# Ethernet Fronthaul Considerations


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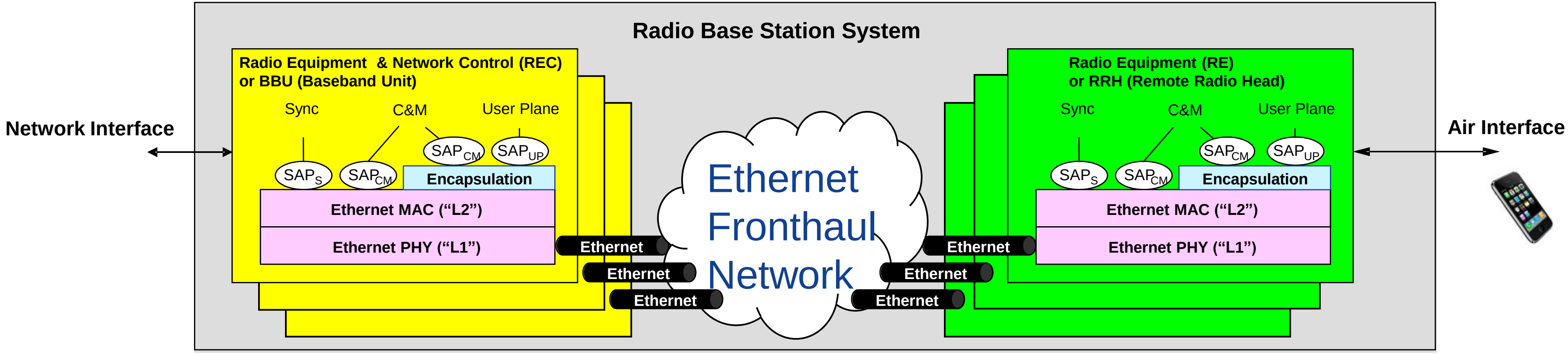
# Motivation / Reasoning to Consider Ethernet for Fronthaul

- Ethernet is a widely adopted & nearly ubiquitous standard technology
- Fronthaul architecture is migrating from traditional RAN with single BBU to single/multiple RRHs to Cloud RAN with centralized multiple BBUs to multiple RRHs
- To utilize the existing Ethernet Standards, Ecosystem, Operator Network Architectures in the networking items





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# CPRI vs. Ethernet

- CPRI
  - Synchronous interface transporting digitized baseband complex in-phase (I) and quadrature (Q) samples over a symmetric serial data link between REC (Radio Equipment Controller) and RE (Radio Equipment) for a radio base station
  - The link is always "On" (never idle) with time division multiplexing the I/Q samples from different antenna-carriers (AxC's) & control information onto a steady data stream
- Ethernet
  - Asynchronous & "bursty" in nature and frames do not arrive synchronously; once a frame is completely processed, no idea when the next frame will arrive ➔ no periodic sync bit or byte
  - With Ethernet, data are transmitted intermittently rather than in a steady data stream
  - Ethernet link can be idle when there is no traffic ➔ with EEE (Energy Efficient Ethernet) taking advantage of the idle period with significant lower power consumption, synchronizing nodes over Ethernet link will be more challenging

# CPRI Fronthaul Requirements

- Symmetric bit rate
- Maximum BER = $10^{-12}$
- To maintain 50 parts per billion (ppb) on the radio interfaces, maximum contribution of the CPRI link to radio frequency error: +/- 2 ppb
    - This error may accumulate in multi-hop configurations
- Long term: RE(s) locked to the REC synchronization
- 3GPP 25.104 and 36.104 specify the minimal Time Alignment Error (TAE) requirements
    - For MIMO or TX diversity transmissions, at each carrier frequency, TAE shall not exceed 65 ns (or ¼ $T_c$)
    - For intra-band contiguous carrier aggregation, with or without MIMO or TX diversity, TAE shall not exceed 130 ns.
    - For intra-band non-contiguous carrier aggregation, with or without MIMO or TX diversity, TAE shall not exceed 260ns
    - For inter-band carrier aggregation, with or without MIMO or TX diversity, TAE shall not exceed 260ns
- CPRI specifies the DL delay accuracy between master and slave port: +/-8.138ns (excluding cable length) to meet the 3GPP minimal TAE requirement ➔ It will be very challenging and even costly for existing Ethernet to meet these stringent requirements



