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Gap Analysis on Wireless Transmission Technologies for VR HMDs

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Abstract

Virtual reality (VR) is gaining popularity due to its ability to engage users on a level which cannot be reached before. However, so far today's many immersive VR systems have relied on a bothersome tether to send power and high fidelity contents to the headset. To overcome this issue, currently great efforts in development and standardization are being made to provide a wireless connection between a PC console and a VR HMD (head mounted displays). A gap analysis between the requirements for wireless VR HMDs and the capabilities of wireless transmission technologies may help close the gaps for technologies and standards developers. Thus in this paper the technical requirements for a reliable operation of wireless VR HMDs are listed and the capabilities of several candidate technologies for wireless portion of the devices are investigated. Finally areas which require more attention are discussed.

요 약

가상현실(VR)은 사용자가 전에는 느껴보지 못했던 수준까지 몰입할 수 있게 되면서 점점 인기를 더해가고 있다. 그러나 지금까지의 대부분의 VR 시스템은 헤드셋 방향으로 전력과 고해상도의 콘텐츠를 전송하기 위해 번거로운 유선을 사용해 왔다. 이를 해결하기 위해 PC 콘솔과 VR HMD(head mounted display) 사이를 무선으로 연결하기 위한 많은 노력이 제품 개발 및 무선 통신기술 표준화에서 현재 진행되고 있다. 본 논문에서는 무선 VR HMD의 기술적 요건과 무선 전송 기술 성능의 격차를 분석한다면 기술 개발자 또는 표준 개발자들로 하여금 그 격차를 줄이도록 하는데 도움이 될 수 있을 것이다. 본 논문에서는 무선 VR HMD의 원활한 동작을 위한 기술 요건을 열거하고 VR 장치의 무선 부분에 대한 후보 기술의 성능을 조사한다. 끝으로 보다 관심을 기울여야 할 영역에 대해 논의한다.

Keywords
virtual reality, wireless, head mounted display, IEEE 802.11ax, IEEE 802.11ay, 5G

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Ⅰ. Introduction

In [1], Virtual Reality (VR) is well defined as the ability to be virtually present in a space created by the rendering of natural and/or synthetic image and sound correlated by the movements of the immersed user allowing interacting with that world. Gradually the use of VR is expected to go beyond early adopters such as gaming to enhancing cyber-physical and social experiences such as conversing with family and acquaintances, business meetings, and disabled persons. And as the growing number of drones, robots, and other self-driving vehicles taking cameras to places that humans could never imagine reaching, we shall see a rapid increase of new content from fascinating points of view around the globe. Ultimately, VR will provide the most personal experience with the closest screen, providing the most connected, most immersive experience witnessed thus far. However, today's most immersive virtual reality systems, like the Oculus Rift and HTC Vive, rely on a bothersome tether to send power and high fidelity imagery to the headset. A dangling cable is not only annoying, it becomes an immersion detractor. The demand for a solution to this issue has spurred a series of new developments for a wireless link between the high-end host PC and the headset. The biggest caveat is that most powerful VR prototypes are inevitably needed to be wired with cables due to the amount of transmitted high-resolution video at high frame rates. It is believed that as the wireless transmission technologies evolves, their performance has come almost close to the point which the wireless link can replace the wired link without a severe degradation. But there are some areas in wireless transmission technologies that still require improvements specially when they are applied to VR HMDs.

Today's VR HMDs can be categorized into three types: the first type is wired VR, which is tethered with PC or console, e.g., Oculus Rift, HTC Vive, and PlayStation VR; the second type is mobile VR, which contains a smartphone inside, e.g., Samsung Gear VR and Google Day-dream View; the third type is wireless all-in-one HMD device, e.g., Oculus Go.

