5G Packet Based Fronthaul

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BRKSPG-2065
Agenda

• RAN Architecture
• Centralized RAN Transport Requirement
• Fronthaul Overview
• Packet based Fronthaul
• Customer Case Study
• Conclusion
5G RAN Transformation
Architectural shifts impacting the evolution of RAN transport

Software Centric
Virtualization, Programmable, Flexible, Any-to-Any Connectivity

Decomposition
Radio Equipment Controller Decomposition, CU/DU Functional Splits

Convergence
Blended SLAs Services, Radio packetization & Statistical multiplexing

Automation
Open, Pervasive Automation, Service Assurance, Network Slicing

New Radio
High Bandwidth, High Density, Low Latency, Precise Timing and Synchronization

Radio Technology Innovation
Higher frequency spectrum
Larger radio channels
Increased network density
Massive MIMO
RAN Decomposition and Virtualization

**Functional Decomposition**
Functions Separated to Allow Flexible Placement and Optimization

**Disaggregation into SW + HW**
Software-Centric Solutions Leveraging COTS Hardware

**Open**
Modular, ORAN, Open, Multi-vendor, More Options = Flexibility and Lower Cost

**Multi-Use Case**
5G NR, LTE, Small Cell, Indoor/Outdoor, mMIMO, Multi-band, mmWave, Private/Public, Enterprise/Consumer, etc.

**Optimize for Lower Cost Operations**
Agility, Lower TCO, Increased Automation

**Enable New Services**
Increased Service Flexibility, Velocity

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**Automation & Multi-Domain Orchestration**

- **Fronthaul**
  - Open

- **Midhaul**
  - Open

- **Backhaul**
  - Open

- **Central DCs**
  - Hybrid Cloud
  - UPF
  - COTS HW

- **Regional DCs**
  - vCU
  - UPF
  - COTS HW
  - Apps

- **Edge DCs**
  - vDU
  - COTS HW

- **Cell site**
  - RAN
  - BBU
  - Packet Core

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**“Modular” System Integration**

- **Multi-Use Case**
  - 5GNR, LTE, Small Cell, Indoor/Outdoor, mMIMO, Multi-band, mmWave, Private/Public, Enterprise/Consumer, etc.

- **Enable New Services**
  - Increased Service Flexibility, Velocity

- **Optimize for Lower Cost Operations**
  - Agility, Lower TCO, Increased Automation

- **Disaggregation into SW + HW**
  - Software-Centric Solutions Leveraging COTS Hardware

- **Open**
  - Modular, ORAN, Open, Multi-vendor, More Options = Flexibility and Lower Cost
RAN Transport Architecture Options

- Higher Speed Interfaces
- Lower Latency
- More Precise Timing & Synchronization
- Any-to-Any Connectivity

**Interface(s):**
- Fronthaul: 1G/25G/100G/200G
- Midhaul: 1G/25G/100G
- Backhaul: 10G/25G/100G/200G

**Typical distance:**
- Fronthaul: <15KM
- Midhaul: >10KM
- Backhaul: >10KM

**1-way latency:**
- Fronthaul: 75us/100 us (LTE)
- Midhaul: 1-25ms
- Backhaul: 10ms

- Fronthaul: 160us (5G NR)
- Midhaul: 10G/25G/100G
- Backhaul: 10G/25G/100G/200G
Benefits of Centralized & Cloud RAN Architectures

Functional & economic advantages

- Enhanced Coordination
- Enhanced RU Management and Policy
- Baseband Pooling, Flexibility of Software
- Enhanced Network Resiliency

Functional Benefits

Economic Benefits

- Reduced Cell Site Management
- Reduced Site Deployment Costs (less physical equipment)
- Service innovation & Commoditization
- Improved Resource Utilization (spatial efficiency)

Economic
Benefits

Enhanced Coordination

Functional Benefits

Economic Benefits

Reduced Site Deployment Costs

Service innovation & Commoditization

Improved Resource Utilization

Spatial efficiency
C-RAN Transport Architecture Components

- Baseband Hotel Router depending on the size of BBU Hotel
  - Fixed
  - Modular
- Low latency L2 switch in case of solution like Ericsson’s Elastic RAN
  - Cisco solution combines above two functionalities into single node (NCS portfolio) – cost saving
  - Tested and validated in multiple customer engagements
- 1588/SyncE – Phase & Frequency clocking support
- Scalable Cloud-RAN Fabric Architecture
  - Interface Flexibility – 1/10/25G/100G
  - Horizontal Scaling for large sites
  - Redundancy
- Platforms: NCS5700/NCS5500/NCS540
Fronthaul
## Radio Standards

<table>
<thead>
<tr>
<th>Proprietary</th>
<th>Internal interface of radio base stations between the <strong>Radio Equipment Control (REC)</strong> and the <strong>Radio Equipment (RE)</strong></th>
<th><strong>CPRI Specification version 7.0</strong> - October 9, 2015 (in addition to 1.4, 2.1, 3.0, 4.0, 4.1, 4.2, 5.0, 6.0, 6.1)</th>
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<tr>
<td><strong>CPRI</strong></td>
<td>To enable efficient and flexible radio data transmission via a <strong>packet based fronthaul transport network like IP or Ethernet</strong></td>
<td><strong>eCPRI 2.0</strong> [ CPRI and eCPRI interworking] – May 10, 2019</td>
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<td><strong>Evolution of CPRI</strong></td>
<td><strong>Structure-agnostic</strong> – any digitized radio data</td>
<td><strong>eCPRI 1.2</strong> - June 25, 2018</td>
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<td><strong>Standard</strong></td>
<td><strong>Structural Mapping of radio protocols for transport over Ethernet frames, using radio over Ethernet (RoE)</strong></td>
<td><strong>eCPRI 1.1</strong> - January 31, 2018</td>
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<tr>
<td><strong>IEEE</strong></td>
<td><strong>Standard for Radio over Ethernet</strong></td>
<td><strong>eCPRI 1.0</strong> - August 31, 2017</td>
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<td><strong>1914.3-2018</strong></td>
<td><strong>1914.1-2019</strong></td>
<td><strong>Network (TSG RAN)</strong></td>
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<tr>
<td><strong>TSG RAN</strong></td>
<td><strong>Native mode</strong> – digitized radio in-phase and quadrature (I/Q) payload</td>
<td><strong>TSG RAN WG1</strong></td>
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<td><strong>Radio Layer 1 specification</strong></td>
<td><strong>TSG RAN WG2</strong></td>
<td><strong>Radio Layer 2 and Radio Layer 3 specification</strong></td>
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<td><strong>TSG RAN WG4</strong></td>
<td><strong>Radio performance and protocol aspects</strong></td>
<td><strong>TSG RAN WG5</strong></td>
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<td><strong>(system)</strong></td>
<td><strong>TSG RAN WG6</strong></td>
<td><strong>Legacy RAN radio and protocol</strong></td>
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<td><strong>O-RAN Alliance</strong></td>
<td><strong>WG4: The Open Fronthaul Interfaces Workgroup</strong></td>
<td><strong>WG1: Use Cases and Overall Architecture Workgroup</strong></td>
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<td><strong>leading the industry towards open, interoperable interfaces and RAN virtualization</strong></td>
<td><strong>O-RAN Fronthaul Interoperability Test (IoT) Version 1.0 - October 2019</strong></td>
<td><strong>WG6: The Cloudification and Orchestration Workgroup</strong></td>
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<td><strong><a href="https://www.o-ran.org/">https://www.o-ran.org/</a></strong></td>
<td><strong>O-RAN Fronthaul Control, User and Synchronization Plane Version 2.0 - July 2019</strong></td>
<td><strong>WG8: Stack Reference Design Workgroup</strong></td>
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<td><strong>Open RAN</strong></td>
<td><strong>O-RAN Fronthaul Management Plane Version 2.0 - July 2019</strong></td>
<td><strong>Telecom Infra Project (TIP)</strong></td>
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<td><strong>WG4: The Open Fronthaul Interfaces Workgroup</strong></td>
<td><strong>O-RAN Fronthaul Yang Models Version 2.0 - July 2019</strong></td>
<td><strong>The OCP Telco Project</strong></td>
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<td><strong>Time-Sensitive Networking for Fronthaul</strong></td>
<td><strong>The OCP Telco Project</strong></td>
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<td><strong><a href="https://ieee802.ie.org/standards/802.1cm/tipline/5076066">https://ieee802.ie.org/standards/802.1cm/tipline/5076066</a></strong></td>
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<td><strong>Open RAN</strong></td>
<td><strong>WG1: Use Cases and Overall Architecture Workgroup</strong></td>
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<td><strong>WG2: The Non-real-time RAN Intelligent Controller and A1 Interface Workgroup</strong></td>
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<tr>
<td><strong>WG5: The Open F1/W1/E1/X2/Xn Interface Workgroup</strong></td>
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<td><strong>WG6: The Cloudification and Orchestration Workgroup</strong></td>
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<tr>
<td><strong>WG8: Stack Reference Design Workgroup</strong></td>
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</tr>
</tbody>
</table>
## RAN Functional Split Consideration

### Functions

- **CU**
  - RRM/RRC
  - PDCP
  - High RLC
  - Low RLC
  - High MAC
  - Low MAC
  - High PHY
  - Low PHY

