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Title: **Introduction to Concept of the 'Network Enablers for seamless HMD based VR Content Service' IG**

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Authors or Source(s): **Seo, Dong-Il Dillon (VoleR Creative)**

Jeong, Sangkwon Peter (JoyFun)

Ryu, Eun-seok (Gachon Univ.)

Abstract: This document is to introduce the IG named Network Enablers for seamless HMD based VR Content Service and to find any possibilities of collaboration between the IG and the RTA TIG.

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Network Enablers
for
seamless HMD based VR Content Service

How a VR HMD is creating an Immersion

I See Closed

II Stereoscopic & Spatial Sound

III Wide FOV

IV Head Tracking

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How a VR HMD is creating an Immersion

I See Closed

II Stereoscopic & Spatial Sound

III Wide FoV

IV Head Tracking

Network Enablers
for
seamless HMD based VR Content Service

See Closed

Be Anywhere

Do Anything

Be Anything

Time

Space

- To create an uninterrupted immersion while experiencing VR, the HMD needs to be see closed to completely block the view of the surroundings

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How a VR HMD is creating an Immersion

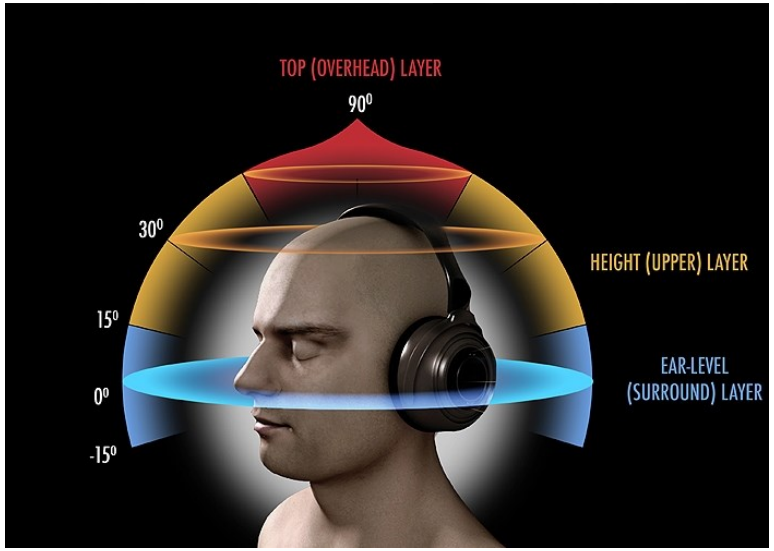
I See Closed

II Stereoscopic & Spatial Sound

III Wide FoV

IV Head Tracking

Stereoscopic & Spatial Sound



- Stereoscopic Images
  - As humans recognize the depth of the world using two eyes, the images displayed through a HMD need to be stereoscopic to understand the depth of the VR world.
  - All VR HMDs are designed to create stereoscopic images though binocular disparity.
- Spatial Sound
  - As illustrated in the diagram on the left, the sound source and the distance the sound travels need to be properly reflected in order to create a proper immersion.

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How a VR HMD is creating an Immersion

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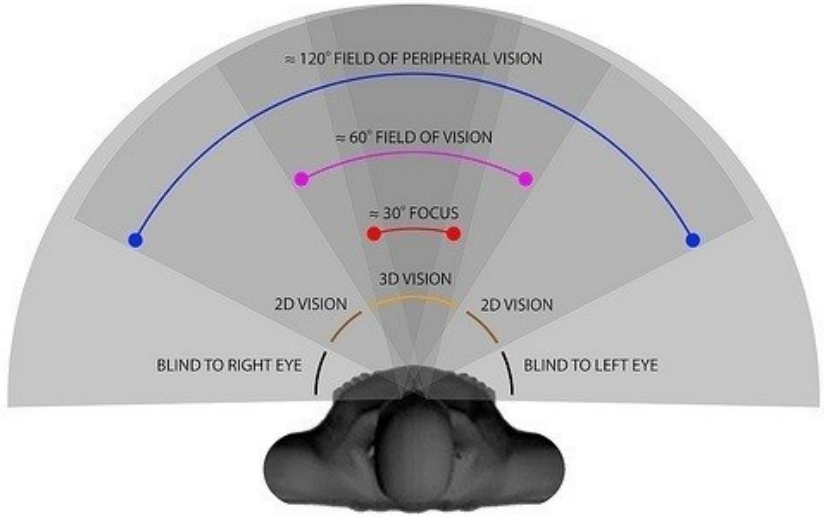
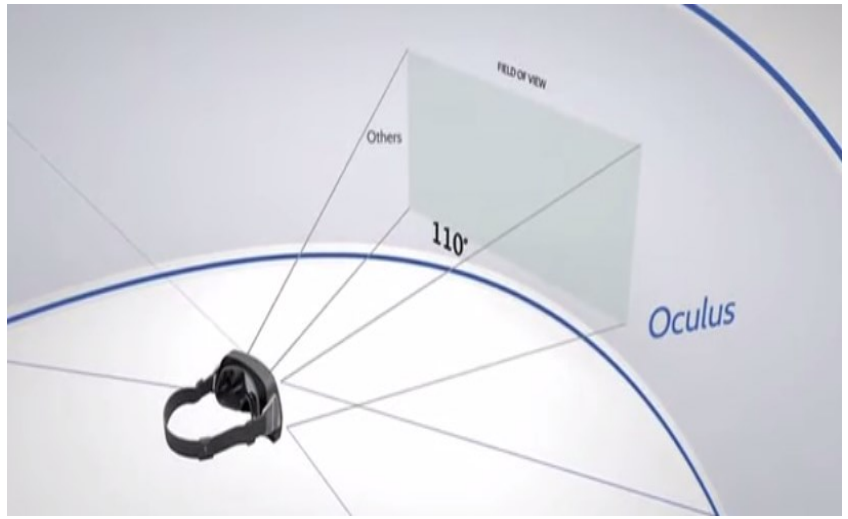
Wide FoV (Field of View)





- Human eyes are capable of viewing up to 120 degrees of FoV. The current VR HMD provides up to 110 degrees of FoV. Hence, the people who are experiencing VR content can be fully immersed as they do not feel like they are seeing the images through a small sized window.

