Prioritized 3D Video Distribution over IEEE 802.11e

C.T.E.R. Hewage, S. Nasir, S.T. Worrall, and M.G. Martini

Abstract: The advancement of 3D video technologies enables us to experience 3D video at home, office and public places. In this paper, a prioritization scheme for backward compatible 3D video distribution over Wireless Local Area Networks (WLANs) is proposed for home/office environments. The scheme is designed to work with the colour plus depth representation format. Colour and depth map sequences have different error sensitivities due to their roles in 3D video rendering. As the colour image sequence is directly viewed by 2D/3D users, its quality influences overall perception more than the depth image sequence. Therefore, the proposed prioritization scheme allocates higher priority for coded colour video stream than for the depth map stream in order to improve the perceived quality of 2D/3D video. The proposed solution is designed for IEEE 802.11e, which supports different traffic classes with various priority levels for improved Quality of Service (QoS). Based on the allocated priorities, 3D data streams are mapped to appropriate medium access classes which differ in terms of packet losses and latency. The objective and subjective quality evaluations show that the proposed scheme improves the quality of 2D/3D video while achieving acceptable 3D depth perception.

Keywords: Colour plus depth video, Prioritized video transmission, IEEE 802.11e, Perceptual3D video quality

1. Introduction

3D video provides a sense of "being there" and offers more natural conditions for viewing and communication. In the future, 3D applications will not be limited to flight simulators, IMAX cinemas, and 3D games only, but will also be available for the wider consumer market. The advancement of 3D capture and processing technologies, and the availability of affordable 3D displays will enable 3D home studios [1]. Moreover, the industry leaders recently formed an alliance to speed the commercialization of 3D into homes [2]. Immersive video content can be delivered within a home/office/public places using wireless links such as WiFi. However, the distribution of 3D video at home/office would be affected due to the availability of other demanding services such as voice, video streaming, web browsing, etc. Therefore, this paper proposes a prioritization scheme for 3D video distribution in the home/office environment using IEEE 802.11e technology.

The artifacts caused by channel errors and packet losses will hinder the overall perception of reconstructed 3D video at the user end. Therefore, it is important to protect 3D video content when transmitted over unreliable communication channels and error protection and concealment techniques can be utilized to recover the error blocks in the transmitted 3D bit-stream. The performance of 3D video transmission over wireless channels - error prone and band–limited - can be further improved with a Joint Source Channel Coding (JSCC) approach [3]. For instance, the error resilience schemes for 3D video transmission can employ error correction codes to protect different 3D video components unequally [4]. However, the introduction of redundant data (e.g., Forward Error Correction (FEC) codes) to the 3D video bit-streams demands more system resources such as storage and bandwidth. Error concealment techniques can also be applied as post-processing at the receiver side to compensate for missing video content [5]. However, the reliability of these techniques is heavily dependent on the availability of surrounding information near the error position in the same view or in the corresponding view.

Therefore, error recovery techniques, which do not impose any additional overhead to already resource demanding 3D video applications, are necessary to transmit 3D video more efficiently. The transmission system parameters (e.g., Modulation Coding Scheme (MCS), transmission power) can be utilized to prioritize different video components based on their importance towards improved perceptual quality. In the case of prioritized transmission, based on allocated system parameters, each video component may face different channel conditions (e.g., packet losses), and the most important parts of the video stream will be given more protection than less important parts. For example, the Unequal Power Allocation (UPA) scheme proposed for scalable video streaming in [6] allocates different power levels for scalable video layers based on their importance. Similarly, 3D video components can be prioritized based on their perceptual importance. Thus, the proposed prioritization scheme in this paper assigns different access priorities to the wireless medium based on the importance of each coded 3D component.

This paper is organized as follows. Section 2 describes the proposed prioritization scheme for 3D video in detail. The prioritization of data streams over IEEE 802.11e is also presented in this section. The experimental work and results are discussed in Section 3. Section 4 concludes the paper.

