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Title: **Why you should care about VR network requirements**

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Abstract: This document is to identify the industry problems for VR and to discuss the network relevance that will help to solve these problems.

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Network Enablers
for
seamless HMD based VR Content Service

Why VR is receiving the attention

Diminishing Return: Industries need a new area to grow

Display

Microprocessor

Telecommunication

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Why consumers are not interested in VR

Reasons that US Internet Users Are Not Interested in Owning a Virtual Reality Headset, by Age, March 2017

% of respondents in each group

	18-24	25-34	35-44	45-54	55-64	65+	Total
Just not interested	43%	39%	53%	54%	51%	67%	53%
Too expensive	65%	52%	46%	51%	32%	32%	43%
I've heard it causes motion sickness	22%	19%	20%	14%	8%	11%	14%
Lack of content	22%	19%	14%	12%	9%	6%	12%
Poor quality of content	5%	5%	4%	3%	2%	3%	3%
Other	3%	8%	5%	5%	20%	12%	10%

Note: n=926 ages 18+
Source: Thrive Analytics, "Virtual Reality Monitor: 2017 Wave I - Highlights," May 10, 2017

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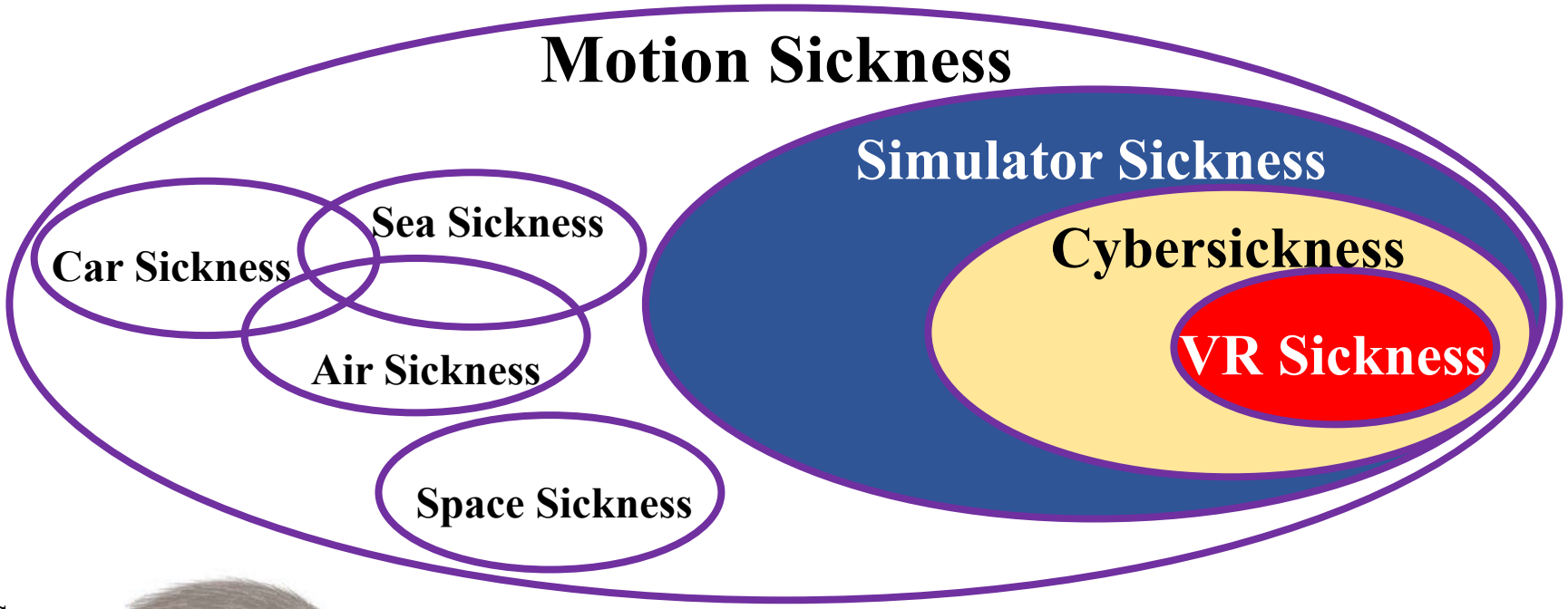
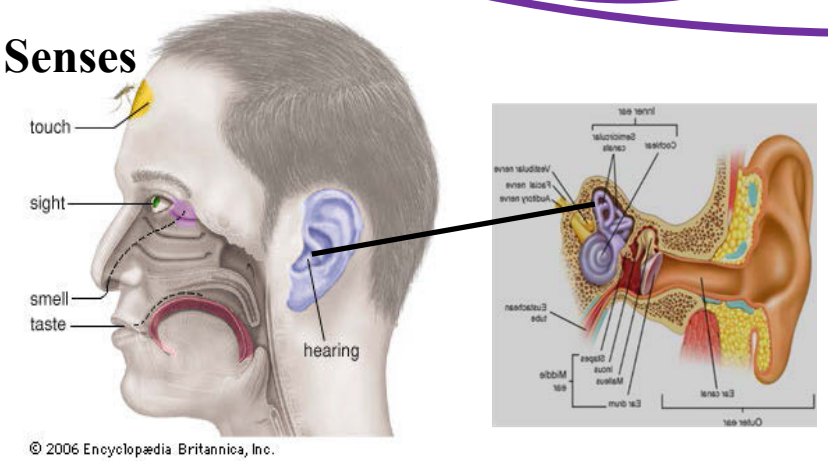
Industry Problems (VR Sickness)