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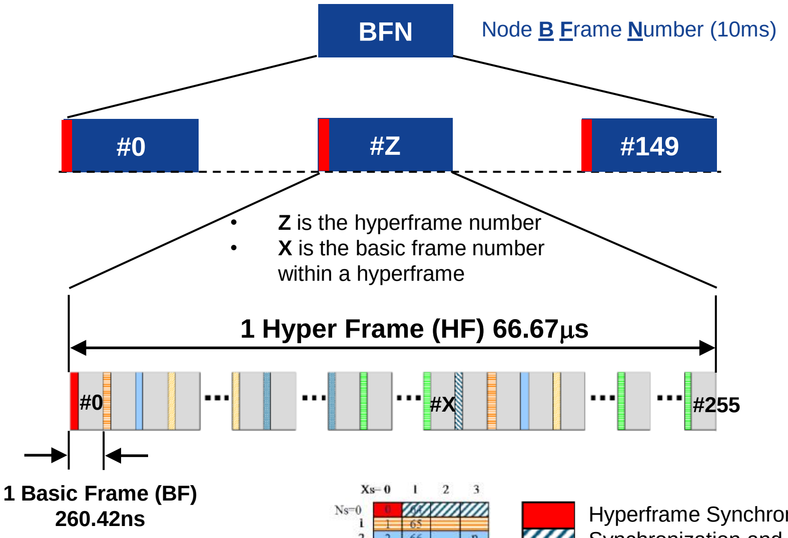
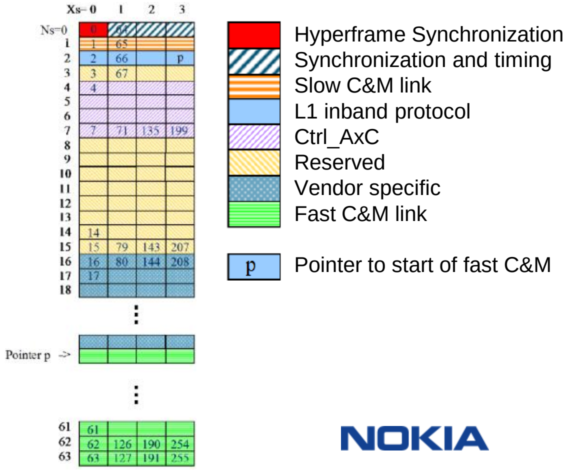
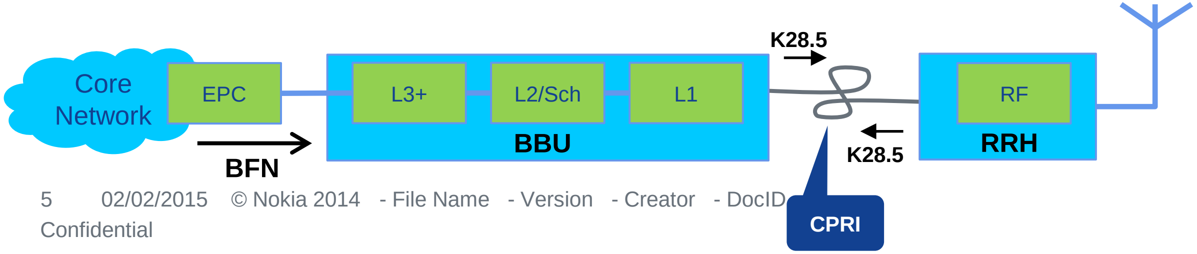
# CPRI Fronthaul Synchronization

