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Requirements for Wireless VR HMDs and Capabilities of Existing Transmission Technologies

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Abstract: Virtual Reality (VR) is currently becoming popular because it can provide unprecedented user experience. However, the immersive VR systems existing today use a physical wire to transmit power and contents to the headset which deteriorates user experience. To resolve this problem, several efforts in development and standardization of technologies are being exerted to devise a wireless connection between a content server and a VR Head Mounted Display (HMD). Analysis of the requirements for wireless VR HMDs and the capabilities of existing wireless transmission technologies may aid in the development of related technologies and standards. In this study, the projected requirements for smooth operation of wireless VR HMDs are enumerated and the capabilities of candidate wireless transmission technologies are studied. Finally, areas which require further enhancement to deliver better quality of experience for VR users are discussed.

Key words: Head mounted display, IEEE 802.11ax, IEEE 802.11ay, virtual reality, wireless, 5G

INTRODUCTION

Virtual Reality (VR) is being used to gradually surpass existing adopters such as gaming to improve cyber-physical and social experiences such as communication with family and friends, business meetings and quality of life of disabled persons. Moreover, as growing number of drones, robots and other self-driving vehicles are capturing images of places that people could never reach, we shall experience a rapid increase in information related to captivating points of view around the globe. Eventually, VR will provide the most personal, most connected and most immersive experience witnessed, thus far. However, the most immersive virtual reality systems existing today, like Oculus Rift and HTC Vive rely on a bothersome tether to transmit power and high-fidelity images to the headset. A dangling cable is not only uncomfortable but also deteriorates the immersive experience. The demand for a solution to this problem has ignited a series of new developments on designing a wireless link between the high-end host PC console and the headset. The difficulty is that most powerful VR systems inevitably need to be wired with cables for transmitting high-resolution videos at high frame rates. It is believed that as wireless transmission technologies evolve, the wireless link can replace the wired link without a severe degradation in performance. However, there are some areas in wireless transmission technologies that still require improvements, especially for application to VR Head Mounted Displays (VR HMDs).

In this study, we introduce HMD-specific network topologies along with their use cases. Then, we discuss wireless transmission technology candidates available now or within 2 years along with their performances. Then, the capabilities of these technologies and the requirements are compared to extract which areas already satisfy the demands for wireless HMD and which areas require further enhancement.

MATERIALS AND METHODS

Use cases: VR HMDs can be used for different purposes and hence, for different network topologies. In this study, four different use cases which are obtained based on the current usage scenarios are introduced.

Case 1: A single VR HMD connected via. a LAN: A VR HMD communicates with a local content server (e.g., a PC or a gaming console) via. a Local Area Network (LAN). The VR content is rendered or decoded in the local content server and transmitted to the HMD over the LAN. An example is that a user is playing a standalone VR game using a VR HMD connected to a game console. In this use case, the user plays within a small confined area and does not move from one area to another (Fig. 1).

