VIAVI Solutions

VIAVI
Verifying Telecom Synchronization Networks

Synchronization Test Use Cases for T-BERD/MTS-5800 and
MAP-2100 with Timing Expansion Module (TEM)

Synchronization test applications let users analyze synchronization problems at telecom interfaces ranging from 1PPS to 25 Gbps. These tests are performed at clock, PDH or Ethernet interfaces using IEEE 1588–2008 (PTP) and Synchronous Ethernet protocols. A highly stable reference module with a Rubidium Oscillator is provided to deliver the necessary accuracy for respective ITU-T measurement metrics and thresholds. The reference module can also be used to validate the performance of GNSS cabling systems and deliver stable 1PPS/10MHz to measurement devices.

Value Proposition

Verify and troubleshoot synchronization networks by performing antenna analysis, time error, frequency error, packet delay variation, or floor packet percentile (FPP) measurements. Unlike other solutions, the T-BERD/MTS timing and synchronization test feature set is a portable solution with pass/fail verdicts applicable to field and provides highly accurate results for lab to field testing.

Capability Overview

Time error measurements are performed while emulating a PTP Telecom Time Slave Clock (T-TSC) thus enabling a true characterization of time error present at any part of the synchronization chain from the Telecom Grand Master (T-GM) to the T-TSC at the end application. Time error measurements present calculated results for maximum time error (Max |TE|), constant time error (cTE) and dynamic time error (dTE) as characterized by Time Interval Error (TIE), maximum Time Interval Error (MTIE) and Time Deviation (TDEV) metrics. These calculated results follow ITU-T recommendations. Required ITU-T profiles can be configured so users can obtain a pass/fail verdict of the performed measurements. 1PPS and 10MHz wander tests (MTIE/TDEV) can be conducted at any device delivering those interfaces.

Benefits

- Validate proper delivery of synchronization services in telecom and LTE Advanced/5G wireless networks throughout the synchronization chain from the Telecom Grandmaster (T-GM) to the Telecom Time Slave Clock (T-TSC)

- Easily perform synchronization measurements with workflows and automatic pass/fail verdicts enabled with a comprehensive library of ITU-T masks

- Enable accurate measurements meeting ITU-T standards with a highly stable reference clock

- Verify adequate installation and function of GNSS systems from the antenna to the GNSS receiver location

- Troubleshoot PTP synchronization problems with packet capture and decode

Intended audience

- Central office, metro/access and wireless technicians who install, turn up, or troubleshoot telecom equipment

- Engineers who design, maintain, or troubleshoot synchronization equipment in the lab or field

Solution Components and Their Capabilities

Timing Expansion Module (TEM)

The Timing Expansion Module includes a GNSS receiver chip set that can receive and decode GNSS constellations such as GPS, Galileo, GLONASS and BeiDou. Delivering a highly stable reference signal necessitates a highly stable oscillator such as Rubidium which is included with the TEM.

Beyond providing the reference signals for synchronization measurements, the TEM can be used to verify the proper installation of GNSS antenna and cabling systems. Its sky plot and signal strength diagrams provide an accurate image of visible satellites and their respective signal strengths. TEM delivers Time of Day (ToD) and 1PPS and 10MHz reference signals to attached mainframes described in the next section. The 1PPS and 10MHz signals are also available on an SMB port for external test equipment.

Measurement Mainframes

VIAVI provides several different mainframes with varying degree of synchronization capability to match the value and performance requirements of different user groups. They are distinguished by the range of the supported test signal rates and their capability to deliver stable reference signals. The measurement capabilities are described in the next sections.

Mainframe	10 Gbps maximum test signal rate	100 Gbps maximum test signal rate	Integrated GNSS	Support for TEM
T-BERD/MTS-5811 and -5822	Y	N	N	Y
T-BERD/MTS-5882	Y	N	Y	Y
T-BERD/MTS-5800-100G	Y	Y	Y	Y
MAP-2100	Y	Y	Y	N

IEEE 1588-2008 (aka PTP, 1588v2) Test and Software Test Options

The 1588v2 test is used to ensure proper connectivity to a PTP master clock by emulating a PTP slave device. In addition, the test measures key performance indicators (KPIs) for the PTP traffic such as PDV and time error. The PDV and time error tests can be run both with the PTP packets encapsulated in Ethernet frames (Layer 2 mode) or with the PTP packets encapsulated in UDP segments (Layer 4 mode). Supported ITU-T profiles include G.8275.1, G.8275.2 and G.8265.1.

Synchronous Ethernet Test

The synchronous Ethernet (SyncE) configuration test ensures that the Ethernet port is providing a valid SyncE signal. This is defined by physical layer signal frequency and by infrequent Ethernet frames containing synch status messages (SSM) at the expected rate and containing quality level information.

Synchronous Ethernet Wander Analysis

With synchronous Ethernet (SyncE) wander analysis, the Ethernet port of a device under test can be evaluated for the stability of the SyncE interface. The test plots the dTEL and the MTIE and TDEV using dTEL against recommended ITU masks. Two Way TE is likewise plotted.

1 PPS Analysis

The 1 PPS analysis test measures the accuracy of a 1 PPS signal relative to a 1 PPS reference signal, which is often sourced from a portable GNSS satellite receiver. This test provides an indication on the stability of the device under test's clock. The 1 PPS Analysis test basically performs a wander test.