- CPRI generates a Basic Frame (BF) for each chip time ($T_C = 1/f_c = 1/3.84$ MHz = 260.42ns) with 1 Control Word (CW) and 15 Words of I/Q sample bits from different AxC's
- 256 BFs form a Hyper Frame (HF) which represents a Symbol (66.67us) and the 1st CW of a HF is used for synchronizing the sender and the receiver of the CPRI bit stream
- 150 HFs form a 10ms Radio Frame, each one denoted by a BFN
- CPRI sync is delivered from BBU to RRH via a 2-way exchange
- At the beginning of each BFN at the BBU in the DL direction, HF and BF counters are set to zero and at the same time CPRI sends the first sync byte K28.5 (assume 8B/10B line coding) of HF #0
- At the RRH side the HF and BF counters are set to zero as well by this 1st sync byte K28.5 from the BBU side and the RRH side also sends its 1st K28.5 back to the BBU side
- BBU and RRH are in sync now!!



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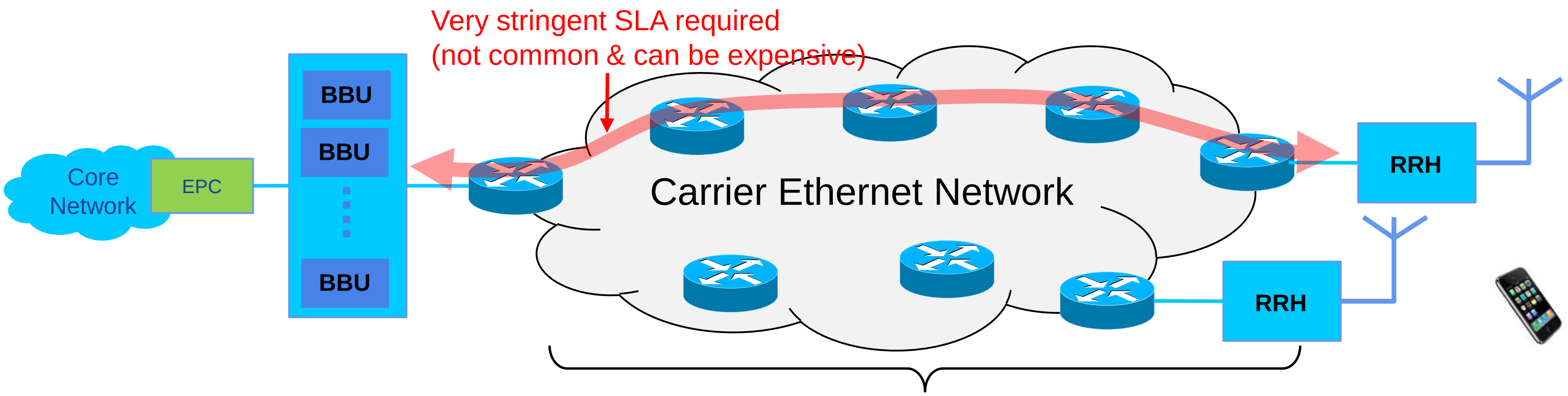
# Ethernet Fronthaul Synchronization

- Precision Time Protocol (PTP) for time/phase/frequency synchronization
  - IEEE1588-2008 over Ethernet
  - IEEE802.1AS – basically a profile of IEEE 1588-2008 with lots of options removed, simplifications




Factors affecting the synchronization levels achievable using PTP

- End-to-end Packet Delay Variation (PDV)
- Switch SyncE capable? (SyncE alone cannot achieve time/phase synchronization)
- Switch local timing source stability (i.e., oscillator quality matters!)
- Switch clock resolution (directly impact timestamp accuracy)
- Switch time awareness (802.1 TSN), e.g., time-sensitive queueing and forwarding, bandwidth and latency reservations so that the time-sensitive queues in the network do not overflow and packets are not dropped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# 6 Active 802.1 TSN Projects Trying to Enhance Ethernet to be Time-Aware

