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Draft Standard for Radio over Ethernet Encapsulations and Mappings

Sponsor

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**IEEE-SA Standards Board**

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# Overview

In order to lower the cost and improve the functionality in a 4G/5G wireless network a centralization of many of the most expensive components of the wireless network is being proposed by the wireless community. This centralization is referred to as a Cloud (or Centralized) Radio Access Network or more commonly as a C-RAN architecture.

The C-RAN architecture lowers the cost because it allows the expensive components of the wireless network to be shared by many antenna sites rather than having dedicated components at/for each antenna site. When an antenna site is busy a greater proportion of expensive resources may be dedicated to that site by reducing the proportion of expensive resources currently dedicated to less busy antenna sites. This can be done dynamically by adaptting to the normal daily changes in traffic patterns within a metro area (or within a building if a pico-cell wireless architecture is being deployed). Likewise, improved functionality becomes possible since a more central location can co-ordinate the Radio Frequency (RF) behavior of multiple antennas, not just those at a single site. For example, this behavior permits multiple antenna sites to co-ordinate transmissions towards a distant user device for the purposes of either improved throughput and/or improved distance.

In order to achieve the goals of a C-RAN architecture, a protocol must exist to separate centrally located expensive parts of the wireless network from the cheaper distributed antenna sites. The nature of this protocol depends in large part on how the functional split is done between the cheaper and the more expensive wireless components. At one extreme, almost all the expensive parts are located next to the antenna site (the current situation) while at the other extreme only very dumb/cheap components are left at the antenna site.

The protocol used to effect this functional split must be carried between the C-RAN central control location and the sites of the antennas. This can be done over dedicated fibers with Wave Division Multiplexing (WDM), it can be done over a Time Domain Multiplexed (TDM) network, or it can be done over a packet switched network. It would be beneficial to carry this protocol over a packet switched Ethernet network due to the ubiquity and cost advantages of Ethernet in the Metro and as a distribution network within buildings. Regardless of the transport mechanism, the network that separates the antenna sites and the C-RAN central control sites is referred to as the Fronthaul network when most of the expensive components are centrally located while the Backhaul network is the case when most of the expensive components are located near the antenna sites. Various intermediate options are also possible and expected with the next generation C-RAN architectures.

Several protocols exist to enable this fronthaul split and the most important one is the Common Public Radio Interface (CPRI). CPRI is an example of an extreme functional split which essentially carries a very low level encoded format that is predominantly just a stream of In-phase/Quadrature (I/Q) samples of the RF signal that the antenna should transmit or receive. CPRI is designed to be transported over an optical fiber pair at a variety of speeds and encoding formats. There are many strict requirements on the protocol such as an end to end delay of no more than 100us and a differential delay of no more than +/- 8ns.

In order to successfully use Ethernet network as a transport network for CPRI or other types of functional split radio protocols for 4G/5G a method of encapsulation of these Radio protocols over Ethernet is required.

Radio Over Ethernet is therefore the use of Ethernet to encapsulate and fronthaul a variety of radio protocols as packets from between the C-RAN and the antenna sites.

There are broadly two types of encapsulation techniques. The simplest encapsulation mechanisms are oblivious to the structure of the protocol they are encapsulating. This we refer to as the structure–agnostic mechanism. The alternative, is an encapsulation mechanism that is partially aware of the structure of the protocol it encapsulates and we refer to this as structure-aware mechanism. This mechanism allows various optimizations.

## Scope

1. This document defines the encapsulation and mapping of radio protocols to be fronthauled over Ethernet networks. Furthermore, both structure-agnostic and structure-aware definitions are provided for the most common and current radio protocol – Common Public Radio Interface (CPRI).
2. This standard does not specify whether or how the Ethernet packets are guaranteed the strict QoS required by the encapsulated radio protocols. It does however recommend the support of 802.1CM profile or equivalent to help ensure such QoS guarantees. Alternative transparent mechanisms are also permitted in conjunction with or in lieu of 802.1CM profile.
3. We expect that a full implementation of Radio over Ethernet would comprise;
* the above mentioned encapsulations,
* a networking tehnology that minimizes delay and PDV,
* a clock distribution mechanism, and
* ingress/egress mapping functions that encapsulate/decapsulate while dejittering and retiming the recovered signal.
1. This specification is concerned with encapsulation and mapping only.

## Purpose

1. The purpose of this standard is to describe the exact header formats and packet encapsulations required to;
* transport any newly defined fronthaul protocol over Ethernet (i.e. the “native RoE” encapsulation that can be used as-is or used to transport other existing fronthaul protocols in a ways described in the next two bullet points
* Transport a C-RAN Radio Fronthaul protocol such as CPRI in a bit transparent manner (structure agnostic) over Ethernet.
* Transport the C-RAN Radio Fronthaul protocol CPRI over Ethernet where knowledge of the frame format is used to optimize the choice of packet sizes/headers/alighnment etc.

## Coverage

1. This specification provides TBD ...

# Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

# Definitions, acronyms, and abbreviations

## Definitions

For the purpose of this document, the following terms and definitions apply. The IEEE Standards Dictionary Online should be consulted for terms not defined in this clause.[[2]](#footnote-2)

TBD

## Acronyms and abbreviations

4G/5G – Fourth Generation and Fifth Generation wireless networking technologies.

