White Paper

1914.3 (RoE) eCPRI Transport

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Background

5G operators must completely change the design of their MFH and MBH networks to allow scaling supporting the massive increases in data traffic and tight latency requirements. This White Paper discusses the network architecture changes, new frame formats, expected timing, and latency requirements, and why they are required. Understanding the combination of these key areas will provide the background to understanding how these networks will look as this industry moves rapidly to 5G.

Technology Overview

The two key changes in the MFH are a move away from the frame format requiring a very-high-throughput link compared to customer traffic throughput, and relocation of network elements based on end-user demands, such as latency.

One often overlooked key element of 5G networks is expansion across many different market segments, rather than just traditional mobile-phone voice and data connections. In addition to the common areas, such as peak data rate (10s of Gbps), standard users (Gbps) and voice, 5G networks are also optimized for areas such as mobility (km/h) – high-speed trains, connection density (millions of connections per km^2) – IOT, traffic volume density ($Tbps/km^2$) – stadiums, etc., low latency (ms) – M2M, while also reducing environmental impact. Such a demanding list of requirements requires both an update to the frame format, and architectural changes in the directly connected network (MFH) and the transport network (MBH) connecting to the operator's core network.

Why New MFH/MBH Architecture?

Most legacy MFH architectures consist either of the BBU and Radio unit in the hut (building at base of antenna), or the BBU in the hut and the RRH mounted at the antenna top, although some architectures are now moving the BBU up to 15 km or more from the RRH. This architecture uses the CPRI protocol to transmit, which requires very high interface rates to carry low volumes of customers' data.

The next generation of networks will either handle much more customer data or will use thousands of different small-data connections, which the current network architecture does not support.

Architectural change required

The network architecture must become more flexible to carry the many different traffic types ranging from URLLC to standard traffic, while maintaining the expected QoE.

Autonomous cars and M2M communications require extremely low network latency, and the network architecture must consider how autonomous cars move from tower to tower without any negative impact on latency or throughput.

Networks must be able to re-configure themselves based on traffic demand, because this is the key to minimizing infrastructure cost. A good example is at a football stadium or concert where there are very large data demands outside and around the venue before and after an event, dropping to almost nothing during the event as extreme data demand moves inside the venue. The network architecture must be sufficiently flexible and able to dynamically reallocate key resource elements to locations with the highest traffic demand.

Architecture

IEEE 1914.1 discusses many different models with the key being the ability of the network to service all different requirements. Key resource elements, such as the DU and CU, must support placement so as to minimize overhead while still ensuring minimum latency at switching between DUs to the same CU.

The traditional MFH network is being split into two key components called NGFI-I and NGFI-II, referenced in general as the xHaul; NGFI-I is the section between the RU and DU, while NGFI-II is the section between the DU and CU.

The DU allows placement of key time-critical RF functionality closer to the RU while also reducing required bandwidth (for same user traffic) for sending to the CU. The CU completes all other required RF processing and outputs IP traffic to the network core.

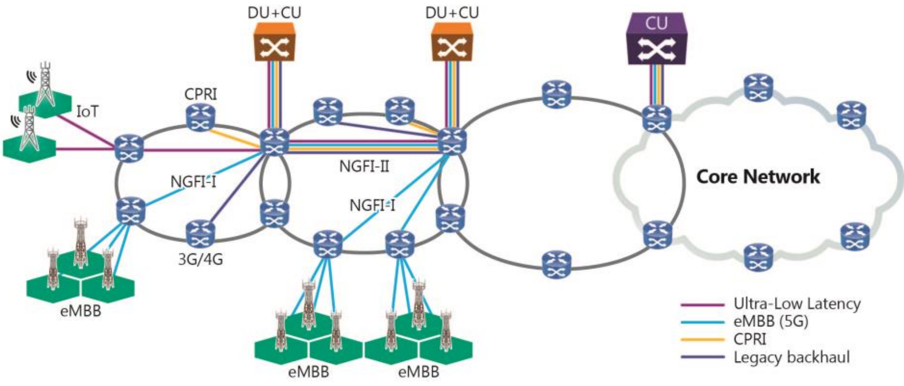

Figure 1 IEEE 1914.1 network architecture

Splitting the historical role of the BBU into these two elements supports creation of a much more flexible architecture by the operator and also supports the more stringent latency and throughput requirements of future networks.

