Support of Uncompressed Video Streaming Over 60GHz Wireless Networks

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***Abstract*—Uncompressed HD (high-definition) video delivery over wireless personal area networks (WPANs) is a challenging problem because of the limited bandwidth and variations in channel. The 60GHz millimeter-wave (mmWave) band has recently drawn much interest because of the huge bandwidth that it can provide from 57-66 GHz unlicensed spectrum available worldwide. However, to date a system design supporting uncompressed HD video over WPAN is still lacking.**

In this paper, we develop, simulate, and evaluate an mmWave system for supporting Uncompressed Video streaming over Wireless *(UVoW)*. New features of the UVoW system incorporates: (i) *UEP* (unequal error protection) where different video bits (MSBs and LSBs) are protected differently, (ii) a *multi-CRC* to determine whether MSB or/and LSB portions are in error, (iii) *UV-ARQ*, uncompressed video retransmission protocol which allows the receiver to request only those portions of a video packet which have high importance. Simulations indicate that the UVoW system achieves significantly higher video quality than normal systems under various wireless channel conditions. This shows that UVoW is a promising wireless system supporting uncompressed HD video.

***Index Terms*—Uncompressed high-definition (HD) video, Gigabit WPAN, 60GHz mmWave, UEP, Network simulator (ns2).**

I. Introduction

Transmission of compressed video with video codecs may not be suitable for some delay sensitive applications such as interactive gaming. The conventional compression schemes (e.g., MPEG2) introduce about a 50:1 or more compression ratio. However, with each compression and subsequent decompression, the video quality is reduced. Moreover, a video display needs to support all possible video codecs for maintaining interoperability with different video sources. This incurs both the cost and complexity at a video display. Furthermore, quite a few video sources are generated uncompressed such as gaming console, PCs, set-top-box, etc. The need for supporting uncompressed HD transmission is obvious. The High-Definition Multimedia Interface (HDMI) allows transfer of uncompressed HD signals between devices via a cable. The current wireless technologies such as MBOA-UWB [1], IEEE 802.11n [2], etc. can support less than 1Gbps (gigabit per second) data rate. Therefore, it is not feasible to transmit uncompressed HD video over existing wireless networks. Instead, a multi-Gigabit wireless solution is required.

Recently, 60GHz millimeter-wave (mmWave) band has been drawing interest because it provides 7GHz contiguous bandwidth for unlicensed operations worldwide. This huge bandwidth coupled with sharp signal attenuation beyond a few meters make the 60GHz mmWave band a suitable candidate for supporting short-range applications such as uncompressed HD video transmission. For instance, a user will be able to stream uncompressed HD video from a handheld device or a personal video recorder to a high-definition television (HDTV), as shown in Figure 1. To help realize this vision, we develop the UVoW system which supports uncompressed HD video including 1080p having video data rate up to 3Gbps.

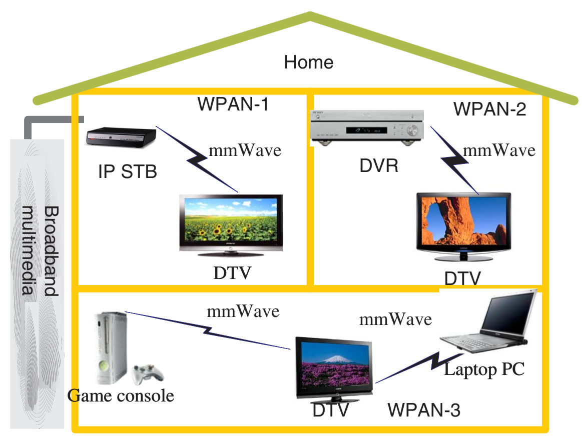

Fig. 1. Configuration of Gigabit WPANs.