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Head & Motion Tracking

<Game: Beat saber>

- With a help of gyro, accelerometer and magnetometer sensors, the user experiencing VR content can freely move his head around to see where he wants to see and this is called head tracking
- The head tracking gives the user a freedom to look around the VR world and this quickly fools the brain that he is inside of the VR world

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Network Enablers
for
seamless HMD based VR Content Service

Limitations of VR QoE due to Technical Shortcomings

I VR Sickness

II Enormous Data Size

III Network Latency

IV Network Handover

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Limitations of VR QoE due to Technical Shortcomings

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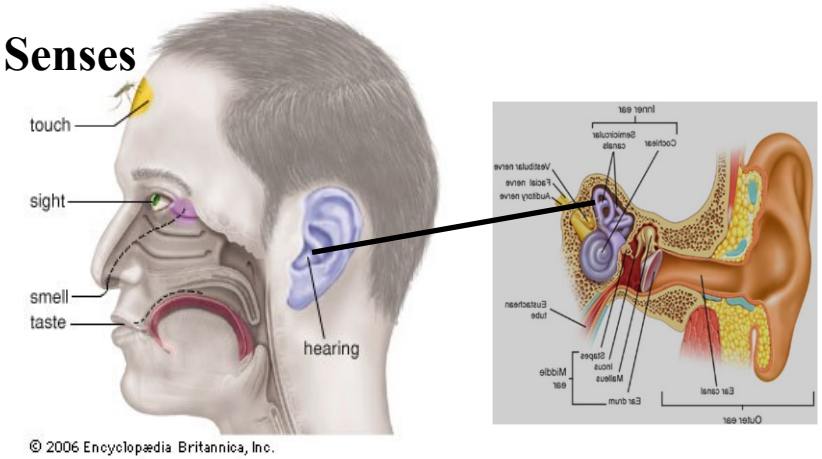
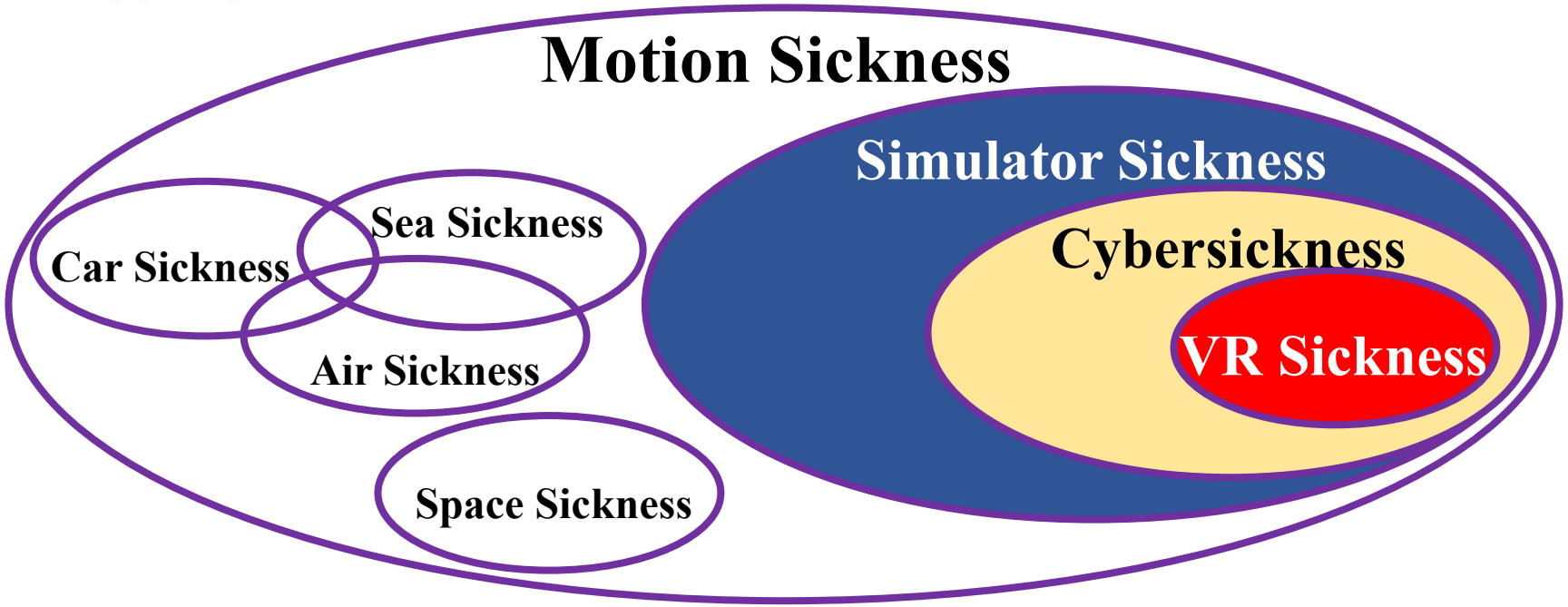
VR Sickness

Six Senses



- VR sickness is a part of Motion Sickness and it is caused by the mismatch of information between the visually received information and the vestibular system.



VR Sickness

- **Technicolor, Oct. 2016 (m39532, MPEG 116th Meeting)**

Requirement	details
pixels/degree	- 40 pix/deg - no HMD is capable of displaying 40pix/deg today
video resolution	- 3 times 4K(3840x1920) vertical resolution = 11520x6480
framerate	- 90 fps - a 90fps framerate offers a latency low enough to prevent nausea
3D Audio	- support of scene-based and/or environmental audio - 360 surround sound, object-based audio, Ambisonics
motion-to-photon latency & motion-to-audio latency	- how much time there is between the user interacts and an image / audio - maximum 20ms
foreground & parallax	- objects in the foreground shall be far enough to prevent nausea - if objects are too close it is likely they can become an important cause of nausea - interactive parallax with background shall be present for such objects - pic1 shows how it is possible to look behind the figure in the foreground

Limitations of VR QoE due to Technical Shortcomings

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IV Handover issue

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Enormous Data Size

❖High Bandwidth Requirements of VR

- Recently, various HMD devices are on the market
- Recommend 12K resolution for reducing nausea with high quality VR
- High Bandwidth and high computational complexity are huddle

↳ Need to reduce the required bandwidth!

The emergence of various HMD
(Gear VR, Oculus Rift, Daydream, PlayStation VR)

Requirement	details
pixels/degree	40 pix/deg
video resolution	11,520 x 6,480
framerate	90 fps

Requirements for high quality VR
Source: Technicolor, Oct. 2016 (m39532, MPEG 116th Meeting)

※ Slide Source: Ryu, eun-seok, Professor of Gachon University(3079-18-0045-00-0003, IEEE 3079 7th meeting)

