of the IPTV video data over the MPEG-2 TS according to their importance as shown in Table 3. The primary difference between the PEPS and the conventional frame prioritization is that the P-frame and B-frame headers are assigned a high priority. Thus, only the P-frame and B-frame data are assigned a low priority. In order to identify the TS packets of IPTV video data with high priority, the PEPS uses two types of information: the MPEG-2 system information and the H.264/AVC NAL header.

Table 4. NAL data classification by NRI value.

NAL Header		NAL Data
Start Code	NRI	
0x00 00 00 01	3	I-frame, SPS, PPS
0x00 00 00 01 0x00 00 00 01	2	P-frame, B-frame (ref=1)
0x00 00 00 01 0x00 00 00 01	0	B-frame (ref=0)

Figure 3 shows the header structures of MPEG-2 system information for containing the program association table (PAT), program map table (PMT), H.264/AVC video stream, and audio stream in payload. According to ISO/IEC standards 13818-1 [26] and 13818-2 [27], the specific packet identifier (PID) numbers are assigned to each TS packet in the MPEG-2 TS header. In addition, it is better to assign a single video frame to a single packet elementary stream (PES) data in order to reduce the complexity of the video streams [14]. Therefore, the payload unit start indicator (PUSI) field of the MPEG-2 TS header, which indicates the start of the payload data, is always set to ‘1’ when the frame header is placed on the MPEG-2 TS packet. Moreover, if the PUSI is set to ‘1’, then the associated data fields, such as PES, will be dynamically included in a MPEG-2 TS packet. Since the stream field value of the PES varies depending on the payload type in the PES data, it can distinguish between a video stream and an audio stream using the value. Therefore, the decoder can determine whether or not the TS packet contains important video data using the information of the MPEG-2 TS header and PES.

Lastly, the NRI value in the NAL header is used to determine the priority of the NAL data as in the conventional data partition prioritization [4, 8]. The primary difference between the two prioritizations is that the PEPS is based the NRI values that are commonly used in the H.264/AVC profiles such as High, Main, and Base profiles. Therefore, the PEPS is not constrained to a specific H.264/AVC profile. Table 4 presents the types of the NAL data that can be distinguished using the NRI value.

Figure 4 presents the algorithm used in the PEPS based on the MPEG-2 TS header, PES, and the NAL header information. The algorithm retrieves the first MPEG-2 TS packet from the received IP packet and checks its PID in the MPEG-2 TS header in order to identify whether it contains PMT or PAT information.

If the PID indicates that either a PMT or a PAT is contained in the MPEG-2 TS packet, then the algorithm assigns a high priority to the current IP packet. Since the PEPS considers video streams with IP packets as one unit, only a single priority can be set even if multiple TS packets exist in the IP packet. Therefore, when the high priority is set, the PEPS does not verify the priorities of the remaining TS packets. For PMTs or PATs, the IP packet is transmitted with a high priority regardless of the priorities of the remaining TS packets.

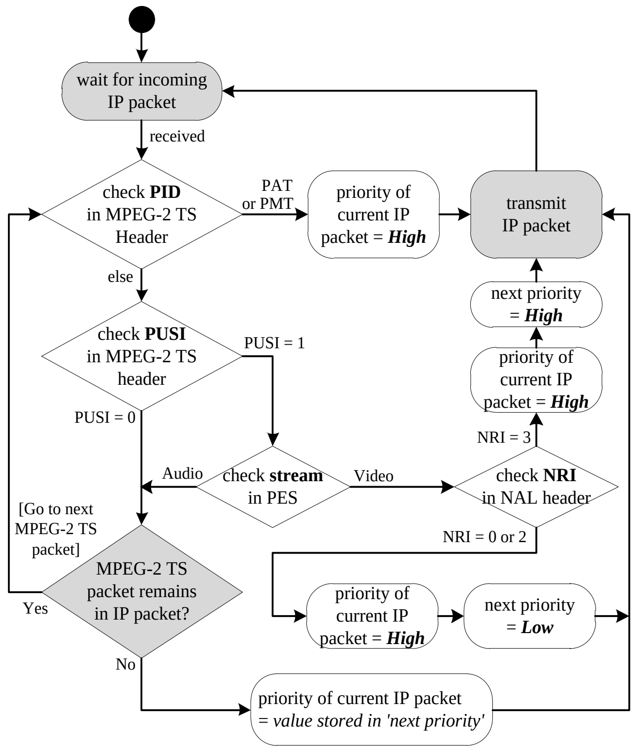


Figure 4. The PEPS algorithm.

