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Wireline Access Network

Synchronous Ethernet (SyncE) Usage for DAA and Mobile X-haul over DOCSIS

Chris Zettinger

Principal Systems Engineer
CommScope

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The Need for Synchronization

- Traditional network synchronization has been based on the accurate distribution of frequency. Wireless networks have evolved to require the distribution of accurate time and phase information.
- There are two basic approaches for distributing synchronization information. The first is to follow a distributed primary reference time clock (PRTC) approach, implementing a global navigation satellite system (GNSS) receiver in the end application, and the second is based on a master-slave hierarchical strategy.
- Master-slave synchronization uses a hierarchy of clocks in which each level of the hierarchy is synchronized with reference to a higher level, the highest level being the Primary Reference Clock (PRC). Clock reference signals are distributed between levels of the hierarchy via a distribution network which may use the facilities of the network. The hierarchical strategy can be used for physical layer frequency distribution as well as higher layer packet-based frequency, phase, and time distribution.

Synchronous Ethernet (SyncE)

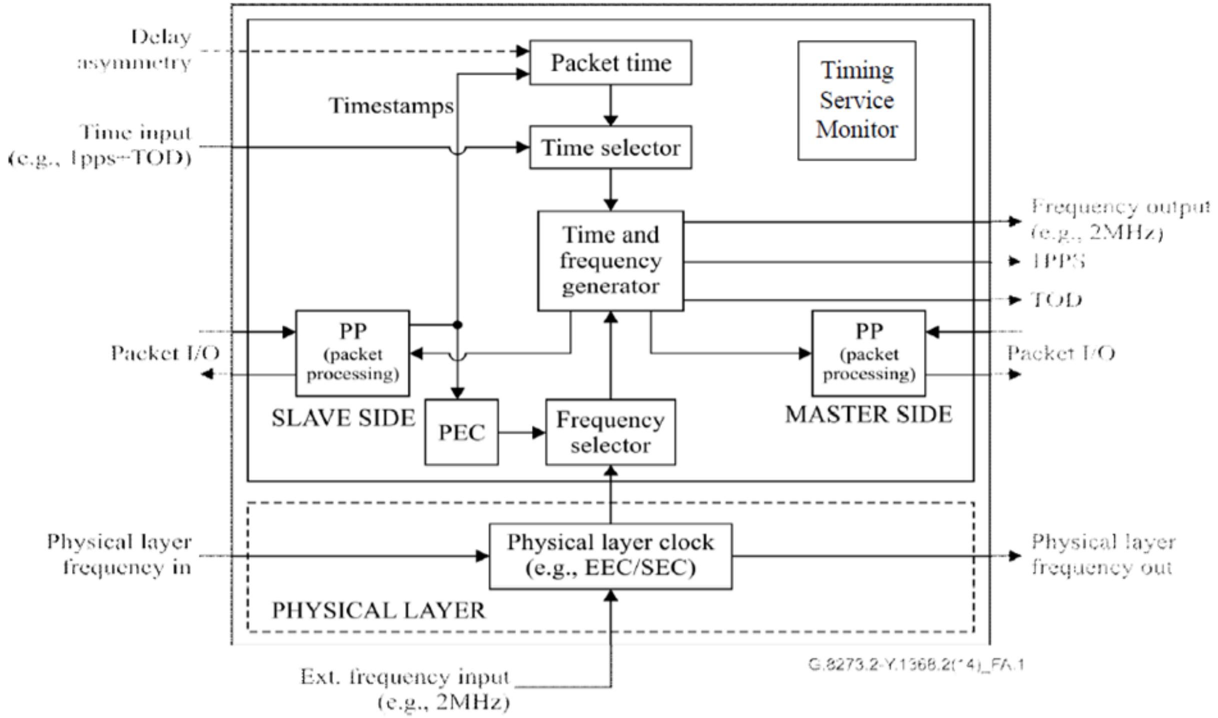
- The ITU has defined mechanisms to use the Ethernet physical layer to distribute frequency information across a network that are similar to the physical layer methods used with synchronous digital hierarchy (SDH)-based network synchronization.
- Synchronous Ethernet (SyncE) uses the edges in the Ethernet data signal to define the timing content of the signal.
- SyncE is a physical layer clock, so it is not subject to packet delay variation.
- All network elements between network segments need to be capable of recovering and passing the frequency downstream.
- An Ethernet Equipment Clock (EEC) is a system clock function that supports SyncE timing distribution.
- The higher information rate and lower noise of SyncE enables a higher clock bandwidth than for a packet-based clock. The bandwidth of the clock PLL in an EEC as defined in G.8262 is in the range of 1 - 10 Hz. The clock bandwidth for an enhanced EEC as defined in G.8262.1 is in the range of 1 - 3 Hz.
- The filtering associated with an EEC defined in G.8262 is sufficient for the cable network use cases identified.

