Best practices for implementing IEEE-1588 in Wireless Backhaul

Abstract

This document provides technical managers and network designers insight into Synchronous Ethernet and IEEE 1588v2 packet synchronization methods for successfully transporting packet data across mobile backhaul networks. The document focuses on the implementation used by Ceragon's high capacity, 4G/LTE microwave solution.

Why is synchronization an issue?

Mobile base stations need a highly accurate timing signal that has to be shared across the entire network. If an individual base station drifts outside of the specified +/- 50 PPB (Parts per Billion) limit, mobile handoff performance degrades, resulting in high rate of disconnected and poor data services quality.

As long as mobile base stations purely rely on TDM-based T1/E1 or SONET/SDH backhaul connections, synchronization is not an issue. Yet, as the aggregate cost of TDM backhaul connections rises, operators are transferring their networks to more cost-efficient packet-based solutions. This move breaks the end-to-end clock synchronization chain that enabled 2G and early 3G networks to remain synchronized.

Unlike legacy TDM networks, packet-based networks are not deterministic. Packets may follow more than one route from source to destination, and their arrival order is not necessarily the same as their transmission order. Packets may also get lost on the way, requiring retransmission. It is obvious then, that packet-based networks cannot inherently support the sub-microsecond level of synchronous timing and frequency accuracy required by mobile base stations.

Mobile Synchronization requirements

The air interface frequency and phase accuracy requirements of some mobile technologies are summarized in the table below

Application	Frequency (ppb)	Phase/Time (µs)	Reference Document
CDMA	±50	±3 (Traceable & Synchronous to UTC)	TIA/EIA-95-B
CDMA2000	±50	±10 (>8hrs) when external timing source disconnected ±3 (Traceable & Synchronous to UTC)	3GPP2 C.S0002-E v2.0 C.S0010-C v2.0
GSM	±50 ±100 (pico BS)		ETSI TS 145.010
UMTS-FDD (WCDMA)	±50 (Wide area BS) ±100 (Medium range BS) ±100 (Local area BS) ±250 (Home BS)	12.8 (MBSFN-3GPP Release 7/8)	3GPP Frequency: TS 25.104 MBSFN:TS 25.346
UMTS-TDD (WCDMA)	±50 (Wide area) ±100 (Local area) ±250 (Home eNB)	±2.5 ±1 (between Macro eNB and Home eNB)	3GPP Frequency: TS 25.105 Phase: TS 25.402 Home eNB: TR 25.866
TD-SCDMA	±50	±3	3GPP TS 25.123
LTE (FDD)	±50 (Wide area) ±100 (Local area) ±250 (Home eNB)	±10 (> 8hours) when external timing source disconnected GPS time	3GPP Frequency: TS 36.104 Time: TS 36.133
LTE (TDD)	±50	≤ 3 (small cell) ≤ 10 (large cell) CDMA handover and Synchronized E-UTRAN ±10 (> 8hours) when external timing source disconnected GPS time	3GPP Frequency: TR36.922 Phase & Time: TS36.133
Mobile WiMAX	±2000 (i.e., 2ppm)	≤ ±1	IEEE 802.16e-2005 WMF-T23-001-R015v01

Table-1: Frequency and phase accuracy requirements of the Air Interface for different mobile technologies and the backhaul network (Source - MEF)

In order to achieve the above frequency and Phase/Time requirements several synchronization technologies are available. This technical brief focuses on packet based synchronization technologies.

Synchronization technologies and interfaces

A carrier-class transport network must be able to meet the synchronization requirements of all the services it supports, regardless of the TDM, or packet-based technology used. A variety of dedicated synchronization interfaces are defined in industry standards: primary reference clock (PRC), building integrated time source (BITS) (T1, E1, 2 MHz, 6 MHz), one pulse per second (1PPS), and time of day (ToD).

	Physical Layer	**Packet Layer**
User/network interface	SDH/SONET, SyncE, PDH	IEEE 1588v2 (PTP), NTP
Dedicated synchronization interfaces	T1, E1, 2MHz, 6MHz,	1PPS, ToD

Table-2: Synchronization technologies and interfaces (Source - MEF)

SyncE and IEEE1588 are valid solutions in a packet network. Selecting one of them depends on whether the application requires frequency (GSM, W-CDMA, etc.) or frequency and phase (TD-SCDMA, WiMAX, etc.).