- **DU**
  - DU Distributed Unit

- **BBU**
  - Baseband Unit

- **RRH**
  - Remote Radio Head

### Split Option

<table>
<thead>
<tr>
<th>Split Option</th>
<th>Fronthaul Interfaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1</td>
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<tr>
<td>Option 2</td>
<td>F1 (3GPP)</td>
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<td>Option 3</td>
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<td>Option 4</td>
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<td>Option 5</td>
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<td>Option 6</td>
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<tr>
<td>Option 7a</td>
<td>eCPRI</td>
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<tr>
<td>Option 7b</td>
<td>ORAN (7-2x) ROE</td>
</tr>
<tr>
<td>Option 7c</td>
<td></td>
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<tr>
<td>Option 8</td>
<td>CPRI</td>
</tr>
</tbody>
</table>

- **Transport costs minimized with higher splits**
- **RF Gains improved with lower splits**
Packet-Based Fronthaul

Stat-muxing opportunity

Option 7-2 Mux

Stat-muxing opportunity

Optical Multiplexing (Passive or Active DWDM)

Packet

Optical

✓ Stat Mux Advantages
✓ Cost Effective
✓ Topology Independent
✓ Service Visibility & Transparency
✓ Scalable E2E Converged IP

✗ Optical multiplexing
✗ Non-scalable, architecturally rigid
✗ Limited-service visibility
✗ Capex dependent scale
✗ Point-to-point, topology dependent

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Comparing TCO for fronthaul
Packet vs optical fronthaul solutions

Packet-based fronthaul

Optical-based fronthaul

TCO Savings
+65% TCO Savings

Savings: +65% ROADM +46% P2P Active DWDM +40% P2P Passive DWDM +13% P2P Passive CWDM

Source: ACG – An Economic Comparison of Fronthaul Architectures for 5G Networks

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Cisco Fronthaul Strategy

- Enable optimal transport for converged packet-based fronthaul supporting resilient and programmable architecture to support RAN innovation

- Accelerate the viability and adoption of open virtualized RAN (vRAN) solutions
eCPRI/ORAN
Fronthaul
RAN and Mobile Core Interfaces

All interfaces are mandatory IP based (except F2 where its optional).
There is a complex set of networking requirements between different 5G components:
1 to 1, 1 to many, many to many.
Same component may need to support all models concurrently!

F2/7.2X : RU to DU - 1 to 1 relationship
F1 : DU to CU - many to 1 relationship
5G and 4G mobile use cases – O-RAN WG-9
Adapted from O-RAN WG-9 Packet Switched Xhaul architecture and solutions
Packet Based Fronthaul

Positioning NCS 540

- Midhaul/Backhaul
  - NCS5700/NCS5500/0/NCS540

- Fronthaul eCPRI/CPRI/TSN
  - Aggregation
    - N540-FH-AGG-SYS (Aggregation)
  - Cell site router
    - N540-FH-CSR-SYS (Cell Site Router)

- Fronthaul eCPRI/100G NNI
  - Aggregation
  - Cell site router

eCPRI/ORAN is fully supported on shipping NCS540 portfolio
eCPRI Trials with NCS540

- Supported radio: Samsung, Ericsson, Nokia, Huawei and all ORAN vendors
- eCPRI Trials with NCS540
- Stat–mux
- TI LFA Failover tests performed
- No cells went down/No call drops during failover tests / VoIP Call ran for 37 mins
- With 80 MHz Channel Bandwidth, 686 Mbps Download Speed was achieved
- Fiber path between NCS540 and BBH is approx. 14 km
Converged Packet based Fronthaul
Cisco Converged Packet-based Fronthaul

Extending to meet the needs of Fronthaul, Midhaul, & Backhaul

BENEFITS

- **Service Convergence**
  - Wireless (4G,5G) and Wireline
  - Fronthaul, midhaul & backhaul

- **Monetization**
  - Enterprise Services

- **High-Speed and Ultra-Low Latency**
  - Forwarding Precise timing and synchronization

- **End to end IP/MPLS based network for a simplified architecture**

- **Open and automated management**
Converged Fronthaul Router Highlights

1. Converged System
   Converged (Wireline + Wireless), Low power & Optimal Form Factor

2. LTE & 5G Radio
   FPGA:CPRI (option 3-8), RoE, eCPRI, ORAN

3. Low latency
   802.1Qbu - Frame Preemption (TSN) support on 10G/25G interfaces

4. Synchronization
   Class C, eEEC, PRTC-A, Better Oscillator

5. Flexible Transport
   SR MPLS/SRv6, BGP VPN, SR PM

6. Silicon
   DNX, 2.5 us ASIC Latency

7. FPGA (Field Upgradeable)
   Radio over Ethernet (RoE) Type 0/Type 1, L1 PHY Offload (FHG) & TSN

8. Quality of Service
   H-QOS & QOS Enhancements

9. Security
   PTP over Macsec, Trust Anchor

10. Automation
    Open & Automated management, NSO & Cisco Crosswork Portfolio
# Cisco Fronthaul Router Models
## NCS 540 family

<table>
<thead>
<tr>
<th>Fronthaul Router</th>
<th>Use Case</th>
<th>Port Config</th>
<th>RU</th>
<th>Capacity</th>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>N540-FH-CSR-SYS</td>
<td>(Cell Site Router)</td>
<td>• 8xCPRI (Option 3-8)</td>
<td>1 RU</td>
<td>300Gbps</td>
<td>IOS XR</td>
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<tr>
<td></td>
<td></td>
<td>• +4x1/10G/CPRI (Option 3-8)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• 8x1/10G</td>
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<td></td>
<td></td>
<td>• 4x10/25G</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• 2x10/25G (802.1Qbu)</td>
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<tr>
<td></td>
<td></td>
<td>• 2x100G</td>
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<tr>
<td></td>
<td></td>
<td>[Packet + CPRI + TSN]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N540-FH-AGG-SYS</td>
<td>(Aggregation)</td>
<td>• 24x10G/25G*</td>
<td>1 RU</td>
<td>900Gbps</td>
<td>IOS XR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• (802.1Qbu, CPRI 3-8)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• 4x100G</td>
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<tr>
<td></td>
<td></td>
<td>[Packet + CPRI + TSN]</td>
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</tr>
</tbody>
</table>

*Universal Port = Port can be used for CPRI or eCPRI or Ethernet (1/10/25GE)
CPRI over Radio over Ethernet (RoE)
Optimized for CPRI Transport Over Ethernet
Fronthaul RoE Structure Agnostic Modes (Type 0 & Type 1)

Optimized to enable CPRI “RoE Structure-Agnostic Tunneling Mode (Type 0)”
• Compatible with all RAN suppliers’ equipment
• RAN vendor CPRI protocol implementation awareness is NOT required
• RoE Tunneling mode does not provide any fronthaul bandwidth reduction (Tested with Ericsson & Huawei)

Extensible to support CPRI “RoE Structure-Agnostic Line Code Aware Mode (Type 1)”
• Solution MUST be tested with every RAN vendor to validate the functionality
• Requires some awareness of CPRI protocol at mapper/demapper
• Fronthaul bandwidth of reduction of 20% by removing 8b10b line coding (Tested with Huawei)
Packet Fronthaul Router operates seamlessly with:
- Ericsson Radio Units, 4G and 5G BBUs
- Huawei Radio Units, 4G BBUs

With Ericsson RU and BBU, Packet Fronthaul Router successfully implements:
- RoE Structure Agnostic Mapper Type-0

With Huawei RU and BBU, Packet Fronthaul Router successfully implements:
- RoE Structure Agnostic Mapper Type-0 between Huawei RU and BBU
- RoE Structure Agnostic Mapper Type-1 between Huawei RU and BBU
- Operates seamlessly with RU Chain Implementation (with Huawei RUs)
- Operates seamlessly with RU-BBU Load-Balancing Implementation (with Huawei BBUs)
Cisco Packetized Fronthaul Demo
## Timing and Synch – Fronthaul Options

<table>
<thead>
<tr>
<th>Distributed RAN</th>
<th>Centralized RAN</th>
<th>Cloud/Midhaul RAN</th>
</tr>
</thead>
</table>
| • ±1.5uS phase between radios  
• Backhaul carries sync from pre-aggregation layer; or  
• GPS at every cell site | • < ±1.1uS between BBU’s  
• Backhaul carries sync or place GPS at every BBU hotel  
• CPRI is synchronous; but eCPRI requires PTP or GPS | • ~±130nS between RU/DU  
• Midhaul carries sync or GPS at every DU hotel  
• eCPRI requires PTP in Fronthaul or GPS at every RU and DU |

### Distributed RAN
- Mobile Core
- Pre-Agg Layer
- WAN/Backhaul
- RU: Remote Unit
- CPRI carries its own time
- Frequency
- Phase

### Centralized RAN
- Mobile Core
- vBBU
- WAN/Backhaul
- Fronthaul
- eCPRI uses PTP

### Cloud/Midhaul RAN
- Mobile Core
- CU
- Centralized Unit
- Midhaul
- DU
- Distributed Unit
- Fronthaul
Streaming Telemetry from Router

- Monitoring your Network: CSR-SYS
- Writing your Query
- Monitoring your Network: AGG-SYS

- CPRI Option X
- RoE Mapper
- RoE Stats
- Deriving clock from Ethernet
- CPRI Option
- Primary Reference Clock
- BBU
- RoE De-Mapper
- N540-FH-CSR-SYS
- N540-FH-AGG-SYS
- Deriving clock from CPRI

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Converged SDN Transport Solution

Access

Transport

Core + Cloud

Services

Cisco Crosswork

Automation

NSO  SR-PCE

Distributed and Common Telco Cloud Platform

SR BGP VPN, SDN Programmability

C-RAN

ACCESS

PRE-AGG

AGG

IP Core

• NCS57xx/55xx

• NCS5xx

• NCS57xx/55xx

• NCS5xx

• NCS57xx/55xx

• ASR99xx

IP Core

IOS XR

IP + Optical  Timing

Security Suite – Zero Trust

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Fronthaul Design
Fronthaul Network Design Options