In data communication all bits are equally important, thereby must be reliably delivered. In contrast, in a video stream some bits are more important than other bits. For instance, in an uncompressed video stream, in comparison to the least significant bit (LSB), the most significant bit (MSB) of a pixel has the maximum impact on the video quality. Therefore, bits can be treated differently and it is not necessary to deliver all bits reliably. An unequal error protection (UEP) provides a way to protect bits in the order of their importance. Numerous studies in the past have shown the benefits of using UEP at the PHY layer in the context of compressed video [3], [4]. UEP can be provided by coding or mapping.

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In UEP by coding mode, a lower coding rate is allocated to more important bits (i.e., MSBs) and high coding rate to less important bits (i.e., LSBs). UEP can also be provided by mapping wherein some symbols have high bit-energy in comparison to other symbols in the constellation diagram [3], while the average energy per symbol remains unaffected. Later, high importance bits are mapped onto those symbols which have high energy/bit such that the corresponding SNR (signal-to-noise ratio) is higher than the less importance bits. In either of the UEP modes, the bit-error-rate (BER) for high importance bits is much lower. In UVoW, we adopt UEP concepts wherein each color component of eight bits is partitioned into 4-MSB (bits 7, 6, 5, 4) and 4-LSB (bits 3, 2, 1, 0). Furthermore, MSB portions are strongly protected against channel errors and LSB portions are weakly protected [5]. We develop some MAC layer schemes that fully exploit the benefits provided by the UEP.

To transmit uncompressed video over wireless channel is a demanding task because of the fading channel and occasionally non-line-of-sight (NLOS) transmissions. To enable high quality video experience wirelessly, we exploit the unequal importance of the uncompressed video information using the following new techniques at the MAC layer:

1) *multi-CRC*: since video pixels are partitioned into two groups based on the perceptual importance, two separate CRCs are provided per video packet so that the receiver can determine which portions are received error free.
2) *UV-ARQ*: a link-layer retransmission protocol in which the receiver indicates the status of both MSB and LSB portions of a video packet. The sender retransmits an MSB portion only using reduced modulation and coding rate to strongly protect high importance MSB portions during poor channel conditions, thereby maintains good video quality. In contrast, LSB portions are never retried.

We simulate the UVoW system using the network simulator (ns2) and evaluate its performance under a variety of network conditions, including random uniform error and bursty error. The effect of retransmission attempts on the video quality is also explored.

The rest of the paper is organized as follows. Section II summarizes the current research activities in the 60GHz band. Section III presents the system architecture of the UVoW system. A performance study is presented in section IV. Finally, Section V concludes the paper.

II. Related Work

Wigwam [6], a project funded by the German Ministry of Research and Foundation is aiming to develop a Gigiabit system for short range communications using mmWave band. In [7] IBM research presented a system level design supporting uncompressed video up to 2Gbps using SiGe radio chipsets in mmWave band. A number of standardization efforts are underway. WirelessHD (WiHD) [8] is an industry-led effort to define a next generation wireless high-definition interface specification for wireless for consumer electronics products. Ecma International TC32-TG20 Task Group [9] is also developing a standard for 60GHz technology for very high data-rate short range unlicensed communications to support bulk data transfer such as downloading data from a kiosk and high-definition multi-media streaming. In addition, the IEEE 802.15.3c Task Group [10] is considering a millimeter-wave alternate physical layer for the IEEE 802.15.3-2003 standard for WPANs. The work is expected to complete in 2008.

Our work here has had a step ahead by developing and simulating the major modules of the system to support uncompressed HD video (1080p data rate up to 3Gbps) over 60GHz mmWave band.

III. UVoW (Uncompressed Video over Wireless) System Architecture

Traditional wireless systems cannot efficiently support uncompressed video because of the limited bandwidth and treating bits equally at the MAC (medium access control) and PHY (physical) layers. UVoW overcomes the bandwidth deficiency by using 60GHz mmWave band which can provide 7 GHz contiguous unlicensed band. The system architecture of UVoW is shown in Figure 2.