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.

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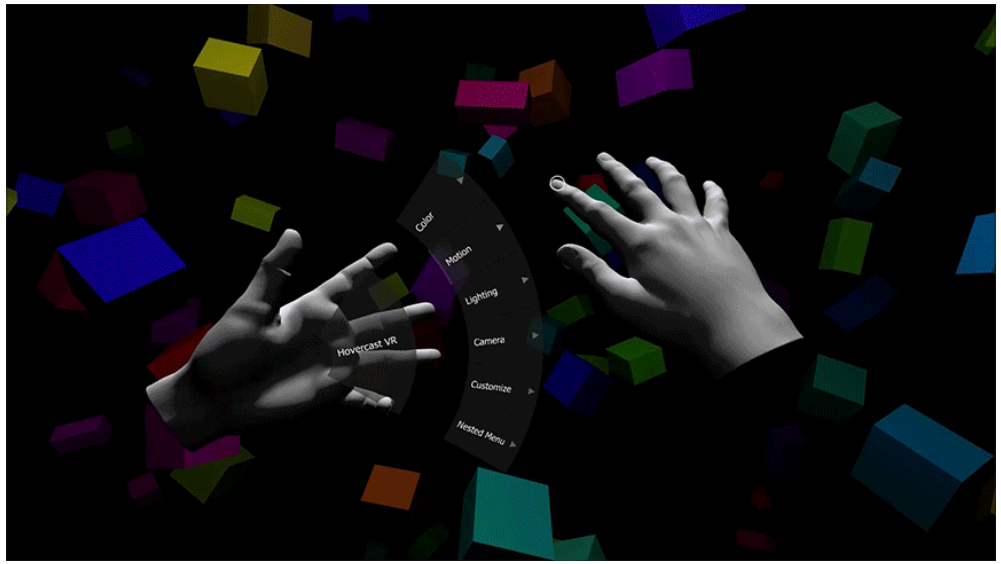
Industry Problems (VR Sickness)



VR Content Design Challenge

VR Hardware/Network Challenge

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Hardware/Network Challenges (VR Sickness)

Low Display Resolution

Low Frame Rate

Motion to Photon Latency

Incorrect Spatial Sound

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Technical Requirements for VR QoE

- **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 = 11,520x6,480
framerate	- 90 FPS - a 90 FPS 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 20 ms
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

