

O-RAN Radio Unit Test System for Promoting Open RAN

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[Summary]

As the importance of Open Radio Access Networks (Open RAN) grows, and wireless access networks become more open, multi-vendor, and virtualized, interoperability issues due to multi-vendor equipment sourcing require test instruments to discover and resolve these issues. We developed a system to test the wireless performance of the O-RAN Radio Unit (O-RU) that transmits/receives wireless signals and to measure the digital data transmission/reception. This test system uses an intuitive Graphical User Interface (GUI) to flexibly set waveforms and offers automated test functions, including synchronization, which we hope will further support the spread of O-RAN.

1 Introduction

The O-RAN Alliance is an international organization promoting open standardization of the Radio Access Network (RAN) part of wireless networks. Open RAN (O-RAN) wireless networks are divided into three parts: the O-RAN Radio Unit (O-RU), O-RAN Distributed Unit (O-DU), and O-RAN Central Unit (O-CU), each with a published open standard interface that facilitates interoperability between equipment from different vendors. As well as resulting in reduced costs due to price competition between many different communications equipment makers, telecommunication companies can freely choose the equipment combination matching their requirements. On the other hand, non-compliance with the standard can cause various interoperability issues and identifying and solving the cause often takes time. Resolving interoperability issues requires tests to confirm that the equipment interface is standards-compliant.

This article describes development of an O-RAN test system with functions for confirming O-RAN operation and compliance with standards.

The system confirms the operation of each function at the C-Plane (control plane), U-Plane (user plane), and S-Plane (Synchronization plane) of the Fronthaul digital data communications section between the O-RU and O-DU and supports the O-RAN Alliance-defined Conformance Test for verifying protocol compliance between the O-DU and O-RU. Moreover, since the system complies with the 3rd Generation Partnership Project (3GPP) TS38.141 standard, it can also evaluate O-RU Radio Frequency (RF) characteristics.

The design concept, details, and features of this developed system are described below.

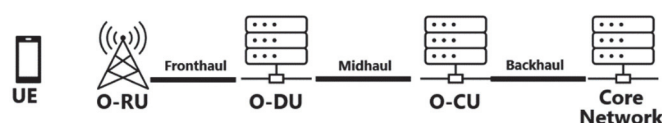


Figure 1 Radio Access Network Components

2 Development Concept

In developing the O-RAN Radio Unit test system, our aim was to build a system that would both test according to the O-RAN/3GPP standards but would also support easy changes test methods to meet the need for verification and non-standard testing. The design concepts are listed below.

(1) Easy Changes to Test Standard Parameters and Test Procedures

When a test result is Fail, the test parameters and procedure can be changed from the test standard to do troubleshooting and specify the issue. In particular, we developed software to support replacing the order, adding, and deleting operation sequence settings.

(2) Flexible Changes to Waveform Patterns

Part of system uses our company's IQproducer waveform generation software to create many different Downlink and Uplink waveforms.

(3) Intuitive GUI for Settings and Operation

GUI-based software was developed to support easy and intuitive operation, including test sequence editing. In particular, an easy-to-understand Tree View format display is used for M-Plane which can be difficult to set and edit without specialist skills. We aimed to create a GUI supporting easy editing by displaying parameter ranges determined by the standard.

(4) Supports Commercial and Existing Products

With respect to hardware, costs were reduced and development time was shortened by using commercial products and our company's existing testers.

3 Test System Configuration

We choose hardware and developed the software based on the above concepts. Figure 2 shows the O-RAN Radio Unit test system hardware configuration and Figure 3 shows the software packages.

(1) Supports MT8000A and MX800046A

The system uses the MX800046A software to measure the O-RU RF characteristics by operating the MT8000A as a base station using 3GPP TS38.141-compliant test item settings. IQproducer creates the Uplink waveform output from the MT8000A.

(2) O-DU Emulator Development

We developed an O-DU Emulator to connect with and test the Fronthaul, O-RU digital interface. Like an actual O-DU, we used a commercial PC server running the Linux operating system (OS) with an accelerator add-in-card (AIC) and developed a Field Programmable Gate Array (FPGA) for the accelerator card and System On a Chip (SoC) software to implement the C/U/S/M-Plane functions defined by the Fronthaul standard. The O-RU Fronthaul is connected via the SFP28 interface of the accelerator card.