If the PID is not a PAT and PMT, the algorithm verifies whether the value of the PUSI in the MPEG-2 TS header is '1' or '0'. If the PUSI is '1', then the TS packet is the start of an audio or video stream and the algorithm verifies whether the TS packet contains video data using the value of the stream in the PES. For video data, an appropriate priority value is assigned to the current IP packet and the variable named "next priority" based on the NRI value in the NAL header. In addition, because the SPS and PPS come with an I-frame header, they are assigned a high priority when the I-frame header is assigned. After that, the IP packet is transmitted to the video client. Because the PEPS only focuses on the video prioritization, the audio data does not influence the determination of the priority of the IP packets. If the PUSI is '0', then a verification is undertaken in order to determine whether there are TS packets remaining in the IP packet. If remaining packets exist, then the algorithm returns to the stage that verifies the PID of the next TS packet; otherwise, the algorithm assigns the priority value stored in the "next priority" variable to the current IP packet. For the I-frame data, the variable has a high priority value. In other cases, the variable has a low priority, which means that the current TS packet contains P-frame or B-frame data. After the assignment, the IP packet is transmitted to the video client.

5. EVALUATION

This section discusses the new evaluation metric PURV and then presents a comparative evaluation between the PEPS and the conventional frame prioritization [10, 11, 13] using a testbed with a wireless network.

5.1 Experimental Environment

The experimental environment is depicted in Figure 5. The video server uses an AMD C-60 1.0 GHz/dual-core processor with 4 GB main memory to generate H.264/AVC video packets with MPEG-2 TS for IPTV system. After being generated, the packets are sent to the IEEE 802.11g AP over an Ethernet connection. Then, the AP transmits the received video packets to the video client over the wireless network (Wi-Fi). In order to prioritize the delivery of the important video data in the video stream over the wireless network, the Wi-Fi multimedia (WMM) [28], which is a function in current Wi-Fi devices such as smart TVs and smartphones, and the differentiated services code point (DSCP) field of the IP header are used to provide differentiated services for the video packets over the Wi-Fi. For example, if a video packet contains an I-frame header, the value '0x38' for the highest priority is assigned to the DSCP field of the IP packet that contains the video packet. The IEEE 802.11g AP has four types of WMM ACs and corresponding queues in order to differentiate the transmission priority based on the DSCP values. Thus, when the IP packet reaches the AP, it is steered to the highest priority queue, which is called "Voice".

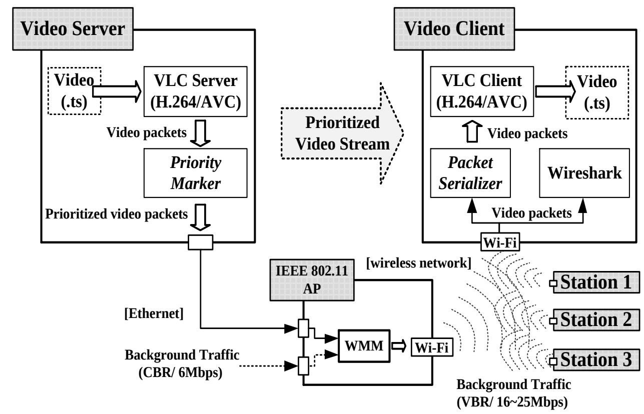


Figure 5. Experiment environment.