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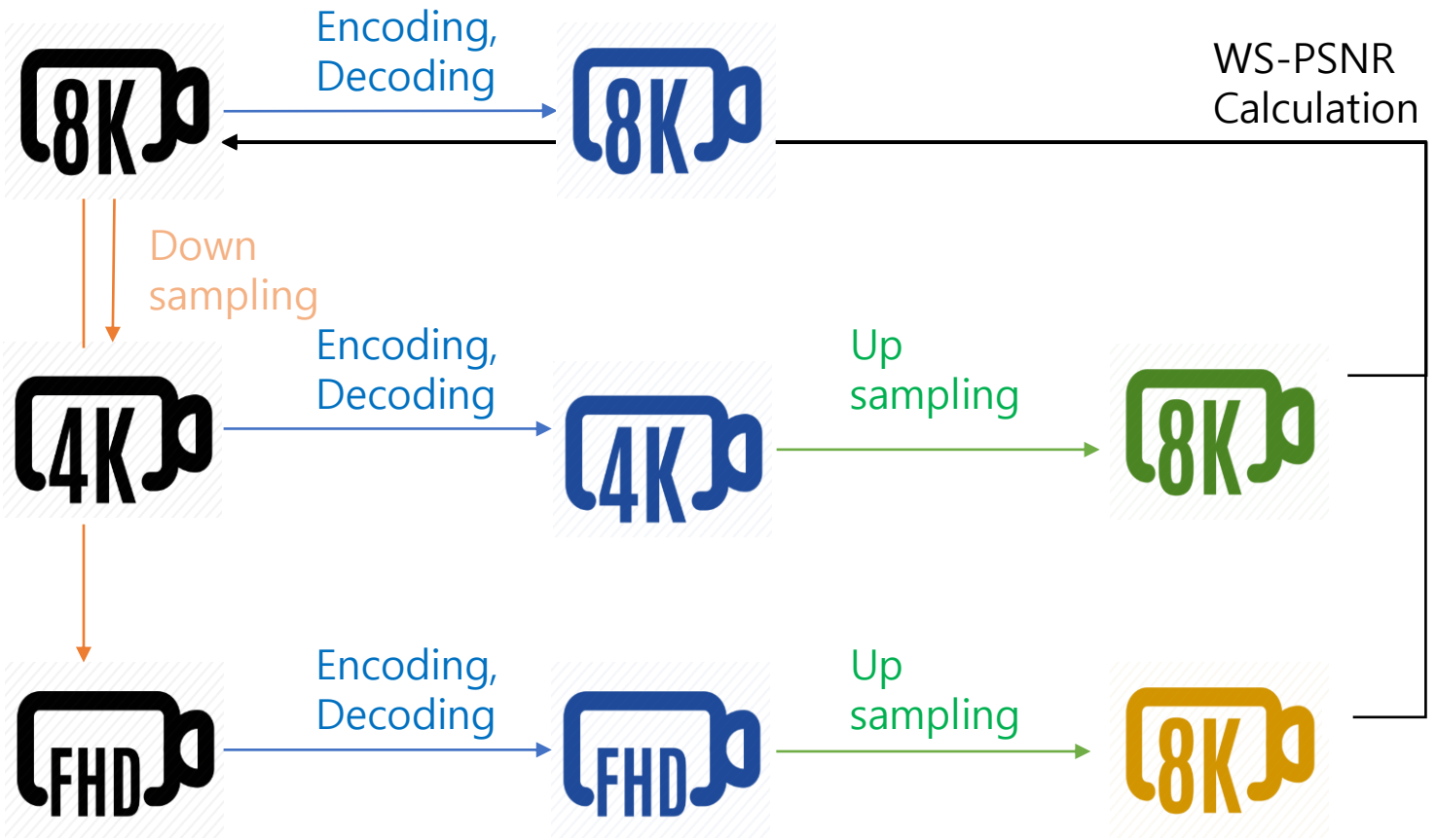
Test Condition

- Test Server : Linux Ubuntu
- Test Sequences : Gaslamp, KiteFlite
- Quantization Parameters : 22, 27, 32, 37
- FPS : 30, 60, 90
- Resolution : HD, UHD 4K, 8K
- Encoder/Decoder: HEVC/H.265 Reference SW

※ Slide Source: Ryu, eun-seok, Professor of Gachon University

360 Video Bitrates/Quality Test Process



※ Slide Source: Ryu, eun-seok, Professor of Gachon University

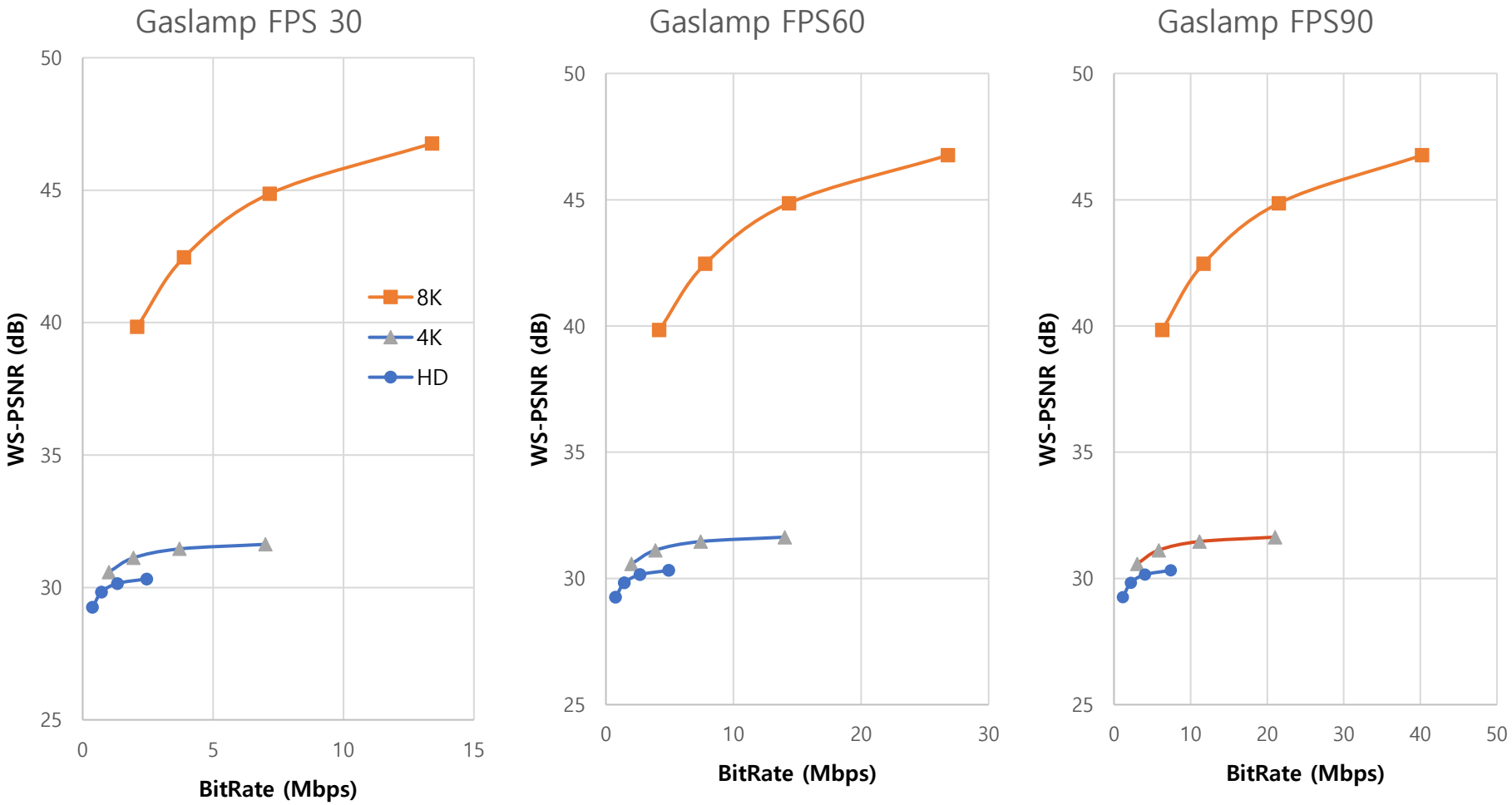
Test Sequences (Defined by ISO/IEC MPEG Standard-I)