2. The Proposed Prioritization Scheme for 3D Video Distribution over WLAN

The monoscopic video plus depth map 3D video representation is widely considered in research and standardization activities due to its simplicity and adaptability [7][8]. The colour image sequence is projected to the 3D space based on the depth pixel values, and this method is commonly known as Depth Image-Based-Rendering (DIBR) [7]. Moreover, this format can be utilized to provide backward compatible 3D video services, where conventional users can view 2D video content by neglecting the depth map stream. With this representation, colour video is the only texture information that is directly viewed by the users. Therefore, the loss of colour video packets will be more noticeable to users (i.e., both 2D and 3D viewers) than the loss of depth video packets. Furthermore, the colour video itself provides certain depth cues (e.g., identification of objects in the foreground and background) during 2D viewing. Therefore, the colour video stream should be allocated more protection compared to the depth map packets in general.

Detailed depth maps are required to generate good quality 3D video using the DIBR technique, especially when the rendering view is too far from the original view. However, the quality of the depth map does not need to be significantly high to render good quality stereoscopic video content which is approximately 6cm apart [9][10][11][12]. For example, the effect of depth map compression on depth perception is not significant according to [9][10]. Furthermore, the effect of depth map transmission errors on the quality of reconstructed 3D video is insignificant compared to the quality degradation due to the loss of colour video packets [11]. The study in [11] also highlights the importance of prioritizing colour video data ahead of depth map information in order to improve the perceived 3D video quality. Moreover, the quality evaluation carried out in [12] shows that the effect of packet losses on depth perception is lower compared to the effect of packet losses on overall image quality. The scheme proposed in this paper therefore allocates higher priority for the colour image stream than the depth map stream to improve the overall quality of received 2D/3D video.

The block diagram of the proposed prioritization scheme is shown in Figure 1. The extractor module separates the received 3D video stream into two colour and depth map packet streams. The prioritization module then maps the colour and depth bit-streams into different medium access levels after evaluating prevailing channel conditions. The functionality of the Prioritization module is described in Subsection 2.1.

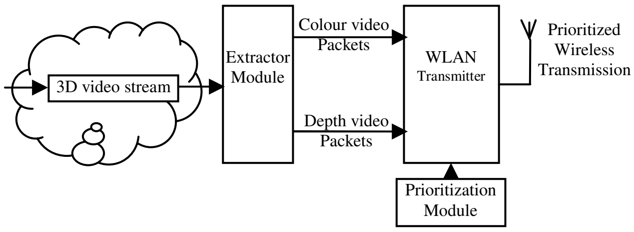

Figure 1: The block diagram of the proposed prioritization scheme

2.1 – Prioritization of 3D video streams with IEEE 802.11e

IEEE 802.11, developed with the Distributed Coordination Function (DCF), is characterised by an easy to implement and robust Medium Access Control (MAC) protocol for best effort services in the wireless medium [13]. However, with DCF, a station might have to wait an arbitrarily long time to send a frame, so that real-time applications such as voice and video may suffer [14]. The IEEE 802.11 working group has developed a new standard known as IEEE 802.11e [15] to provide QoS support for demanding multimedia applications with stringent requirements. IEEE 802.11e defines a single coordination function, called the Hybrid Coordination Function (HCF), which comprises two medium access mechanisms, namely, contention-based channel access and controlled channel access. In particular, the content-based channel access is referred to as Enhanced Distributed Channel Access (EDCA), which is an extension to legacy DCF and provides the MAC layer with per-class service differentiation. The QoS support is realized with the introduction of Traffic Classes (TCs) or Access Classes (ACs). With this approach, frames are delivered through multiple *backoff* instances within one station. These multiple *backoff* instances can be assigned to different traffic categories (i.e. TCs/ACs). Consequently these TCs/ACs get prioritized accesses to the wireless medium since they start transmitting at different time instances [15]. The implementation of legacy DCF and EDCA with different traffic classes and independent transmission queues are shown in Figure 2. The priority levels for each TC/AC can be differentiated based on the parameters selected for Contention Window (CW) size (e.g., CW_{min}, CW_{max}), Arbitrary Inter Frame Space (AIFS) number and retransmitting limit [15]. Depending on the traffic class being assigned, the particular traffic will undergo different packet-dropping probabilities and delay constraints. Therefore, the proposed transmission solution with IEEE 802.11e assigns higher priority for the most important parts of the video bit-stream whereas less important components are assigned to a lower priority TC/AC [16].