In order to control the packet delivery ratio (PDR) of the video streaming, two types of background traffic are generated during streaming: 6 Mbps constant bit rate (CBR) traffic through the IEEE 802.11g AP and a total of 16-25 Mbps variable bit rate (VBR) traffic from three wireless stations. The CBR traffic represents the overhead of multiple video streams in the AP's queue, while the VBR traffic represents the overhead of the wireless network. Finally, three evaluation metrics are used to compare the results of the PEPS with those of the conventional frame prioritization: PURV, direct frame loss ratio, and PSNR.

To implement the proposed PEPS in real devices, several programs were developed including a priority marker and packet serializer. The priority marker assigns appropriate DSCP values to each IP packet based on the significance of its payload for decoding. In addition, the program adds one byte of data space at the end of the payload to store the transmission order information, which is used to manage out-of-order packets. The existing decoders cannot manage the out-of-order deliveries that occur as a result of the prioritized transmissions over wireless networks. Therefore, the packet serializer buffers and sorts the received packets on the video client. During the transmission, the program buffers all transmitted IP packets in front of the VLC client. At the same time, the added transmission order information is used to store the received packets in the appropriate order. After the transmission completes, the program transmits the ordered IP packets to the VLC client. In addition, the Wireshark program

Table 5. Three videos types used in the evaluation.

	Bird [29] (Great Blue Heron Feeding)	Birds [29] (Birds-Lesser Scaup)	Sintel [30] (sintel_trailer)
Format	H.264/AVC High		
Bit Rate	612 kbps		
Frame Rate	30.000 fps		
Resolution	720 x 480		
Sound	none		
Type	Slow motion	Crowded	Fast motion
I-frames	52	53	60
P-frames	442	938	1015
B-frames	1083	586	447
Length	52 sec	52 sec	50 sec

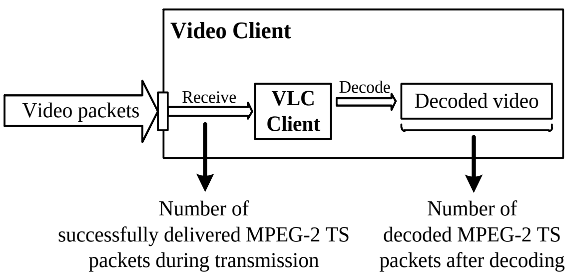


Figure 6. Environment for PURV estimation.

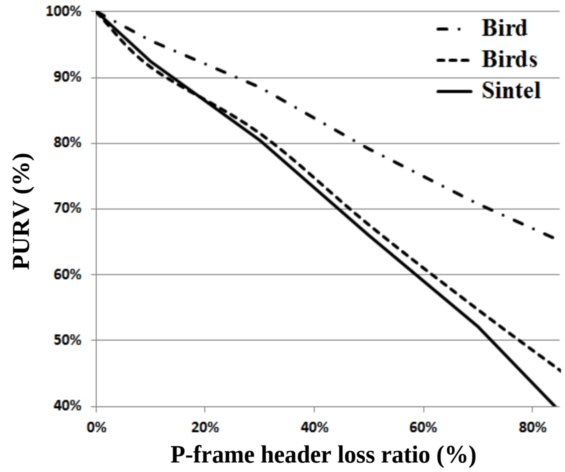
[31] is used to collect statistics on the successfully delivered MPEG-2 TS packets.

Since the performance of video prioritization scheme varies depending on the type of video, three different types of video were used in the evaluation. As shown in Table 5, the three videos were encoded with the same options (H.264/AVC high profile, 612 kbps, 30 fps, 720x480, no sound) and had a length of approximately 50 s. The primary difference between the three video types is the proportion of each frame. Because the video "Bird" is a slow motion video, it contains more B-frames than P-frames. However, because the scenes in the "Birds" and "Sintel" videos change frequently, they have more P-frames than B-frames.