Table 1. The specifications of VR HMD devices

Type	Product	Manufacturer	Resolution per eye, No. of Screens, Display	Field of View [degree]	Refresh Rate [Hz]	Weight [g]	Release Date	Price [$]
Wired HMD	PlayStation VR	Sony	1080x960, 1, OLED	100 [2]	90 (game), 120 (cinema)	610	Oct, 2016	399
	Oculus Rift	Facebook	1080x1200, 2, PenTile OLED	80 horizontally, 90 vertically, 120 diagonally [2]	90 [3]	450	Mar, 2016	499
	Vive	HTC	1080x1200, 2, PenTile OLED	100 horizontally, 110 vertically, 145 diagonally [2]	90	540	Apr, 2016	599
	Vive Pro	HTC	1440x1600, 2, AMOLED	110	90 [4]	Not available	Q1, 2018 [4]	799
	Fove 0	Fove	1280x1440, OLED	100 [5]	70	520	Jul, 2017	599
Smartphone Headset	Gear VR	Samsung	Smartphone resolution	95: Note 4, 90: Galaxy S6	Smartphone refresh rate	318	Aug, 2016	99
	Day-dream View (DV)	Google	Smartphone resolution	90: DV1, 100: DV2 [6]	Smartphone refresh rate	450	Nov, 2016 (DV1) Oct 2017 (DV2)	79 (DV1), 99 (DV2)
Wireless Standalone	Sulon Q	AMD	1280x1440, OLED	110	90	Not available	Not available	Not available
	Oculus Go	Facebook	1280x1440 [7]	Not available	Not available	Not available	H1, 2018	199

Table 2. The specifications of VR HMD wireless add-ons

Type	Product	Manufacturer	Compatible Devices	Additional Latency [msec]	TX Technology or Bandwidth	Mount Type	Release Date	Price [$]	Others
Wireless Add-on	TPCast	HTC	Vive	< 2	4	HMD	Q2 2017	249	5 ft. TX range, 4 W power consumption
	KwikVR [8]	Scalable Graphics	Vive, Rift	< 12 [9]	5 GHz Wi-Fi	Belt	Q3 2017	300	4 hr. battery life, 450 g
	DisplayLink XR [10]	Display Link	Vive	< 2 ~ 3	60 GHz WiGig	HMD or Belt	H2 2017	Not available	2 hr. battery life
	Rivvr	Sixa	Vive, Rift	< 11	5 GHz Wi-Fi	HMD or Belt	Mar. 2018	200	6 hr. battery life, 272 g
	IMR	Immersive Robotics	Vive, Rift	< 1	802.11ac	Belt	Q3 2018	Not available	
	Quark VR	Quark VR	Vive	Not available	802.11ac	Belt	Not available	Not available	
	Nitero	AMD	Vive	< 1	60 GHz	Head	Not available	Not available	
	NGCodec	NGCodec	Vive	Not available	802.11ac and LTE	Head	Not available	Not available	0.2% (500:1) compression ratio
	AMN 2130/2230 chipset [11]	Amimon	Rift, Vive	< 1	5GHz	Not applicable	Jan. 2017	Not available	

The specifications of several VR HMDs and the wireless add-ons that are currently or planned to be on the market soon are shown in Table 1 and Table 2, respectively. Note that some values in the tables are what each manufacturer claims to be and not verified publicly.

In Section II the technical requirements that the wireless HMD devices must have for satisfying experience are provided. And in Section III key capabilities that several wireless transmission technologies can provide for wireless VR HMDs along with their development timelines are investigated. In Section IV the gap analyses between the wireless VR HMD's requirements and the wireless technologies' capabilities are given.

Ⅱ. Technical Requirements of Wireless VR HMDs

Several standardization organizations, such as IEEE 802.11, MPEG, and 3GPP, have recommended the requirements of VR HMDs in their use cases or functional requirements documents as an example which their technology can be applied to. They can be summarized as the eight conditions.