(3) Adoption of MT1000A

The O-DU Emulator transmits U/C-Plane Downlink packets while synchronizing with the O-RU using S-Plane, and as a result, a Downlink waveform is output from the O-RU.

In order to perform RF measurement of the Downlink waveform with the MX800046A, clock synchronization between the O-DU Emulator and the MX800046A is required. Additionally, since accurate analysis of the Downlink waveform and output of the Uplink waveform requires a 1 pulse per second (PPS) signal, the MT1000A is used as the clock source. Combination with the MU100090B and rubidium oscillator in the MT1000A outputs the high accuracy 1PPS and 10 MHz synchronization signals required for RF measurement. Measurement is also possible using a clock synchronized to the Global Positioning System (GPS) signal.

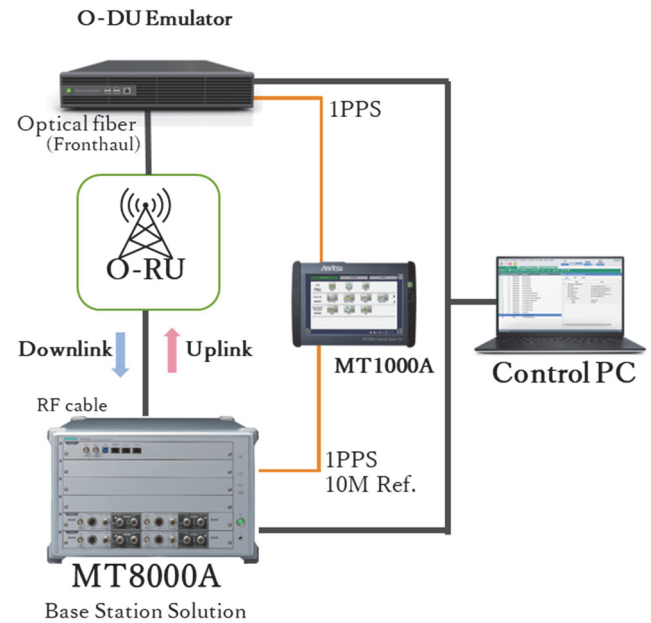


Figure 2 O-RAN Radio Unit Test System

(4) MX773000PC Development

The MX773000PC software running on a Windows PC controls the O-DU Emulator. The MX773000PC can operate and test the C/U/S/M-Plane on the O-DU Emulator with a single GUI. The Downlink waveform created by IQproducer is converted to packet data by the MX773000PC and Downlink tests are implemented by transmission to the O-RU. For Uplink testing, the MX773000PC has a function to capture packet data sent from the O-RU and display the analysis results.

An easy-to-understand Tree View style display makes it easy to edit M-Plane parameters.

(5) MX772000PC Development

To automate the O-RAN Alliance-defined Conformance Test and the 3GPP TS38.141 tests, we developed the MX772000PC software to control the MX773000PC and MX800046A automatically. By using the MX772000PC, the operator can execute tests by sequentially controlling the MX773000PC and MX800046A; the MX772000PC can also automatically done Pass/Fail evaluation at specified threshold values. Since sequences can be edited easily using the GUI, changes from the test standards as well as new tests are performed easily.