BF – Basic Frame

BFN – Node B Frame Number

BER – Bit Error Rate

CPRI – Common Public Radio Interface

CRAN /C-RAN – Cloud / Centralized Radio Access Network

Endpoint – The original sender or the final receiver of a RoE communication

FDD – Frequency Division DuplexI/Q - Inphase and Quadrature

Jitter – Deviation in clock frequency from true periodicity

LAN – Local Access Network

LSB – Least Significant Bit

MSB – Most Significant Bit

PDV – Packet Delay Variation

RoE – Radio over Ethernet

**TAI** – International Atomic Time

TLV – Type Length Value

ToD – Time of DayUTC – Universal Coordinated Time

UTRA – Universal Terrestrial Radio Access (3GPP)

VLAN – Virtual LAN

WDM –Wave Division Multiplexing

## Special Terms

**Term**: Definition

# Radio over Ethernet (RoE) base protocol

Editorial Note: this clause will describe the native RoE encapsulation transport format. The following subclauses will also describe the overall RoE architecture, showing encapsulation and decapsulation function locations, and the mapper function locations. This clause also lists the underlying assumptions a RoE enabled architecture has.

## Overview

### Undelying Network Requirements

Tbd.

* A mesh network comprised of bridges and point to point Ethernet links
* The number of actual links and nodes are not in scope as long as the delay and the PDV are within the required timing.
* The network will need management for delay and packet delay variation
* Highly managed network
* Support for ToD distribution if there is no other means for end points for clock sync
* No retransmission (minimum affective 1012 BER) for RoE traffic.
* Network is required to have sufficient bandwidth to carry RoE traffic.
* The maximum one way delay has to be less than half of the available roundtrip delay.
* Ethernet network that preserves the frame source and destination addresses.

### RoE endpoints

This document uses terms **endpoint** and **RoE endpoint** meaning a RoE capable networking node that is either the originator or the final receiver of a RoE communication. There may be zero or more intermediate networking nodes between RoE endpoints.

Only RoE end-points are required to be RoE aware.

This document also further details the roles of the RoE endpoints in places where it is important to know whether the endpoint has a role of a **RoE master** or a role of a **RoE slave** during the communication

TBD: port mode?

Editor’s note: Can Ethernet port handle multiple mappers at the same time or just one? Proposal – one type.

### Encapsulation and decapsulation functions

Tbd.



Figure 1 - RoE endpoints and supported functions

### Mapper functions

A mapper is a function/process that is capable of converting other transport framing formats to a native RoE framing format and vise versa. This specification describes two flavors of mappers. The first concerns how to separate control data and sample data parts, and packetize the sample data. The second concerns how to process and packetize the control data. The latter is called as “control process” in this specification.

## RoE Ethernet Type

All RoE packets shall use the EtherType value shown in Table 1.

Table 1 - RoE EtherType

|  |  |
| --- | --- |
| **Purpose** | **EtherType** |
| RoE packet | XX-XX16 (\*) |

(\*) The value will be assigned at Sponsor Ballot time.

## RoE encapsulation common frame format

This subclause documents the first 6 or 10 octets of the frame (i.e. the RoE header) that are common to all RoE flow data and control packets. Figure 2 illustrates the frame format and its fields. The offset zero (0) is the first octet of the RoE frame. The common RoE frame has the following header fields:

* **ver** (version) field: 2 bits
* **pkt\_type** (packet type) field: 6 bits
* **S** (start of frame) field: 1 bit
* **flow\_id** (flow identifier) field: 7 bits
* **T** (timestamp select) field: 1 bit
* **extended\_header\_space** field: 0 or 32 bits



Figure 2: RoE encapsulation common frame format – the RoE header

There is no dedicated field for the RoE packet **payload** size. The lower layers transporting (e.g. Ethernet MAC in this specification) has to provide a means for RoE application to determine the size of its payload.

The RoE header is placed into the transport protocol payload field, which in this document context is the Ethernet frame payload field.

### ver (version) field

The **ver** field indicates the version of the RoE protocol and RoE common format for data, control and future packet types.

The version defined in this document is zero (00b). The **ver** field shall be set to 00b.

### pkt\_type (packet type) field

The 6 bit **pkt\_type** field is used to define the RoE packet type and the type of flow carried by the RoE packets. This document reserves packet types listed in Table 2.

Table 2 – RoE pkt\_type values

|  |  |  |
| --- | --- | --- |
| **Binary value** | **Function** | **Description** |
| 000000b | Control Packet | Control packet between two RoE endpoints |
| 000001b | Native RoE data flow packet | Data payload packet with 6 octet RoE frame header. |
| 100001b | Native RoE data flow packet with extended\_header\_space | Data payload packet with 10 octet RoE frame header. |
| 000010b | Data flow packet with mapped CPRI payload | Data payload packet with 6 octet RoE frame header and structure agnostic CPRI payload. |
| 000011b | Data flow packet with mapped CPRI payload | Data payload packet with 6 octet RoE frame header and structure aware CPRI payload. |
| 000100b | Data flow packet with mapped CPRI payload | Data payload packet with 6 octet RoE frame header and structure aware CPRI Slow C&M payload. |
| 000101b – 011111b | -- | Reserved for future packet types |
| 100010b – 111111b | -- | Reserved for future packet types |

### S (start of frame) field

The **S** field indicates a “start of frame”. The start of frame is context and packet type specific. The **S** field has no meaning with RoE control packets and may be overloaded with other functionality in future specifications.

In a case of RoE data packets or other future defined RoE packets the **S** field indicates the start of frame of the upper layer payload it is carrying. For example, in a case of 3GPP Release-12 Long Term Evolution (LTE) radio sample payload, the **S** field indicates the start of 10ms radio frame. The first RoE data packet payload bit is time aligned with the start of frame of the upper layer payload it is carrying.

The bit is set to one (1) if the RoE packet contains in its payload a start of frame in the upper layer payload it is carrying.

The bit is set to zero (0) otherwise.

### flow\_id (flow identifier) field

The **flow\_id** identifies a specific flow between two endpoints. The endpoints are defined as Ethernet packet Source Address (SA) and Destination Address (DA) pair in the context of this specification. The **flow\_id** allows multiplexing up to 128 flows between two endpoints.

The **flow\_id** identifier has no routing function and is solely interpreted by the endpoints. The **flow\_id** identified flow may consist of multiple subflows (i.e. a group flow). The interpretation of flow content and possible subflows is solely controlled by the endpoints.

