Transport 5G Considerations

IEEE 5G Summit

.

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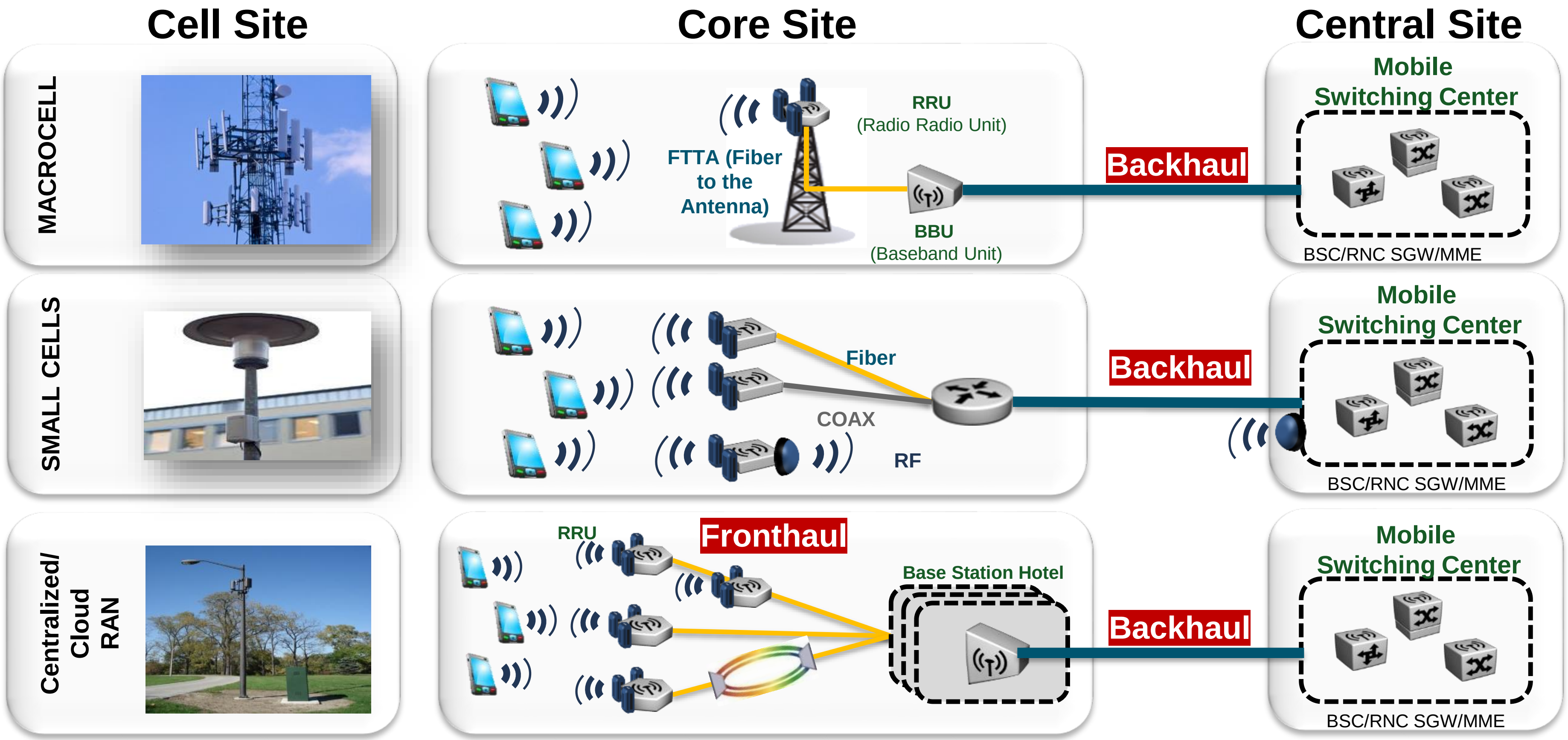
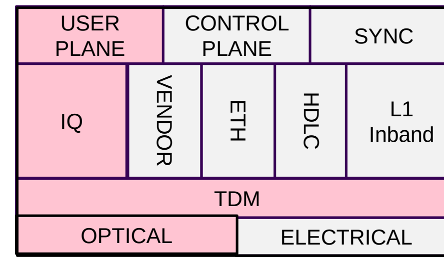
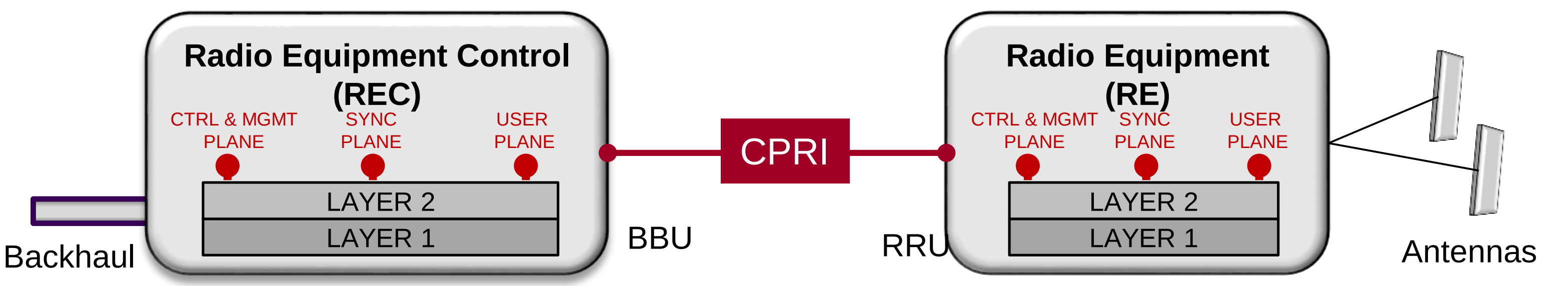
Definition Backhaul, Fronthaul, CRAN



CPRI Technology

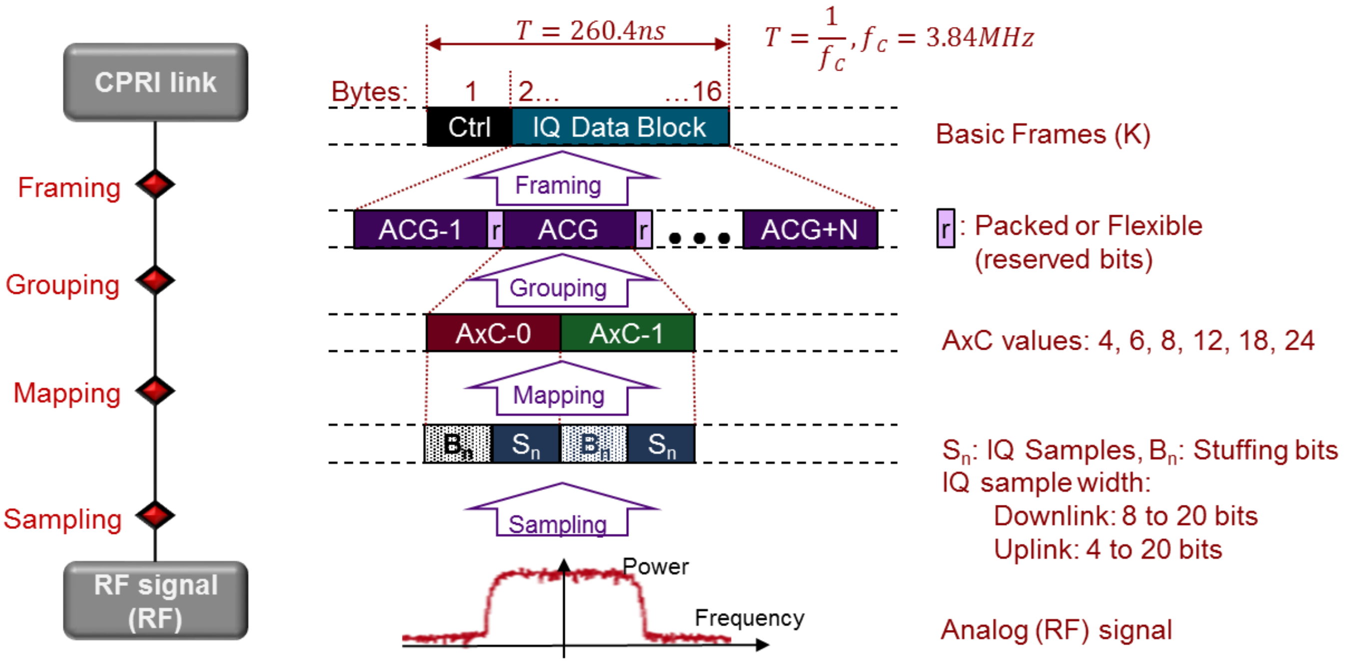
- Layer 1: Physical Transport (optical transmission over fiber)
- Layer 2: multiple components
  - L1 in-band information helpful in troubleshooting L1 related issues
  - IQ data, actual RF data carried, which gives insight into RF related issues like interference.
  - Vendor specific data, etc.





