OPEN Compute Project

Fronthaul Gateway (FHG) Requirements and Use Cases

Revision 1.0

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Revision History

Revision	Date	Author	Description
1.0	7/10/19	Mike Meche	Initial Draft

Contents

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Scope

AT&T has documented technical requirements and use cases for two network devices:1) Fronthaul Gateway (FHG) and 2) Converged Access Switch (CAS) to provide multi-service wireline and wireless service aggregation and transport. The FHG performs a conversion of CPRI to Ethernet using Radio over Ethernet (RoE, IEEE 1914.3) standards, as well as, CPRI/eCPRI interworking, commonly known as Low-PHY offloading, using the O-RAN open fronthaul interface. The CAS is a next generation access aggregation switch based on new Time Sensitive Networking (TSN, IEEE 802.1CM) while acting as an Edge Grand Master (GM) with Primary Reference Time Clock (PRTC). This document specifically addresses the FHG. The details of the CAS are provided in a separate specification. However, both devices will be discussed in the description of the use cases and network architecture.

This document provides requirements and use cases as a guideline for a detailed manufacturing specification to be developed.

Overview

To maximize RAN resources, many carriers are re-architecting portions of their networks into a CRAN (Centralized-RAN) architecture by co-locating baseband units (BBU) in centralized locations (CRAN HUB). The CRAN architecture applies Data Centre Network technologies to allow a low cost, high reliability, low latency, high bandwidth flexible interconnected baseband "Pool" (BBU Pooling). BBU pooling allows for efficient joint processing or CoMP (Coordinated Multi-Point) communications between BBUs and higher utilization of BBU resources which provides CapEx and OpEx savings.

The FHG provide RAN vendor agnostic fronthaul transport on an Open White Box Platform meeting the low latency requirements for fronthaul traffic. FHG eliminates many of the challenges in deploying a CRAN architecture by providing the ability to packetize and aggregate mobile fronthaul traffic over a common physical Ethernet interface that is easily switchable, as well as, being less expensive than alternative solutions such as Dense Wavelength Division Multiplexing (DWDM), for example. The FHG deployed at remote tower locations will be connected by dark fiber to the CAS devices deployed at CRAN hub locations, which will switch fronthaul traffic to the vDU (potentially 4G/5G BBU initially) as well as provide Class C timing and synch to the remote FHG devices.

In support of mobility transport, the FHG will aggregate fronthaul traffic from LTE or 5G radios using the Common Public Radio Interface (CPRI) and 5G NR radios using (eCPRI) over a common high-speed Ethernet transport link. All the new features specified in IEEE 802.1CM-2018 to control packet delay and packet delay variation such as TSN frame preemption (IEEE 802.1Qbu), along with traditional Ethernet traffic prioritization and QOS capabilities are included in the FHG feature set.

The FHG must operate with new high accuracy fronthaul synchronization and timing requirements (IEEE STD 802.1CM-2018 Category A, ITU-T G.8273.2 T-BC, Class C) to ensure error-free operation of new 5G and cooperative radio techniques. All FHG nodes used for fronthaul transport must operate as telecom boundary clocks with full timing support (ITU-T G.8275.1, ITU-T G.8262.1, ITU-T G.8273.2-Class C). Additionally, a CAS deployed at a CRAN hub site will act as Edge GM with PRTC, distributing phase and time accuracy via Precision Time Protocol (PTP) (ITU-T G.8275.1), in accordance with ORAN Config 3, to both Rus and BBU/vDU pools. In the event of GPS outage, the FHG will be able to failover to receive PTP from a Core GM via ITU-T G.8275.2 with Assisted Partial Timing Support (APTS), ITU-T G.8273.4 in order to maintain fronthaul synchronization.

Radio-over-Ethernet (RoE, IEEE 1914.3) standard defines the requirements for mapping and encapsulation of LTE CPRI/OBSAI traffic to Ethernet. FHG specifications also includes functionality to convert a CPRI stream into O-RAN compliant eCPRI. This CPRI to eCPRI conversion is accomplished by moving the lower portion of the PHY layer processing that currently occurs in the 4G BBUs and distributing it to the FHG node. The FHG may support either or both RoE and/or Low PHY features.

System Overview

This document describes the technical specifications of the FHG. The FHG is a high-performance, versatile Time-sensitive packet device designed to address the changing needs of the Fronthaul transport requirements as the Mobile Service Providers start to make the transition from legacy 2G, 3G, 4G toward 5G RAN technologies. It has an open hardware with disaggregated software solution offering the following key features:

- The FHG is designed to support CPRI connections to legacy Remote Radio Head (RRH) systems and next generation 5G RU systems with interfaces that operate at {1Gbps/10Gbps/25Gbps}, and aggregates xHaul traffic onto high speed packet-based transport links with bitrates of {25Gbps/100Gbps}.
- FHG is designed to support the mapping procedures as defined in IEEE 1914.3, for mapping CPRI signals via the RoE {Structure-Aware and Structure-Agnostic} mapping and de-mapping. It is designed to support the Low PHY processing functions as defined in O-RAN specification, for decoding CPRI signal and converting it to eCPRI based packet data.
- Support IEEE 802.1Qbu frame pre-emption on network links operating at or below 25Gpbs.
- Multiple form factors have been specified for the FHG. A mountable 1RU that is designed to operate at Industrial temperature range (-40C to + 65C ambient) as well as a hardened outdoor unit to operate at Industrial temperature range (-40C to + 70C ambient).
- IEEE802.1CM standard, Time Sensitive Networking for Fronthaul, published in July 2018.
- IEEE STD 802.1CM-2018 Category A and ITU-T G.8273.2 Class C time/sync requirements for Telecom Boundary Clock
- A separate timing circuitry block supporting a variety of timing Inputs {TOD, 1PPS, 10Mhz} and Timing Outputs to {1PPS} to adapt to the evolving timing requirements and implementations in the 5G technology evolution.

Standards Compliance

The FHG is required to comply with the following principal industry standards and implementation guidelines in Table 1 – Standards Compliance.

Standards Specification	Notes
IEEE STD 802.1CM-2018 Time Sensitive Networking for Fronthaul, Profile A (support strict priority queuing) for Class 1 & 2 (CPRI and eCPRI) traffic	
IEEE STD 802.1CM-2018 Time Sensitive Networking for Fronthaul – Profile B (support IEEE 802.1Qbu frame preemption and IEEE 802.3br	

Interspersed Express Traffic) on ports used as an NNI port whose date rate is not higher than 25Gbps.	
O-RAN WG4, Control, User and Synchronization Plane Specification, for Low PHY functionality and interfaces	
CPRI Specification v7.0 Common Public Radio Interface	
eCPRI specification v1.2, Common Public Radio Interface: eCPRI Interface Specification	
IEEE 1914.1 NGFI node processing time (latency) class A (< 2us for 25-100GbE).	
IEEE 1914.3-2018 Radio over Ethernet Encapsulations and Mappings	
ITU-T G.8262.1 – Timing characteristics of enhanced synchronous Ethernet equipment slave clock	
ITU-T G.8273.2 Telecom Boundary Clock Class C	See Note 1
ITU-T G.8273.4 – Timing characteristics of partial timing support telecom boundary clocks and telecom time slave clocks	
ITU-T G.8275.1 – Precision time protocol telecom profile for phase/time synchronization with full timing support from the network	
ITU-T G.8275.2 – Precision time protocol telecom profile for time/phase synchronization with partial timing support from the network	
Ethernet Service OAM (IEEE 802.1Q/ag, ITU-T Y.1731, MEF17, MEF 30.1, MEF 35.1)	See Note 2

Table 1 – Standards Compliance

Note 1: Because of the criticality of accurately synchronized clocks in delivering error free fronthaul transport of radio channel information, it is necessary to comply with all clauses and subclauses in Sections 7.1 – 7.4 of the ITU-T G.8273.2 standards, covering not only time error noise generation and holdover performance, but also noise tolerance, noise transfer and transient response. Utilizing state-of-the-art devices that support 1ns timestamping accuracy and automatic compensation of the time error created by the 25GbE RS-FEC are necessary to meet these requirements.

Note 2: The implementation guideline is to build this functionality with a hardware assisted design in order to provide carrier grade OAM and avoid restrictions on PDU rates. It is necessary, for example to generate 3.33ms Continuity Check Message (CCM) PDUs for fast failure detection and to process SLM and DM in hardware to accurately measure frame loss ratio, frame delay and frame delay variation.

FHG Network Deployment Architectures

5G mobile network evolution is driving network operators to deploy massive new capacity with 5G NR radios at new and existing LTE radio sites and is enabling network efficiencies by supporting BBU/DU/vDU centralization and virtualization at CRAN Hub sites.

The network architecture for the deployment of the FHG at a CRAN hub is a disaggregated model consisting of Converged Access Switch (CAS) and distribution layers of FHGs. Figure 1 – FHG and CAS Network Architecture show these multiple layers. Both the FHG and CAS must support IEEE STD 802.1CM-2018 Category A and ITU-T G.8273.2 Class C. The FHG, deployed at the tower sites, Pico sites and in the distribution layer at the HUB site, are described in more details in the Physical Design section of this document.

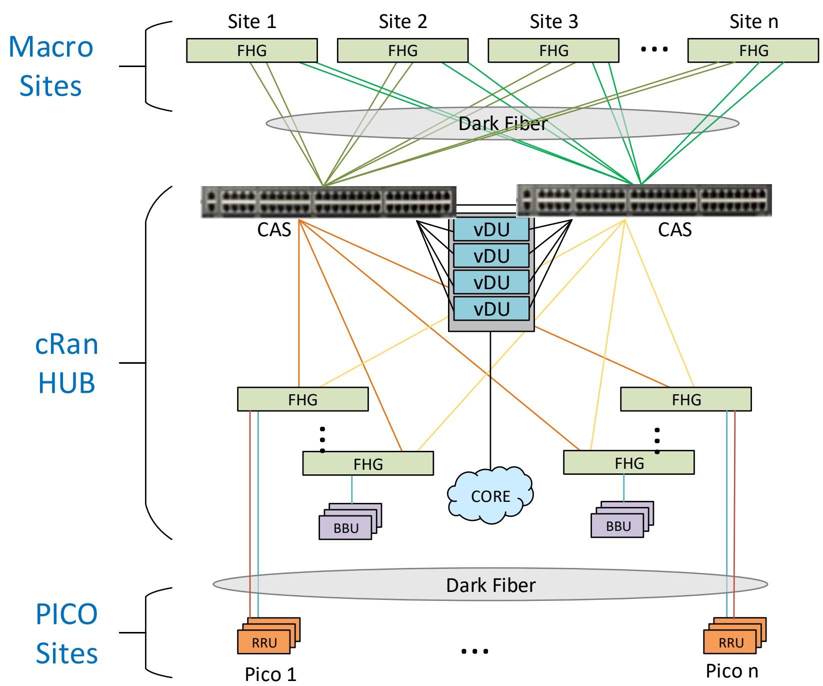

Figure 1 – FHG and CAS Network Architecture

The FHG can support either or both modes of CPRI adaptation: RoE and/or Low PHY. To further clarify the traffic flow within the network architecture, Figure **2** – Traffic Flows illustrates the message paths for the various types of interfaces.