- Gaslamp

- KiteFlite

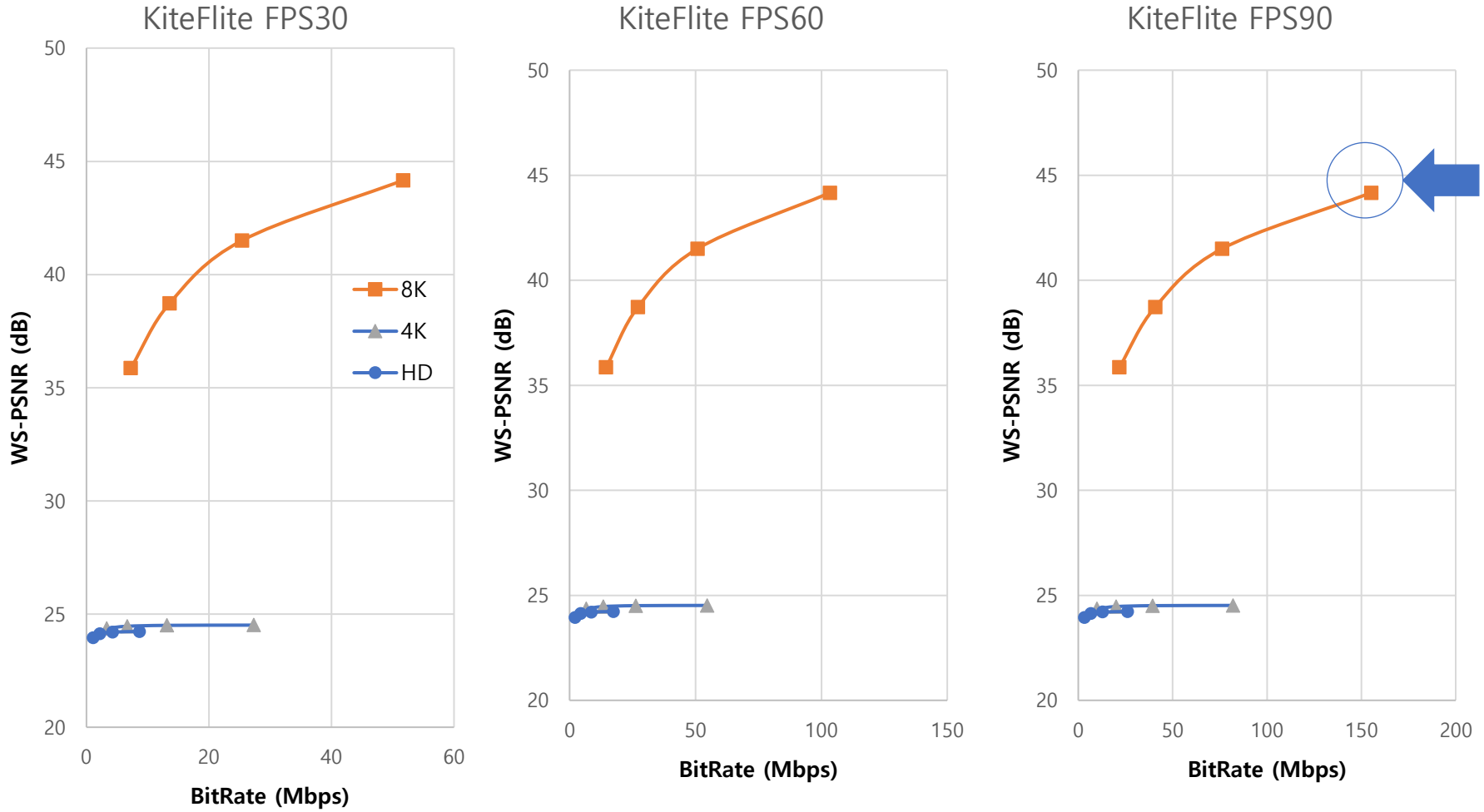
※ Slide Source: Ryu, eun-seok, Professor of Gachon University

Test Results – Plots (1/2)



※ Slide Source: Ryu, eun-seok, Professor of Gachon University

Test Results – Plots (2/2)



※ Slide Source: Ryu, eun-seok, Professor of Gachon University

Test Results - Tables

Bitrate (Kbps)
Y-WSPSNR (dB)

Gaslamp	Bitrate	13402.262	7172.5312	3891.1872	2089.6224	7011.4784	3712.96	1945.3984	1007.4144	2463.2704	1338.2368	721.0432	379.36
	Y-WSPSNR	46.7672	44.8655	42.4664	39.8424	31.6334	31.4593	31.1189	30.5803	30.3217	30.1526	29.8232	29.2542
	QP	22	27	32	37	22	27	32	37	22	27	32	37
	FPS 30	8K				4K				FHD			
Gaslamp	Bitrate	26804.525	14345.062	7782.3744	4179.2448	14022.957	7425.92	3890.7968	2014.8288	4926.5408	2676.4736	1442.0864	758.72
	Y-WSPSNR	46.7672	44.8655	42.4664	39.8424	31.6334	31.4593	31.1189	30.5803	30.3217	30.1526	29.8232	29.2542
	QP	22	27	32	37	22	27	32	37	22	27	32	37
	FPS 60	8K				4K				FHD			
Gaslamp	Bitrate	40206.787	21517.594	11673.562	6268.8672	21034.435	11138.88	5836.1952	3022.2432	7389.8112	4014.7104	2163.1296	1138.08
	Y-WSPSNR	46.7672	44.8655	42.4664	39.8424	31.6334	31.4593	31.1189	30.5803	30.3217	30.1526	29.8232	29.2542
	QP	22	27	32	37	22	27	32	37	22	27	32	37
	FPS 90	8K				4K				FHD			

KiteFlite	Bitrate	51716.5760	25398.2784	13574.6944	7249.1520	27318.0352	13142.3904	6670.8544	3308.9440	8684.0704	4290.9440	2208.0320	1092.8608
	Y-WSPSNR	44.1636	41.5020	38.7266	35.8644	24.5208	24.5100	24.4673	24.3705	24.2303	24.2066	24.1315	23.9529
	QP	22	27	32	37	22	27	32	37	22	27	32	37
	FPS 30	8K				4K				FHD			
KiteFlite	Bitrate	103433.15	50796.557	27149.389	14498.304	54636.07	26284.781	13341.709	6617.888	17368.141	8581.888	4416.064	2185.7216
	Y-WSPSNR	44.1636	41.502	38.7266	35.8644	24.5208	24.51	24.4673	24.3705	24.2303	24.2066	24.1315	23.9529
	QP	22	27	32	37	22	27	32	37	22	27	32	37
	FPS 60	8K				4K				FHD			
KiteFlite	Bitrate	155149.73	76194.835	40724.083	21747.456	81954.106	39427.171	20012.563	9926.832	26052.211	12872.832	6624.096	3278.5824
	Y-WSPSNR	44.1636	41.502	38.7266	35.8644	24.5208	24.51	24.4673	24.3705	24.2303	24.2066	24.1315	23.9529
	QP	22	27	32	37	22	27	32	37	22	27	32	37
	FPS 90	8K				4K				FHD			

※ Slide Source: Ryu, eun-seok, Professor of Gachon University

Conclusion

- Bitrates vary from 40Mbps to 160Mbps according to video content features.
  - 8K resolution and 90 fps contents: 40Mbps ~ 160Mbps
- The WS-PSNR quality of HD and 4K UHD were much lesser than 8K UHD.
- Target video resolution for VR service
  - Fraunhofer HHI and TNO: 12K resolution
  - KETI: 16K resolution
- Considering VR sickness, 160Mbps (hopefully 200Mbps) application layer bandwidth is required for 8K 90fps.
  - Physical layer bandwidth requirement: around 350Mbps
  - If 16K/90fps is considered, 700Mbps (Phy. Layer) bandwidth will be required (estimation).