- Data transmission rate: at least 20Gbps[12]. 1.5Gbps for compressed 4K UHD 3840×2160 24bits/pixel, 60 frames/s, 8bits/color. 8Gbps for compressed 8K UHD 7680×4320 24bits/pixel, 60frames/s, 8bits/color. 18Gbps for uncompressed 4K UHD 3840×2160, 60 frames/s, 8bits/color, (4:4:4) chroma subsampling. 28Gbps for compressed 8K UHD 7680×4320, 60 frames/s, 8bits per color, (4:2:0) chroma subsampling[13].
- Motion-to-photon/audio latency: less than or equal to 20msec [14] and less than 5ms for wireless medium, i.e., between two wireless transceivers[13]. The latency is considered to be a main cause of motion sickness or nausea.
- Jitter: less than 5msec[12]. Greater jitter can cause distortion in video and audio rendering.

- Transmission range: less than 5m[12]. Most likely indoor environments may not exceed the dimension 5meters by 5meters.
- Mobility: less than 4km/h indoor. The HMD is not likely very mobile indoor[12].
- Resolution: 4K UHD (3840×2160) seems to be feasible according to the current display technology. However, an HMD is mounted so closely to the eyes, so the display tends to be enlarged, which results in the need of even higher resolution than 4K UHD. 40 pixels/degree or 12K (11520×6480) is required to satisfy this condition[14].
- Frame rate (or refresh rate): 90 fps (frames per second)[12]. It is directly related to motion-to-photo latency since a lower frame rate allows a user's reaction to be rendered in HMD after some amount of time gap. And the less the frame rate is, the more it can cause fatigue and motion sickness, and all the more so since the display is located close to the eyes.
- PER(Packet error rate): 10^{-2} [12]. This requirement value seems to be too extremely generous and chosen carelessly from IEEE 802.11 TGay, and needs to be corrected. A generally accepted PER value is 10^{-6} [15].

III. Wireless VR HMD Transmission Technology Standardizations

There are several wireless transmission technologies which are applicable to wireless VR HMDs. Some technologies are already standardized and some standards are still under development. In this section, their standardization timeline and their technical capabilities are described.

3.1 IEEE 802.11ax

The High Efficiency WLAN (HEW) Study Group started in March 2013 with a main goal to reduce the performance degradation in a Wi-Fi dense area. One year later the 802.11ax Task Group is formed to develop the standard in May 2014. They have accomplished Draft 2.0 in November 2017. The standard is expected to be completed by the end of 2019. The timeline is shown in Fig. 1.

IEEE 802.11ax is designed to operate in 2.4GHz and 5GHz spectrums. The main goal of IEEE 802.11ax is to achieve four times as high as 802.11ac (the maximum throughput is 3.39Gbps), and provide means to prevent from the throughput deterioration in a high density area[16].

Key technologies that the standard adopted to enhance the throughput are as follows. In addition to MIMO(Multiple-Input and Multiple-Output) adopted in IEEE 802.11n and downlink MU-MIMO(Multi-User MIMO) adopted in IEEE 802.11ac, the new amendment introduces UL(uplink) MU-MIMO and OFDMA(Orthogonal Frequency Division Multiple Access) to improve overall spectral efficiency. The number of supported STAs(Stations) in downlink MU-MIMO increases from 4 in IEEE 802.11ac to 8. It increases the order of QAM modulation to 1024 from 256 QAM(Quadrature Amplitude Modulation) in 802.11ac for increased throughput of 9.607Gbps theoretically. The OFDM symbol length increases from a single value 3.2μs in IEEE 802.11ac to 3.2μs, 6.4μs, and 12.8μs to improve efficiency.