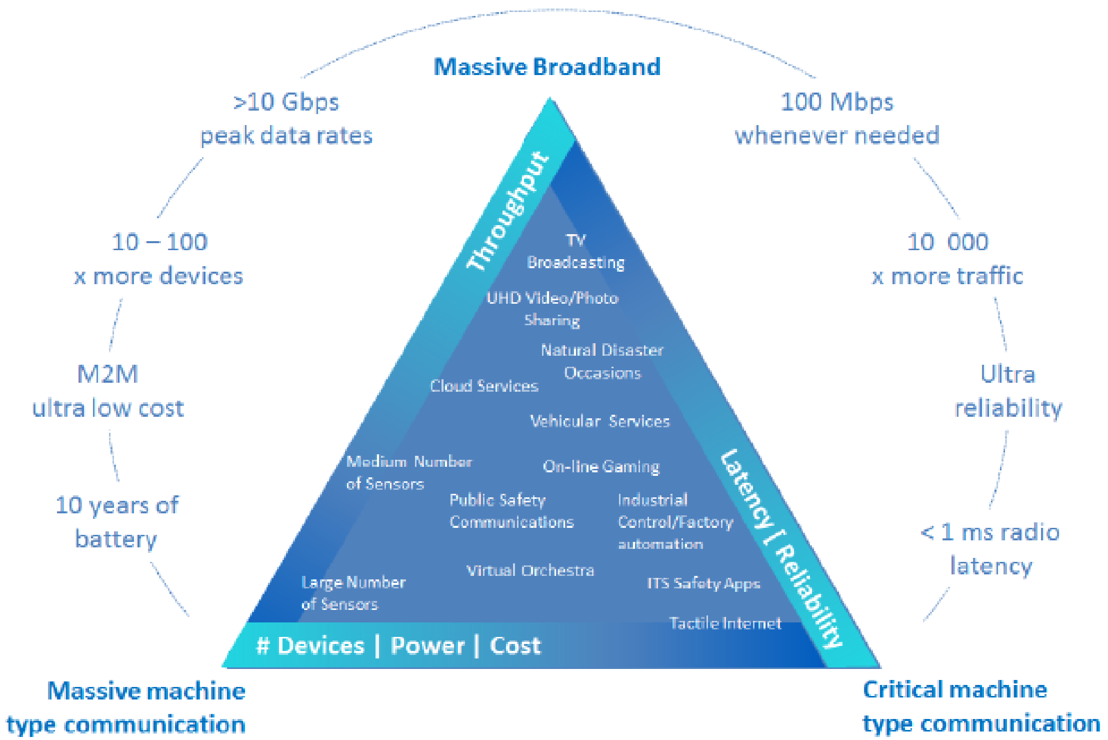
User Plane – CPRI Frame Structure

- An Antenna-Carrier (AxC): IQ data of either Rx or Tx of one carrier at one antenna element.



5G Requirements

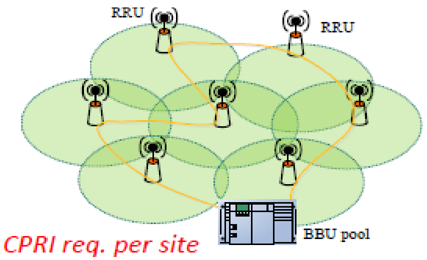
- Diverse set of new applications demand new crosshaul architectures
- Drastic rise of bandwidth requirements for massive broadband
- Ultra low latency requirements for critical machine type communication (MTC)



Source: 5G Crosshaul

5G Challenges for Fronthaul

- CPRI Technology can be scaled up to a certain level with WDM and OTN
- Massive MIMO and 5G bandwidth requirements cannot be met with CPRI
- mMIMO with 64 Tx/Rx -> Bandwidth: 100Gbps+



Challenge by fronthaul b/w BBU and RRU

- Data rate b/w BBU and RRU using CPRI is as high as 9.83Gbps for 8-antenna TD-LTE, requiring 4 fibers for each carrier with 6G SFP

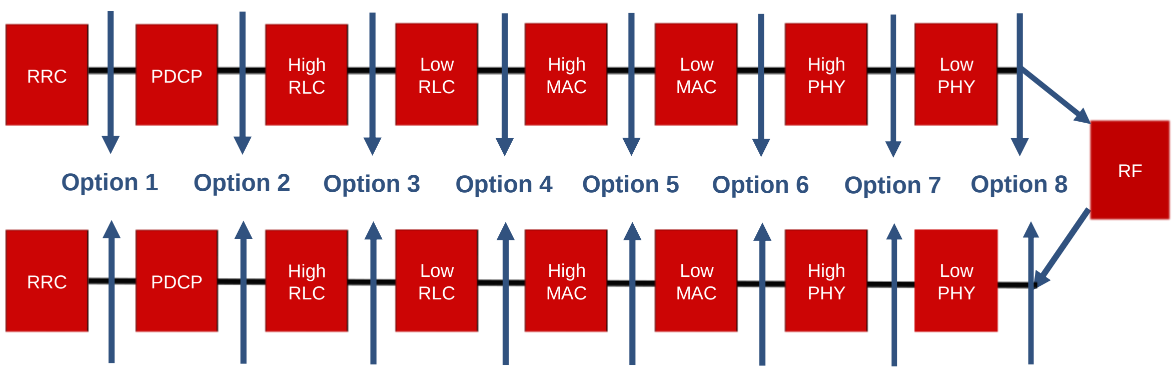
CPRI req. per site

	Typical configuration	# of carriers	CPRI data rate per carrier	Total CPRI data rate before compression
GSM	3 RRU, S6/6/6	36	40Mbps	1.44Gbps
TD-S	3 RRU, S3/3/3	9	300Mbps	2.7Gbps
Current TD-LTE	3 RRU, S1/1/1	3	10Gbps	30Gbps
Medium term TD-LTE	S2/2/2	6	10Gbps	60Gbps
In addition, CPRI has critical requirements on synchronization and latency.				