4G RRH

10G

CPRI over RoE

100G

5G/4G RRH

10/25G

eCPRI

Fronthaul Fabric Design

NCS5500

100G

CPRI over RoE

100G

RoE+eCPRI

eCPRI

CPRI

5G BBU

5G vDU/vCU (7-2x)

4G vDU/vCU (7-2x)

10G

10/25G

4G BBU (CPRI)

100G/25G

10G

Midhaul/Backhaul Interface

5G BBU

4G BBU (CPRI)

10/25G

CPRI over RoE

eCPRI

10/25G

10G

Backhaul Interface

4G RRH

10G

CPRI over RoE

5G/4G RRH

10/25G

eCPRI

Low PHY

100G/25G

100G

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# Fronthaul/Midhaul/Backhaul Calculation

Single Cell Site/3 Sector 6 Carriers

<table>
<thead>
<tr>
<th>Band Number</th>
<th>Band Number</th>
<th>Band [MHz]</th>
<th>MIMO/MIMO Layers</th>
<th>Fronthaul Data Rate (Single Sector Peak) CPRI/ORAN Gbps</th>
<th>FH Data Rate (<em>3</em> Sectors) CPRI/ORAN Gbps</th>
<th>Midhaul Gbps</th>
<th>Backhaul Gbps</th>
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<tbody>
<tr>
<td>5</td>
<td>850 MHz</td>
<td>10</td>
<td>4T4R</td>
<td>2.45 (CPRI option 3)/0.70</td>
<td>7.35/1.40</td>
<td>0.30</td>
<td>0.25</td>
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<tr>
<td>8</td>
<td>900 MHz</td>
<td>10</td>
<td>4T4R</td>
<td>2.45 (CPRI option 3)/0.70</td>
<td>7.35/1.40</td>
<td>0.30</td>
<td>0.25</td>
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<tr>
<td>9</td>
<td>1.8GHz</td>
<td>20</td>
<td>4T4R</td>
<td>4.9 (CPRI option 5)/1.40</td>
<td>14.7/2.80</td>
<td>0.59</td>
<td>0.50</td>
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<tr>
<td>41</td>
<td>2.6GHz</td>
<td>20</td>
<td>4T4R</td>
<td>9.8 (CPRI option 7)/1.40</td>
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<td>0.50</td>
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<td>n78</td>
<td>3.5GHz</td>
<td>100</td>
<td>64T64R/8 layers</td>
<td>15.29</td>
<td>30.59</td>
<td>4.44</td>
<td>3.78</td>
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<td>n257 (Split 2)</td>
<td>28GHz</td>
<td>400</td>
<td>128T128R/4 layers</td>
<td>NA</td>
<td>NA</td>
<td>6.14</td>
<td>5.22</td>
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<td>Total</td>
<td></td>
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<td>FH=LTE CPRI+NR=89.39 Gbps</td>
<td>12.36 Gbps</td>
<td>10.5 Gbps</td>
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</tbody>
</table>

PRB=Physical Resource Block
Statistical Multiplexing (Statmux)=1Max+2 Average

Fronthaul Interface Required=100G/50G
Midhaul Interface Required=25G
Backhaul Interface Required=25G
Customer Case Study
Customer existing CRAN Topology

- Complete Ericsson RAN network
- C-RAN & ERAN in production using passive DWDM solution
- Drawbacks of existing CRAN fronthaul
  - Passive infrastructure static
  - No dynamic fault recovery
  - Limited topology options (hub spoke today)
  - Coloured optics
    - operationally challenging (if not using tuneable)
  - Little to no OAM of fronthaul links
  - Dedicated E-RAN switch

Motivation for Packetized Fronthaul
- Packetized fronthaul enables Flexible and programmable architecture to support RAN innovation e.g. Stats-mux, converged services (4G/5G/Enterprise)
- Leverage IP protection mechanisms (Segment Routing) for improved resiliency and failover in fronthaul network
  - Ring/mesh FH topologies
  - N+1 BBU use case using NSO
  - Cell management with reduced capacity
- Operational simplicity - visibility of fronthaul network with Telemetry, ZTP, topology visualization and automation
Converged Fronthaul

- 5G NR Split 7, eCPRI Ethernet
- NCS540 validated with Ericsson 5G NR
  - Ericsson BBU 6630
  - Ericsson RU 5G AIR6488
- Phase 1 Lab Trials
  - EVPN-VPWS over SR (MPLS) + TI-LFA
  - Dynamic latency measurement of fronthaul link with SR-PM
  - Telemetry for OAM of fronthaul links
- Completed with 100% Success

- 4G Split 8, CPRI “RoE Structure Agnostic Type 0”
- NCS540-FH CSR validated with Ericsson 4G radio
  - Ericsson BBU 6630
  - Ericsson RU 4415
- Phase 1 Lab Trials
  - EVPN VPWS for CPRI over SR (MPLS) + TI-LFA
  - Baseline Testing Completed with 100% Success
  - 4G Cell is up and running. MBB and VoLTE tests were successful
Why Cisco for Fronthaul?

- Packet-based solution with high-speed, Ultra-Low Latency Forwarding to meet and exceed fronthaul requirements
- Converges services while optimizing fronthaul resources
- Flexible and programmable architecture to support RAN innovation
- Simplifies and improves reliability of network operations by extending IP through RAN transport
Supporting Sessions

BRKSPM-2001  5G Converged SDN Transport
BRKSPM-2000  5G Access and DC Edge
BRKSPG-2060  5G Transport: Design Strategies
Resources

- Cisco NCS 540 Fronthaul Router Portfolio Collateral:

- The Deep Edge Podcast “Segment Routing and 5G with Simon Spraggs from Cisco”
  - https://www.buzzsprout.com/1010419/3956699

- 5G transport page
  - www.cisco.com/go/5g-transport
**Additional Resources contd..**

- "5G Transport" session Cisco Live Barcelona 2020

- "Clocking" sessions Cisco Live Barcelona 2020

- Radio and Band info
  - [https://www.sharetechnote.com/](https://www.sharetechnote.com/) (Radio tutorial)
  - Simple lookup for LTE bands
    - [https://www.sqimway.com/lte_band.php](https://www.sqimway.com/lte_band.php) (Simple lookup for LTE bands)
  - Simple lookup for 5G (new radio) bands
    - [https://www.sqimway.com/nr_band.php](https://www.sqimway.com/nr_band.php) (Simple lookup for 5G (new radio) bands)
Converged SDN Transport High Level Design

- [https://xrdocs.io/design/blogs/latest-converged-sdn-transport-ig](https://xrdocs.io/design/blogs/latest-converged-sdn-transport-ig)

5G Features covered:

- Clocking & Synchronization
- 5G Transport SR MPLS/BGP VPN
- Fronthaul will be covered in future release
Thank you
TURN IT UP
Bonus Material
Mobile Network Spectrum

- **High Bands (mm Wave)**: 24GHz and above
  - New
  - 5G

- **Mid Bands**: 3-6GHz
  - Licensed & Unlicensed
  - New
  - 5G
  - 4G

- **Low Bands**: below 1GHz
  - Existing & New
  - Low Bands below 1GHz
  - 4G
  - 3G
  - 2G
  - 600MHz

**Frequency Range 2 (FR2)**

**Frequency Range 1 (FR1)**

- **Canada 3.5G Auction**
- **US C-band Auction**

#CiscoLive
## 5G NR Channel Capacity (& Throughput)

<table>
<thead>
<tr>
<th>Spectral efficiency</th>
<th>bps/Hz (Downlink)</th>
<th>LTE</th>
<th>LTE-A</th>
<th>5G NR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>example</td>
<td>20MHz</td>
<td>3x20MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FDD</td>
<td>FDD</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peak/Max Rate</th>
<th>Theoretical max coded rate</th>
<th>15</th>
<th>23</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>300Mbps</td>
<td>900Mbps</td>
<td>2.3Gbps</td>
</tr>
<tr>
<td>Cell Centre</td>
<td>Minimum rate achieved by top 5% of users</td>
<td>9</td>
<td>13</td>
<td>1.3Gbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>180Mbps</td>
<td>540Mbps</td>
<td></td>
</tr>
<tr>
<td>Typical</td>
<td>Typical median rate</td>
<td>2.0</td>
<td>2.9</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40Mbps</td>
<td>120Mbps</td>
<td>290Mbps</td>
</tr>
<tr>
<td>Edge</td>
<td>Minimum rate achieved by 95% of users</td>
<td>0.1</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2Mbps</td>
<td>6Mbps</td>
<td>120Mbps</td>
</tr>
<tr>
<td>Aggregate cell (multi-user) capacity</td>
<td>Average rate plus multi-user scheduling gain</td>
<td>2.2</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>44Mbps</td>
<td>132Mbps</td>
<td>330Mbps</td>
</tr>
</tbody>
</table>

* Design caveat: RF Channel capacity depends on many factors, like MIMO schedule deployed, UE capabilities, network loading, mobility, etc. Always consult customer for RAN design guidelines.

**Access Transport Bandwidth:** 1G→10G→25G  
**Edge/IP Core Transport Bandwidth:** 10G→100G→400G
RAN Decomposition and Virtualization

- **Functional Decomposition**
  Functions Separated to Allow Flexible Placement and Optimization

- **Disaggregation into SW + HW**
  Software-Centric Solutions Leveraging COTS Hardware

- **Open**
  Modular, ORAN, Open, Multi-vendor, More Options = Flexibility and Lower Cost

- **Multi-Use Case**
  5G NR, LTE, Small Cell, Indoor/Outdoor, mMIMO, Multi-band, mmWave, Private/Public, Enterprise/Consumer, etc.