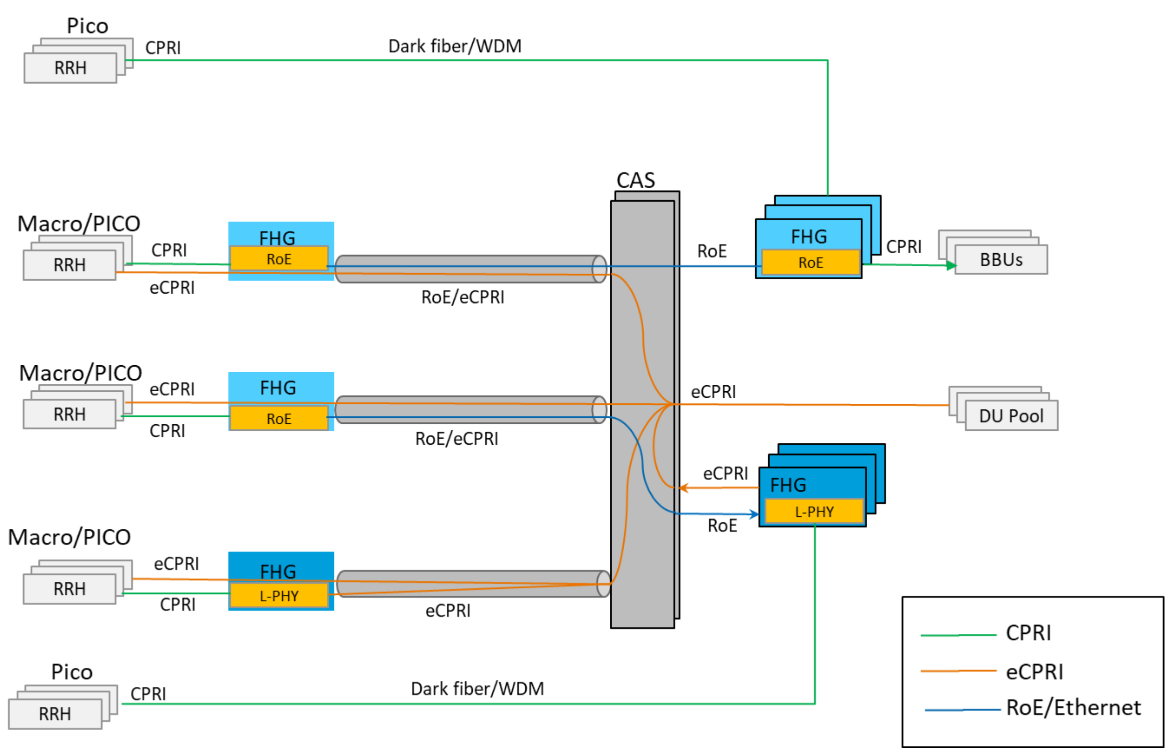

Figure 2 – Traffic Flows

The benefits of these two CPRI adaptations may vary based on the deployment environment. To this end, the document will detail the following deployment environments:

1) Remote Site with Enclosure
2) Remote Site without Enclosure
3) CRAN Hub

Deployment Environments

CRAN HUB

To successfully scale the deployment of the FHG in a CRAN hub site, which must support hundreds of remote towers, the FHGs are deployed in a disaggregated configuration with the CAS being an aggregation point.

FHGs deployed at remote Macro/Micro sites are connected to the CAS device with dark fiber in a point to point type configuration in fiber rich scenarios. Multiple 100GE interfaces may be required to transport the traffic from the remote tower terminating into the CAS. The interfaces may be individual Ethernet – Ethernet connections over dark fiber(s) or may be multiple lambdas carried over a WDM solution in fiber-scarce scenarios.

The CAS will switch eCPRI traffic directly to the 5G BBU / vDU pool. However, the RoE traffic received by the CAS will be switched to an FHG at the distribution layer for conversion from Ethernet to CPRI. Once the conversion to CPRI is completed, the FHG will provide the CPRI stream to the subtended BBU for baseband processing.

For remote locations without an FHG deployment, such as PICO sites, the CPRI and eCPRI interfaces are carried over dark fiber to the Hub and terminated into an FHG at the distribution layer (by-passing the CAS aggregation layer). The FHG at the Hub will switch eCPRI to the CAS and will either covert the CPRI traffic to eCPRI (if Low PHY is supported) or switch the CPRI to the BBU.

Remote Site with Enclosure (Macro/Micro)

The deployment of RRUs within a mobility network occurs at remote sites on various types and sizes of towers, on buildings, and roof tops. These sites can be Macro or Micro deployments. Deployments at these locations, typically provide enclosures where devices such as an FHG can be rack mounted in a 19’ rack. Although the enclosures provide protection from the wind, water and other outside factors, devices deployed in these enclosures must be temperature hardened. Additionally, although these remote enclosures are a typical 19” rack width, the depth is less than that of a data center. FHG deployed in remote enclosures must not exceed 300mm in depth.

Remote Site without Enclosure (PICO)

Small remote (PICO) sites where RRUs are deployed on light or utility poles have far less physical space for the deployment of RAN equipment and do not provide enclosures to house this equipment. Therefore, FHG deployed at a PICO site, must be manufactured to support an outdoor deployment supporting an Ingress Protection rating of IP65.

A mobility carrier may choose to deploy a smaller, hardened version of the FHG at PICO locations or may choose to fronthaul the CPRI from the remote PICO site over dark fiber to a FHG at the CRAN HUB as illustrated in Figure **7** – Low PHY support for PICO as well as what is shown in the Network Architecture in Figure 1 – FHG and CAS Network Architecture.

End to End Network Latency

The mobility network must meet strict end to end latency requirements to ensure the quality of services. For the context of this document, end to end latency is from the egress of the RRU to the BBU and back to the RRU. The processing performed by the BBU is not included in the round-trip time (RTT). The maximum fiber distance between the RRU and BBU is 10km. The round trip (RRT) must not exceed 125 micro seconds.

As described in the Network Architecture section of this document, there could be up to three (3) FHG / aggregation devices between the RRU and the BBU/vDU. The delay budget of 125 micro seconds must include the processing of each of the FHG/aggregation devices between the RRU and BBU. However, Low PHY processing within an FHG is an exception and should not be included in this processing time. This delay budget requirement applies to both CPRI and eCPRI traffic.

Taking into account the (3) devices in the traffic flow path, as well as the time to transmit over the 10km fiber path, each device (FHG and CAS) must be capable of processing each message in less than four (4) micro seconds.

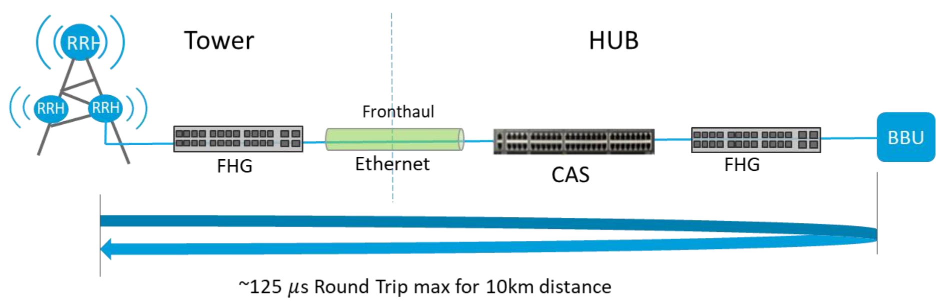

Figure 3– End to End Latency

Use Cases

Use Case: RoE (IEEE 1914.3) Conversion of CPRI into frames

As detailed in the IEEE 1914.3 RoE Standard, the following modes are provided to convert CPRI (applicable for CPRI rates 1-8) into frames for ethernet transport. The average expected packet size for RoE traffic is ~600-700 bytes per packet. The FHG must support all the defined 1914.3 RoE CPRI to Ethernet conversion modes:

1) **Structure-Agnostic (Mapper Type 0) or Tunneling Mode:** Is the simplest of the RoE modes. The CPRI Stream is partitioned and encapsulated into Ethernet frames. In this mode, there is no manipulation of the CPRI structure, therefore specific CPRI details are not required. RoE Tunneling mode is expected to be compatible with all RAN suppliers' equipment. As described, the RoE Tunneling mode does not provide any fronthaul bandwidth reduction.
2) **Structure-Agnostic (Mapper Type 1) or Line Code Aware Mode:** As the CPRI stream is converted to frames, the Line coding information from the 8b/10b CPRI stream is removed. By removing the line code, the fronthaul bandwidth of the resulting Ethernet traffic is reduced by approximately 20 percent. To support this mode, RAN supplier specific information such as AxC frame position and AxC Frame length must be known by the FHG. It may be problematic for RoE Line Code Aware Mode to interwork with all RAN Suppliers' equipment because of proprietary CPRI implementations.
3) **Structure Aware Mode:** Unused AxC containers are removed from the CPRI during the conversion to frames. RoE Structure Aware Mode provides ~46 percent reduction in fronthaul bandwidth reduction in the conversion from CPRI to Ethernet. Structure Aware RoE requires details of the RAN suppliers' CPRI

structure to perform the conversion to frames It may be problematic for RoE Structure Aware Mode to interwork with all RAN Suppliers' equipment because of proprietary CPRI implementations.

To support the RoE conversion, the FHG must be deployed in a bookended or paired configuration where an FHG is located at both the remote radio unit (RRU) as well as at the CRAN Hub. CPRI traffic originated from the RRU terminates at the FHG in the remote location, and the RoE Conversion (mapper) function converts the CPRI to Ethernet (RoE). Once the aggregated Ethernet (RoE) traffic is transported to the FHG in the CRAN Hub, the FHG employs the RoE de-mapper to convert Ethernet back into the original CPRI structure. The FHG must support CPRI 3-8 formats. The FHG then switches the newly reassembled CPRI traffic to the appropriate BBU. Figure 4 – FHG (CPRI to Ethernet Conversion) shows the RoE bookended or paired deployment.

