Low Latency Services and Requirements for 100G EPON

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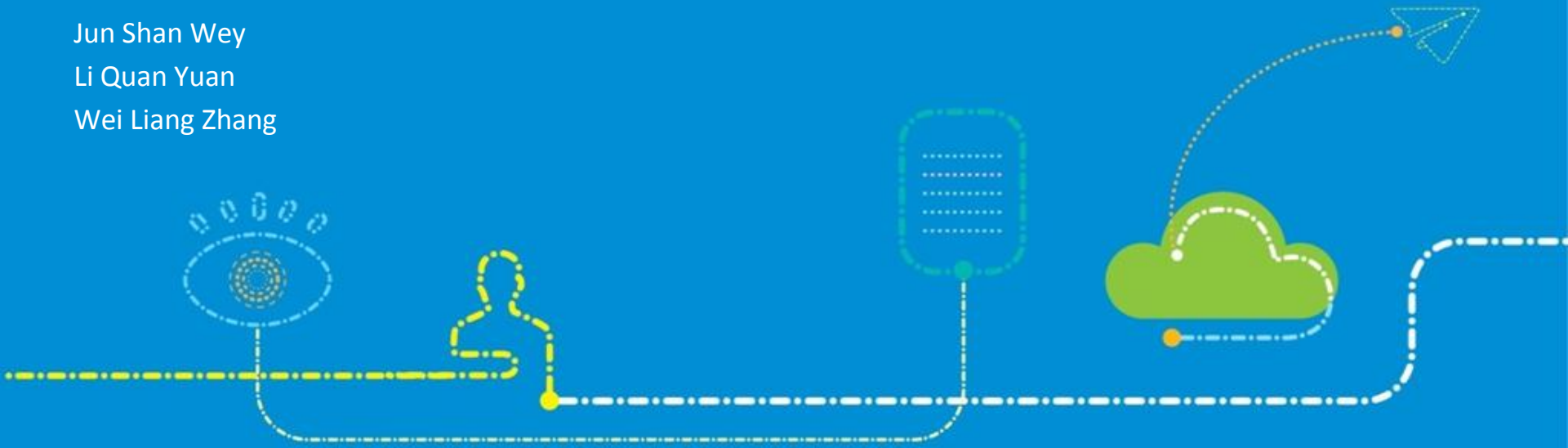


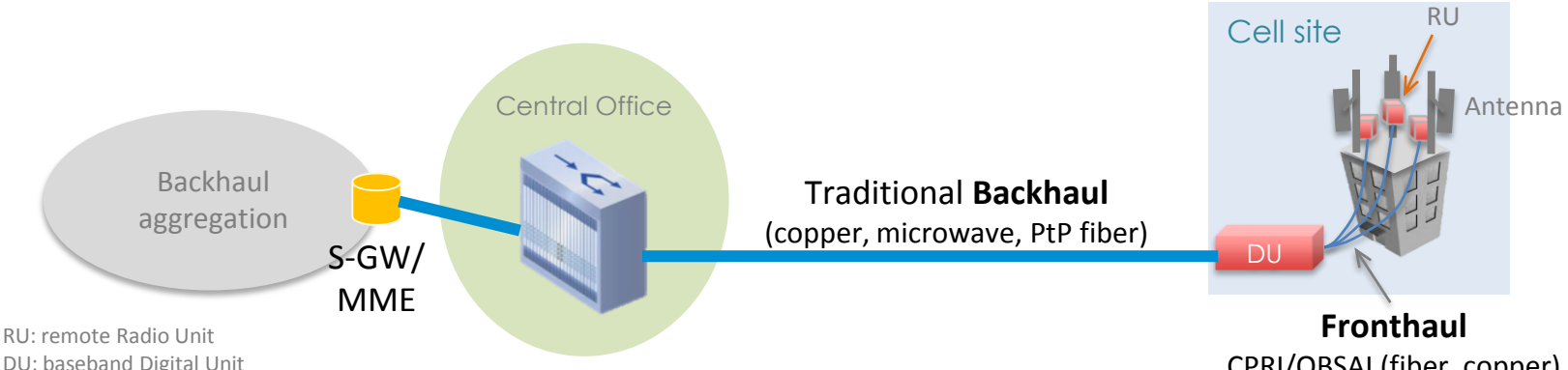
Motivation and purpose of this contribution