- **Optimize for Lower Cost Operations**
  Agility, Lower TCO, Increased Automation

- **Enable New Services**
  Increased Service Flexibility, Velocity

---

**Automation & Multi-Domain Orchestration**

- **Cell site**
  RAN

- **Midhaul**
  Open

- **Backhaul**
  Open

- **Central DCs**
  CP

- **Hybrid Cloud**

---

**“Modular” System Integration**

- **BBU**
  Packet Core

- **vDU**
  COTS HW

- **vCU**
  UPF

- **UPF**
  COTS HW

- **COTS HW**
O-RAN Alliance – Transforming the RAN

• Driving the RAN towards being:
  Open
  Intelligent
  Virtualized
  Fully Interoperable

• WG9 ➔ Open Xhaul transport architecture
  Fronthaul, Midhaul and backhaul
  Working on transport requirements, WDM FH and packet switched xhaul and timing and sync
  Cisco is editor of packet switched xhaul architecture

Filling today’s functional and interface gap
ORAN & IEEE 1914.3 Contribution

- WG4 – Open Fronthaul Interfaces Workgroup
- WG9 – Open X-haul Transport Workgroup
- WG7 – White-box Hardware Workgroup
- IEEE1914.3a: RoE Enhancements
Transition to the Telco Edge

- Far Edge: vCU, edge UPF, vFW, LS-CDN, dCDN, AI, Gaming etc.
- Near Edge: Network Edge
- DC: vUPF, vCMTS, vBNG, OSS/BSS, Voice
- Services Edge (Applications): edge applications, content delivery
- Core Applications
- Cell Site Edge: 10,000s
- Network Edge: 1000s
- Regional DC: 100s
- Central DC: 10s
- RAN, Security, light edge-AI

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Customer Disruption
Software Defined 5G: O-RAN/vRAN Architecture

Zero Touch, End-to-End Automation with NSO, ESC

IPv6 based 5G Ready Transport Network for Backhaul (NCS 500 & NCS 5500)

- ~3000 Edge DCs
- ~50 Regional DCs
- 2 Central DCs

Distributed and Common Carrier-Grade Telco Cloud
Software Defined Programmable Infrastructure

Open, Decomposed, and Virtualized RAN
Edge Computing for Enhanced Experience
New Business Models Including B2B Monetization
End-to-end Closed-Loop Automation

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Elastic RAN Transport Requirement

- ERAN is being used to connect BBU
- ERAN requires L2 connectivity using Ericsson proprietary Inter Digital Link Ethernet (IDLe) cable
- Strict low latency transport requirement
- ERAN can be used in CRAN & D-RAN
CRAN Hub Site Selection Flow Chart

Radio Cell Site Selection

Check optical fiber infra
Fiber Available - Y/N
Fronthaul LTE < 20KM

D-RAN Solution

CRAN Hub Site Selection

CRAN Hub Site Validation

Network Resilience/Solution Robustness

Rackspace/Power/AC available

Backhaul Connectivity Available

Deploy CRAN Hub Site

Check for new CRAN Hub Site

Y

N

Y

N

Y

N

Y

N

Y

N

Y

N

Y

N
Scalable Cloud–RAN Fabric Architecture

- Deployment Flexibility
- Network Scale
- Horizontal Scalability
- Smaller Failure Domain
- Traffic Patterns (east and west)

Smaller CRAN Hub Sites
- Leaf
- Leaf
- BBU
- vCU+vDU
- vDU

Large CRAN Hub Sites
- Spine
- Spine
- Leaf
- Leaf
- ToR
- ToR
- BBU
- vCU+vDU
- vDU
# C-RAN Fabric Portfolio

<table>
<thead>
<tr>
<th>Fixed Platform</th>
<th>Space (RU)</th>
<th>Capacity</th>
<th>Port Density</th>
<th>Timing 1588/Sync-E</th>
</tr>
</thead>
</table>
| NCS 5501 (SE)  | 1          | 800 Gbps | Base: 48x 1/10G + 6x 100G  
Scale: 40x 1/10G + 4x 100G | Scale only |
| NCS-55A1-36H-S/SE | 1          | 3.6 Tbps | 36 x QSFP28 or QSFP+               | Y |
| NCS-55A1-24H     | 1          | 1.8 Tbps | 24 x QSFP28                      | Y |
| NCS-55A1-48Q6H   | 1          | 1.8 Tbps | 48 x SFP28 + 6x100G QSFP28  
24x1G/10G SFP+ +24x1G/10G/25G SFP28 & 6x100G | Y |
| NCS-55A1-24Q6H-S | 1          | 900 G    | 24x 10GE SFP+ + 8x 25GE SFP28 + 2x 100GE QSFP28 | Y |
| NCS 540          | 1          | 300 Gbps | Fixed Ports: 24 x 1/10G & 16 x 1/10/25G  
2 x MPAs of 400 Gbps each: | Y |
| NCS-55A2-MOD (SE)| 2          | 900 Gbps |                                                          | |

<table>
<thead>
<tr>
<th>Modular Platform</th>
<th>Space (RU)</th>
<th>Capacity</th>
<th>Port Density</th>
<th>Timing 1588/Sync-E</th>
</tr>
</thead>
</table>
| NCS560           | 7 slot     | 800 Gbps | Modular. 4 x 100G QSFP28, 40 x 10G SFP+, 96 x 1G  
CSFP                     | Y |
|                  | 4 slot     | 800 Gbps | Modular. 4 x 100G QSFP28, 32 x 10G SFP+ or 72 x 1G CSFP | Y |
eCPRI Standard Overview
eCPRI 2.0

The internal radio base station interface establishing a connection between “eCPRI Radio Equipment Control” (eREC) and “eCPRI Radio Equipment” (eRE) via a packet based transport network is specified.

- eCPRI Ethertype (AEFE16)
- eCPRI can be transported using standard IP/Ethernet routers and switches & it supports Stat-mux
- eCPRI radio may have 10G/25G interfaces
- The specification defines a new eCPRI Layer above the Transport Network Layer. Existing standards are used for the transport network layer, C&M and Synchronization.
The major difference between Split ID and IID is that the data in Split ID is bit oriented and the data in split IID and IU is IQ oriented.

Source: eCPRI 2.0
eCPRI 2.0 contd..

Source: eCPRI 2.0

**Table 4: eCPRI Message Types**

<table>
<thead>
<tr>
<th>Message Type #</th>
<th>Name</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>IQ Data</td>
<td>3.2.4.1</td>
</tr>
<tr>
<td>1</td>
<td>Bit Sequence</td>
<td>3.2.4.2</td>
</tr>
<tr>
<td>2</td>
<td>Real-Time Control Data</td>
<td>3.2.4.3</td>
</tr>
<tr>
<td>3</td>
<td>Generic Data Transfer</td>
<td>3.2.4.4</td>
</tr>
<tr>
<td>4</td>
<td>Remote Memory Access</td>
<td>3.2.4.5</td>
</tr>
<tr>
<td>5</td>
<td>One-way Delay Measurement</td>
<td>3.2.4.6</td>
</tr>
<tr>
<td>6</td>
<td>Remote Reset</td>
<td>3.2.4.7</td>
</tr>
<tr>
<td>7</td>
<td>Event Indication</td>
<td>3.2.4.8</td>
</tr>
<tr>
<td>8</td>
<td>IWF Start-Up</td>
<td>3.2.4.9</td>
</tr>
<tr>
<td>9</td>
<td>IWF Operation</td>
<td>3.2.4.10</td>
</tr>
<tr>
<td>10</td>
<td>IWF Mapping</td>
<td>3.2.4.11</td>
</tr>
<tr>
<td>11</td>
<td>IWF Delay Control</td>
<td>3.2.4.12</td>
</tr>
<tr>
<td>12 - 63</td>
<td>Reserved</td>
<td>3.2.4.13</td>
</tr>
<tr>
<td>64 - 255</td>
<td>Vendor Specific</td>
<td>3.2.4.14</td>
</tr>
<tr>
<td>Byte</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>--------------------------------------</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>eCPRI Protocol Revision</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>eCPRI Message Type</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>eCPRI Payload Size</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 8: eCPRI Common Header format**
# eCPRI Protocol Revision

Source: eCPRI 2.0

**Table 15: Specification release version and protocol revision numbering**

<table>
<thead>
<tr>
<th>Specification release version</th>
<th>Available eCPRI protocol revision values</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0, 1.1, 1.2, 2.0</td>
<td>0001b</td>
<td>The interpretation of the eCPRI message shall follow eCPRI specification versions up to 2.0.</td>
</tr>
<tr>
<td></td>
<td>0010b-1111b; 0000b</td>
<td>Reserved for future eCPRI protocol revisions. Unallocated values can temporarily be used for vendor specific extensions until allocated.</td>
</tr>
</tbody>
</table>
eCPRI Transport
eCPRI Fronthaul Packet Capture

0x01=eCPRI Protocol revision 2.0

0x40=eCPRI Message type=Reserved

Propriety eCPRI Ethertype since eCPRI standard Ethertype is (AEFE16)

eCPRI QinQ User plane
Does eCPRI support Statistical Multiplexing?

