eCPRI Specification V1.0 (2017-08-22)

Interface Specification

Common Public Radio Interface:
eCPRI Interface Specification

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1. Introduction

The Common Public Radio Interface (CPRI) is an industry cooperation aimed at defining publicly available specifications for the key internal interface of radio base stations, such as eCPRI connecting the eCPRI Radio Equipment Control (eREC) and the eCPRI Radio Equipment (eRE) via a so-called fronthaul transport network. The parties cooperating to define the specification are Ericsson AB, Huawei Technologies Co. Ltd, NEC Corporation and Nokia.

<u>Motivation for eCPRI:</u>

Compared to the CPRI [1], eCPRI makes it possible to decrease the data rate demands between eREC and eRE via a flexible functional decomposition while limiting the complexity of the eRE.

<u>Scope of Specification:</u>

The necessary items for transport, connectivity and control are included in the specification. This includes User Plane data, Control and Management Plane transport mechanisms, and means for synchronization.

The eCPRI specification will support 5G and enables increased efficiency in order to meet the needs foreseen for 5G Mobile Networks. In contrast to CPRI, the eCPRI specification supports more flexibility in the positioning of the functional split inside the Physical Layer of the cellular base station.

The scope of the eCPRI specification is to enable efficient and flexible radio data transmission via a packet based fronthaul transport network like IP or Ethernet. eCPRI defines a protocol layer which provides various - mainly user plane data specific - services to the upper layers of the protocol stack.

The specification has the following scope (see Figure 1):

1. 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.
2. Three different information flows (eCPRI User Plane data, C&M Plane data, and Synchronization Plane data) are transported over the interface.
3. 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.

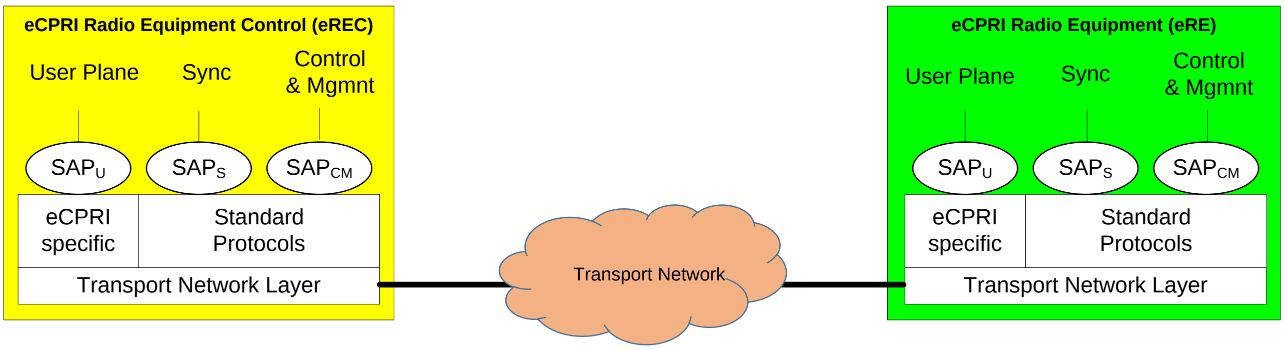

Figure 1: System and Interface Definition

2. System Description

This section describes the eCPRI related parts of the basic radio base station system architecture and defines the mapping of the functions to the different nodes. Furthermore, the reference configurations and the basic nomenclature used in the following sections are defined.

The following description is based on the Evolved UMTS Terrestrial Radio Access (E-UTRA) and 5G. However, the interface may also be used for other radio standards.

2.1. Definitions/Nomenclature

This section provides the basic nomenclature that is used in the following sections.

eCPRI node:

The radio base station system is composed of two basic eCPRI nodes, the eCPRI Radio Equipment Control and the eCPRI Radio Equipment (see Figure 1). The eCPRI Radio Equipment Control and the eCPRI Radio Equipment are described in the following chapter. The radio base station system shall contain at least two eCPRI nodes, at least one of each type: eREC and eRE.

eREC / eRE element:

A hardware or software component within an eCPRI node which alone does not constitute a full eCPRI node.

Protocol planes:

The following planes are outlined:

C&M Plane:	Control and Management data flow for the operation, administration and maintenance of the nodes.
User Plane:	Three data flows covered by the user plane: a) Data flow to be transferred from the radio base station to the User Equipment (UE) and vice versa. b) Real time control data related to a). c) Other eCPRI flows not covered by other protocol planes/flows.
Synchronization Plane:	Data flow for synchronization and timing information between nodes.

eCPRI Protocol Layer:

A Protocol Layer defined by this specification and providing specific services to the upper layers.

Service Access Points:

For all protocol planes except Connection OAM, service access points are defined. These service access points are denoted as SAP_{CM}, SAP_S and SAP_U as illustrated in Figure 1. A service access point is defined on a per logical connection basis.

Logical connection:

A “logical connection” defines the interconnection between SAPs (e.g., SAP_U) across peered eCPRI nodes.

Grandmaster Clock (GM):

Reference clock of a Precision Time Protocol-based Transport network. The GM can be located in the network as well as in the eREC or eRE.

Downlink:

Direction from eNB/gNB to UE.

Uplink:

Direction from UE to eNB/gNB.

Service:

Method to access one or more functionalities via the eCPRI protocol. This method typically involves the transmission/reception of eCPRI messages.

Figure 2 illustrates basic definitions related to service access points.

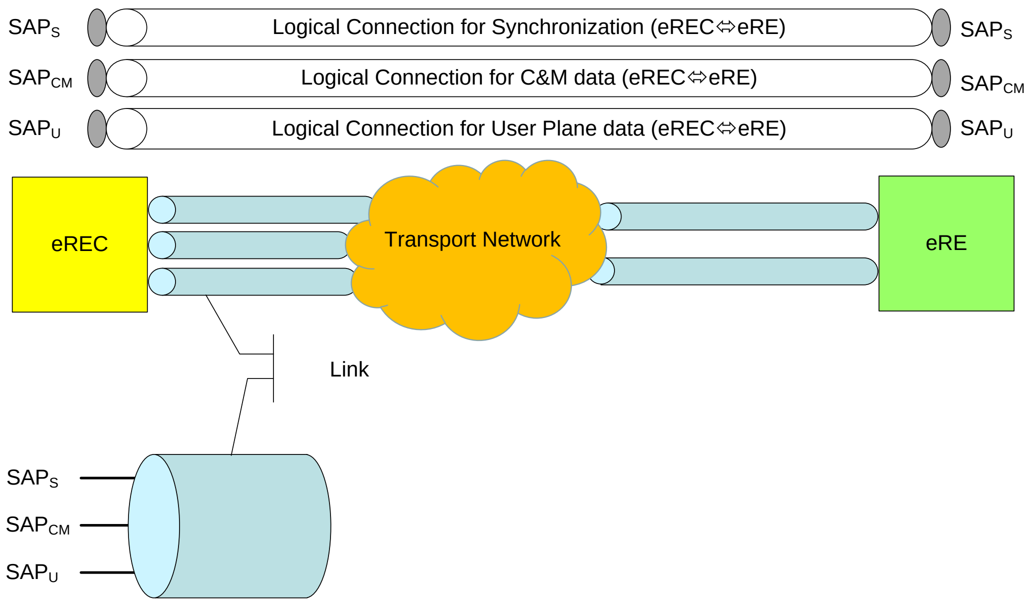

Figure 2: Illustration of basic definitions

2.2. System Architecture

Radio base stations should offer deployment flexibility to mobile network operators, i.e., in addition to an all-in-one radio base station, more flexible radio base station system architectures involving remote radio equipment shall be supported. This may be achieved by a decomposition of the radio base station into two basic building blocks, the so-called eCPRI Radio Equipment Control (eREC) and the eCPRI Radio Equipment (eRE). Both parts may be physically separated (i.e., the eRE may be close to the antenna, whereas the eREC is generally located in a conveniently accessible site) and connected via a transport network.

Typically, the eREC contains part of the PHY layer functions and higher layer functions of the air interface, whereas the eRE contains the other part of the PHY layer functions and the analog radio frequency functions. The basic idea of the functional split between both parts is described in section 2.3.1. Several examples of functional splits are described in informative Annex 6.1.

User plane data (i.e. information flows between split PHY layer functions in eREC and eRE and their real-time control), control and management and synchronization signals are packetized, multiplexed and transferred over the transport network (fronthaul network) which eREC(s) and eRE(s) are connected to.

eCPRI does not constrain the use of network- and data link-layer protocols to form the network, so any type of network can be used for eCPRI provided eCPRI requirements (defined in [15]) are fulfilled. eCPRI also uses existing de-facto/de-jure standard protocols as much as possible where available. The basic idea is illustrated in Figure 1.

Figure 3 shows an example of a system architecture with local eCPRI. eCPRI is used as an internal interface within the eREC and/or eRE (local eCPRI) when the eREC/eRE consists of multiple eREC/eRE elements. In addition, eCPRI and CPRI can coexist in a system. Please note that eCPRI has no backward compatibility with legacy CPRI.

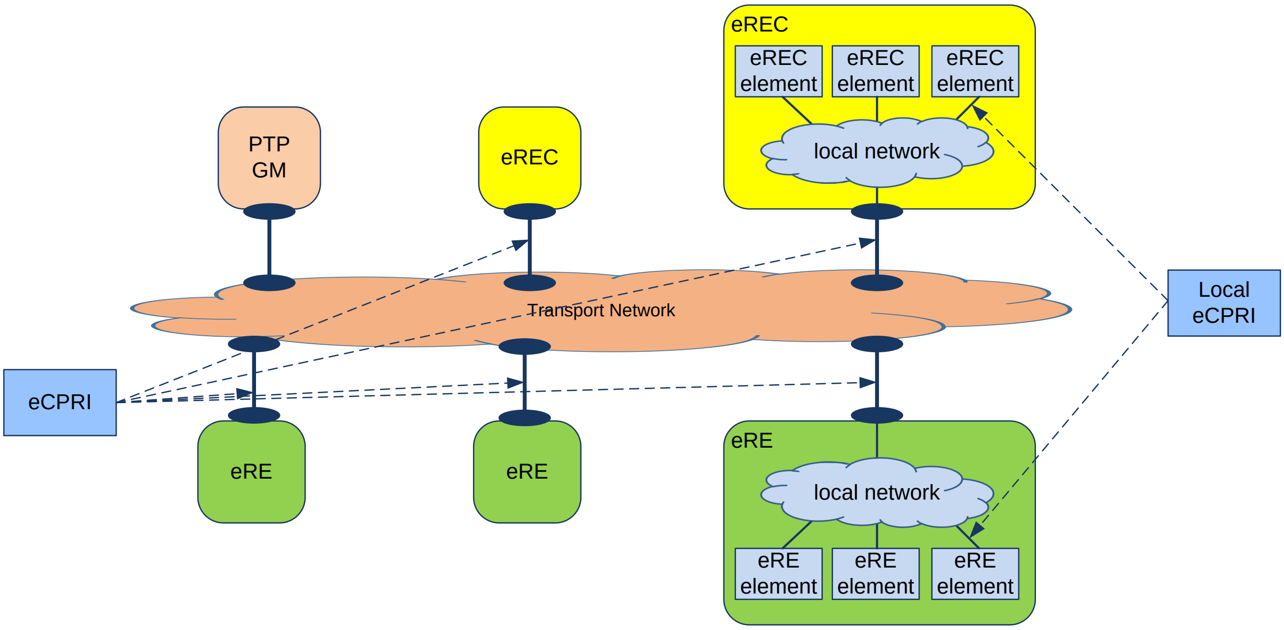

Figure 3: System Architecture example with local eCPRI

2.3. Functional Description

This section provides a description on the functional content of an eNB/gNB. The CPRI concept of a radio base station divided into two nodes, one called REC (Radio Equipment Control) and the other called RE (Radio Equipment) is still valid for eCPRI but with the small change of the naming of the two nodes to eREC and to eRE. The functional split across these two nodes can be outlined more flexibly than it is in the CPRI specification. The functional content of an eNB/gNB (eREC and eRE) is listed in Table 1, references to corresponding 3GPP Technical Specifications are included in the table.

Table 1: Functional content of eNB/gNB

Functions and Protocol Stack of eNB/gNB eREC + eRE	3GPP eNB Reference TS 36.nnn [2]	3GPP gNB Reference TS 38.nnn [3]
Radio Base Station Control & Management	-	-
Backhaul transport	-	-
RRC (Radio Resource Control)	331	331
PDCP (Packet Data Convergence Protocol)	323	323
RLC (Radio Link Control)	322	322
MAC (Medium Access Control)	321	321
PHY (Physical)	201 (General description)	201 (General description)
RF (Radio Functions)	104	104
Measurements	214, 314	215

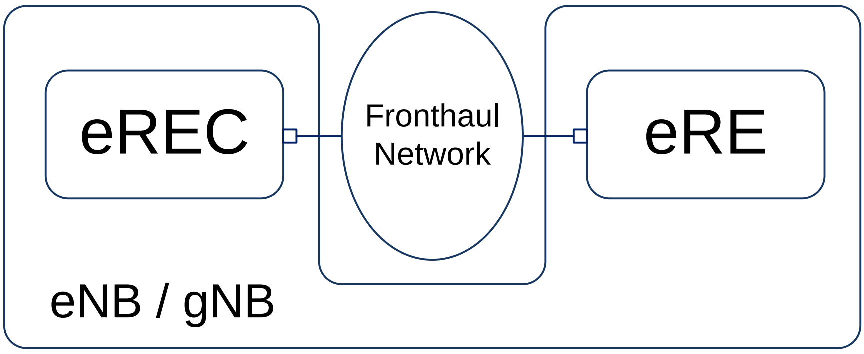

Figure 4: Fronthaul Network definition

Regardless of which functional decomposition between eREC and eRE is selected for a specific implementation, the ‘Fronthaul Network’ is the interface between the two eCPRI nodes eREC and eRE.

The different functions listed in Table 1 can be located either in the eREC or in the eRE. When using eCPRI for either existing or forthcoming radio standards such as the 3GPP 5G (NR) the functional decomposition between eREC and eRE depends on vendor specific choices. Different implementations will be targeting different objectives (radio performance, fronthaul performance adaptions, feature necessity circumstances etc.) leading to a different functional decomposition between eREC and eRE.

2.3.1. Functional Decomposition

Figure 5 shows the protocol stack layers for a 3GPP 4G (LTE) or 5G (NR) radio base station. Five inter-layer functional splits numbered A to E are depicted in the figure. One additional set of intra-PHY splits named “$\{I_D;II_D;I_U\}$” is also shown. For more details of the intra-PHY splits refer to section 6.1.1.

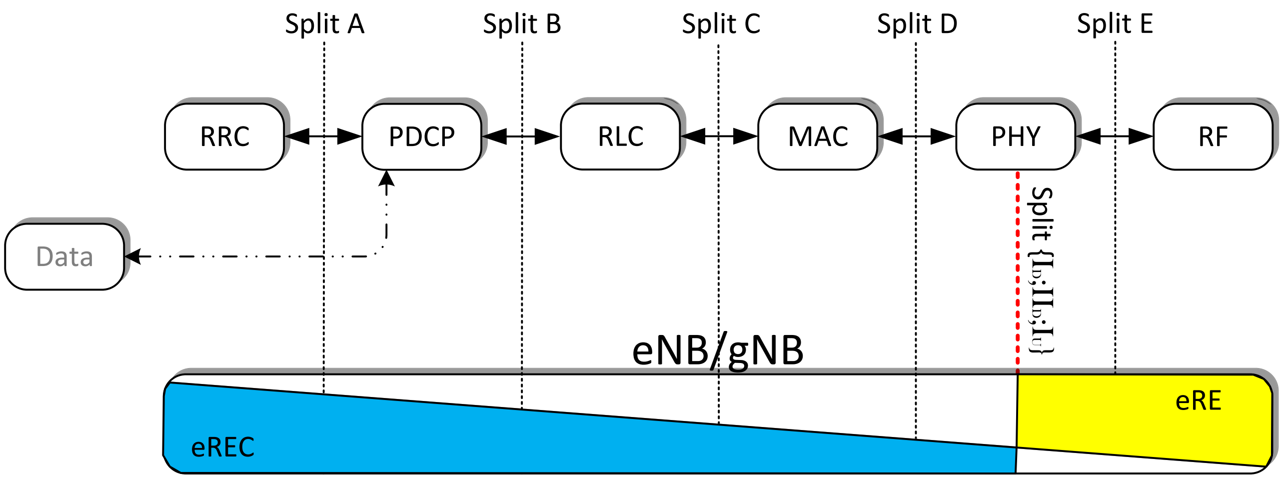

Figure 5: Functional decomposition on RAN layer level

As shown in Figure 5 the eNB/gNB consists of only two units: the eREC and the eRE. For some of the splits an implementation with only two nodes may not be realistic. For instance, Split A with a central RRC and a distributed unit containing the rest of the protocol stack would not support a number of features (such as those requiring cell-coordination) efficiently. eCPRI assumes that the eNB/gNB consists of eREC and eRE(s) only and thus the following text should be read with this in mind. The intra PHY Split is marked with a red line, this is just an example showing how the figure shall be interpreted, the blue and yellow colored areas in a eNB/gNB show what parts are located in eREC and eRE.

The CPRI specification [1] functional decomposition-split for E-UTRA corresponds to split E.

The advantages of the intra-PHY-split are: features such as Carrier Aggregation, Network MIMO, Downlink CoMP, Uplink L1 Comp Joint Processing can be efficiently supported. Some of these features might of course be supported by other splits as well.

Some disadvantages of the intra-PHY-split are: A fronthaul network with “higher” capacity and “lower” latency is required compared to higher layer splits.

Table 2 shows how different splits will set different relative capacity- and latency-requirements on the fronthaul network.

Table 2: Fronthaul requirements vs. splits

Split	Fronthaul capacity needs	Fronthaul latency requirement
A	Low, Scales with # MIMO layers	Relaxed
B	Low, Scales with # MIMO layers	Relaxed
C	Low, Scales with # MIMO layers	Relaxed
D	Low, Scales with # MIMO layers	Very Strict
E	Very High, Scales with # antenna ports	Very Strict
$\{I_D;II_D;I_U\}$	See section 6.1.1	Very Strict

3. Interface Specification

3.1. Protocol Overview

The eCPRI interface includes the following information flows:

1. User plane:
   - User Data:
     User information (to be transmitted from/to the base station to/from the user equipment) with format depending on the underlying functional decomposition between the eREC and the eRE.
   - Real-Time Control data:
     Time-critical control and management information directly related to the User Data.
   - Other eCPRI services:
     eCPRI services such as User Plane support, remote reset, etc.
2. C&M plane:
   - Control and management information exchanged between the control and management entities within the eREC and the eRE. This information flow is given to the higher protocol layers and is considered as not being time critical.
3. Synchronization plane:
   - Synchronization data used for frame and time alignment.

eCPRI defines a protocol for the transfer of user plane information between eREC and eRE via a packet based fronthaul transport network. For C&M and synchronization information flows, existing protocols and standards are referenced as proposals. The interface supports Ethernet-switched or IP-routed fronthaul networks. Figure 6 provides an overview on the basic protocol hierarchy for Ethernet/IP-based eCPRI transport case.