※ Slide Source: Ryu, eun-seok, Professor of Gachon University

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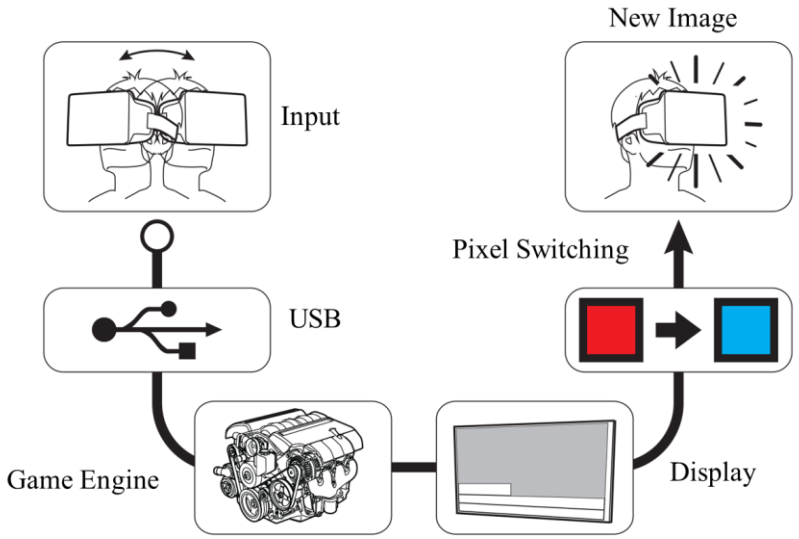
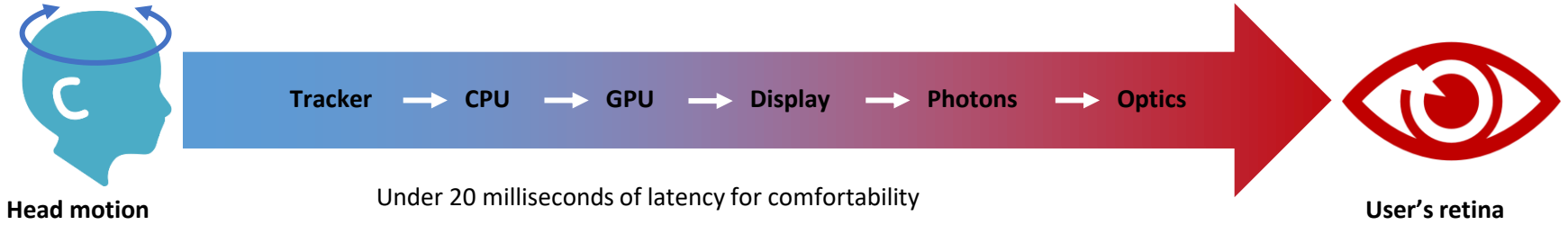
Network Latency



- According to the paper published by Held, Efsathiou, & Greene in 1966, if the MTP (motion-to-photon latency) is too high, it makes people to feel motion sick.
- The paper published by Sheridan & Ferrel in 1963 also states that the high MTP also cause a poor manual performance of human being.
- In 2003, Bernard D. Adelstein from NASA Ames Research Center mentioned in his paper, HEAD TRACKING LATENCY IN VIRTUAL ENVIRONMENTS: PSYCHOPHYSICS AND A MODEL, the MTP needs to be less than 17 ms.
- According to John Carmack, the CTO of Oculus, the MTP must be lower than 20 ms to minimized the VR sickness.
- Hence, the network latency needs to be satisfying this MTP latency condition.



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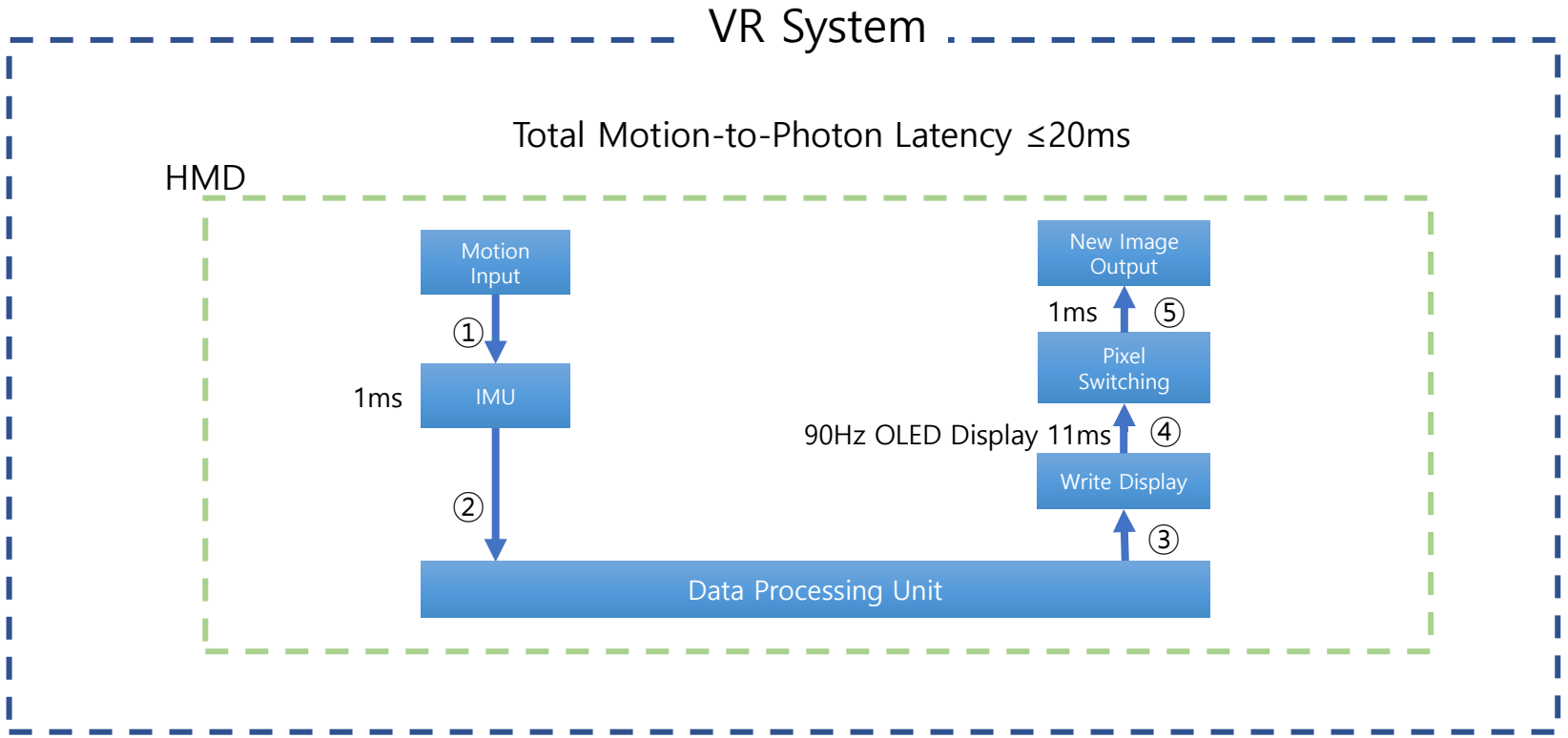
Background Information