T1, E1, 2 MHz, 10 MHz Wander Analysis

The wander analysis test for T1, E1, 2 MHz, and 10 MHz signals measures the accuracy of one of those signals relative to a 2 MHz or 10 MHz reference signal, which is often sourced from a portable GPS receiver.

Application Use Cases

Antenna Test Applications

Antenna Test – Verifying Connectivity

GNSS satellite constellations are typically used as a time and synchronization references since they continuously broadcast both a time of day value that can be used to derive Coordinated Universal Time (UTC) and a very accurate One Pulse Per Second (1 PPS signal). Satellites receivers are extensively used throughout the 4G LTE Advanced and 5G Radio Access Networks (RANs) as sources of frequency, time and phase synchronization.

The most basic form of antenna test involves ensuring that the cabling system between the antenna and the test point is working properly. The test point can be one of many including the cabling that connects a satellite port on a boundary or master clock, the satellite port on a Distributed Unit (DU) or Baseband Unit (BBU), or the satellite port on a Radio Unit (RU).

- Connect the cabling that will be used on one of the above devices to the satellite port on the T-BERD/MTS-5800 or TEM. You will be able to see satellites signals and get a Sky Plot view as noted below.

- If no satellites are visible, apply a 5V charge to power the antenna. If you cannot still see satellites, then assume there is a problem with the cabling from the antenna to the test point. Either the antenna is not connected to the cable or there is another location where the signal is not propagating across.
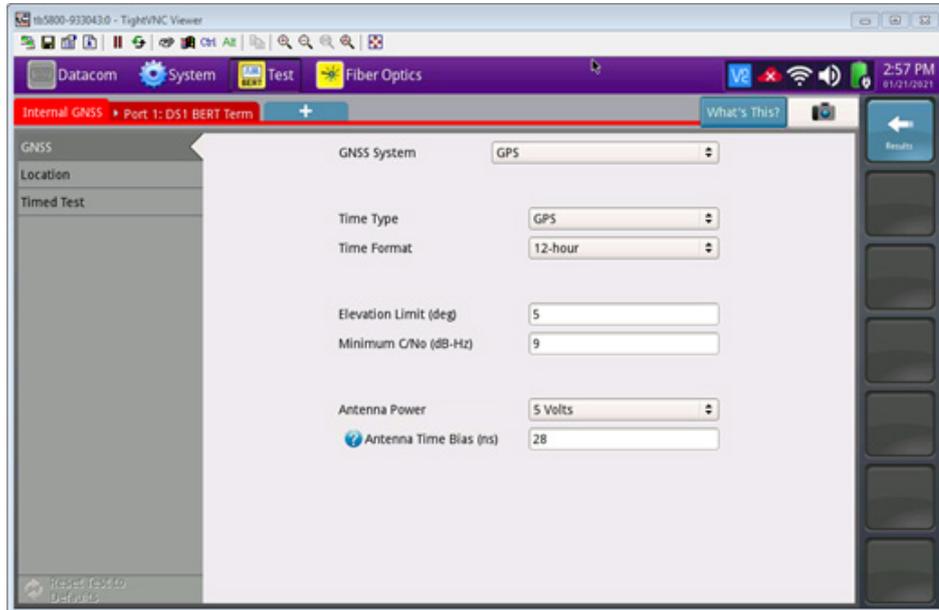
Antenna Test – Basic Measurements

After the cabling system has been verified, the next step is to analyze the information available from connecting to satellite constellations.

- Deployments that use Time Division Duplexing (TDD) over the air technology requires Phase Synchronization. Phase Synchronization is measured via Time Synchronization. In order to properly calculate time, at least 4 satellites are required to calculate an accurate three-dimensional position (altitude, latitude and longitude) on the Earth's geoid. The number of satellites used result should show at least 4 satellites in use.

- The Mean C/No (signal strength) should be greater than 30 dB-Hz in an urban canyon environment. Low signal strength is an indication that the satellites signals are being received after being reflected off other objects are refracted after going through an object such as a wooden roof. In a clear sky environment, the Mean C/No should be greater than 40 dB-Hz. The mean C/No is an average of the signal strengths of all the satellites "in use".

- PDOP is a measure of the Position of Dilution of Precision. In simple terms, the location of the satellite receiver can be better calculated if all the satellites used to calculate the measurement are not bunched up together in the same part of the sky. The further they are spread apart from each other, the better the precision of the calculation. Look for PDOP values in the Excellent (1) to Good (2–5) range. In urban canyon environments this number tends to be higher. In clear sky locations, this number will be closer to 1. Environments where the PDOP is too high should be considered for alternative methods of 1 PPS and Time of Day (ToD) synchronization information.

- 3D Mean Accuracy (mm) is the calculated accuracy of the position. For every meter of inaccuracy, expect a 3.3ns time error. This measurement does not include the propagation delay of any physical media. A value less than 1,000 signifies an accuracy of less than 1 meter and a highly accurate position calculation.