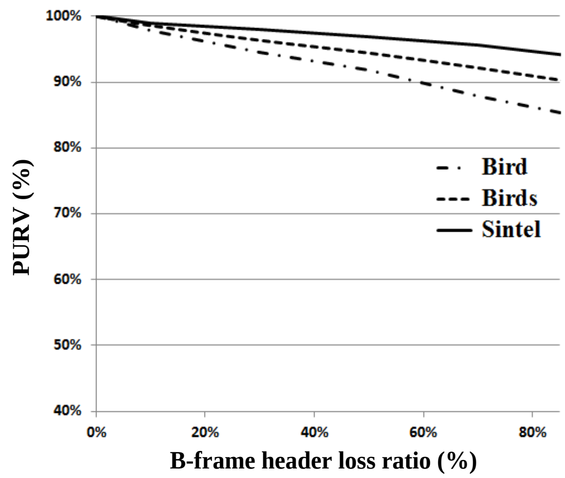
5.2 PURV for Estimating Packet Utilization

As discussed in Section 3, the loss of frame headers causes significant quality degradation for H.264/AVC video streaming. PURV is an evaluation metric that estimates how effectively the received packets are used for decoding and is a more fine-grained unit of performance evaluation than the decodable frame rate discussed in [17]. As shown in Figure 6, PURV is calculated by dividing the total number of decoded MPEG-2 TS packets by the total number of successfully delivered MPEG-2 TS packets, as follows:

$$PURV = \frac{\text{Decoded MPEG-2 TS packets}}{\text{Successfully delivered MPEG-2 TS packets}} \quad (1)$$



(a) PURV as a function of the P-frame header loss ratio.



(b) PURV as a function of the B-frame header loss ratio.

Figure 7. PURV evaluation results.

The difference between the number of delivered video packets and the number of decoded video packets is important because it indicates that some packets cannot be decoded due to lack of complete information. For example, if an IP packet containing frame header information is lost, then the remainder of the IP packets for that frame cannot be decoded and thus are discarded by the decoder.

Figure 7 illustrates examples of P-frame or B-frame header losses in video streaming. For the evaluation, the video server was connected to the video client using an Ethernet cable and some frames headers were selectively removed during the video streaming without background traffic. In Figure 7(a), the increment of the P-frame header losses significantly decreased the PURV in the three videos. Because the "Birds" and "Sintel" videos had more P-frames than the "Bird" video, the impact of P-frame header losses was more significant in those video streams. In contrast, Figure 7(b) presents the impact of B-frame header losses. Because the "Bird" video has more B-frames than the other two videos, it exhibited the sharpest decrement in the graph. However, due to the small amount of data, the B-frame header

Table 6. Priority assignments with WMM and DSCP.

Priority	WMM Access Category	DSCP Value	H.264/AVC over MPEG-2 TS
High	Voice	0x38	SPS, PPS, PAT, PMT, I-frame header, I-frame data
Low	Video	0x28	*P-frame header,* P-frame data
	Best Effort	0x18	*B-frame header,* B-frame data

(a) Assignments in the conventional frame prioritization.

Priority	WMM Access Category	DSCP Value	H.264/AVC over MPEG-2 TS
High	Voice	0x38	SPS, PPS, PAT, PMT, I-frame header, I-frame data, *P- and B-frame headers*
Low	Video	0x28	P-frame data, B-frame data

(b) Assignments in the PEPS.

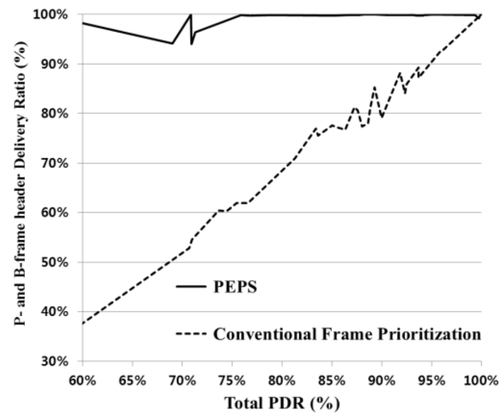
losses incurred a smaller decrement in the PURV in the three videos compared with the P-frame header losses.