Precision Time Protocol (PTP)

- IEEE 1588, Precision Time Protocol (PTP) is a standard for enabling precise synchronization of real-time clocks for devices in communications networks with system-wide synchronization accuracy in the sub-microsecond to micro-second range.
- PTP relies on the transmission of dedicated packets that form the significant instants of a packet timing signal. The timing of these significant instants is precisely measured relative to a master time source, encoded in the form of a time stamp, and distributed to a packet slave clock.
- PTP timing synchronization starts with a Grandmaster. Timing synchronization then propagates across the network through the exchange of PTP messages between each Master and Slave, allowing each Slave node to synchronize to the PTP timing reference provided by its Master.
- There are three 1588 profiles defined by the ITU-T. G.8265.1 supports frequency synchronization, while G.8275.1 and G.8275.2 both support both frequency and phase synchronization.
  - G.8275.1 profile is defined with full timing support from the network, so all network elements participate in the protocol. The current version of the specification requires the use of a physical layer clock, like SyncE.
  - The PTP clock in a T-BC defined in G.8273.2 has a bandwidth of 0.05 - 0.1 Hz.
  - G.8275.2 is defined with only partial timing support from the network, so not all network elements need to be aware and participating in the PTP protocol.
- PTP defines classifications for clock functionality, including Ordinary Clocks and Boundary Clocks.

Introduction Hybrid Mode

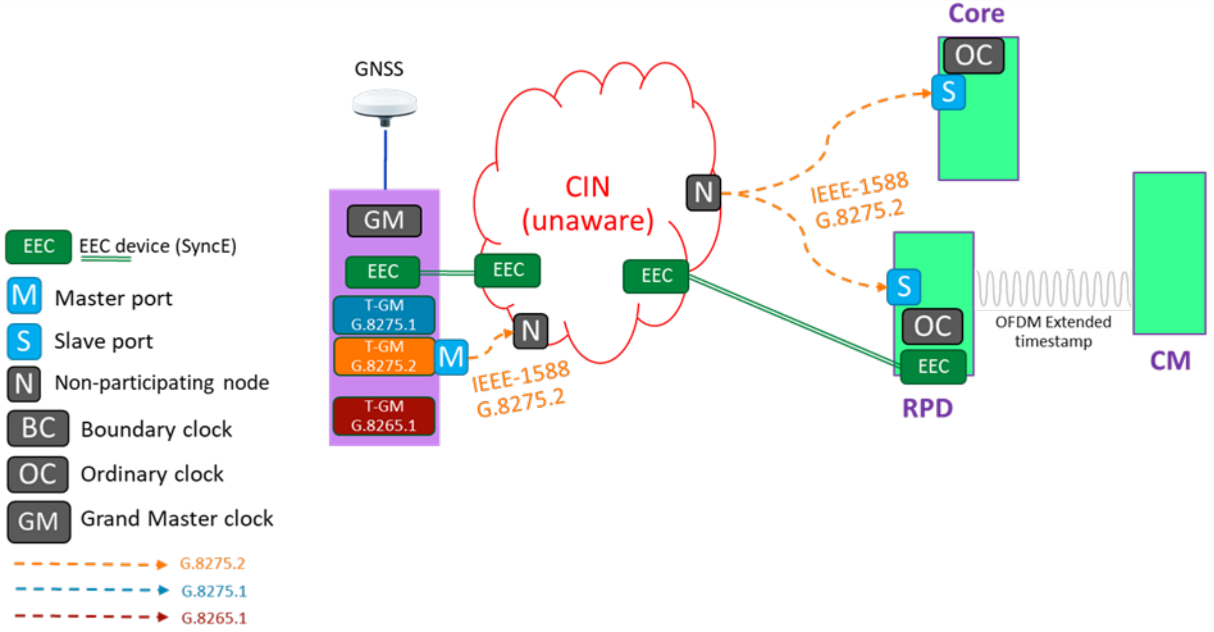
- A node that uses SyncE with an EEC in combination with a packet timing protocol with a Packet Equipment Clock (PEC) may be referred to as a hybrid EEC/PEC clock.
- The source of SyncE within a network should be generated from same source as the PTP domainto avoid frequency drift.
- G.8273.2 provides the functional requirements for a telecom boundary clock or telecom time slave clock when used with full timing support from the network.



Cable Network Requirements

- Timing and synchronization requirements for cable networks come from areas including existing DOCSIS specification requirements, Modular Headend Architecture v2 system requirements, and support of precision timing services, like Mobile Backhaul and other Mobile X-haul use cases.
- CableLabs Specifications
  - Mulpi
  - R-DTI
  - Sync
- ITU-T Specifications
  - SyncE: G.8261, G.8262, G.8262.1
  - PTP: G.8273.2, G.8275.1, G.8275.2

R-PHY Mode



- Remote PHY Device (RPD) separates the Integrated CCAP into a CCAP Core and an RPD that resides in a remote fiber node or remote shelf.
- The CCAP Core and RPD synchronize their DOCSIS clocks in both frequency and phase so that they have a common view of DOCSIS time. This common view is enabled by Remote DOCSIS Timing Interface (R-DTI).
- The RPD also provides timing synchronization to subtended cable modems.
- The system clock of an RPD in hybrid mode consists of an EEC that uses SyncE as its timing reference and a PEC that uses PTP as its timing reference.
- The two timing references are normally traceable to a common frequency source.
- The output of the EEC portion may be used to assist and accelerate the PEC portion in achieving lock to the PTP timing reference.