Source: China Mobile

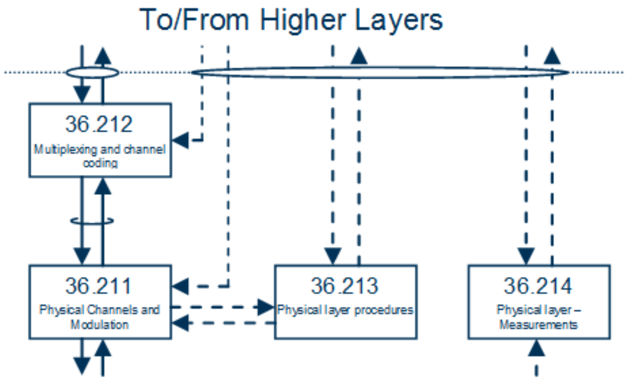
Functional Split Options

- Various functional splits offer options for different use cases
- Option 8: CPRI, extremely bandwidth and latency demanding
- High order options: much lower bandwidth and latency requirements
- Lower order options: provide joint coordination/scheduling for advanced mobility applications



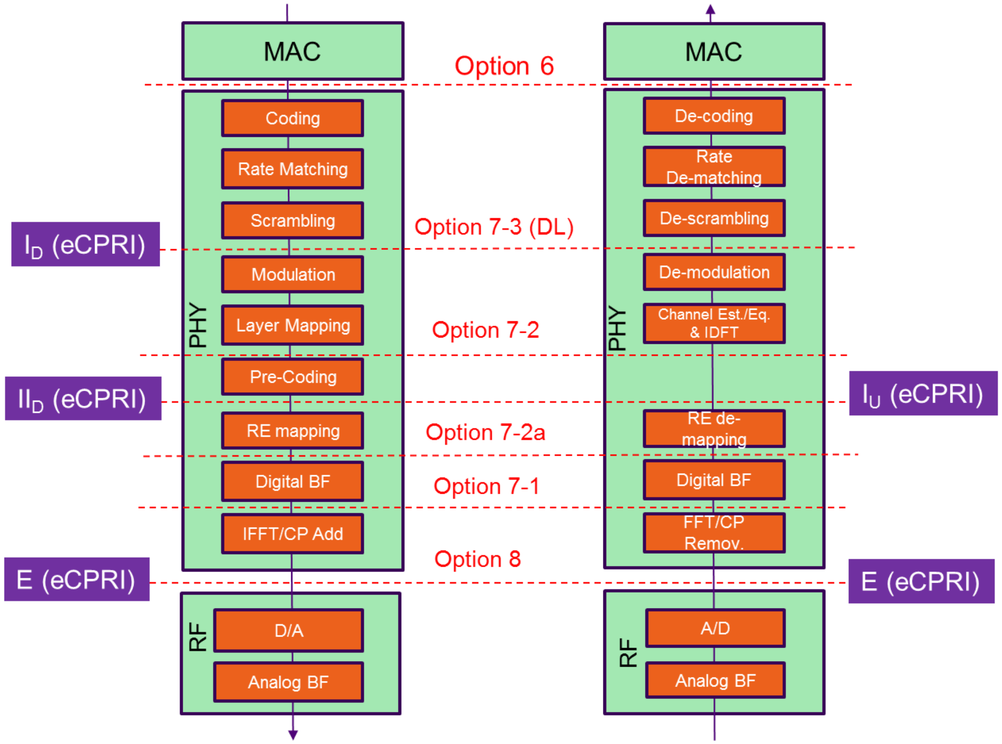
Radio Layer Functions

- RRC (3gpp TS 36.331/38.331)
  - Radio Resource Control
  - Broadcast of general control info, Ue notification on terminating a call
- PDCP (3gpp TS 36.323/38.323)
  - Packet Data Convergence Protocol
  - Data transfer, header compression, ciphering, integrity protection
- RLC (3gpp TS 36.322/38.322)
  - Radio Link Control
  - Data transfer UM, AM, TM
  - ARQ Error Correction
  - Re-segmentation & reassembly
- MAC (3gpp TS 36.321/38.321)
  - Media Access Control
  - Data transfer, radio resource allocation, HARQ, mapping of logical and transport channels
- PHY (3gpp TS 36.2xx/38.2xx)
  - Physical layer

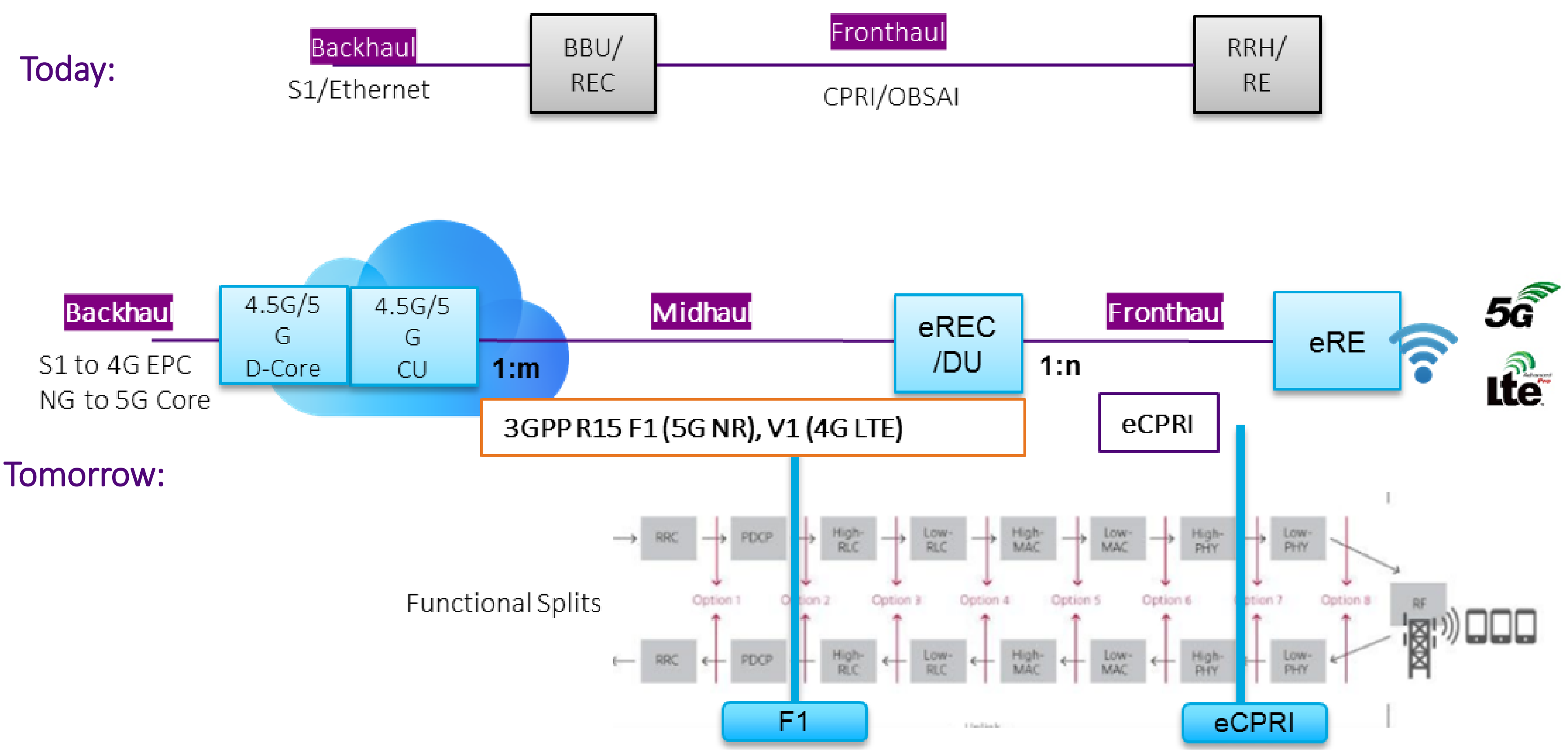


PHY Split

- Option 7-3 has the lowest BW requirements
- Option 7-1: simple DU design, joint equalization
- eCPRI specification does not include C&M, OAM, and Sync services



