



Creating Infinite
Possibilities.

Considerations for the Delivery of Latency-Sensitive, Compute-Intensive Experiences Over A Communication Network

Dhananjay “DJ” Lal

Senior Director, Advanced R&D
Adeia

513.225.4948 DJ.Lal@adeia.com

What we will discuss today:

- Network Powered Experiences: A QoE-centric Viewpoint
- The key determinants of QoE for Immersive Experiences
- Edge-Computing-as-a-service: The Proposed Method

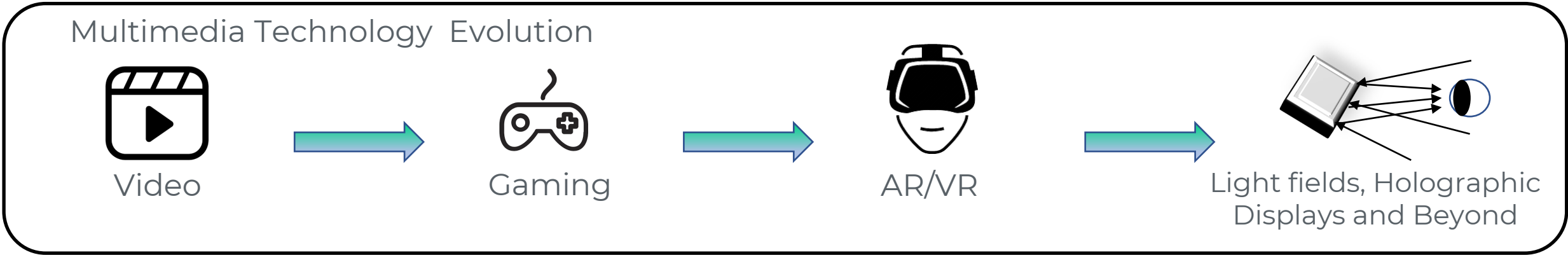


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Network Powered Experiences: A QoE-Centric Viewpoint