Benefits of a Hybrid EEC/PEC Clock System

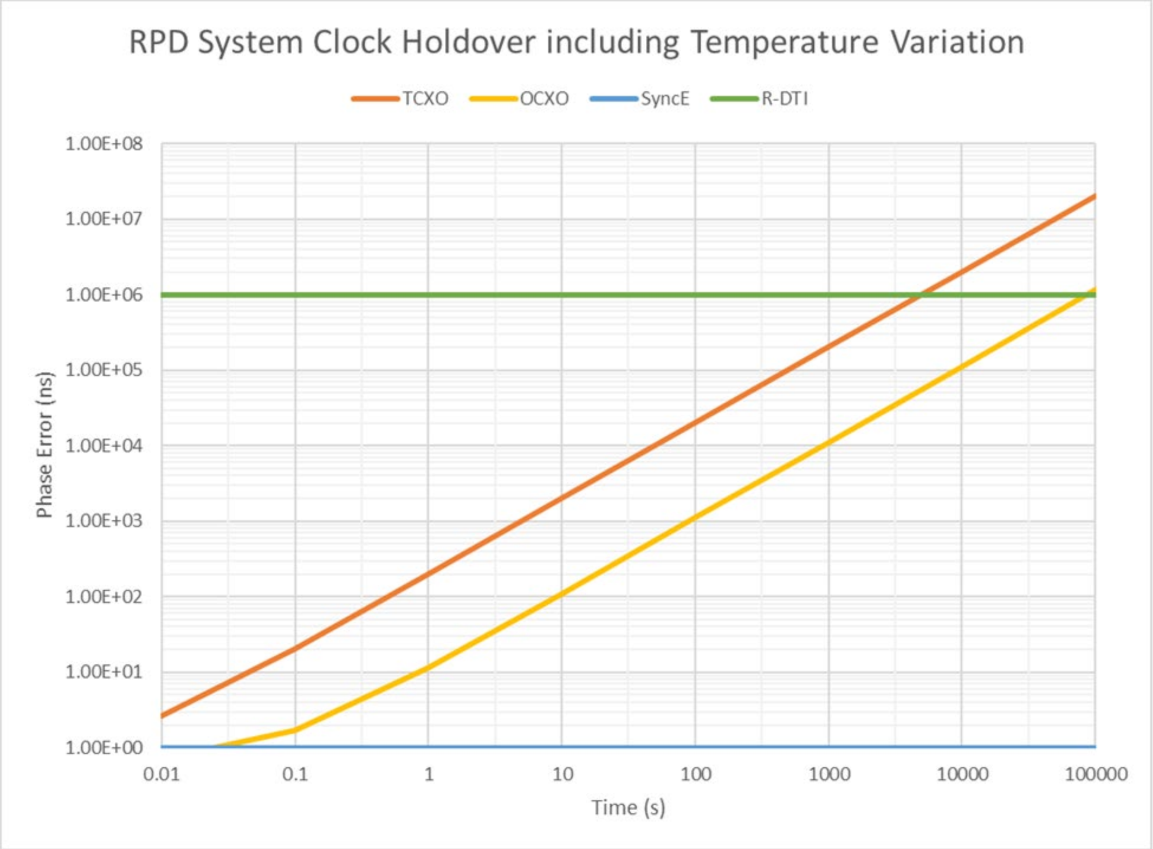
- There are three timing related performance issues that exist in typical RPD implementations that can be improved using a hybrid EEC/PEC clock system.
  - CIN networks may introduce large PDV that can affect the frequency and phase servo algorithm convergence and time accuracy of the RPD.
  - Typical RPD holdover performance is limited while there isn’t a holdover specification defined for an RPD in R-DTI.
  - Services can take a while to be restored during initialization of an RPD since they rely on timing lock notification from the RPD which can last a non-negligible amount of time.

Benefit #1: Time accuracy can be improved

- R-DTI defines the time/phase synchronization accuracy of an RPD to be within ±1 ms when referenced to the 1588 GM for DOCSIS Timing.
- R-DTI requires support for the PTP network profile defined in G.8275.2 with partial timing support from the network.
- Since not all network elements need to be PTP aware, packet delay variation will be imposed on the PTP messages in both directions by each non-participating network element in the timing distribution chain. Long chains of non-participating elements accumulate the packet delay variation and degrade the time accuracy.
- The more stable and accurate frequency associated with the SyncE timing distribution and the physical layer clock assisting the packet equipment clock can result in lower output frequency and phase noise on the output signals from network element and enable improved time accuracy over using PTP alone.
- Assuming SyncE and PTP are traceable to the same PRC, the servo algorithm for PTP could be simplified to lock to phase while frequency is already locked.

