Development of Network Tester for Precision Synchronous Network Verification

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[Summary] The TD-LTE technology using Time Division Duplex (TDD) is being implemented for LTE-Advanced mobile networks offering faster speeds than Long Term Evolution (LTE) systems. Combining Mobile Backhaul (MBH) with TD-LTE increases the need for accurate time and phase synchronization, in turn driving higher demand for high accuracy and reliable evaluation of Precision Time Protocol (PTP) networks. The reported developments extend the functionality of the Network Master Pro MT1000A to support high-accuracy evaluation of PTP networks.

1 Introduction

Mobile operators worldwide are accelerating introduction of LTE-Advanced technology in parallel with LTE to cope with the explosive increase in data traffic volumes resulting from the spread of both smartphones and Internet of Things (IoT) applications. In these circumstances, 3GPP Release 12 incorporates recommendations regarding both the earlier Frequency Division Duplex (FDD) technology and the later Time Division Duplex (TDD) technology offering the advantage of more efficient use of available frequencies. In the LTE-Advanced standard, the former technology is called FDD-LTE and the latter is called TD-LTE[1].

With TD-LTE technology, it is not necessary to separate the uplink and downlink channels and, as a result, the frequency band can be used to the maximum limit. Conversely, radio-wave interference occurs when adjacent base stations send the uplink and downlink channel signals at the same time. As a result, extremely high time precision is required between base stations. The International Telecommunication Union Telecommunication Standardization Sector (ITU-T) G.8271 specifies that the time difference between the Coordinated Universal Time (UTC) constant and the base station time must be 1.5 μs or less. To achieve this, base stations use a precision GPS-disciplined time-synchronization function. However, in locations where a GPS signal is unavailable, such as underground facilities, time synchronization is achieved using Ethernet transmissions[2].

ITU-T is completing standardization of the G.826x series recommendations related to frequency synchronization using Synchronous Ethernet (SyncE) and the Precision Time Protocol (PTP). PTP uses the Ethernet transmission path for high-stability and high ease-of-use time and frequency synchronization.

On the other hand, the need for revising and creating new ITU-T G.827x series recommendations for TD-LTE technology to meet the new requirements of end users has been recognized and the world's mobile operators and systems and device vendors are starting active discussions[3].

Since 2015, existing mobile backhaul (MBH) configurations have been increasingly split into blocks and mobile and fixed network operators are starting to build PTP networks. Holding-down PTP CAPEX requires effective field test solutions for testing time synchronization with high accuracy and for evaluating carrier-class Ethernet.

2 Development Concept

Previous PTP network time accuracy testing required dedicated measuring instruments that are very expensive and caused rising PTP network installation costs. Additionally, evaluating the required performance and function of PTP networks requires very complex test procedures, in turn increasing the complexity of the test instruments and operator training costs. To solve these problems by simplifying operation and supporting low-cost PTP network evaluation measurements, we developed an instrument with:

- Support for the latest telecoms profiles and the latest PTP evaluations using extended PTP measurement functions, including time and phase error measurements.
- New MT1000A GPS-disciplined module for UTC time synchronization for precision PTP measurements while inheriting MT1000A portability.
- Automated test functions to simplify complex PTP network evaluations with simple operations, helping lighten field technicians' workload.

3 Extended PTP Functions

The MT1000A has long had a PTP evaluation function as part of its built-in network measurement functions. However, assuring high-accuracy phase evaluations of TD-LTE networks and support telecom profiles are a growing issue. Supporting the ITU-T G.8275.1 telecom profile protocol emulation function by installing the phase evaluation function for referencing UTC time provides a solution for evaluating the latest PTP networks.

3.1 Support for ITU-T G.8275.1 Telecom Profile

Installing the 10G Multirate Module MU100010A in the MT1000A supports ITU-T G.8265.1 (frequency synchronization profile)[5]. As shown in Figure 1, adding G.8275.1 (phase and time synchronization profile)[6] completed the planned functions for evaluating mobile networks.