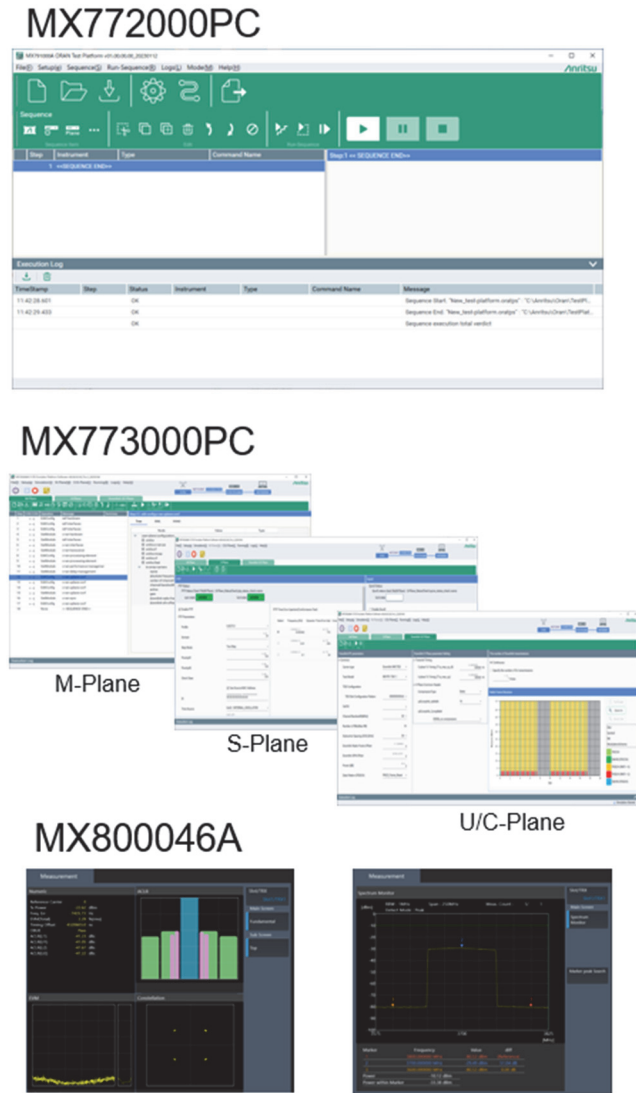


Figure 3 O-RAN Measurement Software

4 Design Features

This section explains the actual design requirements.

4.1 Hardware

4.1.1 Accelerator Card and Server PC

We adopted existing commercial products due to the advantages of lower hardware cost, shorter development time, expandability, and availability for the customers. To make use of these advantages, in choosing hardware, we focused on ease of globally obtaining compliant hardware with legally regulation as well as easy appropriation of design resources with general configurations.

The accelerator card required the following conditions.

- Support for both 25 and 10GbE network interface
- FPGA which can design internal circuits is installed in order to implement unique functions as an O-DU Emulator.
- Adequate FPGA resources supporting expandability

- Timing reference and accurate clock source, such as external 1PPS to implement high clock precision

The AMD (Xilinx) Xilinx T1 telecom accelerator card (T1 card hereafter) was used because it meets the above requirements.

A Dell PowerEdge R750 is used as the Server PC because it supports the two PCIe Gen3 x8 interface slots required by the T1 card, and also has a 25 GbE network card for M-Plane communications with the O-RU via the T1 card.

Other network interface than T1 card on the Server PC can also use to connect with the M-Plane to O-RU, so the T1 card is unnecessary when testing only the M-Plane. Also, if the O-RU uses a network interface different from the C/U/S-Plane for the M-Plane, it is possible to use the NETCONF (Network Configuration Protocol) Client other than the O-DU Emulator for the M-Plane.

4.1.2 FPGA

This section explains the FPGA functions.

The FPGA performs network communications with the O-RU. Figure 4 shows the FPGA internal data flow. The FPGA is composed of Processing System (PS) and Programmable Logic (PL). The PS performs S-Plane processing. When the M-Plane is communicating using the same network interface as the C/U/S-Plane, M-Plane packets are relayed with the Server PC. On the U/C-Plane packets transmission, it transmits the C-Plane and U-Plane data created by the control software with the evolved Common Public Radio Interface (eCPRI) protocol framing repeatedly.