- Synchronous Ethernet is a physical layer technology that delivers a frequency reference. It cannot be deployed over legacy Ethernet networks unless the physical hardware or interfaces are upgraded. Yet, it is not affected by Packet Delay Variation (PDV) or Packet Jitter, which are inherent in Ethernet networks.
- IEEE 1588 delivers clock timing from which both phase and frequency are derived. It can be deployed over legacy Ethernet networks and equipment, but clock recovery is negatively impacted by excessive PDV when the network is highly utilized.

Precision Time Protocol (PTP)

Precision Time Protocol (PTP), described in IEEE 1588, enables the synchronization of distributed clocks. The device that distributes the clock is considered the “Master”. It is responsible for generating periodic Synch frames that provide the frequency distribution.

The end devices are called “Slaves”, “Clients” or “Ordinary clocks.” These devices receive the frames from the Master and apply an algorithm to recover the frequency and phase of the distributed clock. A “Boundary clock” acts as a “regenerator” in the middle of the network. It acts as a Client in relation to the Master-clock and as Master toward the downlink clients.

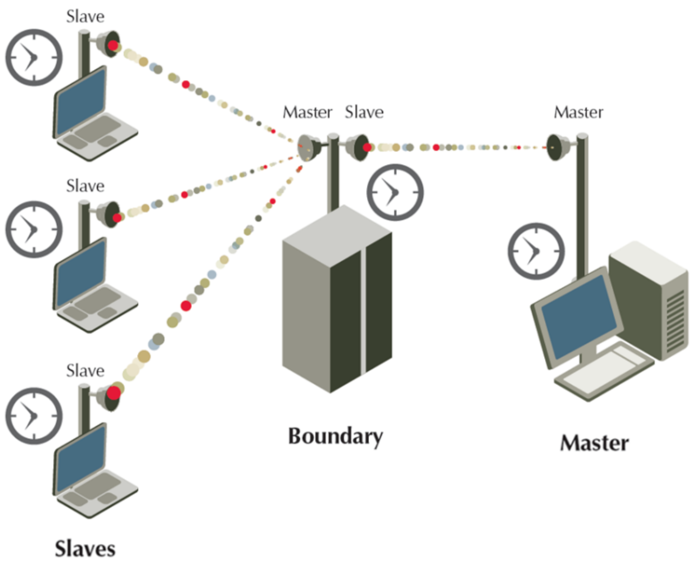

Figure 1: A Boundary clock switch works as Slave in relation to the Master clock, and acts as a Master towards the other connected slaves

A Boundary clock is used when the chain between the master and clients contains too many hops that cause significant delay variation.

A “Transparent clock” is a function that transmission components can implement to compensate for their delay variation. A transparent clock measures the delay of the 1588 packet from the ingress to egress, and adds it to the 1588 frames in a “correction field.” The client reads the “correction field” value from the 1588 packets and uses it in its algorithm to compensate for the delay variation that was added by each node in the transport chain.

Delay Variation in Wireless Transport

The Packet delay variation (PDV) in wireless transport for synchronization over Packet Protocols (e.g. IEEE-1588), dramatically affects the quality of the recovered clock. Slow variations are the most harmful since in most cases they are more challenging to “average” by the receiver.

The two parameters that mostly affect the PDV are "Head-of-Line Blocking” and Adaptive Coding & Modulation (ACM).

"Head-of-Line Blocking” effect on PDV

Head-of-Line blocking occurs when a high priority frame (e.g. containing IEEE-1588 information) needs to wait until the end of transmission of a current frame, which already started to be transmitted.

Adaptive Coding & Modulation (ACM) effect on PDV

Adaptive modulation allows dynamic changes of bandwidth to accommodate for radio path fading - typically due to weather changes. While the capacity per link is reduced, more traffic requiring transmission is accumulated in the buffers and is being delayed.