xHAUL Evolution: Migration for BOTH 4.5G and 5G



Functional Split

- eCPRI doesn't mandate, but recommends split options I_U, II_D/I_D

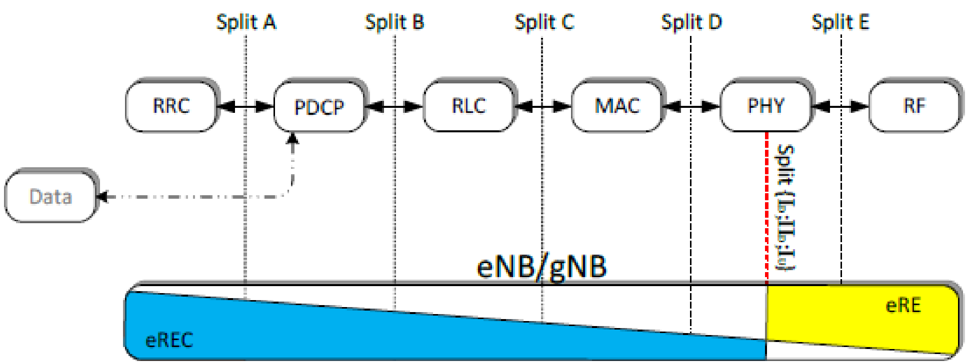
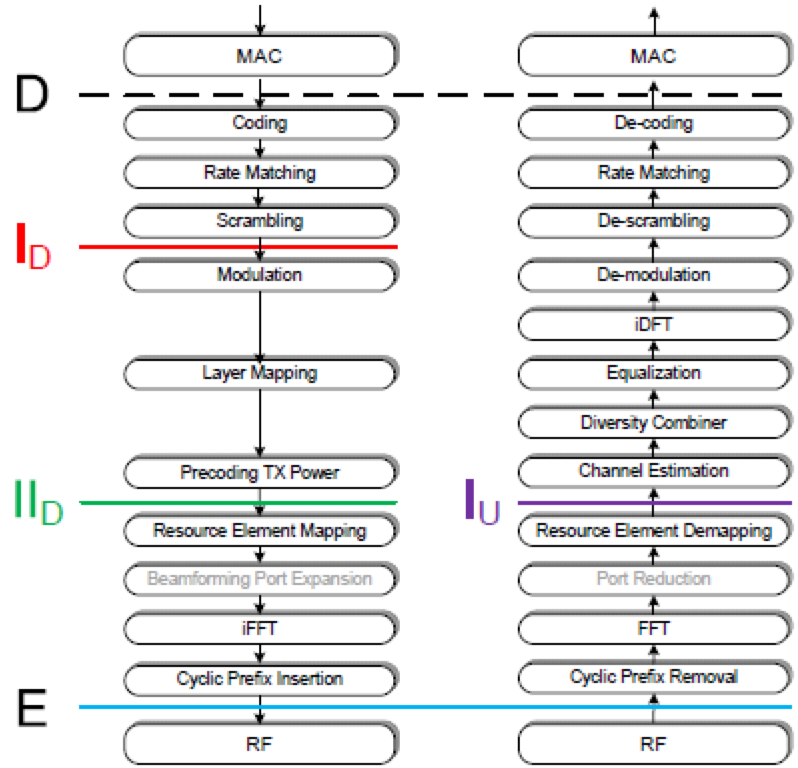


Figure 5: Functional decomposition on RAN layer level



CPRI
Common Public Radio Interface

Physical layer

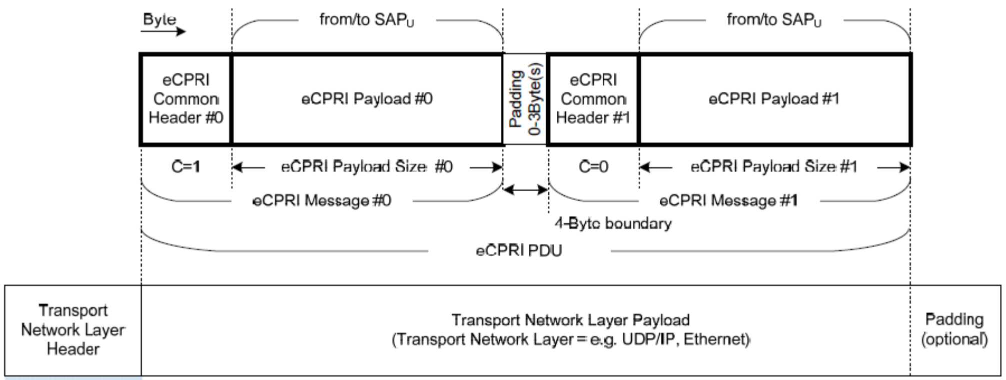
- eCPRI does not mandate any physical layer
- Ethernet PHY and OTN can be valid options
- Most volumes are expected to be Ethernet
- eCPRI physical line rates from 10G to 100G
- Most of the volumes are expected to be 10G initially,
- 25/40GE starting to show up in vendor and SP designs
- 100GE expensive for a radio interface at this time
- Transport SLA's are stringent, for example delay <75us

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

Message Format and Message Types

- eCPRI provides for different message formats
- IQ data format depends on split option:
  - Split E: Time Domain IQ
  - Split I_U, I_D: Frequency Domain IQ
- Split E allows spectrum analysis, but requires much higher BW (>100G)
- Split I_U, I_D requires much less BW, but does not permit spectrum analysis



Message Type #	Name
0	IQ Data
1	Bit Sequence
2	Real-Time Control Data
3	Generic Data Transfer
4	Remote Memory Access
5	One-way Delay Measurement
6	Remote Reset
7	Event Indication
8 – 63	Reserved
64 – 255	Vendor Specific

eCPRI Transport Requirements

User and Control Plane

Table 1 Split E and splits I_D, II_D, I_U requirements

CoS Name	Example use	One way maximum packet delay	One-way Packet Loss Ratio
High	User Plane	100 µs	10^{-7}
Medium	User Plane (slow), C&M Plane (fast)	1 ms	10^{-7}
Low	C&M Plane	100 ms	10^{-6}

Synchronization Plane

Category (note 1)	Time error requirements at UNI, |TE|			Typical applications and time alignment error (TAE) requirements at antenna ports of eREs (for information)	
	Case 1 (note 2)		Case 2 (note 3)	Typical applications	TAE
	Case 1.1 (note 4)	Case 1.2 (note 5)			
A+	N.A.	N.A.	20 ns (relative)	MIMO or TX diversity transmissions, at each carrier frequency	65 ns (note 6)
A	N.A.	60 ns (relative) (note 7)	70 ns (relative)	Intra-band contiguous carrier aggregation, with or without MIMO or TX diversity	130 ns (note 6)
B	100ns (relative) (note 7)	190 ns (relative) (note 7)	200 ns (relative)	Intra-band non-contiguous carrier aggregation, with or without MIMO or TX diversity, and Inter-band carrier aggregation, with or without MIMO or TX diversity	260 ns (note 6)
C (note 8)	1100 ns (absolute) (note 9)		1100 ns (absolute) (note 9)	3GPP LTE TDD	3 us (note 10)

802.1 CM – Timing-Sensitive Networking for Fronthaul

- Requirements for latency, frame loss ratio, and jitter
- Class 1: functional split option 8 (CPRI)
- Class 2: functional split option 7 (eCPRI)
- Latency depending on the type of data, and wireless service

- IQ
  - Latency: 100 µs
  - Frame Loss Ratio: 10^{-7}
- C&M
  - Latency: N/A
  - Frame Loss Ratio: 10^{-6}

- Synchronization
  - Category A+ (Optional)
    - max|TE| ≤ 10 ns [MIMO, transmit diversity]
  - Category A (Mandatory)
    - max|TE| ≤ 45 ns [intra-band contiguous carrier aggregation]
  - Category (Mandatory)
    - max|TE| ≤ 110 ns [intra-band non-contiguous and inter-band carrier aggregation]
  - Category C (Mandatory)
    - max|TE| ≤ 1.36 µs [TDD]

802.1 CM – TSN Profiles

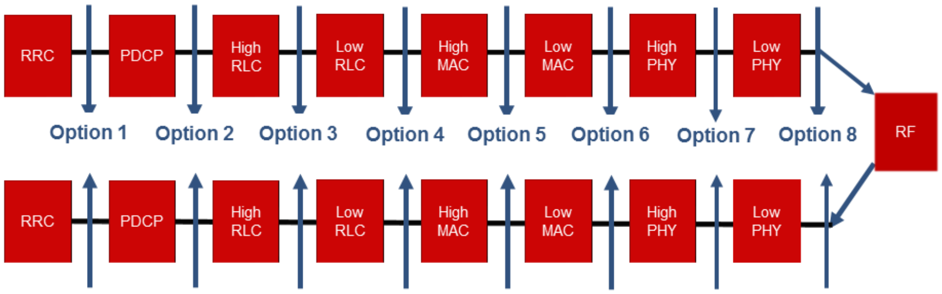
- Profile A and B apply to both class 1 and 2
- Class 1 and 2 User Plane (UP) data treated as CBR
- Solutions for synchronization requirements available according to the category.