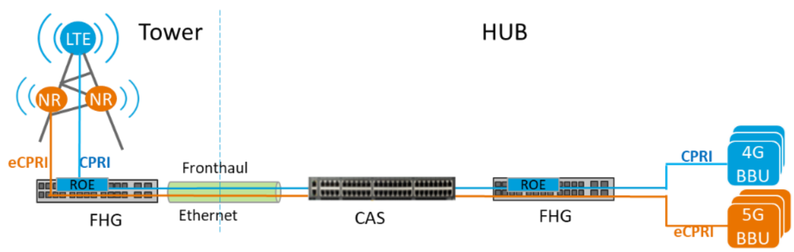

Figure 4 – FHG (CPRI to Ethernet Conversion)

Use Case: Low PHY Conversion of CPRI into eCPRI

The Low PHY function, also known as the "Fronthaul Gateway", facilitates the conversion from CPRI to eCPRI. The Low PHY function can be implemented in the FHG and is standardized in the O-RAN 7.2x functional split. The Low PHY Intellectual Property (IP) or logic to convert the CPRI stream to eCPRI is RAN supplier specific due to the detailed information regarding the CPRI structure used by the RAN supplier. The Low PHY feature is implemented by moving the lowest PHY layer from the BBU into the FHG. The conversion of CPRI to eCPRI will enable the next generation BBUs / vDUs to terminate interfaces that originated from CPRI based RRU in addition to the eCPRI RRUs. The Low PHY feature will facilitate an optimization in the CRAN Hub by eliminating the need for 4G BBUs.

In addition to the financial benefits of the BBU Optimization and Pooling the Low PHY feature provides, there are additional savings/benefits from fronthaul transport bandwidth reductions when deployed at the tower locations (~70 percent) depending on the CPRI AxC fill rate. Low PHY may be deployed co-located at the tower locations or at the CRAN hub. The possible deployment scenarios for an FHG supporting Low PHY are as follows:

Low PHY: Remote Site Deployment

When the Low PHY feature collocates with the RRUs at the tower location, it provides the ability to perform statistical multiplexing as well as significantly reduce the required bandwidth for fronthaul traffic from the tower to the CRAN hub. As mentioned above, the LTE CPRI stream generated by a 4G RRU can then terminate at a vDU with the conversion to eCPRI by the Low PHY function.

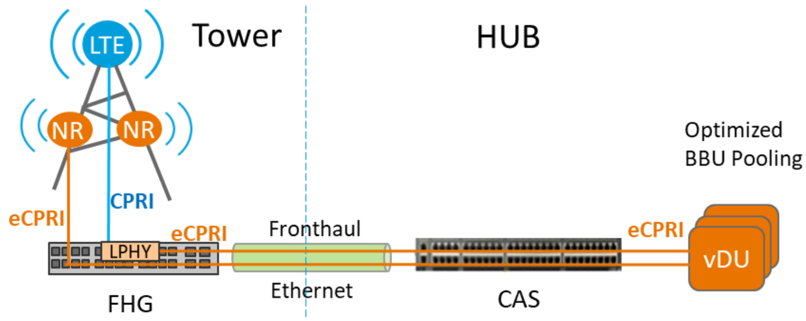

Figure 5 – FHG (CPRI to eCPRI Conversion)

Low PHY: Hub Site Deployment

The Low PHY feature may alternatively deploy at the CRAN Hub site. Low PHY, regardless of deployment location, provides the ability to unify the BBU architecture within the CRAN Hub by allowing legacy 4G LTE radios and 5G NR radios to be serviced by a vDU. With a Hub site deployment of Low PHY, the fronthaul bandwidth reduction is not realized. If Ethernet-Ethernet is a transport protocol between the tower and the Hub, RoE must deploy at the RRU to convert the CPRI for Ethernet transport. Figure **6** – Low PHY at Hub at Hub Site Option 1 shows the Low PHY deployed at the CRAN Hub using Ethernet over dark fiber for transport.

In this deployment scenario, the input to the Low PHY module is RoE Ethernet. When deploying Low PHY at the tower site, co-located to with the RRUs, the input into the Low PHY is CPRI. The Low PHY Module must be capable of supporting both / either CPRI or RoE(Ethernet) as input.

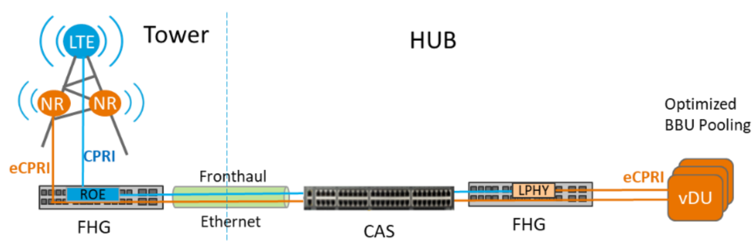

Figure 6 – Low PHY at Hub

In the use case where, remote sites have insufficient space and/or power available (such as PICO sites) to support the deployment of an FHG locally, dark fiber or DWDM may transport the CPRI stream to the CRAN Hub into a FHG box supporting Low PHY. Refer to Figure **7** – Low PHY support for PICO**Error! Reference source not found.**.

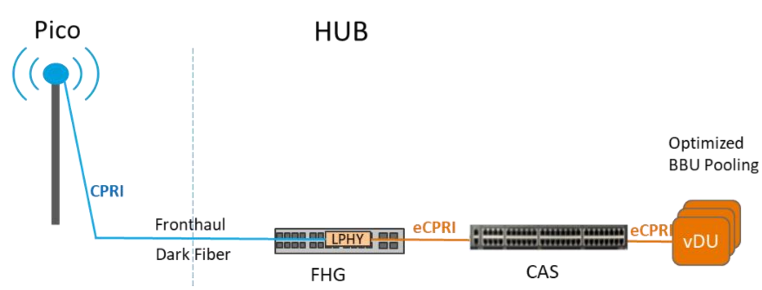

Figure 7 – Low PHY support for PICO

RoE vs Low PHY

To compare the fronthaul bandwidth reduction provided by the various modes of RoE and Low PHY, refer to Figure 8 – RoE vs LOW PHY comparison.

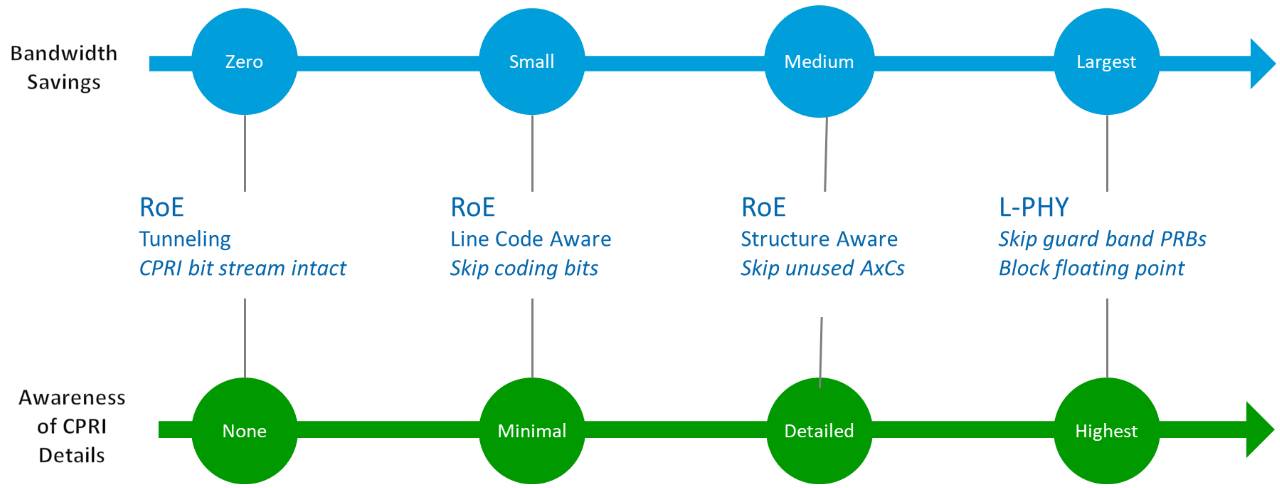

Figure 8 – RoE vs LOW PHY comparison

Use case: CPRI Switching

The FHG must support the capability to switch CPRI traffic from one 10/25Gbps port to on another 10/25Gpbs port. This switching ability allows electronically switching the pairing of RRU to BBUs as required. This capability is especially useful when the tower site does not deploy an FHG and the CPRI signal (carried over dark fiber) terminates to an FHG that does not support Low PHY. Refer to the Figure (Figure 9 – CPRI Switching) for an illustration.

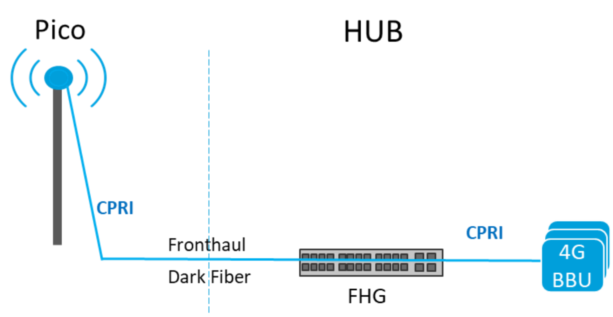

Figure 9 – CPRI Switching

Use case: eCPRI Transport

In addition to aggregating and converting CPRI interfaces, the FHG must also aggregate and statistically multiplex CPRI post RoE conversion, and eCPRI traffic over a common transport interface. The requirement to support 5G (eCPRI) drives additional requirements in the FHG for timing/synch that the document describes below in more detail. With respect to the packet sizing for eCPRI traffic, packet size may range from very small packets (<100 bytes) for control messages to a larger packet size of ~1700 bytes for user and management.

Use case: Ethernet (Business Services) Traffic

With the ever-increasing demand for higher network speeds and more bandwidth, the utilization of RAN resources such as dark fiber must continue to increase efficiencies and maintain a competitive edge. The FHG must be able to switch and route L2 and L3 Ethernet traffic to support the offering of Business Ethernet services (ie: connecting an NTE) as well as management type interfaces for tower support and control. In support of these Ethernet services, the FHG must be able to switch jumbo (9K) packets.

FHG Functional Requirements

Within this section the functional FHG requirements are described.

Timing / Synch

FHG will act as a Telecom Boundary Clock (T-BC) Class C as per ITU-T G.8273.2. The CAS device will act as an Edge Grand Master providing timing to the FHG, RRU, and BBUs. For better frequency synchronization, enhanced synchronous Ethernet equipment (eEEC) slave clock as per ITU-T G.8262.1 is required. This enables Full on path Timing Support (FTS) in the fronthaul, per ITU-T G.8275.1 telecom profile for time.

