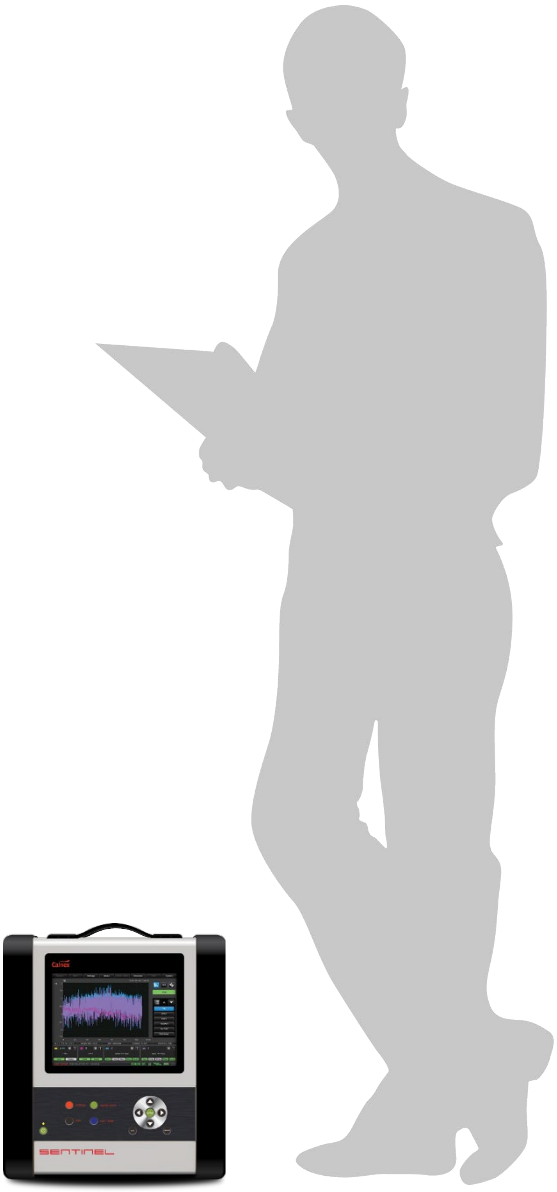
Field Test Plan for Frequency Synchronization using PTP

Calnex Sentinel



Frequency synchronization is critical for all mobile technologies. PTP synchronization to NodeB or eNodeB devices must meet tight ITU-T standard specifications as well as vendor specific limits.

This test plan provides field test procedures to ensure high quality synchronization for 3G or LTE mobile backhaul networks running the PTP protocol.

This test plan is applicable to ALu, Ericsson, Huawei, NSN, and ZTE base stations, and to Huawei, ALu, Cisco, Tellabs, ZTE, Juniper, Ericsson and other cell-site routers/PTN equipment.

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Note: All measurement data shown can be imported to the Calnex Analysis Tool (CAT)[1] for detailed analysis.

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[1] Sentinel includes a single copy of CAT

1 Background

Frequency synchronization is critical for all mobile technologies.

The requirements for different mobile technologies are listed in the table below.

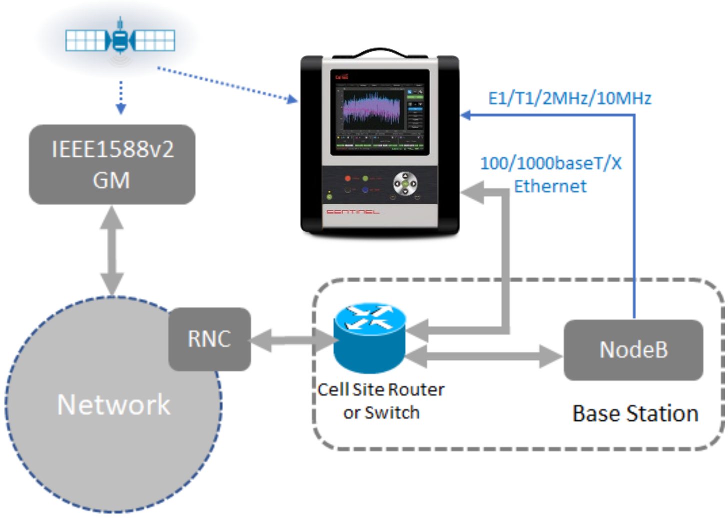
Application	Frequency	Time	Packet Backhaul Spec
CDMA2000	±50 ppb	±3 to 10 µs	
TD-SCDMA	±50 ppb	±1.5 µs	
GSM	±50 ppb	n/a	±16 ppb (G.8261.1)
WCDMA	±50 ppb	n/a	±16 ppb (G.8261.1)
LTE (FDD)	±50 ppb	n/a	±16 ppb (G.8261.1)
LTE (TDD)	±50 ppb	±1.5 µs (<3 km cell radius) ±5 µs (<3 km cell radius)	±16 ppb (G.8261) ±1.1 µs (for ±1.5 µs G.8271.1)
LTE-A MBSFN	±50 ppb	±1 to 5 µs Implementation dependent	±16 ppb (G.8261.1) ±1.1 µs (for ±1.5 µs G.8271.1)
LTE-A CoMP	±50 ppb		
LTE-A eICIC	±50 ppb		
Small Cells	±100 ppb	n/a (FDD) ±1.5 µs (TDD) ±1 to 5 µs (eICIC)	±33 ppb ±1.1 µs (for ±1.5µs G.8271.1)
Home Cells	±250 ppb	n/a (FDD) ±1.5 µS (TDD)	±100 ppb ±1.1 µs (for ±1.5 µs G.8271.1)

Note: The 50 ppb frequency stability requirement is at the Air interface. For the mobile backhaul, it is accepted that this translates to a requirement of 16 ppb. For small cells, the requirements are 100 ppb at the Air interface and 33 ppb for the mobile backhaul.

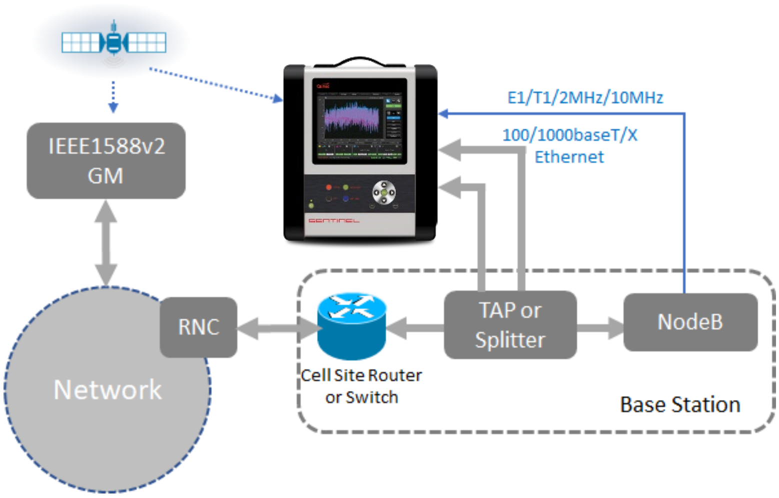
2 Test Setup

Sentinel works as a PTP[2] pseudo slave connecting to a switch or a router in the network. It can also work in Monitor Mode, connecting between the PTP master and slave via an optical splitter or electrical TAP. It measures the performance of the network and the performance of the recovered clock simultaneously. Common interfaces for recovered frequency measurements are E1/T1/2MHz/10MHz.Typical field test setups using Sentinel are shown below.

2.1 Pseudo-slave Mode: Sentinel connects to cell site router.



2.2 Monitor Mode: Sentinel connects to TAP or splitter.



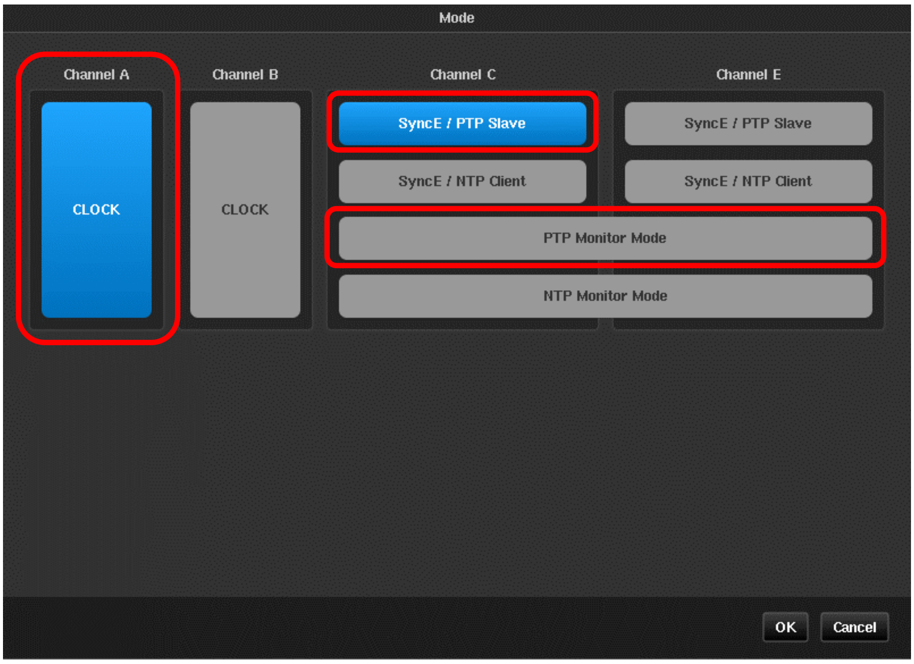
[2] See Appendix A

3 Test Configuration

Before performing any measurements, follow the steps below.

3.1 Operating Mode

From the **Mode** page configure Sentinel operating mode. For Pseudo PTP slave operation select one channel as **SyncE / PTP Slave,** for monitor mode select **PTP Monitor Mode**. For each recovered clock being tested, select a **CLOCK** channel.



NOTE: Each clock module supports the simultaneous measurement of 2 input clocks with frequencies ranging from 0.5Hz to 200MHz.

NOTE: Running in monitor mode requires 2 packet modules.

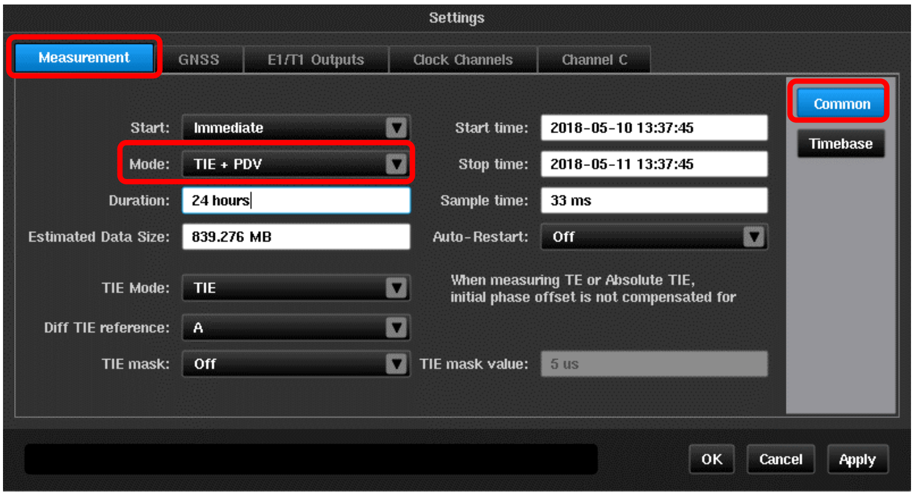
NOTE: If not operating in monitor mode packet modules can be configured for any combination of NTP Client or PTP Slave operation.