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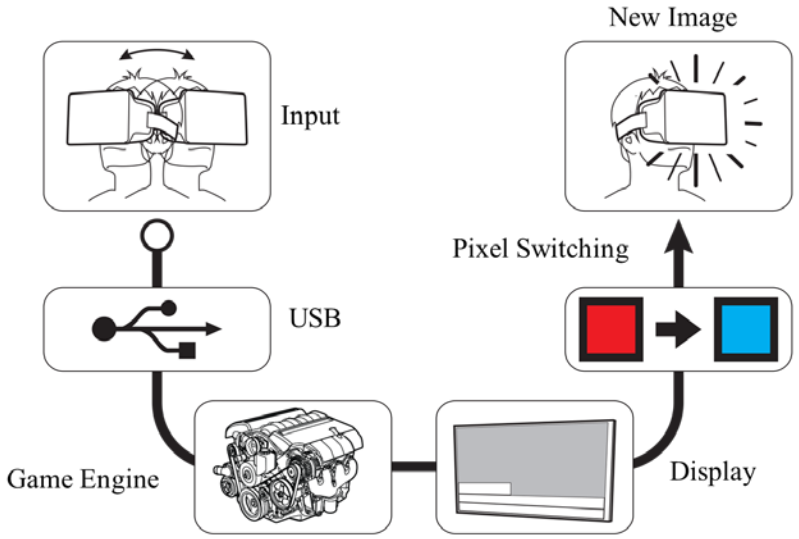
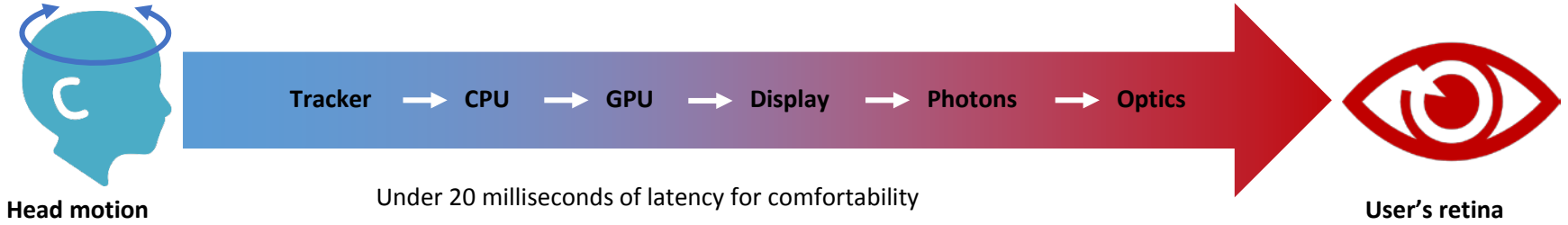
What is Motion to Photon(MTP) Latency?



- 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.