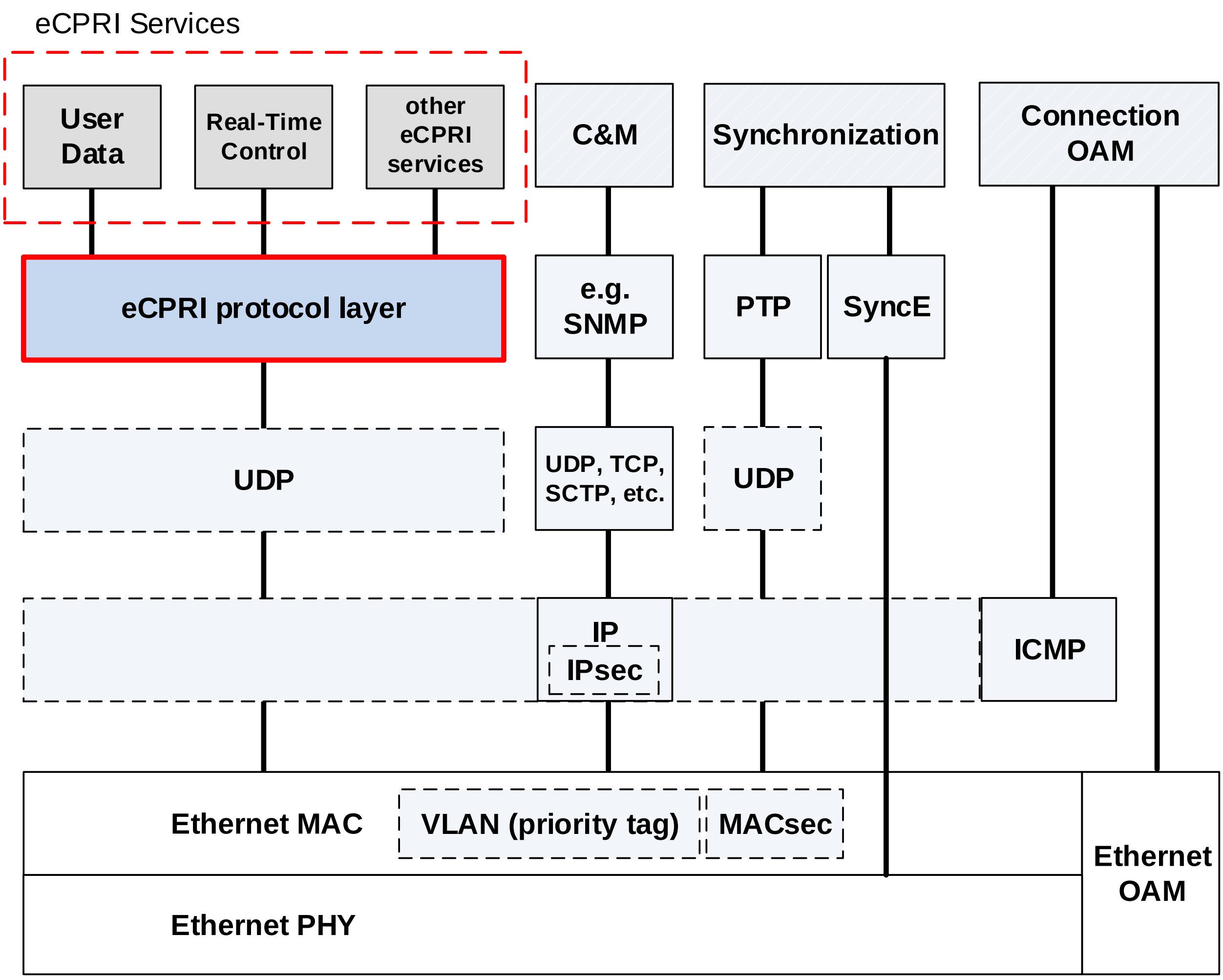

Figure 6: eCPRI protocol stack over IP / Ethernet

For the example of IP/Ethernet based eCPRI transport protocol shown in Figure 6, the following needs to be considered:

- User plane:
  - In case of eCPRI over Ethernet (refer to section 3.2.1) UDP/IP is not used for the User plane.
  - In case of eCPRI over IP (refer to section 3.2.2), Ethernet might not be used, even though Ethernet is still a typical technology used to transfer IP packets.
  - Message types used by eCPRI are described in section 3.2.3 in detail.
- C&M Plane:
  - Please refer to Section 3.3 “C&M Plane” for more information.
- Synchronization Plane:
  - UDP/IP and VLAN are optional, e.g. the ITU-T PTP telecom profile G.8275.1/Y.1369.1 [4] only defines PTP transport over Ethernet. Insertion of VLAN tag is not allowed in this profile, IP and VLAN are thus not possible.
  - Please refer to Section 3.4 “Synchronization Plane” and Annex 6.2 “Synchronization and Timing” for more information.
- Connection OAM:
  - Please refer to Annex 6.4 “Network Connection Maintenance” for more information.
- Please refer to section 3.1.1 for more information on “Ethernet PHY”.

- Please refer to section 3.5 “QoS” for more information on “VLAN (priority tag)”.
- IPsec and MACsec are optional. Please refer to informative Annex 6.8 “Security” for more information.

3.1.1. Physical Layer

The Physical Layer typically follows electrical and optical physical reference standards provided in IEEE 802.3 [5], [6] for the following eCPRI use cases:

1. eCPRI over electrical cable
2. eCPRI over electrical backplane
3. eCPRI over optical fiber

A high flexibility in the choice of connector and transceiver for the optical fiber use case can be achieved by adopting SFP+ [7], [8] and QSFP+ [9], [10].

However, usage of different form factors like CFP, CFP2/4 is not precluded by the eCPRI specification.

The following Table 3 lists typical examples of common Ethernet interface types for 10G, 25G, 40G and 100G Ethernet for the given use cases. Usage of other line rates / interface types is not precluded.

Table 3: Common Ethernet interface types for the given use cases

Use case	Standard / Interface Type	#Lanes	Signal Rate per Lane
Optical	10GBASE-SR/LR/ER ([5], clause 52)	1	10G
	10GBASE-LRM ([5], clause 68)	1	10G
	25GBASE-SR ([6])	1	25G
	40GBASE-SR4 LR4/ER4 ([5], clauses 86/87)	4	10G
	100GBASE-SR10 ([5], clause 86)	10	10G
	100GBASE-SR4/LR4/ER4 ([5], clauses 95/88)	4	25G
Electrical	25GBASE-CR/CR-S ([6])	1	25G
	40GBASE-CR4 ([5], clause 85)	4	10G
	100GBASE-CR10 ([5], clause 85)	10	10G
	100GBASE-CR4 ([5], clause 92)	4	25G
Backplane	10GBASE-KR ([5], clause 72)	1	10G
	25GBASE-KR/KR-S ([6])	1	25G
	40GBASE-KR4 ([5], clause 84)	4	10G
	100GBASE-KR4 ([5], clause 93)	4	25G

3.2. User Plane

3.2.1. User Plane over Ethernet

In this option, eCPRI messages shall be transmitted in standard Ethernet frames[1] [5]. The Ethernet network shall follow the definitions in [15].

The type field of the Ethernet frame shall contain the eCPRI Ethertype ($AEFE_{16}$) [11]. The data field of the Ethernet frame shall contain the eCPRI common header at its beginning, followed immediately by the eCPRI payload. The eCPRI message shall be embedded in the Ethernet frame as a series of octets.

[1] Also, frames with a payload size larger than 1500 octets can be supported

As the minimum size of the data field of an Ethernet frame is 46 octets, if necessary, the eCPRI data field is padded with octets of zero to fill up this minimum size. This padding is not part of the eCPRI message and so is not to be included in the eCPRI payload size field.

An eCPRI node involved in an eCPRI over Ethernet message exchange shall have at least one Ethernet MAC address. All Ethernet MAC addresses within the Ethernet network shall be unique[2]. The assignment between Ethernet MAC addresses and nodes/eCPRI services is out of scope of the eCPRI specification.

The Ethernet MAC header shall provide enough information about the source and the destination of the eCPRI message to deliver the message successfully through the Ethernet network, with the required priority. Further details of the format and definition of the Ethernet frame are out of scope of the eCPRI specification.

3.2.2. User Plane over IP

In this option, eCPRI messages shall be transmitted in UDP/IP packets.

The data field of the UDP datagram contains the eCPRI common header at its beginning, followed immediately by the eCPRI payload. The eCPRI message shall be embedded in the UDP datagram as a series of octets. The UDP datagram shall encapsulate the eCPRI PDU precisely, i.e. without requiring padding octets added to the eCPRI PDU.

An eCPRI node shall have at least one IP address. All IP addresses within the IP network shall be unique [3]. The assignment between IP addresses and nodes/eCPRI services is out of scope of the eCPRI specification.

The header fields of the UDP/IP datagram shall provide enough information about the source and the destination of the eCPRI message to deliver the message successfully through the IP network, with the required priority. Further details of the format and definition of the UDP/IP datagram, and how the IP network is to be maintained are out of the scope of the eCPRI specification.

eCPRI does not specify any range of UDP port values to identify the various eCPRI streams.

3.2.3. eCPRI Message Format

eCPRI messages shall have the format shown in Figure 7 and consisting of a four byte eCPRI common header followed by a variable length eCPRI payload.

[2] Both locally unique and globally unique Ethernet MAC addresses are applicable.

[3] There is no restriction on the IP version (IPv4 or IPv6) used in the IP-routed fronthaul network.

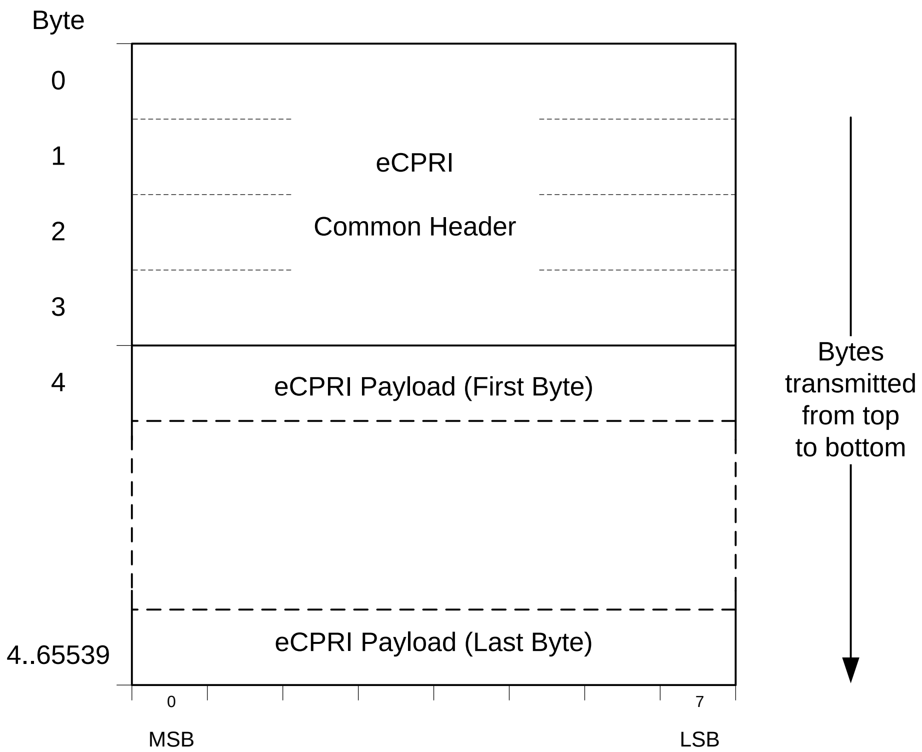

Figure 7: eCPRI message format

3.2.3.1. eCPRI Transmission Byte Order

When the range of a field is too large to fit in a single byte, multiple bytes are used to encode that field. For eCPRI, the byte order of transmission is according to what is known as “network byte order” or “big endian”, i.e. the most significant byte is sent first and the least significant byte is sent last (see [12]).

Example:
The hexadecimal number 0xABCD1234 is sent as the byte sequence 0xAB, 0xCD, 0x12, 0x34.

3.2.3.2. Common Header

eCPRI Message Common Header shall have the format shown in Figure 8.

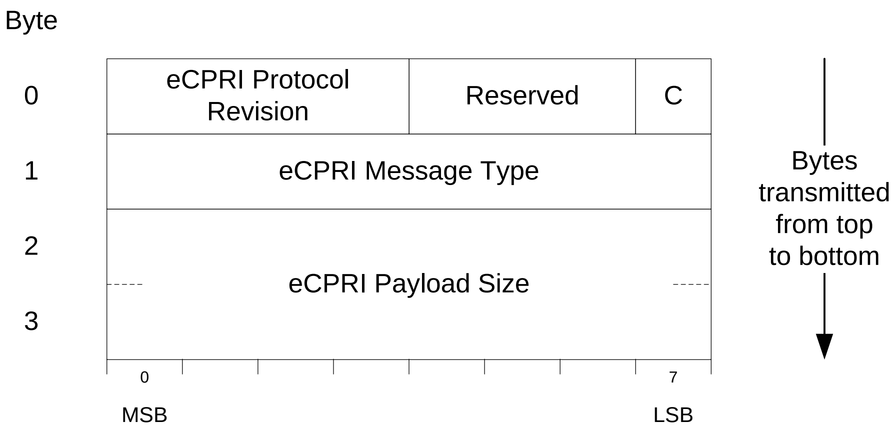

Figure 8: eCPRI Common Header format

Where:

- eCPRI Protocol Revision indicates the protocol version.
  The eCPRI Protocol Revision is a positive integer value, see section 4.4.
- eCPRI Message Type (1 byte, see Table 4) indicates the type of service conveyed by the message.
- eCPRI Payload Size is the size in bytes of the payload part corresponding to the eCPRI message. It does not include any padding bytes following the eCPRI message. The maximum supported payload size is 2^{16}-1 but the actual size may be further limited by the maximum payload size of the underlying transport network.
- “C” is the eCPRI messages concatenation indicator.
  - “C=0” indicates that the eCPRI message is the last one inside the eCPRI PDU.
  - “C=1” indicates that another eCPRI message follows this one within the eCPRI PDU. In this case, 0 to 3 padding byte(s) shall be added to ensure that the following eCPRI message starts at a 4-Byte boundary. Padding byte(s) shall be ignored when received.
- Reserved bits shall be handled according to section 4.2.

3.2.3.3. eCPRI Payload

The payload of eCPRI messages shall follow the format specified in the corresponding eCPRI Message Type sub-section of section 3.2.4. An eCPRI message payload typically includes an eCPRI message header and its associated eCPRI message user data.

3.2.3.4. Mapping Examples

This section explains how eCPRI messages are mapped onto a transport network layer payload with examples.

Figure 9 shows an example in which one eCPRI message is mapped onto a transport network layer payload (e.g. UDP/IP or Ethernet).

Figure 10 shows an example in which two eCPRI messages are concatenated and mapped onto a transport network layer payload (e.g. UDP/IP or Ethernet).

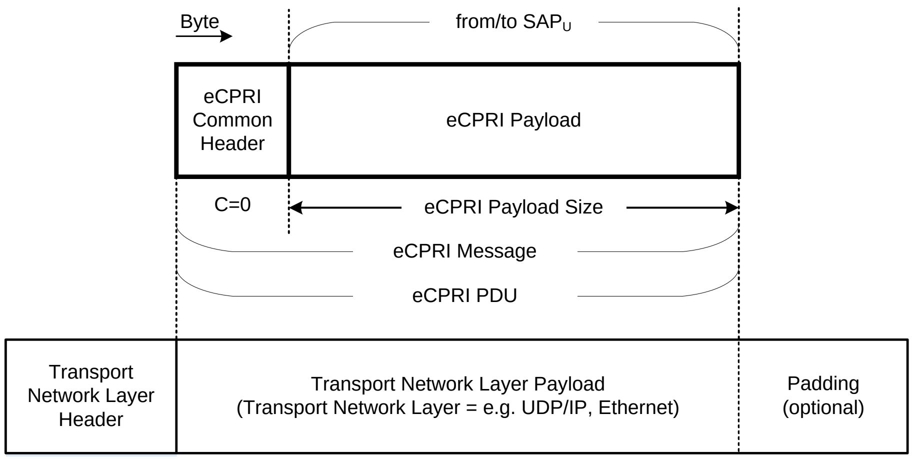

Figure 9: An example of non-concatenated case

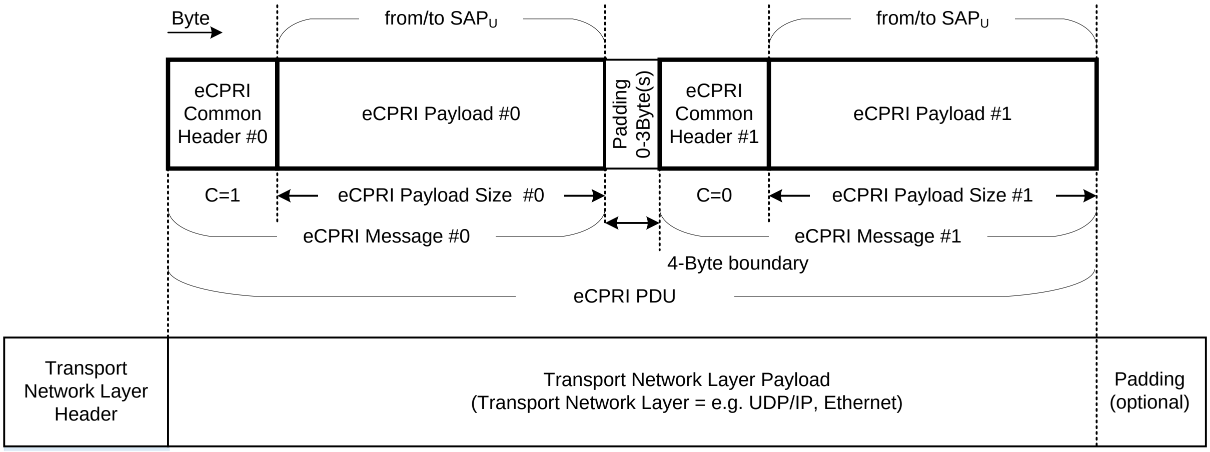

Figure 10: An example of two concatenated eCPRI messages

3.2.4. Message Types

The message types listed in Table 4 are supported by eCPRI. The usage of these types is optional.

Table 4: eCPRI Message Types

Message Type #	Name	Section
0	IQ Data	3.2.4.1
1	Bit Sequence	3.2.4.2
2	Real-Time Control Data	3.2.4.3
3	Generic Data Transfer	3.2.4.4
4	Remote Memory Access	3.2.4.5
5	One-way Delay Measurement	3.2.4.6
6	Remote Reset	3.2.4.7
7	Event Indication	3.2.4.8
8 - 63	Reserved	3.2.4.9
64 - 255	Vendor Specific	3.2.4.10

3.2.4.1. Message Type #0: IQ Data

3.2.4.1.1. Description/Usage

This message type is used to transfer time domain or frequency domain IQ samples between PHY processing elements split between eCPRI nodes (eREC and eRE).

3.2.4.1.2. Message format

Figure 11 shows IQ Data Transfer message format.