This document reserves flow identifier values listed in Table 3.

Table 3 – RoE flow\_id values

|  |  |  |
| --- | --- | --- |
| **Binary value** | **Function** | **Description** |
| 0000000b | NIL flow\_id | Reserved flow\_id indicating that the field shall not be interpreted as any specific flow.  |
| 0000001b – 1111111b | flow\_id number | Flow identifiers available for use to identify specific flows between two endpoints. |

### T (timestamp select) field

The **T** field indicates whether the following 31 bits – timestamp/sequence number – field carries a timestamp or a sequence number.

The bit is set to zero (0) if the timestamp/sequence number field contains a 31 bit **sequence number**.

The bit is set to one (1) if the timestamp/sequence number field contains a 31 bit **timestamp**.

#### Timestamp

The **timestamp** is 31 bits in size and in units of nanoseconds. The timestamp is the presentation time at the RoE packet receiving endpoint and calculated by the RoE packet sending endpoint. Both endpoints shall share the same understanding of the Time of Day (ToD).

The timestamp field is encoded as a 31 bit sliding window capable of representing ~2 seconds worth of time. This implies the timestamp field is capable of encoding a presentation time maximum ~1 second in the future. See Annex B for an example algorithm. The timestamp sliding window size is controlled by the following variables:

* **tstampWindowSize** = “size of the sliding window”; the value shall be a power of 2
* **tstampWindowMask** = **tstampWindowSize**-1
* **tstampTstampMask** = (**tstampWindowSize**\*2)-1

Refer to subclause 4.11 for more details on the timestamp and the presentation time.

#### Sequence number

The **sequence number** field is 31 bits in size and wraps to **seqNumMinimum** after exceeding its maximum value **seqNumMaximum-1**. The highest value for the **seqNumMaximum** is 2^31-1. The following shall hold: 0≤**seqNumMinimum<seqNumMaximum**-1. The sequence number is increased by a constant value **seqNumIncrement** known by both RoE packet sending and receiving endpoint. The **seqNumIncrement** shall comply with: **seqNumIncrement<(seqNumMaximum**- **seqNumMinimum**-1).

The sequence number is initialized to an implementation specific value **seqNumStart** between **seqNumMinimum** and **seqNumMaximum-1** at the endpoint reset. The internal structure of the sequence number is known and interpreted by RoE endpoints.

### extended\_header\_space field

The **extended\_header\_space** field is 32 bits in size and is included in a RoE frame if so indicated by a specific packet type. The content of the extended\_header\_space is defined case by case for RoE packet types that make use of it.

The general rule for using the extended\_header\_space is as follows: there shall always be an accompanying packet type without the extended\_header\_space that otherwise has exactly the same content as the packet with the extended\_header\_space.

### payload field

The content, structure and size of the payload field is specific to a RoE packet type and its definition. The payload may contain a flow of In-phase and Quadrature (I/Q) samples for a single antenna carrier or a group of antenna carriers. Both single and group content is identified by a **flow\_id** between two RoE endpoints. Furthermore, when specific mappers are applied the payload field can contain, for example, an individual antenna carrier component flow of a decomposed CPRI basic frame. In a case of RoE control packets the payload may contain appropriate control and management information, for example, in a form of TLVs or other encoding scheme.

The total RoE payload field size shall always be full octets. If payload size modulo 8 is not 0 then the last octet of the payload is added trailing padding 0-bits until the payload size modulo 8 is 0.

## Bit and octet ordering, and numerical presentation

This document assumes network byte ordering (i.e. big endian). illustrates the bit ordering and numbering within an octet. Similarly illustrates the bit and octet ordering, and corresponding numbering within a 32 bit word.



Figure 3 - bit ordering and numbering within an octet



Figure 4 - bit and octet ordering and numbering within a 32 bit word

The following numerical notations are used in this document:

* Integer value has no specific notation, for example: 69
* Hexadecimal value has a prepended “0x” subscript, for example: 0xdeadbeef
* Binary value has a trailing “b” subscript, for example: 11001010b

## RoE control packet common frame format

This subclause documents the first 6 or 10 octets of the frame that is common to RoE control packets. Figure 5 illustrates the frame format and its fields. The RoE contral packet frame format follows the generic RoE frame format defined in subclause 0 unless stated otherwise.



Figure 5: RoE Control Packet common frame format

### ver (version) field

See subclause 4.2.1.

### pkt\_type (packet type) field

The **pkt\_type** field for a RoE Control Packet shall be set to value 000000b (see Table 2).

### S (start of frame) field

The **S** field has no meaning with RoE Control Packets. It shall be set to 0 by the sender and ignored by the receiver.

### flow\_id (flow identifier) field

The **flow\_id** field shall be set to value 0000000b (see Table 3) unless otherwise specified by a RoE Control Packet **subtype** definition. See subclause 4.4.8 for further details regarding the RoE Control Packet subtypes.

### T (timestamp select) field

See subclause 4.2.5.

### timestamp/sequence number field

See subclause 1.1.1.1. Note that sequence numbers may behave differently between RoE control packets and their associated RoE data packet flows. For example the **seqNumMaximum** and **seqNumIncrement** can be different for RoE control packets and data packets. The RoE control packet subtype specification shall describe the exact sequence number handling.

### extended\_header\_space field

See subclause 4.2.6.

### subtype field

The **subtype** field is size of 8 bits and defines additional control packet types. This document reserves Control Packet **subtype** values listed in Table 4.