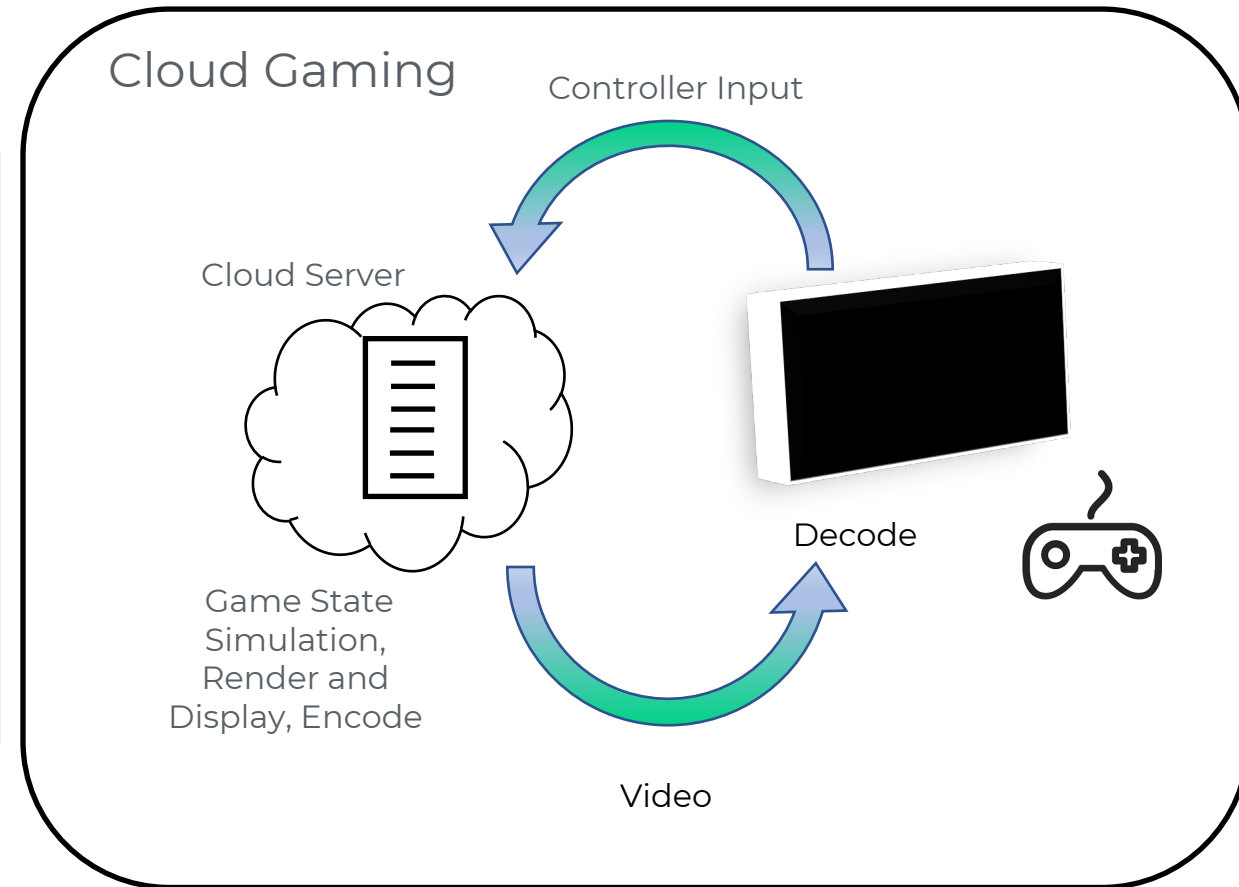
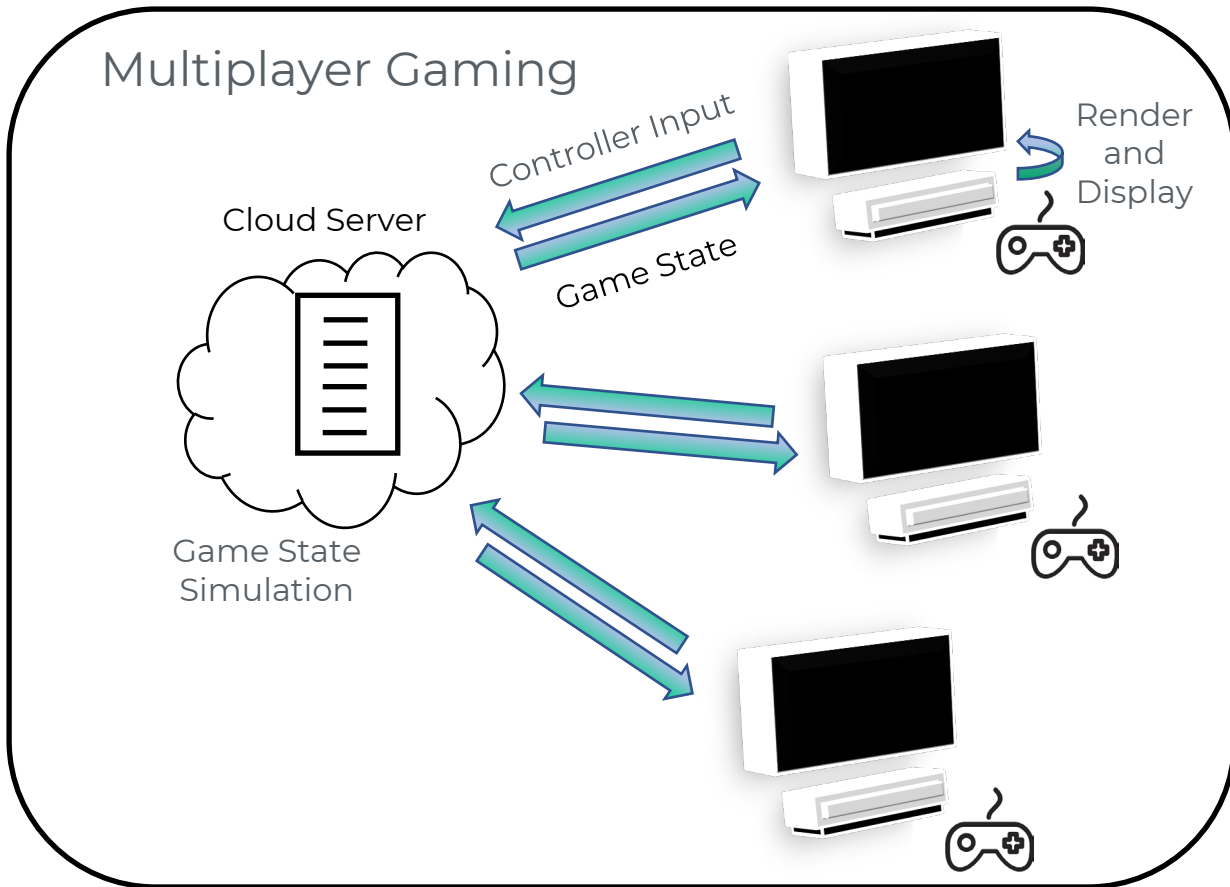
The Evolution of Network Powered Experiences