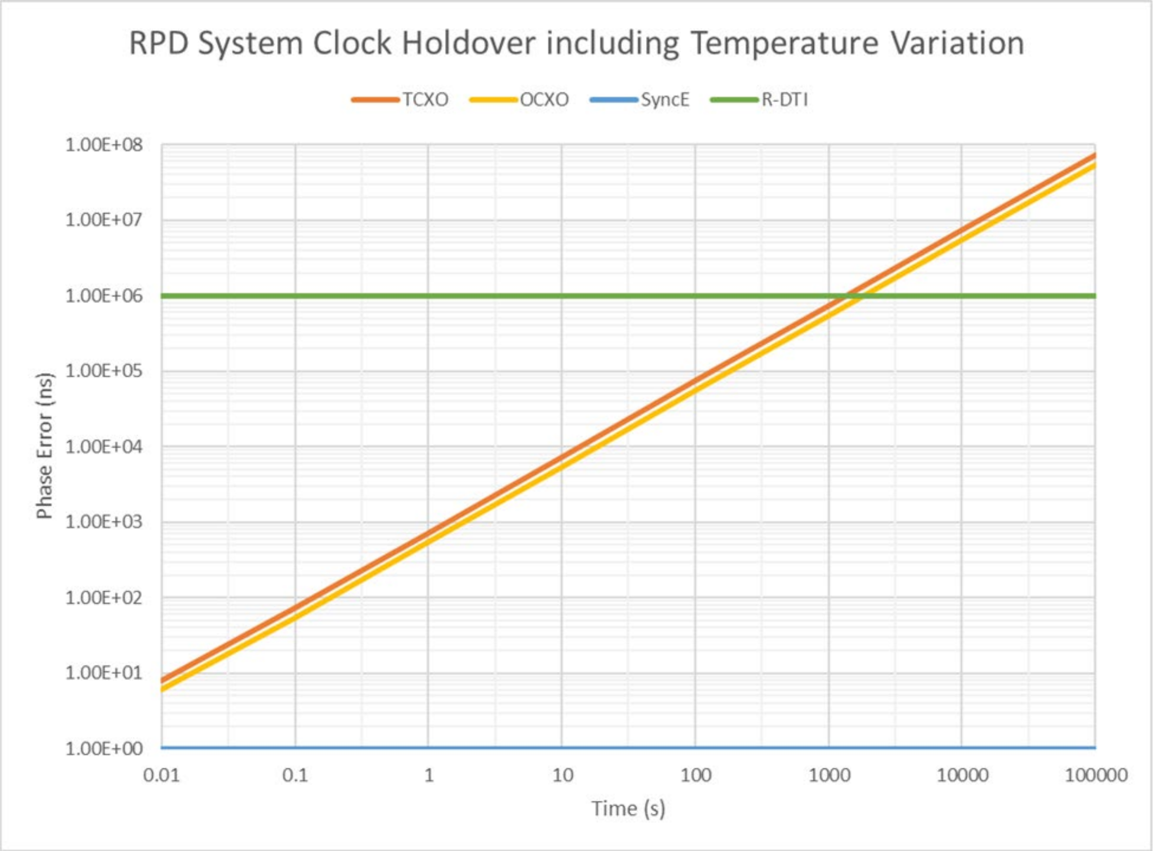
Benefit #2: Improved holdover performance

- A TCXO is normally be used in in the system clock function for RPD applications
- When the packet timing reference from the 1588 GM is interrupted, the RPD's clock will transition into holdover and the RPD's clock output will drift according to the characteristics of the TCXO and the quality of the timing reference frequency estimate prior to the holdover event.
- A TCXO meeting the holdover specifications in G.8262 or G.8262.1 will remain within this ±1 ms level for roughly an hour and 20 minutes.
- An OCXO extends the time the RPD would remain within the ±1 ms accuracy to roughly 1 day (25 hours), but it does come with additional cost and power associated with the OCXO.
- By using SyncE and an EEC to enhance the performance of the RPD's PEC and providing a stable frequency reference that is traceable to the 1588 GM, the time output from the RPD will continue at the correct rate and maintain the correct time for an almost indefinite amount of time.



Benefit #2: Improved holdover performance – (continued)

- R-DTI contains a frequency accuracy requirement of ±530 ppb, A PEC in an RPD which is in frequency-locked state might go into holdover with an additional initial frequency offset of ±530 ppb.
- This will cause the RPD to cross the ±1 ms threshold much faster. RPDs with either a TCXO or an OCXO will remain within this threshold for roughly 25-35 minutes.
- By using SyncE and an EEC to assist the PEC, the time output from the RPD will continue at the correct rate and maintain the correct time for an almost indefinite amount of time.