For example, an IEEE-1588 frame over 28MHz channel will bear a minimum and maximum delay as follows:

- Minimum frame delay: 110µsec, occurs when the link operates at 256QAM modulation and when no other frame started transmission before the transmission of the IEEE-1588 frame
- Maximum frame delay: 800µsec, occurs when the link operates at QPSK modulation and when a 1,518 bytes frame started transmission before the transmission of the IEEE-1588 frame.

Therefore, the worst case Packet Delay Variation (PDV), defined as the difference between the maximum and minimum frame delays, is 690µsec. This worst case PDV may occur on every hop across the network.

When bandwidth is reduced due to ACM change, it is essential that high priority traffic that carries IEEE-1588 packets is given the highest priority using enhanced QoS techniques, and is not subject to delays or discards.

Ceragon sync over packet optimized transport

Ceragon provides an innovative technology embedded in its microwave backhaul product lines, which ensures Ultra Low Packet Delay Variation for Sync IEEE-1588. This is achieved by creating a symmetrical traffic channel that is dedicated to sync-over-packet control frames. This dedicated channel:

- Offers a fixed bandwidth channel, operating independently of the bearer traffic payload channel, which carries Ethernet traffic. Hence Head-of-Line Blocking effect is eliminated.
- Has fixed and symmetrical latency over all ACM points, hence delay-variations are minimized.

While TC and BC are techniques used to compensate for the delay variation inserted by the packets nodes, Ceragon's method solve the problem by providing a parallel channel for the 1588 that does not insert delay variation, and is not affected by the amount of congestion in the packet network.

As result, Ceragon's unique sync over packet optimized transport solution enables a sub 20µsec PDV per hop and **completely eliminates the need for IEEE-1588 Boundary clocks or Transparent Clocks in the transmission network**.

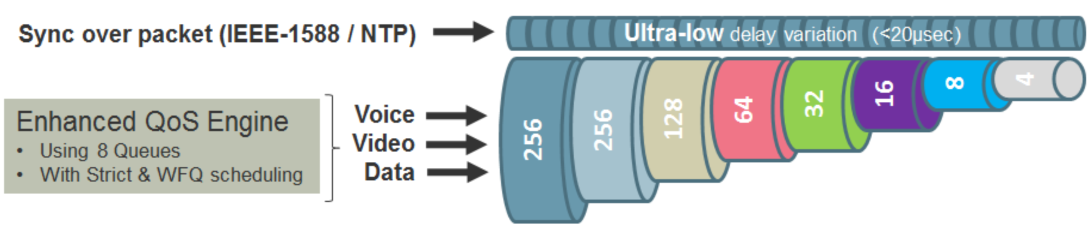

Figure-2 Dedicated symmetrical channel for "Sync-over-packet optimized transport" which does not share bearer traffic network resources, achieving ultra low PDV

1588v2 Transparent Clocks (TCs), Boundary Clocks (BCs) and Ordinary Clock (OCs)

Frequency synchronization is deployed in today's networks without TC and BC functionality. However, time synchronization without TCs and/or BCs can be challenging in some scenarios.

ITU-T study group 15 (Question 13) is undertaking a study to define a profile for Time of Day (ToD) transfer that includes architecture guidelines, functionality and performance limits. The fundamental challenge to clock recovery is Packet Delay Variation (PDV). TCs and BCs are designed to reduce or remove the PDV that a Slave clock has to deal with, thereby helping achieve accurate clock recovery in a network. Nevertheless, some sources of asymmetry remain, such as different cable lengths in the Uplink and Downlink paths. Asymmetry can have an impact on the accuracy of the recovered time synchronization, but it is not an issue for frequency synchronization.

It is important to note that while 1588v2 defines the functional model for a Boundary Clock and a Transparent Clock device, there are no performance specifications defined in any Standards document. To address this, the ITU-T is working to define performance specifications for both TCs and BCs.

Do we need TC, BC and OC in a microwave radio?

Examining the three clocks reveals that even though TC, BC and OC are important for end-to-end synchronization, in most cases they are redundant in a microwave radio.