Spatial Web Adoption will transform the Network into a multi-attribute service entity



Lag: A key Gaming Quality-of-Experience (QoE) determinant

Latency surpasses video quality in shaping user experience, demanding an evolved network



“Button-to-Photon” and “Motion-to-Photon” Latency

The end-to-end latencies that define QoE for Cloud Gaming and Cloud XR respectively

Cloud Gaming
 “Button to Photon”
 Latency Budget

Source: Nokia Blog, “Game on! How broadband providers can monetize ultra-low latency services for gamers”, By Gino Dion

Depicted latency budget of 88 ms < **100 ms worst case “Button to Photon” Expectation**

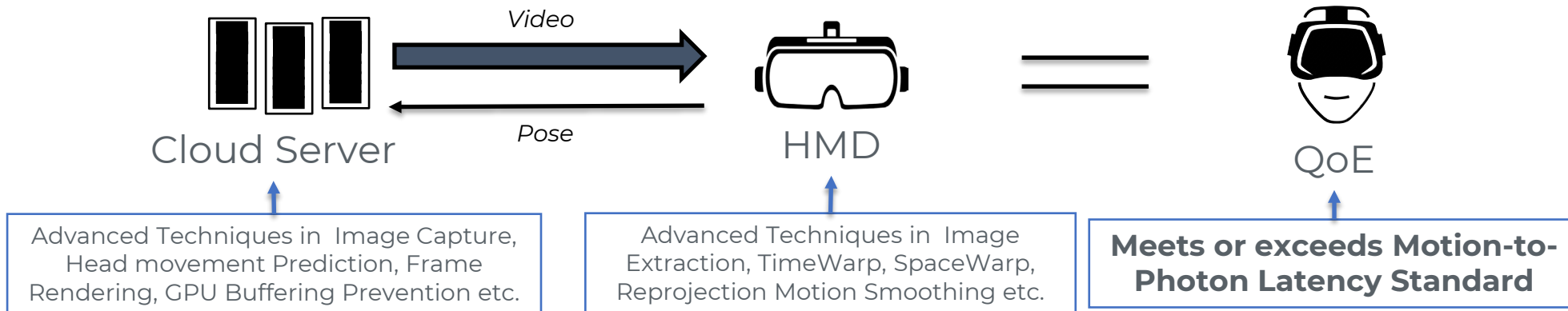
Cloud XR
 “Motion to Photon”
 Latency Budget

Projected Cloud XR Latency Budget

Depicted latency budget of 38 ms > **20 ms worst case “Motion to Photon” Expectation**

Beyond MTP Latency... A QoE-centric Viewpoint

The End-User QoE is dependent on Advanced Techniques and Content Type

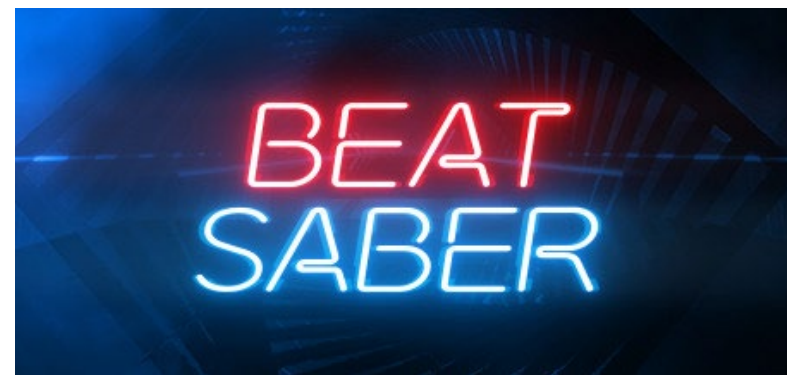


The extent to which the advanced techniques reduce *perceived* latency depends on the nature of the content



theBlu
 A delightful “lean back” experience that may tolerate greater MTP latency