3GPP Functional Split

The 3GPP organization has defined a key section of the transport network called the Functional Split defining at which PHY level the connection between two elements across the xHaul is connected. This allows splitting the network into different segments, allowing only segments closest to the RU to carry all the time-critical traffic, while segments closer to the CU are no longer required to carry this traffic. This enables a very large 2 to 3 times reduction in required bandwidth across NGFI-I and a 5 to 10 times reduction across the NGFI-II links compared to Functional Split Option 8 using the full IQ data including CPRI time-sensitive data. The market generally considers either Option 7.2 or 7.3 to be most likely used for time-sensitive data over 1914.3 or eCPRI, because they offer a good compromise for NGFI-I sections of the network architecture. Options 2 or 3 are largely regarded as the best candidates for the NGFI-II sections because they offer very large bandwidth savings over higher options while enabling sending of required control signals back to the CU.

Frame Formats

As with many standards, there are competing frame formats but while 1914.3 and eCPRI frames offer the same basic functionality and are both designed for the NGFI-I network segment, they have fundamental structural differences. Both 1914.3 and eCPRI use a standard Ethernet frame at the Layer-2 (MAC) level.

RoE 1914.3

The 1914.3 frame is carried directly over the MAC level (Layer 2) of the Ethernet frame with an IEEE-assigned EtherType of FC3D followed by the RoE frame header section, which includes the following areas.

subType: 8-bit section used to identify payload in RoE frame; common subtype frames include Control packet, Structure-agnostic payload, Structure-aware payload, C&M packet, Time domain payload, Frequency domain payload.

flowID: 8-bit section identifying each flow between two end points; up to 255 flows can be maintained.

Length: 16-bit section indicating length of frame after RoE header (excluding FCS).

orderInfo: 32-bit section indicating sequence number or time stamp of each flow.

RoE Payload: Varies depending on frame type (indicated by subType) as does length.

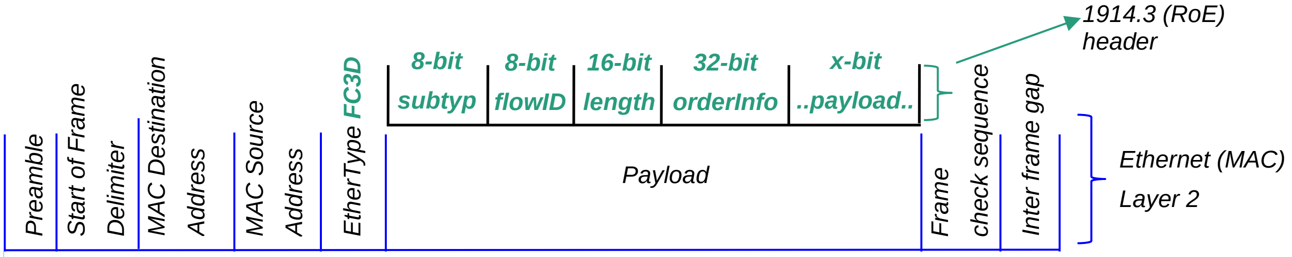

Figure 2 IEEE 1914.3 frame format

The 1914.3 frame can carry four different traffic-frame types identified in the subType section as follows.
Structure-agnostic: Captures constant bit rate of traffic, packetizes it into Ethernet frames, and then extracts payload back into constant bit rate of traffic at far end. CPRI traffic is the common reference used, but the traffic could be any type as long as it is at the correct line rate.
Structure-aware: Requires CPRI traffic type and deconstructs CPRI packets into separate parts placed within Ethernet frames before reconstructing into CPRI frames at far end. Since CPRI packets are separated into different parts, it is possible to send only the required traffic over the Ethernet frames and discard non-utilized areas of the CPRI packets.
Native RoE time domain packet: Captures time domain IQ data without gaps and carries them over Ethernet frames, before reversing process at far end.
Native RoE frequency domain packet: Captures frequency packets and carries them over Ethernet frames, before reversing process at far end.