- In the Huntington Beach meeting, we discussed future services, which might require low latency and impact how standards should be specified (wey_3ca_01_0117)
- Based on feedback from members, there is interest in further investigation of latency related topics
- This contribution provides more detail on both bandwidth and latency requirements of mobile fronthaul for different 5G services and of virtual reality/augmented reality video streaming
- We identified topics to develop in standards to support these services

Mobile Fronthaul Evolution

- What is mobile fronthaul?
- How much bandwidth do we need?
- What is the latency requirement?
- What is the recommended path forward?

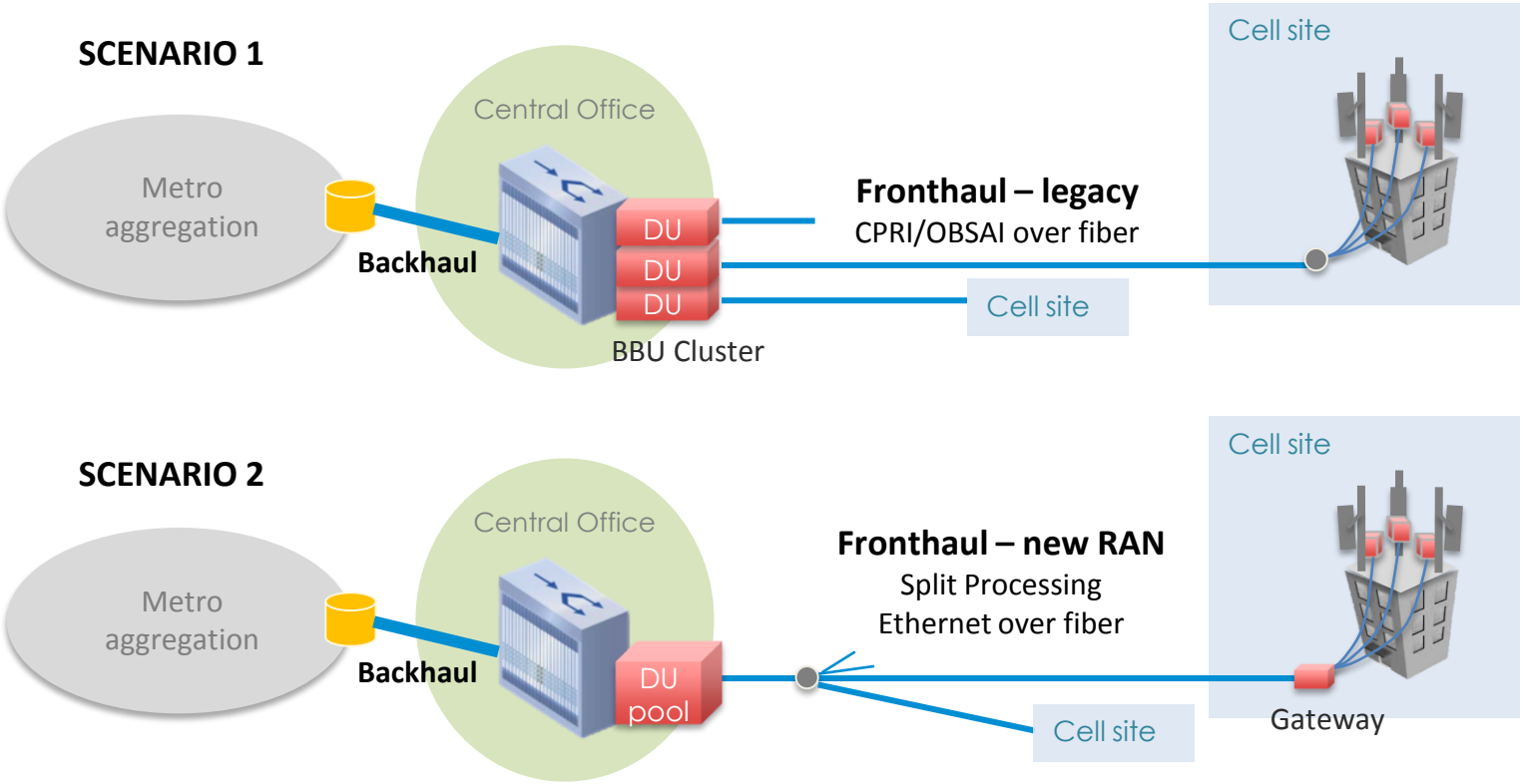
Traditional fronthaul link in Radio Access Network