Source : <https://store.steampowered.com/app/451520/theBlu/>



Beat Saber
 A fast-paced “lean forward” experience that may be intolerant to high MTP latency

Source : https://store.steampowered.com/app/620980/Beat_Saber/

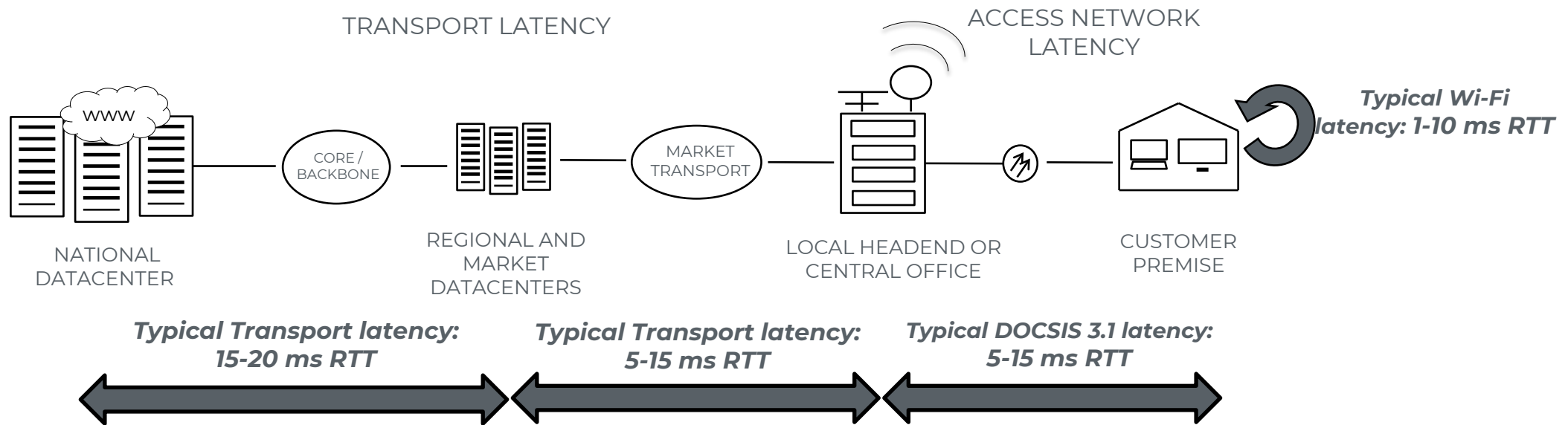


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The Key Determinants of QoE for Immersive Experiences

The Implications of Streaming Cloud XR over the Network

What are the acceptable locations in the network hierarchy for the “Immersive Edge”?



The desired latency for delivering Cloud XR shall determine where the “Immersive Edge Compute” instance is located in the network hierarchy

Delivering Compute for a Variety of AR/VR Experiences

Compute Grade / Compute Intensity is the other key factor beyond latency

- Compute intensity is the capability of the unit used for compute-intensive rendering
- Varies widely across content
- Different grades mapped to Virtual machine (VM) or Container-Host OS configurations
- Each grade defined by a hardware-software specification
 - CPU cores, GPU FLOPS, vRAM etc.
 - OS (Host or Guest)
 - Consider grade on a scale of 1-10 for simplicity

Half-Life: Alyx System Specifications

https://store.steampowered.com/app/546560/HalfLife_Alyx/

SYSTEM REQUIREMENTS	
MINIMUM:	RECOMMENDED:
Requires a 64-bit processor and operating system	Requires a 64-bit processor and operating system
OS: Windows 10	
Processor: Core i5-7500 / Ryzen 5 1600	
Memory: 12 GB RAM	
Graphics: GTX 1060 / RX 580 - 6GB VRAM	

Asgard's Wrath System Specifications

https://www.pcgamingwiki.com/wiki/Asgard%27s_Wrath

	Windows	
	Minimum	Recommended
Operating system (OS)	10	
Processor (CPU)	Intel Core i5-4690 AMD Ryzen 3 1300X	Intel Core i7-7700 AMD Ryzen 5 2500X
System memory (RAM)	8 GB	16 GB
Hard disk drive (HDD)	165 GB	
Video card (GPU)	Nvidia GeForce GTX 1060 AMD Radeon RX 580	Nvidia GeForce GTX 1080 AMD Radeon RX Vega 64