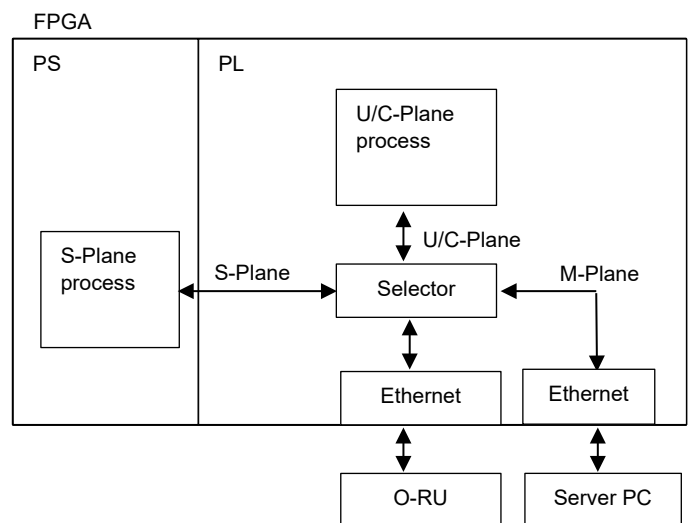


Figure 4 FPGA Data Flow

The 25 and 10GbE interfaces with the O-RU are switched

without changing the FPGA object. Use of Reed Solomon Forward Error Correction (RS-FEC) by the 25GbE interface can be enabled/disabled.

The FPGA PL generates the clock used by the Precision Time Protocol (PTP) as the timing management function. The packet send and receive times used by PTP are acquired and reported to the PS. At PTP One-Step operation, as shown in Figure 5, PL acquires the packet send time and insert it to the Sync message. At Two-Step operation, as shown in Figure 6, PS inserts the Sync message send time acquired by PL to the Follow_Up message. Acquiring the send time using PL increases the time accuracy.

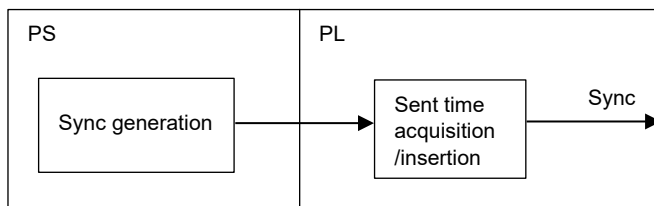


Figure 5 One-Step Operation Sync Message Tx Time Insertion

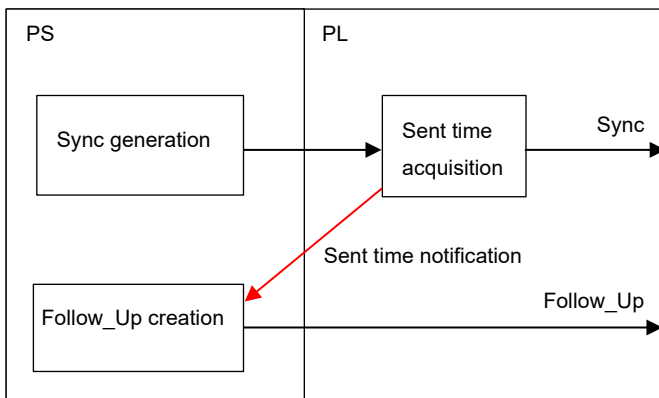


Figure 6 Two-Step Operation Follow_Up Message Tx Time Insertion

4.2 Software

4.2.1 SoC/Linux application

This section shows the SoC software and Linux application software blocks that are controlled from the MX773000PC software.

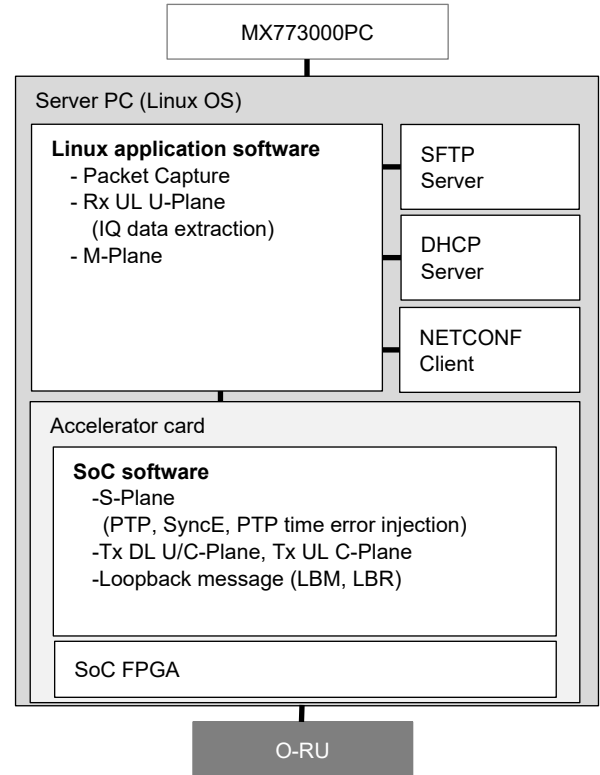


Figure 7 SoC and Linux Application

(1) SoC software

The SoC software is built into the T1 card to communicate with the C/U/S-Plane and test cases.