In general, all video streams are assigned the same access priority (i.e. to the same TC/AC). For example, in case of 3D video transmission, both colour and depth bit-streams should be mapped to the video TC/AC. However, increased traffic in one access class will again degrade the quality of all the bit-streams in that particular traffic class (e.g., 3D video stream, 2D video streams) as all are transmitted with the same *backoff* time parameters. For instance, the number of colour video packets lost may be higher compared to the number of packets lost from the depth image stream. As a solution, the packet-streams which are initially assigned to the same traffic/access class can be later assigned into a different priority traffic class based on their importance in order to increase the robustness of most important video streams. Thus, in this paper the colour image sequence is mapped to a higher priority traffic class whereas the depth image sequence is mapped to a relatively lower traffic class. Even though the quality of the colour image sequence is going to be improved with the proposed method, the depth quality will be degraded and will have larger delay characteristics. Therefore, the selection of priority levels should be performed after considering the network load of the home/office environment and other contextual information such as user preferences.

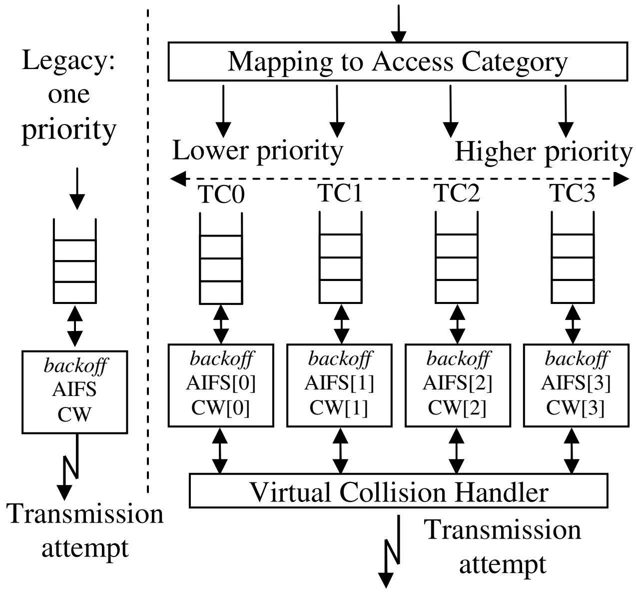

Figure 2: Virtual backoff of Traffic Categories (TCs) with DCF (left) and EDCA (right) methods.

3. Experimental Setup and Discussion

3.1 – Parameter settings

The *Orbi*, *Interview*, *Breakdance*, and *Ballet* sequences are coded with backward compatibly layered configuration (i.e., colour and depth video are coded at the base and enhancement layers respectively) of JSVM reference software codec version 9.8. The *Orbi* and *Interview* sequences are in 720x576 pixels resolution, and are captured at 25frames/s. The resolution and frame rate of the *Breakdance* and *Ballet* sequences are 1024x768 pixels and 15frames/s. 100 frames of these sequences are coded in slices of 200 bytes with IPPP… sequence format and Content Adaptive Binary Arithmetic Coding (CABAC). The slices are introduced to facilitate packet video transmission and robust decoding. The bit-stream extractor module of JSVM is utilized to extract base and enhancement layer packets at the WLAN Transmitter (i.e., home/office gateway). The lost slices of each frame are concealed with *frame copy/slice copy* method of JSVM at the decoder.