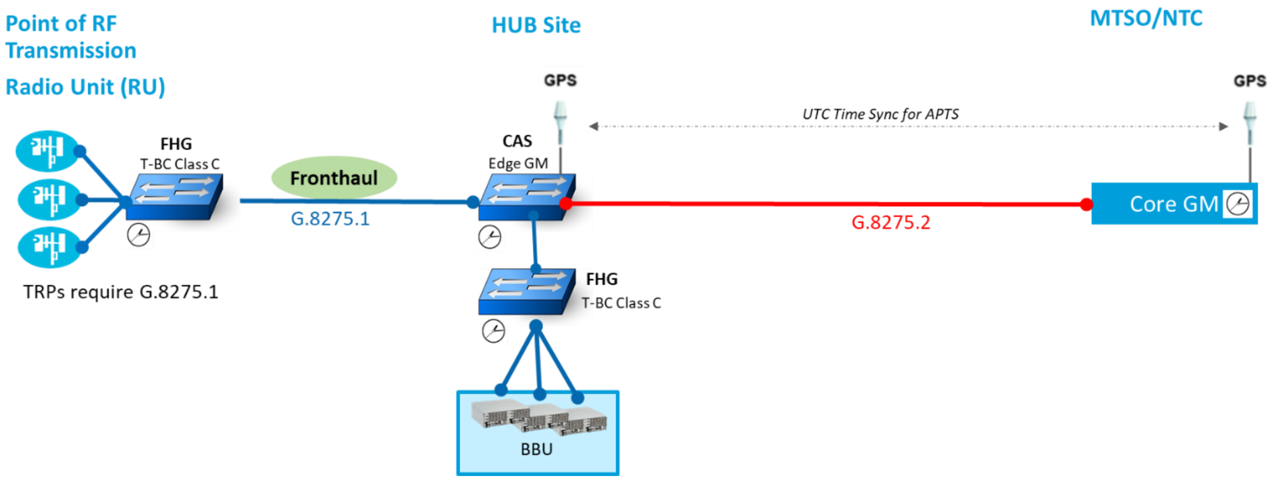

Figure 10– FHG Boundary Clock

TSN Forwarding (IEEE STD 802.1CM-2018) for FHG

The 802.1 Standards group has defined the TSN (Time Sensitive Networking) to enhance switched ethernet for time critical applications such as fronthaul traffic. In this case, to address requirements for the transmission of very low latency and high availability traffic required to support 5G eCPRI fronthaul. The Timing / Synch section of this document describes the requirements for the time synchronization critical for TSN. For the FHG, Frame Pre-emption (802.1Qbu) must be supported on network facing links with link speeds of 25Gbps or less. TSN Frame Pre-emption on links with speeds greater than 25Gpbs is not required.

The forwarding of the TSN switching block is based on the VLAN Bridge specification in IEEE STD 802.1Q, that defines the forwarding of Ethernet packets supporting various networking topologies, which can be provided by Virtual LANs (VLAN) supported by one or more VLAN-IDs (VID) in a fronthaul network. These VLANs can implement the required point-to-point, point-to-multipoint, multipoint-to-point, or multipoint-to-multipoint connections between the source and the destination. The support of at least six different VLAN-IDs is required; including the default PVID (which is untagged, by default, e.g., to carry non-fronthaul traffic).

The Ethernet frames that are supported are RoE, eCPRI and other packets that are transported over the Ethernet infrastructure.

The TSN forwarder supports the following functionality in addition to those for VLAN-aware Bridges:

- Support of the use of at least six VIDs, one of which is the default PVID, configured to be untagged on all Ports.
- Support a minimum of two traffic classes on all Ports, of which both traffic classes support the strict priority queuing algorithm for transmission selection
- Optional support for Frame preemption depending on NNI link rate

The maximum carried payload the fronthaul traffic in a frame is 1700 bytes, and the maximum frame size including headers, tags, etc., is 2000 bytes.

Priority for the user IQ data must be configured as high priority traffic class to decrease the effects of other traffic.

Preferably, the highest priority traffic class is only used for IQ data, which is assumed in the following.

Frame preemption - Frame preemption specification IEEE Std 802.1Qbu and 802.3br.

Frame preemption is the suspension of the transmission of a preemptable frame to allow one or more express frames to be transmitted before the transmission of the preemptable frame is resumed. IEEE Std 802.3br specifies the MAC Merge sublayer, which supports interspersing express traffic and preemptable traffic. The MAC Merge sublayer supports two ways to hold the transmission of preemptable traffic in the presence of express traffic: the MAC Merge sublayer can preempt (interrupt) preemptable traffic being currently transmitted, and the MAC Merge sublayer can prevent starting the transmission of preemptable traffic.

Radio Over Ethernet (IEEE 1914.3) RoE mapper/de-mapper for FHG

The implementation of RoE for the FHG must adhere to the IEEE 1914.3 standard for the conversion of CPRI into frames. CPRI versions 3-8 must be supported. Additionally, the FHG must support conversions for CPRI from both LTE and NR radios.

A provider/manufacturer of a FHG may choose to implement RoE in an instance of an FPGA processor or use an off the shelf ASIC chipset. The Broadcom Monterey (BCM5667x) ASIC provides RoE solution based on 1914.3.

The functional ROE block generates the following types of information flows:

- **User plane** information, which is IQ data in the form of In-phase and Quadrature (IQ) modulation data,
- **Control and Management** (C&M), which is information exchanged between the control and management entities within the REC and the RE, and
- **Synchronization data**, which is used for CPRI frame and time alignment.

The Radio over Ethernet (RoE) (de-)mapper enables the efficient transfer of In-phase Quadrature (IQ) user-plane data, vendor specific data, and control and management information channels across an Ethernet-based packet-switched network. The RoE mapper performs the job of forming Ethernet frames from radio data sources. A RoE de-mapper performs the task of extracting radio data from Ethernet frames. The RoE has two different major modes of operation: the **structure-agnostic** and the **structure-aware RoE** mapping.

In the structure-agnostic RoE mode, the captured bits of a constant bit rate link at the client ingress are packetized into Ethernet frames, and transmits those packets across the network. At the far end, the packetized packets are used to recreate the original bit stream. This mode has two different sub-modes of operations, the tunneling mode and the Line code aware mode. In the tunneling mode, there is no interpretation of any special control characters, and the full bandwidth of the encoded signal rate is transported over a packetized infrastructure. In the Line code aware mode on the other hand, the encoding of the client signal is considered and removes any line coding. Such that the effective required transport bandwidth decreases. At the far end the packet stream is reconstituted and restored to original bit stream.

The RoE Structure-Aware mode, the CPRI frames streams are deconstructed by the RoE mapper into separate control and sample date packet streams, as opposed to the Structure-agnostic, where no control packets are generated but entire data streams (that include the control information). The RoE mapper maps the AxC Container into control word packet streams and sample data packet streams.

The RoE mapper/de-mapper at both sides of the connection must have awareness of the mode of operation, and the protocol it is mapping/demapping; the locations of the special characters must be known a-priori relative to an event that is indicated in the RoE frame and must be user configurable.

The RoE functions comply according to specifications described in the IEEE1914.3 Standard for Radio over Ethernet Encapsulations and Mappings.

Low PHY Processing for FHG

The Low PHY processing converts CPRI to eCPRI and aims to achieve fronthaul bandwidth reduction for the radios connected with CPRI link. It depends on the option being used for functional split and the Low Layer Split 7-2x specified by O-RAN standard (ORAN-WG4.CUS.0-v01.00) shall be applied to the FHG design for interoperability to the DU or BBUs. The processing block diagram of the L-PHY is shown in Figure 11**– Low PHY Functionality** where L-PHY gets connected to the system via two interfaces:

- *CPRI interface*: an interface to the CPRI ports. It decodes the uplink CPRI traffic and restores it to a radio sample stream according to the CPRI protocol defined in the CPRI specification. A single CPRI port carries data from multiple carriers or antennas. In this case, the CPRI interface is responsible for unpacking the data into different radio streams and feeding them into separate L-PHY processing channels. Note that this is a bi-directional interface and for the other direction, reversed operations or procedures shall be performed.
- *eCPRI interface*: an interface to the Ethernet switch. It encapsulates the processing outputs of L-PHY into eCPRI Ethernet packets according to the C/U plane and transport protocol specified by O-RAN standard [reference]. In the other direction, the interface de-encapsulates the eCPRI Ethernet packets into appropriate inputs to the L-PHY.

The Low PHY in the FHG mainly consist of three processing branches for downlink, uplink, and PRACH, respectively. The processing blocks shown in Figure 11– Low PHY Functionality mainly fulfills the tasks of time-frequency domain conversion (FFT/IFFT), MIMO processing (beamforming/precoding) and I/Q compression. Implementation of each of the processing blocks shall strictly comply with the specifications provided by O-RAN and 3GPP standard documents [O-RAN CUS plane] [3GPP 36.211, 36.212].

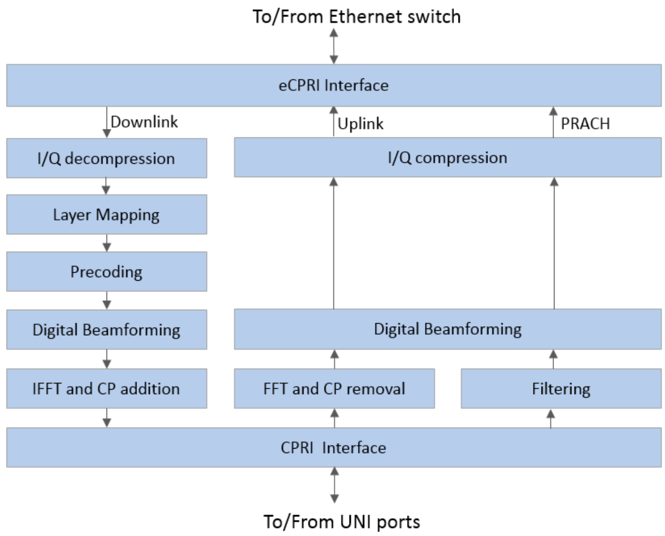

Figure 11– Low PHY Functionality

The Low PHY feature in the FHG must support MIMO capability up to 4 layers at various carrier bandwidths (5MHz, 10MHz, 15MHz, and 20MHz) operating at CPRI 3, 5, and 7 interfaces.

Low PHY within an FPGA

The Intellectual Property (IP) required to perform the Low PHY function in the FHG may be tightly coupled with a specific RAN supplier's CPRI implementation. This Low PHY Intellectual Property (IP) may also vary on specific radio model or frequency. Therefore, the Intellectual Property (IP) to perform the Low PHY (CPRI to eCPRI) conversion must be hosted in a FPGA processor within the FHG.

The FHG with an FPGA supporting Low PHY must provide the ability to perform a remote software upgrade of the Low PHY Intellectual Property (IP). A Mobility Carrier may have multiple RAN providers within a Mobility network requiring multiple implementations of the Low PHY Intellectual Property (IP). The FHG supporting Low PHY is required to support only one implementation of a Low PHY from a given RAN Supplier at a time. However, an FHG supporting Low PHY, must have the capability to perform a software upgrade of the Low PHY Intellectual Property (IP) to transition from one Low PHY Intellectual Property (IP) implementation to another.

Transport Operations, Alarm and Management – OAM

The OAM functional block is responsible for the operation, maintenance and management of the Ethernet Network connection maintenance and network connection control, including the line and client interfaces.