- Based on eCPRI radio testing, **eCPRI does support stat-mux**
- Stat-mux enables optimal transport bandwidth utilization

<table>
<thead>
<tr>
<th>Channel Width</th>
<th>BBU to Radio (Mb/s)</th>
<th>Radio to BBU (Mb/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20Mhz</td>
<td>109.2</td>
<td>4.0032</td>
</tr>
<tr>
<td>40Mhz</td>
<td>197.68</td>
<td>5.2696</td>
</tr>
<tr>
<td>60Mhz</td>
<td>287.76</td>
<td>6.5520</td>
</tr>
<tr>
<td>80Mhz</td>
<td>376.24</td>
<td>7.8192</td>
</tr>
<tr>
<td>100Mhz</td>
<td>466.24</td>
<td>9.1040</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Channel Width</th>
<th>BBU to Radio (Mb/s)</th>
<th>Radio to BBU (Mb/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20Mhz</td>
<td>224.8</td>
<td>144.88</td>
</tr>
</tbody>
</table>

Idle state

Single UE downloading 10G file
# Cisco Live!

## NCS 540 Family

<table>
<thead>
<tr>
<th>NCS 540 Family</th>
<th>Interfaces</th>
<th>Throughput</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>N540-24Z8Q2C-SYS</strong></td>
<td>2x 100/40GE, 8x 25/10/1GE, 24x 10/1GE</td>
<td>300G</td>
<td>GNSS Class B, 1pps/10MHz/ToD</td>
</tr>
<tr>
<td><strong>N540X-16Z4G8Q2C-A/D</strong></td>
<td>2x 100/40GE, 8x 25/10/1GE, 16x 10/1GE, 4x 1GE Copper</td>
<td>300G</td>
<td>GNSS Class C, 1pps/10MHz/ToD, BITS</td>
</tr>
<tr>
<td><strong>N540-28Z4C-SYS-A/D</strong></td>
<td>4x 100/40GE, 28x 10/1GE</td>
<td>300G</td>
<td>Class B, 1pps/10MHz/ToD, BITS</td>
</tr>
<tr>
<td><strong>N540X-12Z16G-SYS-A/D</strong></td>
<td>12x 10/1GE, 12x 1GE, 4x 1GE Copper</td>
<td>140G</td>
<td>GNSS Class C, 1pps/10MHz/ToD, BITS</td>
</tr>
<tr>
<td><strong>N540-12Z20G-SYS-A/D</strong></td>
<td>12x 10/1GE, 20x 1GE</td>
<td>140G</td>
<td>Class B, 1pps/10MHz/ToD, BITS</td>
</tr>
</tbody>
</table>
Cisco and Telstra Complete World’s First 5G Call over Packetized Fronthaul Network

CPRI Tutorial
• A digitized and serial internal radio base station interface that establishes a connection between ‘Radio Equipment Control’ (REC) and ‘Radio Equipment’ (RE)
• Three different information flows (User Plane data, Control and Management Plane data, and Synchronization Plane data) are multiplexed over the interface.
• The specification covers layers 1 and 2
• The user plane data is transported in the form of IQ data
• Each IQ data flow reflects the data of one antenna for one carrier, the so-called antenna-carrier (AxC)
CPRI v7.0 contd..

• The radio base station system is composed of two basic subsystems, the radio equipment control and the radio equipment.

• The subsystems REC and RE are also called nodes.

• Several IQ data flows are sent via one physical CPRI link.

• Antenna-carrier (AxC):
  • One antenna-carrier is the amount of digital baseband (IQ) U-plane data necessary for either reception or transmission of only one carrier at one independent antenna element.

Source: CPRI 7.0
CPRI v7.0 contd..

• Between REC and RE, working link consists of a master port, a bidirectional cable, and a slave port.
  • The master port in the REC and the slave port in the RE.

• **Downlink:**
  • Direction from REC to RE for a logical connection.

• **Uplink:**
  • Direction from RE to REC for a logical connection.
CPRI v7.0 contd..

• Layer 1 defines:
  • Electrical characteristics
  • Optical characteristics
  • Time division multiplexing of the different data flows
  • Low level signaling

• Layer 2 defines:
  • Media access control
  • Flow control
  • Data protection of the control and management information flow

Source: CPRI 7.0
Table 1AA: Functional decomposition between REC and RE (valid for the GSM standard)

<table>
<thead>
<tr>
<th>Functions of REC</th>
<th>Functions of RE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Downlink</strong></td>
<td><strong>Uplink</strong></td>
</tr>
<tr>
<td><strong>Radio base station control &amp; management</strong></td>
<td><strong>Channel Filtering</strong></td>
</tr>
<tr>
<td><strong>Channel Filtering</strong></td>
<td><strong>D/A conversion</strong></td>
</tr>
<tr>
<td><strong>Abis transport</strong></td>
<td><strong>Up Conversion</strong></td>
</tr>
<tr>
<td><strong>Abis Frame protocols</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Channel Coding</strong></td>
<td><strong>Channel De-Coding</strong></td>
</tr>
<tr>
<td><strong>Interleaving</strong></td>
<td><strong>De-Interleaving</strong></td>
</tr>
<tr>
<td><strong>Modulation</strong></td>
<td><strong>De-Modulation</strong></td>
</tr>
<tr>
<td><strong>Frequency hopping control</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Signal aggregation from signal processing units</strong></td>
<td><strong>Signal distribution to signal processing units</strong></td>
</tr>
<tr>
<td><strong>Transmit Power Control of each physical channel</strong></td>
<td><strong>Transmit Power Control &amp; Feedback Information detection</strong></td>
</tr>
<tr>
<td><strong>Frame and slot signal generation (including clock stabilization)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Measurements</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CPRI v7.0 contd..

- IQ Data
  - User plane information in the form of in-phase and quadrature modulation data (digital baseband signals).

- Synchronization
  - Synchronization data used for frame and time alignment.

- L1 Inband Protocol
  - Signaling information that is related to the link and is directly transported by the physical layer. This information is required, e.g. for system start-up, layer 1 link maintenance and the transfer of time critical information that has a direct time relationship to layer 1 user data.

- C&M data
  - Control and management information exchanged between the control and management entities within the REC and the RE. This information flow is given to the higher protocol layers.

- Protocol Extensions
  - This information flow is reserved for future protocol extensions. It may be used to support, e.g., more complex interconnection topologies or other radio standards.

- Vendor Specific Information
  - This information flow is reserved for vendor specific information.

Source: CPRI 7.0
CPRI Frame Structure

- Frame structure
  - 1 Basic Frame (BF) = 16 words (W) = 256 bytes; BF=260.42ns; X= BF Number
  - W = word number in Basic Frame
  - Y = byte number within a word
  - In each BF, word 0 is used as control word (CW)
  - 1 Hyperframe (HF) = 256 BF (basic frame); 1HF=66.67us; Z=HF Number
  - BFN (Node B Frame Number) = 150 HF =10ms
  - BFN is Synchronization Signal every 10msec
  - 256BF/HF*150HF/0.01s=3.84M BF/s
  - 16W/BF*3.84M BF/s=61.44M W/s. So a word width is ½ BBCLK cycle.
  - BBCLK = 30.74 MHZ SYSCLK, Link Speed multiple of BBCLK

Frame Structure of 2.4576Gbps

<table>
<thead>
<tr>
<th>Line rate [Gbps]</th>
<th>Line code</th>
<th>Byte per word</th>
<th>Bit per word</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2288</td>
<td>8b10b</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>2.4576</td>
<td>8b10b</td>
<td>4</td>
<td>32</td>
</tr>
<tr>
<td>4.9152</td>
<td>8b10b</td>
<td>8</td>
<td>64</td>
</tr>
<tr>
<td>9.8304</td>
<td>8b10b</td>
<td>16</td>
<td>128</td>
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<tr>
<td>10.1376</td>
<td>64b66b</td>
<td>20</td>
<td>160</td>
</tr>
<tr>
<td>CPRI line bit rate option</td>
<td>Bit Rate</td>
<td>Line Coding</td>
<td></td>
</tr>
<tr>
<td>---------------------------</td>
<td>------------------</td>
<td>--------------------------------------</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>614.4 Mbit/s</td>
<td>8B/10B line coding (1 x 491.52 x 10/8 Mbit/s)</td>
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</tr>
<tr>
<td>2</td>
<td>1228.8 Mbit/s</td>
<td>8B/10B line coding (2 x 491.52 x 10/8 Mbit/s)</td>
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</tr>
<tr>
<td>3</td>
<td>2457.6 Mbit/s</td>
<td>8B/10B line coding (4 x 491.52 x 10/8 Mbit/s)</td>
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</tr>
<tr>
<td>4</td>
<td>3072.0 Mbit/s</td>
<td>8B/10B line coding (5 x 491.52 x 10/8 Mbit/s)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4915.2 Mbit/s</td>
<td>8B/10B line coding (8 x 491.52 x 10/8 Mbit/s)</td>
<td></td>
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<tr>
<td>6</td>
<td>6144.0 Mbit/s</td>
<td>8B/10B line coding (10 x 491.52 x 10/8 Mbit/s)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>9830.4 Mbit/s</td>
<td>8B/10B line coding (16 x 491.52 x 10/8 Mbit/s)</td>
<td></td>
</tr>
<tr>
<td>7A</td>
<td>8110.08 Mbit/s</td>
<td>64B/66B line coding (16 x 491.52 x 66/64 Mbit/s)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>10137.6 Mbit/s</td>
<td>64B/66B line coding (20 x 491.52 x 66/64 Mbit/s)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>12165.12 Mbit/s</td>
<td>64B/66B line coding (24 x 491.52 x 66/64 Mbit/s)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>24330.24 Mbit/s</td>
<td>64B/66B line coding (48 x 491.52 x 66/64 Mbit/s)</td>
<td></td>
</tr>
</tbody>
</table>
Converged Fronthaul
Traditional Fronthaul Deployment Options are Sub-Optimal for 5G

- Very expensive solution
- Difficult to scale
- Fiber may not be available everywhere

- Limited lambda (λ) scale
- Manual deployments that are time consuming and error prone
- No visibility of the service making it difficult to troubleshoot
- No redundancy

- Expensive due to colored optics
- Active tunable optics have challenge with I-TEMP
- No Statistical Mux
- Topology dependent (Requires ROADM for ring architecture)
What is Converged Fronthaul?