- The purpose of this document is to find a way to minimize the VR sickness.
- Out of all factors causing the VR sickness, motion-to-photon latency is considered as this is the only factor that matters to the network.
- Maximum tolerable motion-to-photon in VR system is 20 ms.
- VR system has some fixed latency from the hardware component such as display
- Current commercial HMDs exist in two types
  - Stand Alone Type
    - All VR content are either rendered or decoded by the embedded processing unit.
  - Display Type
    - All VR content are either rendered or decoded by the external device such as PC or gaming console.
- For the purpose of network analysis, we do not consider the Stand Alone type HMDs as no network issue exist here.
- The following diagrams include the cases where the Display Type HMDs are used.

※ Slide Source: Seo, Dong-Il Dillon, VoleR Creative(21-18-0039-02-0000, IEEE 802.21 86th meeting)

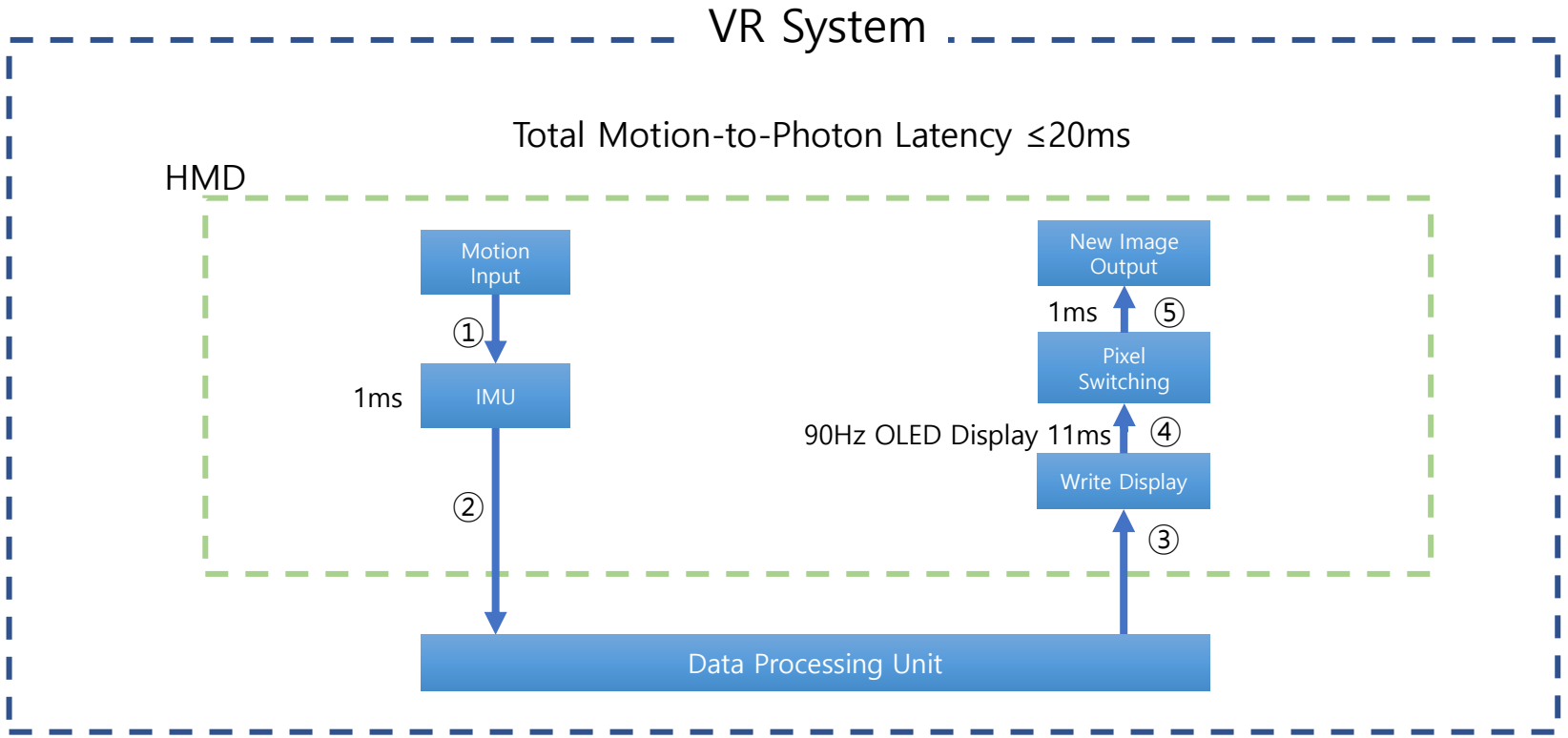
Stand Alone Type



No network latency exist in the connection sections 2 and 3

※ Slide Source: Seo, Dong-Il Dillon, VoleR Creative(21-18-0039-02-0000, IEEE 802.21 86th meeting)

Display Type



Network latency exist in the connection sections 2 and 3

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Network Enablers
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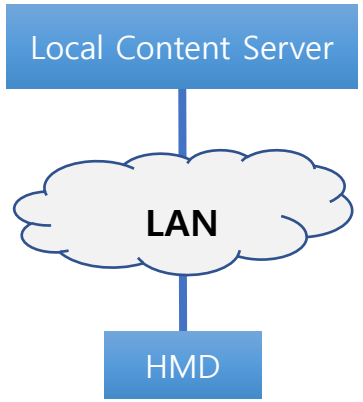
Case 1

Case 1



- HMD is connected to a local content server such a PC or a gaming console by a wired or wireless network.
- VR content is being rendered or decoded in the local content server and HMD is receiving the VR content through either a wired or a wireless network.

* LAN: wired or wireless

※ Slide Source: Seo, Dong-Il Dillon, VoleR Creative(21-18-0039-02-0000, IEEE 802.21 86th meeting)

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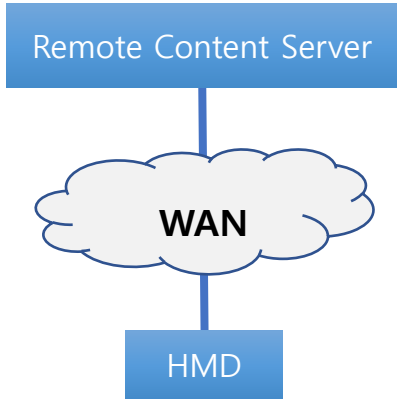
Case 2

Case 2



- HMD is connected to a remote content server such as cloud rendering by wired and wireless network.
- VR content is being rendered or decoded in the remote content server and streamed to the HMD.
- The remote content server is connected via WAN as the remote content server is located outside of the local area.