For the Ethernet layer of eCPRI, Ethernet OAM is required. Ethernet OAM is a common name for the IEEE 802.1Q and ITU-T Recommendation G.8013/Y.1731. The IEEE 802.1Q Ethernet CFM (Connectivity Fault Management) defines three protocols, Continuity Check Protocol (CC), Link Trace (LT) and Loop-back (LB). ITU-T defines the same functions and tools in Y.1731 by the Ethernet continuity check (ETH-CC), Ethernet remote defect indication (ETH-RDI), Ethernet link trace (ETH-LT) and Ethernet loopback (ETH-LB), and also adds more OAM functions like Ethernet alarm indication signal (ETH-AIS), Ethernet loss measurement (ETH-LM) or synthetic loss measurement (ETH-SLM), and Ethernet delay measurement (ETH-DM).

The OAM hardware engine enables an inline mode of performance monitoring for the FHG Ethernet interfaces and the processing of the OAM protocol data units (PDUs) on the forwarding OAM ASIC. This mode of operation has no impact on the CPU performance, and when increasing the number of performance monitoring sessions and achieve a maximum scaling for service OAM performance monitoring sessions a consistent ultra fast timely behaviour is expected. The consistent behaviour is a very important aspect in ability to detect transport network failures and initiate in a dissolute matter the resiliency action.

Service layer OAM must also be provided in compliance to MEF 17, MEF 30.1 and MEF 35.1.

DWDM for Network connection

Ethernet over Dark Fiber is the preferred transport mechanism between tower and CRAN hub locations when fiber is in abundance. However, for situations where fiber from the tower site is scarce, a DWDM solution must be deployed. A supported combination of passive / active DWDM devices may be used to enhance network bandwidth over existing fibers as an alternative to deploying additional fibers. DWDM uses multiple wavelengths (lambdas) over dark fiber to provide additional network bandwidth as compared to using a single color of light for transmissions.

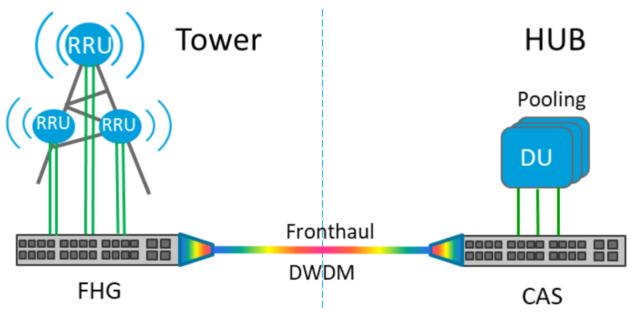

Figure 12– FHG w/DWDM

FHG Management and Automation

The FHG must support a standard NETCONF controller interface (API), CLI, SNMP, and (S)FTP for device management, network element configuration and alarm management. This Controller interface must provide FCAPS management functions (fault, configuration, accounting, performance, and security). The FHG devices are required to leverage Zero Touch Provisioning (ZTP) capability for automating the configuration of the device(s). The FHG devices should incorporate a mechanism to notify the Domain Resource Controller with an event about client port activation and configured signal type. The notification will include all information enabling the Resource Controller to automate the service configuration

Device Management failures should not impact the operations of the devices. Any pending provisioning requests should be queued until the Controller recovers. Software upgrades to the FHG must be performed in automated fashion. The configuration and state of the FHG prior to upgrade must be preserved / restored following the upgrade.

L2/L3 Requirements

The FHG must support a combination of L2 and some L3 capabilities. From a layer 2 functional point of view, as indicated and documented in the Section "TSN Forwarding", Virtual Local Area Networks (VLAN) will be used to differentiate the traffic (data and management independently) within a network. The FHG should have the capability of adding an inner and an outer tag to identify traffic. Tagged and Untagged traffic on the same interface must be supported. The VLAN tag value is determined by Type II ESP agreement. If more than one VLAN tag is contained in the packet, they are carried transparently with no impact on packet forwarding. VLAN-based service binds all traffic coming out of an FHG port with a specified VLAN tag to a given destination and FHG port. The FHG will support VLAN tag push, pop, swap for both VLAN tags. There should be no restriction on use of tag values 1 - 4095 for VLAN tags. The FHG must support at least 4K routes.

From the L3 functionality point of view the FHG must provide support for the following routing and signaling protocols:

- IP/L3 features
  - Static routes -> uses manually-configured routing entries, rather than routing information from a dynamic routing protocol. Typically, the network operator or administrator configures the static routes entries manually into the routing table. Static routes remain fixed and do not change if in the event of a network reconfiguration, or failure.
  - OSPFv2/v3 Open Shortest Path First (OSPF) is a routing protocol for Internet Protocol (IP) networks. It uses a link state routing algorithm and falls into the group of interior routing protocols, operating within a single autonomous system (AS). Must support both OSPF Version 2 in RFC 2328 (1998) for IPv4 and the updates for IPv6 are specified as OSPF Version 3 in RFC 5340 (2008).
  - Border Gateway Protocol (BGP) is a standardized exterior gateway protocol designed to exchange routing and reachability information among autonomous systems (AS) on the Internet. The protocol is often classified as a path vector protocol but is sometimes also classed as a distance-vector routing protocol.
    - BGP v4/v6
      - Support for iBGP and eBGP peers - BGP supports two types of exchanges of routing information: exchanges among different ASs and exchanges within a single AS. When used among ASs, BGP is called external BGP (EBGP) and BGP sessions perform inter-AS routing. When used within an AS, BGP is called internal BGP (IBGP) and BGP sessions perform intra-AS routing.
    - MP-BGP - Multiprotocol BGP (MP-BGP) is an extension to BGP that enables BGP to carry routing information for multiple network layers and address families. MP-BGP can carry the unicast routes used for multicast routing separately from the routes used for unicast IP forwarding. Support for IPv6, L3VPNv4/v6 should be supported
  - MPLS Routing. Multi-Protocol Label Switching (MPLS) for forwarding speed of the routers, and support for large scale IP networks.
    - Static configuration must be supported
    - Dynamic configuration based on RSVP, RSVP-TE and LDP should be supported
  - Link Aggregation Group – LAG must be supported
    - LAG member up to 4 members must be supported
    - ECMP must be supported over the LAG
  - Multicast may be supported.

The FHG must support similar or equivalent features as the following:

- BFD (Bidirectional Forwarding Detection) to quickly detect failures and prevent traffic blackholing)
- Dampening (ie: Interface dampening where an interface should not be allowed to flap in quick succession. As well as Event dampening where syslogs/traps must be throttled and perhaps aggregated)
- Broadcast storm protection at port level (minimum)
- Strong authentication support (GTAC/AAA)
- Port Mirroring
- Unidirectional Link Detection Protocol (UDLD)

Quality of Service Requirements – QoS

In mobile networks, transport and switching network resources are shared among multiple services (e.g. Internet, voice, video, e-mail, and file sharing, and network control traffic), each of which has different QoS requirements in terms of required data rates, acceptable packet loss rates, and packet delay. Particularly, the traffic flows in the fronthaul require very tight latency bounds and ultra-low packet loss.

QoS provides the operator the means to differentiate or classify different traffic flows based on various fields in the received packet header, to differentiate traffic and then apply different forwarding behaviors to that different traffic, such that real-time services can be prioritized over non-real-time services.

Hierarchical Quality of service (HQoS) is the ability to apply traffic schedulers and shapers to a hierarchy of scheduler nodes. Each level of the scheduler hierarchy can be used to shape traffic based on different criteria such as application, user, VLAN, and physical port. The FHG must support 3 schedulers levels of HQoS.

The FHG should support the ability to configure the following QoS behaviors:

- Prioritizing traffic over other traffic based on Layer2 or Layer3 protocol fields or a combination of these fields; such as the source or destination address, priority fields, or a source or destination port number.
- Classifying ingress or egress traffic in any number of simple and combined manners – separate Multicast Queues must be supported
- Controlling the configured ingress or egress interfaces bandwidth.
- Reading and re-writing packet header fields based on the configured QoS forwarding behavior.
- Congestion control dealing with traffic overload situations when there is more data traffic in the network than can be sent with reasonable packet delays, no lost packets, sending the highest priority traffic first based on scheduler queuing priorities. The FHG solution must support shaping support on all levels of scheduler, and three drop precedence colors per queue
- Controlling packet loss based on random early detection (RED) algorithms, must support Drop profiles – per CoS and per port, and strict priority, Weighted Round Robin, and Weighted RR, Weighted deficit Round Robin.

Optics / Transceiver

The FHG must support full duplex GE (Gigabit Ethernet) 10GE, 25GE, 100GE ports. Support for bi-directional (BiDI) optics must be provided to reduce the needs for physical fibers. The FHG must also support DWDM optics for a multi-wavelength solution between Network connections (NNI). The FHG must support compatible third-party optics.

Host CPU

The Host Module will use standard 4Core x86 General CPU, with 16Gb DRAM, and 128GB SSD. Examples of CPU options may include but are not limited to Intel Rangeley, D-1500, NXP multi-core communications processors family such as T1040

BMC

The BMC is associated with CPLD logic and allows for managing the FHG. The BMC may be instantiated with a separate physical device, or a software component available with high reliability from the host module. When the BMC is provided on the host module, then the design must include a simplified, low-cost module to host the BMC software in those cases where a more functional CPU is not desired, and the CPU module would normally be omitted from a build. The BMC must provide management for the following:

1)System, ASIC / FPGA, and Host CPU module power management
2) Temperature monitoring
3) Voltage monitoring
4) Fan control
5) Reset control
6) Programming FPGA/CPLD/and other various flash/BIOS
7) Read the Rx loss and other signals from the SFP and QSFP ports
8) Host CPU Module boot up status
9) System Identifier, including ability to set user-defined identifier, as well as control of locator lamp.
10) Serial number / unique identifier

11) Board revision ID
12) I2C interfaces to Host CPU, USB, temperature sensors, and voltage controllers.

The BMC functionality could be provided in a software solution running on the host CPU as opposed to a specific CPU dedicated for BMC processing. This variant must be both functionally equivalent and preforms the same as the dedicated hardware solution.

MACsec Support

The MACsec capability (IEEE.802.1AE MAC Security standard) should support DOT1Q in the Clear in order to operate over different Ethernet Provider service offerings. The MACSec must support at least 40Gpbs of traffic. Due to this limitation, the MACsec should process only the control messaging.

FHG Physical Design Requirement

1RU Mounted Unit

The Rack mounted FHG must be mountable in a 19" EIA cabinet (supporting both 2 and 4 post mounting). All cabling must be front accessible and adhere to AT&T bend radius standards as specified in ATT-TP76300, section J part 2.10. Air flow must be front to back. FHG devices deployed in remote enclosures must not exceed 300 mm in depth. The height should not exceed 2 RU. These Units must be stackable without any airgap.