- S-Plane (PTP, SyncE (Synchronous Ethernet))

For the S-Plane, we developed a PTP Master function to manage the PTP time in synchronization with the external PPS signal input. To support the O-RAN Conformance test ITU-T G.8275.1 Profile described in section 3.3.3 O-RU Performance Test, we developed a function for adding errors to PTP. In addition, ESMC packet transmission is supported as SyncE. The Quality Level (QL) is included in the ESMC packets as an indicator of the SyncE quality. S-Plane status transitions are tested in accordance with the O-RAN Conformance Test specified in the ITU-T G.8275.1 profile in section 3.3.2 O-RU Functional Test. QL can be set manually to support this test.

- U/C-Plane Tx

The U/C-Plane transmission processing block controls the U/C-Plane packet transmission timing. To support the Delay Management test to verify the O-RU behavior when the packet arrive time is delayed relative to the current time, we implemented manual setting of the transmission timing.

- Loopback Message TRx

We have developed a function to transmit and receive a Loopback message for IEEE 802.1Q-2018 to support the O-RAN Conformance Test specified in section 3.1.13.1 Ethernet Connectivity Monitoring.

- (2) Linux application software

The Linux application software handles communication with the T1 card and M-Plane communications.

- Packet Capture

This function captures and reads packets via the T1 card memory. It outputs the contents of communications with the O-RU to a pcap file that can be read by other applications for efficient debugging.

- Uplink U-Plane IQ Data Extraction

This function has been developed to extract IQ data from Uplink U-Plane packets. Compressed IQ data is extracted automatically, and the extracted IQ data is transferred to the MX773000PC for demodulation analysis.

- NETCONF Client

The NETCONF Client processing block has been developed to supports the M-Plane communication with O-RU. To assure stable connections, NETCONF Client was implemented using the available Open-source Software (OSS) in widespread use. Combined use with the MX773000PC supports data communications based on Yet Another Next Generation (YANG) modules prescribed in the O-RAN specifications. As well as connecting using a static Internet Protocol (IP) address at the O-RU, it also supports connections using NETCONF Call Home used in combination with a Dynamic Host Configuration Protocol (DHCP) server.

4.2.2 MX773000PC

When connecting and testing a combination of O-RU and O-DU from different vendors, issues such as failed connections and different characteristics can occur, making it necessary to investigate the cause at both the O-RU and O-DU, which requires a lot of time to debug and isolate. To simplify this troubleshooting, we developed the MX773000PC O-DU Emulator Platform Software for testing the O-RU in accordance with O-RAN Alliance specifications.

Typical MX773000PC functions are listed below.

- (1) M-Plane Function

- Generating XML (Extensible Markup Language) from Tree

The M-Plane is a management function for the O-RU software, settings, etc., which are implemented using the NETCONF communications protocol. To create the NETCONF XML it is necessary to understand the YANG file format for each YANG module in the O-RAN Alliance specification and to describe the XML in accordance with the YANG file definition, but understanding and describing are very labor intensive. Consequently, the MX773000PC has a built-in function that converts the YANG file format to a Tree View where parameters on the Tree are set to easily create the XML. To improve the readability of NETCONF data expressed in XML format, the Tree also indicates the original parameters hierarchically.

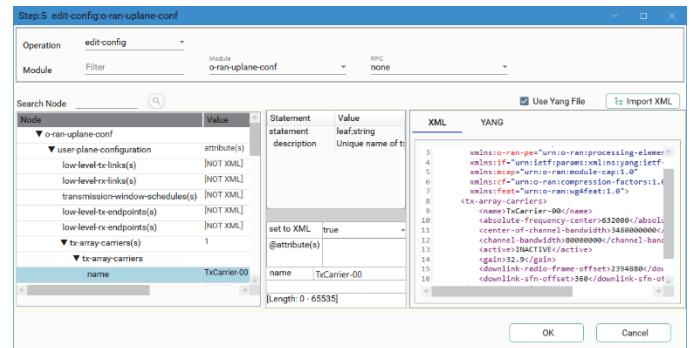


Figure 8 Generating XML from M-Plane Tree

The relationship between the YANG file, Tree and XML is shown below.