Antenna Test – Advanced Measurements

One of the greatest challenges most mobile network operators face is accurately measuring the propagation delay of the cabling infrastructure between the satellite antenna and the RAN equipment. Some modern installation practices attach converters to the antenna and send the signal over fiber to then convert it back to coaxial. This approach has the benefit of overcoming the attenuation of the satellite signal over long stretches of coaxial cable.

Traditional RAN locations employ surge arrestors between the antenna and the equipment to ensure that a direct lightning strike on the antenna will not damage any equipment that it is connected to. At these locations it is not uncommon to use powered and passive splitters. All these devices increase the delay of the satellite signal from the antenna to the RAN equipment.

Regardless of the approach used, measuring the delay between the antenna and the RAN equipment is key to ensuring that the propagation delay of the satellite signal over the cabling infrastructure is accounted for. A typical coaxial cable or single mode fiber have similar propagation delays. The delay is approximately 4.5ns per meter or 1.2ns per foot, but this can vary with different types of cables. A TDR (OTDR and/or coaxial cable sweep equipment) of the fiber or coaxial cable can help measure the end to end delay of the cable but will not help measure the delay across the above mentioned active and passive components.

Using two T-BERD/MTS 5800s you can measure the delay of the cabling infrastructure between the antenna and the RAN equipment by running a 1 PPS Analysis. The 1 PPS analysis test can be used to perform a longer-term wander measurement but, in this case, a very short-term test is used. To run this test, you will need either two T-BERD/MTS-5882, two T-BERD/MTS-5800 with TEMs or a T-BERD/MTS-5800 with a TEM and a T-BERD/MTS-5882.
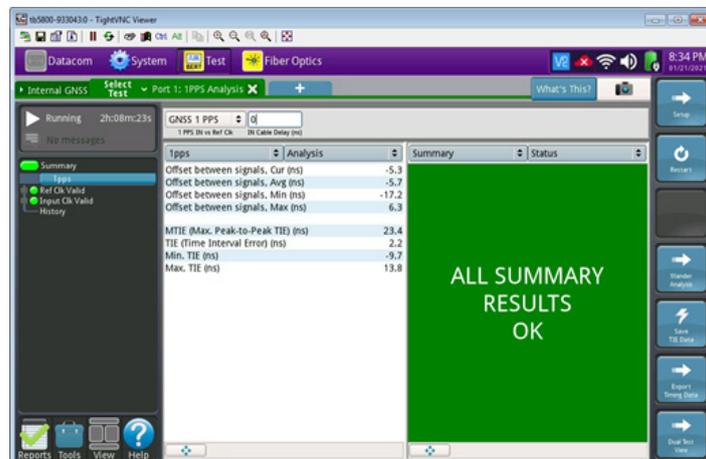
- Connect the VIAVI supplied antenna to the TEM or T-BERD/MTS-5882

- Ensure that the Antenna Time bias is set to the default value of 28ns.

- Perform a 15-minute survey, at a minimum.

- Start the 1 PPS Analysis application

- Connect the cabling under test to the second T-BERD/MTS-5882 or TEM

- Set the antenna time bias to 0.

- Connect the T-BERD/MTS-5882 or TEM's 1 PPS OUT to the second 1 PPS IN of the first test set.

- Go back to the user interface of the first unit. The "Offset between signals. Avg. (ns)" is the value that represents the propagation delay between the cabling under test. If this value is less than 50ns do not adjust.

IEEE 1588–2008 Profiles and Test Applications

Overview

The ITU-T has defined several profiles for using PTP in telecommunications networks. PTP allows for profiles to be defined so PTP can be adapted to different use case scenarios. A profile therefore is a selection of specific PTP configuration options that meet the requirements of a particular use case.

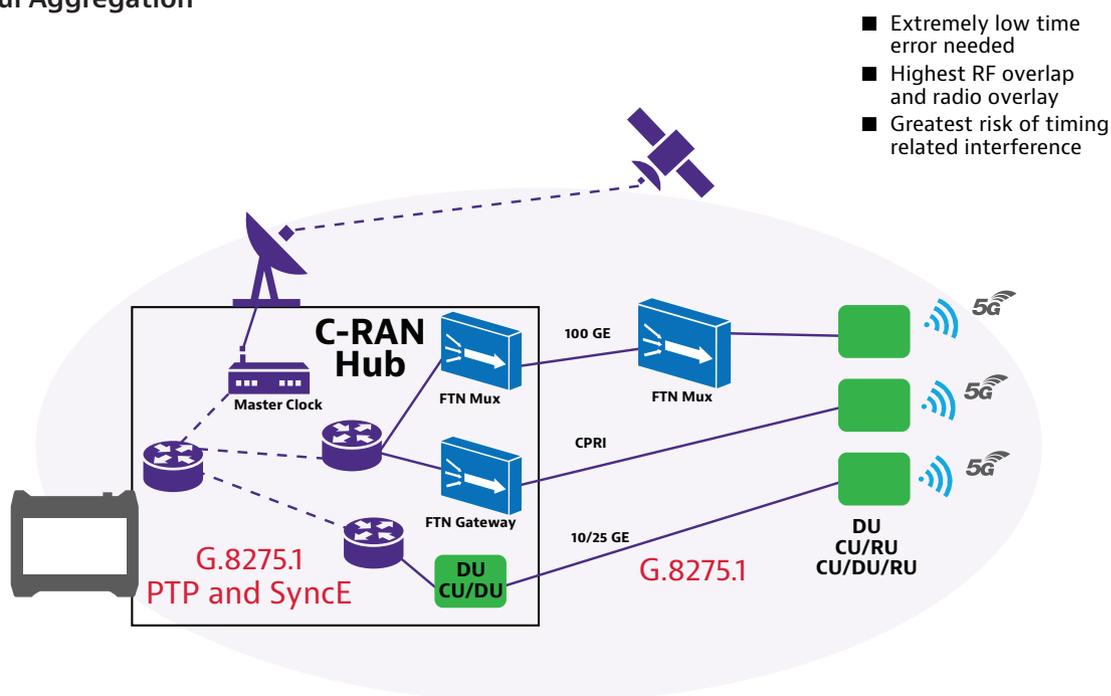| Profile	Profile Name	Transport	Address Mode	Measurement
G.8265.1	Telecom Profile for Frequency Synchronization	UDP (IPv4/IPv6)	Unicast	PTP, Floor Packet Percentile (FPP)
G.8275.1	Telecom Profile for Phase/Time Synchronization, Full Timing Support (FTS)	Ethernet	Multicast	Max TE, cTE, dTE (MTIE/TDEV)
G.8275.2	Telecom Profile for Phase/Time Synchronization, Partial Timing Support (PTS)	UDP (IPv4/v6)	Unicast	Pkt Selected 2W TE APTS: pk to pk PTS: Abs Max