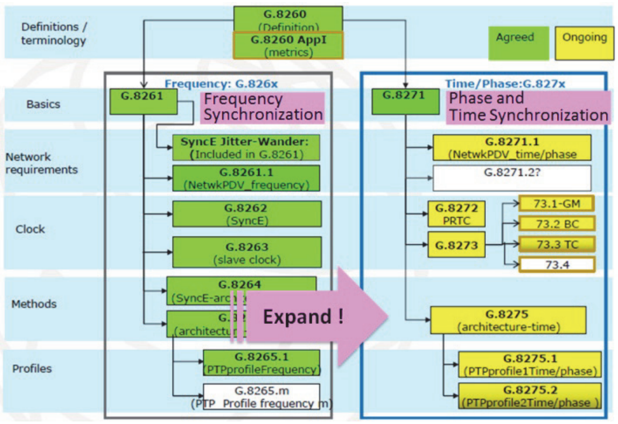

Figure 1 ITU-T Standardization Recommendation Trend

3.2 Measuring Time Synchronous Accuracy using UTC Time

At network synchronization, in addition to synchronization of the frequency between equipment, applications requiring synchronization of time and phase with an absolute time constant are beginning to appear and the field for commercial network synchronization technologies is expanding. In parallel with this, the need for accurate measurement of time synchronization is also expanding. The MT1000A has been developed with a time and phase synchronization function based on GPS-disciplined UTC time for accurate evaluation of network time synchronization. It supports the following two evaluation methods.

- Phase evaluation using 1 Pulse Per Second (1PPS) signal
- Time and phase evaluation using PTP packets

(1) Evaluation using 1PPS signal

As shown in Figure 2, we have developed a phase evaluation measurement function for network equipment that outputs a 1PPS signal for displaying time. It compares the 1PPS signal captured from the GPS with the 1PPS signal from the device under test (DUT) to evaluate the DUT 1PPS phase error compared to absolute time.

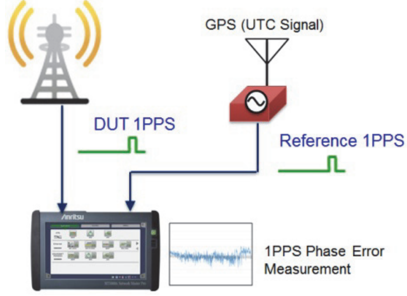

Figure 2 1PPS Signal Comparison

(2) Time and Phase Evaluation using PTP Packets

For PTP synchronous networks, we have developed a measurement function for evaluating time synchronization accuracy using the time τ of PTP packets sent/received by the GPS-disciplined UTC time and the time T of the DUT recorded time inside PTP packet[6].

As shown in Figure 3, the time T1 of the Sync sent by the DUT is compared with the time τ2 of the Sync packet sent by the MT1000A to calculate the Sync One Way Delay (Sync OWD) from the DUT to the MT1000A. In addition, the time τ3 of the DelayReq packet sent by the MT1000A is compared with the time T4 of the DelayReq packet sent by the DUT to calculate the DelayReq OWD.

$$\text{Sync OWD} = \tau 2 - T1$$
$$\text{DelayReq OWD} = T4 - \tau 3$$

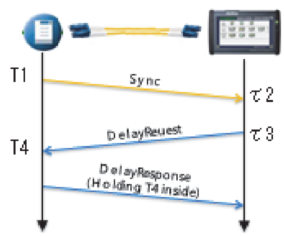

Figure 3 One-Way Delay Measurement

These Sync OWD and DelayReq OWD measurement results are used to subtract the theoretical path delay (5 ns/m) dependence on the connected cable length used for calculation of the time and phase difference (Time Error) of each PTP uplink and downlink signal at the DUT to evaluate the time and phase difference. In addition, the accuracy of the time distribution from the PTP signal master clock time is determined by dependence on the up and down two-way communications. The mean of the TE1 and TE4 time errors in both directions is calculated and displayed as the Time transfer error (Terr) for evaluating the DUT time distribution accuracy[7].

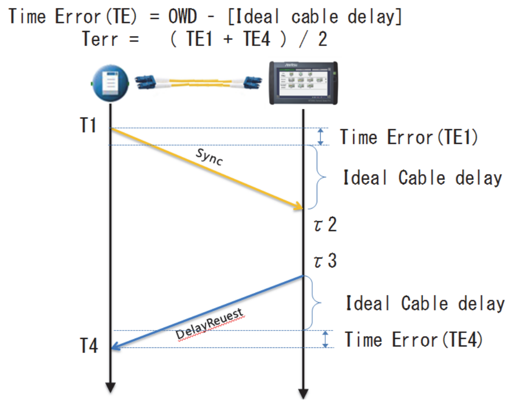

Figure 4 Time Error Calculation

4 Development of Precision GPS-Disciplined Synchronous Oscillator Module

To implement the recently required high-accuracy level[8] evaluations shown in Table 1, we developed a GPS-disciplined oscillator module for synchronizing with UTC at high accuracy. To assure high-accuracy Time Error evaluations even in environments where the calibration signal cannot be obtained from four or more GPS satellites, it is necessary to save time data saved at the previous GPS synchronization for a fixed time. Consequently, the high-stability rubidium oscillator is synchronized to the 1PPS data captured from the GPS signal. To assure no loss of MT1000A portability, we developed a compact module using a small rubidium oscillator device.