- Converged fronthaul implies transporting radio traffic, CPRI, eCPRI and enterprise traffic at the same time.
- Major challenge: Radio traffic requires low latency and enterprise traffic can induce additional latency impacting mobile user experience.
- Existing optical fronthaul technologies cannot deliver cost-effective solution.
# Universal Port Configuration

<table>
<thead>
<tr>
<th>PID</th>
<th>Port Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>N540-FH-CSR-SYS</td>
<td>8xCPRl (Option 3–8) + 4x1/10G Eth/CPRl (Option 3–8) + 2x10/25G TSN + 8x1/10G Eth +</td>
</tr>
<tr>
<td></td>
<td>4x1/10/25G + 2x100G</td>
</tr>
<tr>
<td>N540-FH-AGG-SYS</td>
<td>Port Configuration</td>
</tr>
<tr>
<td></td>
<td>• 24xCPRl (Option 3–8) + 4x100G</td>
</tr>
<tr>
<td></td>
<td>• 24x1/10/25G Eth (TSN) + 4x100G</td>
</tr>
<tr>
<td></td>
<td>• 18xCPRl (Option 3–8) + 6x1/10/25G Eth (TSN) + 4x100G</td>
</tr>
<tr>
<td></td>
<td>• 12xCPRl (Option 3–8) + 12x1/10/25G Eth (TSN) + 4x100G</td>
</tr>
<tr>
<td></td>
<td>• 6xCPRl (Option 3–8) + 18x1/10/25G Eth (TSN) + 4x100G</td>
</tr>
</tbody>
</table>
Flexible & Fully Programmable Architecture
To support evolving radio standards

Field Programmable Gate Array (FPGA) for evolving RAN

- **Flexible platform** to address both short term and long-term requirement for CPRI, eCPRI and RoE
- **Optimized for RoE** type 0 and type 1
- **Future proofed** to allow operators to add new RAN functions and interworking scenarios

IOS XR

IOS-XR Based - Open APIs

- **Common operating system software** across the physical and virtual platforms
- **Optimized performance** for advanced features: SR, EVPN, security
- **Improved service visibility** with telemetry

Adaptable platform to address emerging requirements
Field Upgradeable FPGA

- FPGA is a programmable Phy/Optical front end in Cisco fronthaul router. Hence the same part can be reprogrammed into one of the following modes.
- To change the personality of the device, router software will load the appropriate bit file to the config flash and perform a reload of the product.
Radio over Ethernet (RoE)

RoE Mappers – To carry Radio Traffic over Packet Network

Structure Agnostic RoE Mapper
Function that converts other transport framing formats to a RoE framing format, and a RoE De-Mapper performs the opposite function. This mapper captures bits from one end of a constant bit rate link, packetizes the bits into Ethernet frames, sends the packets across the network, and then recreates the bit stream at far end of the link.

Type-0
✓ Works as a simple Ethernet Tunnel.
✓ Does not remove any Line Coding bits, doesn’t interpret any special characters
✓ If source data is 8B/10B encoded, the 10-bit symbols present on the line will be tunneled by the Mapper as 10 bits data

Type-1
✓ Works as Line Coding Aware Mode
✓ Removes Line Codes and Adds them back
✓ If Source Data is 8B/10B encoded, after decoding process, the 8-bit symbols present on the line will be tunneled by the Mapper as 8-bits
✓ On the other side, the 8-Bit will be encoded back to 10-Bits using standard Coding scheme.
Figure 7—RoE encapsulation in Ethernet frames
Table 3—RoE subType values

<table>
<thead>
<tr>
<th>Binary value</th>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000 0000b</td>
<td>RoE control subtype</td>
<td>RoE message that contains control or management information.</td>
</tr>
<tr>
<td>0000 0001b</td>
<td>Reserved1</td>
<td>Reserved for future use by IEEE Std 1914.3. Reserved subType values shall not be transmitted. RoE messages with Reserved subTypes shall be ignored on receipt.</td>
</tr>
<tr>
<td>0000 0010b</td>
<td>RoE structure-agnostic data subtype</td>
<td>Data payload packet with RoE common frame header and structure-agnostic payload.</td>
</tr>
<tr>
<td>0000 0011b</td>
<td>RoE structure-aware CPRI data subtype</td>
<td>Data payload packet with RoE common frame header and structure-aware CPRI I/Q data.</td>
</tr>
</tbody>
</table>
# CPRI RoE Type 0 Capture

## Source: IEEE 1914.3

| Frame 24 | 2604 bytes on wire (26832 bits), 2604 bytes captured (26832 bits) on interface ens192, id 0 |
| Ethernet II, Src: Cisco_43:b4:19 (d4:6a:35:43:b4:19), Dst: Cisco_ff:be:1c (4c:71:0d:ff:be:1c) |
| MultiProtocol Label Switching Header, Label: 24083, Exp: 0, S: 1, TTL: 255 |
| 0000 0101 1010 1100 0011 .... .... .... .... .... .... .... .... .... = MPLS Label: 24083 |
| 0000 0101 1010 1100 0011 .... .... .... .... .... .... .... .... .... = MPLS Experimental Bits: 0 |
| 0000 0101 1010 1100 0011 .... .... .... .... .... .... .... .... .... = MPLS Bottom Of Label Stack: 1 |
| PM Associated Channel Header: |
| .... 0010 = Channel Version: 2 |
| Reserved: 0x34 |
| Channel Type: Unknown (0x5676) |
| Data (2562 bytes) |
| Data: abcddaaaaabccccfccc3027b0a00000830920053e5af3677... |
| [Length: 2562] |

| Frame 25 | 2600 bytes on wire (26064 bits), 2600 bytes captured (26064 bits) on interface ens192, id 0 |
| Ethernet II, Src: Cisco_ff:be:1c (4c:71:0d:ff:be:1c), Dst: Cisco_43:b4:19 (d4:6a:35:43:b4:19) |
| MultiProtocol Label Switching Header, Label: 100004, Exp: 0, S: 0, TTL: 255 |
| 0001 1000 0110 1010 0100 .... .... .... .... .... .... .... .... .... = MPLS Label: 100004 |
| 0000 0101 1010 1100 0011 .... .... .... .... .... .... .... .... .... = MPLS Experimental Bits: 0 |
| 0000 0101 1010 1100 0011 .... .... .... .... .... .... .... .... .... = MPLS Bottom Of Label Stack: 0 |
| MultiProtocol Label Switching Header, Label: 24006, Exp: 0, S: 1, TTL: 255 |
| 0000 0101 1100 1100 0010 .... .... .... .... .... .... .... .... .... = MPLS Label: 24006 |
| 0000 0101 1100 1100 0010 .... .... .... .... .... .... .... .... .... = MPLS Experimental Bits: 0 |
| 0000 0101 1100 1100 0010 .... .... .... .... .... .... .... .... .... = MPLS Bottom Of Label Stack: 1 |
| Data (2556 bytes) |
| Data: 334b12345678abdfc3d025a00000c302800... |
| [Length: 2556] |
## Type0/Type1 RoE Packetization Overhead Comparison

<table>
<thead>
<tr>
<th></th>
<th>Type-0</th>
<th>Type-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real CPRI data (CPRI data+linecoding)</td>
<td>2560</td>
<td>2560</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Packet size after CPRI frame</td>
<td>2560 B</td>
<td>2048 (8b10b Line coding removed)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RoE Ethernet Header</td>
<td>14B</td>
<td>14B</td>
</tr>
<tr>
<td>RoE Header</td>
<td>8B</td>
<td>8B</td>
</tr>
<tr>
<td>Cisco Custom Header</td>
<td>4B</td>
<td>4B</td>
</tr>
<tr>
<td>MPLS+PW label + CW</td>
<td>4B+4B +4B</td>
<td>4B+4B +48</td>
</tr>
<tr>
<td>Outer Ethernet Header</td>
<td>18B</td>
<td>18B</td>
</tr>
<tr>
<td>Total Ethernet Packet Size at NNI</td>
<td>56B+2560=2616 B</td>
<td>56B+2048B=2104 B</td>
</tr>
<tr>
<td>RoE Packetization Overhead</td>
<td>(2616-2560)*100/2560=2.2%</td>
<td>(2104 - 2048)*100/2048= 2.73%</td>
</tr>
</tbody>
</table>

RoE packetization overhead is SAME regardless of Type 0 and Type 1.
Type0/Type1 NNI egress Interface Traffic Rate Comparison

<table>
<thead>
<tr>
<th>Type-0 NNI Interface Bandwidth</th>
<th>Type-1 NNI Interface Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPRI Option 7 = 9.83 Gbps RoE Packet size = 1024 bytes</td>
<td>10.32 Gbps</td>
</tr>
</tbody>
</table>

Type1 enables 20% Fronthaul Bandwidth Reduction
CPRI RoE Structure Type 0 Enhancements

• Auto negotiation feature
  • Detection of CPRI stream, then enable RoE Transmission

• LOS/LOF propagation to remote packet based fronthaul router
  • Packet transport situation awareness

• Delay measurement and Windowing Function
  • Retiming
  • Packet impairment

• Cisco 1914.3 a contribution (planned to be published later this year)

• RoE Yang models
Cisco 5G Converged SDN Transport

5G Services
- Enhanced Mobile Broadband (eMBB)
- Massive Machine Types Communications (mMTC)
- Ultra-Reliable and Low Latency Communications (URLLC)

Service Orchestration & Programmability
- Cisco Crosswork Portfolio

Service
- Ethernet VPN (EVPN) and L3VPN

Transport
- SR MPLS/SRv6, H-QOS & SR PM Clocking (1588/ SyncE – Phase and Frequency, G8275.1, Class C)
# L3 and L2 Network Efficiencies Are Almost Same!