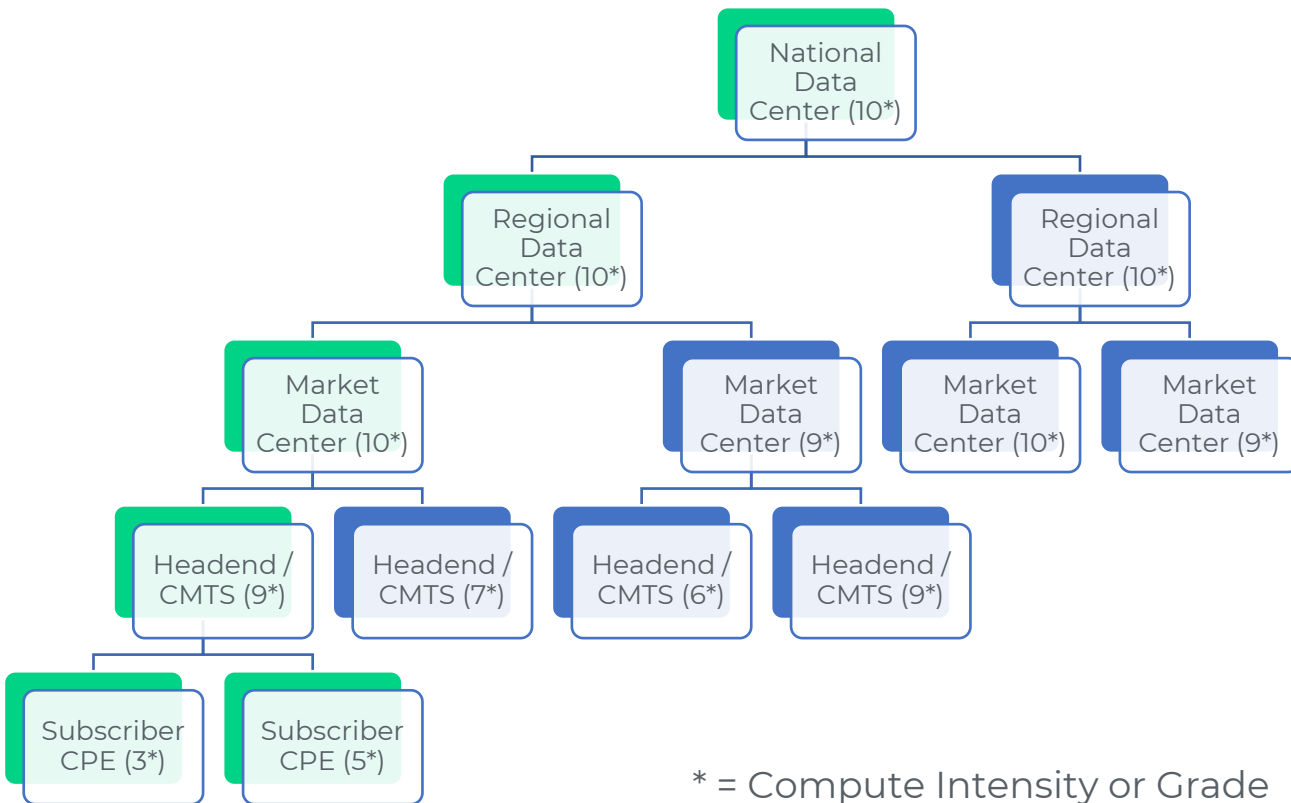


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Edge-Computing-as-a-Service: The Proposed Method

Delivering Compute from within the Network for AR/VR

An operator (CSP) inventories resources to deliver “Edge Computing as a Service”



* = Compute Intensity or Grade



Compute Resource Label	Compute Grade	Total Units	Available (free) Units
.....
CPE – Router Subscriber S	3	1	1
CPE – Set Top Box Subscriber S	5	2	1
Headend / CMTS Domain D	9	10	4
Market Data Center Region R	10	70	33
.....