Note: The key reason for using both time and frequency domain packet transport is because it supports data transport at different Functional Split locations.

Network synchronization is critical for MFH networks and RoE manages the network timing and synchronization over well-defined and commonly used standards, such as IEEE Std 802.1CM™, IEEE Std 1588v2™, ITU-T G826x, ITU-T G8271/Y.1366, and ITU-T G.8275.

eCPRI

The eCPRI frames are carried over an Ethernet frame with different sections carried over different layers of Ethernet frames. The eCPRI core areas, such as User Data, Real-Time Control and other eCPRI services, are carried over any of the following Ethernet layers, Layer 2 directly (MAC→eCPRI), Layer 3 (MAC→IP→eCPRI), Layer 4 (MAC→IP→UDP→eCPRI), and the IEEE-assigned EtherType is AEFE.
The eCPRI Message (header) is made up of four sections plus a reserve section followed by the payload.

eCPRI Protocol Revision:	4-bit section indicating eCPRI protocol revision; it is updated only when change causes incompatibility with earlier version(s).
C:	1-bit section indicating concatenated eCPRI message; 1 indicates that another frame of the same group follows, and 0 indicates the last frame of the concatenated group.
eCPRI Message Type:	8-bit section indicating payload (message) type used in this frame, which includes IQ Data, Bit Sequence, Real-Time Control Data, Generic Data Transfer, Remote Memory Access, One-way Delay Measurement, Remote Reset and Event Indication.
eCPRI Payload Size:	16-bit section indicating size of payload following eCPRI (message) header; note the payload size might be limited by the underlying technology.

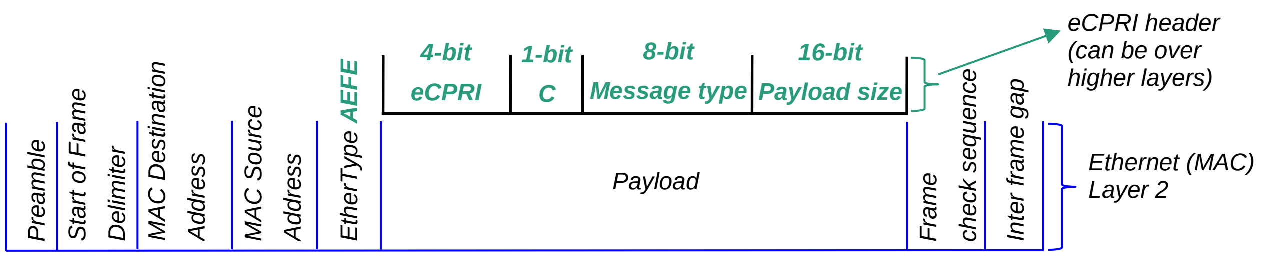

Figure 3 eCPRI frame format (reserve bit's removed)

The eight different payload types carried in the eCPRI frame payload, indicated within the eCPRI Message Type section are as follows:

IQ Data:	Used to transfer time or frequency domain IQ data between eREC (commonly called REC or CU or BBU) and eRE (commonly called RU) with vendor-specific payload structure.
Bit Sequence:	Used to transfer user data in form of bit sequence between eREC and eRE with vendor-specific structure.

Read-Time Control Data: Used to transfer vendor-specific real-time control messages between eREC and eRE which control IQ and Bit Sequence data.
Generic Data Transfer: Used to transfer user plane and control messages for extended data synchronization and generic data transfers between eREC and eRE with vendor-specific details.
Remote Memory Access: Used to read from and write to memory of remote unit (eREC or eRE) with hardware-specific commands.
One-way Delay Measurement: Used to estimate one-way link delay of network allowing eREC and/or eRE to compensate for delay. This is completed by each end element which knows its own compensation value (internal delay) sending a delay request which includes the element internal delay. Upon receiving the request, the far-end element time-stamps the request and returns it. Since this includes both required compensation values, it supports calculation of one-way delay. To work correctly, both elements must be time-synchronized with a common clock.
Remote Reset: Used to reset different elements; an eREC sends the request to eRE with vendor-specific details of the payload reset.
Event Indication: Used to notify other end of a link fault and whether the fault has ceased.