<table>
<thead>
<tr>
<th>Data</th>
<th>Packet Overhead</th>
<th>1500 Bytes Packet</th>
<th>2000 Bytes Packet</th>
<th>9000 Bytes Packet</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2 Only</td>
<td>42</td>
<td>1542</td>
<td>2042</td>
<td>9042</td>
</tr>
<tr>
<td>(IFG+Preamble+Ethernet+Dot1 Q+CRC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L2VPN</td>
<td>64</td>
<td>1564</td>
<td>2064</td>
<td>9064</td>
</tr>
<tr>
<td>IFG+Preamble+Ethernet+MPLS 2 Labels+Ethernet</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L3VPN</td>
<td>66</td>
<td>1566</td>
<td>2066</td>
<td>9066</td>
</tr>
<tr>
<td>IFG+Preamble+Ethernet+MPLS 2 Labels+IP</td>
<td></td>
<td></td>
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</table>

**Network Efficiency**

<table>
<thead>
<tr>
<th>Data</th>
<th>L2 Only</th>
<th>L2VPN</th>
<th>L3VPN</th>
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<tbody>
<tr>
<td>Efficiency</td>
<td>97.28</td>
<td>95.91</td>
<td>95.79</td>
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<tr>
<td></td>
<td>97.94</td>
<td>96.89</td>
<td>96.80</td>
</tr>
<tr>
<td></td>
<td>99.53</td>
<td>99.29</td>
<td>99.27</td>
</tr>
</tbody>
</table>
Precise Timing and Synchronization
Accurate and reliable timing for 5G networks

CPRI protocol delivers Sync

How do we deliver Sync for 5G networks?

ANSWER
Advanced throughput optimization techniques such as Inter-Cell Interference Cancelation, MIMO coordinated multi-point data delivery require precise time synchronization.

- CPRI protocol delivers synchronization natively, eCPRI/RoE does not.
- eCPRI use cases require RAN transport to provide accurate phase and frequency synchronization

Cisco Fronthaul Routers support **stringent phase and frequency synchronization** requirements with up to **Class C timing** capabilities
Timing and Synch – Fronthaul Options contd..

Full RAN

eNB

Aware transport carries time
Also delivers redundancy
GPS at time-isolated sites

Pre-Agg

RU/DU on site

RU/DU

GPS can be on either end of PTP aware transport link

Pre-Agg

RU/DU

Aware transport carries time
Also delivers redundancy
CU doesn’t need phase

Pre-Agg

RU

Aware transport carries time
Also delivers redundancy
CU doesn’t need phase

Pre-Agg

Sync Unaware

Sync Aware

Fronthaul

Midhaul

Backhaul

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**Time Synchronization for RAN Use Cases**

Transmission Diversity
±32.5ns Phase Accuracy
Improves error performance
Data Rate or Capacity

Carrier Aggregation
±65ns Phase Accuracy
Higher Pick Date Rate
Better Load Balancing

Case 1 = T-TSC is integrated in eRE
- Case 1.1 = integrated T-TSC requirements to T-TSC Class B
- Case 1.2 = enhanced integrated T-TSC requirement is total max |TE| is 15 ns

Case 2 = T-TSC is not integrated in eREs
- Case 2

<table>
<thead>
<tr>
<th>Category</th>
<th>Time Error Requirements at UNI</th>
<th>3GPP TAE requirements at antenna ports</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Case 1</td>
<td>Case 2</td>
</tr>
<tr>
<td></td>
<td>Case 1.1</td>
<td>Case 1.2</td>
</tr>
<tr>
<td>A+</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>20 ns Relative</td>
<td>65 ns</td>
</tr>
<tr>
<td>A</td>
<td>N.A.</td>
<td>60 ns Relative</td>
</tr>
<tr>
<td></td>
<td>70 ns Relative</td>
<td>130 ns</td>
</tr>
<tr>
<td>B</td>
<td>100 ns Relative</td>
<td>190 ns Relative</td>
</tr>
<tr>
<td></td>
<td>200 ns Relative</td>
<td>260 ns</td>
</tr>
<tr>
<td>C</td>
<td>1100 ns Absolute</td>
<td>1100 ns Absolute</td>
</tr>
<tr>
<td></td>
<td>3 µs</td>
<td></td>
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</tbody>
</table>

* 3GPP TS 38.104, 38.133

**Transmission Diversity**

**Carrier Aggregation**

**Coordinated Multi Point**

±130ns Phase Accuracy
Higher Pick Date Rate
Better Load Balancing

---

**Transmission Diversity**

±32.5ns Phase Accuracy
Improves error performance
Data Rate or Capacity

**Carrier Aggregation**

±65ns Phase Accuracy
Higher Pick Date Rate
Better Load Balancing

**Coordinated Multi Point**

±130ns Phase Accuracy
Higher Pick Date Rate
Better Load Balancing
Low PHY Function in Cisco Fronthaul router

- CPRI to eCPRI conversion (Time domain to Frequency Domain)
- 4G radio to connect to Split 7 vDU
- Low PHY function in fronthaul router FPGA
- RAN vendor partnership required
RAN Programmability

- Passive DWDM topology is static, failure of a baseband unit requires a site visit to recover the cell
- Using NSO customer can dynamically reconfigure a redundant BBU at the hotel site and rehome the VPWS to recover cell if primary BBU fails
- N+1 BBU deployed at BBH site, with only management config (IP, credentials etc.)
- NSO models and syncs the config of all the baseband units
- In the event of BBU failure, NSO will push failed BBU config at N+1 BBU and migrate VPWS to N+1 BBU
Ring/Partial Ring CRAN topologies

- Enable redundant routed path for fronthaul sites for TI-LFA when Fronthaul link fails
- Use SR-TE + SR-PM to ensure latency constraint met over redundant path
- Enable Capacity management if insufficient fronthaul bandwidth to support both sites, option to disable a band (i.e., disable VPWS) at non-failed site to free up capacity for that same band at failed site
Transport redundancy

- Primary and backup paths might have different transport latencies.
- During a failure there will be traffic outage up to 50ms.
- Idle CPRI frames are sent during packet outage.
- If backup path’s latency within +/- 5usec of primary path’s latency, CPRI stream can be gracefully restarted.
- If the backup path’s latency is outside that window, in this case the HFN/BNF order cannot be maintained and CPRI reset needs to be asserted.
- CPRI will undergo reset and re-establish with updated parameters.
Retimer Buffer

- RoE to CPRI demapper in Cisco fronthaul router has re-timer buffer to cleanup jitter and reordering in the packet transport network.
Fronthaul Technologies Support Summary

- Supported in hardware (FPGA) and Software
- Hardware (FPGA) capable of functionality, FPGA firmware & software are in roadmap

Diagram:
- Radio Interfaces
  - eCPRI
    - 1914.1/1914.3 Radio over Ethernet (RoE)
  - Structure Agnostic
  - Structure Aware
    - Low PHY Function
    - CPRI to eCPRI conversion
  - Type 0
  - Type 1
    - Structure aware (RAN vendor CPRI protocol Awareness)
Converged Services
Optimizing transport performance for fronthaul applications

- **Converge services** onto a single transport network.
- **Segment Routing** provides traffic steering and policing capabilities to optimize traffic path based on static and/or dynamic computations including latency.
- **Frame preemption** with 802.1Qbu/TSN assures that Fronthaul and Midhaul traffic can be prioritized over less latency sensitive flows.
Time Sensitive Networking 802.1CM
Ethernet for Fronthaul

• **Profile A:** Strict priority queuing (no frame pre-emption)
  • IQ data traffic belongs to strict priority traffic class - strict priority algorithm
  • C&M data assigned to lower priority than IQ data

• **Profile B:** 802.1Qbu Frame Pre-emption
  • Strict Priority Queuing + Frame Pre-emption
  • IQ data traffic configured *(frame pre-emption status)* as “express”
  • C&M data assigned to lower priority than IQ data and set “pre-emptable”
  • Frame Preemption up to 25G links
802.1Qbu (TSN)

- Converged platform will have mix of fronthaul and enterprise traffic towards NNI.
  - FH radio traffic can get behind jumbo-packets of enterprise flows (9600 bytes) leading to additional latency
- 802.1Qbu should only be supported on uplink interfaces only and will be supported on 10G/25G interfaces
- Strict Priority + Preemption Offers lowest fronthaul latency and greatest BW utilization
- 802.1Qbu is NOT required on 100G interface
- Frame Preemption is a book-ended solution
- Requires hardware implementation