RU: remote Radio Unit
DU: baseband Digital Unit
S-GW: service gateway
MME: mobile management entity

- CPRI Fronthaul line rate depends on many factors, e.g., number of antennas and sectors, sampling rate, line coding, etc. CPRI Option 10 specifies 24.33Gbps for a 20MHz signal. For a 100 MHz signal, 3 sectors, and 8 antenna/sector, the line rate could be 148 Gbps!
- As values of all the related factors are expected increase drastically in 5G New Radio, it will be extremely difficult to support the CPRI fronthaul bandwidth using current PON systems
- NGMN Alliance recommended the total round-trip latency budget between cell site and the core network must be <10ms, and preferably <5ms. The delay budget allocated to the backhaul link is typically 1/3 of this budget
- Small Cell Forum classifies backhaul system latency as <1ms (good); 1-5ms (OK); >5ms (poor)

Mobile Fronthaul evolution towards Centralized/Cloud RAN



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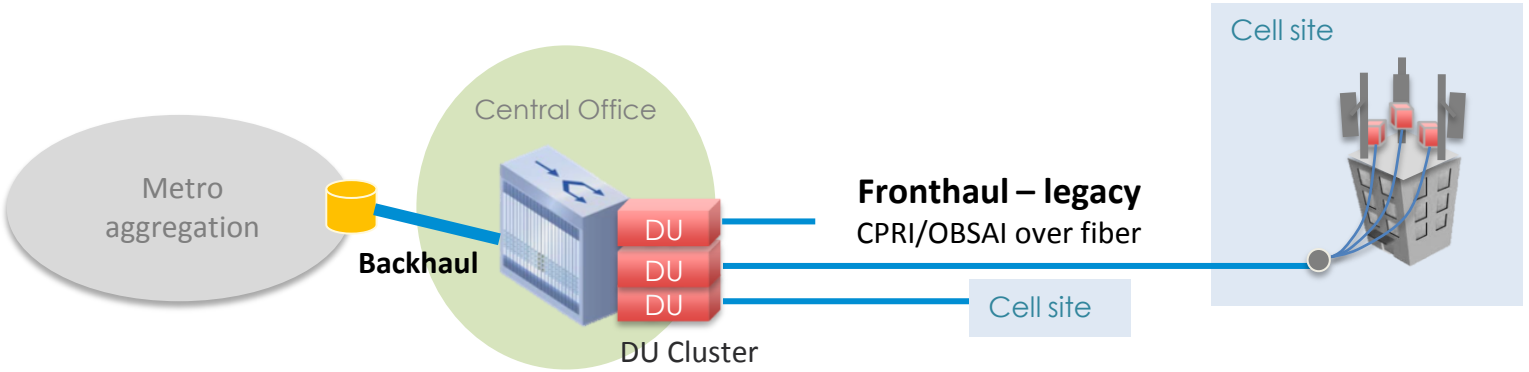
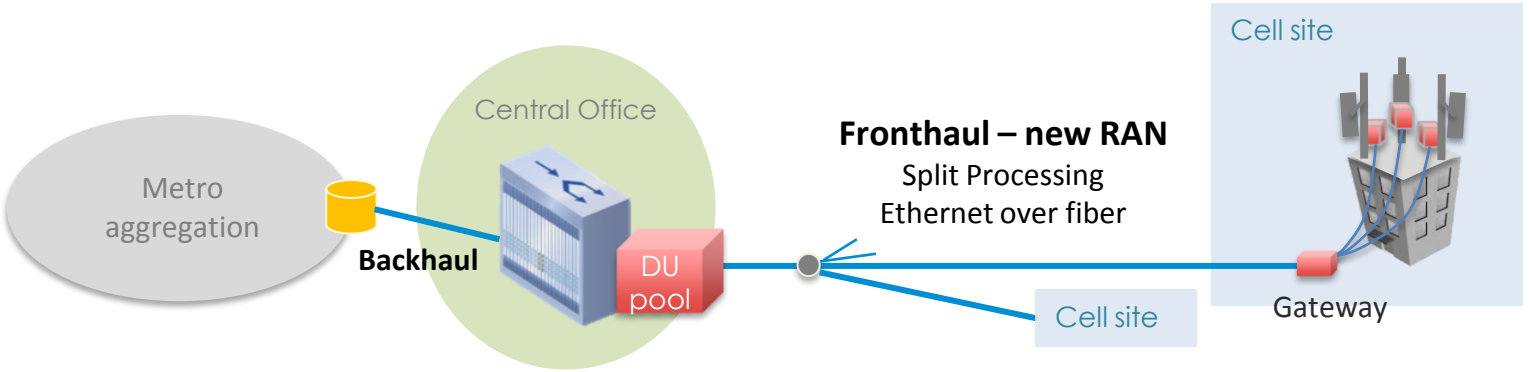
Capacity and latency requirements for Scenario 1