The C&M Plane is carried independently over the Ethernet frames from the core eCPRI components and can be carried over any Ethernet layer and is not restricted to any protocol. The C&M traffic is considered non-time-critical and should only consume a small part of the total link bandwidth. The protocols and any transferred details are vendor specific.
The Synchronization Plane is carried independently over the Ethernet frame from the core eCPRI components. It must be able to synchronize eRE to within the 3GPP-defined timing requirements and can use protocols, such as PTP, SyncE or other methods. This data is considered time critical and is expected to consume only a small part of the total bandwidth. The configuration is vendor-specific.

What's Important to Test and Why

The 1914.3 (RoE) and eCPRI frame formats both use Ethernet in their lower layers, allowing timing areas to be tested using standard Ethernet timing methods. Areas such as latency, routing, switchover time, and BER over the 1914.3 and eCPRI frame formats must also be tested.

Timing

Historically, there have been two key ways for the RRH to acquire accurate timing - either via GNSS (i.e. GPS), or over the PDH interface. With the move to Ethernet and the complexity and cost of using GNSS (especially in built-up environments), several methods of transporting accurate timing over Ethernet have been standardized. The two key standards are PTP (IEEE 1588v2), and SyncE (ITU-T G.826x), which are well defined and allow the timing to be synchronized and maintained across the network. The ability to transport and test timing at all elements is key to a reliable network, because both 1914.3 and eCPRI network elements require very accurate timing to ensure data carried over these networks is placed on the RF interface at an exact time. If the timing is not accurate, the data throughput at the mobile device cannot be maintained while switching between RUs.

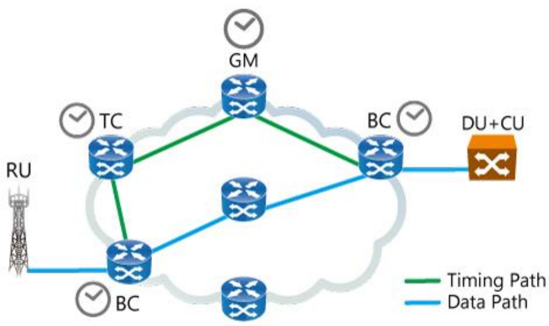

Figure 4 Timing path independent from Data path

Distribution of network timing is independent of the data path and the timing of each node must be checked for accuracy and stability against the Grand Master Clock.
IEEE 802.1CM discusses the required maximum relative Time Error (max|TE|) allowed between two RUs from the clocking source at the edge of a bridged network, depicted as being at the same location as the CU. Table 1 summarizes the max$|TE_{relative}|$ clock requirements at the RUs from the GM across the PTP network.

Table 1 IEEE 802.1CM - max|TE| between RUs

	Category A+	Category A	Category B	Category C
RU to RU, terminating PTP		60 ns	100 ns/190 ns*1	1.1 µs
RU to RU, clocking via 1PPS and ToD	20 ns	70 ns	200 ns	1.1 µs

*1 RU using enhanced internal SC with total maximum absolute time error of 15 ns

Each category in Table 1 represents different types of networks that can be used, offering different types of services based on end-user requirements. The following lists possible network examples for each category.

Category A+: MIMO or Tx diversity at each carrier frequency
Category A: Intra-band contiguous carrier aggregation without MIMO or Tx diversity
Category B: Intra-band non-contiguous carrier aggregation without MIMO or Tx diversity
Category C: LTE-TDD for less than 3-km cell radius

Either PTP, or SyncE and PTP are used to synchronize frequency across the network with the requirement to deliver ±16 ppb. It is possible to maintain a network frequency of better than ±16 ppb from a PTP-only network that is maintaining ±1 µs max|TE| for periods of longer than 1 minute (1000/16 s).