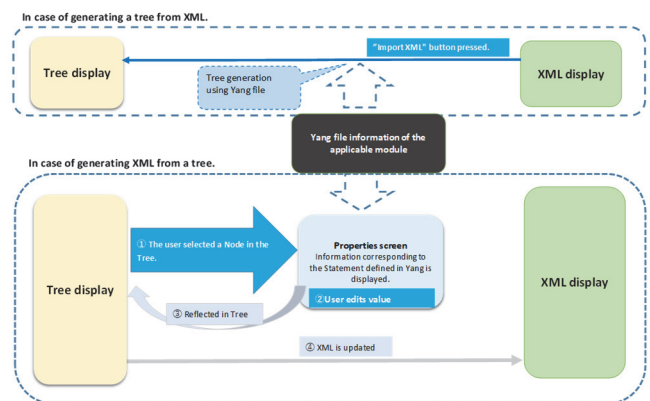


Figure 9 Relationship between YANG File, Tree, and XML

- XML Analysis Function

This built-in function reflects XML acquired from the O-RU as well as from the user's existing XML in the Tree. Acquiring the XML by converting from logs when using the O-DU and O-RU in a live environment supports M-Plane reproducibility tests.

Additionally, the locations of XML description (syntax)

errors and XML parameter settings that do not match the YANG for the specified module are displayed to discover setting mistakes and trouble spots.

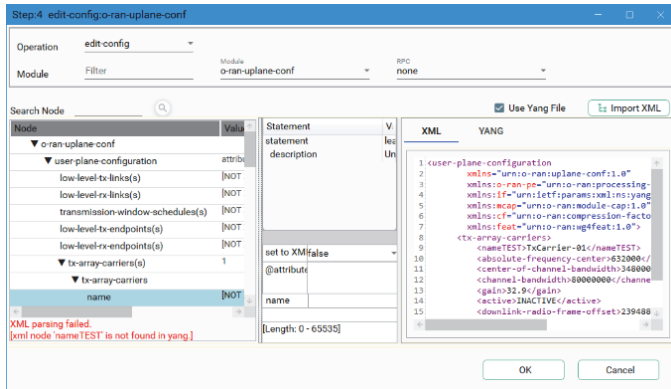


Figure 10 Checking YANG File at Tree Generation from XML

• M-Plane Message Sequential Execution

In addition to the XML addition and editing functions, the MX773000PC has other functions to set the wait time at each step, display user message dialogs, record execution logs, and add/edit comments.

These functions can be executed sequentially at each step.

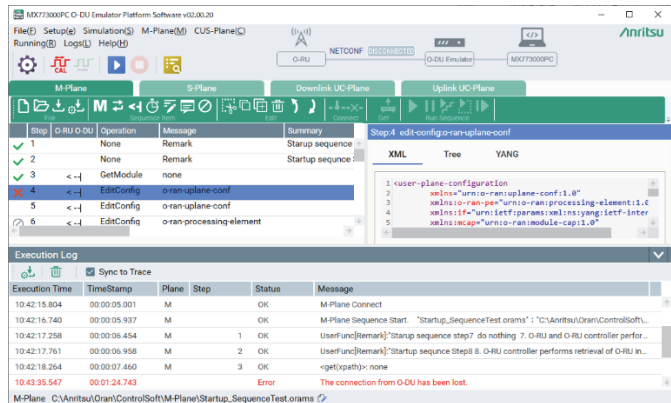


Figure 11 M-Plane NETCONF xml Sequential Execution

(2) U/C-Plane Function

3GPP TS38.141-compliant waveforms must be created to test the O-RAN C- and U-Planes. The MX773000PC has functions cooperating with IQproducer of existing product to create flexible waveform patterns and then for Downlink/Uplink U/C-Plane transmission/reception.