Benefit #3: Reduced time to lock and recover after reset

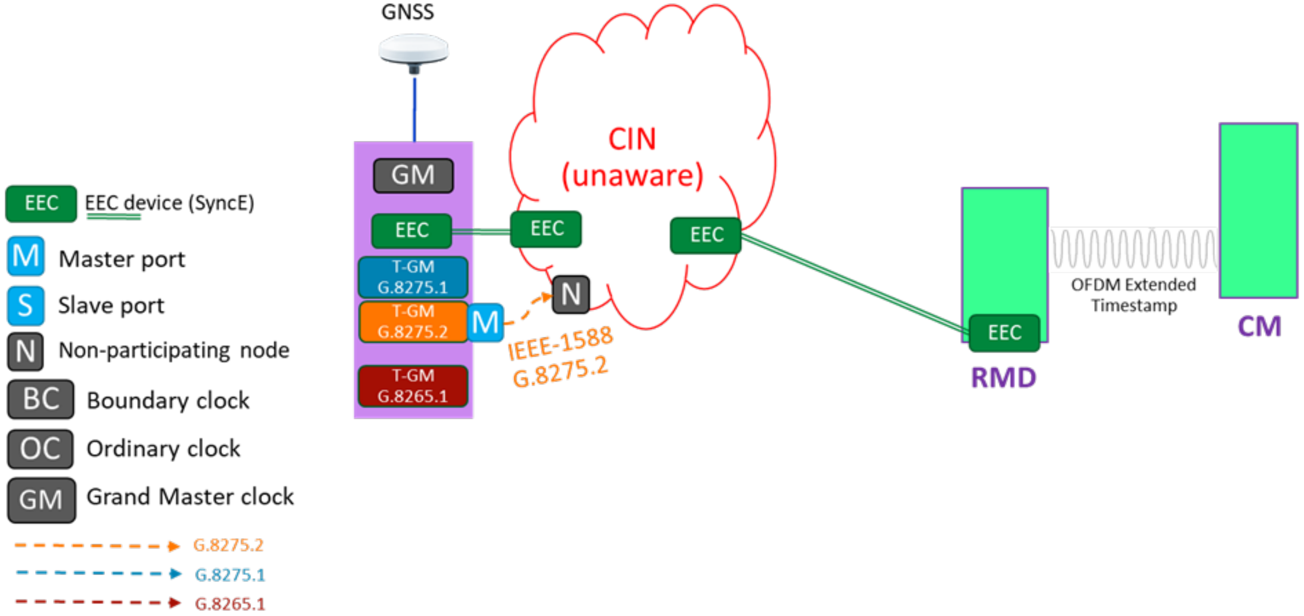
- The RPD's PEC is the source for all downstream DOCSIS timing.
- When exiting reset, the RPD must wait until the PEC achieves frequency lock and phase lock before it can begin to provide services, even services that only require frequency synchronization, like video and OOB services.
- Frequency lock can be achieved in a shorter amount of time than the time required to achieve phase and frequency lock. Phase and frequency lock with the ±1 ms specified in R-DTI can take multiple minutes.
- Techniques can speed the acquisition of phase and frequency lock after a reset.
  - A soft reset with warm start relies on frequency information about the operating conditions of the RPD's packet equipment clock prior to the reset.
  - Warm start is most effective if the reset time is brief and network conditions are stable during the reset time.
- Otherwise, a hard reset will be required. It does not rely on information about the packet equipment clock's prior operating and can take longer to achieve lock.

Benefit #3: Reduced time to lock and recover after reset – (continued)

- Reducing time-to-lock for an RPD system clock using SyncE assistance is partially due to the difference in PLL bandwidths between the two portions of the system clock.
  - The bandwidth of the EEC defined in G.8262 is in the range of 1 - 10 Hz
  - The bandwidth Enhanced EEC defined in G.8262.1 is in the range of 1 - 3 Hz.
  - In contrast, the bandwidth of the PEC in a T-BC defined in G.8273.2 is 0.05 - 0.1 Hz.
- While the frequency locking process is non-linear, the difference in bandwidths between the EEC and Enhanced EEC and the PEC should result in the EEC obtaining frequency lock at least ten times faster than the PEC.
- Since the frequency lock in the Hybrid EEC/PEC clock is dependent on the SyncE timing reference, a larger amount of PDV can be tolerated on the PTP timing reference without significantly increasing the lock time.
- Because of the faster frequency lock that results from the EEC assistance, the RPD can begin to deliver video services while phase lock is still being acquired by the PEC. DOCSIS services may be delayed until phase lock is achieved by the PEC.