Table 1 Required Accuracy Level[8]

Accuracy Level	Required Range	Typical Application
1	1 ms to 500 ms	Billing, alarms
2	5 µs to 100 µs	IP Delay monitoring
3	1.5 µs to 5 µs	LTE TDD (large cell) Wimax-TDD (some configurations)
4	1 µs to 1.5 µs	UTRA-TDD LTE-TDD (small cell)
5	x ns to 1 µs	Wimax-TDD (some configurations)
6	<x ns	Some LTE-A features

4.1 MU100090A Hardware Outline

As shown in Figure 5, the MU100090A module uses a rubidium oscillator to provide a high-accuracy 10-MHz reference clock. Synchronizing the output of the GPS receiver and the rubidium oscillator outputs a clock and 1PPS signal synchronized with UTC. In addition, instead of using the GPS signal, it is also possible to synchronize the rubidium oscillator to a 1PPS signal input to the 1pps Sync Input connector. This maintains the time accuracy with the high-stability rubidium oscillator even when there is no synchronizing signal input to the rubidium oscillator (holdover) because no signal is received from the GPS satellites. As a result, high-accuracy time and phase evaluations are supported even in environments where signals from GPS satellites cannot be captured. The GPS receiver outputs either 3.3-V or 5-V power for the antenna as well as the Time of Day (TOD) signal in NMEA0184 format.

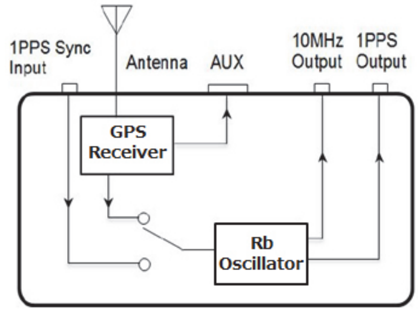

Figure 5 MU100090A Block Diagram

With this configuration, the GPS synchronization accuracy is ±45 ns rms (compared to UTC time) and the holdover accuracy is 300 ns @ 10,000 s. To achieve this accuracy, the GPS synchronization must be 30 minutes and more at 3 hours after supplying power to the rubidium oscillator, and the temperature must be constant during start up.

4.2 MT1000A Configuration at High-Accuracy Time Synchronization

The MT1000A is designed to install various measurement modules in the back panel for customized support for different measurements. Installing the High-Accuracy GPS Disciplined Oscillator Module MU100090A and the 10G Multirate Module MU100010A in the MT1000A supports phase measurements using the 1PPS signal and Time Error measurements using PTP packets. The MU100090A has a built-in rubidium oscillator and GPS receiver. In addition, the MU100010A supports the SFP/SFP+ measurement interfaces covering bit rates up to 10 Gbps for Ethernet communications.

Figure 6 MT1000A/MU100090A/MU100010A Interface Panel

As shown in Figure 7, when performing high-accuracy time synchronization measurements, the clock used for sending and receiving PTP packets and the clock used for generating the reference time are both synchronized to the 10 MHz reference clock of the External Clock, and the whole system is synchronized. In other words, the MU100090A clock output is connected to the MU100010A External Clock In (10 MHz) port and using this clock as the reference clock enables stable and accurate time measurement.

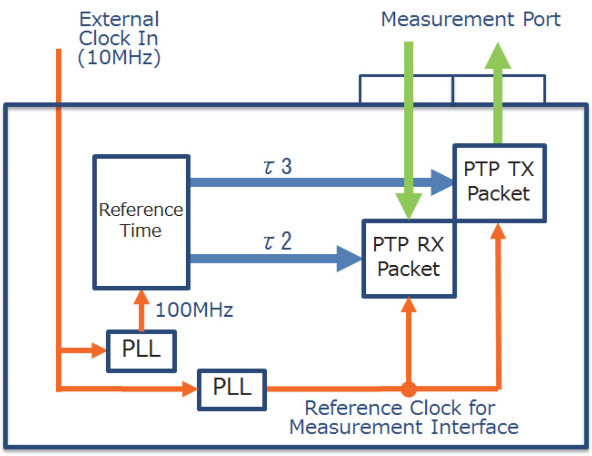

Figure 7 Precision Time Synchronous Measurement Block Diagram

5 Development of Auto-Test Function

At evaluation of network quality for network I&M, two factors greatly increase the risk of rising operating costs (OPEX). The first factor is the increased number of measurement procedures resulting from the increased number of communications standards. The second factor is poorer efficiency due to operation errors and field technician rework.