The 1RU Rack Mounted FHG must support 24x 10/25G UNI Ports with a switching bandwidth of 800Gbps. All 24 UNI ports must support the ability to terminate 25GE eCPRI interfaces for aggregation. Although the 24x 10/25G ports are typically targeted for UNI RAN interfaces, these ports must also support being used as an NNI interface. Therefore, any of the 24x 10/25G ports can be used for accessing traffic coming from a client interface or connecting to a line side core network interface. Table 2 – 1RU Interface Ports provides a summary of the required interface ports.

When utilizing DWDM traffic channels (to achieve required synchronization performance and phase alignment per ITU-T G.8275.1, ITU-T G.8273.2) dedicated Optical Timing ports may be used. Optical Timing ports may also support dedicated IEEE 1588 PTP connections to collocated timing sources (i.e. T-GM clock or BBU/DU ports).

For network interfaces (NNI), the FHG must provide at least 4x 100GE QSFP28 interface ports. TSN Pre-emption (802.1Qbu) must be enabled on ports that are 25Gpbs or less.

Physical Ports	Type	NW Interface	RoE/LPHY	eCPRI Support
18	SFP28	UNI	10Gbps	25Gbps
6	SPF28	UNI	No	25Gbps
4	QSFP28	NNI	No	100Gbps

Table 2 – 1RU Interface Ports

An Industrial temperature range (-40C to + 65C ambient) meeting AT&T TP76200 (Issue 20) / TP76450 (version 17) for Level 3 requirements for sealed GR-3108 OSP Class 2 cabinets is required. These document and general information about AT&T's environmental equipment standards can be found at https://ebiznet.sbc.com/sbcnebs/.

Timing Ports

The 1RU Mounted Unit should support the physical ports to support the 1588 Timing / Synch requirements as described in Table 3 – FHG Timing Ports.

The 1RU Mounted FHG Unit may support dedicated Timing port per high speed NNI interface.

Port Description	Port Type	Input/output	Notes
1pps/ToD	RJ45	Input/output	V.11/RS-242 Time & phase distribution and measurement interface as per ITU-T G.8271 Annex A and G.703
10MHz	SMB	input	Legacy Frequency input
1PPS (50 Ohm)	SMB	Output	50 Ohm phase test measurement interface as per ITU-T G.8271 and G.703
External Optical Timing (OTC)	SFP/SFP+	Input / Output	Optional (Maybe performed in-band)

Table 3 – FHG Timing Ports

(*) OTC = Optical Timing Channel

Management Interfaces

Refer to (Table 4 – FHG Management Interfaces) for a list of Management ports required with the FHG device. Only one Serial input can be active for the Console. Micro USB will have higher priority than RJ45 and USB serial by default.

The RJ-45 OOB Ethernet management port needs to be operational even when all the interfaces on the system are in the shutdown mode. As such it needs to be designed using the standby power rail. It also needs to provide simultaneous connectivity to the X86 CPU and the BMC.

Type	Quantity	Purpose
Micro USB RS232l	1	Console
RJ45 – craft terminal 10M/100M/1G	1	Console
RJ45 RS232 terminal	1	Console
RJ-45 10M/100M/1G	2	Ethernet OOB
In-band Management virtual interface	n/a	IP in band management

Table 4 – FHG Management Interfaces

LED Operations Recommendations

Refer to AT&T Hardware Common Systems Requirements for recommendations on system and interface LED colors and operations.

The indicator lamps (LEDs) must convey the information described in Table 5 – FHG LED Definitions. The number, colors, and flash behaviors are desired but not mandatory.

LED Name	Description	State
PSU	LED to indicate status of Power Supply	Green - Normal Amber - Fault Off – No Power

System	LED to indicate system diagnostic test results	Green – Normal Amber – Fault detected RED - “major” or “critical” failure
FAN	LED to indicate the status of the system fans	Green – All fans operational Amber – One or more fan fault RED - “major” or “critical” failure
LOC	LED to indicate Location of switch in Data Center	Blue Flashing – Set by management to locate switch Off – Function not active
SFP/SFP+SFP28/ QSFP28	LED built into SFP/SFP+ SFP28/QSFP28 cage to indicate port status	On Green/Flashing – Port up (Flashing indicates activity) On Amber – Port up with no active CAS/FHG Off – No Link/Port down
OOB	LED to indicate link status of 10/100/1000 management port	On Green/Flashing - port has link Off – No link

Table 5 – FHG LED Definitions

1RU Power Requirements

The total system power consumption of the 1RU FHG must not exceed 350 watts. All system components chosen for this build must be energy efficient to keep the energy consumption low

Typical power consumption is 300 Watts. The total estimated system power consumption must be specified in watts. This is based upon worst case power assumptions for traffic, optics used, and environmental conditions.

- ATIS TEER (ATIS-0600015.2009) should be measured and provided (Preferred)
- SPECpower_ssj2008 can be substituted for ATIS TEER (Acceptable)
- US EPA Energy Star Certification is favored.
- Power terminations must be clearly labeled and fully protected with a non-metallic, non-flammable cover.
- ATT-TP-76208 lists additional power requirements for under and over voltage, grounding, and current characteristics.

Dual power inlet

The 1RU FHG Device must support dual power inlet connections to provide power resiliency. Please use the below as a general guideline for the dual power inlet connections:

- The system must support AC or DC power input.
- The system must support DC input between -57 and -40VDC or support AC input between 100 & 240 VAC.
- Power inlet physical connectors must have a mechanism that prevents accidental dislodging of the cord.
- DC PSMs have additional physical connection requirements listed in AT&T TP 76450, section 2.4.

Fan Module

The 1RU FHG Device must support a hot swappable Fan Modules. Please use the below as a general guideline for the FAN selection:

- The FAN Module must meet the power requirements of the design, 50W WATT or less
- The FAN must be available with front to back airflow.

The FAN must have a mechanism that prevents accidental dislodging

Grounding Port

The 1RU FHG device must have a dedicated "ground" interface which the personnel handling the FHG Unit must connect to prior to safely contact the device.

Service and Transport OAM

To ensure scalable deterministic carrier grade transport and service OAM, the 1RU FHG must provide the capability of 10s (order of magnitude) sessions of 3.3 CCM.

- Ethernet Service OAM (IEEE 802.1Q/ag, ITU-T Y.1731, MEF17/30.1/35.1) - The implementation guideline is to build this functionality with a hardware assisted design in order to provide carrier grade OAM and avoid restrictions on PDU rates. It is necessary, for example to generate 3.33ms CCM PDUs for fast failure detection and to process SLM and DM in hardware to accurately measure frame loss ratio, frame delay and frame delay variation. FPGA should support 10s of parallel OAM sessions at a minimum.

1RU Design Options

The 1RU FHG has the following design options. However, all must adhere to the specifications for the 1RU device.

RoE ASIC + Low PHY FPGA (Optional)

Broadcom's Monterey (BMC5667x) ASIC chipset provides L2/L3 routing and switching capability as well as the RoE (IEEE 1914.3) support. Figure 13– FHG Monterey illustrates a FHG built with Monterey chipset(s). This solution without an FGA, would only be capability of supporting RoE and not Low PHY. However, Figure 13**–** FHG Monterey Solution shows the Broadcom Monterey chipset(s) with the addition of an FPGA. The additional FGPA(s) could be used to support Low PHY. Two (2) of Xilinx's KU15 FPGAs could be used to provide the Low PHY processing when used with the Monterey ASIC. The Monterey + FPGA combination could be utilized to support both RoE and Low PHY CPRI conversion modes. The details of the individual processor functions, FPGA models and port management are left to the individual manufacturer's design. The RoE ASIC + Low PHY FPGA is suitable for deployment in the Remote Site with Enclosure or the CRAN Hub Locations.

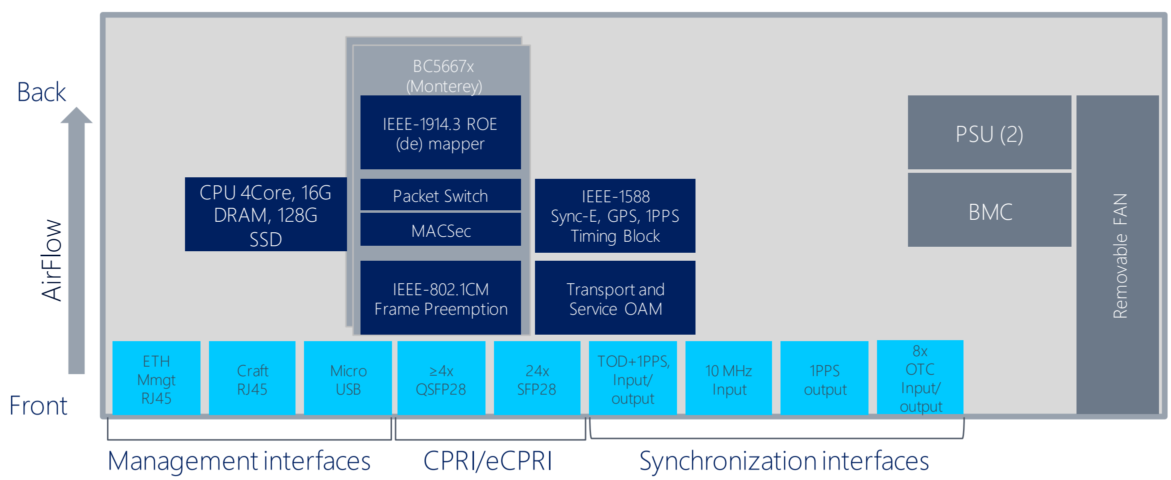

Figure 13**–** FHG Monterey Solution

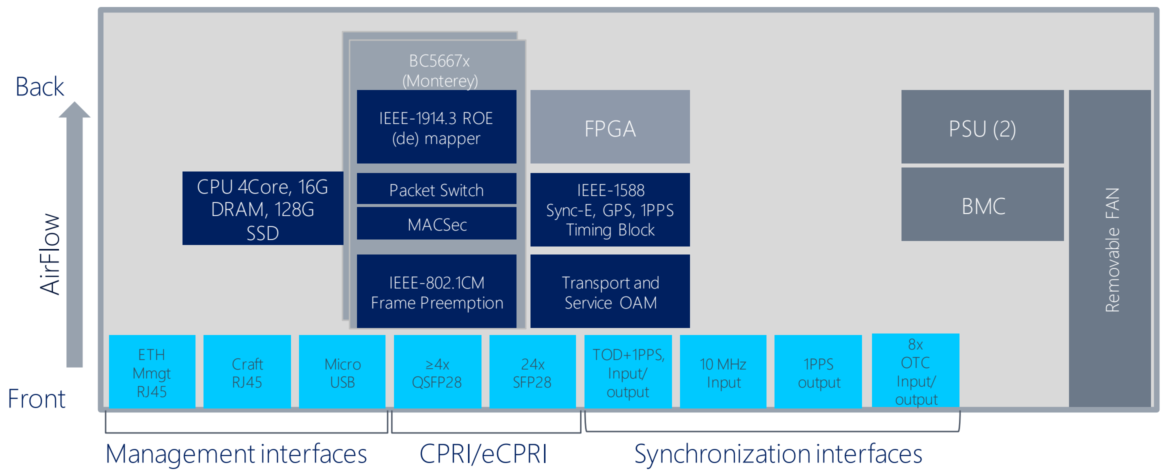

Figure 14– FHG Monterey + FPGA Solution

L2/L3 ASIC + FPGA

This configuration describes an FHG solution that utilizes a L2/L3 ASIC + FPGA. In this case the ASIC could be a Broadcom Qumran MX, Marvel Aldrin 3XL, or Microchip's MARS II chipset. The details of the individual processor functions and port management are left to the individual manufacturer's design. Figure 15– FHG ASIC + FPGA show this option.