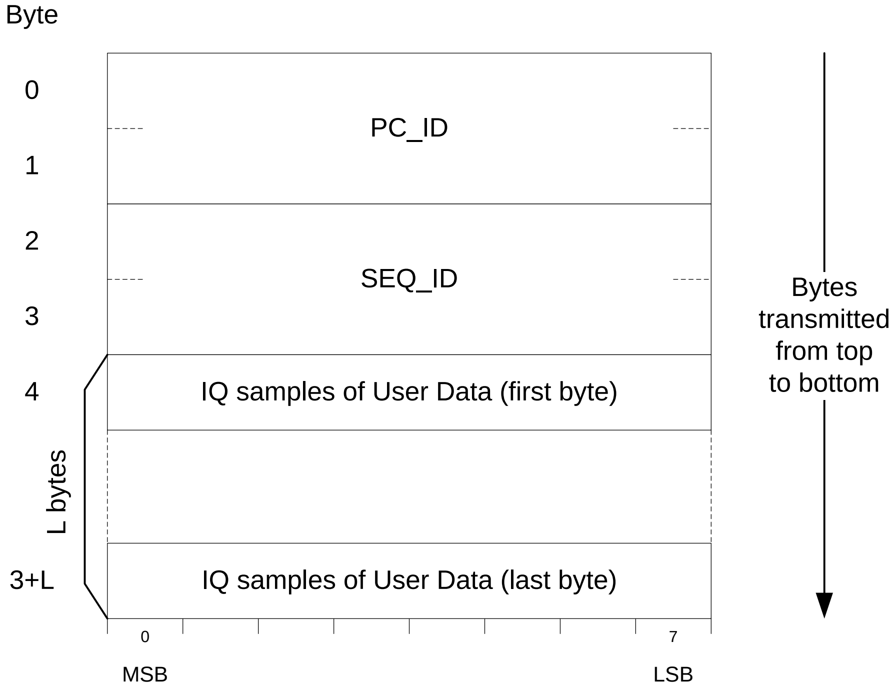

Figure 11: IQ Data Transfer message format

Where:

- PC_ID:
    - An identifier of a series of “IQ Data Transfer” messages.
    - For example, identifier of a physical channel, a user, a layer, an antenna port, etc. which has a common property for PHY processing.
    - How to allocate values to PC_ID is vendor specific.
- SEQ_ID:
    - An identifier of each message in a series of “IQ Data Transfer” messages.
    - For example, identifier of an OFDM symbol, a block of sub-carriers, etc.
    - How to allocate values to SEQ_ID is vendor specific.
- IQ Samples of User Data:
    - A sequence of IQ sample pairs (I, Q) in frequency domain or time domain and associated control information if necessary.
    - Frequency domain IQ or time domain IQ depends on the selected functional split between eCPRI nodes and is vendor specific.
    - The bit width of an IQ sample, the number of IQ sample pairs in a message, and the format of IQ samples (e.g. fixed point, floating point, block floating point), etc. are vendor specific and transmit/receive eCPRI nodes know the actual format in advance.

3.2.4.1.3. Message sequence diagram

Figure 12 shows an example of IQ Data Transfer Sequence. In this example:

- A “Real-Time Control Information” message for PC_ID is transferred before a series of “IQ Data Transfer” messages to inform the remote node how to process IQ samples in following “IQ Data Transfer” messages.
- An “IQ Data Transfer” message with PC_ID is transferred every OFDM symbol period. Each message has a unique SEQ_ID.
- In general, multiple transfer sequence may happen in parallel with different PC_IDs, e.g. for multiple physical channels, users, layers, antenna ports, etc.

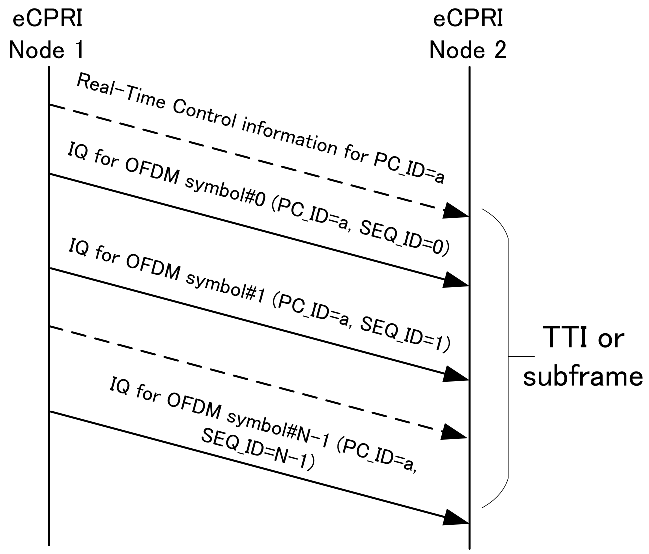

Figure 12: Message sequence diagram (example)

3.2.4.2. Message Type #1: Bit Sequence

3.2.4.2.1. Description/Usage

This message type is used to transfer user data in form of bit sequence between PHY processing elements split between eCPRI nodes (eREC and eRE).

3.2.4.2.2. Message format

Figure 13 shows Bit Sequence Transfer message format.

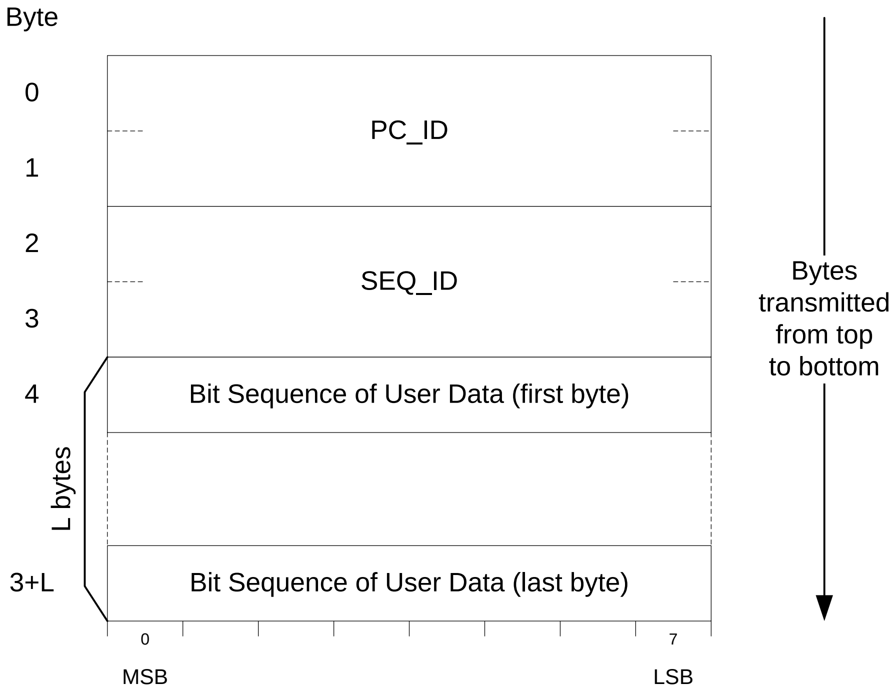

Figure 13: Bit Sequence Transfer message format

Where:

- PC_ID:
    - An identifier of a series of “Bit Sequence Transfer” messages.
    - For example, identifier of a physical channel, a user, a layer, an antenna port, etc. which has a common property for PHY processing.
    - How to allocate values to PC_ID is vendor specific.
- SEQ_ID:
    - An identifier of each message in a series of “Bit Sequence Transfer” messages.
    - For example, identifier of an OFDM symbol, a block of sub-carriers, etc.
    - How to allocate values to SEQ_ID is vendor specific.
- Bit Sequence of User Data:
    - A Bit Sequence of User Data, e.g. channel coded data before modulation mapping.
    - The information carried by the Bit Sequence Transfer message depends on the selected functional split between eCPRI nodes and is vendor specific.
    - The length of a Bit Sequence in a message is vendor specific and known by the transmit/receive node in advance.

3.2.4.2.3. Message sequence diagram

A message sequence example of the Bit Sequence Transfer is shown in Figure 14. In this example:

- A “Real-Time Control Information” message for PC_ID=a is transferred prior to a series of “Bit Sequence Transfer” messages to inform the remote node how to process the user data in bit sequence format in the following “Bit Sequence Transfer” messages.
- A “Bit Sequence Transfer” message with PC_ID is transferred every OFDM symbol period. Each message has a unique SEQ_ID.
- In general, multiple transfer sequences may happen in parallel with different PC_IDs, e.g. for multiple physical channels, users, layers, antenna ports, etc.

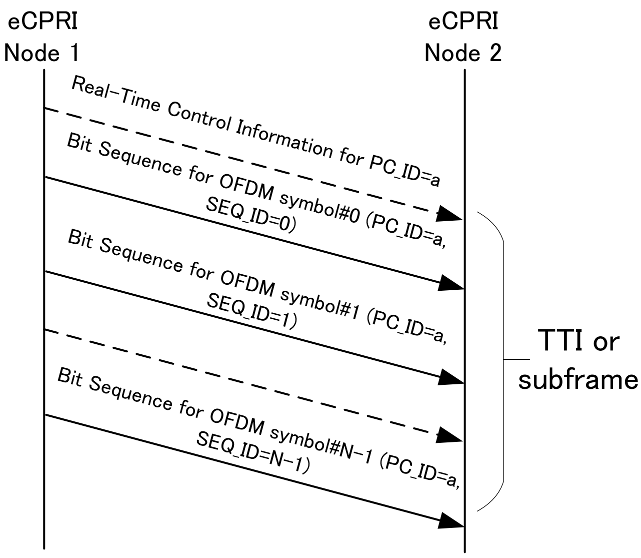

Figure 14: Message sequence diagram (example)

3.2.4.3. Message Type #2: Real-Time Control Data

3.2.4.3.1. Description/Usage

This message type is used to transfer vendor specific real-time control messages between PHY processing elements split between eCPRI nodes (eREC and eRE). This message type addresses the need to exchange various types of control information associated with user data (in form of IQ samples, bit sequence, etc.) between eCPRI nodes in real-time for control/configuration/measurement. However, this type of information highly depends on the selected function split and the actual implementation of these functions. So only the message type for Real-Time Control Data is defined, but not the data format.

3.2.4.3.2. Message format

Figure 15 shows the Real-Time Control Data message format.

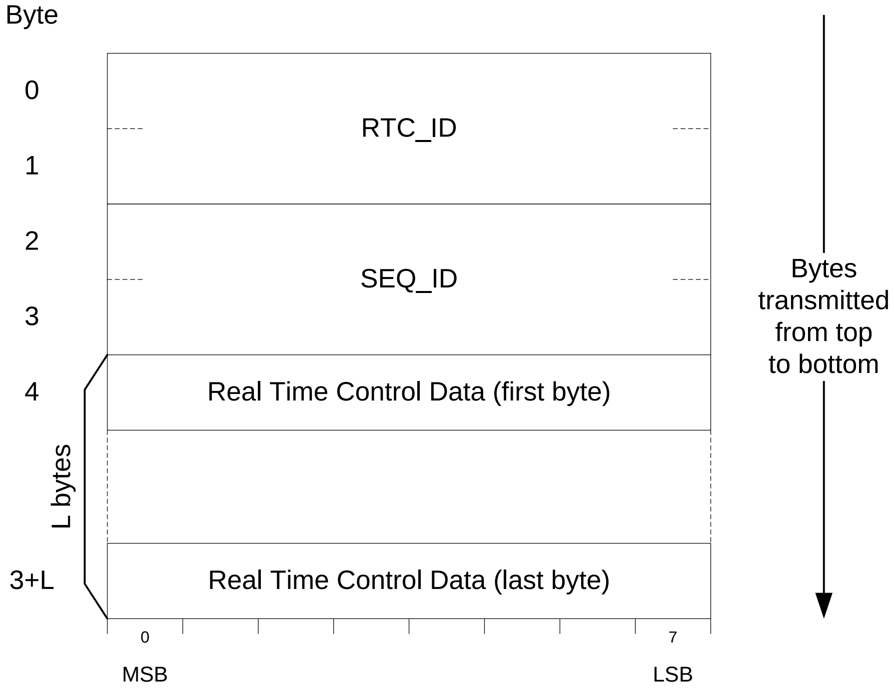

Figure 15: Real-Time Control Data Message format

Where:

- RTC_ID:
  - An identifier of a series of "Real-Time Control Data" messages.
  - For example, identifier for message structures of specific control / configuration / status / measurement and request / response / indication types.
  - How to allocate values to RTC_ID is vendor specific.
- SEQ_ID:
  - An identifier of each message in a series of "Real-Time Control Data" messages.
  - For example, identifier of message sequence, links between request and response messages, etc.
  - How to allocate values to SEQ_ID is vendor specific.
- Real-Time Control Data:
  - The format of this part of the payload is vendor specific.

3.2.4.3.3. Message sequence diagram

Figure 16 shows an example of Real-Time Control Message passing sequence. In this example, Real-Time Control Messages are transferred prior to and/or after the associated user data messages (in form of IQ Data or Bit Sequence).

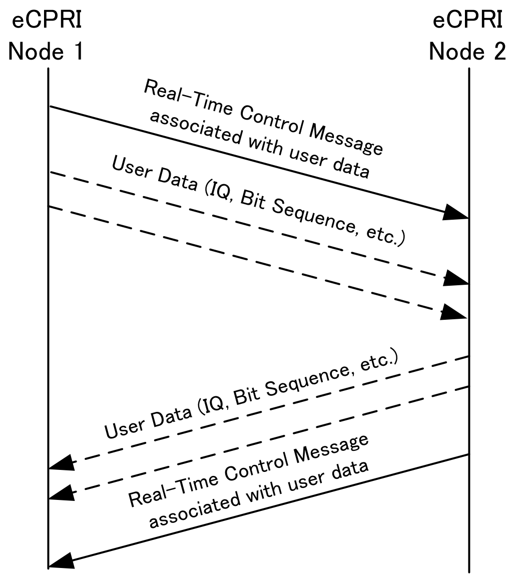

Figure 16: Message Sequence diagram (example)

3.2.4.4. Message Type #3: Generic Data Transfer

3.2.4.4.1. Description/Usage

This message type is used to transfer user plane data or related control between eCPRI nodes (eREC and eRE) providing extended data synchronization support for generic data transfers.

3.2.4.4.2. Message format

Figure 17 shows the Generic Data Transfer message format.

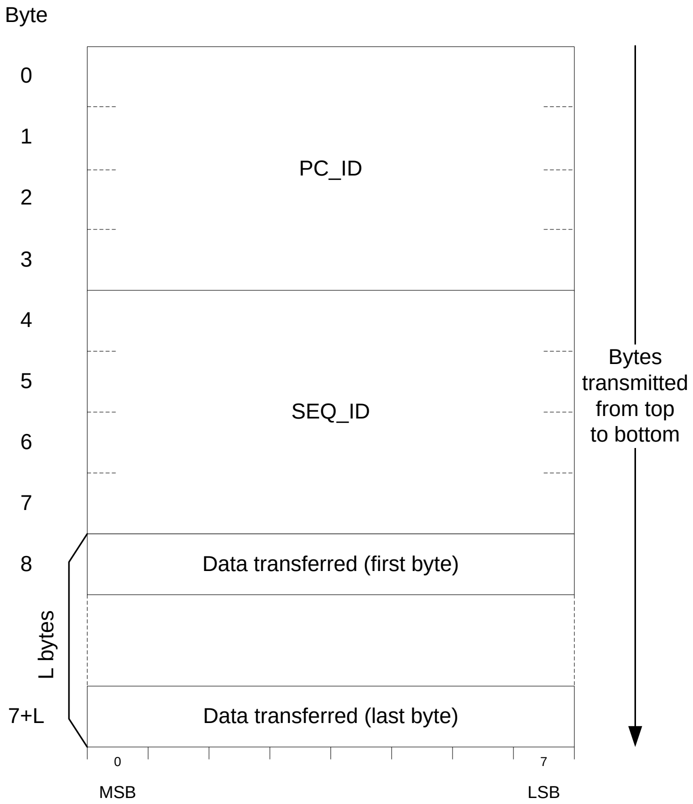

Figure 17: Generic Data Transfer message format

Where:

- PC_ID:
    - An identifier of a series of “Generic Data Transfer” messages.
    - For example, identifier of a physical channel, a user, a layer, an antenna port, etc. or in case of control, an identifier for control / configuration / status / measurement or other indication.
    - How to allocate values to PC_ID is vendor specific.
- SEQ_ID:
    - 4-byte field of each message in a series of “Generic Data Transfer” messages.
    - For example, identifier of
        - message sequence
        - data time relation to frame, OFDM symbol, a block of sub-carriers or sub-carrier etc.
        - identifier for completion of transfer phase
    - How to allocate values to SEQ_ID is vendor specific.
- Data transferred:
    - A sequence of
        - user data samples in frequency or time domain and associated control information if necessary
        - control information
    - User or control data content depends on the selected functional split between eCPRI nodes and is vendor specific.
    - The sample size, the number of samples etc. in a message, and the format of samples (e.g. fixed point, floating point, block floating point), etc. are vendor specific and transmit/receive eCPRI nodes know the actual values in advance.

3.2.4.4.3. Message sequence diagram

Figure 18 shows an example of Data Transfer Sequence. In this example, Generic Data Transfer message type is used to transmit “User data”:

- A “Real-Time Control Information” message for PC_ID is transferred before a series of “Generic Data Transfer” messages to inform the remote node how to process Data samples in following “Generic Data Transfer” messages.
- An “Generic Data Transfer” message with PC_ID is transferred e.g. every OFDM symbol period. Each message has a unique SEQ_ID.
  - SEQ_ID does not need to be continuous.
- In general, multiple transfer sequence may happen in parallel with different PC_IDs, e.g. for multiple physical channels, users, layers, antenna ports, etc.

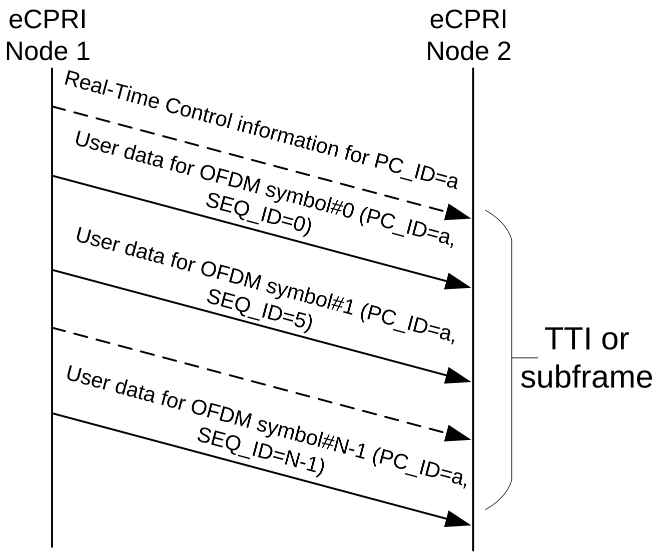

Figure 18: Message sequence diagram (example)

3.2.4.5. Message Type #4: Remote Memory Access

3.2.4.5.1. Description/Usage

The message type ‘Remote Memory Access’ allows reading or writing from/to a specific memory address on the opposite eCPRI node. The service is symmetric i.e. any “side” of the interface can initiate the service.

The service is conceived in a generic way to handle different kinds of write and read access that depend on the hardware used in a specific implementation. It is up to the driver routines for an implementation to map a write/read request to its hardware implementation.

A read or write request/response sequence is an atomic procedure, i.e. a requester needs to wait for the response from the receiver before sending a new request to the same receiver. A write request without response is also defined, this procedure is a one-message procedure.

3.2.4.5.2. Message format

The ‘Remote Memory Access’ message format is shown in Figure 19.