- 802.1ASbt Precise Timing Protocol Gen 2 (gPTP Gen 2)
  - Improve performance & support redundancy & link aggregation & other media
- 802.1Qbu Preemption (collaborating w/ 802.3br Interspersing Express Traffic)
  - Allow time sensitive frames to preempt other frames
- 802.1Qbv Time Aware Shaper (TAS) – Scheduled Traffic
  - Adds windows where non-scheduled traffic is blocked to ensure lowest latency
- 802.1Qca Shortest Path Control & Reservations
  - Uses IS-IS to find all paths through a network – for redundancy
- 802.1CB Frame Replication & Elimination
  - Bridges in a Ring automatically Replicate & Eliminate Duplicate frames
- 802.1Qcc Stream Reservation Protocol Gen 1.1 (SRP Enhancements and Performance Improvements)
  - Bandwidth and latency reservations to avoid time-sensitive queues to overflow and drop packets

# A CPRI-to-Ethernet Mapper?

- Maintain the same end-to-end CPRI service between RE and REC by mapping CPRI into the ubiquitous Ethernet transport
- Operators will need to lease a Carrier Ethernet (CE) network with very demanding SLA that can possibly meet the stringent CPRI requirements
  - Not common and are more expensive
  - Carrier Ethernet service provider may need to upgrade its Ethernet equipments with all the 802.1 TSN features to have a SLA that can possibly meet the stringent CPRI requirements
  - A new CPRI/CE interface and mapping guidelines will be required
- CPRI-to-Ethernet Mapper Location?
  - In the Carrier Ethernet gear?
    - Pros: No impact to RE and REC with CPRI in and CPRI out
    - Cons: More expensive to lease a CPRI-compliant Carrier Ethernet service
  - In the RE and REC?
    - Pros: Ethernet in and Ethernet out in RE and REC
    - Cons: new RE and REC required with potentially significant added cost

 

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# CPRI Requires Significant Transport Resources

- CPRI transports digitized baseband complex in-phase (I) and quadrature (Q) samples over the high speed links between a REC (or BBU) and RE (or RRH)
- 20MHz RF bandwidth requires ~1Gb/s data bandwidth for I/Q data transmission per AxC
  - The I/Q sampling frequency is 30.72MHz and the sampling bit-width is 15 bits for I sample and 15 bits for Q sample. The resulting I/Q sample streaming data rate is then 921.6 Mbps (=30 bits*30.72MHz) per antenna-carrier (AxC). To map to CPRI, need to add a control word (W0) and the streaming data rate is now 16/15*921.6Mbps = 983.04Mbps. 2x2 MIMO will double this to 1966.1Mbps.
- Considering the over sampling in CPRI signal, it is possible to realize I-Q data compression around 50% ratio which can maintain required EVM, latency and other transport performance
- Do we need to send IQ or compressed IQ over CPRI and then over Ethernet? Or, do we bypass CPRI and its overhead?

| Antennas | 2 | 20 | 15 | 10 | 5 | MHz | Bandwidth Ratio |
|---|---|---|---|---|---|---|---|
| Scheme | IQ* | 1966.1 | 1474.6 | 983.1 | 491.5 | Mbps | 100% |
| | IQ with compression | 983.1 | 737.3 | 491.5 | 245.8 | Mbps | 50% |

* Before 8B/10B or 64B/66B line coding overhead

 

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# Some Suggestions

- Before diving into how to map CPRI over Ethernet, maybe we should first study the feasibility, both technically and economically, of transporting CPRI over Ethernet
- Technical Feasibility
  - Can CPRI over Ethernet meet the stringent 3GPP minimal TAE requirement?
  - Do we need dedicated Ethernet link (not shared with other Ethernet access or backhaul)?
- Economical Feasibility
  - Operators willing to pay more to lease a Carrier Ethernet service with very stringent SLA?
  - Who is willing to absorb the cost to provide a CPRI over Ethernet interface, the Carrier Ethernet service provider or the Radio Base Station equipment vendor?
- Other?

  

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