Table 4 – RoE Control Packet subtype values

|  |  |  |
| --- | --- | --- |
| **Binary value** | **Function** | **Description** |
| 00000000b | -- | Reserved for future use.  |
| 00000001b | Tbd | Reserved for RoE |
| 00000010b | Tbd | Reserved for RoE |
| 00000011b | Tbd | Reserved for RoE |
| 00000100b | CPRI11 mapper control words | Ctrl\_AxC and VSD data. |
| 00000101b – 11111111b | Reserved | Control packet subtypes available for use between two RoE endpoints. |

### Payload field

See subclause 4.2.7 for generic definition. The content depends on the control packet subtype.

## RoE pkt\_type 000001b format (data packet)

This subclause describes the native RoE data packet format. The packet payload carries a single flow or a group flow of radio sample data between two RoE endpoints. The common RoE frame header content is described in subclause 0.

### payload data

See subclause 4.2.7 for the generic definition.

The content of the payload field is divided into **RoE.numContainers** bit fields (i.e. containers) that again can be repeated **RoE.numSegment** times. A **RoE.Container[0..RoE.numContainers-1]** array is described as below:

**{**

 **.flow\_id**

 **.ctrl**

 **.lenSkip**

 **.lenContainer**

 **.modulo**

 **.index**

**}**

Each segment is described using **RoE.segment** that has a similar content as a container:

**{**

 **.lenSkip**

 **.lenSegment**

**}**

The container and the segment descriptions work for both extracting data from some source and describing the construction of the RoE payload field as well.

The RoE.numSegments also implicitly defines the amount of data collected before starting to construct one or more RoE packets

#### Container definition

The “**.flow\_id**” identifies to which RoE flow or group of flows this container belongs to. Typically the “**.flow\_id**” equals to an antenna carrier that is placed into separate RoE packets/flows. The “**.ctrl**” defines whether this contrainer is about control (1) or data payload (0). This selection can be used, for example, output data selectively to control or data RoE packets flows. The control data flows are processed by a dedicated entity this document calls as “control process”.

The “**.lenSkip**” describes the number of unused bits and the “**.lenContainer**” the number of actual payload bits per each container. Note that the “**.lenSkip**” bit are only affective when extracting/storing data from/to some other source than RoE payload field. When containers are stored into or read from the RoE payload field “skip bits” are not written or read.

The “**.modulo**” allows skipping containers and skipped containers are handled in a same way as “**.lenSkip**” bits. The modulo operation is applied to a sequence of input data that is counted from 0 to **RoE.numSegments**-1. The segment to select is matched comparing the “**.index**” to the output of the modulo operation. The “**.modulo**” value 0 means container skipping is not used. For example, to skip every second input container set the modulo to 2 to keep every container set the modulo to 1 (and index to 0) and to turn off modulo logic set the modulo to 0..

The above scheme allows constructing rather compex payload fields as well as very simple ones. The container definitions are per direction i.e. there may be different values for transmit and receive directions.

#### Segment definition

The “**.lenSkip**” and the “**.lenSegment**” for the segment describe a bit field that precedes all containers within a segment. The bit field described by the “**.lenSkip**” and the “**.lenSegment**” are not meant for the RoE data packets/flows in a typical case and are likely to require additional control processing before being packetized into any RoE packets. The control data flows are processed by a dedicated entity this document calls as “control process”.

#### Payload example

**Error! Reference source not found.** illustrates how containers and segments relate to each other. The figure is just an example of many possible configurations.



Figure 6 - relation between segments and containers

In the case when a container carries sample data in a form of I/Q components the samples shall be arranged and stored as shown in Figure 7. Effectively bits are stored in a network order (the most significant bit comes first) into the payload field, first the whole I component followed by the whole Q component of the antenna I/Q sample data stream.

In this example one possible way to express 64 time 15 bits I/Q sample pairs as a one antenna carrier flow could be: **RoE.numSegments**=64, **RoE.segment.lenSkip**=0, **RoE.segment.lenSegment**=0, **RoE.numContainers**=1, **RoE.container[0].ctrl**=0, **RoE.container[0].lenSkip**=0, **RoE.container[0].lenContainer**=30 (i.e. 2\*15 bit sample components) and **RoE.container[0].modulo**=0. Note that the example assumes I/Q samples are not interleaved. No padding is required.

If the payload is not I/Q sample data the same bit ordering, continuous storing and padding of bits shall still apply.



Figure 7 – I/Q sample data container and bit ordering

### Control data and the control process

If segments also contain control data, those are handled by a “control process” whose responsibility is to collect a reasonable amount of control data (based on the segment and container rules) before constructing a separate RoE control packet or other Ethernet packet (e.g. in a case of CPRI Fast C&M channel). The control process is responsible for meeting possible timing constraints on delivering control data within the required time frame. The behavior of the “control process” shall be defined by each mapper that makes use of the control data.

## RoE pkt\_type 100001b format (data packet with extended\_header\_space)

This subclause describes the native RoE data packet format with extended\_header\_space added to the common RoE frame header. The packet payload carries a single flow of radio sample data between two RoE endpoints. The RoE packet except for the extended\_header\_space is described in subclause 4.5.

### extended\_header\_space

Tbd.

## RoE pkt\_type 000000b subtype 00000001b format (control packet)

Tbd for RoE endpoint dynamic discovery and configuration purposes.

## RoE pkt\_type 000000b subtype 00000010b format (control packet)

Tbd for RoE endpoint dynamic discovery and configuration purposes.

## RoE pkt\_type 000000b subtype 00000011b format (control packet)

Tbd for RoE endpoint dynamic discovery and configuration purposes.

## RoE pkt\_type 000000b subtype 00000100b (CPRI control words)

Tbd packet format for carrying control words (excuding Fast C&M channel).

## Timing and synchronization considerations

Editors note: This clause lists for example reference time assumptions, and how the synchronization is realized in general.



Figure 8: Presentation time measurement points

### General assumptions

RoE uses Midnight, 1 January 1970 as its epoch. It is assumed (but not mandated) that both RoE endpoints have an access to a reference time source. The time source, when available, shall provide Time of Day (ToD) in nanoseconds and synchronized to international atomic time (TAI).