Compared with the evaluation metric PSNR, PURV is an easier and more precise metric for evaluating the performance of video prioritization schemes. Because PSNR compares the bitmap information between the original video frame and the target video frame when calculating its result, the frame synchronization between two videos should be perfectly matched in order to perform the evaluation. However, for the video transmission experiment, the video frames can be lost during a transmission and thus it breaks the synchronization between the original video and the transmitted video. In order to perform the PSNR evaluation between the two videos, certain types of adjustments are necessary, and these reduce the accuracy of the experiment. In contrast, adjustments are not required in the PURV evaluation: it is sufficient to record the amount of transmitted video packets and the decoded video packets, which can be performed easily using third party programs such as Wireshark.

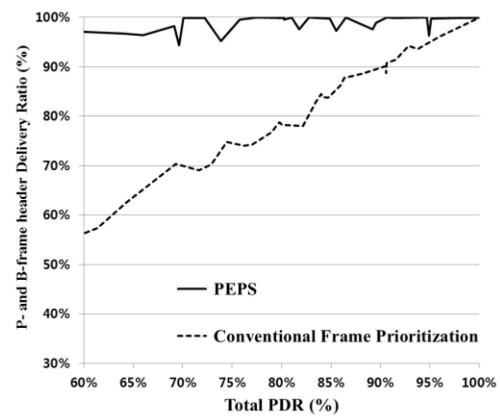
5.3 Evaluation Results

The comparative analysis used the two priority assignments described in Table 6. The primary difference between Tables 6(a) and 6(b) is the priority of the P-frame and B-frame headers. The P-frame and B-frame headers are assigned a low priority in Table 6(a) while they are assigned a high priority in Table 6(b). Furthermore, experiments were performed with a PDR that varied between 60% and 100%. This is consistent with a typical packet loss ratio under moderate interferences in an indoor environment, which is less than 40% [32].

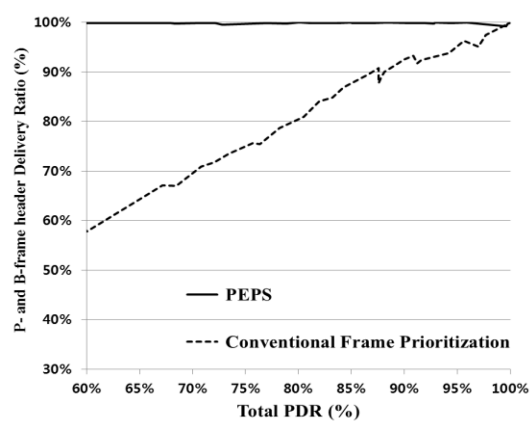
The set of experiments was performed to control the PDR through the introduction of background traffic. Figure 8 shows the P-frame and B-frame header delivery ratios of the two prioritizations as a function of PDR for the three videos. As can be seen in the figure, the P-frame and B-frame header delivery ratios of the



(a) Bird.



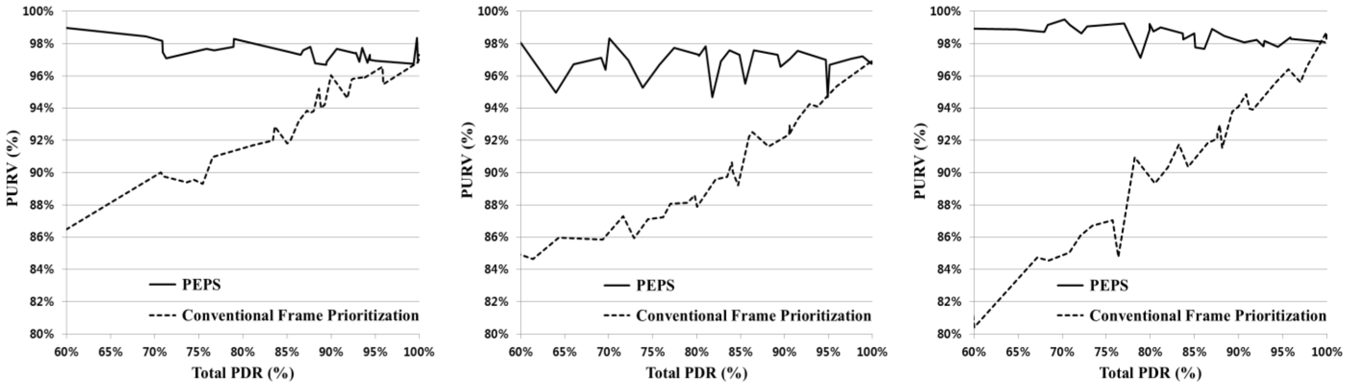
(b) Birds.