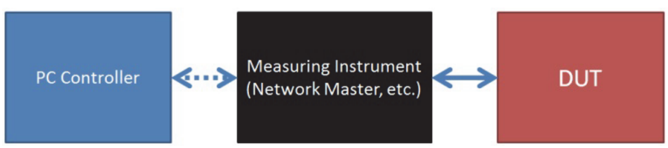

Figure 8 Example of Automation System

Figure 8 shows an example of an automation system using measuring instruments to cut OPEX and reduce the work burden on field technicians. Installing software on a PC controller enables control of measuring instruments using remote commands, such as Standard Commands for Programmable Instruments (SCPI); measurement can be performed using specific sequences for error-free complex tests. However, there are three problems with configuring a test system.

- Requires PC controller in addition to instruments
- Must develop control software to control instruments
- Require skills to create measurement control sequences

To overcome these problems, we developed an auto-test function as a solution with easy operation for evaluating complex networks.

5.1 Auto-Test Function

The Auto-Test Function has tools not just for creating measurement sequences to perform measurement and evaluate results, but also for automating measurement. Measurement scenarios incorporate a set of test contents including the above-described measurement sequence in a file. It includes icons for making settings files, creating measurement sequences, and starting scenarios. The Auto-Test Function has three different software modules for creating, registering, and executing measurement scenarios. The three developed modules are listed in Table 2.

Table 2 Auto-Test Function Software List

Software	Outline
Scenario Creation Tool SEEK (Scenario Edit Environment Kit)	PC application software for creating measurement scenario used in combination with control sequence using GUI
Scenario Manager	Software for managing measurement scenario on MT1000A
Scenario Execution Engine	Software for executing measurement scenario on MT1000A

The auto-test function workflow is shown in Figure 9. The automation workflow for creating and executing the measurement scenario, and managing the results data is shown below.

1. Create measurement scenario to execute using SEEK
2. Register created measurement scenario in MT1000A using Scenario Manager
3. Execute registered scenario using Scenario Execution Engine

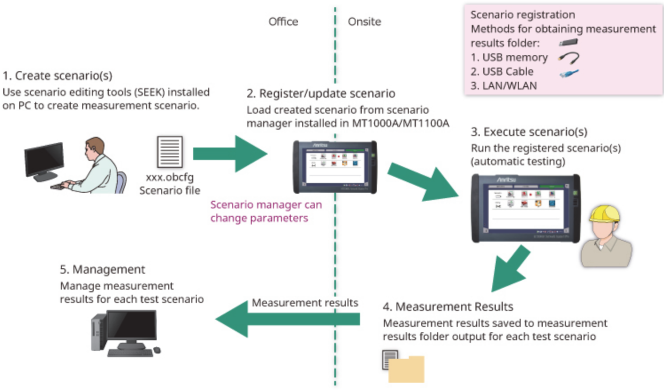

Figure 9 Auto-Test Function Workflow

Using this Auto-Test Function eliminates the need for a PC for controlling the measuring instrument required at general automatic tests as well as the need to develop instrument control software. In addition, it is possible to create measurement scenarios easily and to configure an automatic network test system.

5.2 Scenario Creation Tool (SEEK)

SEEK has been developed as a tool for creating scenarios. SEEK can creates scenarios easily using drag and drop if the sequence is simple. It helps cut the cost of creating measurement control sequences, which can be very expensive for automated measurement.