The difference between G.8275.1 & G.8275.2 is that G.8275.2 is used when part or entire part of the network in not timing aware. Such is the case when a backhaul or midhaul segments of the Ethernet network are provided by a 3rd party.
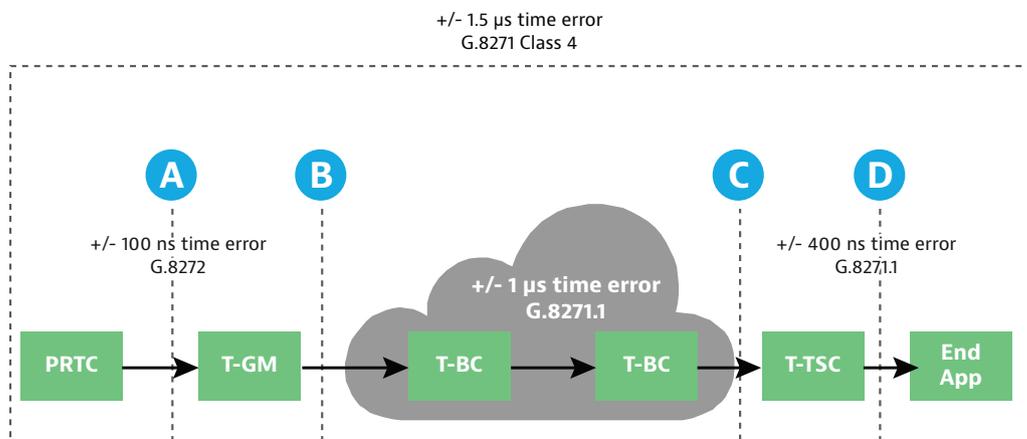
ITU-T G.8271 recommends that Class 4 Networks have an end-to-end Max |TE| of 1.1 μs point A at the input of the telecom grand master (T-GM) to point C at the input of the PTP slave clock (T-TSC). A Class 4 network is one that supports all 4G LTE Advanced and 5G network applications except for location services for emergencies. Also, boundary clocks (T-BCs) have additional requirements depending on their category per G.8273.2. The max |TE|, cTE and MTIE in the table below is a per T-BC time error. The appropriate max |TE| to measure at a specific interface will depend on where in the network the test point is located.

Parameter	Class A	Class B	Class C
max | TE |	100 ns	70 ns	30 ns
cTE	±50 ns	±20 ns	±10 ns
dTE^L (MTIE)	40 ns	40 ns	10 ns

Fronthaul Aggregation

- Extremely low time error needed
- Highest RF overlap and radio overlay
- Greatest risk of timing related interference

Large mobile networks require aggregation points to run efficiently. This is seen most often in large cities where population density requires increased coverage. In these types of situations, the focus is on supporting very tight synchronization requirements via tight boundary clock specifications within the area of coverage where the radios overlap the most. Synchronization with the rest of the network is relaxed but still complies with maintaining a Class 4 Network end-to-end.

Whenever an aggregation point is created such as a C-RAN Hub, the desire to reduce costs will drive the solution away from connecting every DU, BBU, RRH or RU directly to satellite for timing and synchronization. Local master clocks with instead be employed to distribute timing via SyncE and PTP. The cost savings is significant, and the maintenance burden is greatly reduced.

SyncE at the Aggregation Location Only

The typical configuration introduces a local PTP Master Clock. This clock is connected to satellite. The Master Clock will typically supply SyncE to the hierarchy of routers at the aggregation location, connecting directly to the main cell site router. The main cell site router will in turn recover the SyncE frequency from the Master Clock and supply SyncE out all its ports to the other routers. Any equipment at the location can be connected to and recover frequency using SyncE. All Ethernet ports configured to support SyncE can therefore be tested as needed to ensure that SSM messages are propagating across the interface.