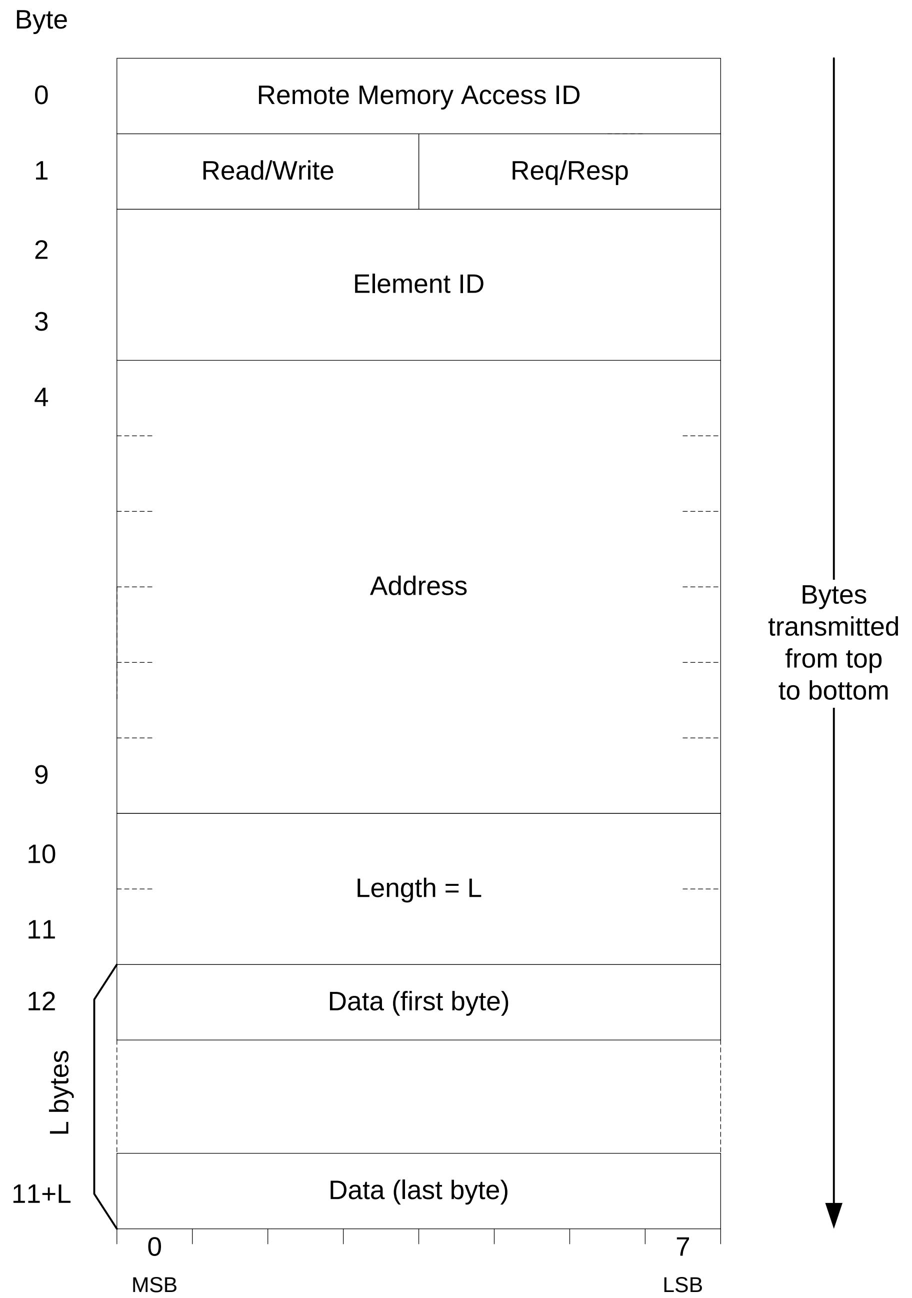

Figure 19: Remote Memory Access message format

Where:

- Remote Memory Access ID:

  The Remote Memory Access ID is used by the sender of the request when the response is received to distinguish between different accesses.

- Read/Write & Request/Response:

  The field consist of two parts, a read or write indication and a request or response indication.

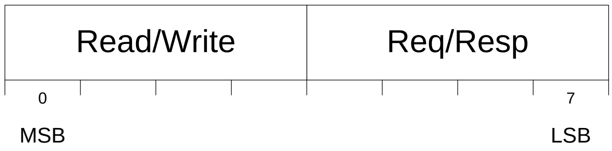

Figure 20: R/W and Req/Resp

The Read/Write and Request/Response fields are coded according to Table 5 and Table 6.

Table 5: Read/Write coding

Value	Read/Write
0000b	Read
0001b	Write
0010b	Write_No_Resp
0011b .. 1111b	Reserved

Table 6: Request/Response coding

Value	Request/Response
0000b	Request
0001b	Response
0010b	Failure
0011b .. 1111b	Reserved

The Response value 0010b (Failure) is used when the receiver of the request is unable to perform the read/write request due to invalid content in received parameters or other faults.

- Element ID:

Depending on implementation the Element ID could be used for instance to point out a specific instance of a generic hardware function.

- Address:

The Address is a 48-bit value. Details such as whether the memory on the opposite node is organized in one or more memory banks or whether an address offset is signaled over the interface etc. are vendor specific. The Element ID could be used for identifying a specific memory hardware instance.

- Length:

For a request, the 2-byte Length field contains the number of bytes that are either to be written to a specific address or read from a specific address.

For a response, the 2-byte Length field contains the actual number of bytes that were either written or read. If for some reason it was not possible to either read or write the full length of data, it will be shown via the difference in the length field.

- Data:

  The first Data-byte after the length-field is either the byte that will be written to the memory address given in the write request or it is the byte read from the memory address given in the read request.

3.2.4.5.3. Message sequence diagram

An eCPRI-node can at any time initiate a Remote Memory Access to another node. Depending on if it is a request or a response and if it is a read or write, different fields will be copied or set according to Table 7.

Table 7: Parameter handling

Action	ID	Read/Write	Req/Resp	Element ID	Address	Length	Data
Read request	Set	Set to Read	Set to Req	Set	Set	Set	No data
Read response	Copied	Copied	Set to Resp	Copied	Copied	Number of read bytes	The read data
Write request	Set	Set to Write	Set to Req	Set	Set	Set	The data to be written
Write response	Copied	Copied	Set to Resp	Copied	Copied	Number of written bytes	No data
Write No response	Set	Set to Write_No_Resp	Set to Req	Set	Set	Set	The data to be written
Failure response	Copied	Copied	Set to Failure	Copied	Copied	Vendor specific	Vendor specific

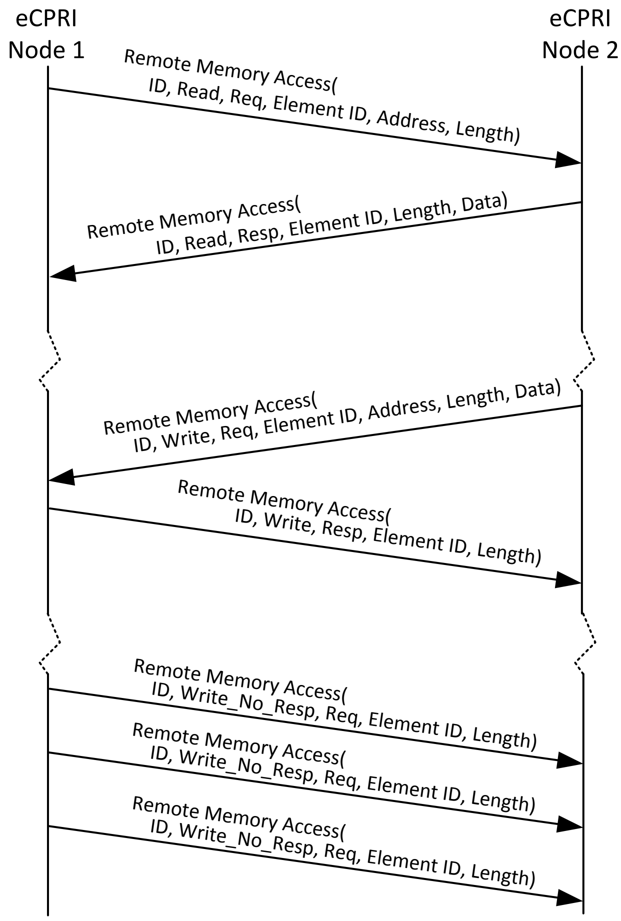

Figure 21: Message sequence diagram (example)

3.2.4.6. Message Type #5: One-Way Delay Measurement

3.2.4.6.1. Description/Usage

The message type 'One-Way delay measurement' is used for estimating the one-way delay between two eCPRI-ports in one direction. The sender of the message will sample the local time (t_1) and include a compensation value (t_{cv1}) and send it to the receiver. The receiver will time stamp the message when it arrives (t_2) and send that together with an internal compensation value (t_{cv2}) back to the sender. The one-way delay measurement can be performed without or with a Follow_Up message (1-Step and 2-Step versions). The decision of which version to use is vendor specific.

The One-Way delay value is calculated according to equation (1):

$$t_D = (t_2 - t_{CV2}) - (t_1 + t_{CV1}) \quad (1)$$

With the two compensation values, it is possible for a specific implementation to set the reference points for the measurements as suited for a specific implementation. The exact locations of the reference points are vendor specific.

Example: Time sampling according to Clause 90 in IEEE 802.3-2015 [5], in this case the time sampling is in between MAC and PHY layers.

The service assumes that both nodes are time synchronized to a common time with an accuracy sufficient for the eCPRI service.

The usage of eCPRI message type 'One-Way delay measurement' regarding which node initiates a transmission, the frequency of measurements, response deadline, etc. is vendor specific.

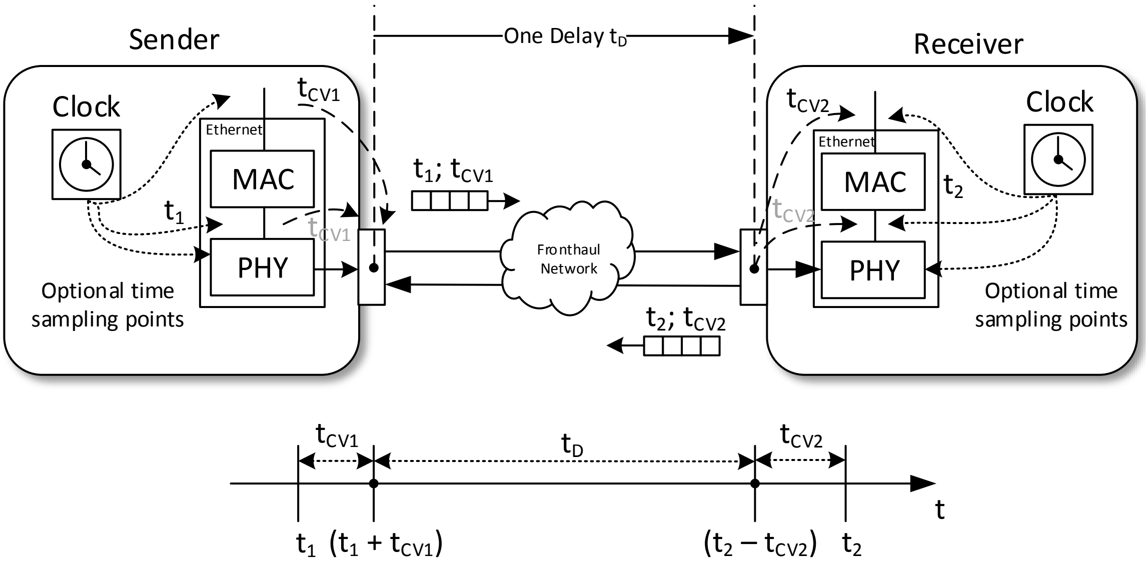

Figure 22: One-Way delay measurement of the delay Sender -> Receiver

3.2.4.6.2. Message format

The ‘One-Way delay measurement’ message format is shown in Figure 23.

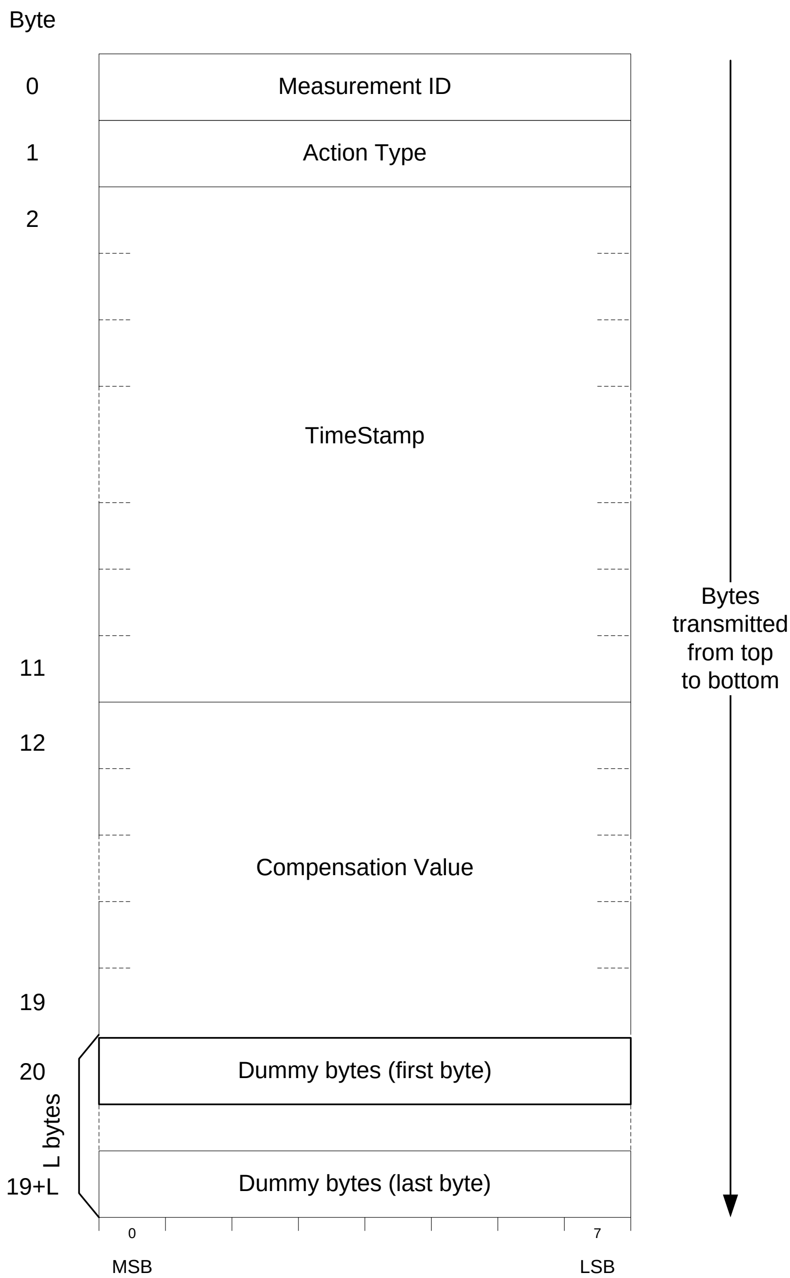

Figure 23: One-Way delay measurement message

Where:

- Measurement ID:

  The Measurement ID is a 1-byte value used by the sender of the request when the response is received to distinguish between different measurements, i.e. the receiver of the request shall copy the ID from the request into the response message.

- Action Type:

  The Action Type is a 1-byte value described in Table 8.

Table 8: Action Type

Action Type	Description
0x00	Request
0x01	Request with Follow_Up
0x02	Response
0x03	Remote Request
0x04	Remote request with Follow_Up
0x05	Follow_Up
0x06 … 0xFF	Reserved

Value 0x00 and 0x01 are used when an eCPRI node initiates a one-way delay measurement in direction from its own node to another node. Value 0x02 is used when an eCPRI node needs to know the one-way delay from another node to itself. See section 3.2.4.6.3 for usage.

- TimeStamp:

When Action Type is set to 0x00 (Request) in the message this field will contain the time stamp t_1 and when Action Type is set to 0x02 (Response) the time stamp t_2. When action type is set to 0x01 (Request with Follow_Up) the time stamp information fields shall be set to 0b in all bits, the corresponding time information values are sent in the Follow_Up message.

When Action Type is set to 0x03 or 0x04 (Remote Request and Remote Request with Follow_Up) the time stamp information fields shall be set to 0b in all bits.

When using the Follow_Up message (2-Step version) the Follow_Up message (Action Type set to 0x05) the time information values t_1 and t_{CV1} will be set to the TimeStamp field.

The time information values follow the format specified in IEEE 1588-2008 [13] Clause 5.3.3.

The value consists of 2 parts, one ‘seconds’-part and one ‘nanoseconds’-part. The first 6 bytes are the seconds and the next 4 bytes are the nanoseconds.

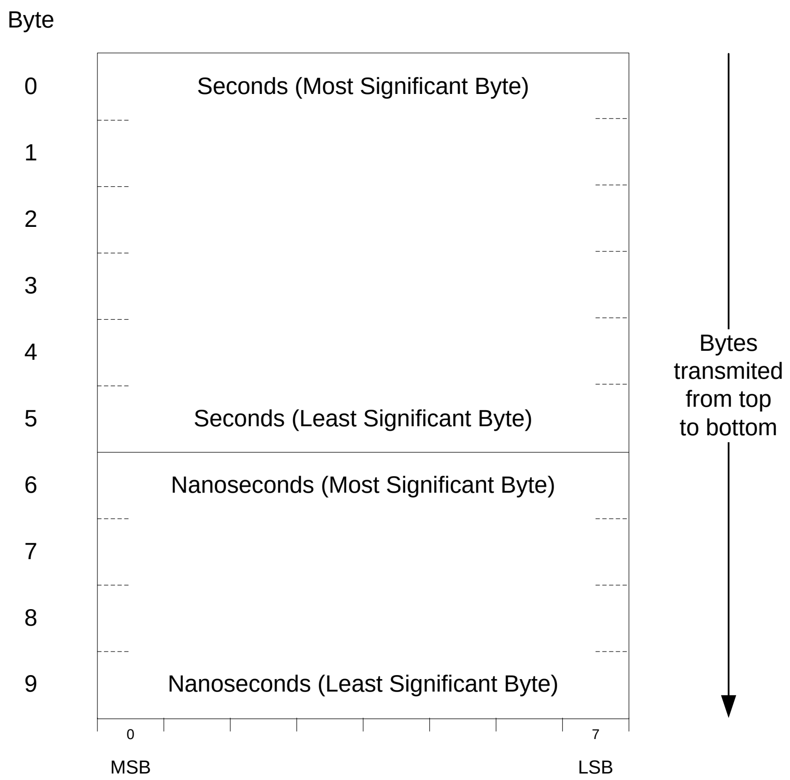

Figure 24: TimeStamp

- Compensation value:

  When Action Type is set to 0x00 (Request), 0x02 (Response) or 0x05 (Follow_Up) in the message, this field will contain the 'Compensation Value' which is the compensation time measured in nanoseconds and multiplied by 2^{16} and follows the format for the correctionField in the common message header specified in IEEE 1588-2008 Clause 13.3 [13]. When Action Type is set to 0x03 (Remote Request) or 0x04 (Remote Request with Follow_Up) the time information fields TimeStamp and Compensation Value are set to 0b in all bits.

  A Compensation Value of 0 (zero) is a valid value.

  Example: A Compensation Value of 183.5 ns is represented as $0000000000B78000_{16}$.

- Dummy bytes:

  The number of dummy bytes included in the eCPRI-payload will be defined by the eCPRI payload size field in the eCPRI common header, see section 3.2.3.1

  Due to network characteristics, a small message might take shorter time through the network than a large one, with the dummy bytes the one-way delay estimation can be improved.

  The insertion of dummy bytes is only needed when the Action Type set to 0x00 (Request) or to 0x01 (Request with Follow_Up).

3.2.4.6.3. Message sequence diagram

The message sequence diagram shown in Figure 25 is divided in 2 parts:

Part I shows the sequence when Node 1 initiates a delay measurement in direction Node 1->Node 2.

Part II shows the sequence when Node 1 initiates a delay measurement in direction Node 2->Node 1.

An eCPRI-node can at any time initiate a one-way delay measurement by setting the Action Type to 0x00 (Request), 0x01 (Request with Follow_Up) 0x03 (Remote Request) or 0x04 (Remote Request with Follow_Up). The Measurement ID received in the request shall be copied in the response.

Figure 26 shows the same sequences as Figure 25 but with the usage of the Follow_Up message.