NOTE: Sentinel automatically measures the TIE of the SyncE recovered clock of any configured PTP / NTP channel.

3.2 Measurement Mode

From the main GUI display window, select **Settings > Measurement > Common**.

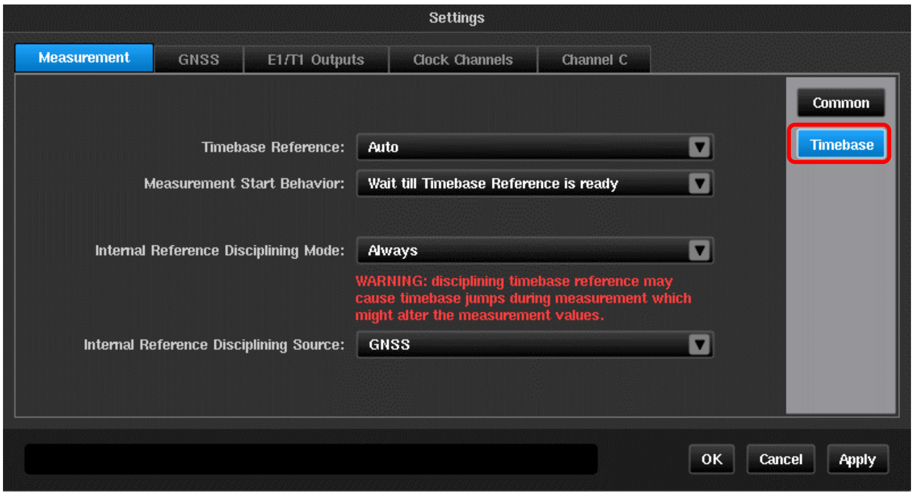
Set **Mode** to **TIE + PDV** and set the required test duration. The recommended test duration is 24 hours for normal network performance test. If intermittent issues occur in the network, a longer test duration may be required in order to capture the intermittent issues.



3.3 Time Base

Set Sentinel to use the **Internal** clock as time base reference and choose **GNSS** signal as the **Internal Reference Disciplining Source**. Set **Measurement Start Behavior** to **Wait till Timebase Reference is ready**, and **Internal Reference Disciplining Mode** to **Always** if a GNSS reference is available. Otherwise, set to **Not during the measurement** if no reference is available.

For other options of time configurations, please consult Sentinel user manual[3]



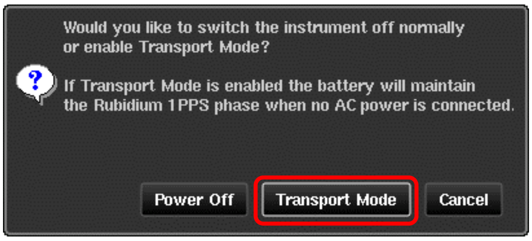
NOTE: From a cold start, it takes around 15 minutes for the internal Rubidium timebase to warm up. With the GNSS antenna connected, the GNSS receiver needs to lock to at least 3 satellites before it can output a valid reference to the Rubidium for disciplining. If less than 3 satellites are locked, the Rubidium will go into holdover.

NOTE: If no GNSS signal is availabile at the test site, the internal Rubidium can be disciplined in advance by applying a GNSS signal in the lab before going on site. The embedded battery on the Sentinel will keep the Rubidium in holdover during the transportation from lab to the field by setting Sentinel into transport mode. To achieve high accuracy, it is recommended to train the Rubidium in the

[3] Calnex Document CX3001

lab for at least 12 hours. If Sentinel was last disciplined less than a week ago, this time can be shortened to 6 hours.

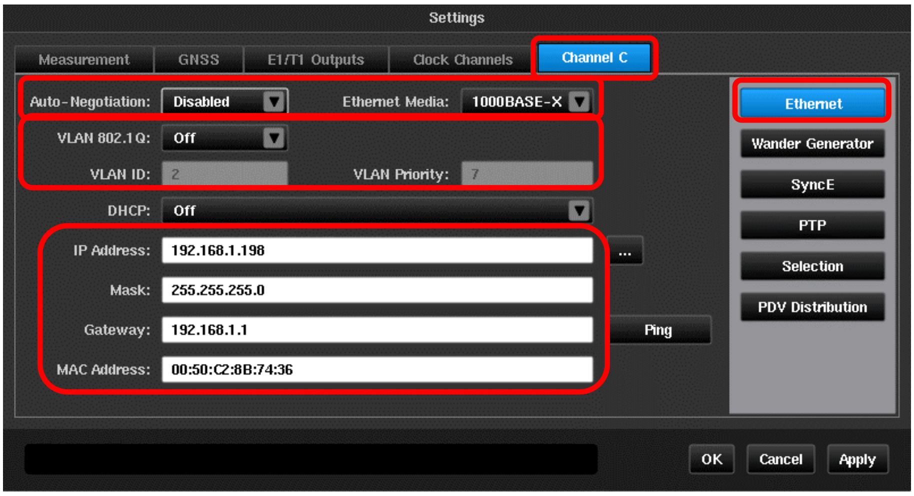
NOTE: To put Sentinel in Transport Mode, press the button on the front panel. The following window will be displayed. Click on **Transport Mode**.



NOTE: Without mains power supply, the battery can keep the internal Rubidium powered for up to 3 hours. Once mains power is supplied again, the Rubidium will be powered by the main supply and the battery will start to re-charge.

3.4 Physical Interface Setup

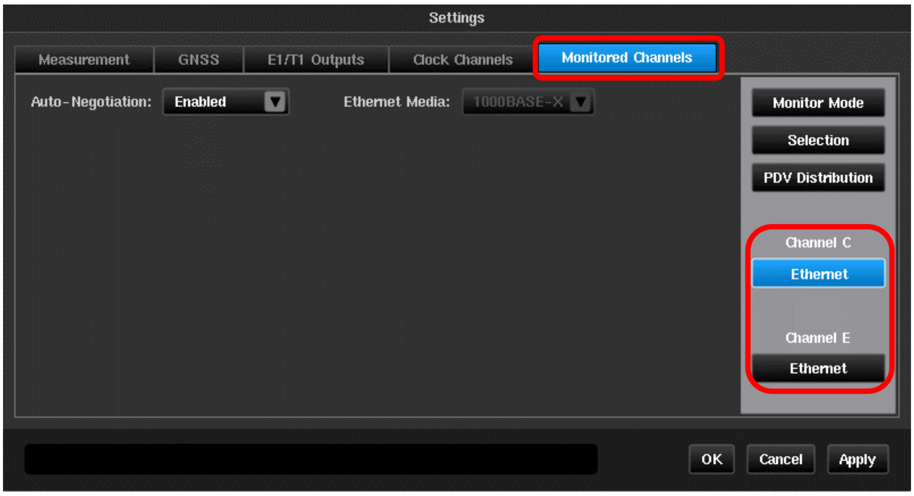
Each packet module that is being used should be configured to match the media that it is connected to. For PTP Pseudo Slave mode this is done through the **Settings > Channel *x* > Ethernet** page.



Ensure that the physical media properties match the properties of the port being connected to. Any required VLAN configuration should be entered. If a DHCP server is not being used then the IP properties should be manually entered.

NOTE: Prior to testing, an IP address should have been provisioned by the operator along with details of the network mask and gateway address.

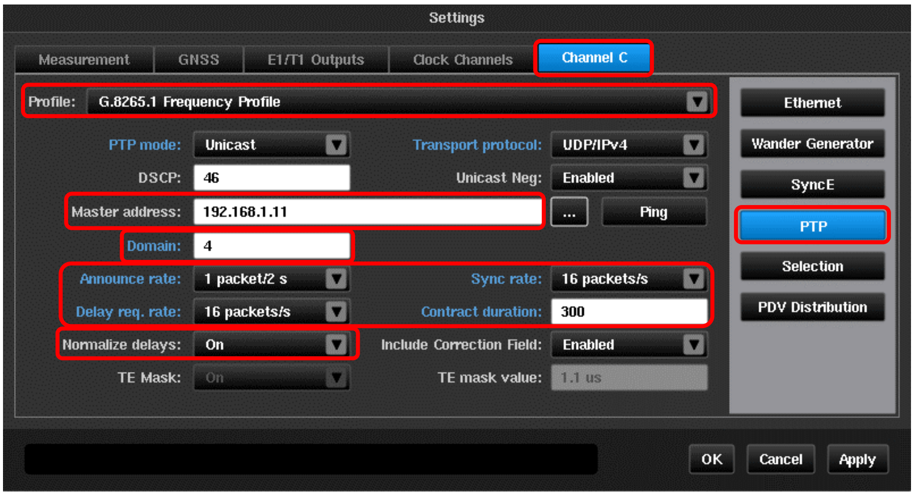
For monitor mode the media properties can be set through the **Settings > Monitered Channels > Ethernet** page.



There is an Ethernet page for both channels used and these should be set to the same values. Electrical TAPs may require **Auto-Negotiation** to be **Enabled** while optical splitters generally require a fixed rate to be entered.

3.5 PTP Setup

In Pseudo Slave mode, select **G.8265.1 Frequency Profile** on the **Settings > Channel *x* > PTP** page, then configure the PTP slave related parameters i.e. Domain, Master address, and packet rates as required. Ensure **Normalize delays** is **On**.

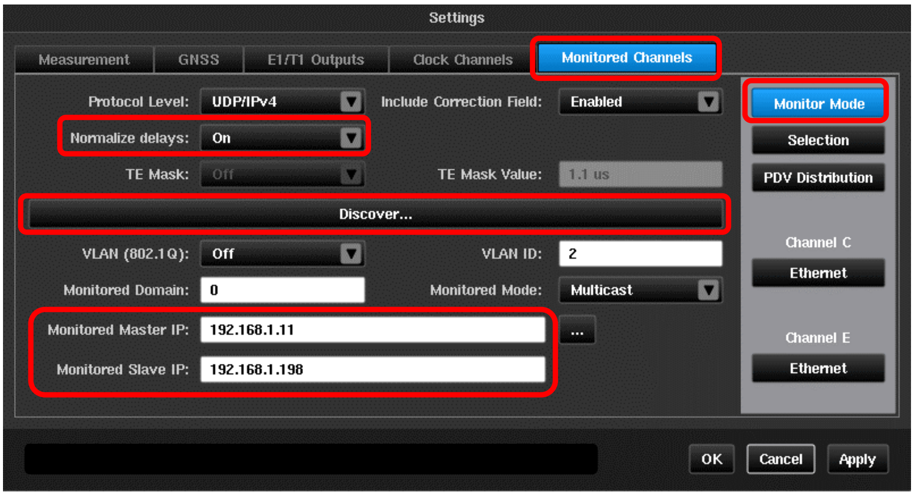


NOTE: Ensure the IP address of the Sentinel pseudo-slave is provisioned before going out into the field.