(c) Sintel.

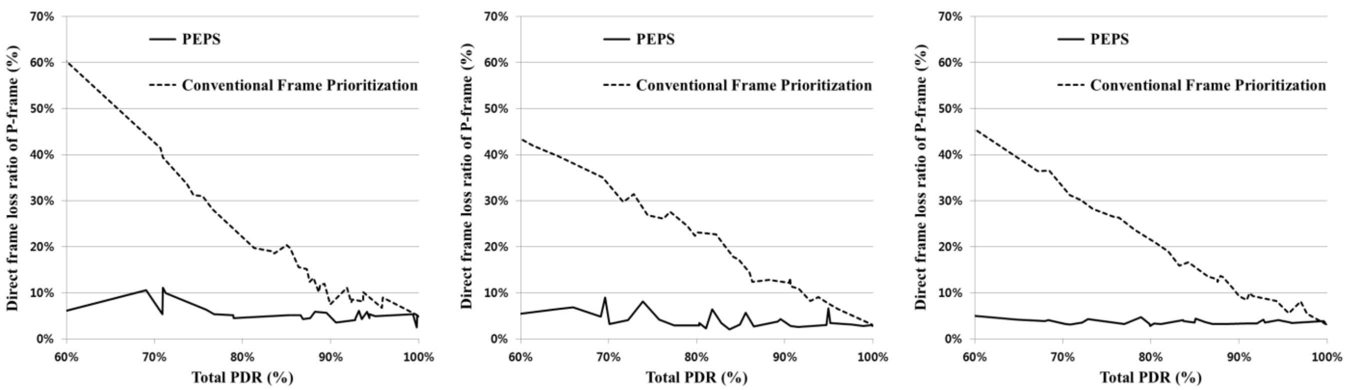
Figure 8. P-frame and B-frame header delivery ratio as function of PDR.

proposed PEPS are much higher than those of the conventional frame prioritization. These differences result in significant differences in the PURV between the two prioritizations as shown in Figure 9. As seen in Figure 9, the PEPS results in much higher PURV values than those of the conventional frame prioritization. In particular, the differences become more significant, as much as 12-19%, when the network environment worsens. This clearly demonstrates the performance improvement provided by the PEPS in terms of error-resilient transmission of video streaming.



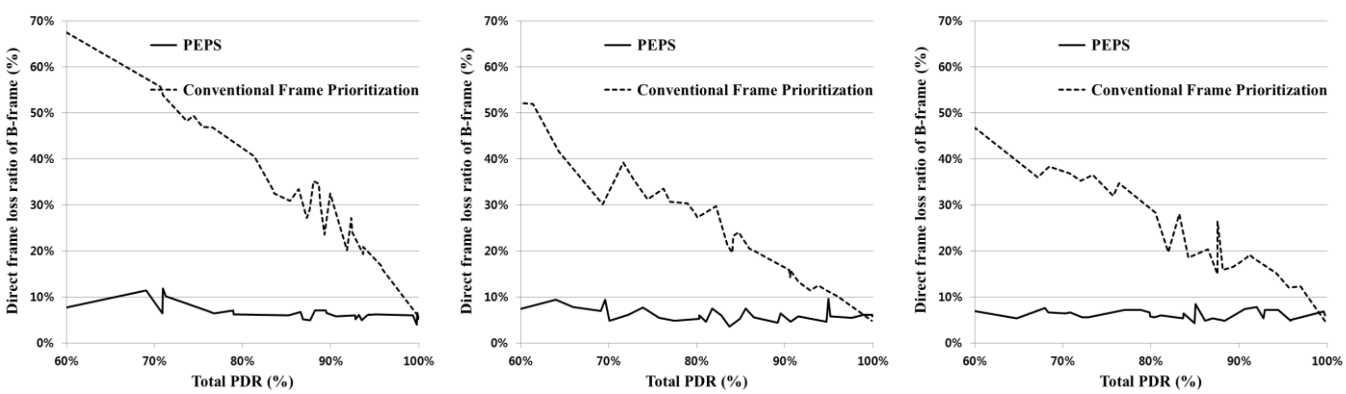
(a) Bird. (b) Birds. (c) Sintel.