* WAN: wired + wireless

※ Slide Source: Seo, Dong-Il Dillon, VoleR Creative(21-18-0039-02-0000, IEEE 802.21 86th meeting)

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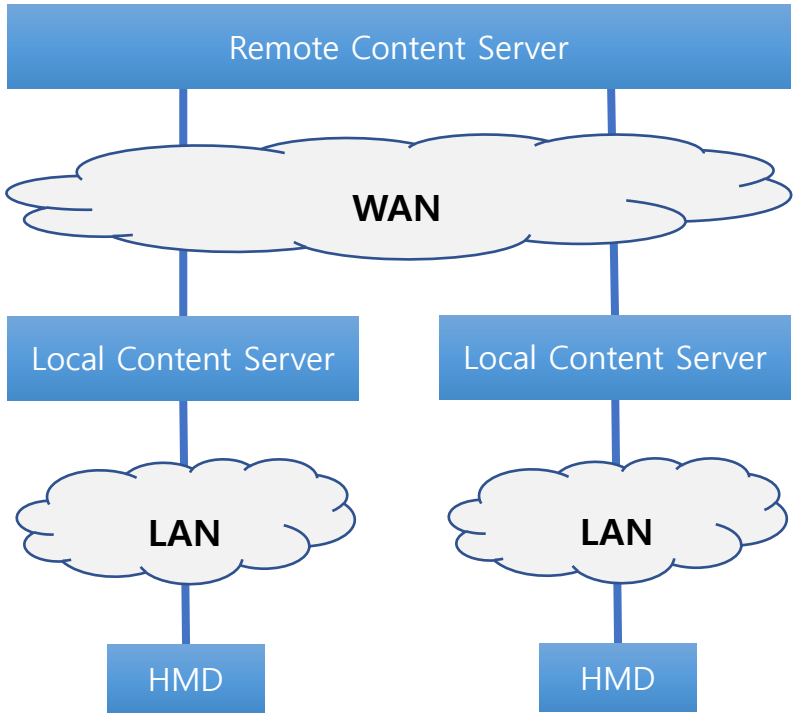
Case 3

Case 3



- This is an extended version of case 1 – more than one VR system are connected to the remote content server.
- HMD is connected to a local server like case 1 and the local content server is rendering or decoding VR content and send it back to the HMD.
- The remote content server in this case is computing the content sent by the local content servers and redistributing the calculated data back to the local content servers rather than rendering the content in local content server.

* LAN: wired or wireless
* WAN: wired + wireless

※ Slide Source: Seo, Dong-Il Dillon, VoleR Creative(21-18-0039-02-0000, IEEE 802.21 86th meeting)

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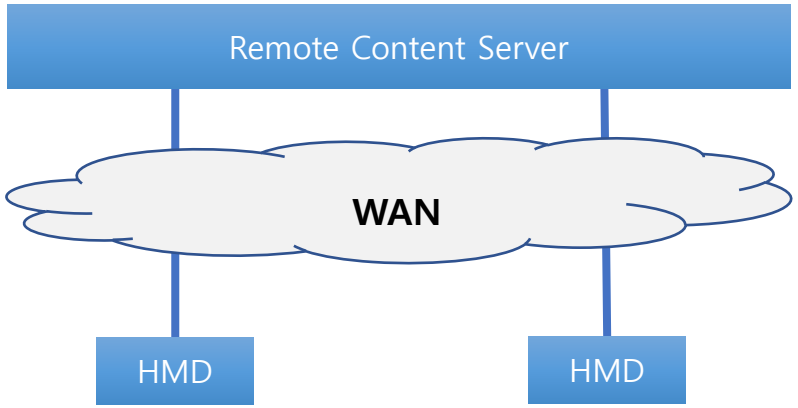
Case 4

Case 4



- This is an extended version of case 2 - more than one HMD are connected to the remote server.
- HMD is connected to a remote server like case 2 and the remote server is rendering or decoding VR content and send it back to the HMD.

* WAN: wired + wireless

※ Slide Source: Seo, Dong-Il Dillon, VoleR Creative(21-18-0039-02-0000, IEEE 802.21 86th meeting)

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Network Enablers
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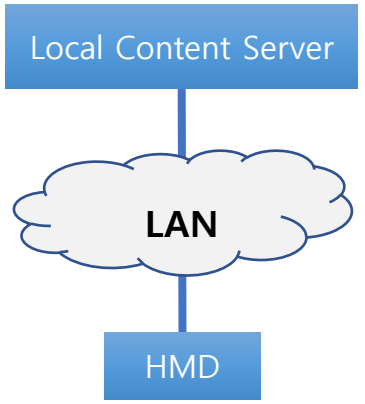
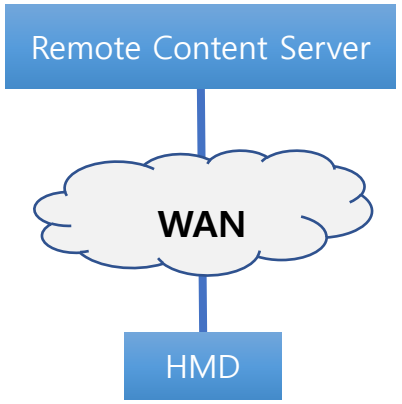
Diagrams