NOTE: ITU-T G.8265.1 profile requires the slave to negotiate the message rates with the IEEE1588 GM. Ensure that the message rates entered for Sentinel can be supported by the IEEE1588 GM.

In monitor mode the PTP GM / Slave pair to be monitored can be configured on the **Settings > Monitored Channels > Monitor** Mode page. This can be configured manually or the **Discover** function used. Pressing the **Discover** button will bring up a pop-up box with a list of all PTP flows detected. Selecting the appropriate flow will cause the **Monitored Domain**, **Master IP** and **Slave IP** boxes to be automatically populated along with the appropriate protocol and transport options.

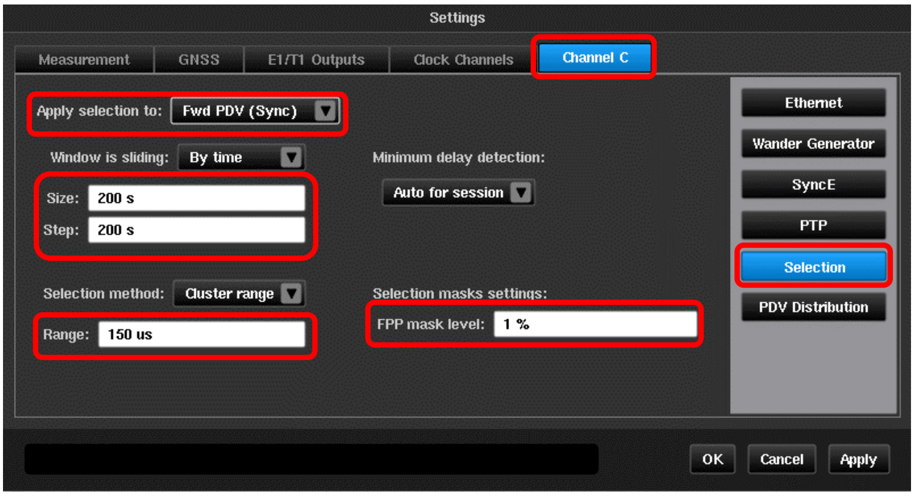
Ensure **Normalize delays** is set to **On.**



3.6 Packet Selection for FPP Measurements to G.8261.1

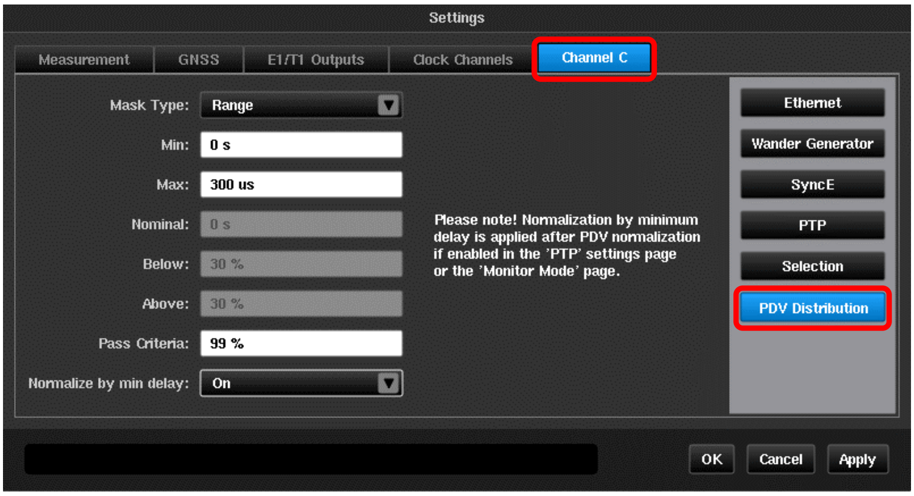
From the **Settings > Channel x > Selection** or **Settings > Monitored Channels > Selection** page, configure the packet selection parameters as follows.

1. Select **Fwd PDV (Sync)** from the **Apply selection to** dropdown box.
2. Set the parameters for packet selection.
3. Set Pass/Fail **FPP mask level** to 1% for FPP analysis. Please refer to appendix C for the ITU-T definition of FPP



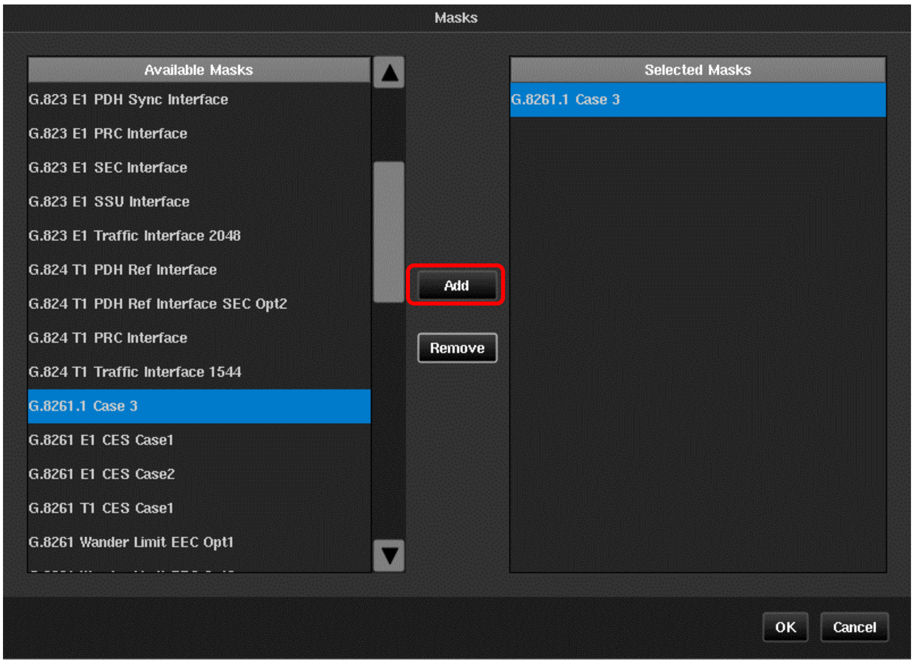
3.7 Vendor Specific Network PDV Distribution (PDD) Pass/Fail Criteria

Configure the Pass/Fail criteria for Packet Delay Distribution (PDD) analysis. This Pass/Fail criteria is vendor specific. Please consult vendors for parameters. If vendor has no specification for network PDV, then there is no need to configure this page.



3.8 Select Recovered Clock Mask

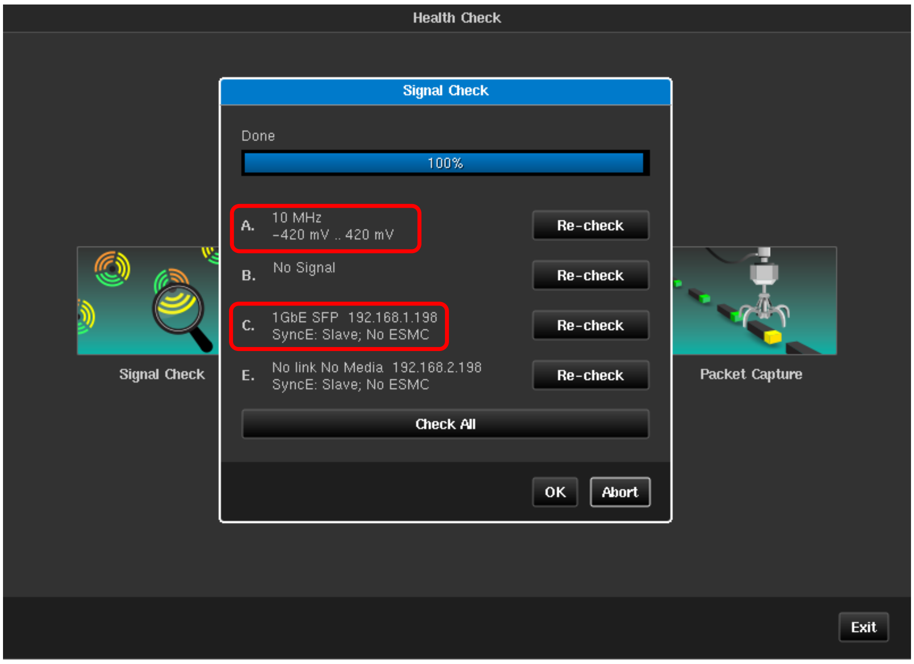
Select clock metric related masks from the **Masks** tab. Mask **G.8261.1 Case 3** is recommended for network conformance test. This mask is explained in Appendix B.



3.9 Signal Check

1. Click on the **Health Check > Signal Check** button.

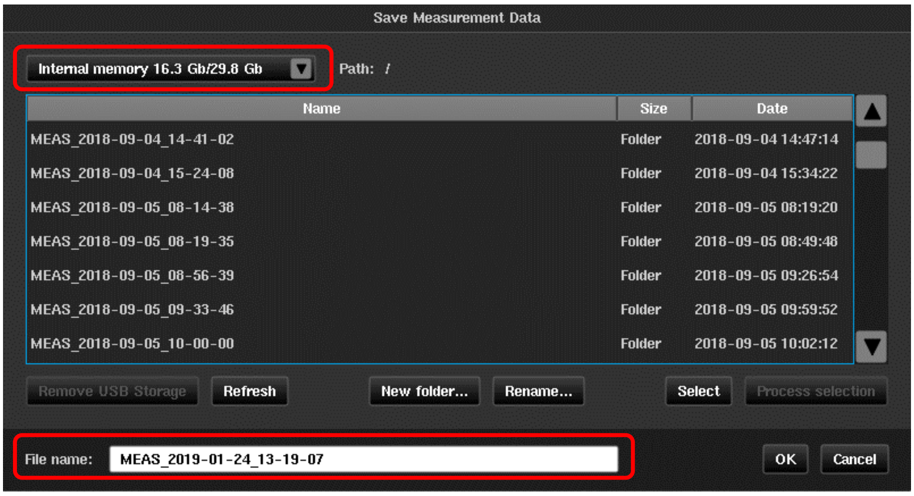
2. Make sure the signal check detects the expected signals. An example screen shot is shown below.



3.10 Start the Test

1. Click on the **Start** button.

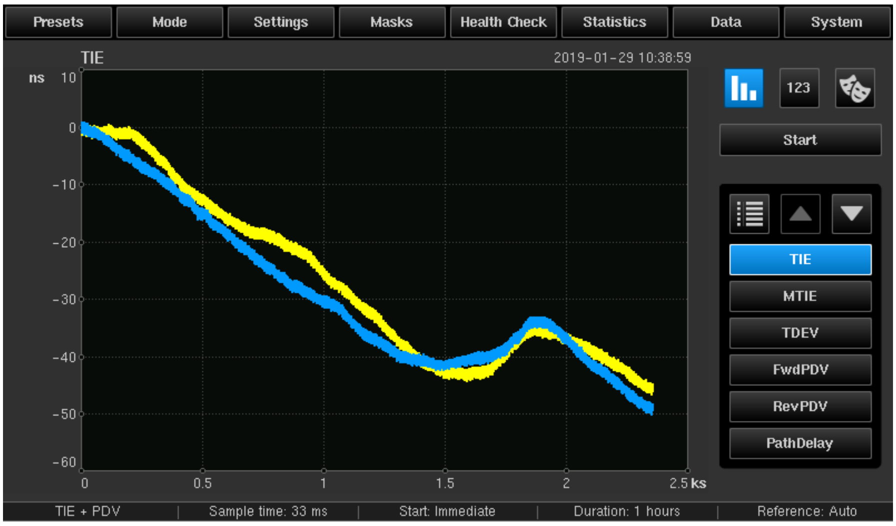
2. Sentinel will prompt you to select where to store the measurement results. The results can be either saved on Sentinel or external USB sticks.