• Downlink Function

Using this function, the MX773000PC can transmit any Downlink U/C-Plane packet to the O-RU. The waveform is generated by using IQproducer and the generated waveform data is installed in the Server PC. Installed waveforms are listed in the GUI to switch easily to the waveform to output by selecting the waveform data from the list.

Additionally, the selected waveform is also displayed as a graph on the GUI to set and confirm the waveform Radio Frame Structure.

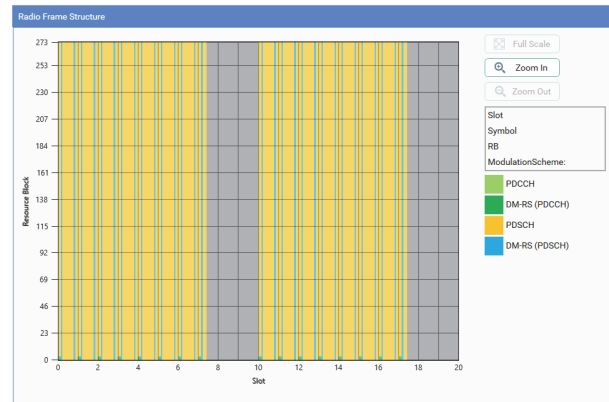


Figure 12 Downlink Waveform Display

• Uplink Function

Using this function, the MX773000PC can transmit any Uplink C-Plane packet to the O-RU and receive the Uplink U-Plane from the O-RU. Additionally, there is a function for analyzing the received U-Plane and displaying results as a graph.

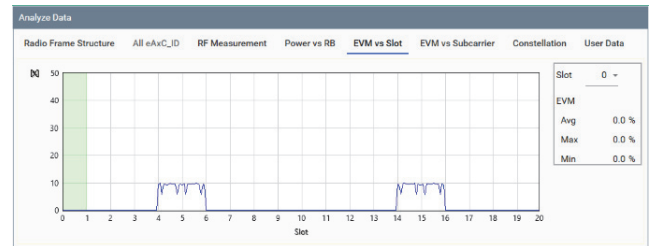


Figure 13 Uplink Analysis Results Display

(3) S-Plane Function

While mobile networks require precision time synchronization, because multi-stage switches and other transmission equipment in the transmission path cause delay. Using this function, the MX773000PC simulates the latency state in the transmission path by adding Time Error to the S-Plane and has a built-in function for measuring the C-Plane and U-Plane.

PTP Time Error Injection(Conformance Test)

Select	Frequency [Hz]	Dynamic Time Error [ns]	Constant Time Error [ns]
☒	0.003362 0.1 0.003362	24.710 710	710.1396 710
☐	0.003362 0.1 0.01	24.710 239	710.1396 1181
☐	0.003362 0.1 0.1	24.710 24	710.1396 1396

Figure 14 Example of Time Error Input Parameters

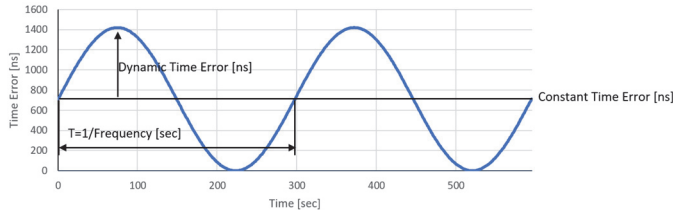


Figure 15 Time Error Injection Graph

4.2.3 MX772000PC

The O-RAN Alliance Working Group 4 (WG4) defines the O-RAN Conformance Test for the evaluating the O-RU, while 3GPP defines the TS36.141 and TS38.141 standards.

We developed the MX772000PC ORAN Test Platform to automate these tests and support continuous testing and pass/fail evaluations.