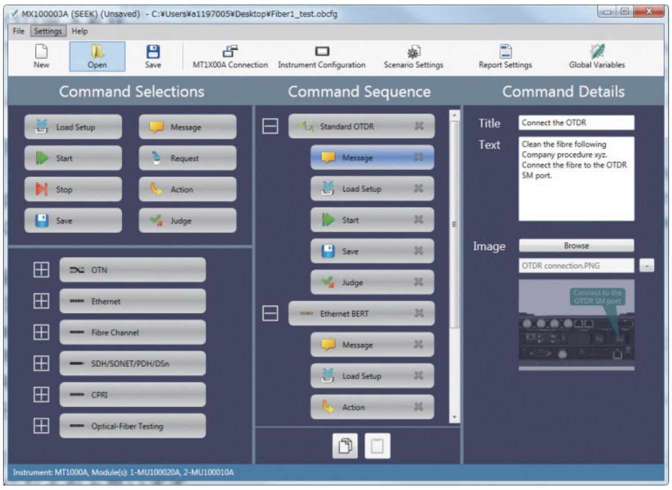

Figure 10 MX1000003 (SEEK) Screen

As shown in Figure 10, SEEK is configured with three screens. The first is Command Selections on the left side of the screen. This part is an arrangement of simplified icons for commands used by scenarios. The second part is Command Sequence in the screen center. It is used to create scenarios by dragging and dropping command icons from the Command Selections section. The third part is Command Details on the right side of the screen. It is used for detailed settings for each command. Messages, etc., for displaying the executing scenario can be set at this screen. In addition, SEEK has a function for taking settings data required for scenario creation from the MT1000A and for moving created scenarios to a target MT1000A. SEEK has strong support for scenario creation, but on the other hand, it has a built-in scripting language assuming complex sequences and evaluations to support wider user applications.

5.3 Scenario Manager

The Scenario Manager is a tool for managing scenarios created with SEEK on the MT1000A. Table 3 shows the main functions.

Table 3 Scenario Manager Function

Function	Details
Register/Delete	Registers SEEK-created scenarios in main frame and deletes registered scenarios from main frame.
Display/Non-Display	Switches between display and non-display of registered scenario icons.
Edit	Adjusts scenario variables, such as parameters.

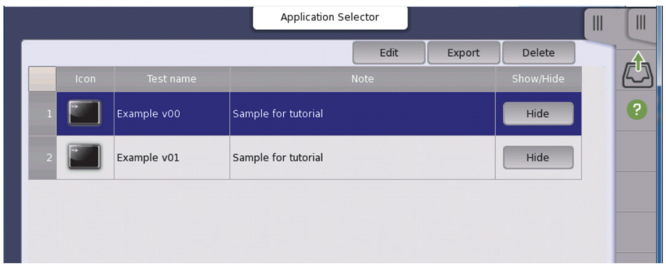

Figure 11 Scenario Manager Screen

We incorporated scenario management itself into the instrument because users must be able to manage scenarios themselves. By using this function, every stage from scenario management to execution can be executed on one MT1000A, simplifying operation and management of automatic measurement.

5.4 Scenario Execution Engine

Clicking the icon of a scenario registered in the MT1000A with the Scenario Manager starts the Scenario Execution Engine to execute the scenario. The Scenario Execution Engine interprets the scenario and executes the steps one-by-one.

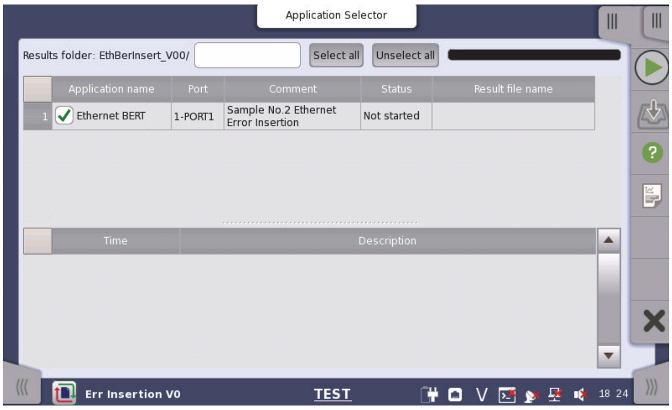

Figure 12 Scenario Start Screen

Simply pressing the start icon at the top-right of the screen executes the previously created scenario to cut the operator's workload by automating the measurement and eliminating complex instrument operations. In addition, the Scenario Execution Engine combines the following functions to reduce the risk of operation errors.

(1) Scenario Error Warning Function

This supporting function evaluates the occurrence of errors in scenarios. When it detects no errors during scenario execution, it displays green; if an error occurs, it is highlighted in red, helping locate problems at a glance.

Figure 13 Execution Error Handling Procedure

(2) Operation Procedure Attention Function

This function displays message pop-ups at the screen top like the example in section 5.2 to prompt the operator about the next operation. Figure 14 shows an example of a prompt to confirm a cable connection.

Figure 14 Scenario Warnings

(3) Automatic Measurement Results Save Function

After measurement is completed, this function creates a file directory for each measurement to auto-save the results data. This overcomes the problem of an operator forgetting to save data.

6 Conclusion

To meet the evaluation needs for recent PTP networks, we have developed a new network measuring instrument supporting carrier-class Ethernet evaluations with PTP network evaluation and auto-testing functions.

Time and phase synchronization technologies are key in supporting future mobile systems such as 5G and we expect this instrument to meet new measurement needs and help promote growth of future networks.

References

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