Next Generation Fronthaul Interface - Use Cases & Scenarios

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Fronthaul impact by 4G/5G RAN evolution
## General RAN requirement

<table>
<thead>
<tr>
<th></th>
<th>4G/4G+ (Rel.13)</th>
<th>5G</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RAN technologies</strong></td>
<td>LTE/LTE advanced</td>
<td>5G new radio (NR)</td>
</tr>
<tr>
<td><strong>Bandwidth</strong></td>
<td>100MHz and up (*)</td>
<td>850MHz (**)</td>
</tr>
<tr>
<td><strong>Peak data rate requirement</strong></td>
<td>1Gbps DL, 500MHz UL</td>
<td>20Gbps DL, 10Gbps UL</td>
</tr>
<tr>
<td><strong>Peak spectral efficiency</strong></td>
<td>30bits/Hz down, 15bits/Hz up</td>
<td>30bits/Hz down, 15bits/Hz up</td>
</tr>
<tr>
<td><strong>End-end delay requirement</strong></td>
<td>20ms RRT</td>
<td>eMBB: 4msDL+4ms UL URLCC: 0.5ms DL+0.5msUL</td>
</tr>
</tbody>
</table>

(*) BW will increase with LAA
(**) FCC 16-89
User Case: CoMP

Coordinated Multi Point

<table>
<thead>
<tr>
<th>CS/CB</th>
<th>Joint TX/RX (JT/JR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Coordinated scheduling</td>
<td>• Joint inter-site transmission for downlink</td>
</tr>
<tr>
<td>• Coordinated beamforming</td>
<td>• Joint inter-site reception for uplink</td>
</tr>
<tr>
<td>• Fast coordination on TTI level</td>
<td>• Improves cell edge performance</td>
</tr>
<tr>
<td></td>
<td>• Signals from multiple sites need be combined at PHY of receiver for max benefit</td>
</tr>
<tr>
<td></td>
<td>• eMBMS is using JT</td>
</tr>
</tbody>
</table>

Fronthaul requirement

- Relax of user-plane requirement if PHY is at cell site
- Low latency signaling links needed for site coordination
- Suitable function splitting options:
  - PHY at cell site to reduce total throughput requirement
  - MAC scheduler at BBU for fast inter-site coordination
- Low latency & high throughput data link required for signal combing in PHY
- Suitable Function splitting options:
  - PHY at BBU or
  - split PHY

CoMP CS/CB example (20MHz BW, 4CA, 4x4 MIMO)

CoMP JP/JR example (20MHz BW, 4CA, 4x4 MIMO)
**User Case: FD-MIMO**

**Full Dimension MIMO**
- Practical solution of Massive-MIMO to reduce implementation complexity for cell densification
- Active array systems (AAS) to steer beams in both azimuth and elevation directions
- Simultaneous beams to support high order MU-MIMO
- Separated beamforming for CSI reference signals
- Possible RT coordination among AASs to reduce inter-site interference
- Large number of TxRUs at cell site for antenna phase control

**Fronthaul requirement**
- Massive connections to each cell site (per each TxRU, up to 64 of them)
- Suitable function splitting options:
  - PHY at cell site to reduce total throughput requirement
  - MAC scheduler at BBU for fast inter-site coordination

FD-MIMO example (20MHz BW, 8 beams, 2 layers/beam)

**Fronthaul requirement**
- Throughput: ~3.84Gbps
- Latency (data): <2ms
- Latency (signaling): <100us

**Backhaul**
- AASs at cell sites
- Core NW
- BBUs (C-RAN/V-RAN)
- NGFI fronthaul

**Diagram notes:**
- BBU: Baseband Unit
- BB: Backhaul Backhaul
- PHY: Physical Layer
- RLC: Radio Link Control
- MAC: Medium Access Control
- Sch: Scheduler
- PDCP: Packet Data Convergence Protocol

**Diagram diagram:**
- Fast coordination
- Low latency signaling
User case: IOT

IOT use case categories

Non-critical apps

- Massive numbers
- Low cost/low power
- Low mobility
- Small data packets
- Infrequent transmission
- Non-time critical