The proposed scheme has been tested for performance over a simulated WLAN environment using the Network Simulator 2 (NS-2) platform. NS-2 is a widely used open source discrete event simulation tool for network performance evaluations developed at the UC Berkeley. The specific version used for these experiments has been built upon version 2.28 with an 802.11e EDCA extension model implemented by the Planète project-team at the INRIA Sophia Antipolis, France [17].

A wireless scenario with seven nodes is considered. Four different ACs, namely AC_VO, AC_VI, AC_BE, and AC_BK are employed for voice, video, best-effort and background traffic respectively. The AC_VO has the highest access priority to the wireless channel whereas AC_BK class traffic has the least access priority. 3D video streaming (i.e., colour and depth video streams) is simulated as flowing from the Access Point (AP) to a node (i.e., Node 2 in the simulation) in the wireless network. When no prioritization is taking place for 3D video, both colour and depth video streams are allocated to the video access class (i.e. AC_VI), as shown in Table 1. In order to check the performance of the proposed prioritization scheme, the depth video stream is mapped first to best-effort (i.e., AC_BE) and then to background (i.e., AC_BK) access classes. The services used by each node and their access classes in the simulation are listed in Table 1. Different prioritization levels for each access class are obtained through changing the CW parameters (i.e., CW_{min},

CW_{max} and CW_{offset}) of each station. A total simulation time of 30s is considered. This simulation is run for 20 times to obtain average results.

Table 1: Simulated Data streams over WLAN

Stream	Service	Access Class (AC)
1	Voice (flows from AP to Node 1)	AC_VO
2	Colour video stream of 3D video with 200bytes MTUs (flows from AP to Node 2 over UDP)	AC_VI
3	Depth map stream of 3D video with, 200 bytes MTUs (flows from AP to Node 2 over UDP)	AC_VI (no prioritization), AC_BE and AC_BK
4	2D video streaming with 1024 bytes MTUs (flows from AP to Node 3 over UDP)	AC_VI
5	FTP stream with 1500 byte MTUs (flows from Node 4 to Node 5 over TCP)	AC_BE
6	FTP stream with 256 byte MTUs (flows from Node 5 to Node 6 over UDP)	AC_BE
7	FTP stream with 256 byte MTUs (flows from Node 6 to Node 7 over UDP)	AC_BK

3.2 – Results and discussion

Table 2 shows the average packet loss rates and delay characteristics with and without prioritization. The average packet loss rate is reduced for the colour stream when the depth stream is mapped to a lower prioritization access class (i.e. AC_BE, AC_BK). However, due to other traffic in lower priority access classes, the depth bit-stream faces comparably higher average packet loss rates. The delay characteristics are also improved for the colour bit-stream, when the depth bit-stream is mapped to a lower prioritization class. According to Table 2, the depth stream is subjected to longer delays, when it is assigned to a lower prioritization access class than when it is mapped to AC_VI. However, depth stream delay characteristics are at acceptable levels compared to the delay requirements of real-time multimedia applications.

*Table 2: Average packet loss rate and delay characterisct*s *with and without prioritization*

Depth Priority	Average Packet Loss Rate (%)		Delay Characteristics (ms)					
	Colour Stream	Depth Stream	Colour Stream			Depth Stream		
			Min	Max	Mean	Min	Max	Mean
Depth @ AC_VI (no prioritization)	3.2	3.2	0.12	55.21	39.72	0.30	55.96	39.94
Depth @ AC_BE	0	5.22	0.12	7.91	0.91	0.12	101.22	76.07
Depth @ AC_BK	0	8.74	0.12	7.95	1.03	0.12	249.39	168.82