<table>
<thead>
<tr>
<th>Port Rate</th>
<th>Without Frame Preemption delay (1500 bytes delay)</th>
<th>Without Frame Preemption delay (9600 bytes delay)</th>
<th>With Frame Preemption (123 bytes delay)</th>
<th>Frame Preemption Advantage (compared to 9600 bytes delay)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1G</td>
<td>12,000 nsec</td>
<td>76,800 nsec</td>
<td>984 nsec</td>
<td>~ 75 usec</td>
</tr>
<tr>
<td>10G</td>
<td>1,200 nsec</td>
<td>7,680 nsec</td>
<td>98.4 nsec</td>
<td>~ 7.5 usec</td>
</tr>
<tr>
<td>25G</td>
<td>480 nsec</td>
<td>3,072 nsec</td>
<td>39.36 nsec</td>
<td>~3 usec</td>
</tr>
<tr>
<td>100G</td>
<td>120 nsec</td>
<td>768 nsec</td>
<td>9.84 nsec</td>
<td>758 nsec</td>
</tr>
</tbody>
</table>
Supported Features (Partial List)

- RoE Structure—Agnostic Tunneling Mode (Type 0)
- RoE Structure—Agnostic Line Code Aware Mode (Type 1)
- TSN 802.1Qbu 10/25G
- Class C Clocking
- SR MPLS/SRv6
- BGP VPN (EVPN/L3VPN)
- Clocking – Class C, G.8275.1
- GTP load balancing
- Y1564 (Service Activation)
- Zero Touch Provisioning
- Microwave Adaptive Bandwidth – "Ethernet bandwidth notification (ETH-BN) / G.8013 Bandwidth Notification Messages"
- Telemetry
Fronthaul Design
CPRI / eCPRI Bandwidth Calculation Factors

- **CPRI**
  - “Number of antennas” has an impact on the bit rate for split E (Split 8)

- **eCPRI (Split 7)**
  - Factors that will have an impact on the final needed bit rate of the link between eREC and eRE.
    - Throughput (closely related to the available and used air bandwidth)
    - Number of MIMO-layers
    - MU-MIMO support (y/n)
    - Code rate
    - Modulation scheme
    - Beamforming algorithm
    - Number of antennas
# Fronthaul/Midhaul/Backhaul Transport Bandwidth Calculation

## LTE CPRI

<table>
<thead>
<tr>
<th>Carrier (Band Number)</th>
<th>Number of Sectors</th>
<th>Band</th>
<th>Sub Carrier Spacing (SCS) Numerology</th>
<th>Bandwidth [MHz]</th>
<th>CPRI Option</th>
<th>MIMO (Number of Antennas)</th>
<th>CPRI Mux (if any) CPRI mux configuration details</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>15kHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- For CPRI fronthaul bandwidth calculation, there is no stat–mux in fronthaul since CPRI is TDM traffic.
  - This means if there is CPRI option 7 between REC and RE
    - Packet based fronthaul must support “10G+RoE overhead” bandwidth to carry CPRI option 7 traffic
- Midhaul & backhaul calculation will take into account stat–mux

## 4G/5G eCPRI/ORAN

<table>
<thead>
<tr>
<th>Carrier (Band Number)</th>
<th>Number of Sectors</th>
<th>4G/5G</th>
<th>Band</th>
<th>Sub Carrier Spacing (SCS) Numerology</th>
<th>Bandwidth [MHz]</th>
<th>MIMO Layers</th>
<th>MIMO (Number of Antennas/ Antenna Elements in case of Massive MIMO)</th>
<th>Radio Unit Interface Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>15kHz or 30kHz (&lt; 6 GHz) 120kHz or 240kHz (&gt; 24 GHz)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- eCPRI supports stat–mux
  - Stat–mux fronthaul calculation in case of three sectors, 1 Peak + 2 Average (50% of peak)
- Midhaul & backhaul calculation will take into account stat–mux
#CiscoLive

Fronthaul/Midhaul/Backhaul Calculation
Single Cell Site/3 Sector 6 Carriers

<table>
<thead>
<tr>
<th>Band Number</th>
<th>Band</th>
<th>Bandwidth [MHz]</th>
<th>MIMO/MIMO Layers</th>
<th>Fronthaul Data Rate (Single Sector Peak) CPRI/ORAN Gbps</th>
<th>FH Data Rate (*3&quot; Sectors) CPRI/ORAN Gbps</th>
<th>Midhaul Gbps</th>
<th>Backhaul Gbps</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>850</td>
<td>10</td>
<td>4T4R</td>
<td>2.45 (CPRI option 3)/0.70</td>
<td>7.35/1.40</td>
<td>0.30</td>
<td>0.25</td>
</tr>
<tr>
<td>8</td>
<td>900</td>
<td>10</td>
<td>4T4R</td>
<td>2.45 (CPRI option 3)/0.70</td>
<td>7.35/1.40</td>
<td>0.30</td>
<td>0.25</td>
</tr>
<tr>
<td>9</td>
<td>1.8G</td>
<td>20</td>
<td>4T4R</td>
<td>4.9 (CPRI option 5)/1.40</td>
<td>14.7/2.80</td>
<td>0.59</td>
<td>0.50</td>
</tr>
<tr>
<td>41</td>
<td>2.6G</td>
<td>20</td>
<td>4T4R</td>
<td>9.8 (CPRI option 7)/1.40</td>
<td>29.4/2.80</td>
<td>0.59</td>
<td>0.50</td>
</tr>
<tr>
<td>n78</td>
<td>3.5G</td>
<td>100</td>
<td>64T64R/8 layers</td>
<td>15.29</td>
<td>30.59</td>
<td>4.44</td>
<td>3.78</td>
</tr>
<tr>
<td>n257 (Split 2)</td>
<td>28G</td>
<td>400</td>
<td>128T128R/4 layers</td>
<td>NA</td>
<td>NA</td>
<td>6.14</td>
<td>5.22</td>
</tr>
</tbody>
</table>

**Total**

- Fronthaul Interface Required=100G/50G
- Midhaul Interface Required=25G
- Backhaul Interface Required=25G

FH=LTE CPRI+NR=89.39 Gbps

12.36 Gbps | 10.5 Gbps

PRB=Physical Resource Block
Statistical Multiplexing (Statmux)=1Max+2 Average

Fronthaul Interface Required=100G/50G
Midhaul Interface Required=25G
Backhaul Interface Required=25G
Maximum transmission bandwidth configuration 38.101
FR1 : below 6 GHz

Sub Carrier Spacing (SCS) Numerology

Channel bandwidth PRB Values

<table>
<thead>
<tr>
<th>μ</th>
<th>SCS (kHz)</th>
<th>5 MHz</th>
<th>10 MHz</th>
<th>15 MHz</th>
<th>20 MHz</th>
<th>25 MHz</th>
<th>30 MHz</th>
<th>40 MHz</th>
<th>50 MHz</th>
<th>60 MHz</th>
<th>70 MHz</th>
<th>80 MHz</th>
<th>90 MHz</th>
<th>100 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>15</td>
<td>25</td>
<td>52</td>
<td>79</td>
<td>106</td>
<td>133</td>
<td>160</td>
<td>216</td>
<td>270</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>1</td>
<td>30</td>
<td>11</td>
<td>24</td>
<td>38</td>
<td>51</td>
<td>65</td>
<td>78</td>
<td>106</td>
<td>133</td>
<td>162</td>
<td>189</td>
<td>217</td>
<td>245</td>
<td>273</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>N/A</td>
<td>7.9</td>
<td>13</td>
<td>17.3</td>
<td>22.3</td>
<td>27.4</td>
<td>36.7</td>
<td>46.8</td>
<td>56.9</td>
<td>67</td>
<td>77</td>
<td>87.1</td>
<td>97.2</td>
</tr>
</tbody>
</table>
Maximum transmission bandwidth configuration 38.101
FR2 : above 24 GHz

<table>
<thead>
<tr>
<th>µ</th>
<th>SCS (kHz)</th>
<th>50 MHz</th>
<th>100 MHz</th>
<th>200 MHz</th>
<th>400 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>60</td>
<td>66</td>
<td>132</td>
<td>264</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>47.5</td>
<td>95</td>
<td>190.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1210</td>
<td>2450</td>
<td>4930</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>120</td>
<td>32</td>
<td>66</td>
<td>132</td>
<td>264</td>
</tr>
<tr>
<td></td>
<td></td>
<td>46.1</td>
<td>95</td>
<td>190.1</td>
<td>380.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1900</td>
<td>2420</td>
<td>4900</td>
<td>9860</td>
</tr>
</tbody>
</table>

\[ N_{RB} \text{ max}, BW = \text{channel bandwidth}, GB = \text{minimum guardband} \]

Source: https://www.sqimway.com/store_nr.php
Fronthaul Network Design Options

Fronthaul Fabric Design

- **4G RRH**
  - 10G CPRI over RoE
  - 10G eCPRI Low PHY

- **5G/4G RRH**
  - 10/25G CPRI over RoE

- **NCS5500**
  - 100G

- **5G BBU**
  - CPRI over RoE
  - 100G/25G
  - 5G vDU/vCU (7-2x)
  - 4G vDU/vCU (7-2x)

- **4G BBU (CPRI)**
  - 100G/25G

- **CPRI over RoE**

- **eCPRI**

- **Low PHY**

- **Backhaul Interface**

- **Midhaul/Backhaul Interface**

- **10G**

- **10/25G**

- **100G**

- **100G/25G**
Open & Automated Management
Outcome-driven automation

Flexible NSO function packs
To automate provisioning of multi-vendor domains

Open APIs and management interfaces
To enable full operational lifecycle of the products

Cisco Crosswork Portfolio
To provide full suite of FCAPs applications

Closed-loop and outcome-driven automation, on premises and in the cloud.
Simple integration into legacy RAN management domains & other NMS/OSS systems