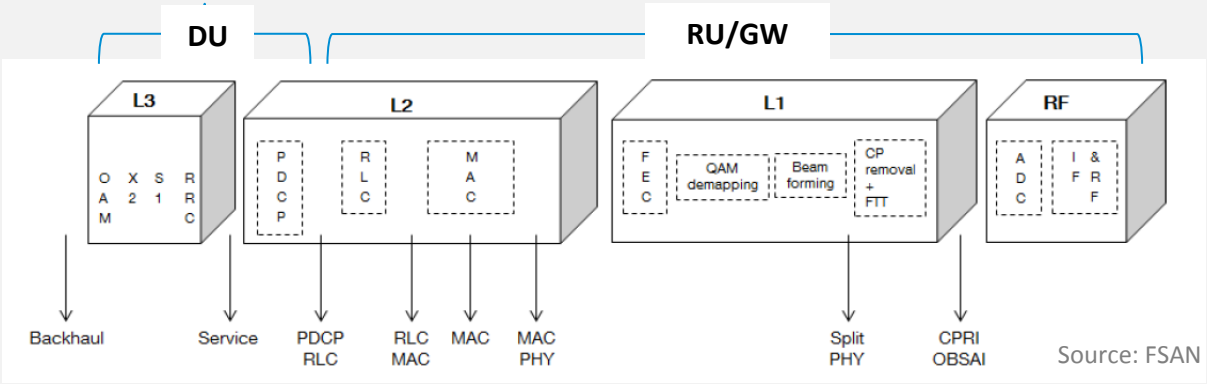


- Same capacity requirements as in the traditional case
- Total round-trip delay = processing time in RU + 2x transit time in fiber + processing time in DU
  - Max round-trip processing delay per link is 5 μs (CPRI spec v7.0, clause 7.1.8.1)
  - Max total round-trip delay between RU and DU is therefor ~105 μs/10km or ~210 μs/20km (note: round trip delay in fiber is 10 μs/km)
- NGFI (next gen fronthaul interface) specification:
  - Transport equipment one-way delay is ~220 μs, which requires <10 μs one-way forwarding time per equipment for a 20km link

Capacity and latency requirements for Scenario 2



Many potential functional split options!