At the aggregation point, test access points for 1 and 10 GE SyncE include:

- the Master Clock

- ports on the main cell site router

- ports on the secondary cell site routers

- any xWDM equipment

- BBUs, DUs and CUs

- Fronthaul Transport Multiplexors

- Fronthaul Transport Gateways

Two levels of testing are recommended. The first level involves connecting to the port and seeing if SSM messages are being transmitted. This is a very common first level troubleshooting step or even a basic installation check to ensure that all ports configured properly.

The second level of testing involves performing an Ethernet Wander analysis to confirm the frequency drift of the device under test. These tests are uncommon to perform in a field environment but can be extremely valuable to confirm if a device is drifting because it no longer is receiving, directly or indirectly, SyncE from the Master Clock or from the GNSS satellites. When performing a wander analysis, the appropriate MTIE and/or TDEV masks needs to be selected for the test set to automatically render pass/fail verdicts.

PTP Profile

The main test application with a fronthaul aggregation scenario is testing with PTP. The G.8275.1 Profile calls for a very simple configuration. The PTP protocol is sent over Ethernet frames and multi-casted to all devices on the subnet. The only real thing to configure for the test is the PTP Domain being used which should be set in the 24 to 43 range with 24 being the default. Most installation use Domain 24 since Ethernet subnetting is extensively used to separate the traffic at Layer 2.

Interface rates that commonly carry PTP traffic include 1 GE, 10GE and 25GE interfaces. In networks that use fronthaul transport network multiplexors (FTN), 100 GE interfaces are typically used between the multiplexors, however testing PTP at 100 GE is not very common because it implies performing an out of service test that would affect all traffic between multiplexors.

Typical pass/fail criteria call for measuring max |TE| and cTE. A wander measurement (dTE test) is can be performed as well using ITU supplied masks for MTIE and TDEV.

DU Provided Timing

At specific locations where aggregation is not being used, a DU with a satellite antenna is installed. This scenario is very similar from a connectivity perspective to a 4G setup where the BBU is connected to satellite and it transmits timing and synchronization over the CPRI interface to an RRH. The difference is that in this scenario the timing and synchronization is being provided using PTP and SyncE.

This scenario will also use the ITU-T G.8275.1 and SyncE profiles as previously described in the fronthaul aggregation application. The test points include any 10GE or 25GE interfaces on the DUs and RUs as well as any fronthaul transport network multiplexors and xWDM equipment to which the DU and RU may connect.
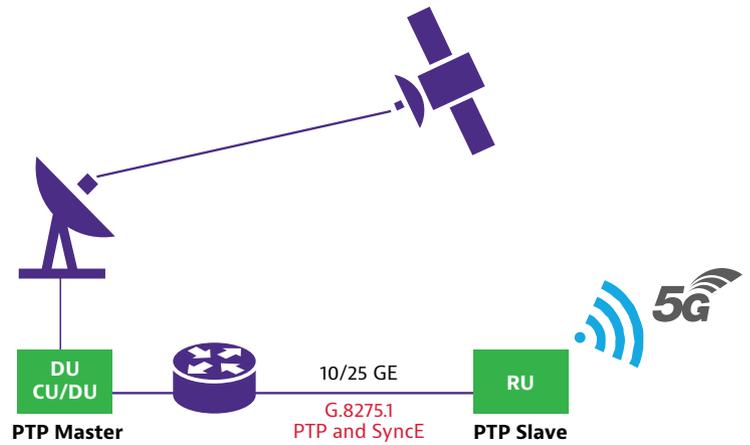
## DU Provided Timing with Subtending (Daisy Chaining) RUs

In other specific locations where aggregation is not being used, a DU with a satellite antenna could be serving as a master clock to multiple RUs. This scenario is also similar from a connectivity perspective to a 4G setup. However, in this scenario the first RU which connects directly to the DU must also act as a boundary clock to the other RUs that connect to it. If more than two (2) RUs are daisy chained, each RU, except the last one, needs to perform as a boundary clock and correct any noise received from the prior boundary clock. In other words, it should act as a low pass filter for frequencies from 0.05 through 0.1 Hz.

This scenario still uses the ITU-T G.8275.1 and SyncE profiles as previously described. The test points include any 10GE or 25GE interfaces on the DUs and RUs as well as any fronthaul transport network multiplexors and xWDM equipment to which the DU and RU may connect. Particular attention should be placed on testing Sync PDV at boundary clock locations to characterize filtering performance.
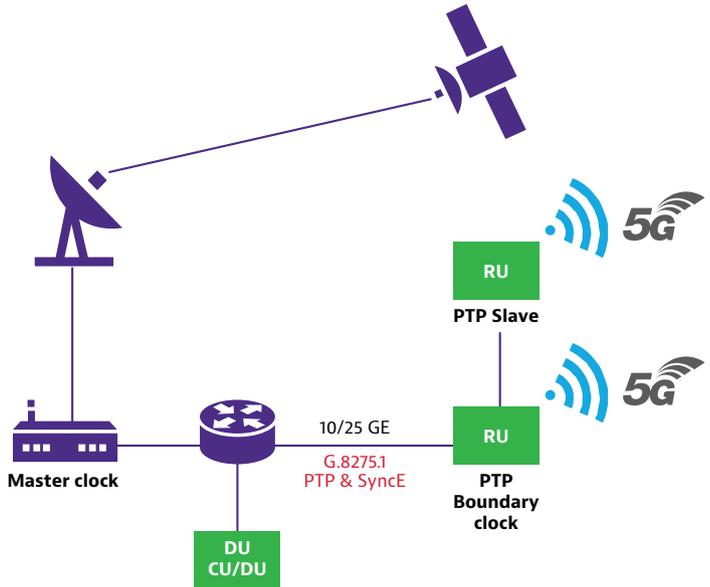
Aggregated Networks with 3rd Party Network Segments