The goal is to deliver the optimal QoE with satisfying QoS



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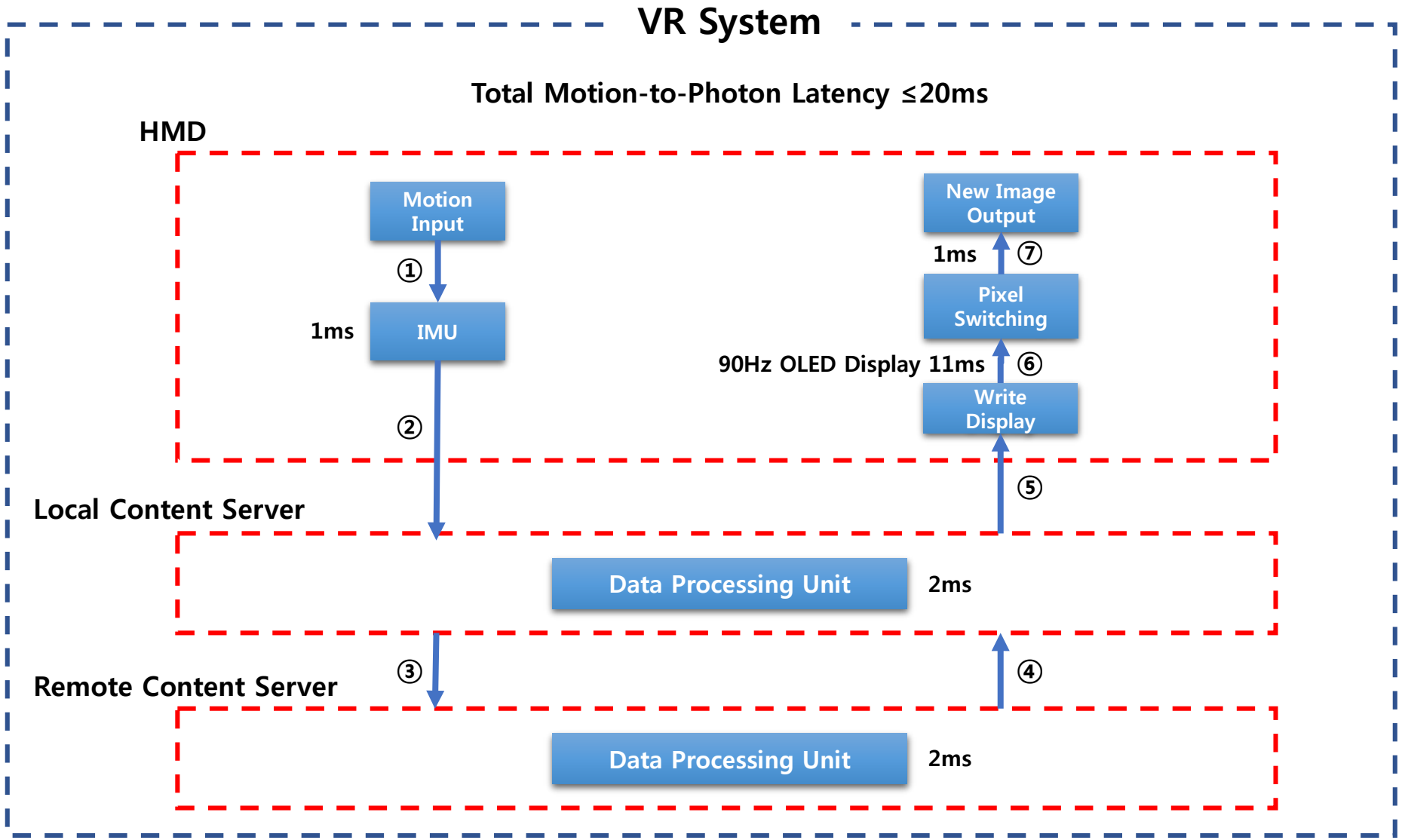
Components Contributing to MTP Latency



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Network Components Contributing to MTP Latency

Case	Status of each node							Remarks
	①	②	③	④	⑤	⑥	⑦	
1	direct	HDMI	Wired LAN	Wired LAN	HDMI	chip	display Panel	Wired Network
2	direct	on Board	Wireless LAN	Wireless LAN	on Board	chip	display Panel	Wireless Network
3	direct	on Board	WAN	WAN	on Board	chip	display Panel	Backbone Network
4	direct	LAN	n/a	n/a	LAN	chip	display Panel	Local Network
5	direct	on Board	WAN	Wireless LAN	on Board	chip	display Panel	Network Handover

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Network Requirements for VR Application

		VR HMD Requirements
Data transmission rate		> 20 Gbps
Latency		<5 ms (LAN)
Jitter		< 5 ms
Transmission range	Indoor	5 m
	Outdoor	Several hundred meters
Mobility	Indoor	Pedestrian speed < 4 km/h
	Outdoor	200 km/h
PER		10^{-6} [1]

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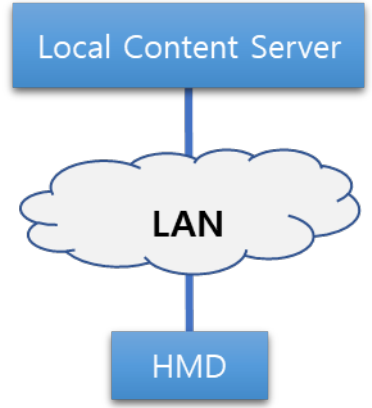
Use Case I