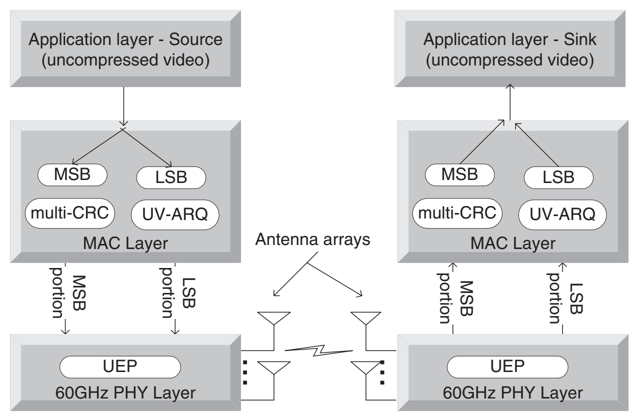

Fig. 2. UVoW system architecture.

The PHY layer is equipped with array antennas which can form a directed beam towards a desired angular direction to maximize SINR (signal-to-interference and noise ratio). In 60GHz band, the spacing between antenna elements ($\lambda/2$) is about 2mm which results in a small form factor of the UVoW devices.

To support 1080p high-definition video transmission in 60GHz band is very challenging. Although the average data rate which PHY can support can achieve close to the requirement, the packets can still often get lost or in-error owing to channel fading, and retransmissions allowed are limited because of stringent delay requirements. We rely on UEP to overcome this deficiency. Information bits are first scrambled to randomize the input sequence. Then the 4 MSB (most significant bits) are parsed into the first data path, and the second 4 LSB (least significant bits) are parsed into the second data path, which allow better error protection for the MSBs of video pixels, as shown in Figure 3.

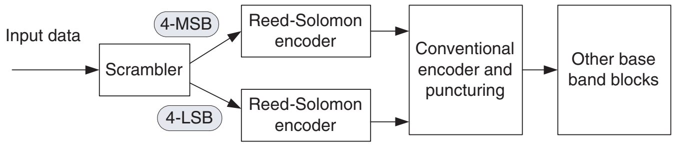

Fig. 3. Block diagram of the PHY layer (transmitter) in the UVoW.

In contrast to one CRC scheme in the traditional wireless systems designed for data communication, the UVoW provides multiple CRCs per video packet. The MAC layer partitions an uncompressed video stream into MSB and LSB portions, and the multi-CRC appends a separate CRC field to both MSB and LSB portions, as shown in Figure 2. The UV-ARQ takes the benefits of the multi-CRC to prioritize retransmission of MSBs over LSBs. These schemes are described in detail in the following subsections.

A. *multi-CRC*

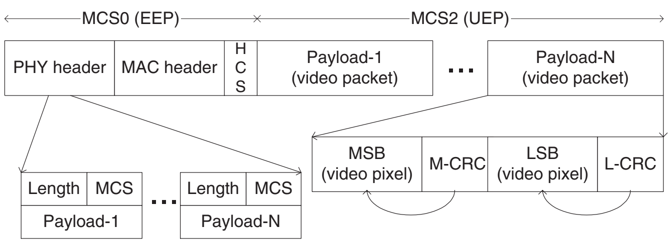

Fig. 4. The frame structure used in the UVoW.

Figure 4 shows the frame structure used in the UVoW. Among other fields the PHY header indicates the length and MCS (Modulation and Coding Scheme) for each payload. Since multiple payloads are encapsulated within one MAC frame, the PHY header includes the same number of the length and MCS fields. The PHY layer supports multiple modulation rates, as shown in Table I.