The reconstructed image quality under these conditions is shown in Table 3. When both colour and depth map streams are mapped to the same video access class (i.e. AC_VI), the quality of both streams are at acceptable levels. However, the colour image quality is lower or at similar level to that of the corresponding depth map stream in most of the cases. When the depth bit-stream is mapped to a lower priority access classes, colour image is reconstructed with superior quality and hence can be used to deliver better quality 2D/3D video services. Figure 3 illustrates sample frames from each test sequence with and without the use of proposed prioritization scheme. This figure also shows improved colour image quality, achieved with the proposed method compared to the un-prioritized transmission of 3D video. However, due to reduced priority access to the wireless medium, depth stream has been subjected to higher packet loss probabilities than the colour image stream. Therefore, the depth image quality has been degraded with the proposed system (see Table

3). Moreover, according to Table 3, the depth quality degradation is significant for high motion activity sequences such as *Orbi* and *Ballet*. Sample depth frames with the proposed system are shown in Figure 4. This also shows that depth image quality is reduced even though some depth map characteristics (e.g. identification of different objects) are still remaining intact. According to these objective results and subjective illustrations, it can be concluded that the proposed method allows the colour image to be reconstructed with better quality compared to the depth map sequence.

Table 3: Image quality with and without prioritization

Depth Priority	*Orbi* PSNR (dB)		*Interview* PSNR (dB)		*Breakdance* PSNR (dB)		*Ballet* PSNR (dB)	
	Colour	Depth	Colour	Depth	Colour	Depth	Colour	Depth
Depth @ AC_VI (no prioritization)	31.88	34.82	35.24	38.60	34.70	34.67	35.61	33.30
Depth @ AC_BE	37.95	31.32	37.15	35.92	38.14	31.61	39.23	29.68
Depth @ AC_BK	37.95	29.53	37.15	33.89	38.14	29.52	39.23	27.59

Figure 3: Sample colour frames with and without the proposed prioritization scheme (both colour and depth streams @ AC_VI): Orbi (Top left), Interview (Top right), Ballet (Bottom left) and Breakdance (Bottom right)

Original Depth | Depth @ AC_VI | Depth @ AC_BE | Depth @ AC_BK

Figure 4: Sample Orbi depth frames with and without the proposed prioritization scheme

However, subjective tests are conducted to evaluate the effect of these impaired depth images on the perception of 3D. The test sequences are displayed on Philips multi-view autostereoscopic display (42") and Single Stimulus Quality Scale (SSCQS) method is utilized to obtain each subject's feedback. Subjects rate the test sequences for two 3D perceptual attributes namely, *overall image quality* and *depth perception*. The Mean Opinion Scores (MOS) are calculated for each test sequence after averaging the opinion scores across all subjects. Figures 5 (*Orbi/Interview*) and 6 (*Break dance/Ballet*) show MOSs for *overall image quality* and *depth perception*. The test points A,B,C, and D in *x*-

axis refer to the error free condition, depth @ AC_VI, depth @ AC_BE, and depth @ AC_BK respectively. When the depth stream is mapped to the same access class as colour stream (i.e. AC_VI), both *overall image quality* and *depth perception* degrades rapidly (see test point B of Figures 5 and 6) compared to the error free case. The overall perception of image quality has improved with the proposed prioritization scheme (see test points C and D of Figures 5 and 6). However, perceived image quality is not as good as that of error free conditions when the depth stream is mapped to the best-effort (i.e. AC_BE) or background (i.e. AC_BK) access classes. This suggests that *overall image quality* is influenced by highly corrupted depth map sequences. Furthermore, the amount of degradation in perceptual quality is not significant when depth bit-stream is mapped from best-effort access/traffic class (i.e. AC_BE) to the background access/traffic class (i.e. AC_BK). The *depth perception* attribute of 3D viewing is not affected by the impaired depth images received with the proposed prioritization scheme. It is evident that the improved colour image quality achieved with the proposed method has positively influenced *depth perception* (the resultant good quality colour images have provided additional depth cues to keep the *depth perception* at acceptable levels).