Class 4 synchronization requires a 1.5 µs max |TE| end-to-end. However, there are times when portions of the network are provided by third parties. The G.8275.2 profile with support for Assisted Partial Timing Support (APTS) can be used to meet requirements. The default PTP Domain for these networks is 44 with the range of valid domain numbers spanning 44 to 63. Implementing a G.8275.2 network creates a distributed timing architecture to improve the accuracy and resiliency of the timing network.
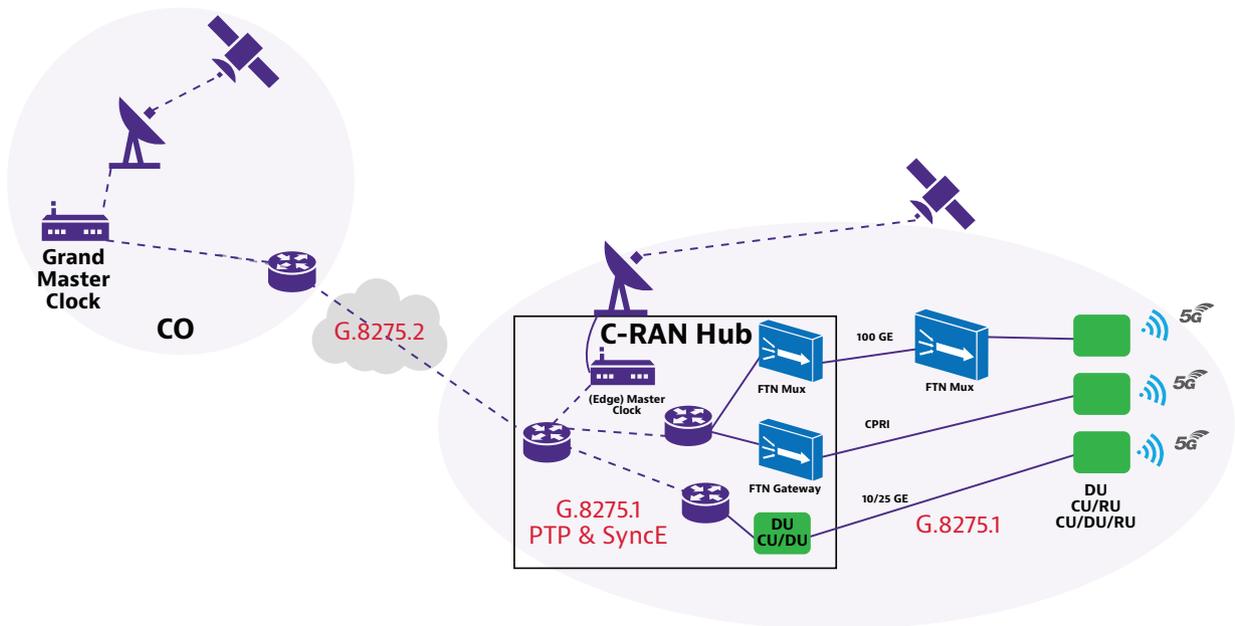

In this scenario a local Master clock is inserted in the design at an aggregation location to drive satellite-based timing and synchronization accuracy and to support Ethernet based multicast PTP messages to routers, CU/DU/RUs, gateways and multiplexors. This local master clock is connected back to a true grand master located at a more centralized part of the network such as a Mobility Switching Office/Central Office.

The PTP packets are typically sent unicast between the grand master and the local master clock. These are sent using IPv4 or IPv6. The most common field deployments use a separate port on the master clock at the aggregation point to exchange the PTP unicast packets. The main cell site router will use a VLAN to segregate this traffic. None of the devices at the aggregation point other than the main cell site router and the "Edge" Master clock see this traffic.

To measure the performance of PTP over the 3rd party network segment, ITU-T recommends using a packet select two-way time error measurement (pktSelected2wayTE). In this APTS scenario, the result is calculated peak-to-peak. The methodology of the measurement applies a low-pass filter to the selected packets. G.8271.2 specifies the pass/fail criteria. It is expressed in terms of taking the filtered packets in a 200 second window duration and measuring that the peak-to-peak max |TE| does not exceed 1,100 ns across 0.25% of samples in either direction between the grand master and the local master clock.