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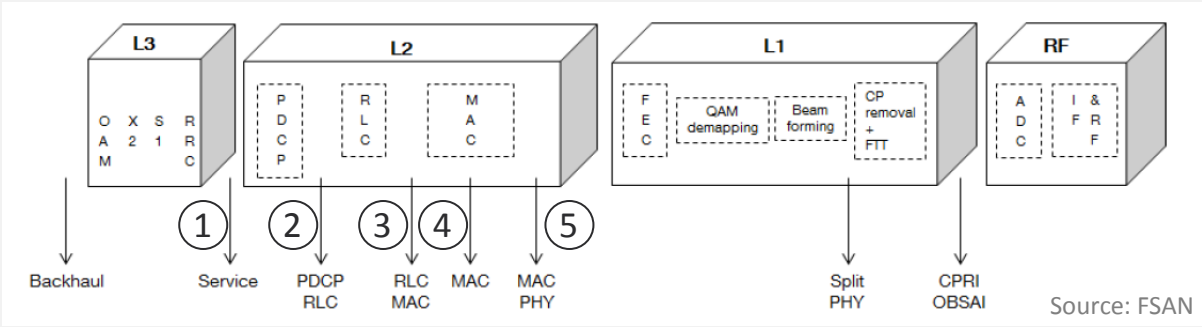
Capacity requirements for different functional split options



Functional Split Option	System Capacity for Different Signal Bandwidth			
	10 MHz	20 MHz	200 MHz	1GHz
Option 1	0.38 Gbps	0.76 Gbps	7.6 Gbps	38 Gbps
Option 2	0.36 Gbps	0.72 Gbps	7.2 Gbps	36 Gbps
Option 3	0.36 Gbps	0.72 Gbps	7.2 Gbps	36 Gbps
Option 4	0.36 Gbps	0.72 Gbps	7.2 Gbps	36 Gbps
Option 5	0.4 Gbps	0.8 Gbps	8 Gbps	40 Gbps

NGMN 5G system latency requirements

- NGMN stated the E2E RTP latency for a 5G system could be < 1 ms. What are these use cases? Do they need to, can they, be supported by new generation PON?
- **Ultra-low latency use case**:
  - Tactile internet where humans will wirelessly control real and virtual objects, manufacturing, remote medical care, autonomous cars
- **Ultra-high reliability & ultra-low latency use case**:
  - Collaborative robots in manufacturing: not valid
  - Automated traffic control and driving, remote object manipulation (e.g. remote surgery)
- To support these machine type communications use cases, our estimate for the PON segment is 10-20 µs for round-trip latency not including the fiber path delay

Use case category	User Experienced Data Rate	E2E Latency	Mobility
Broadband access in dense areas	DL: 300 Mbps UL: 50 Mbps	10 ms	On demand, 0-100 km/h
Indoor ultra-high broadband access	DL: 1 Gbps, UL: 500 Mbps	10 ms	Pedestrian
Broadband access in a crowd	DL: 25 Mbps UL: 50 Mbps	10 ms	Pedestrian
50+ Mbps everywhere	DL: 50 Mbps UL: 25 Mbps	10 ms	0-120 km/h
Ultra-low cost broadband access for low ARPU areas	DL: 10 Mbps UL: 10 Mbps	50 ms	on demand: 0-50 km/h
Mobile broadband in vehicles (cars, trains)	DL: 50 Mbps UL: 25 Mbps	10 ms	On demand, up to 500 km/h
Airplanes connectivity	DL: 15 Mbps per user UL: 7.5 Mbps per user	10 ms	Up to 1000 km/h
Massive low-cost/long-range/low-power MTC	Low (typically 1-100 kbps)	Seconds to hours	on demand: 0-500 km/h
Broadband MTC	See the requirements for the Broadband access in dense areas and 50+Mbps everywhere categories		
Ultra-low latency	DL: 50 Mbps UL: 25 Mbps	<1 ms	Pedestrian
Resilience and traffic surge	DL: 0.1-1 Mbps UL: 0.1-1 Mbps	Regular communication: not critical	0-120 km/h
Ultra-high reliability & Ultra-low latency	DL: From 50 kbps to 10 Mbps; UL: From a few bps to 10 Mbps	1 ms	on demand: 0-500 km/h
Ultra-high availability & reliability	DL: 10 Mbps UL: 10 Mbps	10 ms	On demand, 0-500 km/h
Broadcast like services	DL: Up to 200 Mbps UL: Modest (e.g. 500 kbps)	<100 ms	on demand: 0-500 km/h