Figure 9. PURV as function of PDR.



(a) Bird. (b) Birds. (c) Sintel.

Figure 10. Direct frame loss ratio of P-frame as function of PDR.

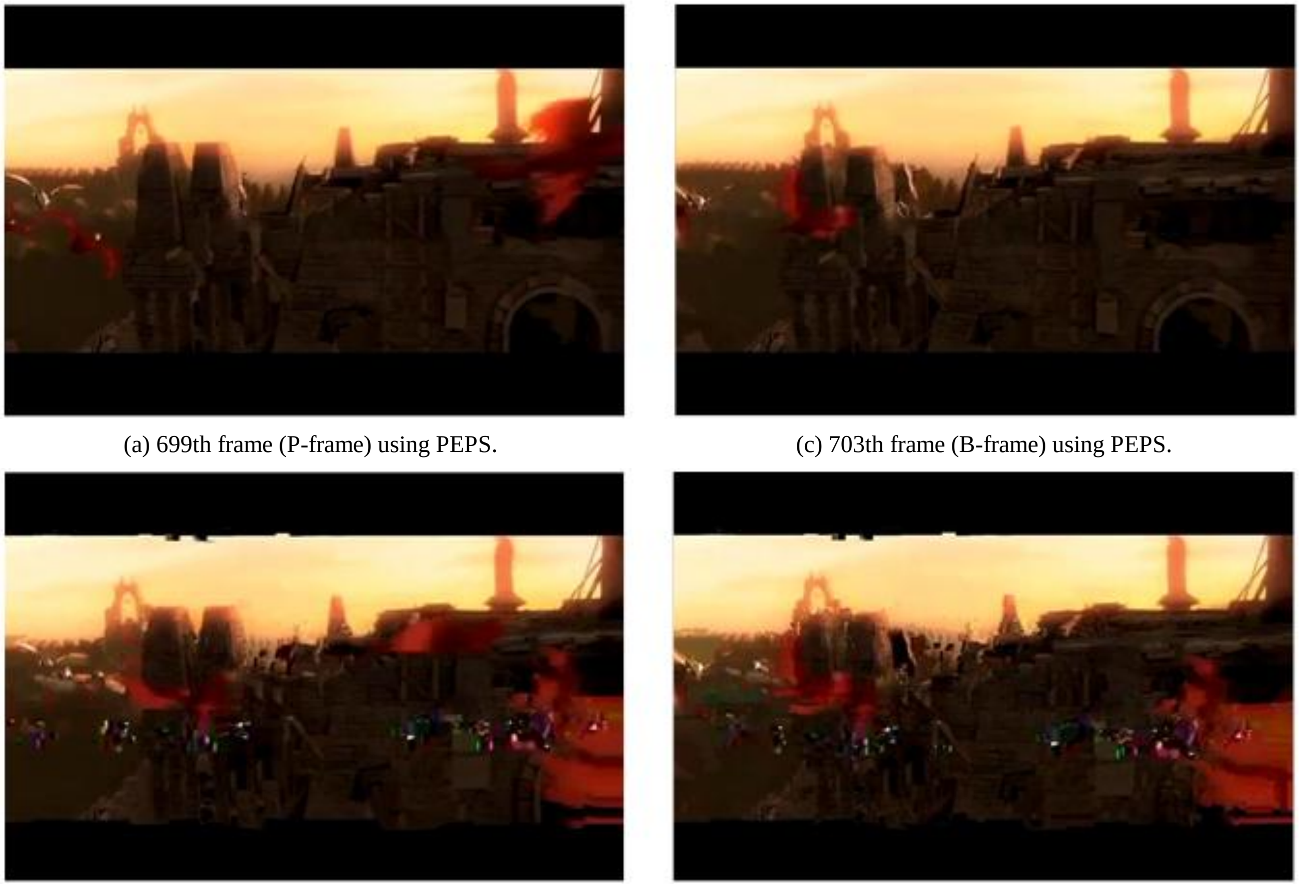


(a) Bird. (b) Birds. (c) Sintel.