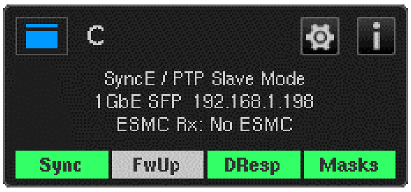
NOTE: For longer term measurements, it is always recommended to use external USB memory sticks to ensure sufficient storage space.

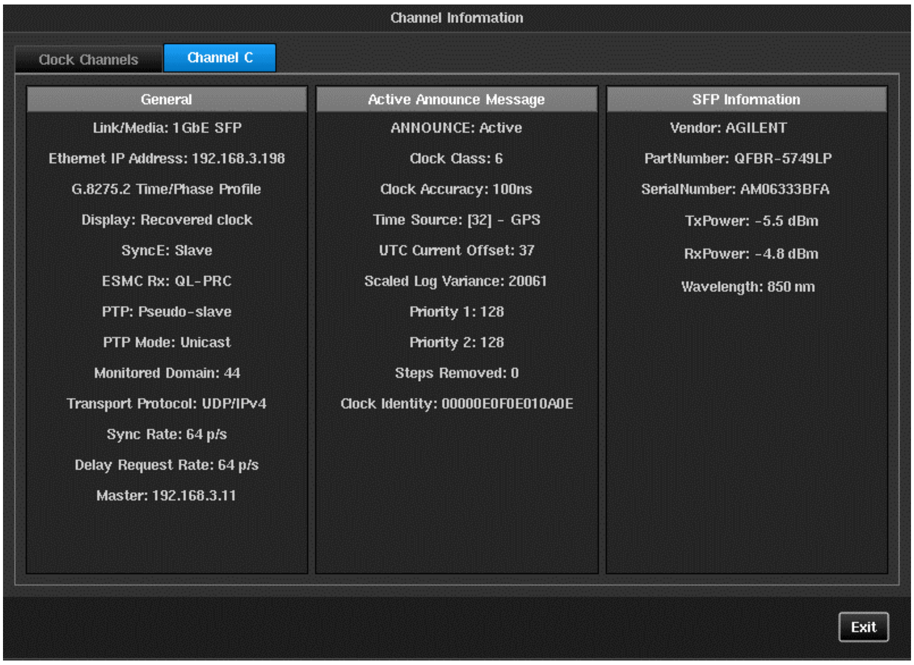
4 Measurement Results Display

Once the measurement starts, the TIE graphs of the recovered clock and SyncE will be displayed on the main GUI window. All TIE graphs will be displayed in the same window, but highlighted in different colors.



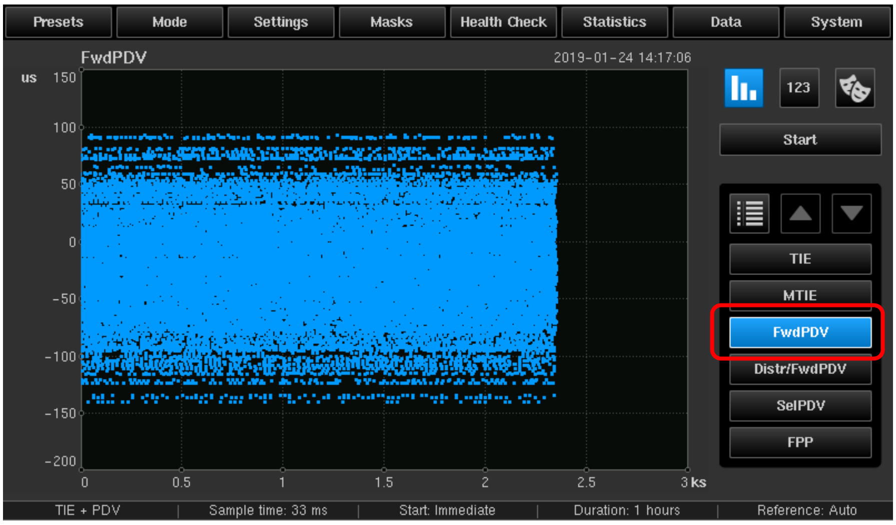
If the PTP GM and the Sentinel emulated Slave establish the session successfully, the negotiated parameters will be displayed in the channel specific widget as below and on the information page accessed by pressing the button.





Pressing the top left button on the channel widget gives the option of hiding the graph or bringing it to the foreground.

The PDV for the forward direction (from GM > slave) is also graphed. To view PDV for forward direction click on the **Fwd PDV** button.



NOTE: Sentinel also graphs the PDV for the reverse direction (Slave > GM). If **Normalize delays** is set to **Off**, Sentinel can also calculate Path Delay and 2Way Time Error. These metrics are not required or quantified for frequency synchronization.

5 Test Cases

The following Test Cases 5.1 and 5.2 evaluate the performance of the network and the recovered clock against the ITU-T G.8261.1 recommendation. Test Cases 5.3, 5.4 and 5.5 provide further troubleshooting and debugging information to perform further analysis on the results of 5.1 and 5.2.

Note: All test cases can run at the same time, that is, ONE single test.

5.1 Network PDV to ITU-T G.8261.1

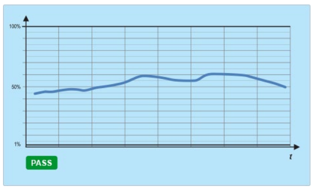
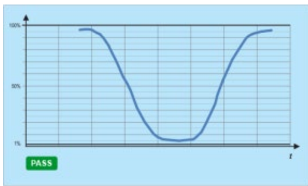
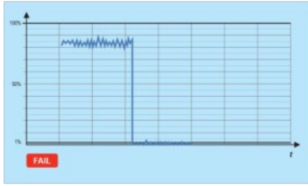
The Floor Packet Percent (FPP) metric is specified in ITU-T G.8260 and is used to evaluate the Network PDV. Pass/Fail evaluation is compared against the limit specified in ITU-T G.8261.1. Please refer to the Appendix for more information.

5.1.1 FPP Measurement and Analysis

To view FPP, click on the **FPP** button on the metrics menu. The Pass/Fail mask and the FPP graph will be displayed in the same window. The test fails if the FPP value ever falls below the mask.

Presets
Mode
Settings
Masks
Health Check
Statistics
Data
System
FPP
2019-01-29 11:14:49
%
90
80
70
60
50
40
30
20
10
0
0
0.5
1
1.5
2
2.5 ks
123
Start
TIE
MTIE
FwdPDV
Distr/FwdPDV
ESMCQuality
FPP
TIE + PDV
Sample time: 33 ms
Start: Immediate
Duration: 1 hours
Reference: Auto
A
10 MHz
Clock
Masks
Channel B
SWITCHED OFF
C
SyncE / PTP Slave Mode
1GbE SFP 192.168.1.198
ESMC Rx: No ESMC
Sync
FwUp
DResp
Masks
Channel E
SWITCHED OFF

5.1.2 Sample FPP Test Results

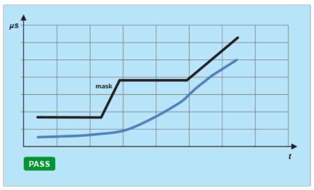
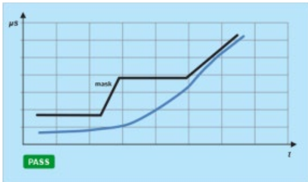
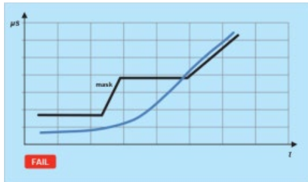
Example Results			
	Above FPP limit - Pass	FPP close to limit	FPP below limit - Fail
Possible Causes	n/a	• Priority setting wrong • Network congestion • Re-route event • Network equipment failure	• Priority setting wrong • Network congestion • Re-route event • Network equipment failure
Possible Impact	n/a	• Congestion causes depopulation of the floor delay • Re-routes move the floor, reducing "headroom' for the FPP analysis	• Congestion causes depopulation of the floor delay • Re-routes move the floor, eliminating all packets within the cluster range
Next Action	n/a	• Visual inspection for re-routes and/or congestion • If re-route event occurs, segment the data into separate data sets • Apply FPP analysis separately to each data set • If congestion, check PTP running at highest priority. • Check for over-subscription of allocated data rate • Measure further back in the network	• Visual inspection for re-routes and/or congestion • If re-route event occurs, segment the data into separate data sets • Apply FPP analysis separately to each data set. • If congestion, check PTP running at highest priority • Check for over-subscription of allocated data rate • Measure further back in the network

5.2 Recovered Clock Stability to ITU-T G.8261.1[4]

5.2.1 Compare with MTIE Mask

To view MTIE and compare with the mask, click on the **MTIE** button. The G.8261.1 mask will also appear in the same display area as a dashed line. Multiple masks can be selected at the same time for comparison. The screenshot shows the 10MHz and SyncE recovered clocks wander measurement. The test passes if the clock MTIE is always below the mask.

5.2.2 Sample G.8261.1 Test Results

Example Results			
	Within G.8261.1 limits	Close to G.8261.1 limits	Outside G.8261.1 limits
Possible Causes	n/a	• The network PDV is stressing the slave to its limit with the current network configuration • Network equipment failure	• The network PDV is too stressful for the slave • The priority setting for PTP packets may be too low • The traffic level in the network may be too high • Temperature variation may impact the performance of clocks • Network equipment failure
Possible Impact	n/a	• Interference at air interface • Drop calls • Handover failure • Slow data transmission	• Interference at air interface • Drop calls • Handover failure • Slow data transmission
Next Action	n/a	• Share the PDV capture with the PTP slave vendor (and NodeB vendor if external slave is used) • Replay the PDV in the lab to troubleshoot and adjust the slave algorithm to increase margin • Consider re-routes and/or re-engineering the network to reduce PDV stress • Measure further back in the network • Re-test	• Share the PDV capture with PTP slave vendor (and NodeB vendor if external slave is used) • Replay the PDV using Paragon-X in the lab to troubleshoot and adjust Client algorithm to enable it to pass mask • Consider re-routes and/or re-engineering the network to reduce PDV stress • Measure further back in the network • Re-test

[4] ITU-T G.8261.1 specifies the wander limit at the clock out interface of a PTP client

5.3 PTP Packet-to-Packet PDV Capture

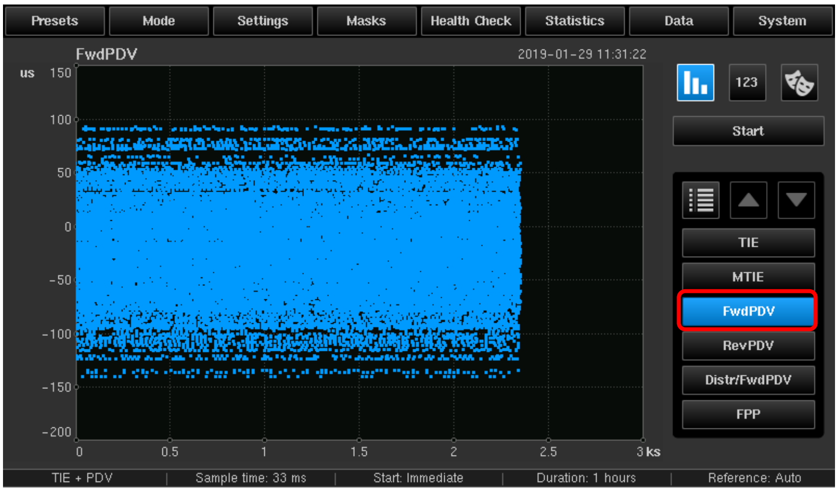
The PTP PDV graph gives information such as:

- Average/standard deviation of PDV
- Delay jumps due to routing changes

From the PDV graphs, post-analysis can be performed on the data such as packet metrics. These PDV files can be sent back to the operator's lab or the vendor's R&D center's to reproduce the exact same PDV conditions experienced by the slave in the network and take remedial action.