Case 1: A Single VR System Connected via a LAN

In the picture below, a user is playing a VR game using a VR HMD connected to a game console system known as PlayStation 4 with HDMI (High Definition Multimedia Interface) and USB (Universal Serial Bus) cables. The HDMI cable is delivering both video and audio for the VR game that are rendered in real time by the game console (shown in figure) to the VR HMD. The USB cable is delivering the head tracking data from the VR HMD to the game console to reflect the user's head position so that the game console can render both the video and the audio of the VR game accordingly in real time.

Goal: Replace the wired link to wireless to provide more optimal QoE

- Must support over 90 Hz of frame rate and over 2K resolution video quality with very low latency and low jitter

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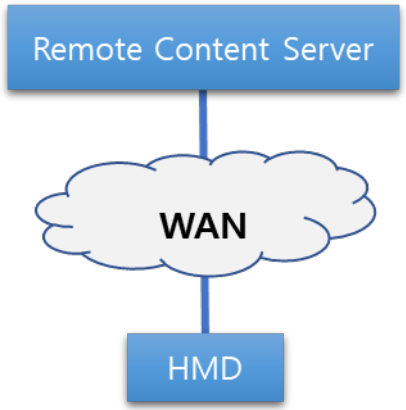
Use Case II



Case 2: A Single VR System Connected via a WAN

In the following picture, a user is watching a baseball game in a virtual reality environment using a mobile phone-based VR HMD system. The baseball game in this scenario is being captured with a 360-degree camera and it is being streamed to the VR HMD in real time. The head tracking data is also transferred to the camera via a mobile network to display the view where the user is looking at. In this scenario, the VR content service is rendered or decoded in the remote content server. . It is important to note that the remote content server is located outside the local network and wide area network (WAN) consists of both wired and wireless networks.

Goal: Must deliver optimal QoE via WAN

- Must support over 90 Hz of frame rate and over 2K resolution video quality with very low latency and low jitter

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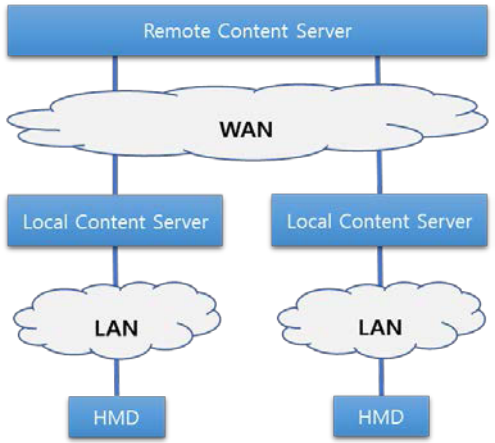
Use case III



Case 3: Multiple VR Systems Connected via a LAN

In the following picture, a user is playing a virtual reality game and competing against other remote players using a VR HMD system that is connected to local server (e.g., a PC or a Laptop). The HDMI cable connecting the VR HMD system and the local server is used to receive the video and the audio data of the VR game content, the service of which is being rendered real time in the local server. The USB cable connecting the VR HMD and the local server is used to exchange the head tracking data so the server can render the video and the audio data accordingly. The remote content server is calculating the scores and the consequential data caused by the remote users' input. These data are sent to the local content server so it can render the video and the audio of the VR game content accordingly.