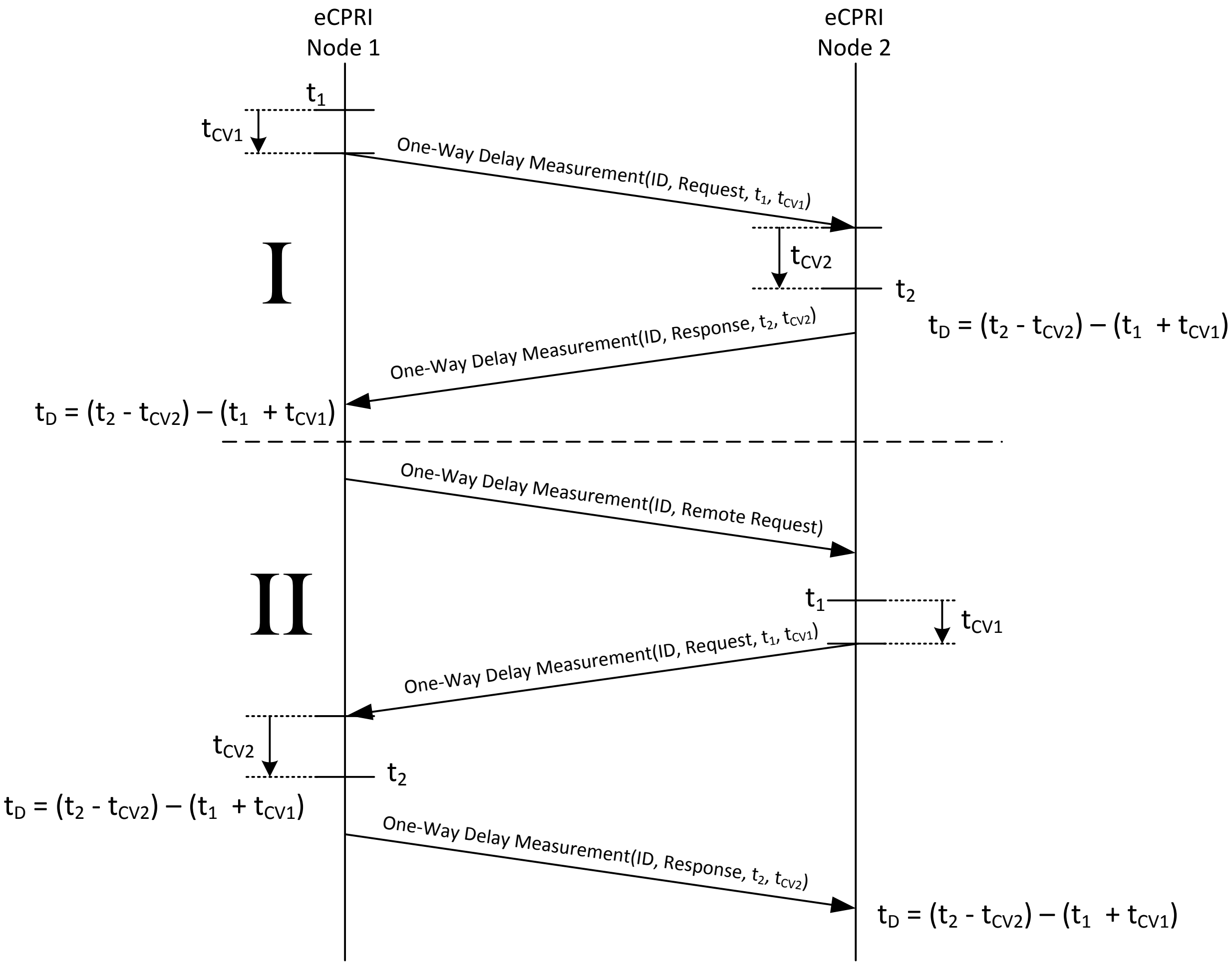

Figure 25: Message sequence diagram without Follow_Up (example)

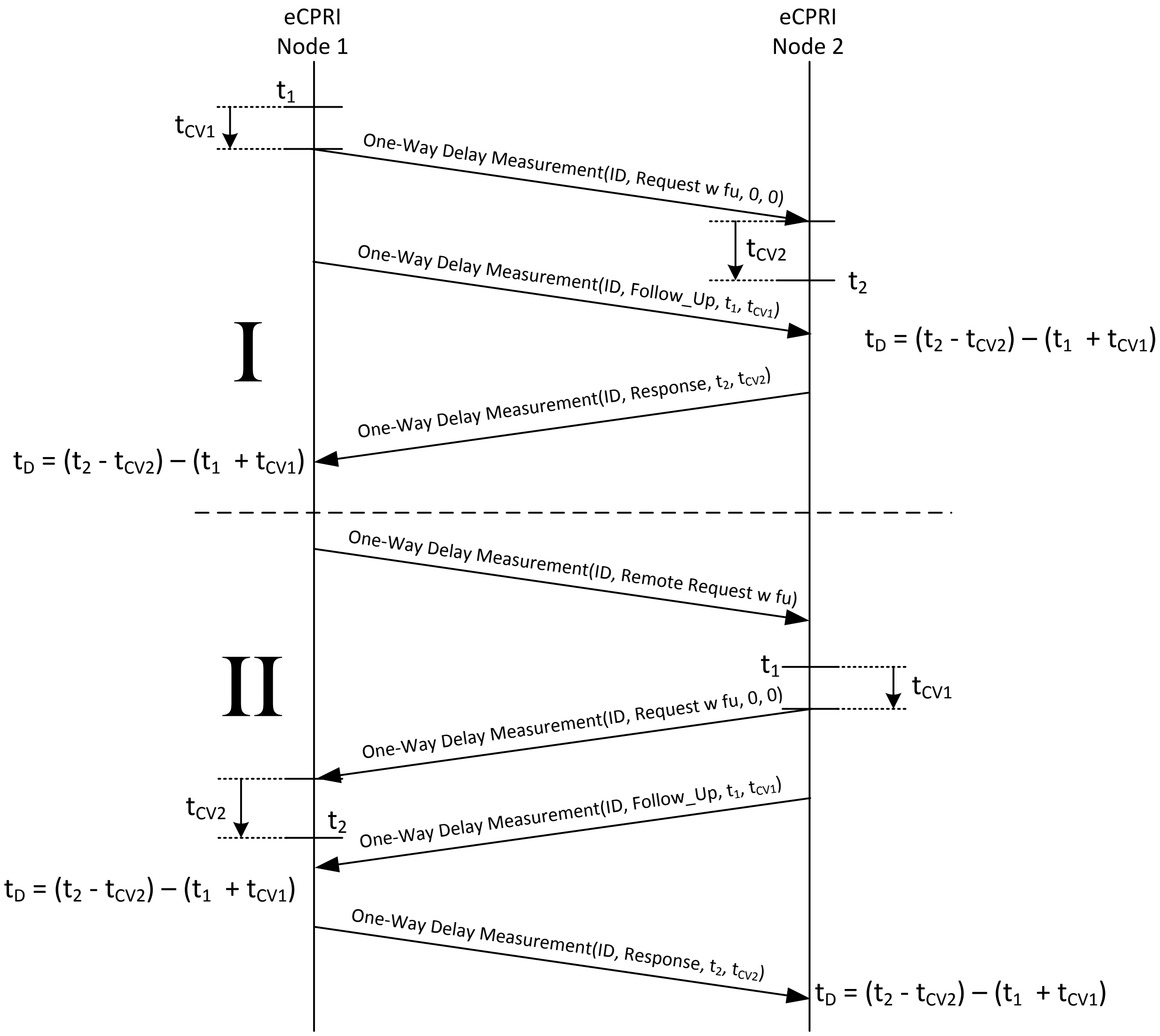

Figure 26: Message sequence diagram with Follow_Up (Example)

3.2.4.7. Message Type #6: Remote Reset

3.2.4.7.1. Description/Usage

This message type is used when one eCPRI node requests reset of another node. A “Remote Reset” request sent by an eREC triggers a reset of an eRE. Upon reception of a valid “Reset request”, the eRE shall send a “Remote Reset” Indication before performing the requested reset.

3.2.4.7.2. Message format

Figure 27 shows the Remote reset message format.

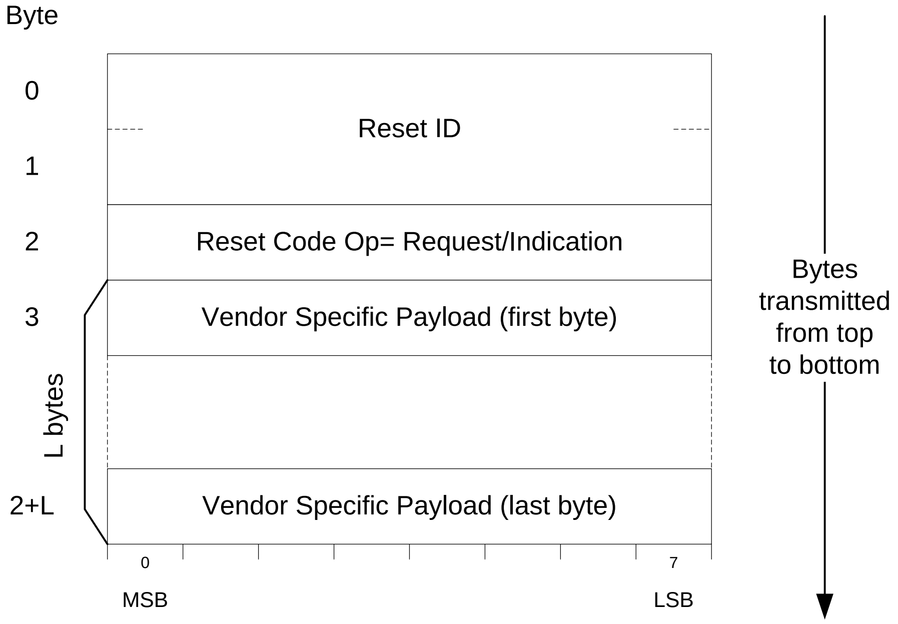

Figure 27: Remote reset message format

Where:

- Reset ID:
  - Depending on implementation the Reset ID could be used for instance to point out a specific instance of a generic hardware function.
  - How to allocate values to Reset ID is vendor specific.
- Reset Code Op:

  The Reset Code Op is a 1-byte value described in Table 10.

Table 9: Reset Code Op

Reset Code Op	Description
0x00	Reserved
0x01	Remote reset request
0x02	Remote reset response
0x03,,,0xFF	Reserved

- Vendor Specific Payload bytes:

  Vendor Specific Payload bytes are used to carry optional vendor-specific information. The vendor-specific information can contain data items such as authentication parameters or any parameters to select a specific reset behavior. This specification does not detail any concrete reset behavior.

3.2.4.7.3. Message sequence diagram

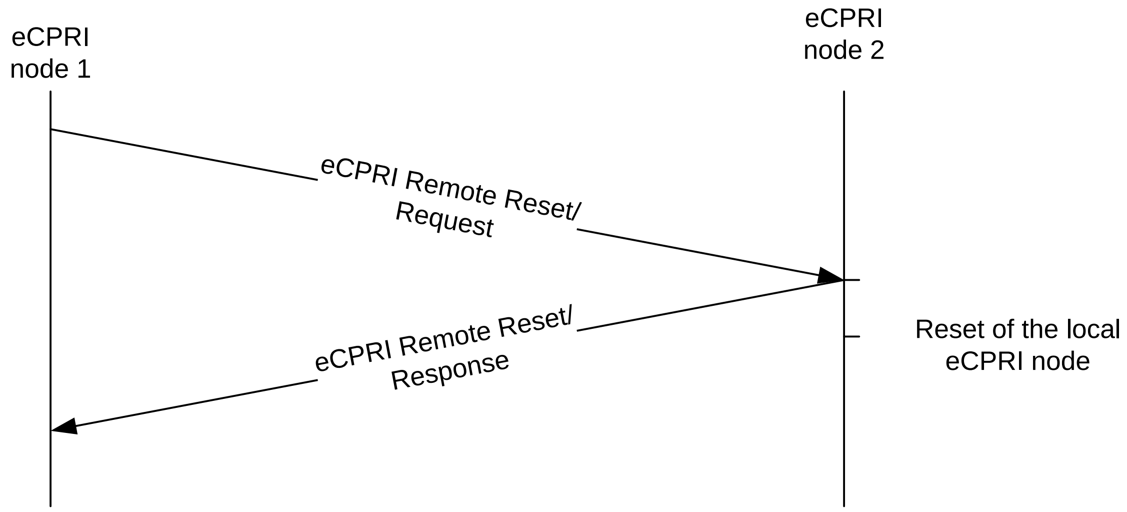

Figure 28: Message sequence diagram (example)

3.2.4.8. Message Type #7: Event Indication

3.2.4.8.1. Description/Usage

The message type ‘Event Indication’ is used when either side of the protocol indicates to the other end that an event has occurred. An event is either a raised or ceased fault or a notification. Transient faults shall be indicated with a Notification.

Faults/Notifications sent on eCPRI level should be relevant to the eCPRI services. For instance, faults in the user plane processing, power usage fault situations etc. The faults and notifications should be related to the user data processing.

One Event Indication can either contain one or more faults, or one or more notifications. Faults and notifications cannot be mixed in the same Event Indication.

Other faults/notifications related to an eCPRI node such as temperature faults, power supervision, etc. would normally be sent via the C&M plane.

An eCPRI node is modelled as consisting of N Elements, a fault or notification is connected to 1 Element. The detailed mapping of a specific implementation of HW and SW to Elements and their associated faults/notification is vendor specific.

A fault/notification may be connected to the node itself. In that case a predefined Element ID number is used, see Table 11.

The Event/Fault Indication message could be sent from an eCPRI node at any time.

For consistency check a synchronization request procedure is defined. This procedure will synchronize the requester with the current status of active faults. Transient faults will not be synchronized.

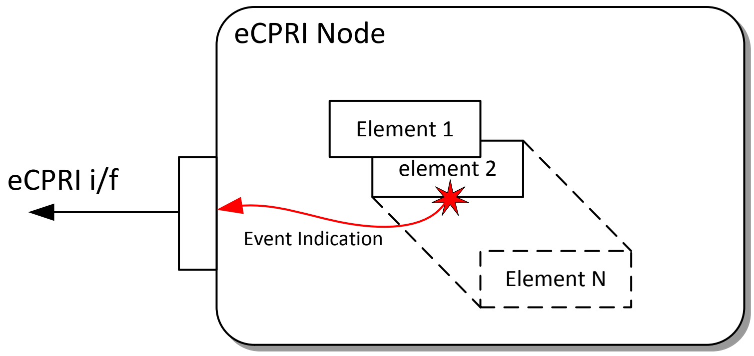

Figure 29: Model for event indications

3.2.4.8.2. Message format

The Event Indication message format is shown in Figure 30.

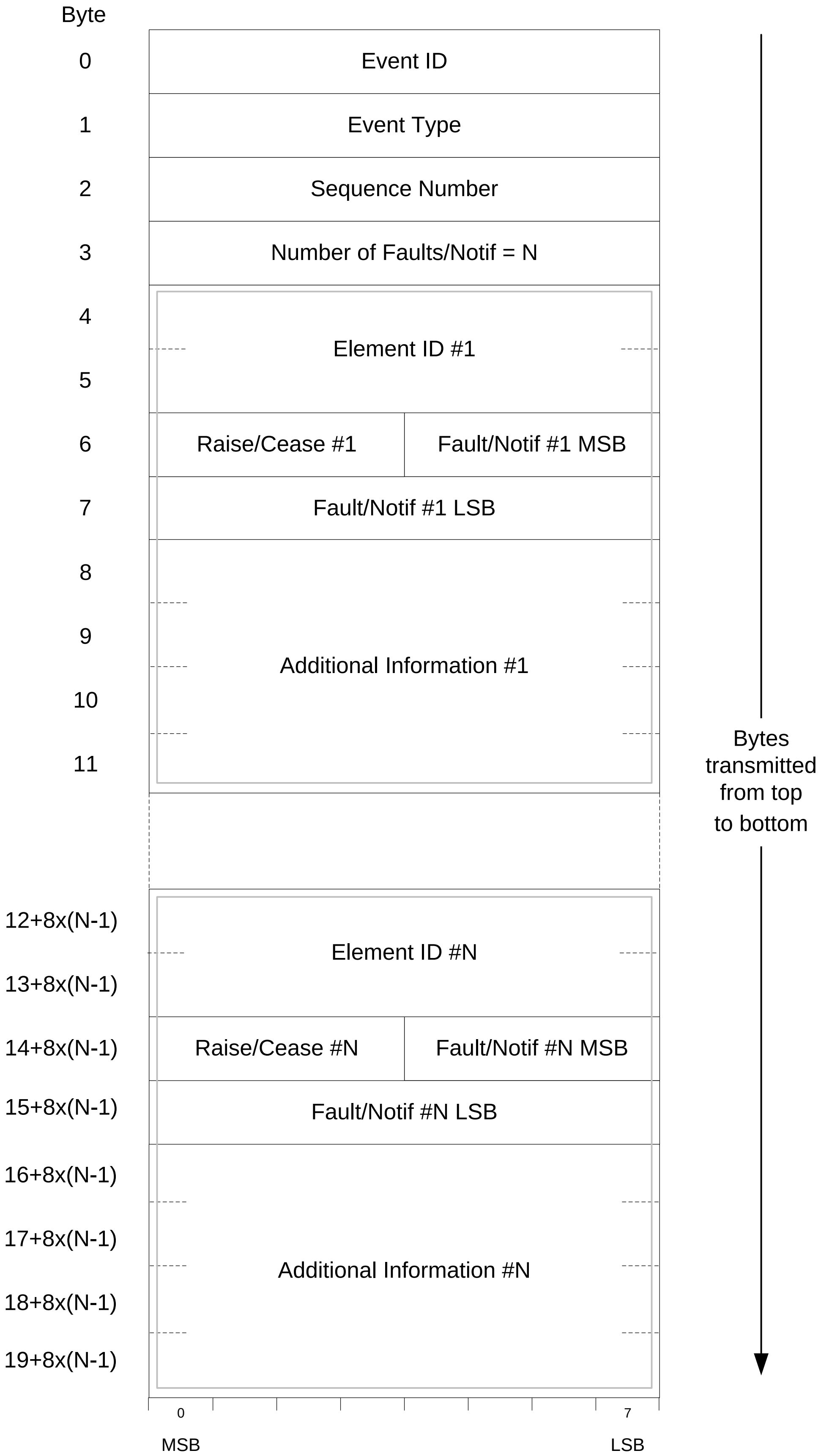

Figure 30: Event indication message

Where:

- Event ID

  A 1-byte value set by the transmitter of an Event Indication or a Synchronization Request to enable identification of the acknowledge response.

- Event Type

Table 10: Event Type

Event Type	Description
0x00	Fault(s) Indication
0x01	Fault(s) Indication Acknowledge
0x02	Notification(s) Indication
0x03	Synchronization Request
0x04	Synchronization Acknowledge
0x05	Synchronization End Indication
0x06…0xFF	Reserved

- Sequence Number

  The Sequence Number is a 1-byte value that is incremented each time the transmitter sends the “Event Indication” with Event Type set to 0x00 (Fault(s) Indication). The receiver will use the sequence number to ensure that the correct status for a specific combination of {Element-ID; Fault-value} is used. Due to the nature of the packet based fronthaul network, packets might be delivered out of order and a sequence number is needed to handle this scenario. When a fault indication is not acknowledged the transmitter will re-transmit the fault, setting the sequence number to the same value used in the initial transmission.

- Number of Faults/Notifications

  Number of fault indications or notifications attached in the same message.

- Element ID:

Table 11: Element ID

Element ID Number	Usage
0x0000 … 0xFFFE	Vendor specific usage
0xFFFF	A fault or notification applicable for all Elements i.e. the node

- Raise/cease:

  First nibble in the same byte as the Fault/Notification Number.

Table 12: Raise/ceased

Raise/Cease	Description
0x0	Raise a fault
0x1	Cease a fault
0x2 … 0xF	Reserved

- Fault/Notification Numbers:

  A 12-bit number indicating a fault or notification divided between 2 bytes.

Table 13: Fault/Notification numbers

Fault Indication and Notification Numbers	Usage
0x000 … 0x3FF	eCPRI reserved Faults
0x400 ... 0x7FF	eCPRI reserved Notifications
0x800 ... 0xFFF	Vendor Specific Fault Indications and Notifications
eCPRI Faults and Notifications	
0x000	General Userplane HW Fault
0x001	General Userplane SW Fault
0x002 ... 0x3FF	eCPRI reserved
0x400	Unknown message type received
0x401	Userplane data buffer underflow
0x402	Userplane data buffer overflow
0x403	Userplane data arrived too early
0x404	Userplane data received too late
0x405 … 0x7FF	eCPRI reserved

- Additional Information:

  If available, additional information regarding the fault/notification for vendor specific usage.