When excessive PDV accumulates over a large number of hops, a Boundary Clock "breaks" the network into smaller segments with lower PDV and "cleans" the clock in between (re-timing). Ceragon's unique "Sync-over-packet optimized transport" (explained above) offers drastically reduced PDV per hop, which makes the Boundary Clock redundant. In a common mobile network, the maximum number of microwave hops between fiber sites and cell-sites is about to 6-10 and is typically even smaller. Hence, though in some scenarios a Boundary Clock within the aggregation site edge router is necessary, there is no real benefit for an additional Boundary Clock inside the radio domain.

Ordinary Clock / Client (OC) modules are already integrated in every NodeB/eNodeB that have a high quality oscillator clock. Adding OCs in the microwave radio at an edge site is therefore redundant. The Transparent Clock (TC) may be used to compensate for the negligible effects of PDV, created by the integrated switching element within the radio node. However, this is not applicable for the radio link itself. To solve this issue, Ceragon offers "sync over packet optimized transport".

IEEE-1588 performance – Test Case

The G.8261 provides a definition for 1588 tests, whose topology is illustrated below. According to these tests, the allowed cumulative PDV over 10 network devices is 230µsec (about 23µsec per hop) resulting from calculating the expected Head of Line Blocking effect.

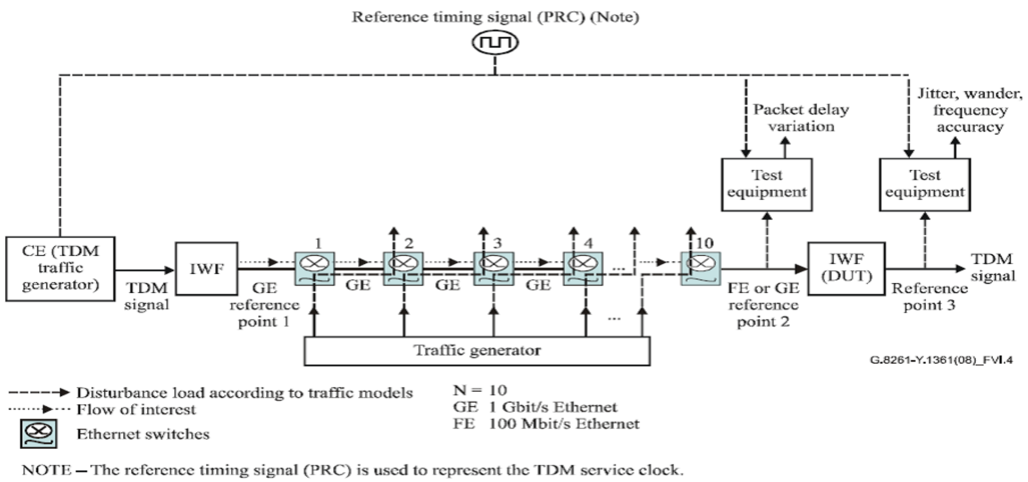

Figure-3 IEEE 1588 performance test topology

Ceragon tested the PDV in two scenarios – with and without “Sync-over-packet optimized transport” feature.

The test included a set-up of three chains of microwave radios with 7,14 & 28MHz channel bandwidth respectively, and used ACM that changed modulation every 6 minutes.

Without using optimization techniques, the resulting PDV achieved was **3msec.** However, by using Ceragon’s unique Packet Synch optimization, the PDV dropped to **35µs - a 100 factor improvement.**

Evolution of Network Timing from TDM to Carrier Ethernet

Operators who choose to maintain a hybrid (TDM/IP) network, can deploy SyncE and IEEE-1588 as they begin to migrate voice traffic from TDM to packet-based networks. TDM circuit emulation services (CES) are transported across packet-based networks. Synchronization is essential to support frequency accuracy and stability. Lack of stability ("wander" and "jitter") or accuracy ("frequency offset") will cause bit errors and/or frame slips (underflows and overflows of frame buffers). The result would be loss of packets in the PDH framing, which can severely affect TDM traffic performance.

The figure below shows an evolutionary approach to timing options as networks grow and evolve from TDM to packet-based infrastructures. Variety, flexibility, and interoperability of synchronization tools provide options for a smooth evolution.