### RoE Presentation time

The RoE presentation time is used to achieve time synchronization between the RoE endpoints. The presentation time is calculated by the RoE sender and represents the time when the RoE packet payload has to be played out from the RoE receiver packet buffer to the consumer of the payload data.

### Presentation time measurement points

Figure 8 illustrates the measurements planes for the RoE presentation time. When a RoE sender calculates the presentation time at the RoE receiver, it has to take the entire end to end delay between the RoE sender and receiver reference planes into account. The end to end delay consists of the networking delay (i.e. the transit time), processing and buffering delays at both RoE endpoints. The buffer at the RoE receiver side has to be big enough to compensate packet delay variation introduced by the network and internal processing at both endpoints.

The method for measuring the end to end delay is implementation and deployment specific.

# RoE link setup

## Variables

RoE.numContainers

RoE.numSegments

RoE.container[0..n].lenContainer

RoE.segment.lenSkip

RoE.segment.lenSegment

RoE.segment.flow\_id

RoE.container[0..n].lenContainer

RoE.container[0..n].flow\_id

RoE.container[0..n].modulo

RoE.container[0..n].index

RoE.container[0..n].ctrl

seqNumIncrement

seqNumMinimum

seqNumMaximum

seqNumStart

CPRI10.lenBasicFrame

CPRI10.numBasicFramesPerPacket

tstampWindowSize

tstampWindowMask

tstampTstampMask

Tbd.

## Synchronizing endpoints

Tbd.

# RoE mappers

Editor’s note: This clause defines one or more mappers to/from existing radio framing formats to/from RoE native transport encapsulation format.

## Overview

Editor’s note: This subclause defines a mapper to/from CPRI v6.1 framing to/from RoE transport. It captures both structure agnostic and structure aware cases. Proposal to handle 8B/10B and 64B/66B CPRI PHYs as separate mappers.

## CPRI structure agnostic mapper

This subclause defines a structure agnostic CPRI to RoE mapper. This mapper does not interpret the CPRI frame content in any way. The mapper packetizes a number of CPRI Basic Frames into a RoE packet payload.

This mapper shall remove the 8B/10B line coding used by CPRI for line rate options 1 to 7. The mapper shall be aware of the start of the radio frame. In the context of this mapper and CPRI v6.1 specification the radio frame is the 10ms frame number, which for UTRA-FDD would be aligned with NodeB Frame Number (BFN).

The RoE header sequence numbers are used i.e. T-flag shall be set to zero (0).

This document names structure agnostic CPRI mapper as “**CPRI10**”.

### RoE pkt\_type 000010b format (data packet)

The mapper extracts/stores **CPRI10.lenBasicFrame** octets from/to the CPRI stream i.e. an individual CPRI Basic Frame (BF). **CPRI10.numBasicFramesPerPacket** are stored/extracted to/from RoE packets. If **CPRI10.numBasicFramesPerPacket**>1 then the mapper shall ensure the BF that starts the 10ms radio frame is the first BF in the RoE packet payload. For each RoE packet that starts the 10ms radio frame the RoE header **S**=1. Otherwise the **S**=0.

The **.modulo** logic is applied to the current Basic Frame number.

Other RoE configuration parameters shall be set as follows:

* **RoE.numSegments**=**CPRI10.numBasicFramesPerPacket**
* **RoE.segment.lenSkip=0**
* **RoE.segment.lenSegment=0**
* **RoE.numContainer**=1
* **RoE.container[0].lenSkip**=0
* **RoE.container[0].lenContainer**=**CPRI10.lenBasicFrame**\*8
* **RoE.container[0].flow\_id**=?
* **RoE.container[0].ctrl**=0
* **RoE.container[0].modulo**=0
* **seqNumMinimum**=0
* **seqNumMaximum**=256\*150/**CPRI10.numBasicFramesPerPacket**
* **seqNumIncrement**=1

Editor’s note: Draw example figure here.

### Use of sequence number

The sequence number is incremented by one (1) for each sent RoE data packet and the sequence number wraps around every 256\*150/**CPRI10.numBasicFramesPerPacket** sent packets (e.g. if there are 8 BFs per RoE packet the **seqNumMaximum** is 4800). Note that sequence number may be non-zero when RoE header S-flag is set.

### Use of RoE control packets

## There are no associated control packets for the “CPRI10” mapper. CPRI structure-aware mapper

Editor’s note: This is what we call “better” mapper.

Editor’s note: Proposal to require that GSM and other “non-UMTS Chip” antenna carriers are already resampled to some integer divisible UMTS Chip rate within CPRI traffic before the mapper is applied.

Editor’s note: the mapper only concerns how to put bits on wire and what processing is needed for that. How the packets are actually handled (e.g. timing wise) is not part of this.

This subclause defines a structure-aware CPRI to RoE mapper that looks into the CPRI frame and is able to further divide its content into different components. The mapper packetizes a number of CPRI Basic Frames worth of I/Q samples/AxC Containers for one AxC into a RoE data packet payload.

This mapper shall remove the 8B/10B line coding used by CPRI for line rate options 1 to 7. The mapper shall be aware of the start of the radio frame. In the context of this mapper and CPRI v6.1 specification the radio frame is the 10ms frame number, which for UTRA-FDD would be aligned with NodeB Frame Number (BFN).

The RoE header sequence numbers are used i.e. T-flag shall be set to zero (0) for both RoE data and control packets.

This document names structure-aware CPRI mapper as “**CPRI11**”.

### Handling of I/Q payload

#### RoE pkt\_type 000011b format (data packet)

Editor’s note: This is rather under specified and assumes that everything complies to some integer fraction of UMTS Chip rate.