3.2.4.8.3. Message sequence diagram

An eCPRI node can at any time send an Event Indication to the peer node. Depending on what Event Type, different fields will be set or copied according to Table 14.

Table 14: Parameter handling

Event Type	Event ID	Sequence Number	Nbr of Faults or Notifications	Fault/Notification(s)	Raise/Cease	Additional Information
Fault Indication	Set	Increment	> 0	Fault(s)	Raise or Cease	Vendor Specific
Fault Indication Acknowledge	Copied	Copied	0	Not included	Not included	Not Included
Synchronization Request	Set	Set to 0	0	Not included	Not included	Not Included
Synchronization Acknowledge	Copied	Set to 0	0	Not included	Not included	Not Included
Synchronization End Indication	Copied	Set to 0	0	Not included	Not included	Not Included
Notification	Set	Set to 0	>0	Notifications	Set to 0x0	Vendor specific

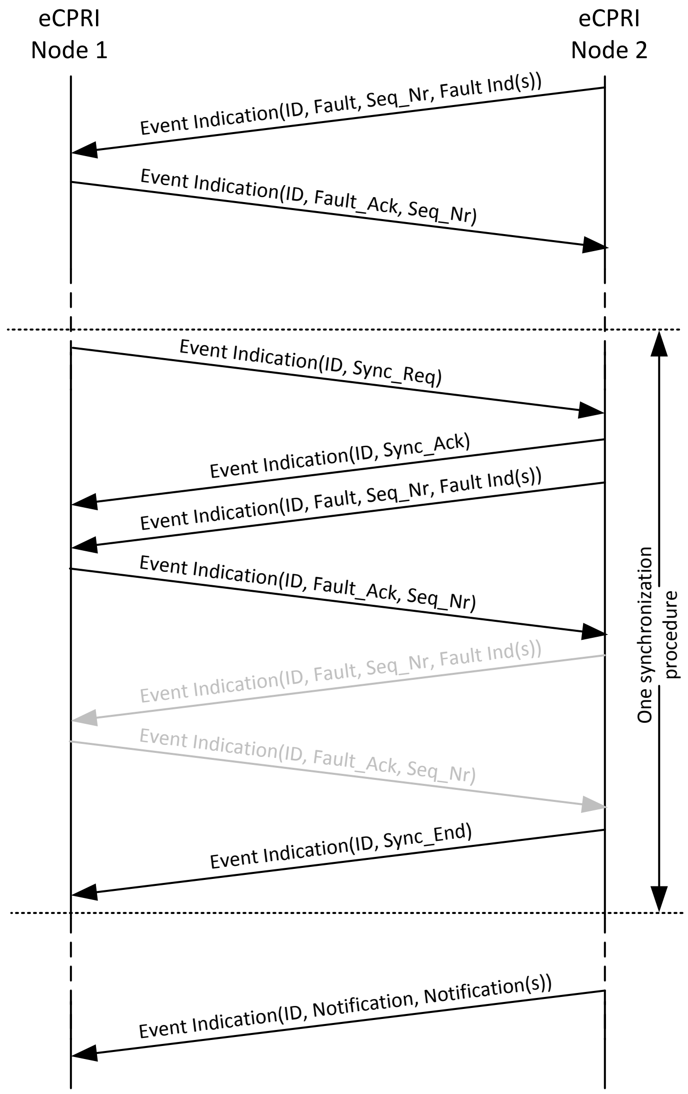

Figure 31: Message sequence diagram (example)

The first part of the sequence above shows when Node 2 detects a fault condition which is signalled to Node 1 and Node 1 acknowledges the reception of the indication.

The middle part of the sequence diagram shows a Synchronization procedure. The procedure is started with a Synchronization-Request sent by Node 1, signals marked in grey might be send due to number of faults or due to the implementation. The request is acknowledged by Node 2, Node 2 then sends the current list of raised faults to Node 1, the sequence is ended when Node 2 sends the Synchronization-End message. In the Synchronization procedure the ‘Event ID’ set by Node 1 in the request message will be used during the full procedure.

The last part of the sequence shows when Node 2 sends a notification to Node 1, this notification is not acknowledged by Node 1.

3.2.4.9. Message Type #8-#63: Reserved

eCPRI message types from 8 to 63 are reserved for future eCPRI specifications.

3.2.4.10. Message Type #64-#255: Vendor Specific

eCPRI message types from 64 to 255 are not defined in eCPRI. These are for vendor specific usage. Vendor specific message types shall not be reserved (before any specific usage is defined) by any 3rd parties (other than CPRI and vendors).

Vendor specific usage shall be guaranteed.

3.3. C&M Plane

Control and management information will be exchanged between eCPRI entities (eREC and eRE) on any commonly used transport protocols. The C&M information will not be transmitted via the eCPRI specific protocol. The details of this information flow is out of the scope of the eCPRI specification. The intention is that this information will use protocols (e.g. TCP) over the IP protocol but any other solution is not precluded.

The C&M information flow will be considered as non-time-critical and utilize a small part of the total bandwidth between eCPRI entities. The majority of this information flow will be considered as background traffic, the rest are interactive traffic that is needed to keep control of the eCPRI node. See section 6.6 for considerations regarding priority for C&M data.

3.4. Synchronization Plane

The eCPRI nodes shall recover the synchronization and timing from a synchronization reference source, and the air interface of the eRE shall meet the 3GPP synchronization and timing requirements. The synchronization information will not be transmitted via the eCPRI specific protocol. The details of this information flow are out of the scope of the eCPRI specification. The intention is that this information will use existing protocols (e.g. SyncE, PTP) but any other solution is not precluded.

The synchronization information flow will be considered as time-critical and will utilize a small part of the total bandwidth between eCPRI nodes.

3.5. QoS

The quality of service (QoS) control for eCPRI is done by setting different priority for different traffic flows depending of the needed quality of service. If the eCPRI fronthaul network is Ethernet-switched the priority field (PCP field) in the VLAN-tag shall be used for QoS of eCPRI, see further details below. If the eCPRI fronthaul network is IP-routed the Differentiated Services (DiffServ) can be used.

3.5.1. VLAN Tagging for Ethernet-switched fronthaul networks

For an Ethernet network with Ethernet bridges a VLAN tag according to the IEEE 802.1Q-2014 [14] shall always be added by the eRE or eREC and provided to the Ethernet network. The VLAN ID does not need to be set if only the priority is used in the VLAN tag. In that case the VLAN ID (VID field) is set to zero (the null VID). The priority is set in the PCP field of the VLAN tag.

Normally a C-tag with a priority in the PCP field is set by the eCPRI nodes (VID is optional), but other cases may exist depending on the network type and what kind of customer service interface to the network is used. For further details and options see [14].

The use of the VLAN ID (VID field), including the null VID, is fully vendor specific and agreed with the network provider.

How to use the priority field (PCP field) is vendor specific. See section 6.6.

3.5.2. QoS for IP-routed fronthaul networks

QoS for IP-routed fronthaul network can be done by DiffServ. The DiffServ uses the DSCP field in the differentiated services field (DS field) in the IP header for classification purposes. How to use the DSCP field for QoS in an IP-routed fronthaul network is fully vendor specific.

Other ways to do QoS in an IP-routed fronthaul network are possible.

4. Forward and Backward Compatibility

In order to allow for forward and backward compatibility of eCPRI, the following requirements are introduced.

4.1. Fixing eCPRI Protocol Revision Position

For forward and backward compatibility, the eCPRI Protocol Revision field in the common header shall be fixed in all revisions. This is in order to find the eCPRI protocol revision correctly.

4.2. Reserved Bits and Value Ranges within eCPRI

Within the eCPRI message format some data parts are reserved for future use by the CPRI specification group. These parts may be used in future releases of the eCPRI specification to enhance the capabilities or to allow the introduction of new features in a backward compatible way. The reserved data parts are of two different types:

1. Reserved bits in the eCPRI common header or reserved bits within a specific message payload
2. Reserved value ranges in both eCPRI common header and within a specific message payload.

Reserved data parts of type 1: the transmitter shall send 0's for the reserved bits, and the receiver shall not interpret the reserved bits.

Reserved data parts of type 2: the transmitter is only allowed to use values that are defined by this specification or as defined within a vendor specific range. The receiver shall discard the message when receiving a message with illegal values.

4.3. eCPRI specification release version

The eCPRI specification release version is indicated by two digits (version A.B). The following text defines the digits:

- The first digit A is incremented to reflect significant changes (modification of the scope, new section…).
- The second digit B is incremented for all changes of substance, i.e. technical enhancements, corrections, updates etc.

4.4. Specification release version mapping to eCPRI protocol revision

The eCPRI common header field "eCPRI Protocol revision" indicates the protocol version number, which will be denoted by 1, 2, 3, … The protocol revision number will be incremented only when a new specification release version includes changes that lead to incompatibility with previous specification release versions.

The simple sequence and the well-defined rule for non-compatibility between different specification release versions allows for a simple, efficient and fast start-up procedure. The following table provides the mapping between specification release version and protocol revision number.

Table 15: Specification release version and protocol revision numbering

Specification release version	Available eCPRI protocol revision values	Comment
1.0	0001b	The interpretation of the eCPRI message shall follow eCPRI specification version 1.0.
	0010b-1111b; 0000b	Reserved for future eCPRI protocol revisions. Unallocated values can temporarily be used for vendor specific extensions until allocated.

This table shall be updated when new specification release versions become available.

5. Compliance

An eCPRI compliant interface shall fulfill the following requirements:

- An eCPRI compatible interface shall follow the normative parts of this specification.
- One or more eCPRI message types are used over the interface for eREC and eRE communication.
- eCPRI message types in use are implemented per requirements defined for them.

6. Annex A - Supplementary Specification Details (Informative)

6.1. Functional Decomposition

6.1.1. eCPRI Functional Decomposition

The functional content of the PHY[4] layer is shown in Figure 32. Process stages marked with grey text are optional, i.e. in a non-massive antenna configuration those stages are not present. The eCPRI specification focuses on three different reference splits, two splits in downlink and one split in uplink (Split I_D, II_D and I_U). Any combination of the different downlink/uplink splits is possible.

Nevertheless, any other split within the PHY layer (and also any other inter/intra layer split) is not precluded to be used with the eCPRI specification.

The major difference between Split I_D and II_D is that the data in Split I_D is bit oriented and the data in split II_D and I_U is IQ oriented.

In Figure 32 only the data plane processing stages are shown, but in parallel to this, a user data real time control flow also exists. Depending on where the split is, this real-time control data is e.g. modulation scheme, Tx power, beamforming information etc. The bit rate of this real-time control flow differs between different splits. As a rule of thumb the closer to the MAC layer the split is, the more real time control data needs to be sent between the two eCPRI nodes eREC and eRE.

It is possible to implement e.g. a PRACH preamble detection process in the eRE and handling of SRS in the eRE thus lowering the bit rate needs in uplink direction, these options/possibilities are however not shown in Figure 32. Also, in downlink the reference signals and synchronization signals could be generated internally on the eRE with just an initial configuration by the eREC, this is not shown in the figure either.

One of the major objectives of a new functional split between eREC and eRE compared to the classical CPRI functional split is to lower the bit rates on the fronthaul interface. When looking at the different processing stages performed in the PHY-layer (see Figure 32) in downlink direction, three processes will mostly increase the bit rate. These three processes are modulation, the port-expansion being done in combination with the beam-forming process and the IFFT+cyclic-prefix-process (i.e. going from the frequency domain to the time domain). By moving the split upwards in the figure the fronthaul bit rate will be lowered and vice versa. But conversely the bit rate for the user plane real-time control data will increase when moving the split point towards the MAC layer and vice versa.

4 Currently an E-UTRA PHY layer layout

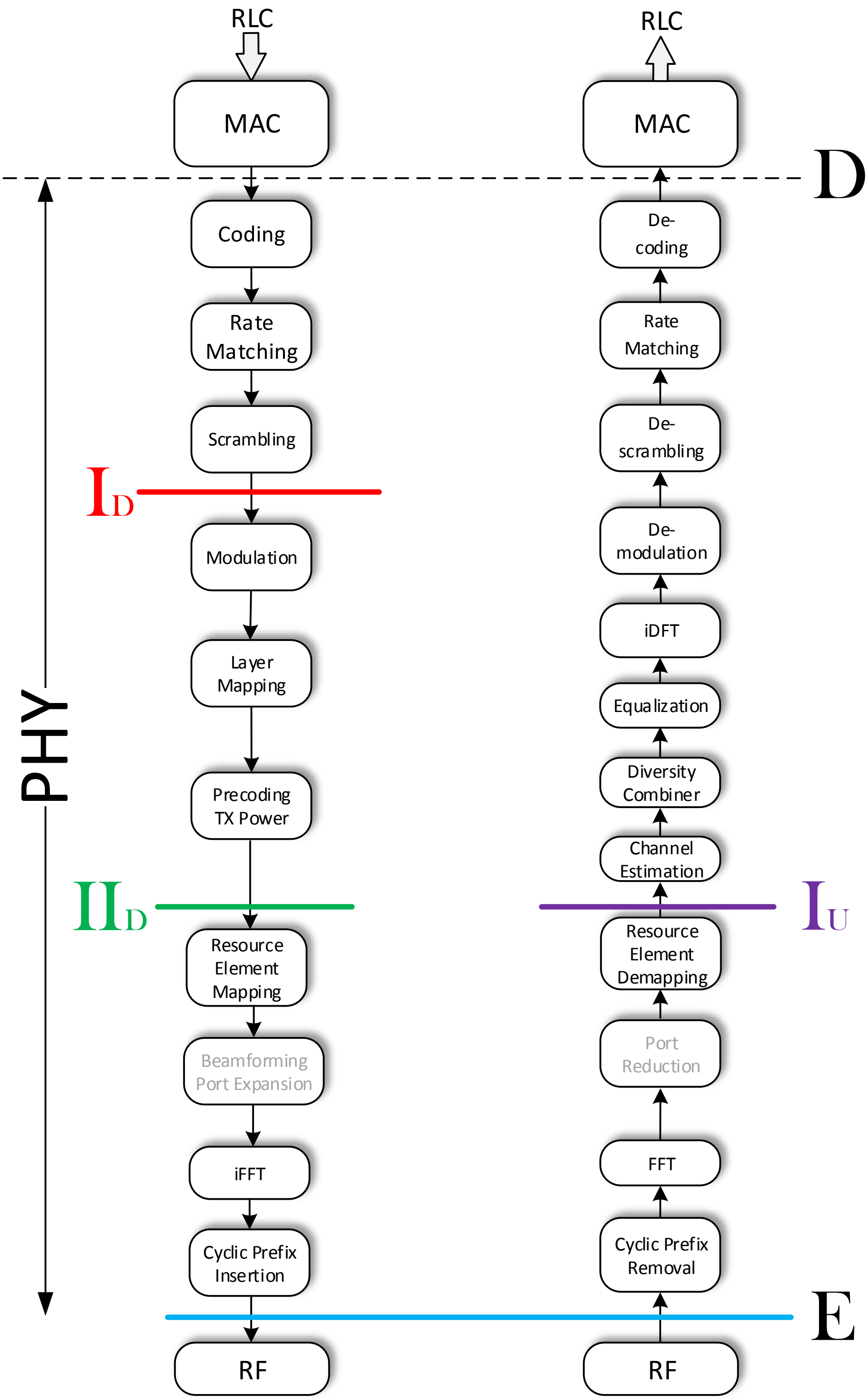

Figure 32: PHY layer and eCPRI Splits

6.1.2. Bit rate calculations / estimations

When making the decision for what split to implement one major issue will be the bit rate capacity on the link between the eREC and the eRE. When moving the split point from the MAC-PHY boundary towards the RF layer the bit rate will increase for each step. This applies for the user data, the opposite is true for the control data needed to process the data on the eRE, i.e. the bitrate for the control data will decrease when moving the split towards the RF layer. However, the sum of the bit rates for the user data and the control data will not remain the same.

It is assumed that the control algorithm for e.g. beamforming resides in the eREC and that control data for these stages must be transmitted from eREC to eRE.

When going to a split that is above the split E there are many factors that will have an impact on the final needed bit rate of the link between eREC and eRE. The most relevant factors are:

- Throughput (closely related to the available and used air bandwidth)
- Number of MIMO-layers
- MU-MIMO support (y/n)
- Code rate
- Modulation scheme
- Selection of beam-forming algorithm
- Number of antennas

When making a comparison of the needed bit rate between an eCPRI split and the classical CPRI split (split E) one needs to set a specific use case, i.e. realistic assumptions must be made regarding the abovementioned bit rate impacting factors.

However, the setting of a value to these factors only has an impact on the eCPRI-split bit rate. It is only the “Number of antennas”-factor that has an impact on the bit rate for split E.

There are on the other hand other factors that have an impact on the needed bit rate for a split E implementation as well which are not mentioned in the bullet list above. These factors are mainly: sample frequency for the IQ-data, used IQ-format (number of bits per IQ-sample) and the presence of IQ compression algorithms or not.

The following values are used for the forthcoming bit rates calculations:

- Throughput: 3/1.5 Gbps (downlink/uplink, end-user data rate, transport block from/to MAC)
- Air bandwidth: 100 MHz (5 * LTE20) -> 500 PRB
- Number of downlink MIMO-layers: 8
- Number of uplink MIMO-layers: 4 (with 2 diversity streams per uplink MIMO layer)
- MU-MIMO: No
- TTI length: 1 ms
- Digital beamforming where BF-coefficients calculation is performed in eREC.
- Rate matching assumptions: Code rate: ~0.80
- Modulation scheme (Downlink & Uplink): 256 QAM
- Number of antennas: 64
- Subcarrier spacing: 15 kHz
- IQ sampling frequency: 122.88 Msps (3.84*32)
- IQ-format: 30 bits per IQ-sample
- No IQ compression

Table 16: PHY layer splits bit rate estimations

	Split D		Split I_D		Split II_D		Split E
	User Data [Gbps]	Control [Gbps]	User Data [Gbps]	Control [Gbps]	User Data [Gbps]	Control [Gbps]	User Data [Gbps]
eREC→ eRE	3 (assumption)	<< 1	< 4	< 10	~ 20	< 10	236
			Split I_U				
eRE → eREC	1.5 (assumption)	<< 1	~ 20	< 10			236

6.2. Synchronization and Timing

An eCPRI node shall recover the frequency and time/phase from its synchronization reference source (see Figure 3). In an eCPRI installation all eCPRI nodes (eRECs and eREs) need to be time synchronized to a common time reference, see sections 6.2.1 and 6.2.2 for more information.

Different solutions exist for synchronization of eREC and eRE.

6.2.1. Synchronization of eRE

Depending on which 3GPP features a specific eCPRI installation supports, different timing accuracy requirements are applicable for the eRE node. [15] defines four different timing synchronization requirement categories each one targeting different timing accuracy requirements for different use cases. The different categories will supply different timing accuracy at the edge of the fronthaul network, i.e. “almost” at the input-port on the eRE. With the knowledge of the expected supplied timing accuracy it will be possible to implement an eRE that will fulfill the final timing accuracy requirement on the air interface according to the 3GPP requirements.

The eRE shall also fulfill requirements set by 3GPP on the transmission frequency accuracy and the phase noise (implicit requirement).

6.2.2. Synchronization of eREC

The timing accuracy requirement on the eREC is relaxed compared to the requirement set on the eRE (see 6.2.1). Actually, the eREC does not need to have a high quality frequency available since it is the eRE that will generate the frequency for air transmission locally. Nevertheless, there will be a vendor specific requirement set on the eREC regarding the eREC timing accuracy. Such a requirement is needed to be able to send data at correct time to the eRE from the eREC thus to give the eRE time for its processing of the data before being transmitted on the air interface and for buffer handling due to network latency variation. The requirement value depends on vendor specific choices related to desired performance for the wireless network, expected delay variation in fronthaul network etc.