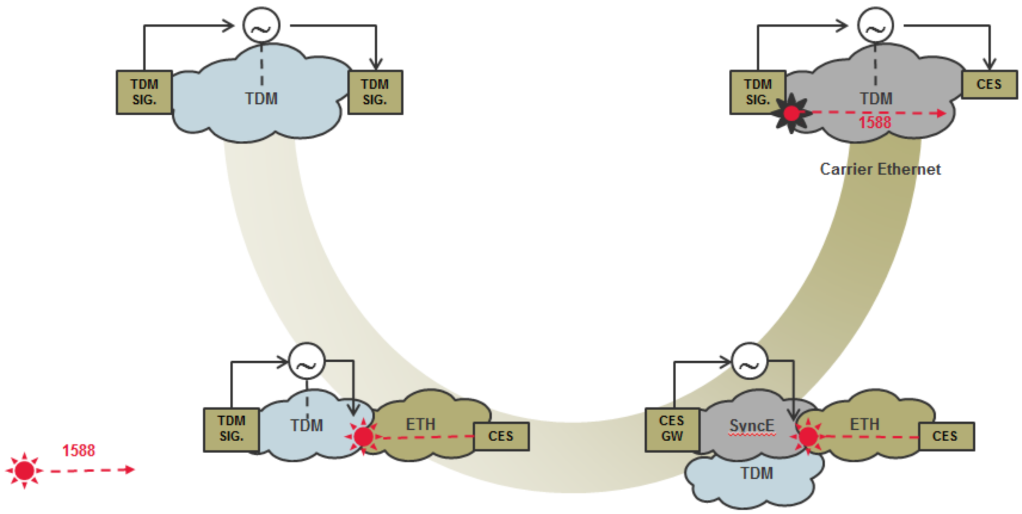

Figure-4 Evolution of Network Timing from TDM to Carrier Ethernet (Source - MEF)

Interoperability with an Ethernet over SONET (EoS) network requires using TDM circuit emulation service (CES) via a CES gateway. IEEE 1588v2 is required across the EoS cloud to maintain time of day (ToD). As Synchronous Ethernet (SyncE) is implemented in the overlay Carrier Ethernet network, the operator still supports the TDM CES traffic but uses SyncE and IEEE 1588. SyncE is used both to recover and distribute frequency at the physical layer in Ethernet-based networks, using the same principles that were developed for synchronization based on SDH/SONET. In the final stage of evolution, the full packet Carrier Ethernet network supports all traffic, including TDM CES using SyncE and 1588v2 for ToD.

Summary

Operators should carefully consider the synchronization options and designs over microwave networks. Ceragon offers an effective synchronization design that supports various synchronization techniques, based on Native TDM, SyncE (ITU-T G.8261), IEEE1588-2008 Packet-based synchronization, or external GPS equipment via standard timing interfaces. This variety offers mobile operators multiple synchronization options and enables hybrid synchronization network designs.

References

- MEF (March 31, 2011) - Packet Synchronization for Mobile Backhaul - A Formula for Deploying 1588v2 and Synchronous Ethernet: Investigate – Test – Deploy
- IEEE1588™-2008, Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems
- ITU-T Recommendation G.8260 (08/2010), Definitions and Terminology for Synchronization in Packet Networks

ABOUT CERAGON

Ceragon Networks Ltd. (NASDAQ: CRNT) is the premier wireless backhaul specialist. Ceragon's high capacity wireless backhaul solutions enable cellular operators and other wireless service providers to deliver 2G/3G and LTE/4G voice and data services that enable smart-phone applications such as Internet browsing, music and video. With unmatched technology and cost innovation, Ceragon's advanced point-to-point microwave systems allow wireless service providers to evolve their networks from circuit-switched and hybrid concepts to all IP networks. Ceragon solutions are designed to support all wireless access technologies, delivering more capacity over longer distances in any given deployment scenario.

Ceragon's solutions are deployed by more than 230 service providers of all sizes, and in hundreds of private networks in more than 130 countries.

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