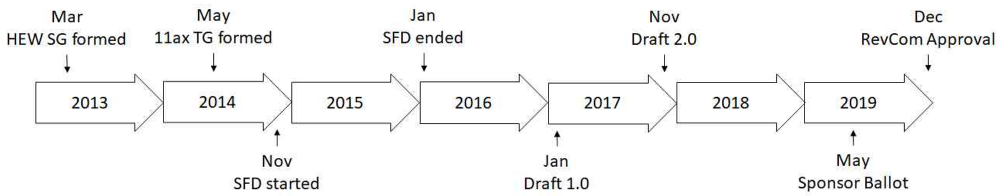

Fig. 1. IEEE 802.11ax standard development timeline

The standard defines a Trigger Frame which an AP (access point) sends to STAs for scheduling in uplink MU-MIMO. It defines a multi-STA BA (block ACK) format, a MU-RTS (request to send)/CTS (clear to send) sequence format, and a MU cascading sequence format to enhance the transmission efficiency. It adds an UL OFDMA-based Random Access scheme so a STA can transmit a uplink data at an arbitrary RU (resource unit) frequency. In order to utilize further the spatial reuse, they adopted a BSS (basic service set) color signaling which includes BSSID information so a STA may consider a new transmission even if the detected signal level from a neighboring network exceeds legacy signaling detection threshold[17].

3.2 IEEE 802.11ay

To develop the follow-up of IEEE 802.11ad, IEEE 802.11ay is formed in May 2015 to support a maximum throughput of 100 Gbps or even higher using the unlicensed mm-Wave (60GHz) band, while maintaining or improving the power efficiency per STA. They have completed draft 1.0 in January 2018. The standard is planned to be completed in December 2019. The timeline is as shown in Fig. 2.

IEEE 802.11ay includes mechanisms for channel bonding and channel aggregation. In channel bonding, a single waveform covers at least two contiguous 2.16 GHz channels, whereas channel aggregation has a separate waveform for each aggregated channel. IEEE 802.11ay mandates that EDMG (Enhanced Directional Multi-Gigabit) STAs must support operation in 2.16 GHz channels as well as channel bonding of two 2.16 GHz channels. Channel aggregation of two 2.16GHz or two 4.32GHz (contiguous or non-contiguous) channels and bonding of three or four 2.16GHz channels are optional. To achieve both beamforming and multiplexing gain, IEEE 802.11ay defines new 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 made to up to eight stations[18].

3.2 3GPP

To reach a fully interconnected VR world the VR HMD need to be mobile even in an outdoor environment beyond the communication range of Wi-Fi. The only technology that can provide that kind of accessibility is through the LTE (Long Term Evolution), a 4G candidate, but the data transmission speed is not fast enough to provide a proper operation for a standalone HMD in outdoor environments. 5G which is expected to be deployed in 2018 and later can be a most favorable candidate for nomadic HMD users. The timeline of 5G standardization in ITU-R and 3GPP is shown in Fig. 3[19].

The 3GPP (3rd Generation Project Partnership) has completed a technical report on VR services over 3GPP in September 2017[1]. In the report they divided the VR video processing into several blocks and describe each block's functions in detail for the purpose of VR rendering