- Profile A
  - Strict Priority Queue
  - Frame Size: 1522 with 802.1Q C-VLAN tag
  - Traffic Classes
    - IQ: Highest
    - C&M: Lowest

- Profile B
  - Frame Preemption [802.1bu and 802.3br]
  - Frame Size: 1522 with 802.1Q C-VLAN tag
  - Traffic Classes
    - IQ: Express
    - C&M: Pre-emptable

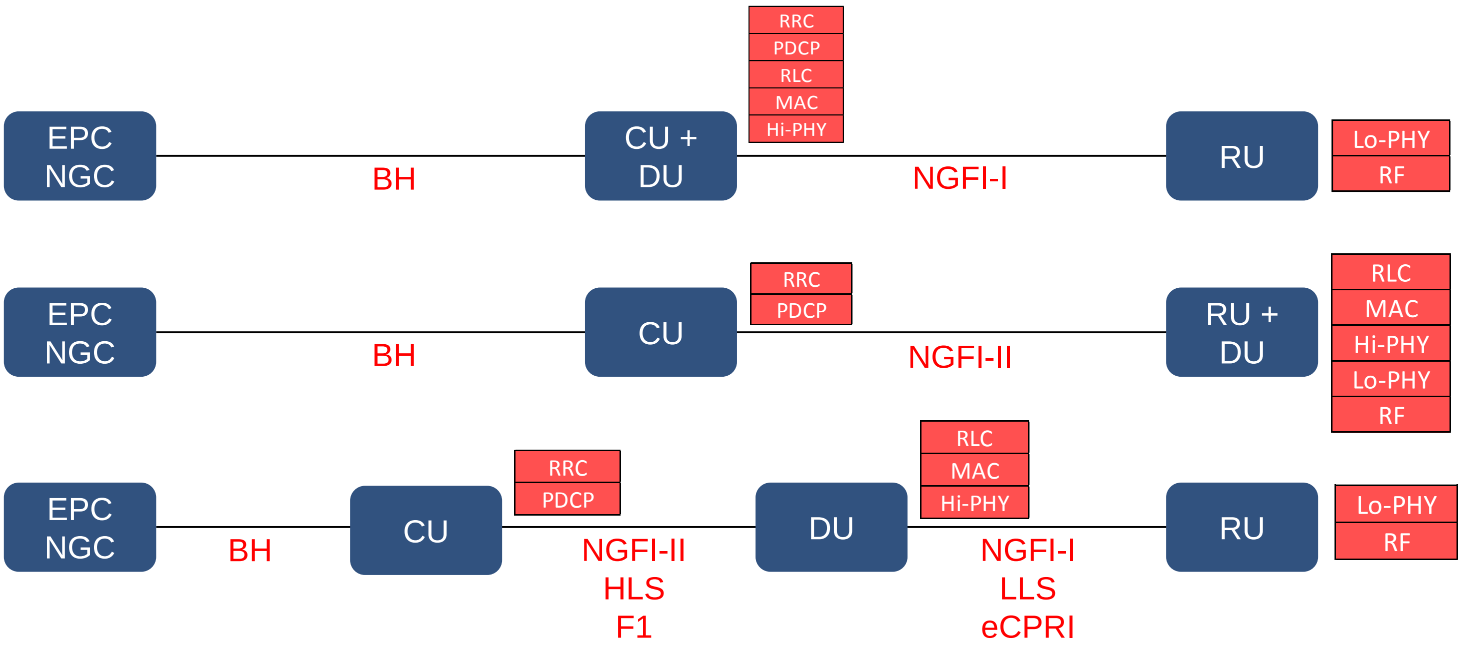
IEEE 1914.1: Packet-based Fronthaul Transport Network

- Architecture for the transport of mobile fronthaul traffic
- Analyzes different functional splits
- Purpose:
  - enables critical 5G use cases such as mMIMO, CoMP, CRAN
  - simplifies network design, lowers costs by leveraging mature Ethernet-based solution
  - Fronthaul architecture: unified management & control, common networking protocol and network elements -> migration to C-RAN/V-RAN
  - Improves bandwidth efficiency, network scalability, sync performance and supports cooperative radio modes



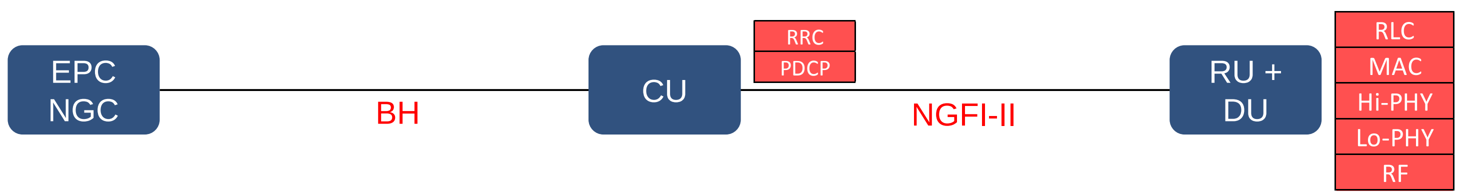
Single and Double Split Network Models

- NGFI I: interfacing low layers of base station processing chain
- NGFI II: interfacing mid/high layers of base station processing chain



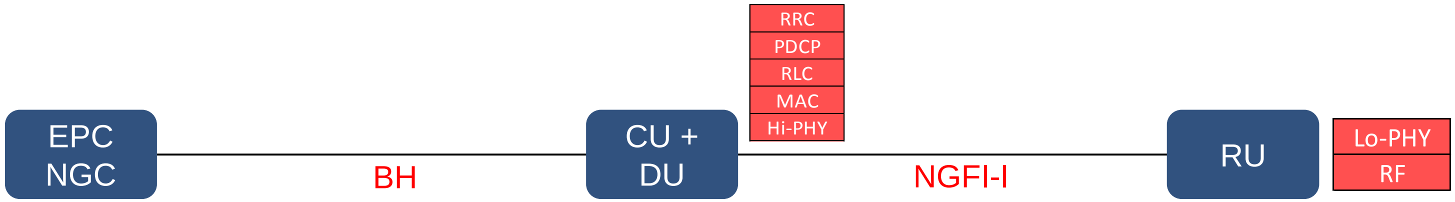
Massive MIMO macro base station

- NGFI II (aka Lower Layer Split or lls, with eCPRI being an example):
  - Optimized for mobility applications requiring coordination of radios
  - Time Alignment Error determined by radio features; e.g. 65ns for MIMO
  - Latency bounded by backhaul: orders of milliseconds
  - Throughput is a factor of cell no, spectral efficiency, available spectrum, and transport overhead



C-RAN based macro model

- NGFI-I (aka Higher Layer Split or hls)
  - Optimized for fixed wireless access with massive bandwidth demand
  - Time Alignment Error determined by radio features; e.g. 65ns for MIMO
  - Latency < 100 microseconds
  - Throughput is a factor of cell no, spatial layers, component carriers, compression ratio, sub-carrier spacing, (I)FFT block size, size samples, and transport overhead