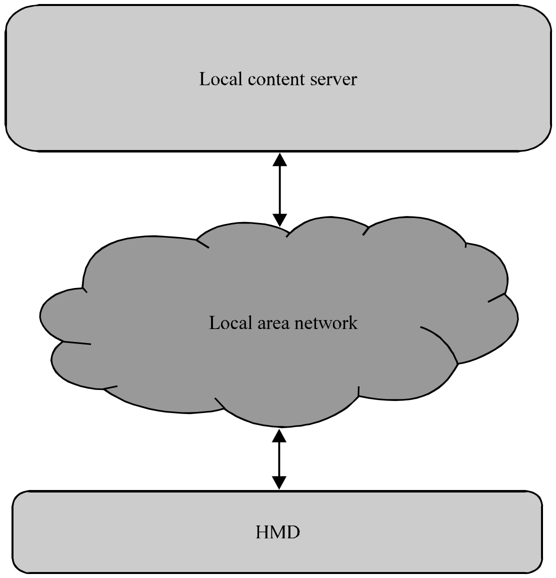

Fig. 1: Case 1-A single VR HMD connected via. a LAN

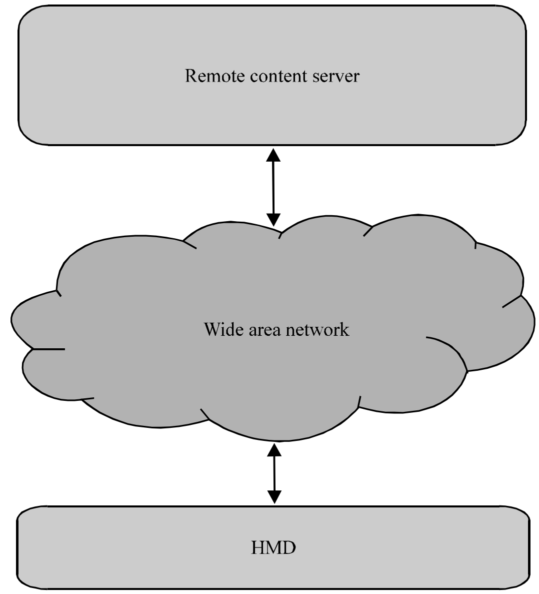

Fig. 2: Case 2-A single VR HMD connected via. a WAN

Case 2; A single VR HMD connected via. a WAN: A VR HMD communicates with a remote content server (such as to a cloud service provider) and receives the VR content over a Wide Area Network (WAN). In this scenario, the VR content is rendered or decoded in the remote content server and transmitted to the HMD over the WAN. It is important to note that the remote content server is located outside the local network and the wide area network may consist of both wired and wireless networks. An example is that a user is watching a baseball game in a VR environment using a mobile phone-based VR HMD system. In this use case, since, the users move from one area to another, the mobility is an important issue to be considered (Fig. 2).

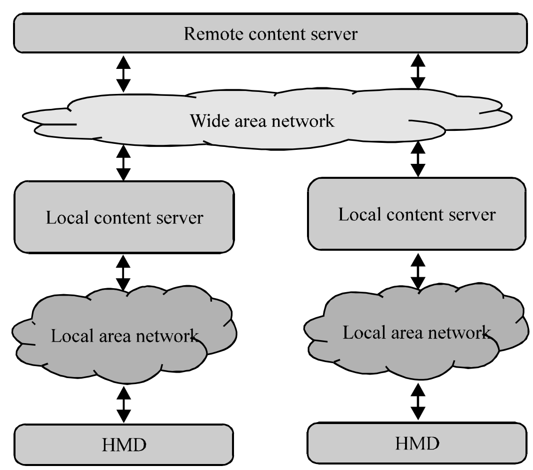

Fig. 3: Case 3-Multiple VR systems connected via. a LAN

Case 3; Multiple VR HMDs connected via. a LAN: Multiple VR HMDs are connected to a remote content server. The VR HMD receives the VR content rendered or decoded in the local content server. The remote content server computes the data sent by the local content servers and distributes the calculated data back to these servers. An example is that a user is playing a VR game and competing against other remote players by using a VR HMD that is connected to a local server. Like use case 1, the user plays within a small confined area and does not move from one area to another (Fig. 3).

Case 4: Multiple VR HMDs connected via. a WAN: More than one VR HMDs communicate with the remote content server and receive the VR content rendered or decoded in the remote content server. An example is that two or more users are watching a live streamed video game match from their respective home by using their mobile phone-based VR HMDs. Like use case 2, the users move from one area to another and the mobility is an important issue to be considered (Fig. 4).

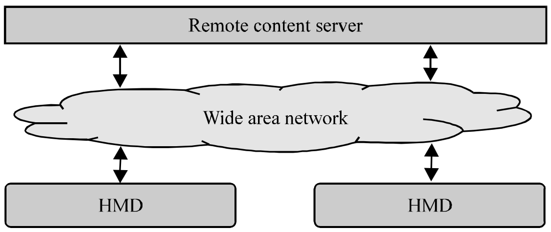

Fig. 4: Case 4-Multiple VR systems connected via. a WAN

RESULTS AND DISCUSSION

Technical requirements of wireless VR HMDs: Several standards organizations such as IEEE 802 (Sun, 2015), MPEG (Moving Picture Experts Group) (Jeong *et al*., 2018) and 3GPP (Third Generation Project Partnership) (Anonymous, 2015) have identified both network and non-network related issues and functional requirements for VR HMDs. It is necessary that the VR industry imposes new network requirements for the connectivity between a content server and an HMD device. Examples of these requirements are higher frame rate, lower motion-to-photon latency, higher data transmission rate, low jitter, longer transmission range, better mobility, higher resolution and low packet error rate. We highlight few such important requirements.

Peak data rate:

- Peak data rate should be 1.5 Gbps for compressed 4K UHD 3840×2160 24 bits/pixel, 60 frames/sec, 8 bits/color
- Peak data rate should be 8 Gbps for compressed 8K UHD 7,680×4,320 24 bits/pixel, 60 frames/sec, 8 bits/color
- Peak data rate should 18 Gbps for uncompressed 4K UHD 3, 840×2, 160, 60 frames/sec, 8 bits/color, (4:4:4) chroma subsampling
- Peak data rate should be 28 Gbps for uncompressed 8K UHD 7,680×4, 320,60 frames/sec, 8 bits/color, (4:2:0) chroma subsampling

Jitter:

- Jitter should be <5 msec (Sun, 2015)
- Greater jitter can cause distortion in video and audio rendering

Transmission range:

- For an indoor environment, it should not exceed 5×5 m
- For an outdoor environment, it may reach up to several 100 m