The RoE ASIC + Low PHY FPGA is suitable for deployment in the Remote Site with Enclosure or the CRAN Hub Locations.

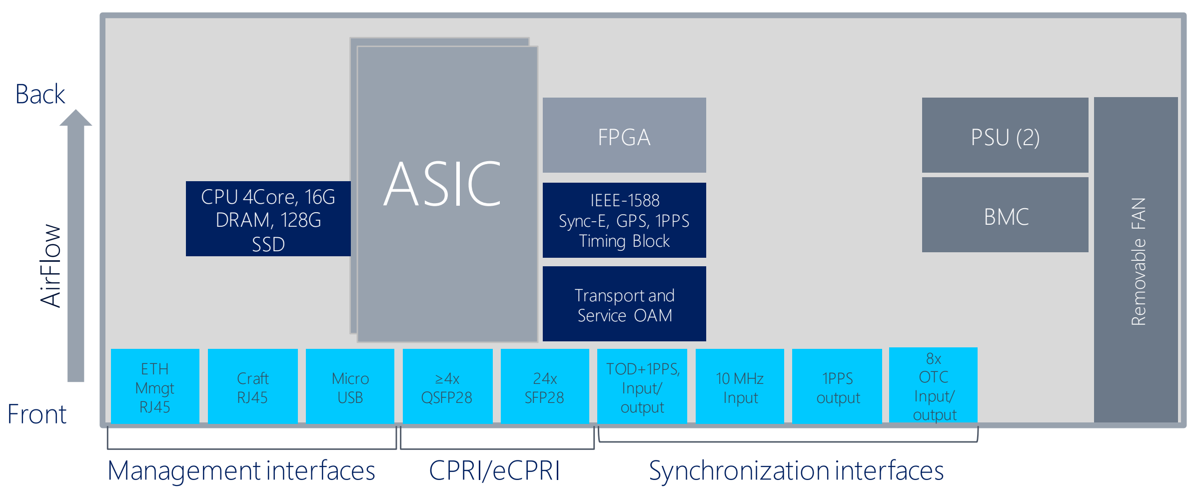

Figure 15– FHG ASIC + FPGA

FPGA

In deployment scenarios, where limited L2/L3 functions are required in the FHG, an FPGA only solution could be used to host either the RoE or Low PHY intellectual property (IP). One possibility of this deployment scenario is that of the CRAN Hub where the FHG is deployed subtended to a CAS.

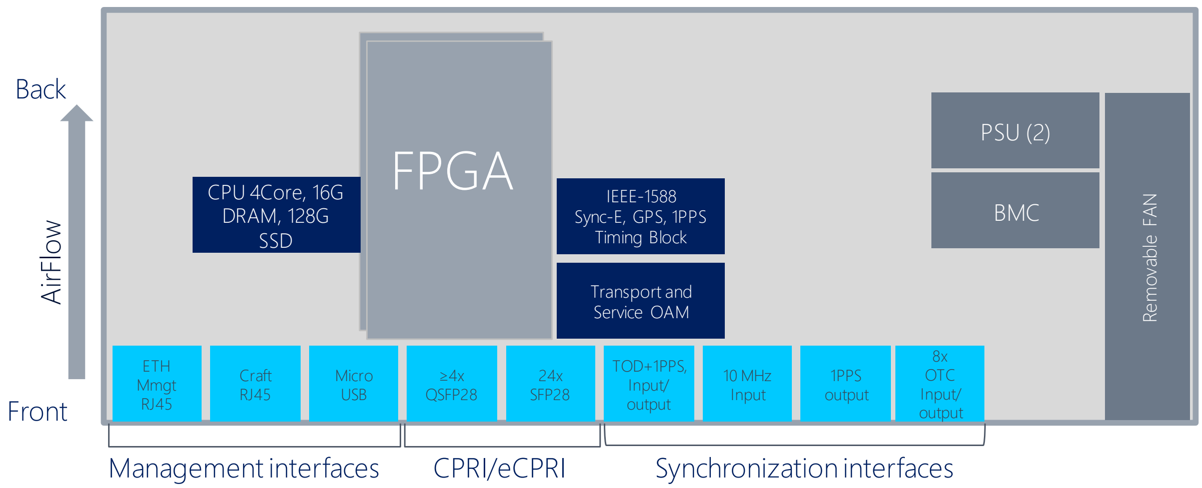

Figure 16– FHG with FPGA

Open Edge Chassis Design FHG Overview

Module Sled based Chassis Unit as an alternative to the 1RU Mountable version of the FHG, the Open Edge Chassis (OCP submission) is also a via design option.

The dimensions of the Open Edge Chassis are shown in Figure 17– Open Edge Chassis.

This chassis-based design is 3U, 19" mountable and EIA-310 compatible. The Open Edge Chassis supports 1U and 2U, half width sleds. More details on the Open Edge Chassis can be found at the following location: https://www.opencompute.org/wiki/Telcos/openEDGE#Documents.

The 1U half sled power feed capacity is 400W. While the 2U half Sled power feed capacity is 700W.

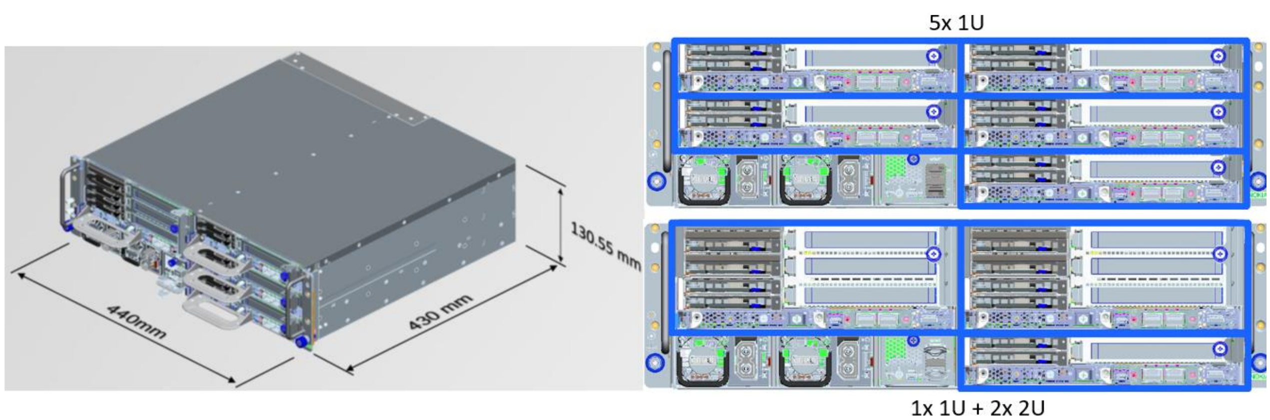

Figure 17– Open Edge Chassis

Sled Design Options

Like the design options for the 1RU Mounted unit, viable solution designs include the following options for routing and CPRI conversions:

1) Monterey (BMC5776x) + FPGA (Optional)
2) L2/L3 ASIC + FPGA
3) FPGA

Although the Open Edge Chassis described here is based on the current OCP specification, continuous technological evolution can lead to future revisions of the chassis hardware design. Therefore, physical details of the chassis and sleds should not be limited to the current OCP specification and are left, for now, to the individual manufacturer's design.

FHG Outdoor Hardened Unit

The outdoor hardened unit is designed to be deployed outdoor without additional enclosures or shelters. The device must support the ability to be pole, wall or strand mounted. The dimensions of the device shall not exceed 10"x8"x4" (HxWxD) and not exceed 35 pounds. The device must support either AC (100 to 240 VAC) or DC (-57 to -40VDC). Multiple SKUs would represent these different powering options. AT&T requires that the stand mount device support AC power.

The outdoor hardened FHG unit device must support a total of 8x 1G/10G/25G UNI Ports with a switching bandwidth of 200Gbps. All 8 UNI ports must support the ability to transport 1G/10G/25GE eCPRI interfaces, while no more than 6 will be used for CPRI. Although the 8x 1G/10G/25G ports are typically targeted for UNI RAN interfaces, these ports must also support being used as an NNI interface. Therefore, any of the 8x 25G ports can be used for accessing traffic coming from a client interface but equally connect to a line side-facing interfacing, facing the core network. Additionally, one (1) NNI port must support the ability to transport 1 x 100G.

When utilizing DWDM traffic channels (to achieve required synchronization performance and phase alignment per G.8275.1, G.8273.2) dedicated Optical Timing ports may be used. Optical Timing ports may also support dedicated IEEE1588 PTP connections to collocated timing sources (i.e. T-GM clock or BBU/DU ports).

Because of targeted deployment environments in densely populated metropolitan areas, the Outdoor Hardened Unit must be passively cooled. The interface port requirements are shown in Table 6 – Outdoor Hardened FHG Interface Ports.

Physical Ports	Type	NW Interface	RoE/LPHY	eCPRI Support
6	SFP28	UNI	10Gbps	25Gbps
2	SPF28	UNI	No	25Gbps
1	QSF28	NNI	No	100Gbps

Table 6 – Outdoor Hardened FHG Interface Ports

The device must be NEBS 3 OSP Class 4 (-40C to + 70C Ambient), IP65 compliant meeting AT&T TP76200 (Issue 20) / TP76450 (version 17) for a device of this class. These document and general information about AT&T's environmental equipment standards can be found at https://ebiznet.sbc.com/sbcnebs/.

Synchronization Interfaces

The Outdoor Hardened should support the physical ports to support the 1588 Timing / Synch requirements as described in the following.

Port Description	Port Type	Input/output	Notes
1pps/ToD	RJ45	Input/output	V.11/RS-242 Time & phase distribution and measurement interface as per ITU-T G.8271 Annex A and G.703
External Optical Timing (OTC)	SFP/SFP+	Input / Output	Optional out-of-band dedicated bidirectional optical timing channel for improved accuracy and external connection to T-GM/PRTC equipment.