6.3. Link Delay Management

The following section provides a description of the link delay management in eCPRI. Figure 33 shows an example of an eREC and eRE connected via an eCPRI network. Both eREC and eRE clocks are synchronized to a common grand master clock (in this example via PTP).

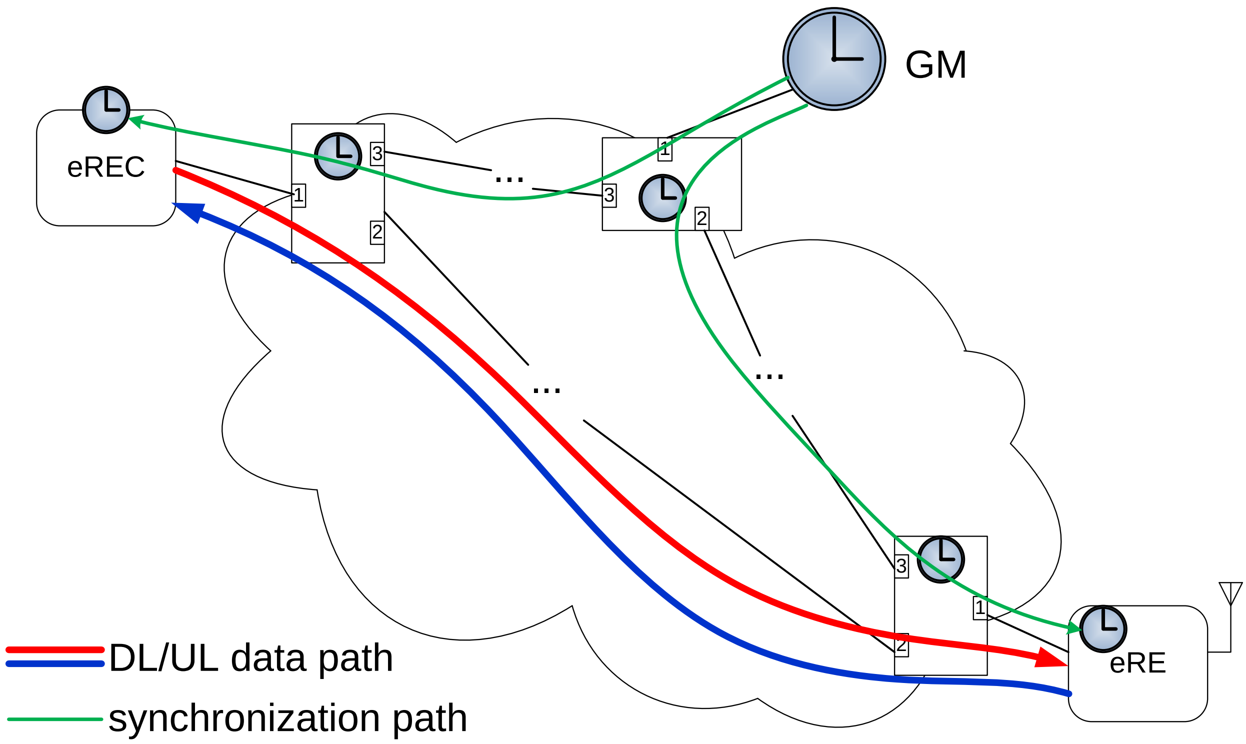

Figure 33: eCPRI topology example with synchronization via PTP

6.3.1. Reference Points for Delay Measurement

The reference points for delay management are the input and the output points of the equipment, i.e. the connectors of eREC and eRE as shown in Figure 34.

Reference points R1 to R4 correspond to the output point (R1) and the input point (R4) of the eREC, and the input point (R2), and the output point (R3) of an eRE. The antenna is shown as “Ra” for reference.

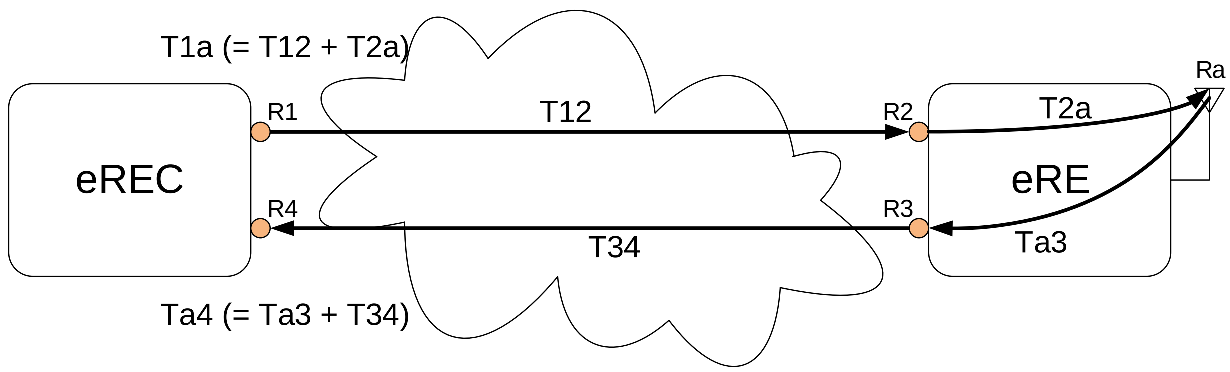

Figure 34: Definition of reference points for delay management

The definitions for the different delays are given in the following.

Note: The eRE delay definitions refer to the delay between the transmission/reception of an IQ sample at the antenna Ra and the reception/transmission of data packets containing the corresponding information at the fronthaul interface R1/R4 (eREC) and R2/R3 (eRE). In case of time domain IQ functional split, the assignment is straight forward since an eCPRI message carries IQ samples. In case of frequency domain functional split, the information associated to an IQ sample is contained in a set of N packets, e. g. frequency domain IQ data for one OFDM symbol + related control information or user data for one OFDM symbol + related control information.

Please note that N can vary per symbol/TTI according to the number of users/used resource blocks.

- T12 is the transport network delay of a user data packet between eREC (R1) and eRE (R2) in DL direction. T12 may not be constant for every data packet and shows a statistical variation, but its range is limited by e.g. the profile of deployed transport network:

  $$0 \leqq T12\ min \leqq T12 \leqq T12\ max$$

  Where:

  - T12 max is given as the maximum one way end-to-end latency, see e.g. [15].
  - T12 min is 0 in general, but in case the minimum latency of some or all network elements are known, it can be determined by the sum of all fiber delays and minimum forwarding delays of the network nodes along the DL data path.

- T34 is the transport network delay of a user data packet between eRE (R3) and eREC (R4) in UL direction. T34 may not be constant for every data packet and shows a statistical variation, but its range is limited by e.g. the profile of deployed transport network:

  $$0 \leqq T34\ min \leqq T34 \leqq T34\ max$$

  Where:

  - T34 max is given as the maximum one way end-to-end latency, see e.g. [15].
  - T34 min is 0 in general, but in case the minimum latency of some or all network elements are known, it can be determined by the sum of all fiber delays and minimum forwarding delays of the network nodes along the UL data path.

- T1a is the timing difference between the transmission of a user data packet at the output point R1 of the eREC and the transmission of IQ samples at the antenna Ra of the eRE. The transmission of the earliest IQ sample which is generated from the transmitted user data is used as the reference timing at the antenna Ra. T1a may not be constant but its range is limited by e.g. eREC design specification:

  $$0 \leqq T1a\ min \leqq T1a \leqq T1a\ max$$

  Where:

  - Both T1a min and T1a max are vendor specific values; in general, T1a min is related to the best case processing time of user data and T1a max is related to the worst case processing time and the output buffer size.

- T2a is the timing difference between the reception of a user data packet at the input point R2 of eRE and the transmission of IQ samples at the antenna Ra. The transmission of the earliest IQ sample which is generated from the received user data is used as the reference timing at the antenna Ra. T2a may not be constant but its range is limited by e.g. eRE design specification:

  $$0 \leqq T2a\ min \leqq T2a \leqq T2a\ max$$

  Where:

  - Both T2a min and T2a max are vendor specific values; in general, T2a min is related to the worst case eRE processing time of user data and T2a max is related to the input buffer size and the worst case eRE processing time.
  - If a user data packet arrives outside of this reception window (i.e. earlier than T2a max or later than T2a min), the user data packet may not be used and consequently IQ samples related to this user data packet may not be generated correctly.

- Ta3 is the timing difference between the reception of IQ samples at the antenna Ra and the transmission of a user data packet at the output point R3 of eRE. The reception timing of the earliest IQ sample necessary to generate the user data packet is used as the reference timing at the antenna Ra. Ta3 may not be constant but its range is limited by e.g. eRE design specification:

  $$0 \leqq Ta3\ min \leqq Ta3 \leqq Ta3\ max$$

Where:

- Both Ta3 min and Ta3 max are vendor specific values; in general, Ta3 min is related to the best case eRE processing time of user data and Ta3 max is related to the worst case eRE processing time and the output buffer size.

- Ta4 is the timing difference between the reception of IQ samples at the antenna Ra of the eRE and the reception of a user data packet at the input point R4 of the eREC. The reception timing of the earliest IQ sample necessary to generate the user data packet is used as the reference timing at the antenna Ra. Ta4 may not be constant but its range is limited by e.g. eRE design specification:

$$0 \leqq \text{Ta4 min} \leqq \text{Ta4} \leqq \text{Ta4 max}$$

Where:

- Both Ta4 min and Ta4 max are vendor specific values; in general, Ta4 min is related to the input buffer size and the worst case eREC processing time. Ta4 max is related to the eREC worst case processing time of user data.
- If a user data packet arrives outside of this reception window (i.e. earlier than Ta4 min or later than Ta4 max), the user data packet may not be used and (a part of) the UL user data may be lost or degraded.

The DL timing relations are shown in Figure 35. eREC and eRE clocks are synchronized to a common GM and it is assumed that both eREC and eRE know the timing relation between air frame start and their clocks. The time point when the first IQ sample of a DL air frame has to be transmitted at the antenna is indicated by the red line on the right.

By definition, the following equation has to be satisfied:

$$\text{T1a} = \text{T12} + \text{T2a}$$

This equation implies that fluctuation of transport network latency and the eREC transmission timing has to be absorbed by the input buffer of eRE; moreover the minimum/maximum limits of these three variables are not independent; i.e. following conditions have to be met in order not to lose DL user data.

$$\text{T1a min} \geqq \text{T12 max} + \text{T2a min}$$

$$\text{T1a max} \leqq \text{T12 min} + \text{T2a max}$$

“Tx window size at R1” $\leqq$ “Rx window size at R2” - “max fluctuation of transport network latency”

Where:

“Tx window size at R1” = T1a max - T1a min

“Rx window size at R2” = T2a max - T2a min

“Max fluctuation of transport network latency” = T12 max - T12 min

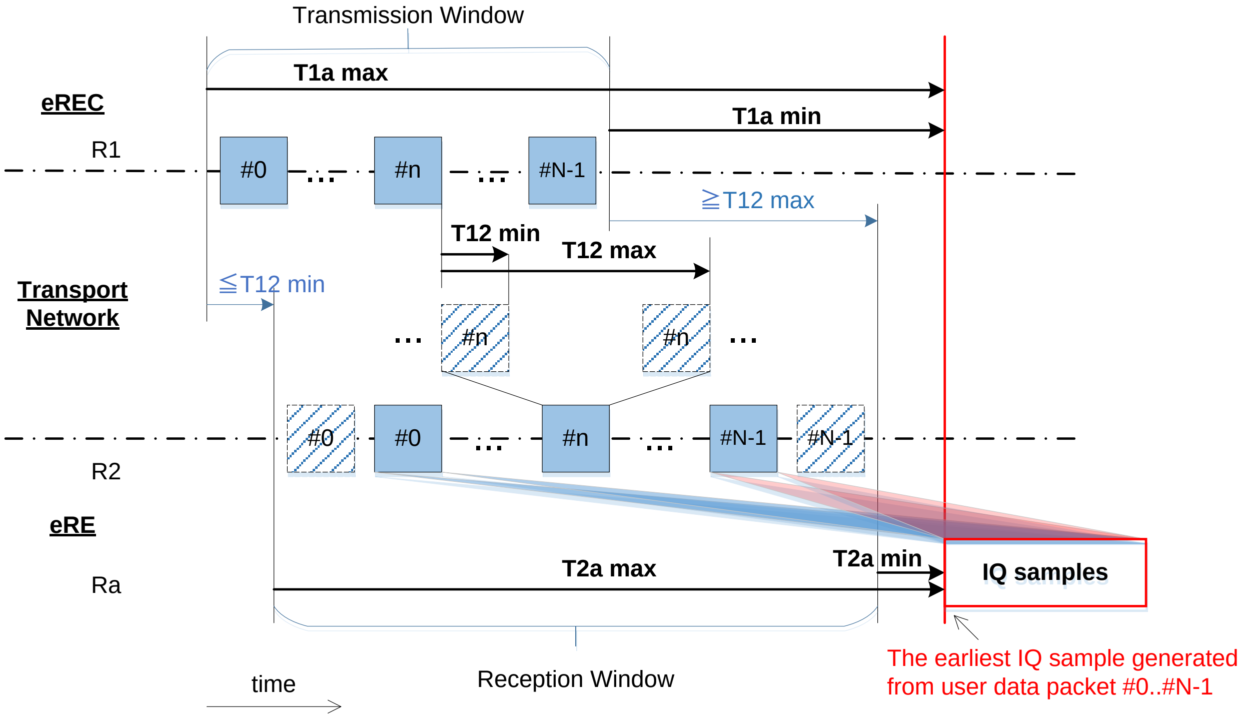

Figure 35: Timing relations in DL direction

The UL timing relations are shown in Figure 36. The time point when the first IQ sample of a UL air frame to be received at the antenna is indicated by the red line on the left.

By definition, the following equation has to be satisfied:

$$Ta4 = Ta3 + T34$$

Therefore the minimum/maximum limits of these three variables are not independent; i.e. following conditions have to be met in order not to lose UL user data.

$$Ta4\ min \leqq Ta3\ min + T34\ min$$

$$Ta4\ max \geqq Ta3\ max + T34\ max$$

"Rx window size at R4" ≧ "Tx window size at R3" + "max fluctuation of transport network latency"

Where:

"Tx window size at R3" = Ta3 max – Ta3 min

"Rx window size at R4" = Ta4 max – Ta4 min

"Max fluctuation of transport network latency" = T34 max – T34 min

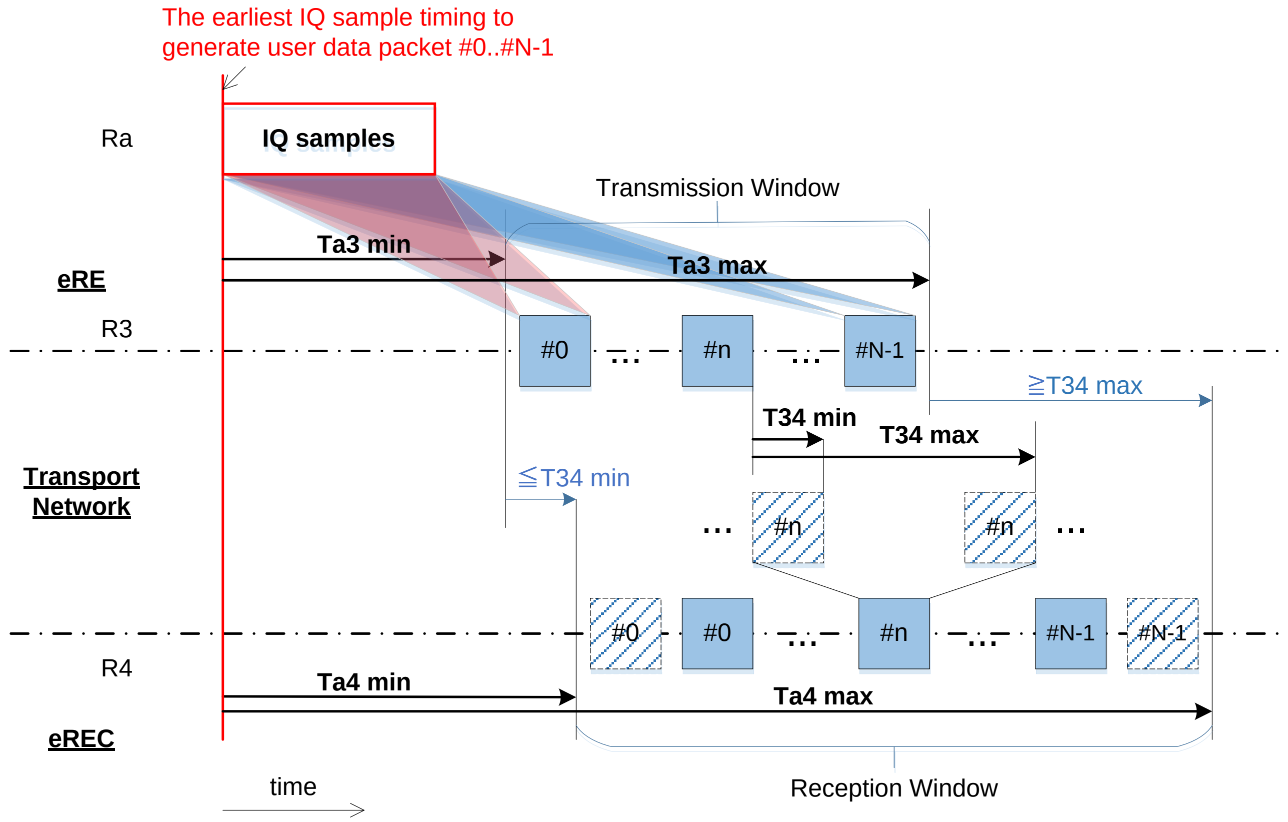

Figure 36: Timing relations in UL direction

6.3.2. Delay Management example

Figure 37 shows a model of UL/DL eCPRI user data transmission between eCPRI nodes (eREC and eRE). Both transmitter and receiver side of eCPRI nodes have buffer memories to absorb the fluctuation of transport network delay as well as the variation of processing time in eCPRI nodes which depends on the traffic and processing load. The goal of delay management is to avoid the overflow/underflow of buffer memories and to decrease the overall delay, the necessary size of buffer memories, etc. at the same time. Additionally a sort of traffic shaping may be necessary at the transmitter side to avoid unnecessary traffic congestion. Flow control with fast feedback loop is not considered in this example.