Conclusion for 5G MFH

- Both capacity and latency requirements depend on the choice of functional split point
- 100G-EPON should be able to support the MFH bandwidth requirements for the new RAN scenario with split processing
- Latency requirements of machine-type communications are extremely stringent: estimate for the PON segment is 10-20 μs (round-trip delay) not including fiber path delay. New innovations will be needed
- Impact on specifications of channel bonding, downstream traffic scheduling, and DBA optimization should be considered
- IEEE 802.3ca should coordinate the effort with other SDOs to choose the preferred functional split option

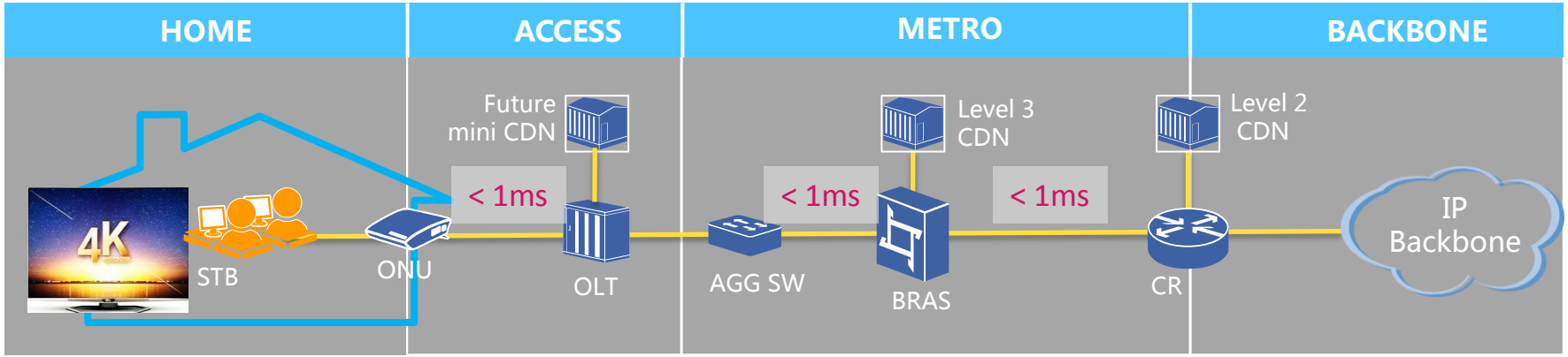
Big Video Services

- How much bandwidth do we need to stream a VR video?
- What is the latency requirement?
- Can the existing network support a good VR experience?

How much bandwidth do we need to stream a VR video?

- Non-VR video stream with H.265 encoding (more detail in the appendix):
  - 4K format: 12-15 Mbps/video stream (OTT), 22.5-75 Mbps (IPTV)
  - 8K format: 48-60 Mbps/video stream (OTT), 90-300 Mbps (IPTV)
- VR video stream:
  - 4K format is the bare minimum starting point. 8K is preferred
  - Typical video format for VR is 2:1 as opposed to 16:9. The same video for regular TV is converted to 2:1 by the camera or headset for VR viewing
  - Need two streams for stereoscopic experience: **>600 Mbps/VR stream (1200 Mbps for VR+)** could be needed
  - Other video encoding techniques to reduce file size are being explored, e.g., Cube Maps by Facebook

Can the existing network support a good VR experience?