5.3.1 View PDV Graph

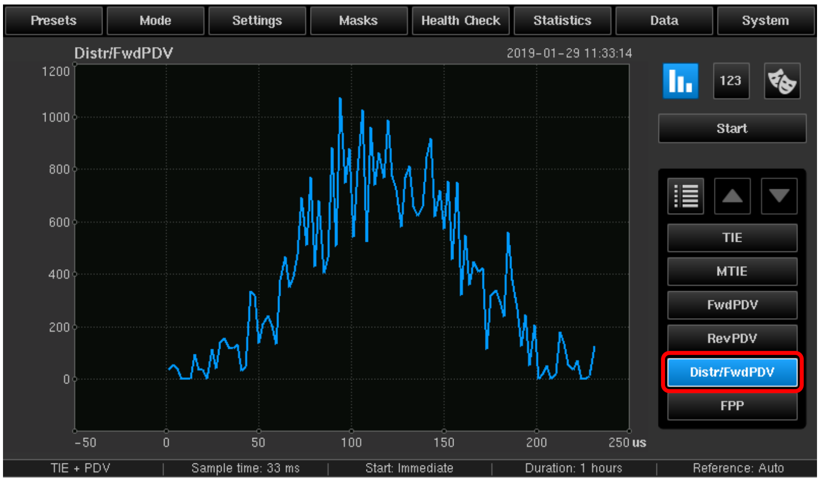
To view the PDV graphs for Sync, Del-Request and Path Delay, click on Fwd PDV (Sync), Rev PDV (Del-Req), and Path Delay from the measurement menu.`



5.4 Packet Delay Distribution (PDD) Analysis

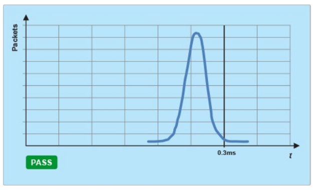
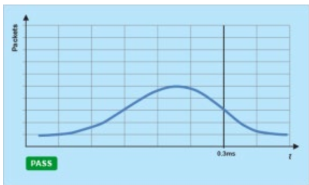
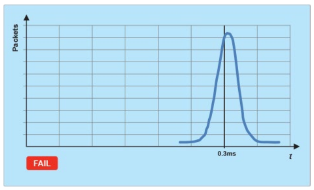
Performing PDD analysis is important for many vendor's NodeB equipment. Many NodeB devices have a specification where the distribution of the packets should meet particular limits.

5.4.1 Analyze and View PDD



To analyze PDD on the Sentinel, select **Distr/Fwd PDV** metrics menu.

5.4.2 Sample PDD Test Results

Example Results			
	Within PDD limits - Pass	PDD close to limits	PDD outside limits - Fail
Possible Causes	n/a	• Priority setting wrong • Network congestion • Re-route event • Network equipment failure	• Priority setting wrong • Network congestion • Re-route event • Network equipment failure
Possible Impact	n/a	• Congestion causes depopulation of the floor delay • Re-routes move the floor, reducing “headroom’ for the PDD analysis.	• Congestion causes depopulation of the floor delay • Re-routes move the floor, eliminating all packets within the cluster range.
Next Action	n/a	• Visual inspection for re-routes and/or congestion • If re-route event occurs, segment the data into separate data sets • Apply PDD analysis separately to each data set • If congestion, check PTP running at highest priority. • Check for over-subscription of allocated data rate. • Measure further back in the network	• Visual inspection for re-routes and/or congestion • If re-route event occurs, segment the data into separate data sets • Apply PDD analysis separately to each data set • If congestion, check PTP running at highest priority. • Check for over-subscription of allocated data rate. • Measure further back in the network

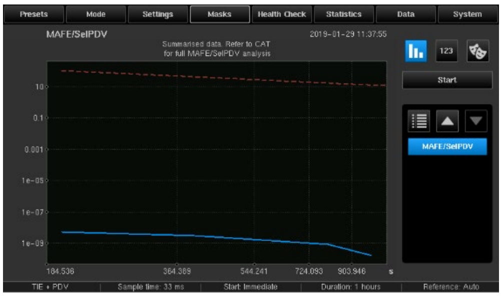
NOTE: Consult each vendor for their specific Pass/Fail PDD limits. These limits are not available from the ITU-T standards.

5.5 MAFE (Maximum Average Frequency Error)

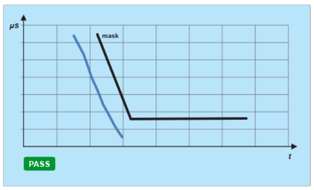
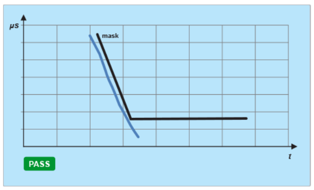
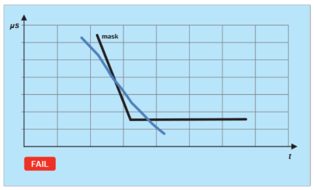
MAFE is a metric specified in ITU-T G.8260 that can be used to analyze the Network PDV further. In particular, this is a metric used to evaluate Network PDV when PTP Slaves integrated into Nokia Systems Networks' FlexiBTS are used.

5.5.1 MAFE Calculation and Analysis

Before performing PDV capture, configure the packet selection parameters and select packet metrics related to masks.



5.5.2 Sample MAFE Test Results

Example Results			
	Within MAFE limits	MAFE close to limits	MAFE outside limits
Possible Causes	n/a	• Priority setting wrong • Network congestion • Re-route event • Network equipment failure	• Priority setting wrong • Network congestion • Re-route event • Network equipment failure
Possible Impact	n/a	• Congestion causes depopulation of the floor delay • Re-routes move the floor, reducing "headroom' for the MAFE analysis.	• Congestion causes depopulation of the floor delay. • Re-routes move the floor, eliminating all packets within the cluster range.
Next Action	n/a	• Visual inspection for re-routes and/or congestion. • If re-route event occurs, segment the data into separate data sets. • Apply MAFE analysis separately to each data set. • If congestion, check PTP running at highest priority. Also check for over-subscription of allocated data rate. • Measure further back in the network	• Visual inspection for re-routes and/or congestion. • If re-route event occurs, segment the data into separate data sets. • Apply MAFE analysis separately to each data set. • If congestion, check PTP running at highest priority. Also check for over-subscription of allocated data rate. • Measure further back in the network

6 Test Results Interpretation

6.1 With Slave Clock Output

Slave Clock Output (5.2) / Network PDV (5.1)	**Pass**	**Fail**
Pass	OK	Contact PTP Slave vendor * Please refer to the “next action” in section 5.2
Fail	Network PDV is high but PTP slave can work OK with it **	Network re-route or re-engineer may be required. Please refer to the “next action” in sections 5.1 and 5.2

* Network PDV has been deemed to meet FPP limits. However, Network PDV packet-to-packet analysis as well as Packet Delay Distribution (5.3, 5.4, and 5.5) should also be analyzed and sent to the PTP Slave vendor to allow troubleshooting.

** Although the PDV is OK for this PTP slave, any software update to the slave or using a different PTP slave in the network, may cause a failure. It is advised that further testing is performed to validate the slave's performance.

6.2 Without Slave Clock Output

In case of no clock output from the slave, always check the measurement results from section 5.3, 5.4 and 5.5 for further actions.

Note: This test procedure focusses on frequency synchronization using PTP. Please refer to other test documents from Calnex for frequency synchronization using NTP[5] and synchronization test for TDD-LTE.[6]

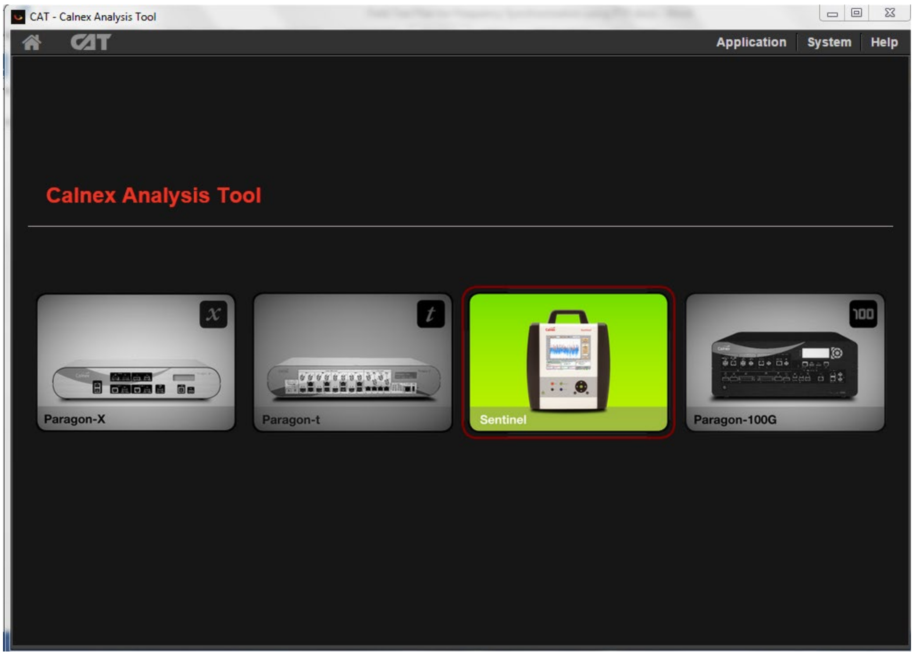
If any files other than those required for the metric were loaded then they can be de-selected or closed from the Select File page.

[5] Calnex Document number CX5017
[6] Calnex Document number CX5019

7 Offline Analysis and Report Generation using CAT

7.1 Overview

The Calnex Analysis Tool (CAT) is standalone software for MTIE/TDEV, MAFE, FPP and PDD analysis. The captured raw data from Sentinel[7] can be imported to CAT for comprehensive metric analysis, including pass/fail masks. Reports are easily generated with a single click from CAT, presenting results to your customers/colleagues in a professional manner.