TABLE I
TRANSMISSION MODES IN THE UVOW

Index	Mode	Modulation	Code rate		Data rate (Gbps)
			MSB (bits [7-4])	LSB (bits [3-0])	
MCS0	EEP	QPSK	1/3		0.940
MCS1	EEP	16-QAM	2/3		3.761
MCS2	UEP	16-QAM	4/7	4/5	3.761
MCS3	MSBonly retransmission	QPSK	2/3	N/A	1.881

The PHY and MAC header are coded using the most robust modulation index, MCS0, which is EEP wherein all bits are equally protected. For video payloads UEP coding mode is used. The UVoW architecture is very flexible allowing encapsulation of both data and video payloads within one MAC frame. Each payload can be separately coded and indicated in the PHY header so that the receiver can accurately demodulate the received payloads. A typical uncompressed video packet is formatted as shown in Figure 4 wherein the upper nibble (4-MSB) of color components are grouped together and called as MSB, and a CRC (M-CRC) is appended. Similarly, the lower nibble (4-LSB) of color components are grouped together and a separate CRC (L-CRC) is provided.

B. *UV-ARQ (Uncompressed video-ARQ)*

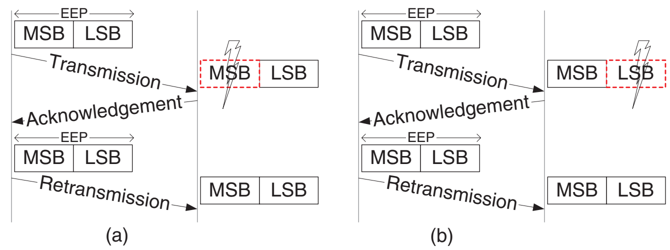

Fig. 5. Traditional ARQ schemes use single CRC. Even partial bits are received correctly; the sender retransmits another copy of the original packet.

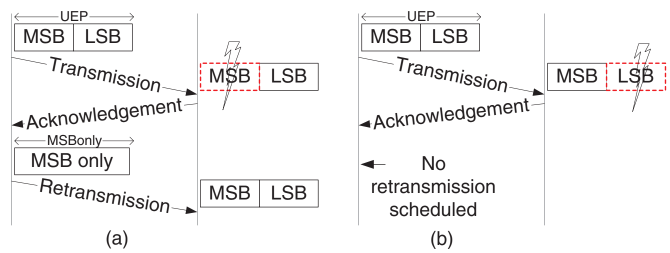

Fig. 6. UV-ARQ protocol sequence: If LSB portion is received in error then no retransmission is scheduled.

Wireless systems designed for data communication sends a packet with a checksum appended. The receiver re-computes the checksum. If an error is detected by failed checksum, the receiver requests for the retransmission of the whole packet. However, it is possible that a chunk of bits are correctly received. As shown in Figure 5(a) & 5(b), in both cases partial bits are correct, however, the sender retransmits another copy of the whole packet.

UV-ARQ protocol improves upon this by using two bits per video packet in the Ack to indicate the status of both MSB and LSB portions. If the MSB portion is received correctly, then the retransmission is not solicited. Otherwise, a robust modulation and coding mode (MSBonly as shown in Table I) is used to reliably retransmit the MSB portion only. Figure 6 illustrates the functioning of the UV-ARQ which can be summarized as follows:

- The sender appends multiple CRCs per video packet, and transmits the packet to the receiver.
- The receiver re-computes checksum for the MSB and LSB portions. The receiver signals to the sender about the status of the MSB and LSB portions.
- If the MSB portion is correctly received then the sender skips the retransmission of the LSB portion as shown in Figure 6b. Otherwise, the sender retransmits the MSB

portion only using the *MSBonly* mode as shown in Figure 6a.

- Since the same *time* is granted to retransmit the MSB portion as for the original video packet, reduced rate modulation index can strongly protect the retransmitted MSB portion against channel errors by proving a higher SNR (Signal-to-Noise Ratio).