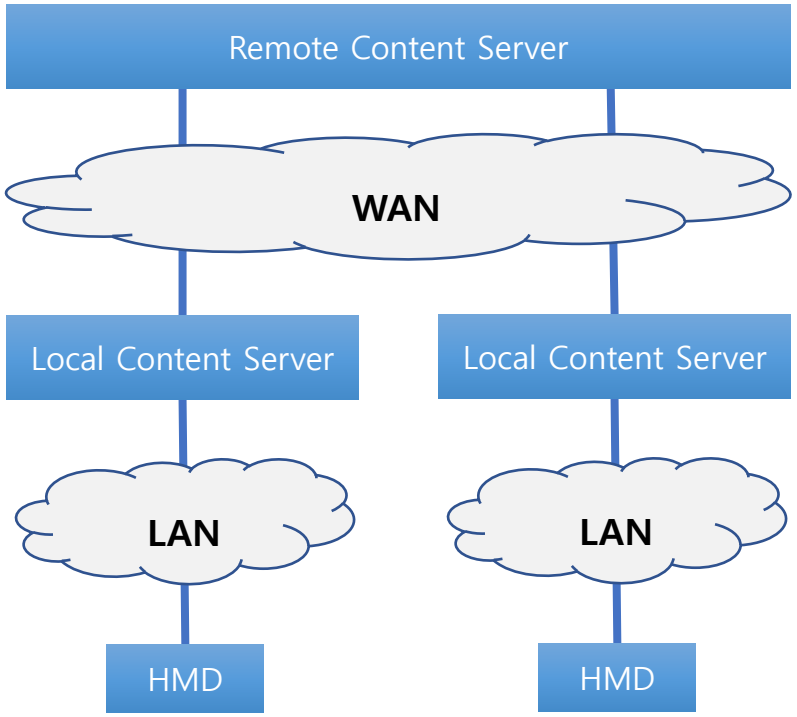
Case 1



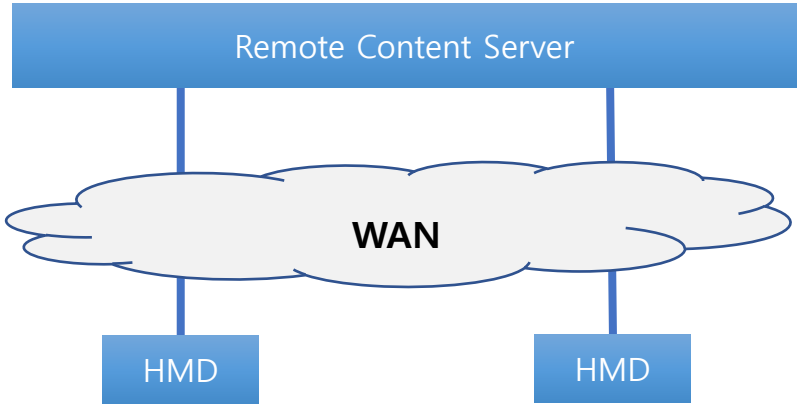
Case 2



Case 3



Case 4



* LAN: wired or wireless
* WAN: wired + wireless

※ Slide Source: Seo, Dong-Il Dillon, VoleR Creative(21-18-0039-02-0000, IEEE 802.21 86th meeting)

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Limitations of VR QoE due to Technical Shortcomings

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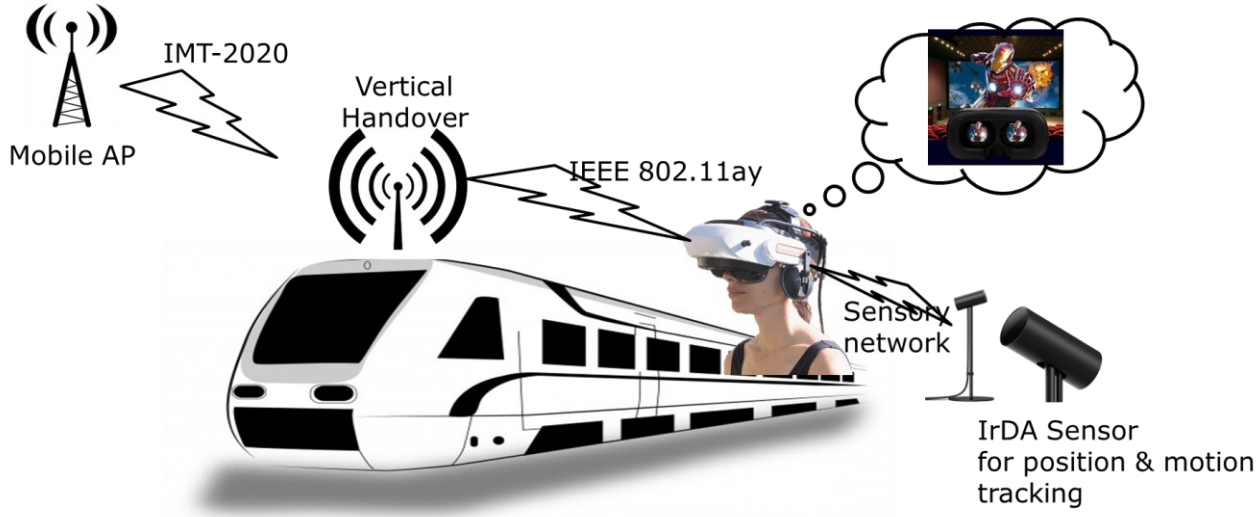
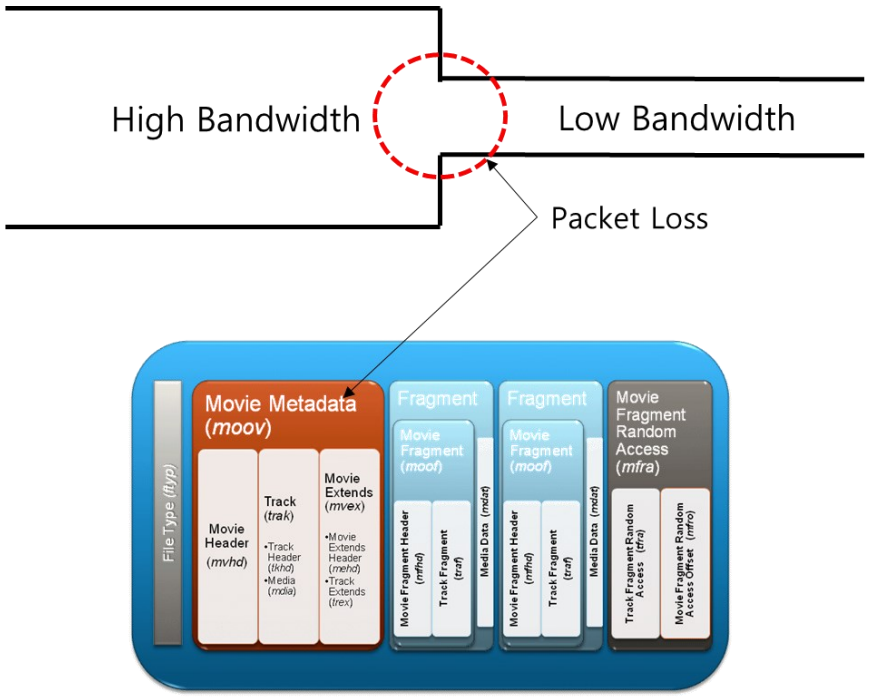
Handover Issue



- Moving users in a wireless environment implies that network handover will inevitably occur. Whether it is a horizontal handover in a homogeneous network or a vertical handover in a heterogeneous network, network handover will inevitably occur.
- As mentioned above, in order to provide a good user experience, the HMD-based virtual reality content need a bandwidth infrastructure that can transmit a large amount of data. However, we cannot expect to have a high-performance bandwidth environment at all time. Therefore, a network handover from a high-performance bandwidth network such as IMT-2020 to a relatively low-performance bandwidth environment such as IMT-Advanced may occur.
- In this case, there may be a case where data of VR content fails to be transmitted at the time of handover occurrence and especially, when an error occurs in a packet containing the header data which has a structural information of the entire transmitted data, it can be very fatal.

Handover Issue



- When the data cliff occurs, the video file consisted of various packets shown in the left figure below may lose its Movie Header file which contains the overall movie data structure information; and the packets without this Movie Header file will be useless as the device will not be able to recognize what the file is for.
- the user experiencing the VR service cannot experience optimal quality of the service and it will be difficult to use the movie service itself.
- At least, the situation in figure 4 needs to occur in order to protect the header packet data loss during the network handover.
- In order to achieve this, the speed of network change should not be a sudden drop so that the header packet is securely transferred when the network signal connected to the 1 Gbps network is connected to the network with much lower speed.

Network Enablers
for
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Conclusion

- Good QoE is essential for HMD based VR content to be commercially successful.
- Defining the minimum network data throughput is important for optimal VR QoE.
- The minimum network throughput includes both wired and wireless network as well as mobile network and PAN (Personal Area Network)
- If we can find a way to satisfy the network requirements for optimal VR QoE, this will also help to satisfy the network requirements that RTA TIG is targeting to develop.
- If possible, we can conduct a tutorial session on VR gaming network requirements for next year's March plenary together.

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