7.2 Selecting ITU-T G.8261.1 Metrics in CAT

By default CAT will determine which metrics to display based on the type of measurement files that are loaded. This can lead to clutter and may indicate a false failure on metrics and limits that are not specific to ITU-T G.8261.1.

Copy the measurement files from Sentinel to the PC that CAT is running from. Either open all the .dset files from CATs Select File tab or drag and drop all the .dset files onto the CAT window.

Sentinel generates the following .dset files:

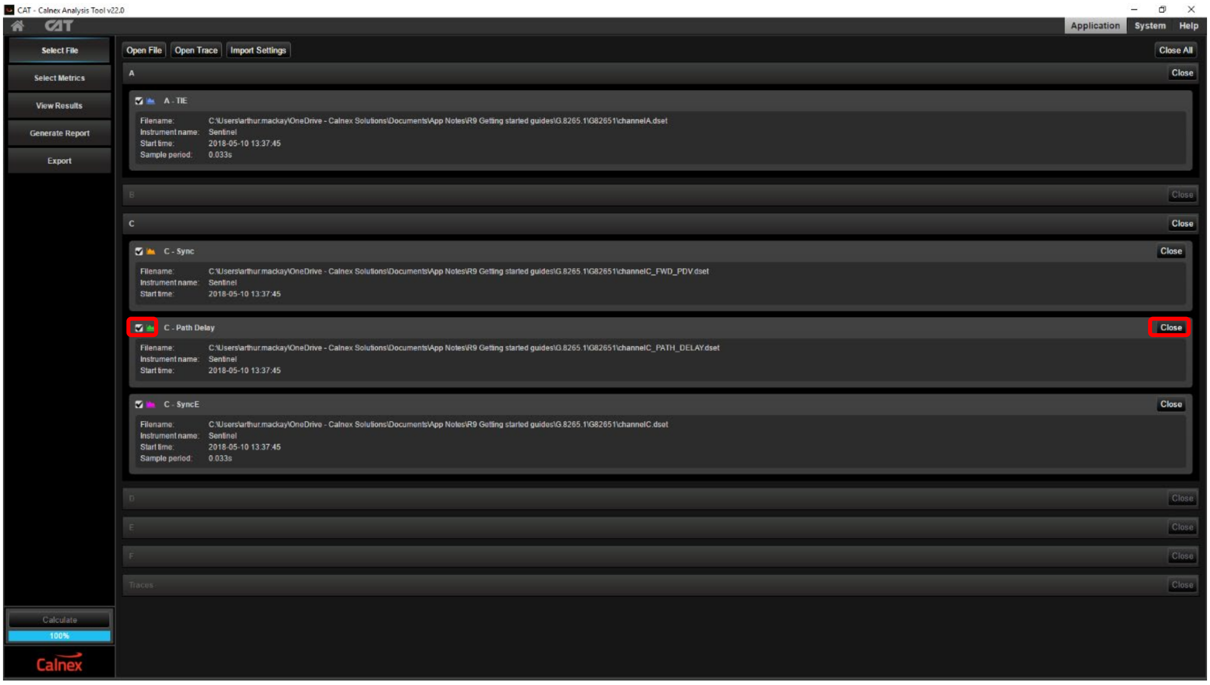
- channel*X*.dset – Raw TIE data for a clock or reference channel
- channel*X*_ESMC_QUALITY.dset – SyncE SSM message transitions
- channel*X*_FWD_PDV.dset – Raw PDV calculated from PTP Sync messages
- channel*X*_REV_PDV.dset – Raw PDV calculated from PTP Delay Request / Delay Response messages
- channel*X*_PATH_DELAY.dset – calculated PTP path delay.

Where *X* is the associated measurement channel A to F.

NOTE: Only channelA.dset and channelC_FWD_PDV.dset need to be loaded to generate the ITU-T G.8261.1 metrics for this test setup. If the SyncE recovered clock is to be verified then channelC.dset should also be loaded.

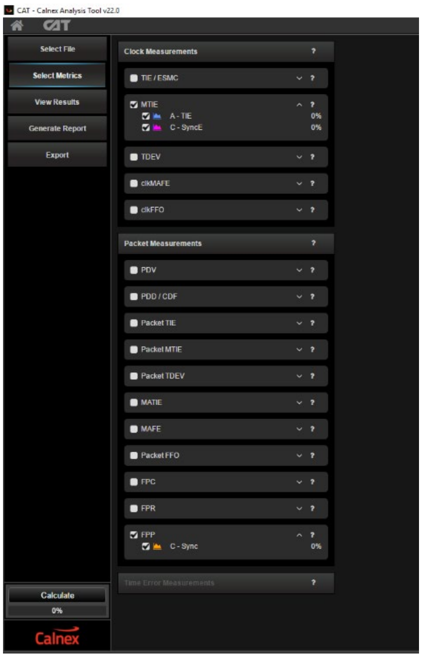
[7] Data can also be imported from Calnex Paragon-X and Calnex Paragon-t products

If any files other than those required for the metric were loaded then they can be de-selected or closed from the **Select File** page



7.3 Selecting Metrics

Select required metrics for analysis from **Application > Select Metrics** after the measurement files have been imported.

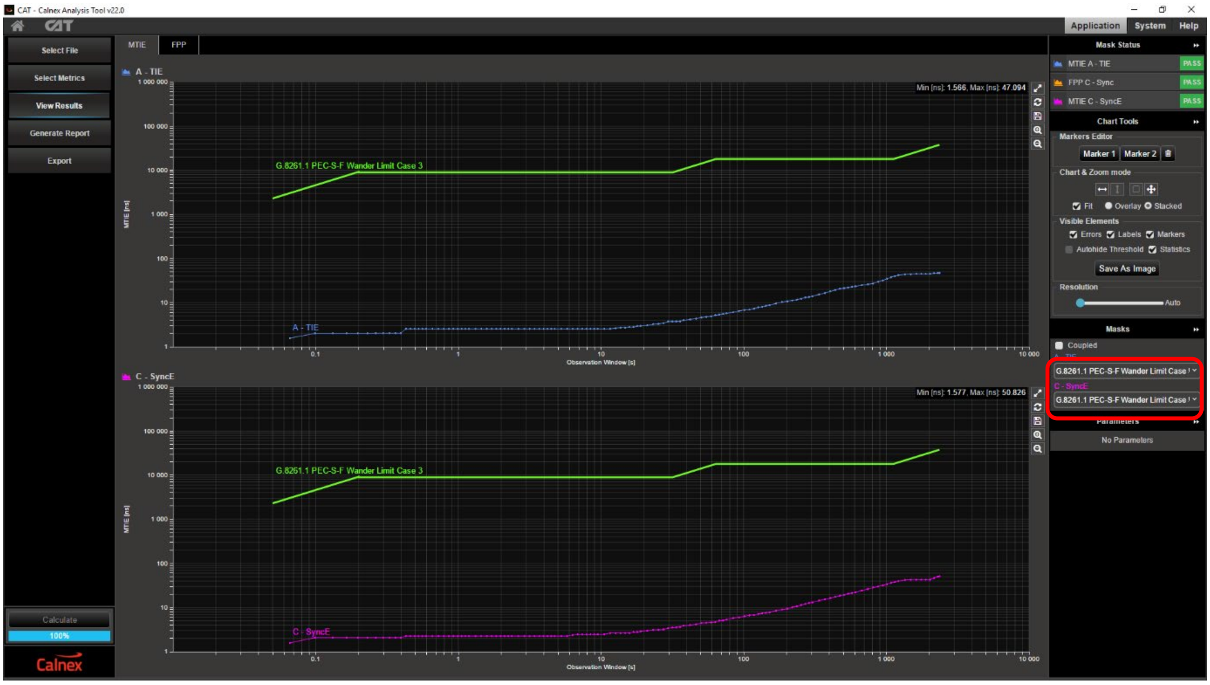


The clock measurements box should enable MTIE for the 10MHz recovered clock (A TIE) and SyncE recovered clock (C – SyncE) if that is being tested.

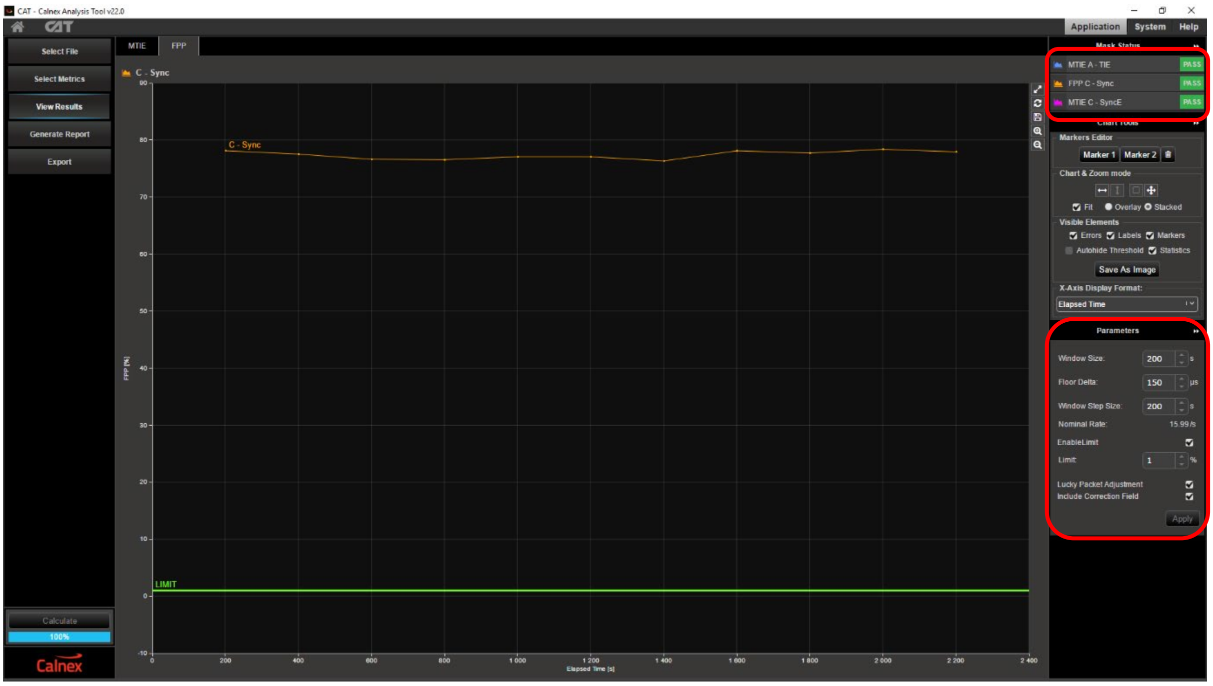
FPP should be enabled in the packet measurements box.

All other metrics should be cleared. Press the **Calculate** button to generate the metric data.

The ITU-T G.8261.1 recovered clock mask is set on the **MTIE** tab on the **View Results** page.