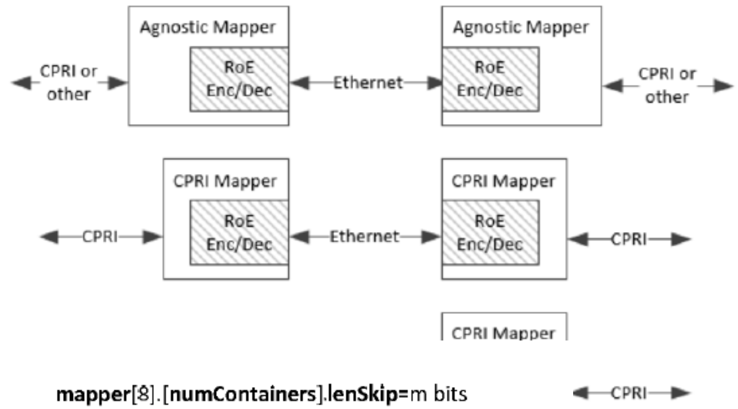
VIAVI

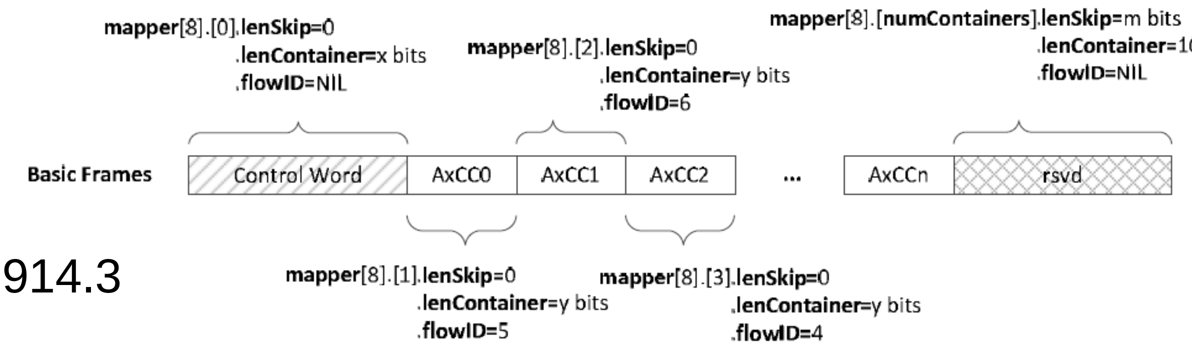
NGFI Transport Classes of Service

	Latency	Priority Level
Data plane:		
Subclass 0 (uRLLC):	50 us	0
Subclass 1 (split options 6-8):	100 us	1
Subclass 2 (split options 2-5):	1 ms	2
Subclass 3 (split options 2-3):	3 ms	3
Subclass 4 (legacy backhaul):	10 ms	4
C&M:		
Low latency RAN CP:	100 us	2
Sync	TBD	TBD
Transport C&M:		
Transport network CP:	1 ms	2

IEEE 1914.3 Radio over Ethernet (RoE)

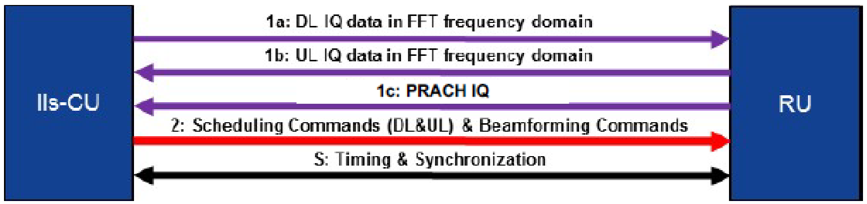
- Scope: encapsulation of digitized IQ into Ethernet
- Purpose:
  - Save cost:
    - Ethernet eco system, scalability 100GE+
    - Converged xhaul
  - Challenge:
    - CPRI delay/jitter SLA's
    - Limited BW gain





IEEE 1914.3

xran: U-/C-/S-Plane



Plane	ID	Name	Contents	Periodicity
U-Plane	1a	DL Frequency Domain IQ Data	DL user data (PDSCH), control channel data (PDCCH, etc.), …	< slot
	1b	UL Frequency Domain IQ Data	UL user data (PUSCH), control channel data (PUCCH, etc.), …	< slot
	1c	PRACH Frequency Domain IQ Data	UL PRACH data	< slot
C-Plane	2	Scheduling Commands & Beamforming Commands	Scheduling information, FFT size, CP length, Subcarrier spacing, UL PRACH scheduling DL and UL Beamforming commands (e.g., beam index) and scheduling	~ slot
S-Plane	S	Timing and Synchronization	SyncE SSM & IEEE 1588 PTP packets	

xran frame formats and priorities

Preamble (8 Bytes)	Destination MAC Address (6 Bytes)	Source MAC Address (6 Bytes)	VLAN Tag (4 Bytes)	Type/Length (Ethertype) (2 Bytes)	Payload (42…1500 Bytes)	FCS (4 Bytes)	IFG (12 Bytes)

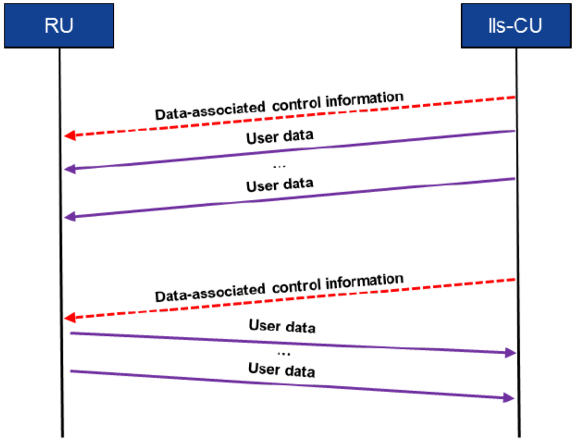
- eCPRI
- UDP (optional)
- IP (optional)
- Eth L2 + VLAN
- Eth L1

Plane	L2 CoS Priority (range 0-7)	L3 DSCP Code
S-Plane	Default: 7 (1)	Not applicable
U-Plane	Default: 7 (2)	EF (Expedited Forwarding)
C-Plane	Default: 7	EF (Expedited Forwarding)
M-Plane	Default: 2	AF2x (Assured Forwarding)
Other traffic	Default: 1	BE (Best Effort)

(1) Applicable if vLAN is applied which will be possible when ITU-T G.8272.2 is adopted in the future.

(2) Use of multiple separate priorities for U-Plane is not precluded e.g., via higher prioritization of some channels (e.g., PRACH), or services (URLLC) over other U-Plane traffic, although the specific mechanism is not yet identified.

xran: Section Types and data exchange ladder



Section Type	Target Scenario	Remarks
0	Unused Resource Blocks or symbols in Downlink or Uplink	Indicates to RU that certain Resource Blocks or symbols will not be used (idle periods, guard periods). Likewise, there are no associated U-Plane messages containing IQ data for this Section Type. The purpose is to inform the RU that transmissions may be halted during the specified idle interval for e.g. power-savings or to provide an interval for calibration.
1	Most DL/UL radio channels	Here "most" refers to channels not requiring time or frequency offsets such as are needed for mixed-numerology channels
2	reserved for future use	
3	PRACH and mixed-numerology channels	Channels requiring time or frequency offsets or different-than-nominal SCS values
4	Reserved for future use	
5	UE scheduling information (UE-ID assignment to section)	Provides scheduling information for UE-IDs
6	Channel information	Sends UE-specific channel information from the lls-CU to the RU
5-255	Reserved for future use	

eCPRI Protocol Stack

- eCPRI only focuses on eCPRI services
- Transport OAM, Synchronization and C&M are outside of eCPRI
- Synchronization can be GPS, or PTP/SyncE
- OAM can use Y.1731