 The mapper extracts/stores **CPRI11.lenBasicFrame** octets from/to the CPRI stream i.e. an individual CPRI Basic Frame (BF). The mapper buffers **CPRI11.numBasicFramesForRoEPacket** worth of CPRI BFs and then stored/extracted individual AxC containers to/from one or more RoE packets. If **CPRI11.numBasicFramesForRoEPacket**>1 then the mapper shall ensure the BF that starts the 10ms radio frame is the first BF in the RoE packet payload. For each RoE packet that starts the 10ms radio frame the RoE header **S**=1. Otherwise the **S**=0. The **.modulo** logic is applied to the current Basic Frame number.

The below RoE configuration parameter example is for CPRI line rate option 3 (assuming 20MHz LTE and 2x2 MIMO) and CPRI mapping method 1 without any stuffing bits. The AxC0 has flow\_is 1 and the AxC1 has flow\_is 2 i.e., there will be two RoE data packet flows.

The I/Q sample size is 15 bits per component.The AxC Container Block contains 256 BFs. One RoE data packet will contain 64 I/Q samples i.e. 8 BFs worth of samples.

The RoE configuration parameters shall be set as follows:

* **RoE.numSegments**=**CPRI11.numBasicFramesForRoEPacket=8**
* **RoE.segment.lenSkip=0**
* **RoE.segment.lenSegment=32**
* **RoE.numContainer**=16
* **RoE.container[0,2,4,6,8,10,12,14].lenSkip**=0
* **RoE.container[0,2,4,6,8,10,12,14].lenContainer**=**30**
* **RoE.container[0,2,4,6,8,10,12,14].flow\_id**=1
* **RoE.container[0,2,4,6,8,10,12,14].ctrl**=0
* **RoE.container[0,2,4,6,8,10,12,14].modulo**=0
* **RoE.container[1,3,5,7,9,11,13,15].lenSkip**=0
* **RoE.container[1,3,5,7,9,11,13,15].lenContainer**=**30**
* **RoE.container[1,3,5,7,9,11,13,15].flow\_id**=2
* **RoE.container[1,3,5,7,9,11,13,15].ctrl**=0
* **RoE.container[1,3,5,7,9,11,13,15].modulo**=0
* **seqNumMinimum**=0
* **seqNumMaximum**=256\*150/**CPRI11.numBasicFramesForRoEPacket**
* **seqNumIncrement**=1

The RoE.container definition describes 16 container fields, 8 for each AxC. This creates two RoE data packet flows with different flow\_id and each RoE data packet then contains 8\*8\*30 bits worth of CPRI AxC Containers.

The same above example with 14 bits per I/Q component and 2 bits of stuffing between each AxC container:

* …
* **RoE.container[0,2,4,6,8,10,12,14].lenSkip**=2
* **RoE.container[0,2,4,6,8,10,12,14].lenContainer**=**28**
* **RoE.container[0,2,4,6,8,10,12,14].flow\_id**=1
* **RoE.container[0,2,4,6,8,10,12,14].ctrl**=0
* **RoE.container[0,2,4,6,8,10,12,14].modulo**=0
* **RoE.container[1,3,5,7,9,11,13,15].lenSkip**=2
* **RoE.container[1,3,5,7,9,11,13,15].lenContainer**=**28**
* **RoE.container[1,3,5,7,9,11,13,15].flow\_id**=2
* **RoE.container[1,3,5,7,9,11,13,15].ctrl**=0
* **RoE.container[1,3,5,7,9,11,13,15].modulo**=0
* **…**

Editor’s note: Draw example figure here.

#### Use of sequence numbers with RoE pkt\_type 000011b

The sequence number is incremented by one (1) for each sent RoE data packet and the sequence number wraps around every 256\*150/**CPRI11.numBasicFramesForRoEPacket** sent packets (e.g. if there are 8 BFs worth of I/Q samples for one AxC per RoE packet the **seqNumMaximum** is 4800). Note that sequence number may be non-zero when RoE header S-flag is set.

Editor’s note: if there is a need to count also radio frames then the size of the seqNumMaximum has to be increased. For example: seqNumManimum = 480000 would wrap after 100 BFNs i.e. have 1 sec worth of sequence number window.

#### Use of timestamp with RoE pkt\_type 000011b

Not defined in this version of the specification.

#### Use of flow\_id with RoE pkt\_type 000011b

Each AxC shall map to **flow\_id** values starting from 1. For example AxC0 maps to **flow\_id** 1. The maximum number of supported concurrent AxCs between two RoE endpoints is therefore 127.

###

### Handling of CPRI Control Words

The “CPRI11” has multiple “control process” mappers to process CPRI Hyper Frame control words. Table 5 lists the control process mappers, their respective naming/variable prefixes and which sub-channels they (typically) concern. The mapper definitions and variables have the common prefix **CPRI11.ctrl**. Unless otherwise stated all variables are assumed to be prefixed with **CPRI11**.

The **CPRI11.ctrl.cw\_size** defines the size of the CPRI control word (Tcw) in octets i.e. Tcw/8 for all control process mappers. The value shall be between 1 and 16. Note that in cases where the CPRI control word size (Tcw) is less that the CPRI word size (T) the mapper shall handle required padding or skipping unused bits implicitly. Unused bits are intrepreted as zero (0) bits.

Table 5 Control Process mappers for CPRI control words

|  |  |  |
| --- | --- | --- |
| **Mapper description** | **CPRI control words** | **Mapper prefix** |
| Synchronization and L1 protocol fields | Sub-channels 0 & 2 | CPRI11.ctrl.sync\_l1 |
| AxC\_ctrl and VSD data | Sub-channels 4->7 & 16->(p-1) | CPRI11.ctrl.axc\_vsd |
| Slow C&M channel | Sub-channel 1 | CPRI11.ctrl.slow |
| Fast C&M channel | Sub-channels p->63 | CPRI11.ctrl.fast |

The control words the “control process” mappers operate upon is structured in the same way as CPRI structures it. Areas not extracted or transported to/from the CPRI stream are assumed to be all zero (0). Figure 9 illustrates the known CPRI Hyper Frame control words construction. From the processing point of view control words are always processed in the order they arrive i.e., the first element is the control word 0 (Ns=Xs=0), the second element is the control word 1 (Ns=1, Xs=0), etc. The control process mappers are applied to the control words as they arrive and then stored into the memory as a dense array for possible second stage processing (such as placing data into RoE data packet payload field).