Mobility of device:

- For an indoor environment, it should be >4 km/h
- For an outdoor environment, it may reach up to 300 km/h

Packet Error Rate (PER):

- PER (before error correction schemes are applied) should be $<10^{-2}$

Resolution:

- 40 pixels/degree or 12K (11520×6480) is required (IEE, 2018)
- While 4K UHD (3840×2160) seems to be sufficient for the current display technology, the requirement is higher than 4K UHD. This is because HMD is mounted very closely to the human eyes and the display tends to be enlarged

Frame rate 90 frames per second: It is important to note that the frame rate is directly related to the motion-to-photon latency. A lower frame rate allows a user's reaction to be rendered in HMD after a reciprocal of the frame rate. The lesser the frame rate is the more fatigue and motion sickness it can cause. The total motion-to-photon/audio latency in the VR system should be ≤20 m/sec Anonymous (2015). This implies that the motion-to-photon latency for the wireless medium, i.e., between two wireless transceivers, should be <5 m/sec Table 1 shows how closely the use cases described in section II are related to each network requirement. Resolution and frame rate requirements which are not the characteristics of transmission technologies are omitted in this comparison.

Wireless VR HMD transmission technology standardizations: Several wireless transmission technologies are being developed which can be adopted for wireless VR HMDs. Some technologies are already standardized and some standards are still under development. In this study, their technical capabilities are described briefly with emphasis on VR HMD requirements.

IEEE 802.11ax: The 802.11ax task group was formed to develop the standard in May, 2014. They have developed Draft 3.0 as of July, 2018. The standard is expected to be completed by the end of 2019. The 802.11ax operates in both 2.4 and 5 GHz frequency bands. The main goal of 802.11ax is to achieve four times the throughput of 802.11ac (its maximum throughput is 3.39 Gbps) and provide means to prevent throughput deterioration in a high-density area (Anonymus, 2018).

Table 1: Relation between use cases and network requirements

	Network requirements					
Use case	Data rate	Latency	Jitter	TX range	Mobility	PER
Single VR system via. LAN	•	•	•	•	○	•
Single VR system via. WAN	•	•	•	•	•	•
Multiple VR systems via. LAN	•	•	•	•	○	•
Multiple VR systems via. WAN	•	•	•	•	•	•

The main technologies that the standard adopted to enhance the throughput are as follows, starting with the physical layer. Along with Multiple-Input and Multiple-Output (MIMO) adopted in 802.11n and DownLink (DL) Multi-User MIMO (MU-MIMO) adopted in 802.11ac, 802.11ax introduces UpLink (UL) MU-MIMO and Orthogonal Frequency Division Multiple Access (OFDMA) to improve the overall spectral efficiency. The number of supported stations within a Basic Service Set (BSS) in DL MU-MIMO is increased from 4 in 802.11ac to 8 in 802.11ax. The highest order of Quadrature Amplitude Modulation (QAM) has been increased to 1024 in 802.11ax from 256 in 802.11ac for attaining an increased throughput of 9.607 Gbps theoretically. The OFDM symbol length is increased from a single value of 3.2 ìs in 802.11ac to 3.2, 6.4 and 12.8 μsec in 802.11ax to improve efficiency.

In the MAC layer, the standard defines a trigger frame which an Access Point (AP) sends to stations for scheduling in uplink MU-MIMO. It defines A multi-Station (STA) Block ACK (BA) format, a MU-Request To Send (RTS)/ Clear To Send (CTS) sequence format and a MU cascading sequence format to enhance the transmission efficiency. It also adds an UL OFDMA-based random access scheme, so that, a station can transmit an uplink data at an arbitrary Resource Unit (RU) frequency. In order to further utilize the spatial reuse scheme they adopted a BSS color signaling which includes BSS Identification (BSSID) information, so that, a station may consider a new transmission attempt even if the detected signal level from a neighboring network exceeds the legacy signaling detection threshold.

IEEE 802.11ay: To further develop on the 802.11ad standard, the IEEE 802.11ay task group was formed in May 2015 to achieve a maximum throughput of 100 Gbps or higher using the unlicensed mm-wave (60 GHz) band while maintaining or improving the power efficiency per STA. They have completed draft 2.0 as of August, 2018. The standard is planned to be completed in December, 2019.

802.11ay includes mechanisms for channel bonding and channel aggregation and features the following schemes mainly in the physical layer. In channel bonding, a single waveform covers at least two contiguous 2.16 GHz channels whereas in channel aggregation, a separate waveform exists for each aggregated channel. The 802.11ay mandates that Enhanced Directional Multi-Gigabit (EDMG) stations must support operation in 2.16 GHz channels as well as channel bonding of two 2.16 GHz channels. Channel aggregation of two 2.16 or two 4.32 GHz (contiguous or non-contiguous) channels and bonding of three or four 2.16 GHz channels are optional. To achieve both beamforming and multiplexing gain, IEEE 802.11ay defines mechanisms to enable MIMO operation including both single-user MIMO and downlink MU-MIMO. The maximum number of spatial streams per station is eight and downlink MU-MIMO transmission can be performed for up to eight stations (IEEE., 2018).