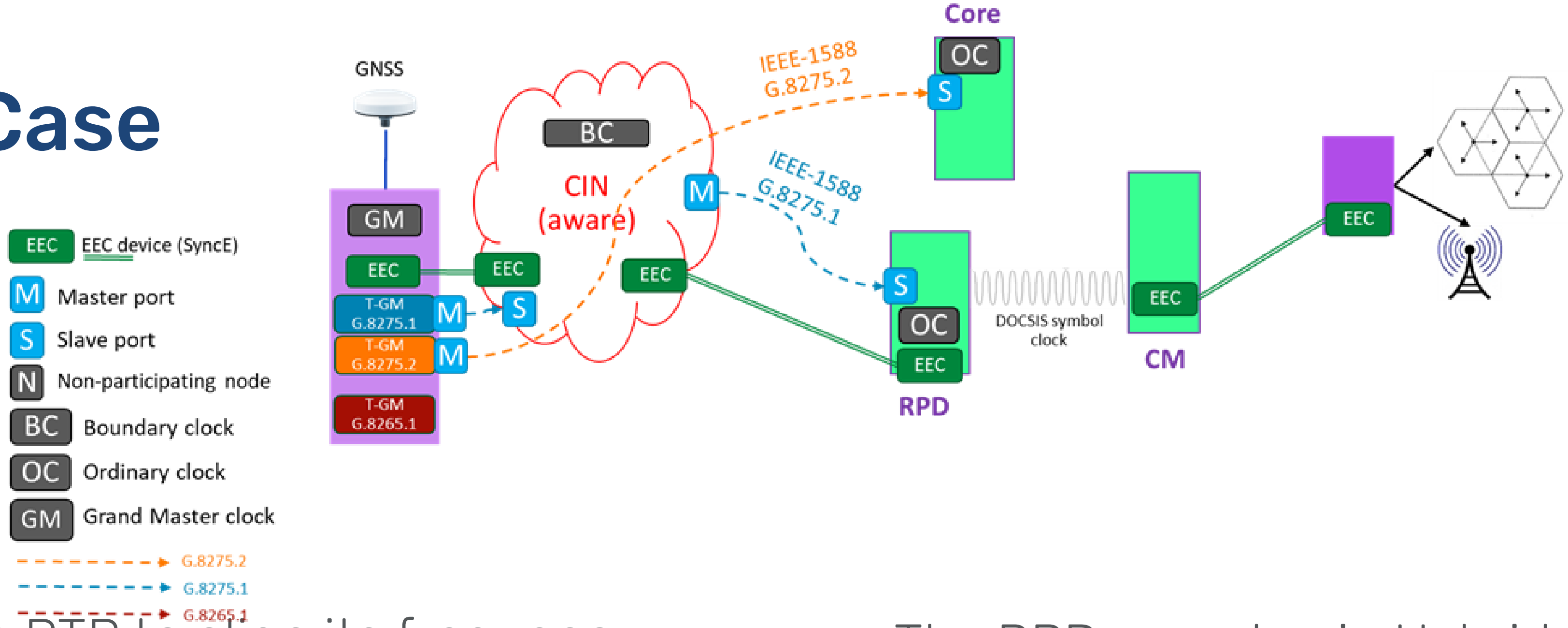
	Hard Reset	Soft Reset / Warm Start	Hard Reset with SyncE Assist
Frequency lock achieved	minutes, depends on network PDV	within a minute	within seconds

RMD Mode



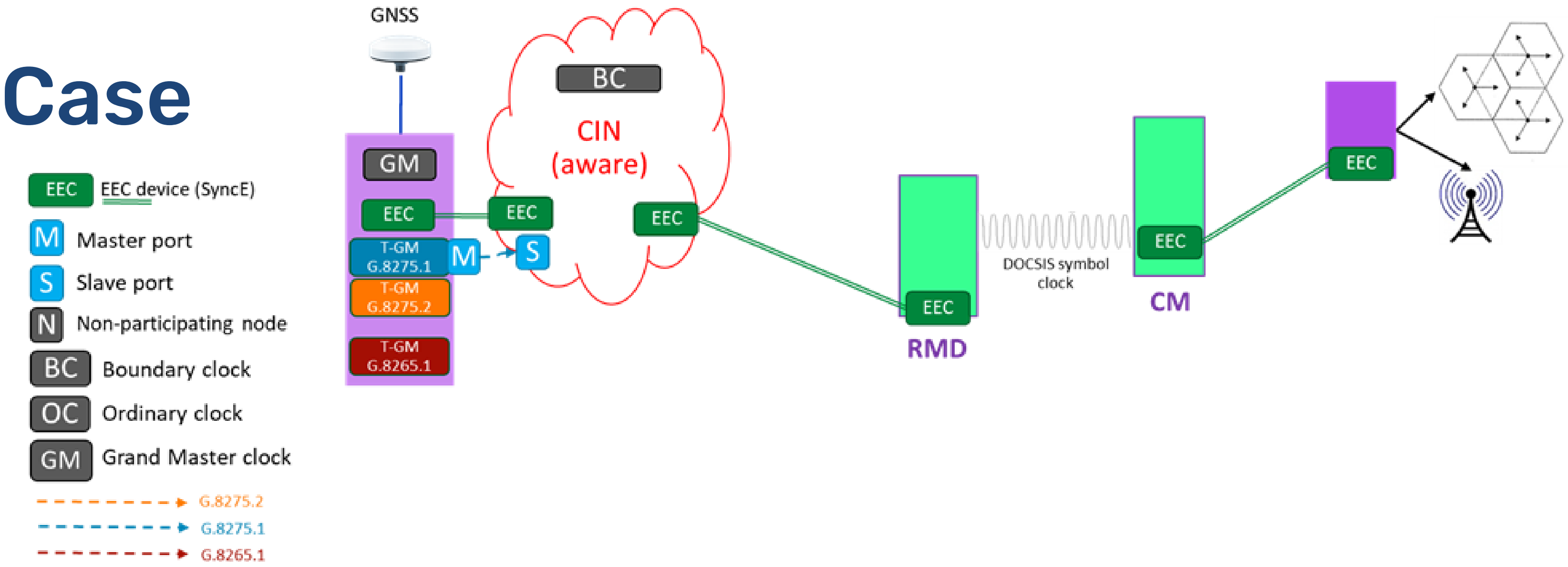
- The RMD collocates the DOCSIS MAC and the PHY within a device, eliminating the complexity of synchronizing between two devices for DOCSIS operation that the RPD requires.
- There are four options for timing the RMD: free-run, frequency synchronized using the PTP profile defined in G.8265.1, frequency synchronized using SyncE, and frequency and phase synchronized using the PTP profile defined in G.8275.2.
- For applications that require external timing, frequency synchronization may be provided via SyncE, or by PTP. The PTP-based options will have a higher amount of noise as a result of the packet delay variation in the timing distribution network.
- The wider bandwidth of the EEC in the RMD's system clock function enables a faster lock time and faster restoral of service after a reset.
- In contrast to the RPD application, the faster restoral of service when using SyncE for frequency synchronization applies to both DOCSIS and non-DOCSIS services.