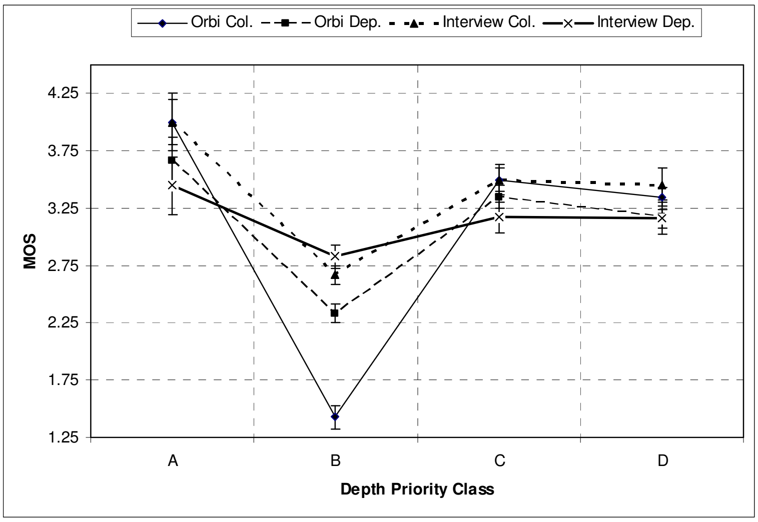

Figure 5: Orbi and Interview subjective quality (Col: Overall image quality and Dep: Overall depth perception) with and without prioritization

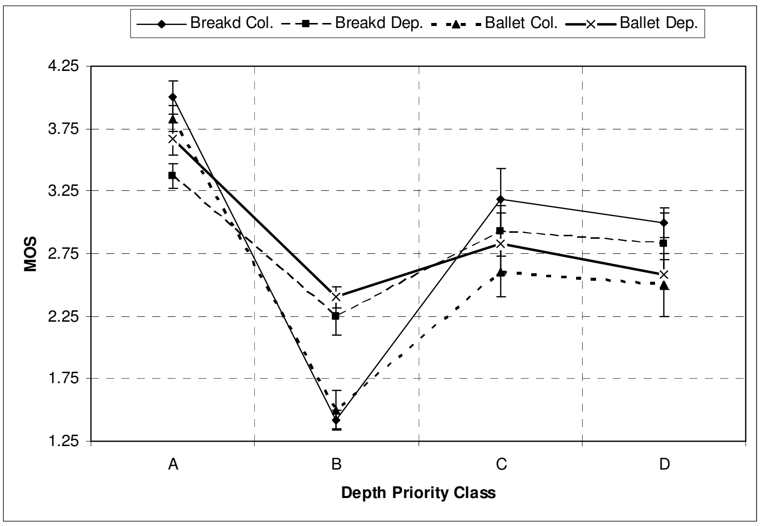

Figure 6: Breakdance and Ballet subjective quality (Col: Overall image quality and Dep: Overall depth perception) with and without prioritization

4. Conclusions

A prioritization scheme for colour plus depth 3D video transmission (backward compatible 3D video services) over WLAN is proposed and analyzed. The colour and depth streams have different usage and importance towards the reconstructed content and perceptual quality. As colour image sequences are directly viewed by 2D/3D users and due to the possibility of rendering good quality stereoscopic video even with impaired depth map sequences (i.e. with acceptable depth image quality), they are prioritized ahead of depth map sequences in the proposed prioritization method. The solution is implemented using the different priority levels defined in IEEE 802.11e MAC protocol. Results show that the overall perception of image quality is improved with the proposed prioritization scheme. Even though the depth quality is affected with the proposed scheme, the effect on the perceived depth of reconstructed stereoscopic video is insignificant. Therefore, prioritization methods for 3D video as described in this paper can be utilized to deliver better 2D/3D video services over unreliable channels.

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