Goal: Must deliver optimal QoE via LAN and WAN

- Must support over 90 Hz of frame rate and over 2K resolution video quality with very low latency and low jitter

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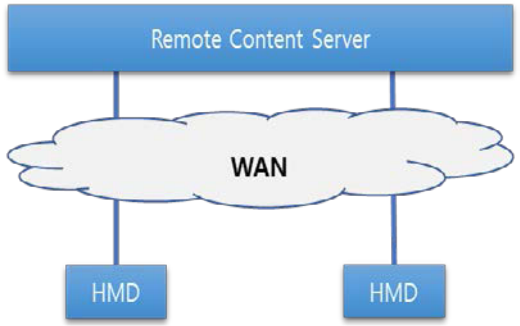
Use Cases IV



Case 4: Multiple VR Systems Connected via a WAN

In the following picture, two or more users are watching a live streamed video game match from their respective home using their mobile phone-based VR HMD systems. The users watching the same content in a virtual movie theater rendered in a cloud service provider and they are being represented as a form of a virtual avatar in the virtual reality theater. They are able to interact with each other and also can communicate via audio. The live-streamed video game match and the virtual reality theater are all being rendered in a remote server situated in the cloud service provider network and the VR HMD system is only running a small application for obtaining the cloud rendered VR content.

Goal: Must deliver optimal QoE via WAN with multiple nodes

- Must support over 90 Hz of frame rate and over 2K resolution video quality with very low latency and low jitter

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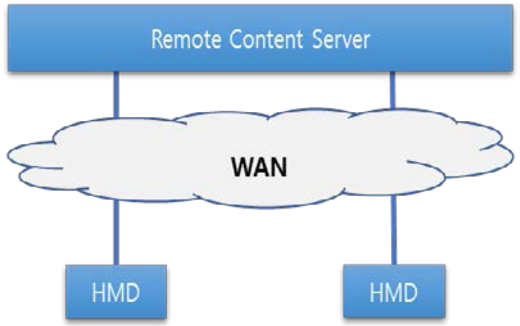
Use Cases V



Case 5: Special Use Case – Change of Network

In the following picture, a user is watching a streamed movie using a mobile phone-based VR HMD while travelling in a bus or a train. The movie is encoded in the remote server and sent to the VR HMD system via a wide area network. The VR HMD system is only decoding the content sent by the remote server.

Goal: Must deliver optimal QoE with network mobility

- Must support over 90 Hz of frame rate and over 2K resolution video quality with very low latency and low jitter

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Goals & Technical Challenges

- Goals
  - Replace the last mile cable (e.g. ,HDMI cable connecting the HMD with the content server) with a wireless link for optimal QoE . However, the backbone connection will be a cable (e.g., Ethernet) which would require to satisfy the same QoE and deterministic delivery.
  - Increase the mobility with link hand-over optimization
- Technical Challenges
  - Network requirements are directly related to MTP latency
  - For VR HMD based VR Content Service, the network should provide the following features:
    - Link Layer Issues: Jitter, Latency
    - High Layer Issue: QoS, QoE & Mobility

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Industry Relevance

❖ Industry Beneficiaries for Network Standards

- Mobile Network Infrastructure Providers
  - Immediate killer app for 5G is immersive media (VR & AR) for Telecom Companies
  - Need to have good VR QoE to grab more users to their 5G network
- HMD Manufacturers
  - Stand-alone also known as all-in-one devices are designed to create a better QoE as it eliminates the cord that was attached to the device
  - Added processor and batteries in a limited physical case space increase the weight and the heat; hence network solution is required to for cloud VR service
- Content Creators
  - Creating more compelling visual experience comparable to the modern PCs and gaming consoles for VR using the stand-alone device is very challenging
  - Current wired system limits the QoE of VR content; hence, needs a cloud VR
- Platform Holders
  - Want to aggregate compelling VR content to grow their VR content ecosystem

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Conclusion

- Various other Standard Organizations such as Khronos Group, ISO/IEC JTC1/SC24, SC29 WG11(MPEG), IEEE 3079, IEEE 2048 are developing technical standards for VR
- MTP Latency is directly related to the network issues that IEEE 802 should consider when developing network standards for VR.
  - Link layer requirements need to be addressed by PHY & MAC
  - QoS, QoE and Mobility need to be addressed by above layer 2
- SG is currently discussing
  - additional use cases
  - link layer requirements
  - scope for PAR/CSD
  - with all IEEE 802 WGs
- Looking forward to your input & participation

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