Current 3GPP IOT air interface technologies

<table>
<thead>
<tr>
<th></th>
<th>R13 Cat-M1</th>
<th>R13 NB-IOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max BW</td>
<td>1.4MHz</td>
<td>200kHz</td>
</tr>
<tr>
<td>Peak data rate</td>
<td>1Mbps</td>
<td>70kbps</td>
</tr>
<tr>
<td>RF Sample frequency</td>
<td>1.92MHz</td>
<td>480kHz</td>
</tr>
<tr>
<td>Modulation order</td>
<td>Max: 16QAM</td>
<td>QPSK</td>
</tr>
<tr>
<td>Num of UE RX antenna</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Operation mode</td>
<td>Standalone</td>
<td>Standalone Guards-band In-band</td>
</tr>
<tr>
<td>Coverage extension</td>
<td>15dB</td>
<td>20dB</td>
</tr>
<tr>
<td>Software PHY</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

Fronthaul requirement

<table>
<thead>
<tr>
<th>Throughput</th>
<th>76.8Mpps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latency</td>
<td>~500us</td>
</tr>
</tbody>
</table>

NB-IOT example (4 Tx antennas for RF)

RRUs at cell sites

Core NW

More suitable for Fronthaul over Ethernet & all processing functions centralized at BBU

Requirement on scalability of aggregated small data packets
## Fronthaul Impact by current & future RAN technologies

### Current RAN technologies

<table>
<thead>
<tr>
<th>Fronthaul impact</th>
<th>Capacity</th>
<th>Latency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CoMP CS/CB/JT</strong></td>
<td>Real time intra/inter-site coordination</td>
<td>Proportional to user data rate</td>
</tr>
<tr>
<td><strong>CoMP JR</strong></td>
<td>Real time intra/inter-site Signal combining</td>
<td>Proportional to BW &amp; number of TX antennas. Significant larger than user data rate</td>
</tr>
<tr>
<td><strong>FD-MIMO</strong></td>
<td>Large number of antennas at cell site. High order MU-MIMO</td>
<td>Proportional to user data rate x order of MU-MIMO users.</td>
</tr>
<tr>
<td><strong>LTE-M/NB-IOT</strong></td>
<td>Large number of devices, small packets</td>
<td>Low capacity requirement. Aggregation &amp; Scalability requirement</td>
</tr>
</tbody>
</table>

### Future RAN technologies

<table>
<thead>
<tr>
<th>Fronthaul impact</th>
<th>Capacity</th>
<th>Latency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Massive MIMO (eMBB)</strong></td>
<td>Massive number of antennas + cross-site BF/MIMO among small cells</td>
<td>Astronomical increase of capacity requirement due to the vast increase of user data rate, i.e. 20xLTE-A and ≥ x10 MIMO order</td>
</tr>
<tr>
<td><strong>Massive IOT (mMTC)</strong></td>
<td>Massive number of devices</td>
<td>Low capacity requirement. Aggregation &amp; Scalability requirement</td>
</tr>
<tr>
<td><strong>URLLC</strong></td>
<td>Ultra low delay Ultra reliable</td>
<td>Depends on the application, i.e. VR with RT Video dramatically impacts capacity</td>
</tr>
</tbody>
</table>
# Function split option summary

<table>
<thead>
<tr>
<th>BBU</th>
<th>RRU</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDCP</td>
<td>RF</td>
</tr>
<tr>
<td>RLC</td>
<td>PHY</td>
</tr>
<tr>
<td>MAC/Scheduler</td>
<td></td>
</tr>
<tr>
<td>PHY</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
<th>Option 4</th>
<th>Option 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>All processing functions centralized at BBU</td>
<td>PHY split</td>
<td>PHY&amp;MAC split</td>
<td>MAC&amp;RLC split</td>
<td>RLC&amp;PDCP split</td>
</tr>
<tr>
<td>Rough estimate of Throughput (T) (bi-direction)</td>
<td>~60<em>Ntx</em>BW T1</td>
<td>8<em>L</em>MSC<em>BW T2~0.8</em>T1</td>
<td><del>2*R T3</del>T1/8</td>
<td>~2*R T4&lt;T3</td>
</tr>
<tr>
<td>Latency requirement</td>
<td>micro sec range</td>
<td>micro sec range</td>
<td>mili sec range</td>
<td>mili sec range</td>
</tr>
<tr>
<td>CoMP performance</td>
<td>Combining gain &amp; Coronation gain</td>
<td>Combining gain &amp; Coordination gain</td>
<td>Coordination gain</td>
<td>Diversity gain only</td>
</tr>
<tr>
<td>Data types</td>
<td>I/Q samples</td>
<td>OFDM symbols Control/signaling</td>
<td>MAC PDUs Control/signaling</td>
<td>RLC PDUs Control/signaling</td>
</tr>
<tr>
<td>Notes</td>
<td>Current CPRI solution</td>
<td>HARQ combining&amp; FEC centralized or IRC also centralized</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ntx: number of TX antennas, BW: bandwidth, R: peak data rate, MCS: modulation order, L: number of MIMO layers