A **Network Compute Orchestrator** organizes and maintains resources in an “Available Compute Resource” Table

Content and Network information Tables to allocate compute

Application Service Provider (ASP) Content Table

- The key information needed to provide adequate QoE for any content
- May be measured under test conditions or derived by correlating user ratings with session latency

Content	Compute Grade / Intensity (descriptor 1-10)	RTT Latency, Customer to Compute (milliseconds)
.....
Content-X	8	30
Content-Y	6	10
.....

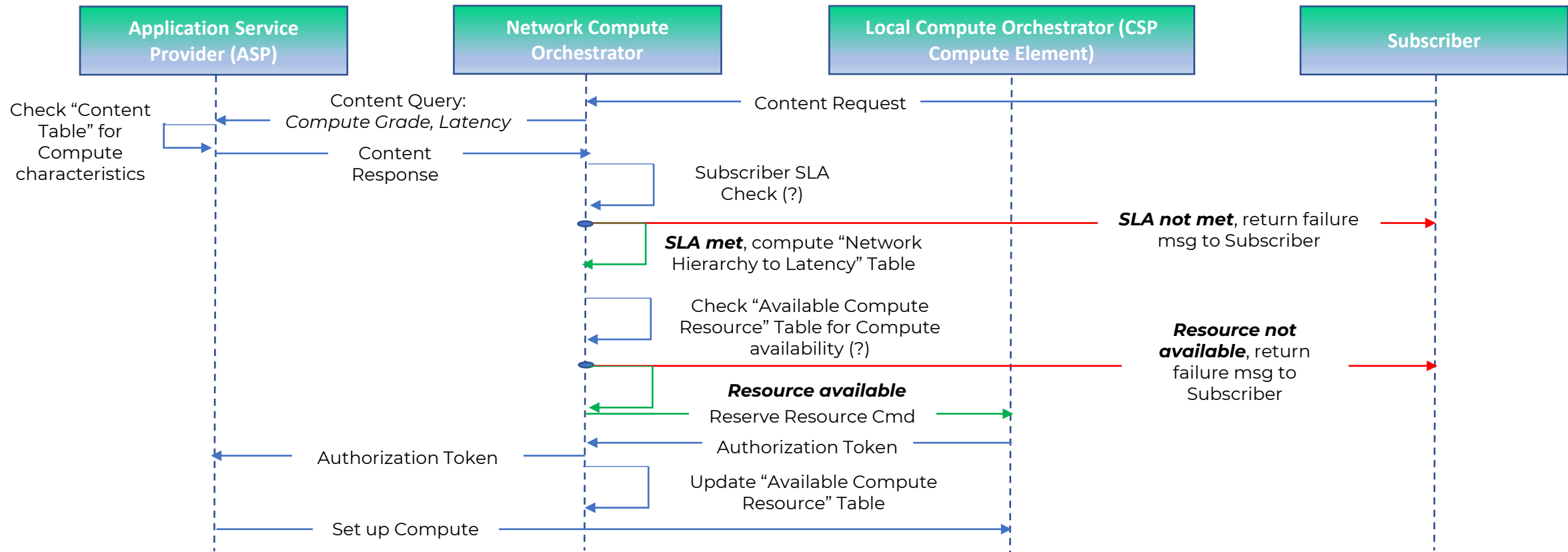
Network Hierarchy to Latency Table

- Built on-demand from the point-of-view of a subscriber when service is requested
- Relies on a latency measurement system in the operator network

Hierarchy	Compute Resource Label	RTT Latency, Customer to Level/Compute (milliseconds)
1	CPE – Router Subscriber S	3
2	CPE – Set Top Box Subscriber S	3
3	Headend / CMTS Domain D	9
4	Regional Data Center Region R	23
5	National “Cloud” Data Center NOC	55

Allocating Compute: A Sample Session Setup

How the service provider delivers the compute resource to the application provider



Related Discussion and Concluding Remarks

- The proposed method can handle “split rendering” with minor modifications
- The proposed method can be tweaked to account for jitter when available

- **Investigated the interplay between AR/VR content’s intrinsic properties and QoE**
- **An experience’s intrinsic properties are perceived latency and compute intensity**
- **When modeled accurately, the network can provide the compute expected to deliver the QoE even the “motion-to-photon” latency expectation of 20 ms is not met**
- **Presented a method to manage the network resources for “on-demand” delivery of immersive experiences**



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Thank You!

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