Latency

Network latency is very critical in the NGFI-I network segment and ensuring that it is within required limits must be confirmed at network installation. Networks like URLLC place very strict requirements on the NGFI-I segment and a delay of microseconds is critical. Both the 1914.1 and eCPRI standards require a known network latency, ensuring delivery of the frame payload to the RF interface accurately and reliably.
Different standards offer insight into network latency requirements; 3GPP discusses how latency from the BBU to UE and back RTT must be within 1 ms for URLLC, while IEEE 802.1CM requires a latency of 100 µs across the transport network between the CU and RU. IEEE 1914.1 focuses on the area of the transport network, offering more in-depth details, splitting it into sub-classes based on network segments and traffic types. Network requirements vary greatly and some basic examples are listed in Table 2.

Table 2 IEEE 1914.1, 802.3CM and 3GPP latency examples

Service type	Source	BBU–UE	NGFI-I	NGFI-II	Comment
URLLC/ cM2M	1914.1	-	50 µs	50 or 100 µs	NGFI-II segment possible if total latency ≤150 µs
4G/eMBB/M2M	1914.1	-	100 µs	1 or 3 ms	NGFI-II depends on operator assigned priority level
URLLC	802.3CM	-	100 µs		From RU to CU or CU to RU
E2E URLLC	3GPP	0.5 ms	-	-	From UE to BBU or BBU to UE
E2E eMBB	3GPP	4 ms	-	-	From UE to BBU or BBU to UE

Note: NGFI-I and NGFI-II values are cumulative, so the second example is in the range of 1100 µs to 3100 µs.
BBU to UE is 1-way, but engineers often quote 3GPP standards as RTT, twice the Table 2 values.

Routing

Historically, MFH networks have been point-to-point, but with the move to centralized processing using DU and CU configurations in 5G networks, it is important to confirm routing and throughput across or around the network. This allows for a much more flexible and reliable xHaul network, changing it from a simple point to point network to a carrier class network with expectation of maximum up time. IEEE 1914.1 defines different requirements for the xHaul network availability with the highest class being six 9s or 99.9999% of available uptime. The five 9s of availability uptime is commonly called carrier grade, but the stringent requirements placed by applications on the network the uptime requirement has increased. The difference between Class A and B is 32 seconds per year to 5 minutes 15 seconds per year, making Class A much more stringent.

Table 3 Network availability time

Class	A	B	C	D
Availability minimum	99.9999%	99.999%	99.99%	99.9%

IEEE 802.1CM specifies the maximum FLR that IQ data can tolerate as 10^{-7}; CPRI also defines a maximum FLR of 10^{-7} for eCPRI networks.

With transport networks now being comprised of many individual elements and multiple routable paths, testing is critical to assure required network uptime. The ability to insert PRBS into 1914.3 or eCPRI-framed payloads allowing accurate BER testing while confirming correct network routing and the ability to carry the required bandwidth is critical to ensuring network stability.

Network switching time

With xHaul networking equipment requiring very stringent time synchronization across the transport network, it is also very important to ensure minimal re-routing when a network segment is down. Testing and ensuring re-routing time not only minimizes downtime and data loss, but also ensures the RU is not taken out of service by its NMS. SDH/SONET/PDH networks are normally expected to have a 50 ms or better switching time and this requirement has commonly carried over to Ethernet. However, this is now considered by some as too large for xHaul networks. While some discuss 4G networks with a switching time of >10 ms causing NMS to take RRH offline, the NGFI-I recommended switching time of 50 ms remains current, but after more evaluation a more stringent switching time might be required for future networks.

Conclusion

As operators move to 5G there will be a massive increase in network throughput requirements, requiring the new frame structures developed by the IEEE 1914.3 and eCPRI standards to be utilized carring traffic more efficiently. The transition also requires a new network architecture defined in the IEEE 1914.1 standard. These new networks will be required to adhere to strict timing, latency, routing, switching, and availability requirements. Testing during network I&M will be the key to assuring the end-user expected transport network reliability and uptime.