3GPP: To attain a fully interconnected VR scenario, the VR HMD needs to be mobile even in an outdoor environment beyond the transmission range of Wi-Fi. The only technology which can provide this level of accessibility is Long Term Evolution (LTE), one of the 4G technologies but the data transmission speed is not sufficiently fast to ensure proper operation for a standalone HMD in outdoor environments. The 5G which is being deployed gradually, since, the end of 2018 (Do, 2017) can be the most favorable candidate for mobile HMD users. The 3rd Generation Project Partnership (3GPP) has published a technical report on VR services over 3GPP in September 2017 (Do, 2017).

Comparison of existing technology capabilities and wireless VR HMD requirements: In this study, the capabilities of existing wireless transmission technologies are compared with the requirements of a wireless VR HMD system. This comparison will help understand which features already satisfy the requirements and which areas need further enhancement. This comparison is illustrated in Table 2. With IEEE 802.11ax, the data rate may not meet wireless VR HMD's requirement when the resolution is as high as 7,680×4,320 or the content is not uncompressed. If VR HMD is used in an indoor environment (i.e., a short transmission range), the 802.11ax technology is expected to suffice the rest of the requirements even though some capabilities are currently not completely known.

With IEEE 802.11ay, most of the wireless VR HMD requirements will be met except the latency (VR HMD requirement: 5 msec vs. 802.11ay capability: 10 msec).

Table 2: VR Requirements and capabilities of wireless transmission technology candidates

	Capabilities			
Variables	VR HMD requirements	802.11ax (Anonymus, 2018)	802.11ay	IMT-2020 (Anonymous, 2015)
Data transmission rate	~20 Gbps (Sun, 2015)	~10 Gbps (at least 4 times improvement over 802.11ac)	~100 Gbps	20 Gbps peak,100 Mbps user-experience data rate
Latency	~5 m sec (at wireless medium) (Sun, 2015) 20 m sec (motion-to-photon/audio)	"A desirable level to meet QoS requirements in high dense deployment scenario"	10 m sec	1 m sec
Jitter	<5 m sec (Sun, 2015)	Not specified	Not specified	Not specified
Transmission range				
Indoor	5 m (Sun, 2015)	Not specified	10 m indoor	Not specified
Outdoor	Several hundred meters	Not specified	100 m outdoor	Not specified
Mobility				
Indoor	Pedestrian speed <4 km/h (Sun, 2015)	Not specified	3 km/h	500 km/h
Outdoor	200 km/h	Not specified	3 km/h	500 km/h
PER	10^{-8} (Sun, 2015)	Not specified	~10^{-8}	Not specified

HMD's latency requirement and 802.11ay's latency capability must be carefully investigated to avoid undesirable user experiences. 802.11ay's super-fast transmission rate of 100 Gbps or higher will be sufficient to support 4K video or even higher resolution such as 8K. However, mobility may become an issue due to the directional propagation of an electromagnetic wave in the 60 GHz band. This may be largely associated with the beamforming algorithm which requires further enhancement when it is used in applications that involve mobility such as a wireless VR HMD application.

The 5G or IMT-2020 technology can support a high-resolution video up to 8K, if a compression is exerted. (VR HMD requirement: 20 Gbps versus IMT-2020 capability: 20 Gbps). However, in an outdoor environment, especially in a crowded area, wireless VR HMD may suffer from poor image quality due to the limited throughput (VR HMD requirement: 20 Gbps vs. IMT-2020 capability: 100 Mbps). However, the 5G technology works effectively when VR HMD is used in high mobility conditions such as in public transportation.

CONCLUSION

The demand for wireless VR HMDs has grown recently and some of the technical requirements are already met by the currently available technologies. In this study, the key requirements for wireless VR HMDs are listed and the discrepancies between the capabilities of existing technologies and the wireless VR HMD requirements are analyzed. The area that largely needs enhancement is the data transmission rate and this limitation will become more severe as the resolution of HMD increases. The latest technologies such as IEEE 802.11ay and 5G can satisfy most of the wireless VR HMD requirements; However, latency and mobility for IEEE 802.11ay and data rate for 5G are aspects that will require more attention to provide an undistracted user experience. Efforts to improve data rate and latency when a new wireless transmission technology for example as discussed in IEEE 802.11 EHT (Extremely High Throughput) study group as a follow-up technology of IEEE 802.11ax is standardized will help provide good quality of experience for VR users.

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