RPD Use Case



- The RPD uses PTP to align its frequency and phase for R-PHY operation and generates the downstream DOCSIS frequency and timestamp traceable to the PTP clock domain.
- For the downstream clock to be SyncE-traceable, the input SyncE and PTP should be generated from the same source.
- The RPD operates in Hybrid mode so that SyncE may be used to assist the PTP clock for functions like holdover and fast-lock.
- Cores usually only support G.8275.2 as defined in [R-PHY]. Supporting different profiles for RPD and Core will require different GMs.

RMD Use Case



- The RMD’s system clock is locked in frequency via SyncE.
- Without a requirement for phase synchronization in this application, the RMD may use an arbitrary time of day or use NTP to establish the system’s time of day.
- The lower amount of noise on the SyncE timing reference allow for a wider bandwidth of the EEC in the RMD system clock function.
- This enables a faster lock time, faster restoral of service after a reset and more accurate holdover for a SyncE-based RMD system clock over a PTP-only timing approach.

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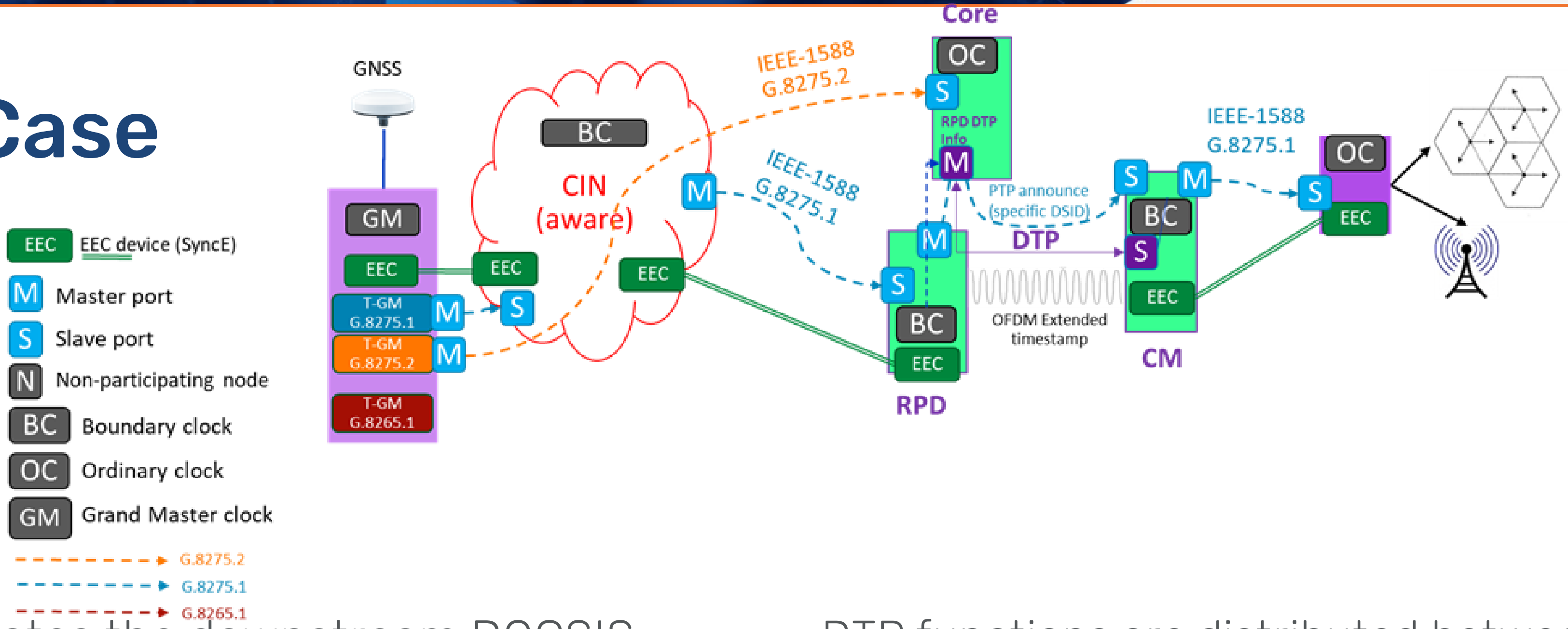
RPD Use Case