IV. Performance Study of UVoW

In this section, we evaluate the performance of UVoW using ns2 based simulations. We enhanced the IEEE 802.15.3 MAC by implementing the UVoW related features described in the previous section. We consider two important performance metrics, goodput and PSNR (peak signal-to-noise ratio), for the performance study. These two metrics are described below:

- *Goodput (in Gbps)*: is defined as the successful bits received by the receiver. These successful bits are indicated by MSB or LSB CRCs. The goodput is computed per video frame.
- *PSNR (in dB)*: for a received $N_1 \times N_2$[1] 8-bit image, the PSNR is represented as,

$$PSNR = 20\log_{10}\frac{255}{\sqrt{\frac{1}{N_1 * N_2}\sum_{i=0}^{N_1-1}\sum_{j=0}^{N_2-1}[f(i,j)-F(i,j)]}}$$

where f(i,j) is the pixel value of the source video frame, and F(i,j) is the pixel of the reconstructed video frame at the display. By using ns2 trace file, we create the uncompressed video frame. The measured PSNR indicates the difference between the transmitted and the received video frame. We assume that in the event of errors all bits of a video portion (i.e. MSB or LSB) are corrupted which gives us the lower bound on the PSNR.

We compare the performance of the UVoW against a system using the EEP mode for video payloads. In both cases, we consider encapsulating at most four video packets within one MAC frame. In the EEP case, erroneous video packets are selectively retransmitted as shown in Figure 5. The rest of the simulation parameters are presented in Table II.

A. Effect of retransmission

To study the effect of retransmissions on the performance of UVoW, we consider random uniform error case. Figure 7 plots the PSNR for three retransmission policies. We note that moving from no-retransmission to single retransmission case, the PSNR improvement is 33%. Further increase in the number of retransmissions has diminishing improvement in the PSNR (<1%), suggesting that one MSBonly retransmission suffices. *In the remainder of the performance study, we set the retry limit to one*.

B. random uniform error case

Figures 8 and 9 show the goodput and the PSNR per video frame for both UVoW and EEP, respectively. EEP treats MSB

[1]In our simulation study, N_1 and N_2 are equal to 1080 and 1920, respectively.

TABLE II
NS2 SIMULATION PARAMETERS

Simulation Parameters			
Application rate	2.98Gbps (1920*1080p HD uncompressed video 60Hz, 24bits per pixel)		
Video packet size	23,506 bytes		
MAC header	54 bytes		
Ack	8 bytes		
PHY rate	Data: Table I, Control: 10Mbps		
Random uniform BER	EEP	UVoW	
		MSB	LSB
	2.727×10^{-07}	1.074×10^{-07}	5.602×10^{-07}
Burst loss	Bad state for 1 video frame duration every 10 video frames		
Bursty BER BER (good state)	EEP	UVoW	
		MSB	LSB
	1.619×10^{-07}	5.344×10^{-08}	2.727×10^{-07}
Bursty BER BER (bad state)	EEP	UVoW	
		MSB	LSB
	5.602×10^{-07}	3.290×10^{-07}	8.642×10^{-07}
SIFS	$2\mu s$		
Superframe duration	20msec		

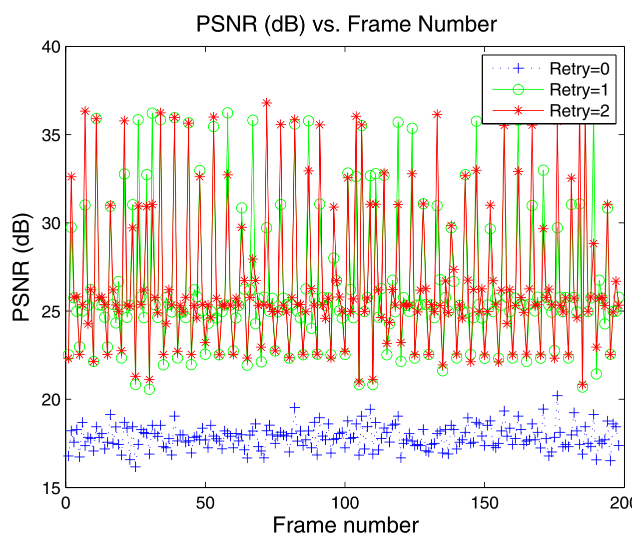

Fig. 7. The effect of the number of retransmissions on the PSNR. Results for the UVoW are shown.