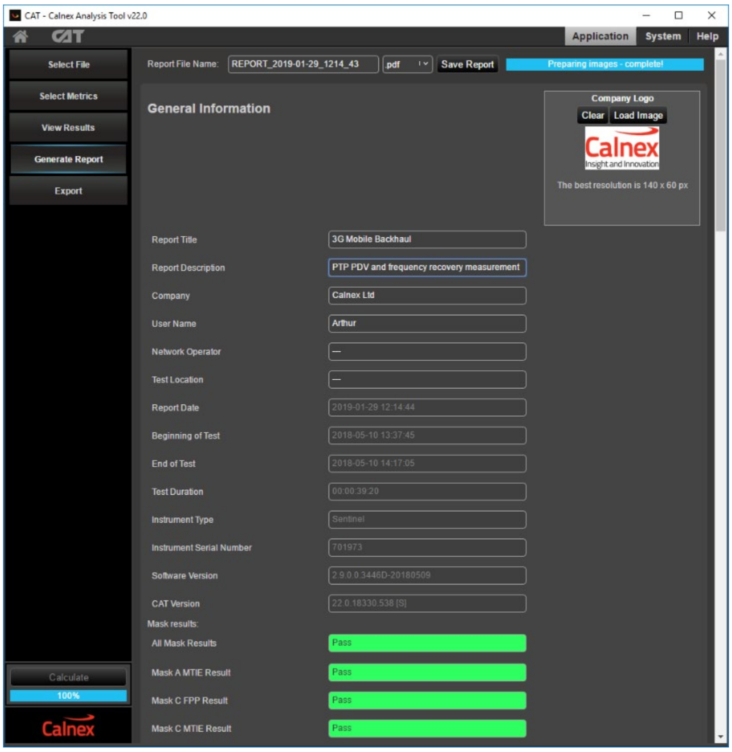


The FPP results can be viewed on the **FPP** tab. By default the parameters are set for the ITU-T G.8261.1 limits but can be adjusted if necessary. A summary of the Pass / Fail status of each metric is shown in the top right corner.

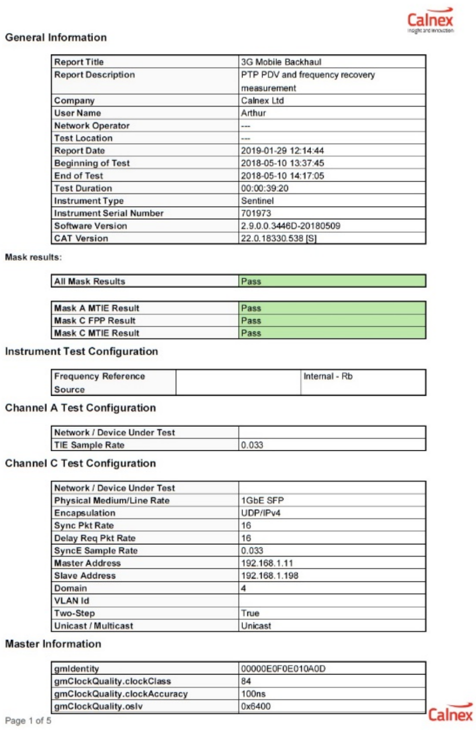


7.4 Generating a Report[8]

To create a report, simply click on "Generate Report" from CAT GUI.



Front cover shows General and Test Configuration, with Pass/Fail clearly indicated.



Calnex

General Information

Report Title	3G Mobile Backhaul
Report Description	PTP PDV and frequency recovery measurement
Company	Calnex Ltd
User Name	Arthur
Network Operator	---
Test Location	---
Report Date	2019-01-29 12:14:44
Beginning of Test	2018-05-10 13:37:45
End of Test	2018-05-10 14:17:05
Test Duration	00:00:39:20
Instrument Type	Sentinel
Instrument Serial Number	701973
Software Version	2.9.0.0.3446D-20180509
CAT Version	22.0.18330.538 [S]

Mask results:

All Mask Results	Pass

Mask A MTIE Result	Pass
Mask C FPP Result	Pass
Mask C MTIE Result	Pass

Instrument Test Configuration

Frequency Reference Source		Internal - Rb

Channel A Test Configuration

Network / Device Under Test	
TIE Sample Rate	0.033

Channel C Test Configuration

Network / Device Under Test	
Physical Medium/Line Rate	1GbE SFP
Encapsulation	UDP/IPv4
Sync Pkt Rate	16
Delay Req Pkt Rate	16
SyncE Sample Rate	0.033
Master Address	192.168.1.11
Slave Address	192.168.1.198
Domain	4
VLAN Id	
Two-Step	True
Unicast / Multicast	Unicast

Master Information

gmIdentity	00000E0F0E010A0D
gmClockQuality.clockClass	84
gmClockQuality.clockAccuracy	100ns
gmClockQuality.oslv	0x6400

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Calnex

[8] See Appendix D for an example report

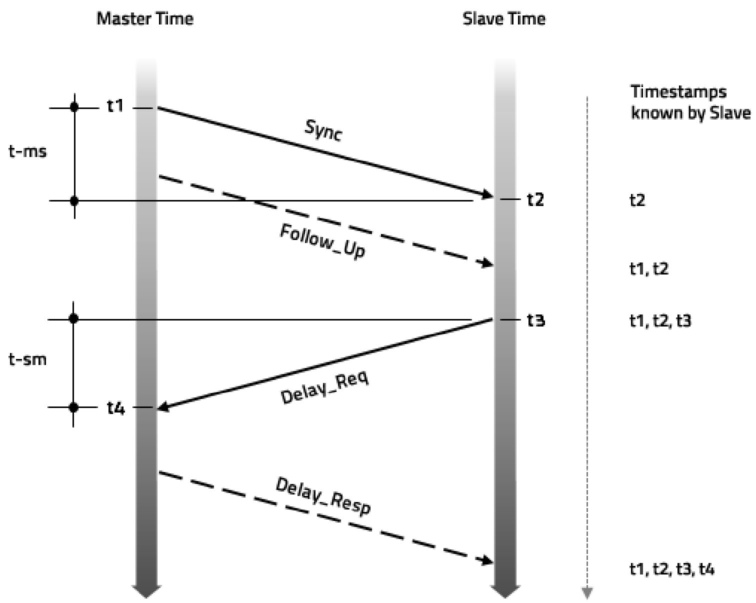
Appendix A: PTP (1588) Synchronization Technology

PTP (Precision Time Protocol) is an industry-standard protocol that enables the precise transfer of frequency and time to synchronize clocks over packet-based Ethernet networks. It synchronizes the local slave clock on each network device with a system Grandmaster clock and uses traffic time-stamping, with sub-nanoseconds granularity, to deliver the very high accuracies of synchronization needed to ensure the stability of base station frequency and handovers. Timestamps between master and slave devices are sent within specific PTP packets and in its basic form the protocol is administration-free.

Of course, the precision and performance of PTP is based on the precision of the timestamp. The timestamps of incoming and outgoing packets clearly need to be recorded and assessed to ensure synchronization of master and slave devices. Differences in time and frequency between clocks and subsequent equipment corrections need to be evaluated, while clocks must be measured to ensure they are within their specified limits. Further, delays and drifts in sync and their effect on the transfer of timing through the network need to be considered too. Here, we examine the precision of timestamp synchronization, as well as the accuracy of clocks under various network scenarios, before deploying equipment in an operational network.

There are two types of message in the PTP protocol: Event Messages and General Messages. Event messages are timed messages whereby an accurate timestamp is generated both at transmission and receipt of the message. General messages do not require timestamps but may contain timestamps for their associated event message.

Events messages include Sync, Follow-up, Delay-Request and Delay-Response. The PTP workflow is shown below.



Once the Slave knows the timing of t1, t2, t3, and t4, it can calculate the mean propagation delay (Tmpd) of the messages path and slave clock offset. This can be calculated by:

- Tmpd = ((t2-t1) + (t4-t3)) / 2
- Offset = t2-t1-Tmpd

Appendix B: ITU-T Recommended Network Limits for Packet Networks

Maximum average time interval error (MATIE) and Maximum average frequency error (MAFE)

MATIE and MAFE describes maximum phase or frequency deviations. MATIE/MAFE include a noise averaging function similar to TDEV.

MATIE can be estimated by the following formula:

$$\mathrm{MATIE}(n\tau_0) \cong \max_{1 \le k \le N-2n+1} \frac{1}{n} \left| \sum_{i=k}^{n+k-1} (x_{i+n} - x_i) \right|$$

$$\text{for } n = 1, 2, \ldots, \text{integer part } (N/2)$$

where x_i is the packet time error sequence (and is a random sequence), $n\tau_0$ is the observation window length, n is the number of samples in the window, τ_0 is the sample interval, N is the number of samples in the data set, and k is incremented for sliding the window. MATIE describes the maximum of average time changes between adjacent windows of length $n\tau 0$.

There is a simple relationship between MATIE and MAFE:

MAFE may be estimated as:

$$\mathrm{MAFE}(n\tau_0) = \frac{\mathrm{MATIE}(n\tau_0)}{n\tau_0}$$

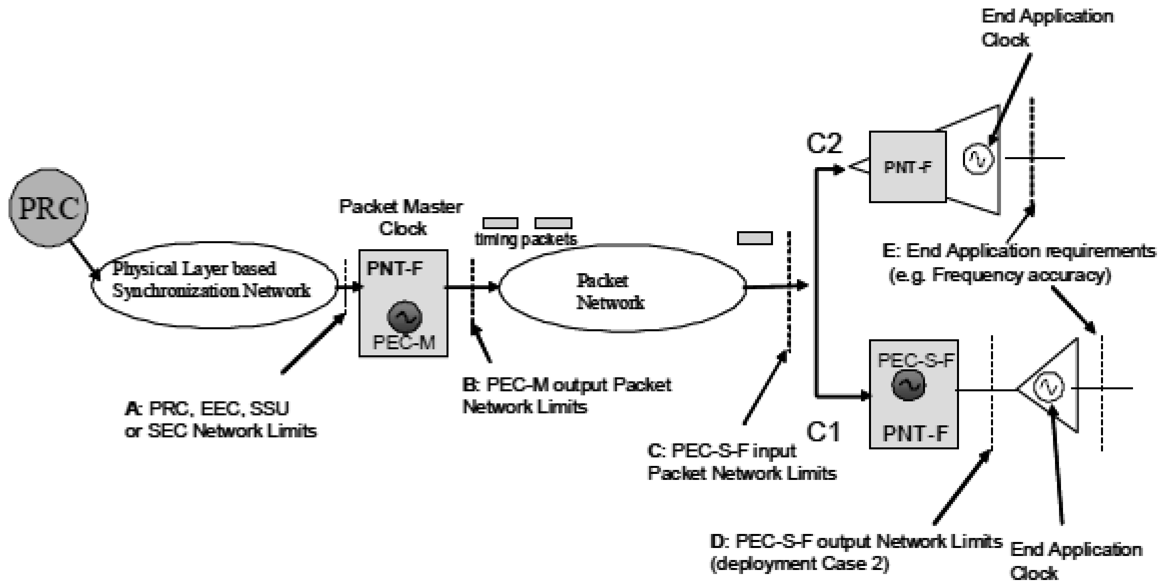
which is the average of MATIE over the observation window length.

Floor Packet Percent (FPP) by definition is the percentage of packets that fall into the given fixed cluster range starting at the observed floor delay.

MATIE, MAFE and FPP are applicable to defining the network limits.

Network Limits

ITU-T G.8261.1 defines different level of reference points and their network limits in packet networks for frequency synchronization as follows.