**Challenge:** If different vendor devices deployed at two sides of the splitting point, are they interoperable?
C/V-RAN Fronthaul Challenges
Fronthaul CPRI capacity requirements for various network deployment scenarios

- **Rural LTE Macro**
  - 3 Sector
  - 3 Antenna x Carriers
  - 10MHz, 2x2 MIMO

- **Sub Urban LTE Macro**
  - 3 Sector
  - 9 Antenna x Carriers
  - 40MHz, 4x4 MIMO

- **Outdoor LAA Small Cell**
  - 1 Sector
  - 4 Antenna x Carriers
  - 120MHz, 4x4 MIMO

- **Urban LTE Macro**
  - 6 Sector
  - 24 Antenna x Carriers
  - 60MHz, 8x8 MIMO

- **Urban 5G Macro**
  - 6 Sector
  - 6 Antenna x Carriers
  - 400MHz, 128x128 MIMO

* Assuming NR radio frame structure similar to LTE

I/Q sample data rate for 400MHz chBW, 128x128 MIMO: ~2360 Gbps*

CPRI bit rate increases with:
- # Antenna x Carriers
- MIMO Order
- ChBW size

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**Total CPRI bit rate**

- 10 Gbps
- 100 Gbps
- 200 Gbps
- 1000 Gbps

**# CPRI Links**

- 1 x 4.9 Gbps CPRI 5
- 2 x 2.5 Gbps CPRI 3
- 2 x 24.3 Gbps CPRI 10
- 4 x 9.8 Gbps CPRI 7
- 5 x 24.3 Gbps CPRI 10
- 15 x 9.8 Gbps CPRI 7
- 7 x 24.3 Gbps CPRI 10
- 20 x 8.1 Gbps CPRI 7

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CRAN network deployment scenarios
Fronthaul Transport and C/V-RAN

Fronthaul Challenges when deploying C/V-RAN
- Today CPRI is the preferred transport protocol to implement the RAN functional split between Radio (I/Q) and Baseband, however
  - CPRI bit rate linearly increases with
    - Channel bandwidth
    - MIMO order
    - Number of sectors
  - Cloud/Virtual RAN deployment over CPRI demands fiber and WDM, however
    - fiber is not everywhere available and costly to deploy
    - CPRI/WDM does not support
      - switching
      - CoS and manageability
      - Strict Latency requirements when CoMP is considered
  - CPRI does not scale well with the continuous increase of Peak User throughput and Cell Site capacity
  - Need a more agile transport mechanism for wide deployment of Cloud RAN, where Operators should be able to choose the access medium (i.e. copper, fiber, mW) and protocol (i.e. GPON, metro Ethernet) based on network economics and technology trends.
Next Generation Fronthaul Transport and C/V-RAN

Next Generation Fronthaul Interface (NGFI)

- Should support:
  - Legacy C-RAN deployment
    - Include CPRI to ensure fronthaul transport continuity for legacy RRU/BBUs
    - Migration from CPRI/WDM architecture to CPRI/packet/WDM architecture
    - Consider latency requirements for inter-BBU pool co-ordination
    - Further optimize CPRI bit rate \(\rightarrow\) compression
  - Support LTE HW protocol split evolution
    - All possible protocol split architectures, so operators can choose the split architecture based on medium (copper, fiber, MW), distance (BBU-RRU, BBU-BBU) and spectrum efficiency
  - Support New Radio (5G) air interface
    - Massive MIMO and URLCC pose great challenges for Fronthaul capacity and latency
    - All possible functional split options for 5G RAN

NGFI should be defined with both current (LTE) and future (5G) RAN technologies in mind
Q&A Discussion