Low Latency Services and Requirements for 100G EPON

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Jun Shan Wey
Li Quan Yuan
Wei Liang Zhang
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

- 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

**SCENARIO 1**

- Metro aggregation
- Central Office
- Fronthaul – legacy
  - CPRI/OBSAI over fiber
- Cell site
- BBU Cluster

**SCENARIO 2**

- Metro aggregation
- Central Office
- Fronthaul – new RAN
  - Split Processing
  - Ethernet over fiber
- Cell site
- Gateway

DU: Distributed Unit
DU pool: Distributed Unit pool
Gateway: Network Gateway
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 $\mu$s (CPRI spec v7.0, clause 7.1.8.1)
  - Max total round-trip delay between RU and DU is therefore $\sim 105 \mu s/10km$ or $\sim 210 \mu s/20km$ (note: round trip delay in fiber is 10 $\mu$s/km)
- NGFI (next gen fronthaul interface) specification:
  - Transport equipment one-way delay is $\sim 220 \mu s$, which requires $< 10 \mu s$ one-way forwarding time per equipment for a 20km link
Capacity and latency requirements for Scenario 2

Many potential functional split options!

Source: FSAN
### Capacity requirements for different functional split options

<table>
<thead>
<tr>
<th>Functional Split Option</th>
<th>System Capacity for Different Signal Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 MHz</td>
</tr>
<tr>
<td>Option 1</td>
<td>0.38 Gbps</td>
</tr>
<tr>
<td>Option 2</td>
<td>0.36 Gbps</td>
</tr>
<tr>
<td>Option 3</td>
<td>0.36 Gbps</td>
</tr>
<tr>
<td>Option 4</td>
<td>0.36 Gbps</td>
</tr>
<tr>
<td>Option 5</td>
<td>0.4 Gbps</td>
</tr>
</tbody>
</table>

Source: FSAN
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

<table>
<thead>
<tr>
<th>Use case category</th>
<th>User Experienced Data Rate</th>
<th>E2E Latency</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadband access in dense areas</td>
<td>DL: 300 Mbps, UL: 50 Mbps</td>
<td>10 ms</td>
<td>On demand, 0-100 km/h</td>
</tr>
<tr>
<td>Indoor ultra-high broadband access</td>
<td>DL: 1 Gbps, UL: 500 Mbps</td>
<td>10 ms</td>
<td>Pedestrian</td>
</tr>
<tr>
<td>Broadband access in a crowd</td>
<td>DL: 25 Mbps, UL: 50 Mbps</td>
<td>10 ms</td>
<td>Pedestrian</td>
</tr>
<tr>
<td>50+ Mbps everywhere</td>
<td>DL: 50 Mbps, UL: 25 Mbps</td>
<td>10 ms</td>
<td>0-120 km/h</td>
</tr>
<tr>
<td>Ultra-low cost broadband access for low ARPU areas</td>
<td>DL: 10 Mbps, UL: 10 Mbps</td>
<td>50 ms</td>
<td>on demand: 0-50 km/h</td>
</tr>
<tr>
<td>Mobile broadband in vehicles (cars, trains)</td>
<td>DL: 50 Mbps, UL: 25 Mbps</td>
<td>10 ms</td>
<td>On demand, up to 500 km/h</td>
</tr>
<tr>
<td>Airplanes connectivity</td>
<td>DL: 15 Mbps per user, UL: 7.5 Mbps per user</td>
<td>10 ms</td>
<td>Up to 1000 km/h</td>
</tr>
<tr>
<td>Massive low-cost/long-range/low-power MTC</td>
<td>Low (typically 1-100 kbps)</td>
<td>Seconds to hours</td>
<td>on demand: 0-500 km/h</td>
</tr>
<tr>
<td>Broadband MTC</td>
<td>See the requirements for the Broadband access in dense areas and 50+Mbps everywhere categories</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Ultra-low latency**

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>E2E Latency</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL: 50 Mbps, UL: 25 Mbps</td>
<td>&lt;1 ms</td>
<td>Pedestrian</td>
</tr>
</tbody>
</table>

**Resilience and traffic surge**

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>E2E Latency</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL: 0.1-1 Mbps, UL: 0.1-1 Mbps</td>
<td>Regular communication: not critical</td>
<td>0-120 km/h</td>
</tr>
</tbody>
</table>

**Ultra-high reliability & Ultra-low latency**

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>E2E Latency</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL: From 50 kbps to 10 Mbps, UL: From a few bps to 10 Mbps</td>
<td>1 ms</td>
<td>on demand: 0-500 km/h</td>
</tr>
</tbody>
</table>

**Ultra-high availability & reliability**

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>E2E Latency</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL: 10 Mbps, UL: 10 Mbps</td>
<td>10 ms</td>
<td>On demand: 0-500 km/h</td>
</tr>
</tbody>
</table>

**Broadcast like services**

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>E2E Latency</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL: Up to 200 Mbps, UL: Modest (e.g. 500 kbps)</td>
<td>&lt;100 ms</td>
<td>On demand: 0-500 km/h</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Format</th>
<th>Bandwidth</th>
<th>RTT Time Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic 4K</td>
<td>45Mbps</td>
<td>&lt; 20 ms</td>
</tr>
<tr>
<td>Basic 8K</td>
<td>180 Mbps</td>
<td>&lt; 16 ms</td>
</tr>
<tr>
<td>VR+</td>
<td>1200 Mbps</td>
<td>&lt; 12 ms</td>
</tr>
</tbody>
</table>
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
Thank You  谢谢！
# Bandwidth and other requirements for different video formats

## IPTV broadcast

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Quasi 4K</th>
<th>Basic 4K</th>
<th>Ultra 4K</th>
<th>Quasi 8K</th>
<th>Basic 8K</th>
<th>Ultra 8K</th>
<th>VR</th>
<th>VR+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>3840x2160</td>
<td>3840x2160</td>
<td>3840x2160</td>
<td>7680x4320</td>
<td>7680x4320</td>
<td>7680x4320</td>
<td>3840x2160</td>
<td>7680x4320</td>
</tr>
<tr>
<td>Frame rate</td>
<td>30P</td>
<td>60P</td>
<td>120P</td>
<td>30P</td>
<td>60P</td>
<td>120P</td>
<td>120P</td>
<td>120P</td>
</tr>
<tr>
<td>Color depth</td>
<td>8bit</td>
<td>10bit</td>
<td>12bit</td>
<td>8bit</td>
<td>10bit</td>
<td>12bit</td>
<td>12bit</td>
<td>12bit</td>
</tr>
<tr>
<td>Average bit rate (bps)</td>
<td>15M</td>
<td>30M</td>
<td>50M</td>
<td>60M</td>
<td>120M</td>
<td>200M</td>
<td>200M</td>
<td>800M</td>
</tr>
<tr>
<td>Bandwidth requirement (bps)</td>
<td>22.5M</td>
<td>45M</td>
<td>75M</td>
<td>90M</td>
<td>180M</td>
<td>300M</td>
<td>300M</td>
<td>1200M</td>
</tr>
</tbody>
</table>