and LSB equally, therefore, achieves higher overall goodput. However, UVoW achieves better PSNR because MSB portions, which contribute more towards the PSNR, are strongly protected during both transmission and retransmission. On average, UVoW has 18% higher PSNR than the EEP case.

C. bursty error case

In this section we present the performance results under burst error conditions. Using the Gilbert-Elliot model we simulate the burst of packet loss. The Gilbert-Elliot model is characterized by a two state Markov chain, [11], [12], [13]. The parameters for the good and the bad channel states are given in Table II. During the bad channel state, UVoW protects an LSB portion poorly which is evident from lower Goodput (Figure 10). However, MSB portions are strongly protected which helps in maintaining a high PSNR (Figure

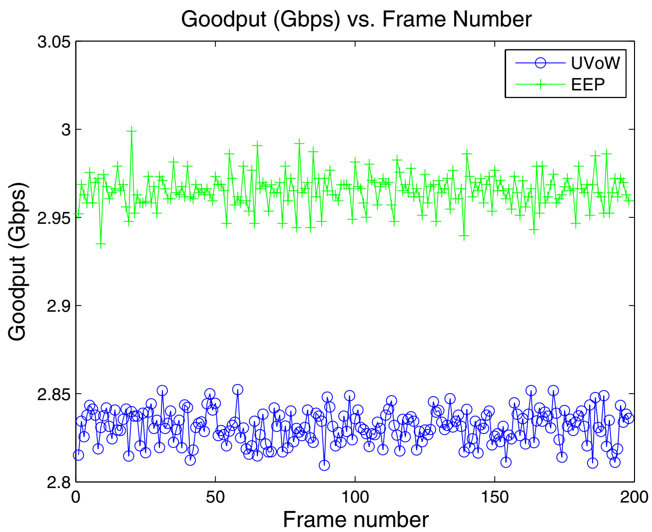

Fig. 8. Goodput as a function of the video frame number under random uniform error case.

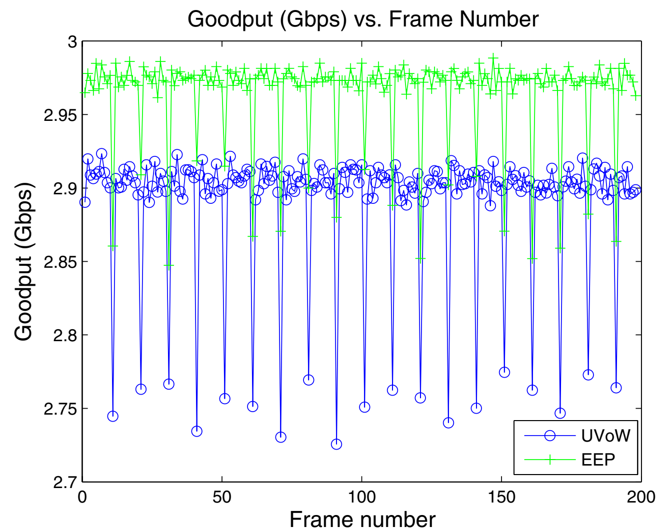

Fig. 10. Goodput as a function of the video frame number under burst loss case.