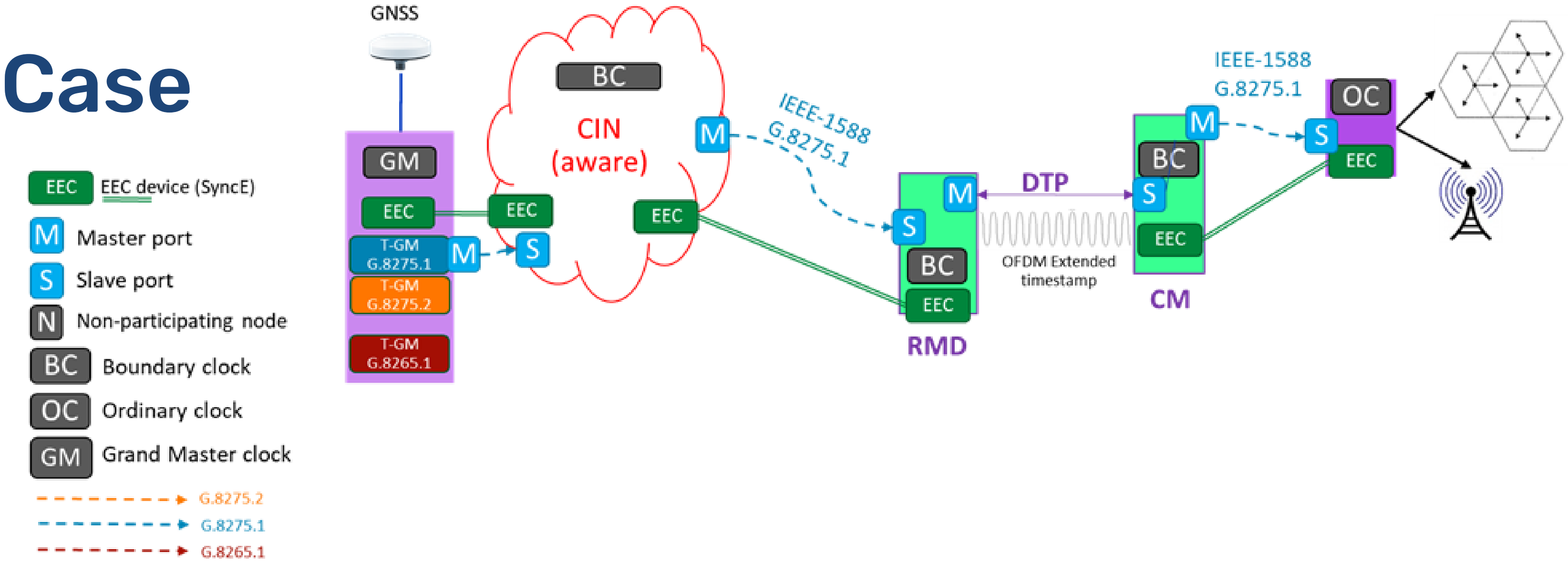
- The RPD generates the downstream DOCSIS frequency and timestamp traceable to the PTP clock domain.
- For the downstream clock to be SyncE-traceable, the input SyncE and PTP should be generated from the same source.
- The RPD operates in Hybrid clock mode so that SyncE may be used to assist the PTP clock for functions like holdover and fast-lock.

DTP functions are distributed between the RPD and the Core, so there is synchronization complexity.

Cores usually only support G.8275.2 as defined in [R-PHY]. Supporting different profiles for RPD and Core may require different GMs.

PTP announce message delivery is from the RPD to Core via UEPI to forward to the CMs. Core needs to encapsulate the PTP announce messages on the UEPI PW from the RPD and forward to all CMs on relevant DSIDs.

RMD Use Case



- RMD's system clock is frequency and phase locked via PTP with SyncE assistance.
- Lower noise on the SyncE timing reference allows for a wider system clock bandwidth.
- This enables a faster lock time, faster restoral of service after a reset and more accurate holdover.
- The lower noise on the system clock allows for lower noise and better accuracy of the timestamps.
- DTP functions are co-located in the RMD so there isn't the complexity associated with coordinating and synchronizing between two devices.

Summary/Conclusion

- Synchronous Ethernet (SyncE) is used mainly in telecom networks to provide frequency synchronization.
- The cable industry more commonly uses IEEE1588 PTP for time synchronization.
- The paper investigated the impact of providing SyncE support in DAA R-PHY and R-MACPHY applications as well as mobile backhaul (LTE and 5G) applications.
- SyncE provides multiple benefits over the traditional PTP-only based implementations:
  - Improved timestamp accuracy
  - Improved holdover performance
  - Reduced time to lock and reduced time to recover services after reset
- SyncE is a valuable functional addition to the cable network.
- Since converged interconnect networks (CINs) are generally new networks, requiring SyncE support for equipment in the CIN is a reasonable requirement.

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Thank You!

Chris Zettinger

Principal Systems Engineer
CommScope
chris.zettinger@commscope.com