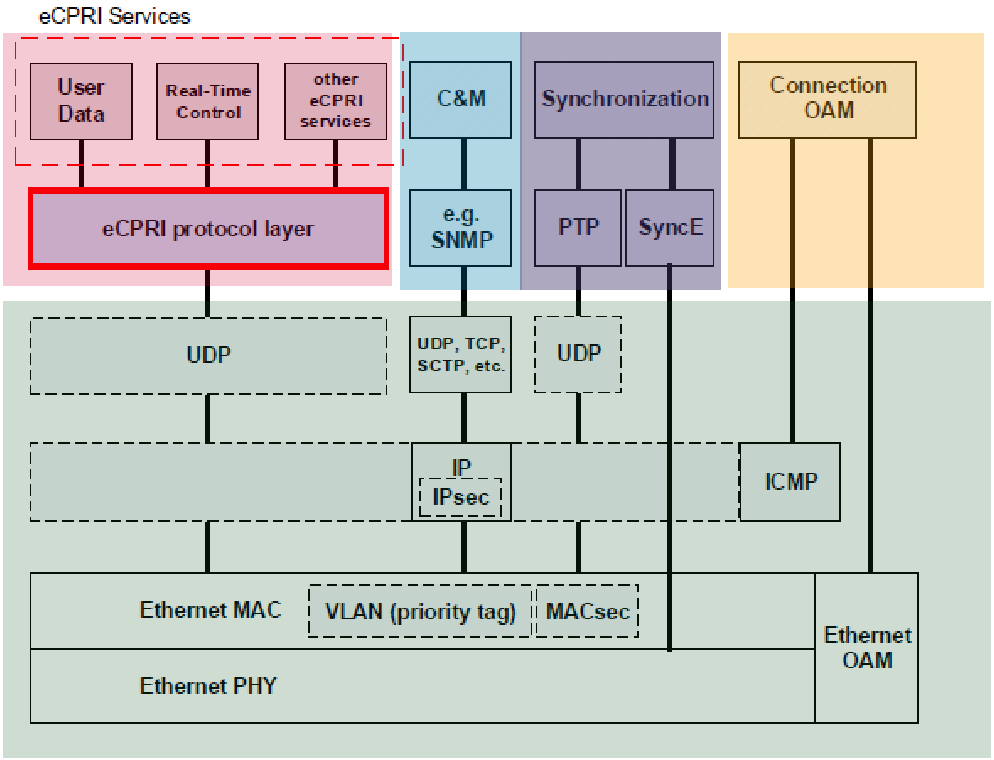
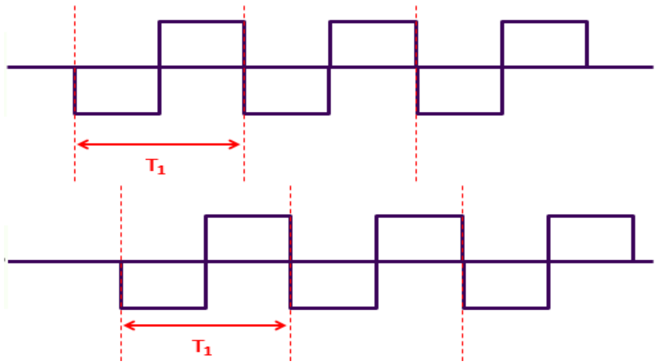


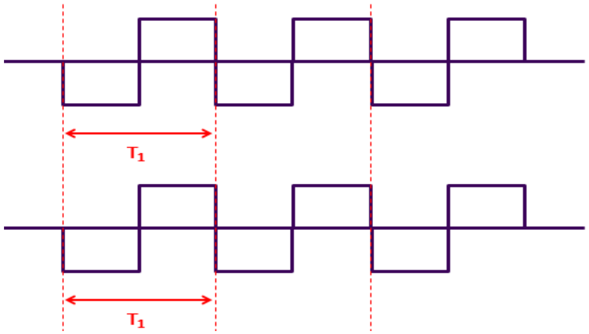
Figure 6: eCPRI protocol stack over IP / Ethernet

Wireless Synchronization Standards

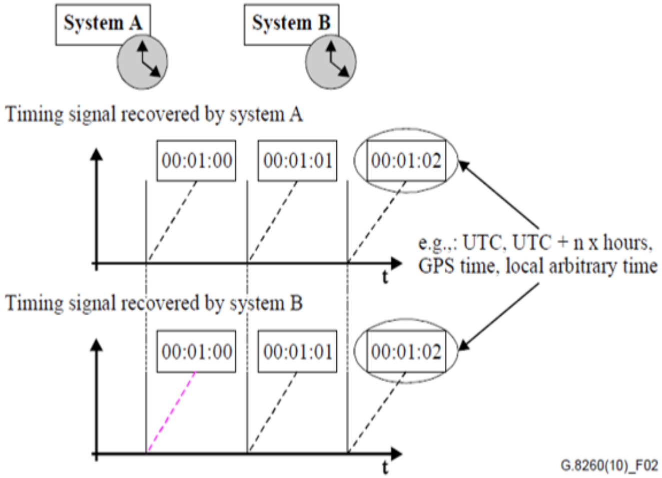
Frequency, Phase, and Time Synchronization



Frequency Synchronization



Phase synchronization

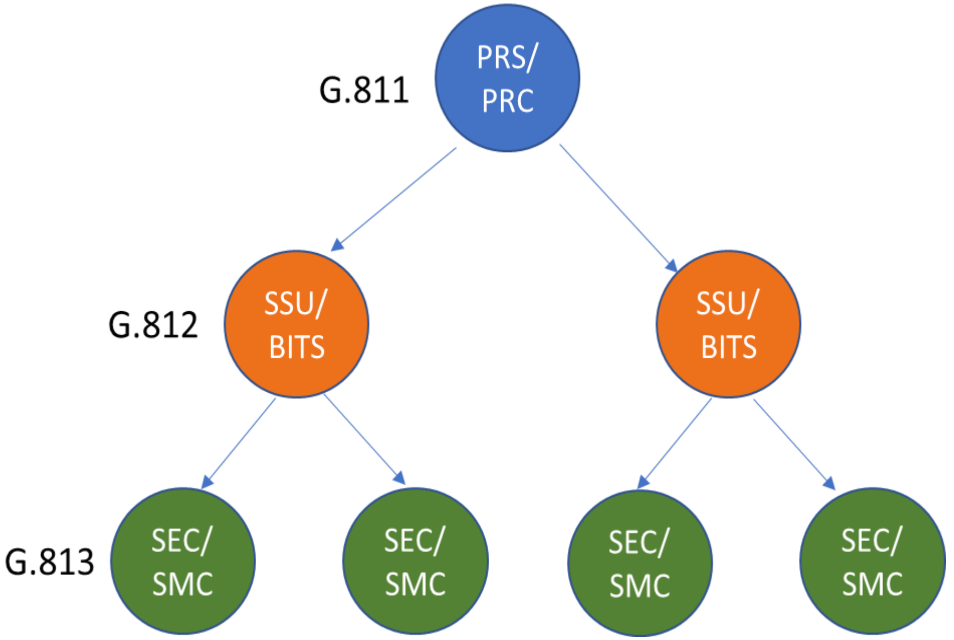


Time Synchronization

Clock Stratums and Hierarchy

- ANSI T1.101 defines five categories of stratum classes
- Primary Reference Source/Clock to be traceable to stratum 1
- Typical networks deploy 1 or multiple PRC/PRS
- Master-Slave hierarchy deliver synchronization quality to downstream nodes
- When connection to upstream nodes lost, clocks transition to holdover mode

Stratum	Accuracy
1	$1x10^{-11}$
2	$1.6x10^{-8}$
3/3E	$4.6x10^{-6}$
4	$32x10^{-6}$



BITS: Building Integrated Time System
SECS: Synchronous Equipment Clock
SMC: SONET Minimum Clock
SSU: Synchronization Supply Unit

Time Error, Jitter and Wander Measurements

- Time Error (TE): difference of time between a clock and a reference clock
- Time Interval Error (TIE): difference of time *interval* between a clock and reference
- Jitter/Wander: short-/long-term variation of significant instance from ideal position
- Jitter measured in Unit Interval
- Wander (nano seconds)
  - Maximum Time Interval Error (MTIE):
  - Time Deviation (TDEV)