Figure 11. Direct frame loss ratio of B-frame as function of PDR.

In addition, the high performance of PEPS can also be verified using the direct frame loss ratio. Figure 10 and Figure 11 demonstrate that the direct frame loss ratios of the two prioritizations as function of the PDR for the P-frames and B-frames of the three videos. As seen in the figure, the PEPS results in a lower direct frame loss ratio, as much as 40-60%, than that of the conventional frame prioritization in all experiment results.

Consequently, the video client has a lower number of freeze frames when it plays the video transmitted using the PEPS. For example, Figure 12 shows the PSNR results of "Sintel" video for the two prioritizations when PDR was approximately 92%. As seen in the figure, the PEPS results in higher PSNR values than the conventional frame prioritization when the transmitted frames are frozen; the PSNR values are higher by an average of 5% for



(a) 699th frame (P-frame) using PEPS.

(c) 703th frame (B-frame) using PEPS.

(b) 699th frame (P-frame) using conventional frame prioritization.

(d) 703th frame (B-frame) using conventional frame prioritization.

Figure 13. Comparison of decoded video frames.

the total video stream. This effect is also clearly seen in Figure 13, which compares the 699th video frame (a P-frame) and the 703th video frame (a B-frame) between the two prioritizations. The frames based on the PEPS are much clearer while the frames based on the conventional frame prioritization exhibit a significant amount of distortion.

Regarding the processing requirements for the PEPS, the code occupies less than 10 Kbytes in memory and incurs a negligible processing delay (less than 1 ms) per IP packet on the video server. Therefore, the PEPS does not have a significant impact on the end-to-end delay of the video stream.

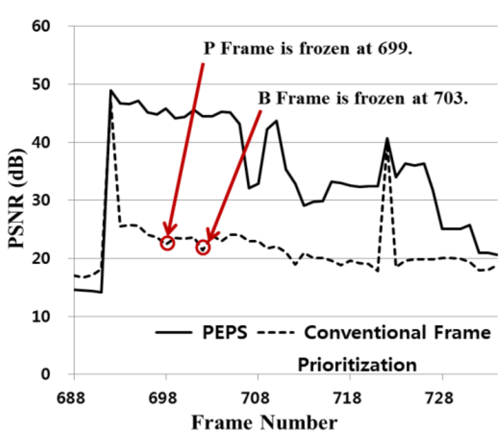


Figure 12. PSNR for "Sintel" video on PDR 92%.

In summary, the PEPS exhibits better performance than the conventional frame prioritization for IPTV system in terms of PURV, direct frame loss ratio, and PSNR. This demonstrates that the PEPS significantly improves the quality of the video streaming over lossy wireless networks.

6. CONCLUSION AND FUTURE WORK

This paper proposed a novel cross-layer PackEt Prioritization Scheme (PEPS) for IPTV system that provides highly error-resilient transmission of important video data over wireless networks. This was achieved based on the MPEG-2 system information and the H.264/AVC NAL header information, and their transmission with a high priority. In order to demonstrate the implementation of the PEPS, the WMM of IEEE 802.11 was used to prioritize the video stream, which is a general function of current Wi-Fi devices. This indicates that the proposed PEPS can be applied to the existing smart devices such as smart TVs and smartphones. The evaluation on a testbed demonstrated that the proposed PEPS results in a significant performance enhancement over the conventional video prioritization for IPTV system in terms of PURV, direct frame loss ratio, and PSNR.

For future work, the PEPS will be applied to various smart devices over wireless networks, such as the network between a smartphone and a smart TV, over wireless networks. In addition, the PEPS will be applied to the management of 3D video synchronization issue and the secure transmission of the high definition (HD) video issue over wireless networks.

7. ACKNOWLEDGEMENTS

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