Figure 9 CPRI Hyper Frame worth of Control Words

The control process mappers for Slow C&M and Fast C&M channels, and Ctrl\_AxC and VSD blocks use the following common **container** construction:

**{**

 **.cw\_sel**

 **.cw\_start**

 **.cw\_num**

**.flow\_id**

**.filter\_mode**

**.hfn\_modulo**

**.hfn\_index**

**.offset**

**.value**

**.mask**

**}**

There can be, depending on the case, one or more containers per control process mapper. Each control process mapper for Slow C&M, Fast C&M, Ctrl\_AxC and VSD have the following common construction:

**{**

 **.container[0..n]**

**}**

The **.cw\_sel** is a four bit mask for selecting sub-channel words (Xs) to extract. The selected sub-channel words equal to “logical or” of corresponding sub-channel masks. See Table 6 for the mask values.

Table 6 Sub-channel word bit masks

|  |  |
| --- | --- |
| **Binary mask** | **Sub-channel word (Xs index)** |
| 0000b | sub-channel processing disabled – container not in use. |
| 0001b | Xs = 0 |
| 0010b | Xs = 1 |
| 0100b | Xs = 2 |
| 1000b | Xs = 3 |

The number of containers depend on the used control word mapper. Both the **CPRI11.ctrl.slow** and **CPRI11.ctrl.fast** have only one container e.g., **CPRI11.ctrl.fast.container**. The **CPRI11.ctrl.axc\_vsd** has an array of eight (8) containers i.e., **CPRI11.ctrl.axc\_vsd[0..7]**. The combination of **.cw\_sel** and multiple containers allow handling of arbitrary areas within CPRI control words as illustrated in Figure 9.

The **.cw\_start** defines the start of sub-channel (Ns) and has the valid range from 0 to 63. The **.cw\_size** defines the number of extracted sub-challes and the valid range is from 1 to 64. The mask defined by **.cw\_sel** applies to the “area” defined by the **.cw\_start** and **.cw\_num**, The specific mapper definitions may have more specific restriction to the ranges. If there are multiple containers the areas they define shall not overlap each other.

The **.flow\_id** maps to RoE header **flow\_id** field.

The **.filter\_mode** specifically concerns the control process mapper when it has to generate a RoE packet. See Table 7 for further details.

Table 7 Hyper Frame filtering options

|  |  |
| --- | --- |
| **.filter\_mode** | **Description** |
| 0 | Filtering is disabled. RoE packet is generated on every Hyper Frame. |
| 1 | Non-zero content i.e., the extracted content has non-zero values. |
| 2 | Periodic generation according to modulo logic. |
| 3 | Extracted content has changed since the previously generated RoE packet. |
| 4 | Pattern match. |

The **.hfn\_modulo** operates on the entire extracted (Hyper Frame size) CPRI control words area and combined with **.hfn\_index** allows selecting specific Hyper Frames for further processing. The **.hfn\_modulo** has the valid range from 1 to 150. The **.hfn\_index** has the valid range from 0 to 149. The modulo logic is synchronized with the current Hyper Frame Number (HFN). For example **current\_HFN**%**.hfn\_modulo** would select Hyper Frame control words for control process mapper processing when the reminder of the modulo operation equals to **.hfn\_index**.

The **.offset**, **.value** and **.mask** concern the pattern match **.filter\_mode**. The **.offset** has valid range from 0 to 4095. Both **.value** and **.mask** are 32 bit values. The pattern match is applied to the Hyper Frame after applying other parser options such as **.cw\_sel**, .**cw\_start** and **.cw\_size**. The offset is relative to the extracted (dense array of) control words. The match is true when the 32 bit value extracted from the memory equals to the **.value** after applying a “logical and” to it using the **.mask**.

Whenever parameter configurations refer to a value “**p**” that refers to the pointer in CPRI control words (see Figure 9) indicating the start of Fast C&M channel sub-channels.

#### Synchronization and L1 protocol fields

CPRI Synchronization and L1 protocol fields are not transported over the RoE. They are only provided for the local use by the “control process”. The following information is supported (using CPRI control word notation):

* HFN (Hyperframe number) at location Z.64.0 i.e., control word 64.
* BFN (CPRI 10ms frame number) at locations Z.128.0 and Z.192.0 i.e., control words 128 and 192.
* Protocol version at location Z.2.0 i.e., control word 2.
* HDLC bit rate at location Z.66.0 i.e., control word 66.
* L1 signaling at location Z.130.0 i.e., control word 130.
* Ethernet pointer at location Z.194.0 i.e., control word 194.

#### pkt\_type 000100b (data packet for Slow C&M channel)

The Slow C&M channel shall have the following parameterization:

* **CPRI11.ctrl.slow.container.cw\_start**=1
* **CPRI11.ctrl.slow.container.cw\_num**=1
* **CPRI11.ctrl.slow.container.flow\_id**=0

The Slow C&M channel should have the following parameterization:

* **CPRI11.ctrl.slow.container.cw\_sel**=1111b
* **CPRI11.ctrl.slow.container.filter\_mode**=0

The rest of the parameters depend on the deployment.