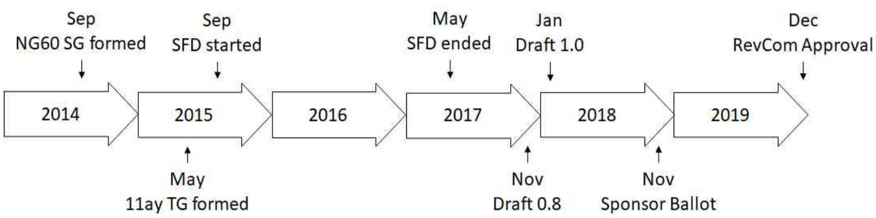

Fig. 2. IEEE 802.11ay standard development timeline

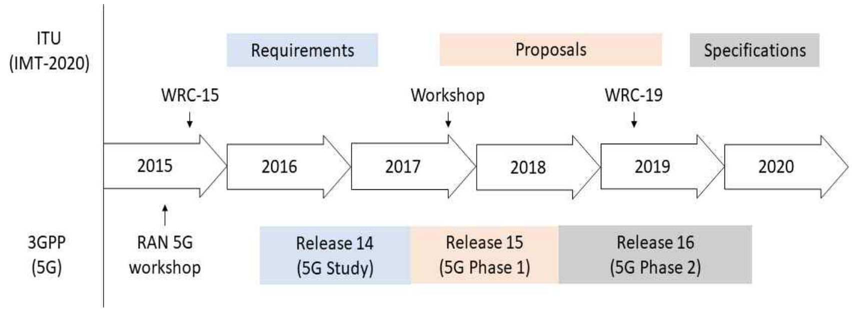

Fig. 3. ITU-R IMT-2020 and beyond standard development timeline

Table 3. VR requirements and capabilities of wireless transmission technology candidates

	VR HMD Requirements	Capabilities		
		802.11ax [16]	802.11ay [13]	IMT-2020 [18]
Data rate	~ 20 Gbps [12]	~10 Gbps (at least 4 times improvement over 802.11ac)	~100 Gbps	≤ 20 Gbps peak, ≤ 100 Mbps user-experience data rate
Latency	~ 5 ms (at wireless medium) [12], ≤ 20 ms (motion-to-photon/audio) [14]	"A desirable level to meet QoS requirements in high dense deployment scenario"	10 ms	1 ms
Jitter	< 5 ms [12]	Not specified	Not specified	Not specified
PER	10^{-6} [15]	Not specified	~ 10^{-8}	Not specified
Distance	5 m [12]	Not specified	≤ 10 m indoor, ≤ 100 m outdoor	Not specified
Device mobility	Pedestrian speed < 4 km/h [12]	Not specified	3 km/h	500 km/h

They also list various use cases for VR such as Event broadcast/multicast, VR streaming, Distributing 360 A/V content library in 3GPP, Live services consumed on HMD, Social TV and VR, Cinematic VR, Learning application, VR calls, User generated VR, Virtual world communication, HMD-based legacy content consumption, and Use cases for Highlight Region(s) in VR video. They also provide several way to evaluate audio and video quality and propose the video/audio latency values.

Ⅳ. Comparison of Capabilities and Requirements

In this section the capabilities that wireless transmission technologies can provide are compared with the requirements that a wireless VR HMD system may need. This comparison will help understand what more enhancements are needed in what areas, and what features already satisfies the requirements of wireless VR HMDs.

With IEEE 802.11ax the data rate may not meet the wireless VR HMD's requirement when the resolution is high or the compression is low. As long as the VR HMD is used in an indoor environment, the 802.11ax technology is expected to suffice the rest of the requirements even though some capabilities are not fully specified.

With IEEE 802.11ay most of the wireless VR HMD requirements will be met except the latency (VR HMD: 5ms versus 802.11ay: 10ms). The latency requirement and 802.11ay's capability must be carefully investigated to avoid undesirable user experiences. The 802.11ay's 100 Gbps or higher, super-fast transmission rate using 802.11ay's channel bonding and MIMO, will be enough to support help 4K video or even higher resolution such as 8K. The mobility may be an issue due to the directional propagation of an electromagnetic wave in 60GHz band even in a close space (VR HMD: 4km/h versus 802.11ay: 3km/h). It may be greatly associated to the beamforming algorithm, which requires further enhancement when it is used to applications that involves some degrees of mobilities, such as wireless VR HMDs.

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

Ⅴ. Conclusion

The demand for wireless VR HMDs has grown recently, but some of the technical requirements for wireless VR HMDs are already met by the currently available technologies. This paper has listed the key requirements for wireless VR HMDs and analysized the discrepancies between the requirements and the capabilities. The area in which more efforts need to be made is mostly the data transmission rate and this limitation will become more severe as the resolution increases. The new technologies such as IEEE 802.11ay and 5G can cover most of the wireless VR HMD requirements, but latency and mobility for IEEE 802.11ay and data rate for 5G will require more attention to provide an undistracted user experience.

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