Network limits are specified at different level of reference points. At reference point C, the packet network limits are expressed in terms of the relevant PDV based metric as follows:

With window interval W = 200s and fixed cluster range δ = 150μs starting at the floor delay, the network transfer characteristic quantifying the proportion of delivered packets that meet the delay criterion should satisfy

FPP (n, W, δ) ⩾ 1%

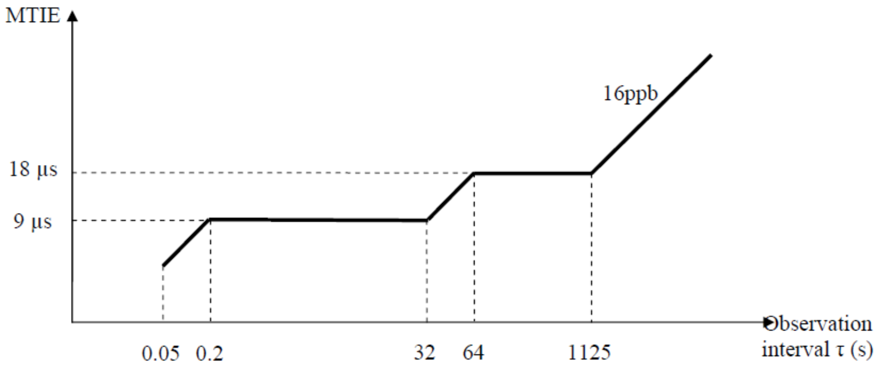
That is the floor packet percentage must exceed 1%.

MAFE and FPP are packet based network limits at reference point C which are mentioned in this document as test procedure 5.1 and 5.5.

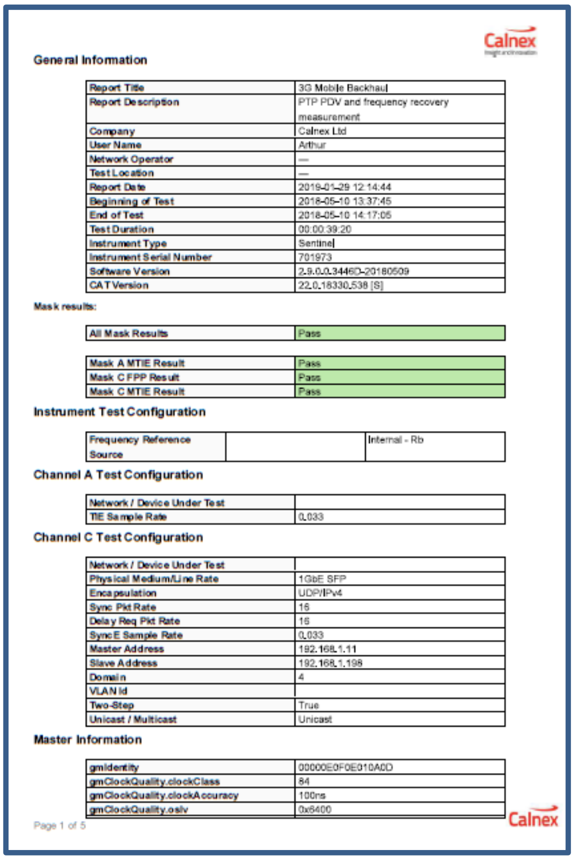
Appendix C: ITU-T Recommended Slave Clock Network Limits

Per the above network reference model, ITU-T also defines the network limit in terms of frequency wander at reference point D. This is to measure the accuracy or wander of the recovered Slave clock normally done at the frequency output interface on Slave (NodeB), such as 2MHz, 2Mbits or 10MHz.

The output wander network limit applicable at reference point D is provided by the graph below. It is in terms of MTIE. This is discussed in section 5.2 in this document.



Appendix D: Example Generated Report



Calnex

General Information

Report Title	3G Mobile Backhaul
Report Description	PTP PDV and frequency recovery measurement
Company	Calnex Ltd
User Name	Arthur
Network Operator	—
Test Location	—
Report Date	2019-01-29 12:14:44
Beginning of Test	2018-05-10 13:37:45
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Test Duration	00:00:39:20
Instrument Type	Sentinel
Instrument Serial Number	701973
Software Version	2.9.0.0.3446D-20180509
CAT Version	22.0.18330.538 [S]

Mask results:

All Mask Results	Pass

Mask A MTIE Result	Pass
Mask C FPP Result	Pass
Mask C MTIE Result	Pass

Instrument Test Configuration

Frequency Reference Source		Internal - Rb

Channel A Test Configuration

Network / Device Under Test	
TIE Sample Rate	0.033

Channel C Test Configuration

Network / Device Under Test	
Physical Medium/Line Rate	1GbE SFP
Encapsulation	UDP/IPv4
Sync Pkt Rate	16
Delay Req Pkt Rate	16
SyncE Sample Rate	0.033
Master Address	192.168.1.11
Slave Address	192.168.1.198
Domain	4
VLAN Id	
Two-Step	True
Unicast / Multicast	Unicast

Master Information

gmIdentity	00000E0F0E010A0D
gmClockQuality.clockClass	84
gmClockQuality.clockAccuracy	100ns
gmClockQuality.oslv	0x6400

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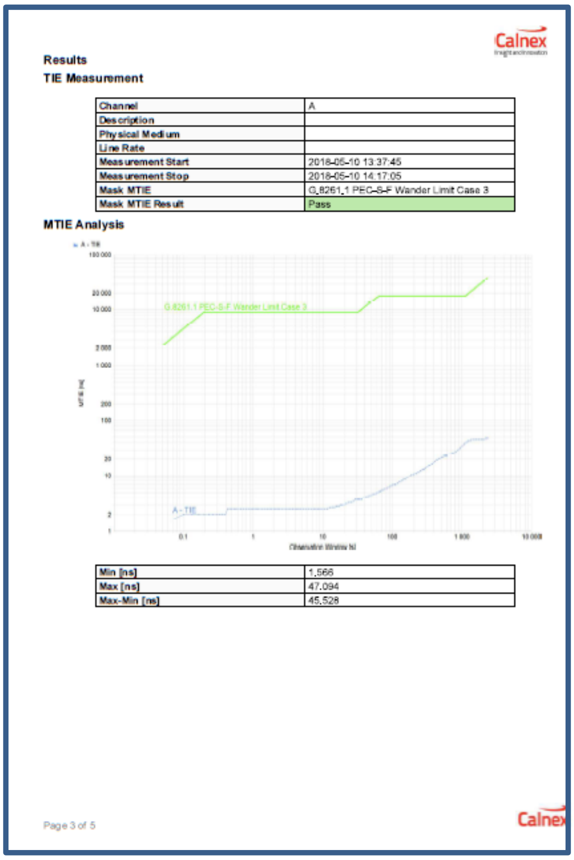

Calnex

Results

TIE Measurement

Channel	A
Description	
Physical Medium	
Line Rate	
Measurement Start	2018-05-10 13:37:45
Measurement Stop	2018-05-10 14:17:05
Mask MTIE	G.8261.1 PEC-S-F Wander Limit Case 3
Mask MTIE Result	Pass

MTIE Analysis

Min [ns]	1.566
Max [ns]	47.094
Max-Min [ns]	45.528

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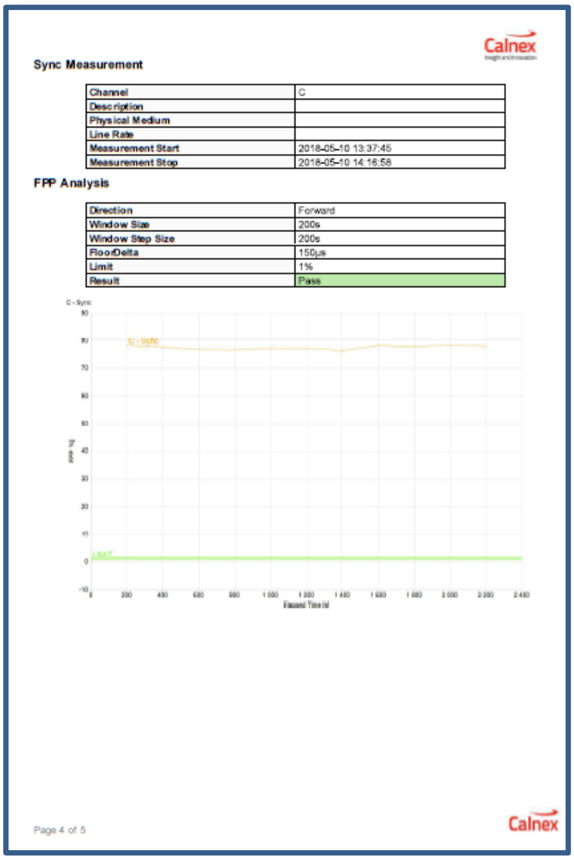

Calnex

Sync Measurement

Channel	C
Description	
Physical Medium	
Line Rate	
Measurement Start	2018-05-10 13:37:45
Measurement Stop	2018-05-10 14:16:58

FPP Analysis

Direction	Forward
Window Size	200s
Window Step Size	200s
FloorDelta	150µs
Limit	1%
Result	Pass

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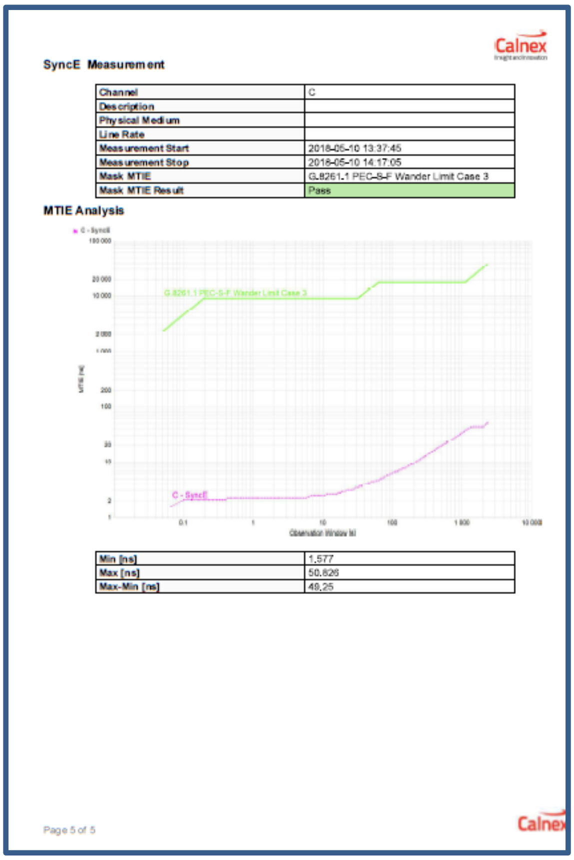

Calnex

SyncE Measurement

Channel	C
Description	
Physical Medium	
Line Rate	
Measurement Start	2018-05-10 13:37:45
Measurement Stop	2018-05-10 14:17:05
Mask MTIE	G.8261.1 PEC-S-F Wander Limit Case 3
Mask MTIE Result	Pass

MTIE Analysis

Min [ns]	1.577
Max [ns]	50.826
Max-Min [ns]	49.25

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