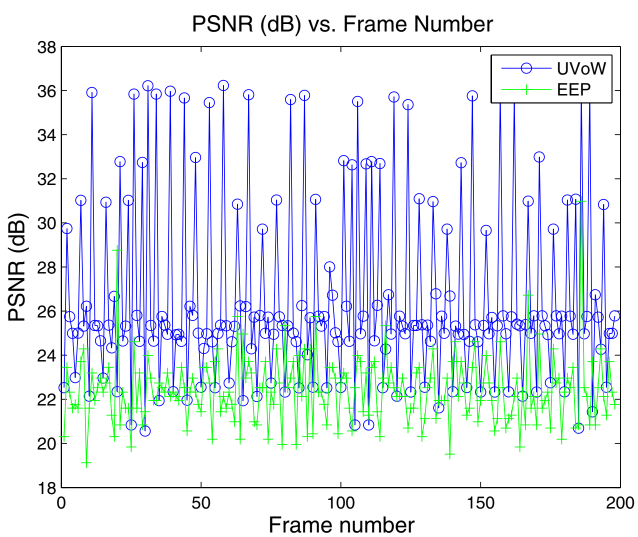

Fig. 9. PSNR as a function of the video frame number under random uniform error case.

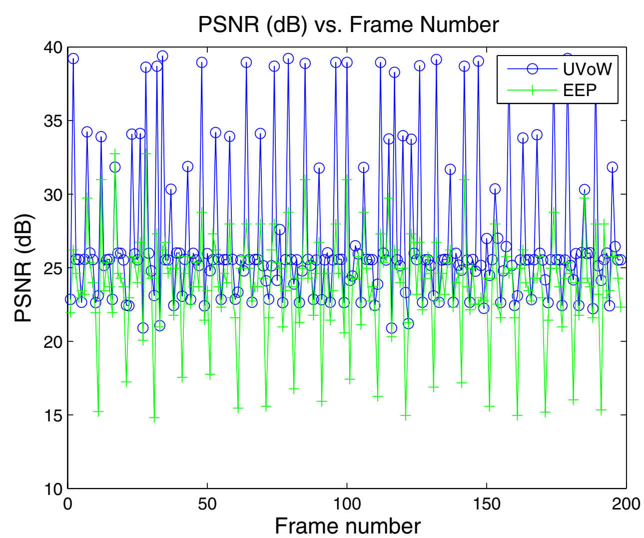

Fig. 11. PSNR as a function of the video frame number under burst loss case.

11). On average, UVoW achieves 14% higher PSNR than EEP.

Table III summarizes the PSNR results shown in Figures 9 & 11 for random uniform error case and burst error case, respectively.

TABLE III
SUMMARY OF THE PSNR RESULTS SHOWN IN FIGURES 9 & 11.

	random uniform error case		*burst error case*	
	Mean	Standard Deviation	Mean	Standard Deviation
UVoW	26.54	4.09	27.02	5.06
EEP	22.42	1.52	23.83	3.39

D. Discussions

We can make the following observations:

- Goodput is not a good evaluation metric for video transmission, although it has been a major metric for many wireless transmission systems.
- Aggregation of a small number of packets (4 video packets in our case) is sufficient.
- One time retransmission is sufficient for the cases we simulated.
- Under poor channel conditions, UVoW system maintains significantly good PSNR quality for both random uniform error case and burst error case.
- In some cases the PSNR value drops below 25dB when the MSB only retransmission is lost. This suggests that

the PSNR feedback from the receiver to the sender can be used to adaptively try second retransmission, if the video play-back time allows. We did not simulate this option.

Our results can be summarized as follows:

- MSB portion should be reliably transmitted / retransmitted to mitigate the affect of poor channel conditions.
- Having more than one retransmission does not show any significant benefits towards improving the video quality.

V. Conclusions

In this paper, we present a 60GHz mmWave wireless system that supports un-compressed HD video streaming (UVoW). UVoW incorporates unequal error protection techniques with multi-CRC and UV-ARQ to treat video bits in the order of their importance. Simulations show that the UVoW maintains a good video quality under frequent channel errors. This shows the UVoW system would enable transmission of uncompressed HD video wirelessly over the next generation personal area networks.

Acknowledgements

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