- Existing network should be sufficient to support the latency requirement of VR video streaming
- Packet loss rate (1 error/8 hrs) is within expectation (<1.0 x 10^{-5}) when tested in a G-PON network
- Interactive VR will have more stringent requirements, which is unknown at the moment. Synchronization between video and audio could add another dimension of complexity

Format	Bandwidth	RTT Time Delay
Basic 4K	45Mbps	< 20 ms
Basic 8K	180 Mbps	< 16 ms
VR+	1200 Mbps	< 12 ms

Conclusion and proposal

- Mobile fronthaul/backhaul services for future 5G networks demand high capacity and low latency
- Big video services will require high capacity network. Interactive VR services have unknown stringent latency requirements
- Proposal of topics to further develop in standards:
  - Further latency reduction in the case of channel bonding
  - Optimize downstream traffic scheduling to reduce latency
  - Optimize DBA to minimize latency: grants always ready for upstream traffic. Grant to one ONU could be limited to microsecond level

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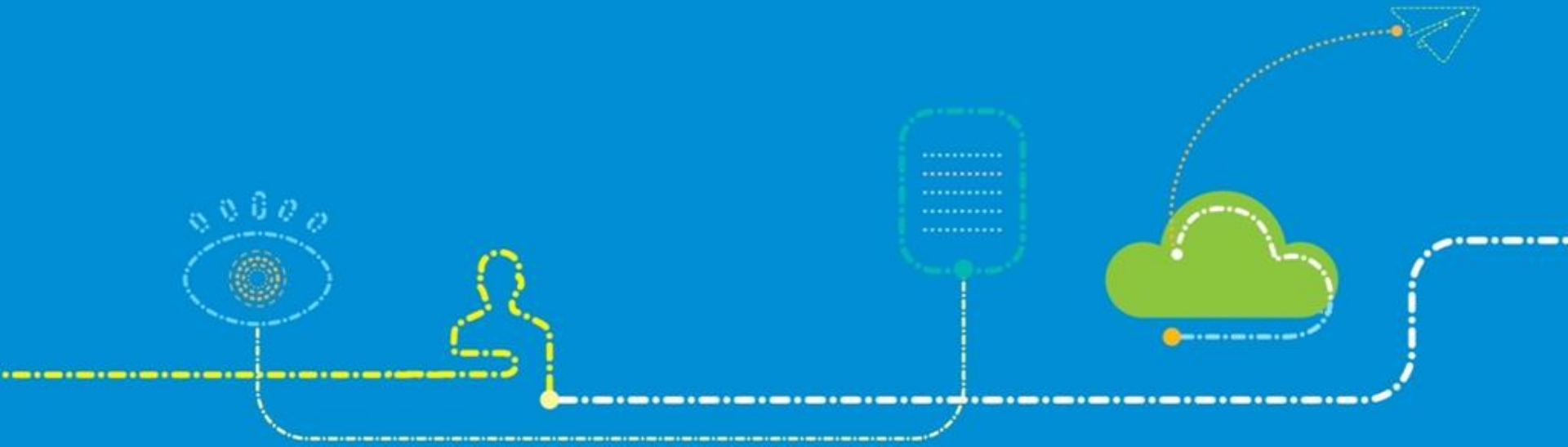
Thank You 谢谢！



Bandwidth and other requirements for different video formats

IPTV broadcast

	Quasi 4K	Basic 4K	Ultra 4K	Quasi 8K	Basic 8K	Ultra 8K	VR	VR+
Resolution	3840x 2160	3840x 2160	3840x 2160	7680x 4320	7680x 4320	7680x 4320	3840x 2160	7680x 4320
Frame rate	30P	60P	120P	30P	60P	120P	120P	120P
Color depth	8bit	10bit	12bit	8bit	10bit	12bit	12bit	12bit
Compression algorithm	H.265	H.265	H.265	H.265	H.265	H.265	H.265	H.265
Average bit rate (bps)	15M	30M	50M	60M	120M	200M	200M	800M
Bandwidth requirement (bps)	22.5M	45M	75M	90M	180M	300M	300M	1200M