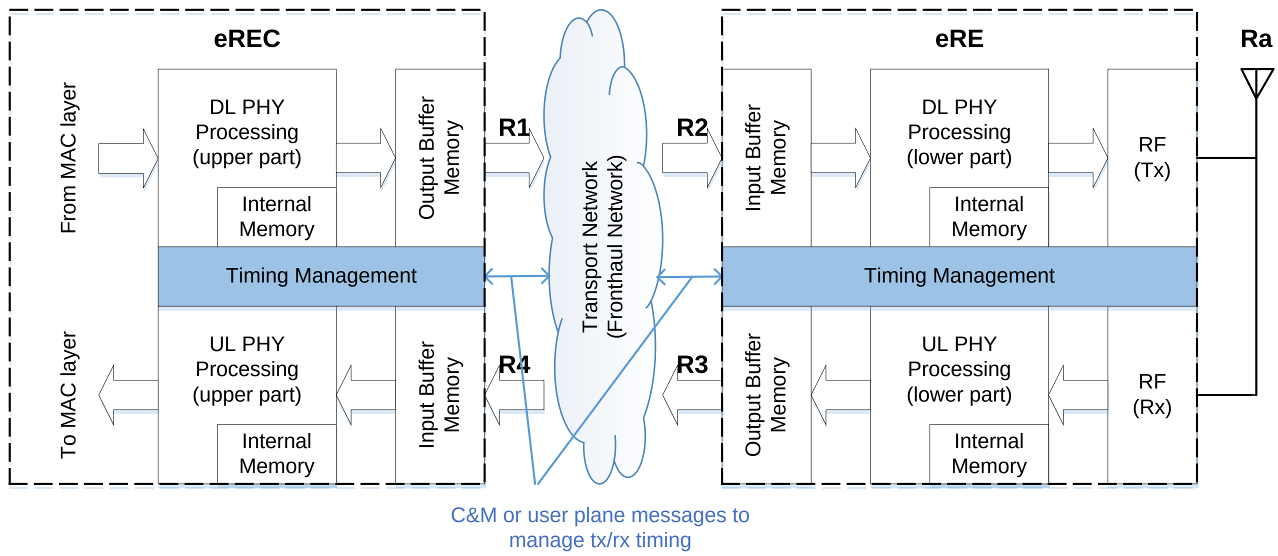

Figure 37: Delay management model example

eREC functions:

- Measure the actual typical/maximum/minimum one-way delay between the eREC and the eRE (UL and DL direction) in addition to the nominal maximum/minimum transport network delay and allocate the optimum delay budget to the eREC, the eRE and the transport network.
  - eCPRI service “one-way E2E delay measurement” is used.
  - Measure the delay periodically if necessary.
- Manage the transmission timing of UL/DL user plane messages in order to ensure that messages arrive at the eRE properly (i.e. within the reception windows at the eRE), considering:
  - UL/DL frame timing at the antenna of the eRE (strictly defined by 3GPP specification)
  - Deadline of each user plane message (or a group of messages) for the eRE to start/complete UL/DL processing to avoid buffer underflow.
  - The maximum size of the input buffer at the eRE as well as the remaining size to avoid buffer overflow.
  - The actual delay of the transport network and processing time in the eRE based on reports from the eRE.
- Declare the allowable reception window timing for each (or a group of) UL user plane message(s) relative to the air interface frame timing.
  - The end of the window (deadline) depends on the processing time in the eREC (vendor specific), especially HARQ related processing.
  - The beginning of the window depends on the input buffer size in the eREC (vendor specific)
- Monitor the actual reception timing of (critical) user plane message and the input buffer status, and request the eRE to adapt the transmission timing if necessary.

eRE functions:

- Manage the transmission timing of UL user plane messages in order to ensure that messages arrive at the eREC properly (i.e. within the reception windows at the eREC).
- Declare the allowable reception window timing for each (or a group of) UL/DL user plane message(s) relative to the air interface frame timing.
  - The end of the window (deadline) depends on the processing time in the eRE (vendor specific).
  - The beginning of the window depends on the input buffer size in the eRE (vendor specific).
- Monitor the actual reception timing of (critical) user plane messages and the input buffer status, and report them to the eREC.
  - At least, the occurrence of buffer overflow/underflow (late delivery) should be reported.
  - Reports may be transferred by C&M plane or eCPRI services (“Real-Time Control Data” or “Event Indication”) depending on its time criticality.
- Additionally, traffic shaping of UL user data may be necessary to avoid unnecessary transport network congestion, especially in case the transport network bandwidth is shared by multiple synchronized TDD eREs.

Figure 38 shows an example of DL user data transmission timing between the eREC and the eRE.

In this example, we assume:

- The eREC transmits user data each OFDM symbol interval (e.g. 67usec for LTE).
- The eRE has the input buffer large enough to store full messages for 3 OFDM symbols.
- Only worst cases (regarding min/max delay of transport network, maximum processing time in the eRE) are considered.

- The transmission timing of the first IQ sample of OFDM symbol #n at the eRE antenna Ra is used as the reference timing. This timing is strictly defined by 3GPP specification, so fluctuation is not allowed.
- The eREC transmits all user data packets which are necessary to generate OFDM symbol #n within the transmission window [T1a max, T1a min] before its first IQ sample is transmitted from the eRE antenna.
- The eRE receives all user data packets which are necessary to generate OFDM symbol #n within the reception window [T2a max, T2a min] before its first IQ sample is transmitted from the eRE antenna.

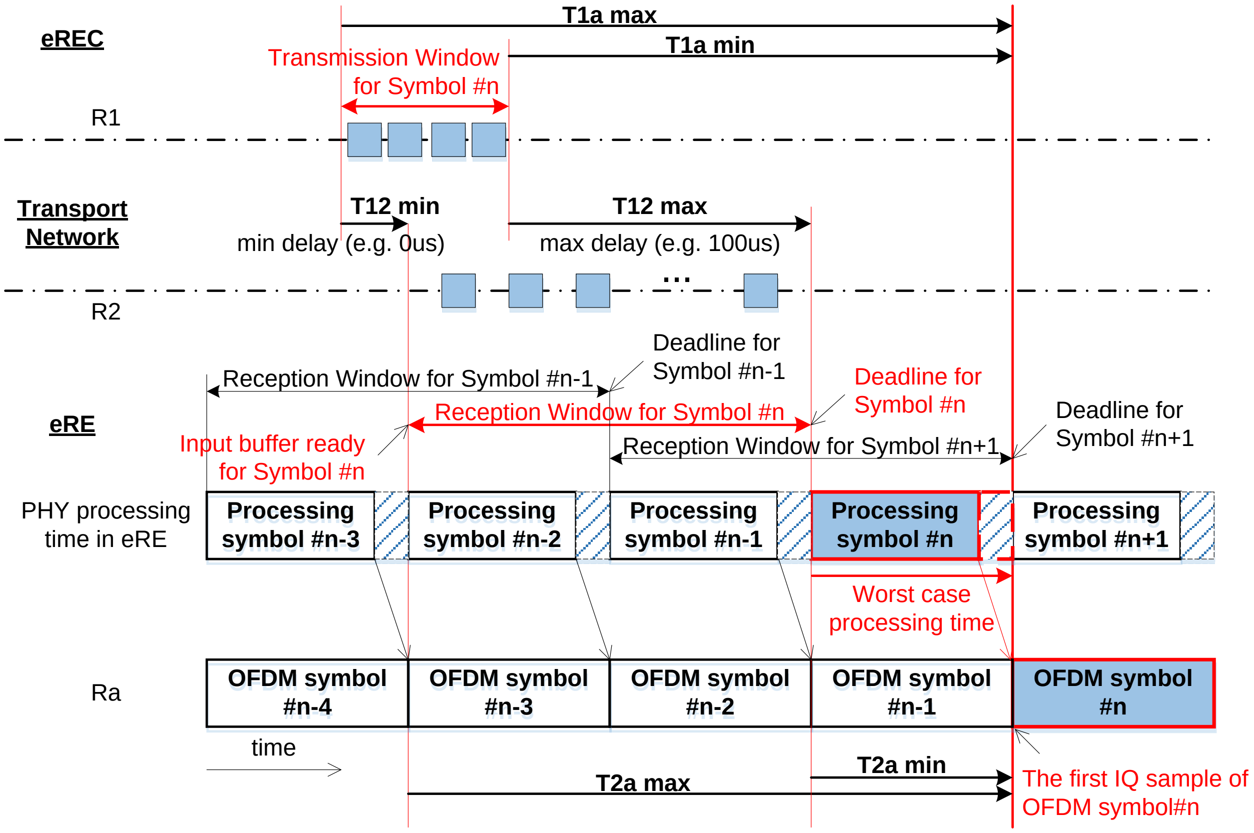

Figure 38: DL user data transmission timing example

6.4. Network Connection Maintenance

Network connection maintenance and network connection control is out of scope of the eCPRI specification. There are a number of different methods and standards that can be used.

For the Ethernet parts of eCPRI (if applicable for the User plane data and for IP over Ethernet), the Ethernet OAM can be used. Ethernet OAM is a common name for the IEEE 802.1Q [14] and ITU-T Recommendation G.8013/Y.1731 [16]. 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).

For the IP parts of the eCPRI (e.g. the C&M flow), the Internet Control Message Protocol (ICMP) can be used. ICMP for IPv4 is defined in RFC 792 [17] and for IPv6 it is defined in RFC 4443 [18].

An eCPRI node needs to have either a unique MAC address or a unique IP address. How to do or get these addresses is out of scope of the eCPRI specification.

6.5. Networking

6.5.1. Difference between eCPRI and CPRI

This subsection describes the major differences between eCPRI and CPRI (e.g. CPRI v7.0). The main audience of this section is anyone familiar with CPRI and who would like to understand the difference between eCPRI and CPRI networking quickly. So it may not be valuable to new readers of eCPRI who are not interested in CPRI.

Figure 39 shows an example network by CPRI. CPRI has the following characteristics:

- CPRI is a point-to-point interface by nature.
- There is a master-port and a slave-port connected directly by optical/electrical cable(s) (a hop).
- Networking functions are application layer functions and not supported by the CPRI interface itself.
- Supported topologies depend on REC/RE functions,
- Supported logical connections include:
    - Point-to-point (one REC – one RE).
    - Point-to-multi-point (one REC – several REs).
- Redundancy, QoS, security, etc. are REC/RE functions (if required).

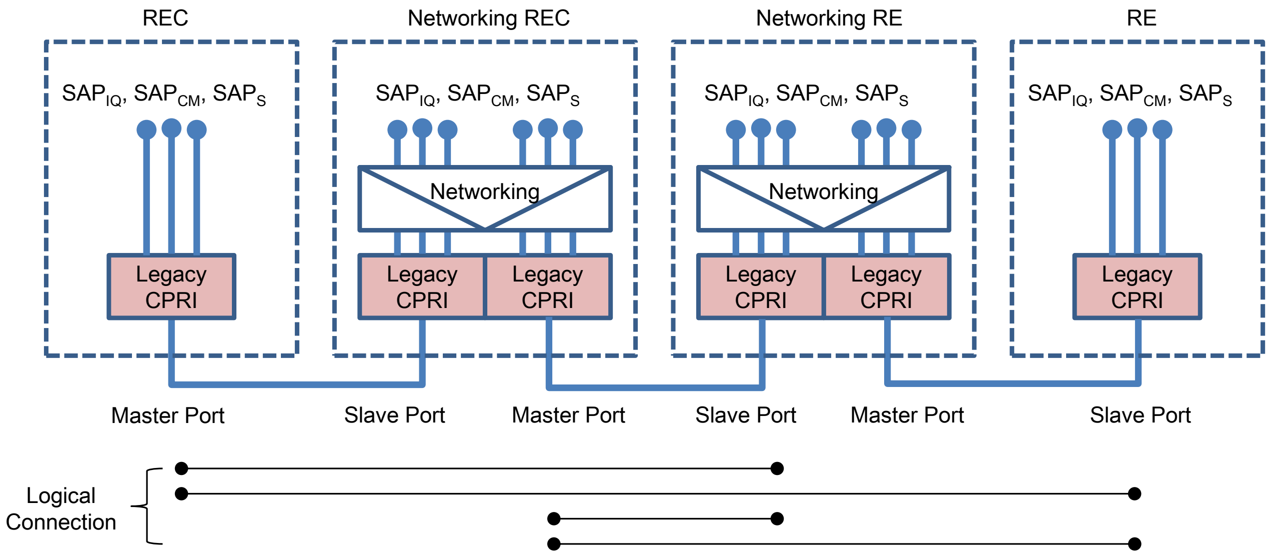

Figure 39: Network by legacy CPRI

Figure 40 shows an example network by eCPRI. eCPRI has the following characteristics:

- An eCPRI network consists of eCPRI nodes (eRECs and eREs), transport network, as well as other network elements not shown in Figure 40 (including GM/BC for timing, EMS/NMS for management).
- There is no longer a master port/slave port classification at physical level.
    - SAP_S: master of PTP and Synchronous Ethernet is not a eREC in general.
    - SAP_{CM}: some of M-plane may be managed by EMS/NMS.
- The eCPRI layer is above the transport networking layer.
- The eCPRI layer does not care about the actual transport network layer topology.
- The transport network may include some local network, e.g. local switch(es) provided by the eREC/eRE vendors.

- Supported logical connections include:
    - Point-to-point (one eREC – one eRE), same as legacy CPRI.
    - Point-to-multi-point (one eREC – several eREs), same as legacy CPRI
    - Multi-point-to-multi-point (eRECs – eREs, eRECs – eRECs, eREs - eREs), new for eCPRI but not always necessary.
- Redundancy, QoS, security, etc. are mainly transport network functions; eCPRI nodes need to implement proper transport network layer protocols to support these capabilities if required.

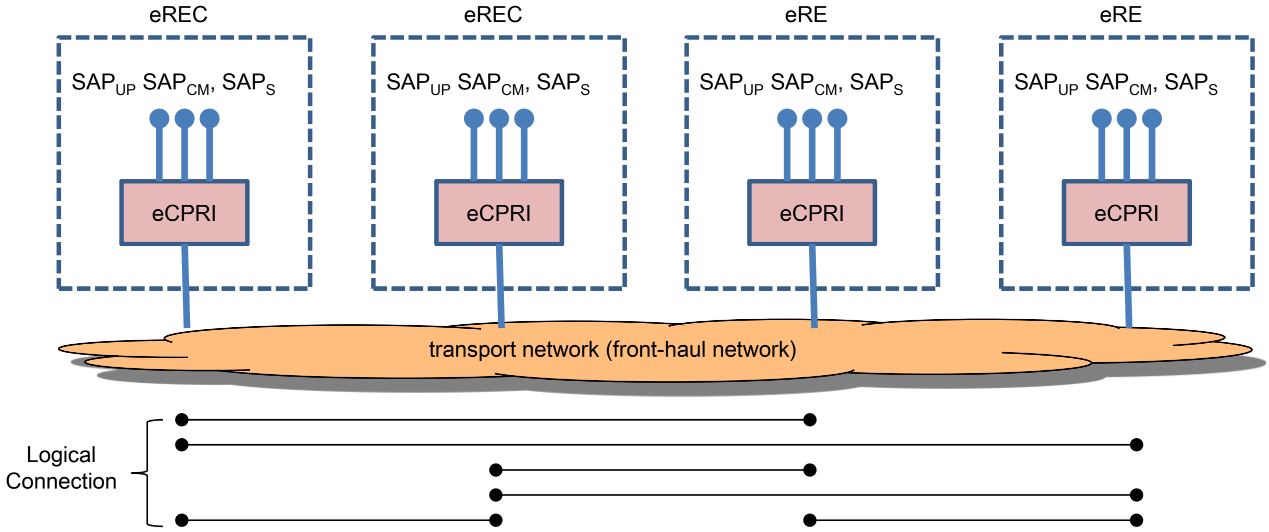

Figure 40: Network by eCPRI

6.6. Priority considerations

The User data and Real-Time Control data are the most time sensitive flows and normally require a high priority. The traffic on the User Plane can in many cases be split into different kind of traffic with different need of QoS. In that case it might be good to have several priorities for the User Plane Data.

The C&M data flow is normally not time sensitive and can be set to a low priority. But it may be wise to have two different priorities for C&M. One with lower priority than the User Plane Data that can be used for C&M considered as background traffic, and one with higher priority than the User Plane Data for the interactive traffic. The interactive traffic (including critical operation and emergency) needs to come through even if the amount of User Plane Data exceeds the available network bandwidth.

Note that for an Ethernet-switched fronthaul network there are only up to eight priorities available and in a provider network other traffic might need at least one priority. So even if there is a lot of traffic with different need of QoS (e.g. for the User Plane Data) it will be good to keep down the total number of QoS levels.

6.7. Message Ordering Considerations

The eCPRI transport network may not guarantee preservation of the eCPRI messages order (i.e. the order in which a sequence of eCPRI messages is transmitted by the source node may be different from the order in which the sequence is received at the destination node). Order preservation may not be guaranteed even assuming the same priority, type of message, source node and destination node.

This is partially addressed by the inclusion of a sequence related ID field for some of the eCPRI message types.

6.8. Security

This section covers security considerations related to eCPRI traffic. If the transport network is not safe for a particular flow then an eCPRI network end-to-end security system should be implemented in the eREC node and eRE node for that flow.

6.8.1. eCPRI Network Security Protocol

eCPRI Network Security Protocol suites include IPsec in IP traffic and MACsec in Ethernet traffic, IPsec and MACsec are designed to provide interoperable, high quality, cryptography-based security for IP and Ethernet traffic. The set of security services offered includes access control, connectionless integrity, data origin authentication, protection against replays (a form of partial sequence integrity), confidentiality (encryption), and limited traffic flow confidentiality. These services are provided at the IP or Ethernet layer, offering protection for Ethernet or IP and/or upper layer protocols.

The details of IPsec and MACsec usage is vendor specific.

6.8.2. eCPRI Network Security Specification

Vendors can choose e.g. IPsec or MACsec to ensure the security of transmission.

6.8.2.1. User plane

User plane over IP

- IPsec or MACsec are both optional solutions to provide transmission security.

User plane over Ethernet

- MACsec is an optional solution to provide transmission security.

6.8.2.2. C&M plane

TLS, IPsec or MACsec are optional solutions to provide transmission security and access control for eCPRI C&M plane.

6.8.2.3. Synchronization plane

There is no eCPRI recommendation for security aspects related to the synchronization plane.

7. List of Abbreviations

3GPP	3rd Generation Partnership Project
BC	Boundary Clock
C&M	Control and Management
CFM	Connectivity Fault Management
CoMP	Coordinated Multipoint
CCP	Continuity Check Protocol
CFP	C Form-factor Pluggable
CPRI	Common Public Radio Interface
DiffServ	Differentiated Services
DL	Downlink
DSCP	Differentiated Services Code Point
EMS	Element Management System
eNB	Evolved NodeB
eRE	eCPRI Radio Equipment
eREC	eCPRI Radio Equipment Control
ETH-CC	Ethernet Continuity Check
ETH-AIS	Ethernet Alarm Indication Signal
ETH-LT	Ethernet Link Trace
ETH-LB	Ethernet Loopback
ETH-RDI	Ethernet Remote Defect Indication
ETH-LM	Ethernet Loss Measurement
E-UTRA	Evolved Universal Terrestrial Radio Access
FFT	Fast Fourier Transform
GM	Grandmaster
gNB	5G base station name
GPS	Global Positioning System
HW	Hardware
ICMP	Internet Control Message Protocol
IDFT	Inverse Discrete Fourier Transformation
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
IP	Internet Protocol
IPsec	Internet Protocol Security
IQ	In-phase and Quadrature
L1	Layer 1
LT	Link Trace
LLC	Logical Link Control
LB	Loop-Back
LSB	Least Significant Bit

LTE	Long Term Evolution
MAC	Media Access Control
MACsec	Media Access Control Security
MIMO	Multiple Input, Multiple Output
MSB	Most Significant Bit
MSps	Mega Sample per second
MU-MIMO	Multi-User MIMO
NMS	Network Management System
NR	New Radio Access Technology (for 5G)
OAM	Operations, Administration and Maintenance
OFDM	Orthogonal Frequency-Division Multiplexing
PCP	Priority Code Point
PDCP	Packet Data Convergence Protocol
PDU	Protocol Data Unit
PHY	Physical Layer
PRACH	Physical Random Access Channel
PTP	Precision Time Protocol
QoS	Quality of Service
QSFP	Quad Small Form-factor Pluggable
RE	Radio Equipment
REC	Radio Equipment Control
Req	Request
Resp	Response
RF	Radio Frequency, Radio Functions
RLC	Radio Link Control
RRC	Radio Resource Control
Rx	Receive
SAP	Service Access Point
SCTP	Stream Control Transmission Protocol
SFP	Small Form-factor Pluggable
SNMP	Simple Network Management Protocol
SRS	Sounding Reference Signal
SW	Software
t_1	Timestamp 1
t_2	Timestamp 2
TCP	Transmission Control Protocol
t_{cv1}	Compensation Value 1
t_{cv2}	Compensation Value 2
t_D	One way delay
TTI	Transmission Time Interval
Tx	Transmit

UDP	User Datagram Protocol
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication System
VID	VLAN Identifier
VLAN	Virtual LAN

8. References

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9. History

Version	Date	Description
V 1.0	2017-08-22	First eCPRI specification