Appendix I

Specification Requirements

This White Paper discusses many key points that must be complied with by a modern transport network connecting key elements of 4G-TDD or 5G networks. Extracts are provide below for easy reference, but, for a full understanding, click the reference links above each table.

Maximum relative time error $Max|TE_{relative}|$

	Category A+	Category A	Category B	Category C
RU terminating PTP		60 ns	100 ns/190 ns[*1]	1.1 µs
RU clocking via 1PPS and ToD	20 ns	70 ns	200 ns	1.1 µs

Latency requirements per network segment

Service type	Source	BBU–UE	NGFI-I	NGFI-II	Comment
URLLC/ cM2M	1914.1	-	50 µs	50 or 100 µs	NGFI-II segment possible if total latency ≤150 µs
4G/eMBB/M2M	1914.1	-	100 µs	1 or 3 ms	NGFI-II depends on operator assigned priority level
URLLC	802.3CM	-	100 µs		From RU to CU or CU to RU
E2E URLLC	3GPP	0.5 ms	-	-	From UE to BBU or BBU to UE
E2E eMBB	3GPP	4 ms	-	-	From UE to BBU or BBU to UE

Network uptime

Class	A	B	C	D
Availability minimum	99.9999%	99.999%	99.99%	99.9%

Note: FLR of 10^{-7}

Network switching time

- 50 ms NGFI-I (further evaluation required for a faster switching time)
- 50 ms NGFI-II

References

CPRI http://cpri.info

IEEE 1914 (Working Group) http://sites.ieee.org/sagroups-1914

IEEE Std 802.1CM™ http://www.ieee802.org/1/pages/802.1cm.html

- IEEE Standard for Local and metropolitan area networks – Time-Sensitive Networks for Fronthaul.

ITU-T G.8261/Y.1361 http://www.itu.int/rec/T-REC-G.8261/en

- Timing and synchronization aspects in packet networks

ITU-T G.8262/Y.1362 http://www.itu.int/rec/T-REC-G.8262/en

- Timing characteristics of a synchronous Ethernet equipment slave clock

ITU-T G.8264/Y.1364 http://www.itu.int/rec/T-REC-G.8264/en

- Distribution of timing information through packet networks

ITU-T G.8275 https://www.itu.int/rec/T-REC-G.8275/en

- Architecture and requirements for packet-based time and phase distribution.

ITU-T G.8271/Y.1366 https://www.itu.int/rec/T-REC-G.8271/en

- Time and phase synchronization aspects of packet networks.

IEEE Std 1588v2™ https://standards.ieee.org/findstds/standard/1588-2008.html

- IEEE Standard for a Precision Clock Synchronization Protocol.

Acronyms

3GPP	3rd Generation Partnership Project
5G	5th Generation (telecom network)
BBU	Base-Band Unit
BC	Boundary Clock
CPRI	Common Public Radio Interface
CU	Central Unit
cM2M	critical Machine to Machine
DU	Distributed Unit
eCPRI	eCommon Public Radio Interface
eRE	eCPRI Radio Equipment
eREC	eCPRI Radio Equipment Control
FLR	Frame Loss Ratio
GM	Grand Master Clock
GNSS	Global Navigation Satellite System
IOT	Internet of Things
IQ	In-phase and Quadrature modulation
M2M	Machine to Machine
MBH	Mobile Back Haul
MFH	Mobile Front Haul
MIMO	Multiple-Input and Multiple-out
NMS	Network Management System
QoE	Quality of Experience
PDH	Plesiochronous Digital Hierarchy
PRBS	Pseudo Random Bit Sequence
PHY	Physical Layer
RF	Radio Frequency
RoE	Radio over Ethernet
RU	Radio Unit
RRH	Remote Radio Head
RTT	Round Trip Time
SC	Slave Clock
SDH	Synchronous Digital Hierarchy
SONET	Synchronous Optical Network Technologies
TC	Transparent Clock
UE	User Equipment
URLLC	Ultra-Reliable Low Latency Communications

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