Table 7 – Outdoor Hardened FHG Timing Ports

(*) OTC = Optical Timing Channel

Management Interfaces

The required Management Interface for the Outdoor Hardened Unit is documented in table below. It also needs to provide simultaneous connectivity to the X86 CPU and the BMC.

Type	Quantity	Purpose
RJ45 – craft terminal 10M/100M/1G	1	Console
1xRJ-45 10M/100M/1G	1	Ethernet OOB
In-band Management virtual interface	n/a	IP in band management

Table 8 – Outdoor Hardened Management Interfaces

Ground Ports

The FHG devices must have a dedicated "ground" interface which the personnel handling the FHG Unit must connect to prior to safely contact the device.

Host CPU

4Core General CPU, with 16GB DRAM, and 128GB SSD

Service and Transport OAM

To ensure scalable deterministic carrier grade transport and service OAM, the 1RU FHG must provide

- Ethernet Service OAM (IEEE 802.1Q/ag, ITU-T Y.1731, MEF 17, MEF 30.1, MEF 35.1) - The implementation guideline is to build this functionality with a hardware assisted design in order to provide carrier grade OAM and avoid restrictions on PDU rates. It is necessary, for example to generate 3.33ms CCM PDUs for fast failure detection and to process SLM and DM in hardware to accurately measure frame loss ratio, frame delay and frame delay variation. FPGA should support 10s of parallel OAM sessions.

Outdoor Hardened Unit Power Requirements

The total system power consumption of the Outdoor Hardened Unit FHG must not exceed 120 watts. All system components chosen for this build must be energy efficient to keep the energy consumption low.

Typical power consumption is 100 watt. The total estimated system power consumption must be specified in watts. This is based upon worst case power assumptions for traffic, optics used, and environmental conditions.

Please use the below as a general guideline for the power inlet connections:

- The system must support AC or DC power input.
    - This may be accomplished with multiple SKUs
- The system must support DC input between -57 and -40VDC or support AC input between 100 & 240 VAC.
- PSMs have additional physical connection requirements listed in AT&T TP 76450, section 2.4.

Outdoor Hardened Design Options

The Outdoor Hardened Unit has the following design Options. However, all these options must adhere to the specifications for the Outdoor Hardened Unit described above.

RoE ASIC

Broadcom's Monterey (BMC5667x) ASIC chipset provides L2/L3 routing and switching capability as well as the RoE (IEEE 1914.3) support. The Broadcom Monterey chipset used in the outdoor hardened FHG is a smaller version than the one used in the 1RU Mounted Unit. Figure 18– Outdoor Hardened w/Monterey shows this option.

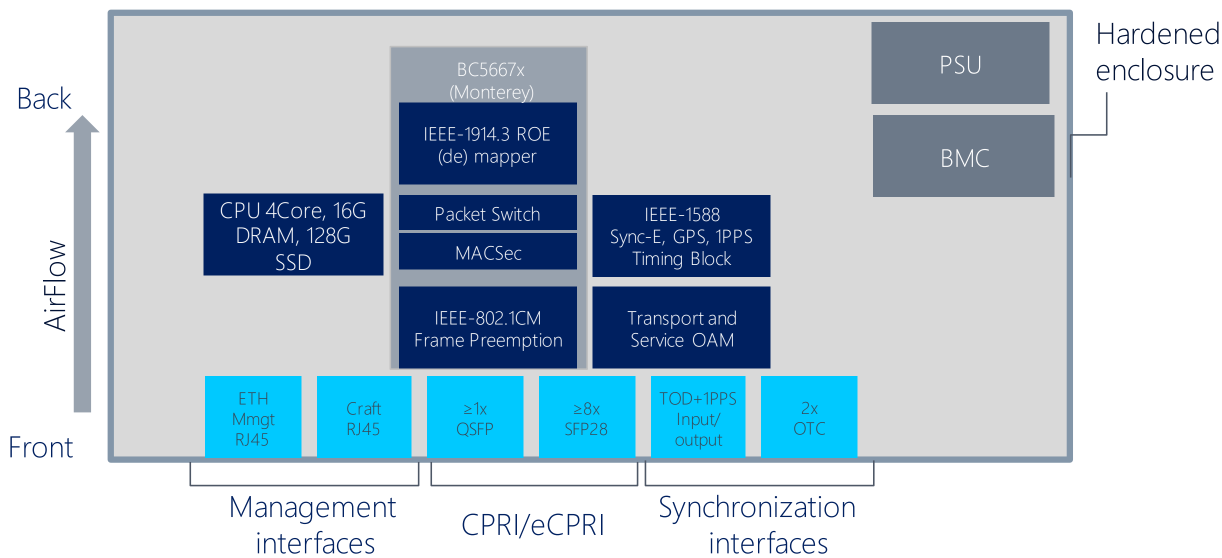

Figure 18– Outdoor Hardened w/Monterey

FPGA + ASIC (Optional)

This configuration describes an FHG solution that utilizes a FPGA + optional ASIC. The ASIC could be used to provide the L2/L3 functions. The FPGA would be utilized to support either the RoE or the Low PHY functions. In the case where an ASIC is not included in the design; the FPGA would be required to also perform the L2/L3 functions. Xilinx's KU15 FPGAs could be used, as an example, as the FPGA processor. However, the details of the individual processor functions and port management are left to the individual manufacturer's design. Figure 19– Outdoor Hardened w/FPGA + ASIC (optional) show this option.

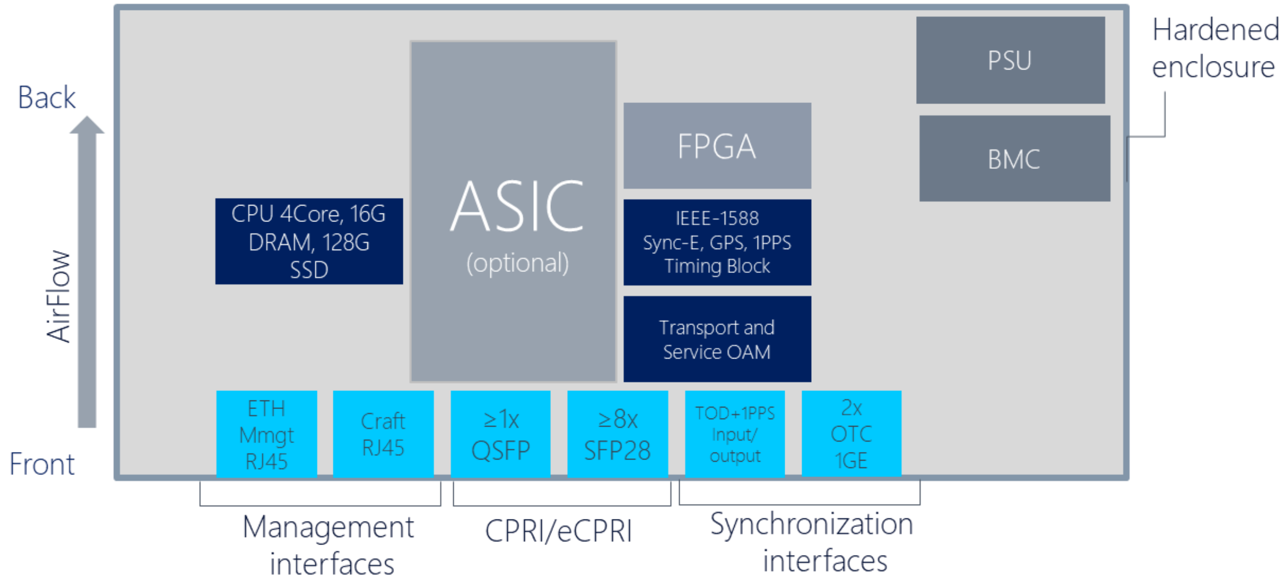

Figure 19– Outdoor Hardened w/FPGA + ASIC (optional)

FHG Software Support

The FHG supports a base software package composed of the following components:

Network OS (NOS)

The AT&T FHG is an open hardware platform that must support any supplier's NOS. Equipment should be available with Open Network Linux, and AT&T expects to develop open source support for this platform over time.

BMC support

Open BMC with Redfish implementation is the target platform. Commercial BMC with IPMI 2.0 is acceptable.

ONIE (Open Network Install Environment)

To allow installation and boot of ONL. ONIE version 2014.08 or greater will be supported

Open Network Linux

See http://opennetlinux.org/ for latest supported version

Specification Requirements

AT&T has established specifications for servers and NFVI communications equipment that are intended to be used in Central Offices. These specs revisit classical NEBs requirements – particularly in the face of new resiliency and availability architectures. Servers and switches that are not a single point of failure for their services (e.g. follow a typical cloud resiliency model) follow ATT-TP-76207. Telco devices that do have or comprise single points of failure for their services including this specification follow ATT-TP-76208.

This specifications is subject to follow ATT-TP-76208 which is available at this URL: https://ebiznet.sbc.com/sbcnebs/Documents/ATT-TP-76208_vOLT%20Equipment%20Standards.pdf

These requirements are partially repeated here. Specifications that require testing must be confirmed by an accredited agency recognized by the National Cooperation for Laboratory Accreditation or ISO/IEC Guide 25 or ISO/IEC 17025. Note: These specifications are limitations placed on any design. The actual performance of FHG must meet or exceed these specifications.

Environmental

- Light weight is favored
- Humidity 5% to 85% non-condensing (operational and storage)
- Vibration – IEC 68-2-36, IEC 68-2-6
- Shock – IEC 68-2-29 • Acoustic Noise Level – Under 78dB in 26-degree C
- Altitude: -200ft (-60 meters) to 6000ft (1830 meters).

Safety

Fire Spread: Field conditions for telco deployment may require deployment in existing Carrier Communications Spaces that utilize Fire Code Exemptions and do not have automatic fire suppression. NFVI equipment, like the FHG deployed in these locations must meet enhanced fire spread requirements:

Generally, the equipment must meet ATIS-0600319.2014 *Equipment Assemblies – Fire Propagation Risk Assessment Criteria* (see note below).

Note: Equipment may conform to this requirement by way of inherent design features that include all three items below:

1. Height of 2 RU or less
2. Metallic 5-sided enclosure with a metallic or non-metallic front cover or faceplate
3. Non-metallic materials shall comply with ATIS-0600307 4.1

For equipment that does not meet the fire spread requirements of ATIS-0600319.2014 by way of inherent design features noted above, the manufacturer must attest that the equipment has successfully passed the burn test as referenced in the ATIS document.

- UL/ Canada
- CB (Issued by TUV/RH)
- China CCC

Electromagnetic Compatibility

- GR-1089-CORE
- FCC Title 47, Part 15, Subpart B Class A

ROHS

Restriction of Hazardous Substances (6/6)

Compliance with Environmental procedure 020499-00 primarily focused on Restriction of Hazardous Substances (ROHS Directive 2002/95/EC) and Waste and Electrical and Electronic Equipment (WEEE Directive 2002/96/EC)