Standard	Title
G.810	Definitions and terminology for synchronization networks
G.811	Timing characteristics of Primary Reference Clocks (PRC)
G.812	Timing requirements of slave clocks suitable for use as node clocks in synchronization networks
G.813	Timing characteristics of SDH equipment slave clocks (SEC)
G.823	The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy
G.824	The control of jitter and wander within digital networks which are based on the 1544 kbit/s hierarchy
G.825	The control of jitter and wander within digital networks which are based on the synchronous digital hierarchy (SDH)

Wireless Synchronization Requirements and Methods

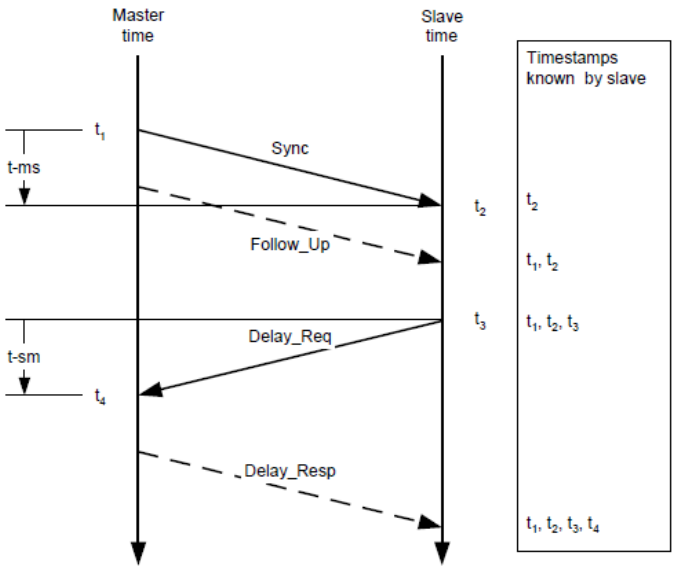
- Wireless standard bodies (such as 3gpp) define sync requirements
- GPS/GNSS primary source of synchronization
- T-carriers/PDH/SONET/SDH/SyncE physical layer network synchronization
- PTP/NTP: packed based network synchronization

Radio technology	Frequency sync	Time/Phase Sync
GSM	50-100 ppb	
CDMA 2000		3-10 us
UMTS/WCDMA-FDD	50-100 ppb	
WCDMA-TDD		3 us
LTE-FDD	50-100 ppb	
LTE-TDD	50-100 ppb	3-10 us

Technology	Frequency	Time/Phase	Network based?
GPS	Y	Y	
PTP/NTP	Y	Y	Packet layer based
SyncE	Y	N	Physical layer based
E1/E3/DS1/DS3, 2/10 MHz BITS/SSU, SONET/SDH	Y	N	Physical layer based

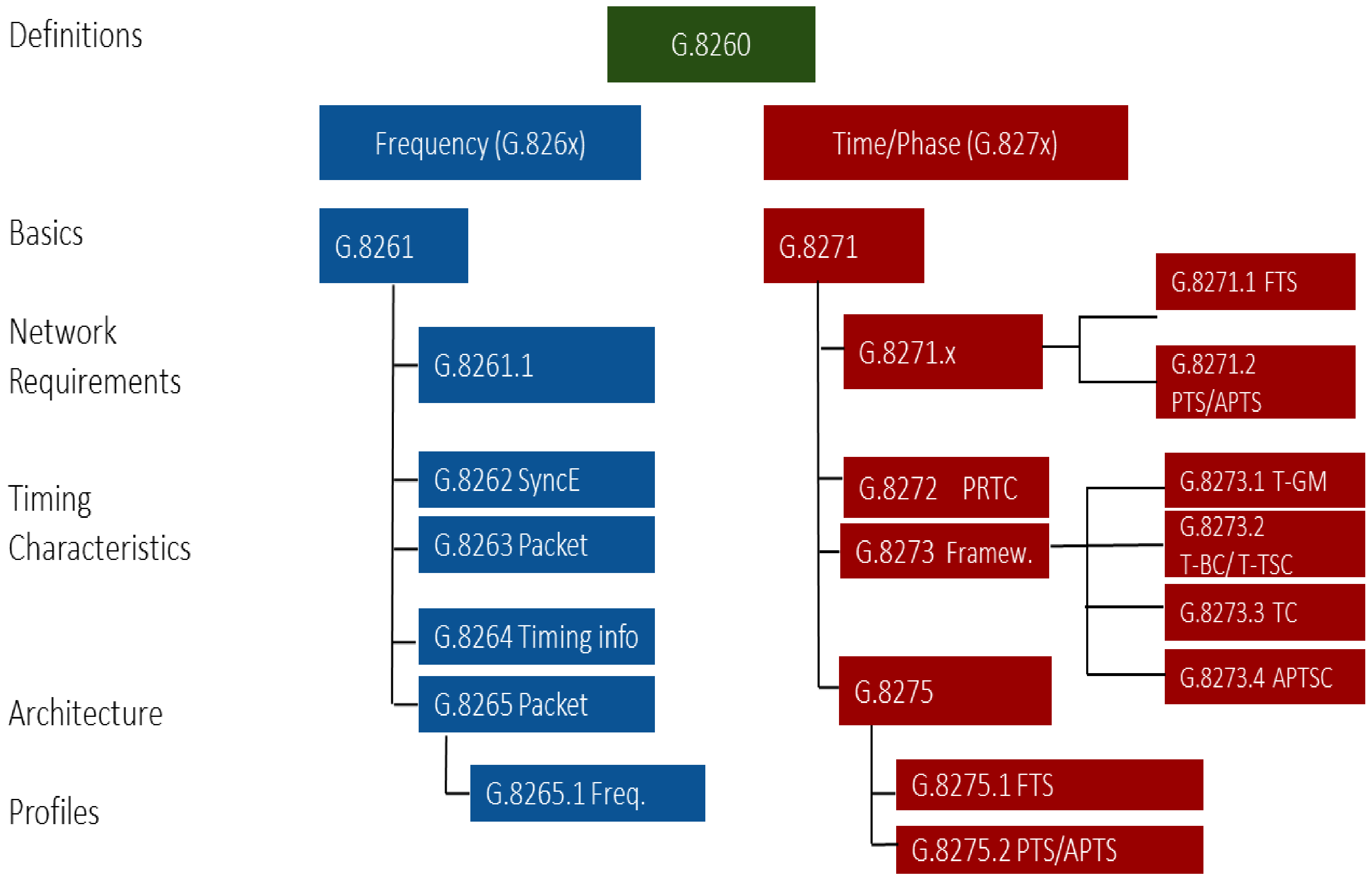
Precision Time Protocol (PTP)/IEEE 1588™-2008

- Enables precision synchronization of clocks based on network communicatio
- Message exchange between master and slave
- Ordinary clocks, boundary clocks, transparent clocks, management nodes
- End-to-End & Peer-to-Peer delay mechanisms
- PTP Profiles: enables interoperability for specific applications



Event messages	General messages	Comments
Sync	Follow_up	
Delay_Req	Delay_Resp	
Pdelay_Req	Pdelay_Resp_Follow_Up	Only in PTP networks using Peer-to-Peer Delay mechanism
Pdelay_Resp		
	Management	
	Announce	
	Signaling	

ITU-T Synchronization Standards



Outlook

- LTE-Advanced, LTE-Advanced Pro will further drive the need for network based timing in wireless networks
- 5G fronthaul (eCPRI) drastically increases the requirements for timing/phase synchronization.
- To compare: Max|TE| limits are:
  - LTE backhaul: 1100 ns
  - eCPRI Category B: < 200 ns (intra-band non-contiguous carrier aggregation)
  - eCPRI category A: < 70 ns (intra-band contiguous carrier aggregation)
  - eCPRI category A+: 20 ns (MIMO or TX diversity)