## Partial Timing Support as a backup to Satellite Based Timing

In networks where satellite-based timing is extensively deployed already, PTP can be used as a backup to satellite in case it goes down, typically due to weather. This approach is called Partial Timing Support (PTS). In this scenario DUs and CU/DUs will have a direct connection to satellite but will also exchange IPv4/IPv6 encapsulated PTP packets with a grand master clock.
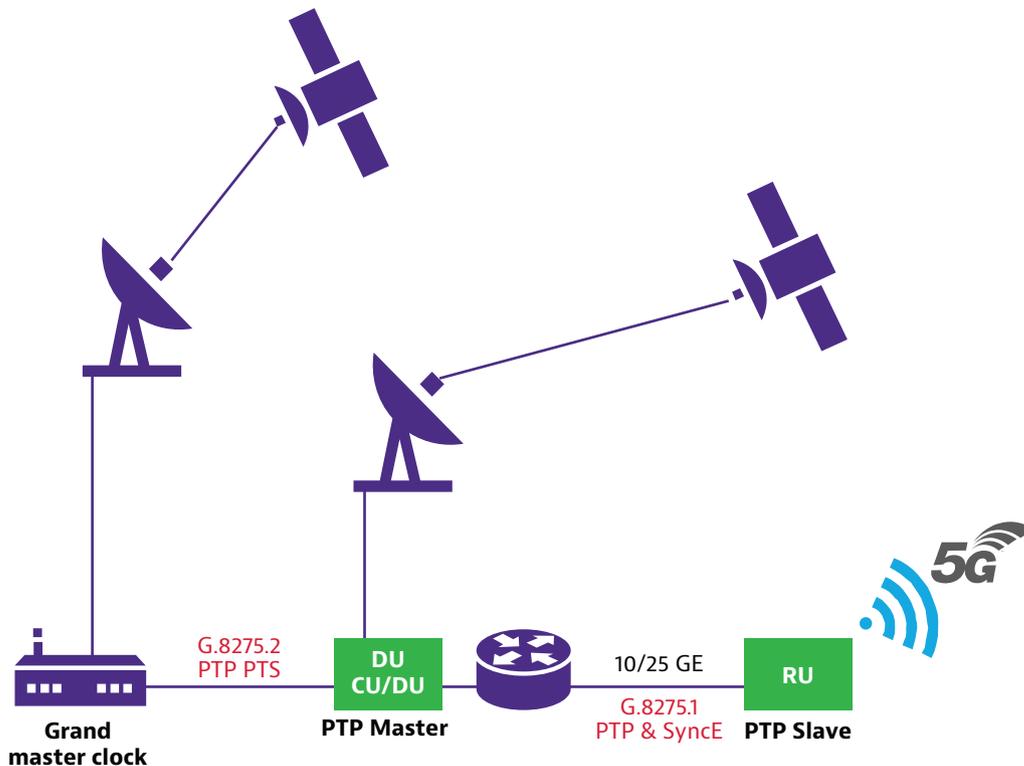
Similar to the APTS approach already mentioned, the PTS measurement methodology applies a low-pass filter to the selected packets. The pass/fail criteria are expressed in terms of taking the filtered packets and measuring that the absolute max |TE| over the lifetime of the measurement to ensure it does not exceed 1,100 ns. A 200 second window is still used and 0.25% of samples are taken in either direction between the grand master and the local master clock.

Frequency Distribution over Packet Networks

PTP can be used to distribute frequency over a packet network by using the G.8265.1 profile. The typical network configuration that uses PTP in this way is very similar to the one mentioned above for APTS. However, the goal is different. PTP used for frequency distribution is used to stabilize the oscillator of a clock in case the 1PPS signal that is recovered from satellite is no longer present. The PTP frequency profile is therefore useful for both DUs trying to keep frequency and phase synchronization with CUs and RUs as well as with BBUs using CPRI to maintain RRHs synchronized. Older RAN equipment implementations used FTP for backup to satellite.
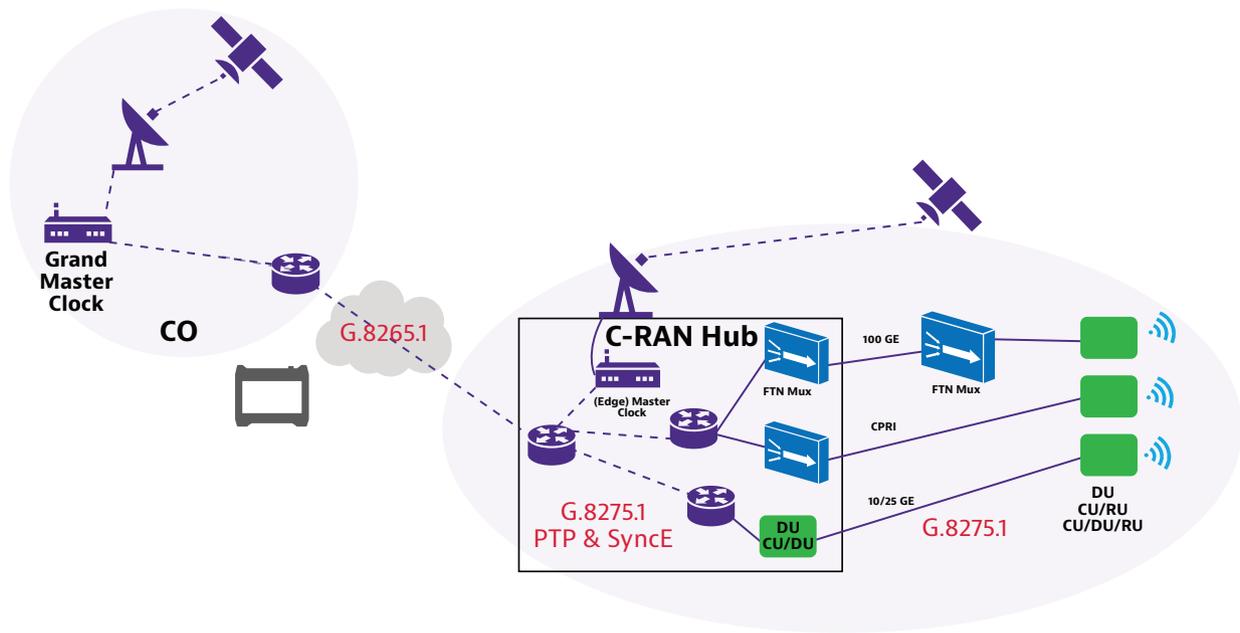
The use case for PTP Frequency synchronization typically uses a one-step PTP master that does not send out a FollowUp message with an additional time stamp. In this regard, a one-step master will reduce bandwidth utilization on a network. A G.8265.1 network send out PTP messages in IPv4/IPv6 packets and send them out unicast to specific slaves that sign up to receive the messages.