The Slow C&M channel content is transported over RoE data packets. The payload is described as follows and the parameters apply to control words as available for the “control process”:

* **RoE.numSegments**=1
* **RoE.segment.lenSkip=**0
* **RoE.segment.lenSegment=**0
* **RoE.numContainer**=1
* **RoE.container[0].lenSkip**=0
* **RoE.container[0].lenContainer**=**CPRI11.ctrl\_cw\_size**\* \*num\_of\_1s\_in\_**CPRI11.ctrl.slow.container.cw\_sel**
* **RoE.container[0].flow\_id**=**CPRI11.ctrl.slow.container.flow\_id**
* **RoE.container[0].ctrl**=0
* **RoE.container[0].modulo**=0
* **seqNumMinimum**=0
* **seqNumMaximum**=150
* **seqNumIncrement**=1

Editor’s note: if there is a need to count also radio frames then the size of the seqNumMaximum has to be increased. For example: seqNumManimum = 15000 would wrap after 100 BFNs i.e. have 1 sec worth of sequence number window.

#### Pkt\_type 000000b subtype 00000100b (Ctrl\_AxC and VSD data)

Figure 10 illustrates the RoE control packet format for transporting either Ctrl\_AxC or VSD data. The control process mapper does not differentiate the payload content between the two. The mapper knows whether the payload belongs to Ctrl\_AxC or to VSD based on the **.axc\_vsd.container[n].cw\_start** and **.axc\_vsd.container[n].cw\_num** definitions. This implies both ends has to know which mapped setting was used to construct the packet. The RoE header **flow\_id** is used to index the container definition (i.e., **flow\_id** values from 1 to 8).



Figure 10 Control Packet format for transporting Ctrl\_AxC and VSD data

In a case of Ctrl\_AxC data transport the following parameterization shall be used:

* **CPRI11.ctrl.axc\_vsd.container.cw\_start**= value between 4 and 7
* **CPRI11.ctrl.axc\_vsd.container.cw\_num**= value between 1 and 4 so that **.cw\_start**+**.cw\_num** <= 8
* **CPRI11.ctrl.axc\_vsd.flow\_id**=index to container definition

In a case of VSD data transport the following parameterization shall be used:

* **CPRI11.ctrl.axc\_vsd.container.cw\_start**=value between 16 and **p** (see Figure 9)
* **CPRI11.ctrl.axc\_vsd.container.cw\_num**=value between 1 and **.cw\_start**-**p** so that **.cw\_start**+**.cw\_num** <= 8
* **CPRI11.ctrl.axc\_vsd.flow\_id**=index to container definition

The Ctrl\_AxC and VSD data transport should have the following parameterization:

* **CPRI11.ctrl. axc\_vsd.container.cw\_sel**=1111b

#### Fast C&M channel packets

The “control process” shall extract the control words for the Fast C&M channel and create an appropriate Ethernet packet out of those. The Fast C&M channel is sent/received as native Ethernet traffic. The used Physical Coding Sublayer (PCS) shall be according to the underlying link.

The Fast C&M channel shall have the following parameterization:

* **CPRI11.ctrl.fast.container.cw\_start**=**p** (see Figure 9)
* **CPRI11.ctrl.fast.container.cw\_num**=64-**p**

The Fast C&M channel should have the following parameterization:

* **CPRI11.ctrl.fast.container.cw\_sel**=1111b
* **CPRI11.ctrl.fast.container.filter\_mode**=0

The rest of parameters are not needed.

FFS: handling of Ethernet packets with payload less than 64 octets. Proposal to zero pad the packet to minimum required 64 octets.

#### Use of sequence numbers with pkt\_type 000100b

The following shall apply:

* seqNumMinimum=0
* seqNumMaximum=150
* seqNumIncrement=1

Editor’s note: see sub-section 6.3.2.2 editor’s note for larger sequence number.

#### with

The following shall apply:

* **seqNumMinimum**=0
* **seqNumMaximum**=150
* **seqNumIncrement**=1

Editor’s note: see sub-section 6.3.2.2 editor’s note for larger sequence number.

1. Header examples
2. Timestamp calculation example algorithm

The following C-like pseudocode algorithm example illustrates how the RoE header timestamp field is used to calculate:

* a 64 bit presentation time out of the 31 bit onwire timestamp value (ptime\_2\_tstamp);
* a 31 bit onwire timestamp value out of the 64 bit presentation time (tstamp\_2\_ptime).

The calculation of the 64 bit presentation time out of the 31 bit onwire timestamp value also requires the knowledge of the local time. Both the RoE packet sender and the receiver shall have their clocks synchronized and share the same view of time.

#define TWINDOWMASK 0x00003fffffffffffLL // tstampWindowMask

#define TTSTAMPMASK 0x00007fffffffffffLL // tstampTstapMask

#define TWINDOWSIZE 0x0000400000000000LL // tstampWindowSize

**// 64 bit presentation time to 31 bit onwire timestamp value.**

**// The input ptime is a 64 bit Time of Day in nanoseconds**

uint64\_t ptime\_2\_tstamp( uint64\_t ptime ) {

 // Actual window is less what we send over the wire

 return ptime & TTSTAMPMASK;

}

**// 31 bit onwire timestamp value to 64 bit presentation time.**

**// The input local\_time is a 64 bit Time of Day in nanoseconds**

uint64\_t tstamp\_2\_ptime( uint64\_t local\_time, uint64\_t tstamp ) {

 // mask out window size of bits of the local time

 uint64\_t ptime = local\_time & ~TWINDOWMASK;

 if ((local\_time ^ tstamp) & TWINDOWSIZE) {

 // Window under/overflow taking place.. flip the

 // timestamp MBS to take that into account.

 tstamp ^= (local\_time & TWINDOWSIZE);

 } else {

 // Timestamp and local time in the same window

 // "half". Just take window worth of bits.

 tstamp &= TWINDOWMASK;

 }

 // Adjust local time with timestamp

 return ptime+tstamp;

}

# Bibliography (informative)

Tbd.

1. The Institute of Electrical and Electronics Engineers, Inc.

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