Measuring the performance of these networks uses the ITU Floor Packet Percentile (FPP) Measurement as described in ITU G.8260. The FPP measurement is conducted in windows, typically 200 second windows per the recommended default. The received packets are filtered and measured against the fastest packet received in the window. The default methodology uses a 150 µs cluster to calculate the difference between the fastest packet and the one received. The expectation is that 1% of the received packets should be within this cluster so the receiving slave clock can use the received PTP packets to recover frequency. The fastest packet value is then carried over and used in subsequent windows.

Commonly Performed Field 1PPS Measurements

A One Pulse Per Second (1PPS) measurement is not commonly performed in most field scenarios. However, having clocks and instruments with a 1 PPS output allows the usage of the T–BERD/MTS to compare the stability of the device under test to the 1PPS received from satellite.

ITU recommends a dynamic time error measurement dTE be performed by measuring MTIE and TDEV over a period of time and comparing them to recommended ITU-T masks. The T-BERD/MTS-5800 supports applying different ITU-T MTIE and TDEV masks from G.8271.1, G.8272 and G.8273.2 to measure T-BC, PRTC, and slave (T-TSC) performance.

The typical 1 PPS Analysis test performed in the field is not a long-term Wander analysis. Most people using this test, deploy it to get a rough order of magnitude deviation from the satellite provided 1 PPS in ns as previously described in the advanced antenna measurement section.
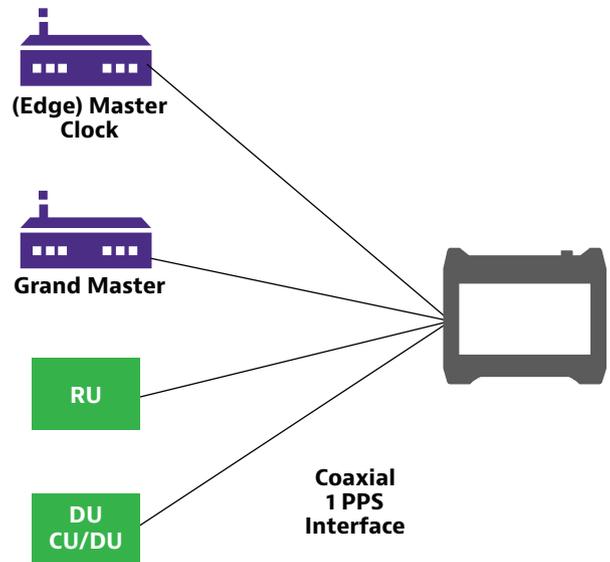
Ordering Information

Description	Part Number
T-BERD/MTS-5811P and T-BERD/MTS-5822P	Various packages are available. Please contact your sales representative for a free initial consultation
T-BERD/MTS-5882	
T-BERD/MTS-5800-100G	
MAP-2100	
Timing expansion module (TEM)	C5TEM-R
10/100/1000 Mbps and 1 GE Optical IEEE 1588v2 (PTP)	C5LS1588
10GE Optical IEEE 1588v2 PTP	C510G1588
25GE Optical IEEE 1588v2 PTP	C525G1588
1 PPS, 2 MHz and 10 MHz Timing and Clock Analysis	C5TIMING
1 GE Optical SyncE (SSM Messages)	C5LSSYNCE
10 GE Optical SyncE (SSM Messages)	C510GESYNCE
1 GE Optical Ethernet Wander	C5LSETHWANDER
10 GE Optical Ethernet Wander	C510GETHWANDER
PDH (DS1, DS3, etc.) Rx and Tx Electrical Wander	C5PDHWND
Ethernet One-Way-Delay Test 10/100/1000, 1GE, 10GE	C5OWD
Ethernet One-Way-Delay Test 25GE, 40GE and 100GE	C5100GOWD
GNSS Option (T-BERDs with built-in GNSS, MAP-2100)	C5GNSS