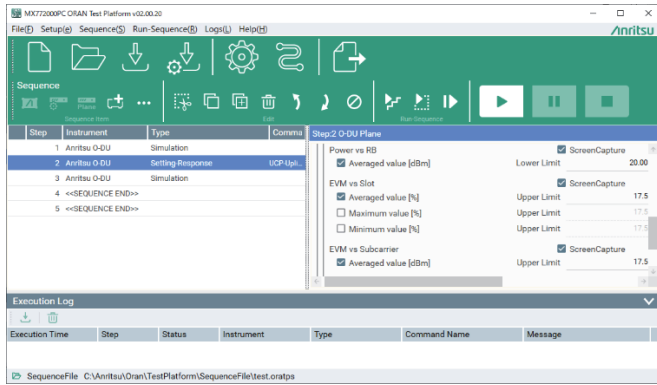


Figure 16 Sequential Execution of Pass/Fail Evaluation for Each Tester Settings and Results

The MX772000PC software controls multiple software, such as the MX773000PC and MX800046A, as well as the hardware to execute step settings line-by-line and the M/S/U/C-Plane tests sequentially. As well as controlling MX773000PC and MX800046A, it also has functions to set the wait time at each step, display user dialogs, record execution logs, add step comments, and repeat any step, and add/edit settings. These functions can be combined flexibly into an automated sequence supporting near-to-live environment testing.

The pass/fail sequence execution result for each step is displayed. In addition, pass/fail evaluation results are displayed for the entire sequence after execution of the whole sequence is finished.

- M-Plane Test

This function controls the MX773000PC and sets the O-RU M-Plane. It has a built-in pass/fail function to evaluate whether the setting result is the expected value.

- Downlink U/C-Plane Test

This function controls the MX773000PC and transmits U/C-Plane packets to the O-RU. It also controls the MX800046A, and acquires and evaluates analysis results for the Downlink signal output from the O-RU. Additionally, as well as evaluating one measurement result, it also has a function to evaluate multiple measurement results during a specified period.

- Uplink U/C-Plane Test

This function controls the MX800046A and transmits the Uplink signal to the O-RU. Additionally, it also controls the MX773000PC and transmits the Uplink C-Plane to the O-RU. It also has a built-in function to evaluate acquired analysis results after receiving Uplink U-Plane packets from the O-RU and performing signal analysis at the MX773000PC.

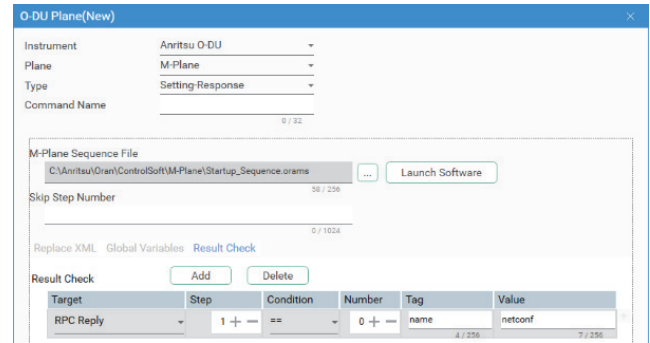


Figure 17 MX773000PC Control (M-Plane Pass/Fail Condition Settings)

- S-Plane Function

This function controls the MX773000PC and performs O-DU and O-RU PTP and SyncE synchronization functions as well as adds Time Error to PTP for testing.

4.2.4 MX800046A/IQproducer

This software creates the waveform data using IQproducer at Downlink/Uplink testing and transmits and receives RF signals. Although there have been base-station manufacturing solutions prior to this development, the Downlink/Uplink test in the O-RAN Conformance Test measures bit errors (mostly for PN23 patterns) on the Physical Downlink Shared Channel (PDSCH)/Physical Uplink Shared Channel (PUSCH), so this measurement item was to be added to the functionality.

When receiving the Downlink and executing RF analysis at the MX800046A, the PDSCH data is analyzed simultaneously after De-Scrambling. Moreover, analysis settings and expected measurement values can be generated

automatically from Downlink waveform information created by IQproducer when creating the waveform.

The expected PDSCH data values generated when the waveform is created as well as the MX800046A analysis results are acquired by the MX772000PC to calculate and evaluate the bit error rate and count.

5 Conclusion

We developed the O-RAN Radio Unit Test System for the growing Open RAN market.

This automated test system uses an intuitive GUI to confirm that O-RAN Radio Unit operation complies with the 3GPP TS38.141 and O-RAN Conformance Test items.

Future development is focused on test solutions to resolve equipment interoperability issues between Open RAN equipment, which we hope will help spread and grow Open RAN.

References

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- 2) 3GPP TS38.141-1 NR Base Station (BS) conformance testing Part 1: Conducted conformance testing
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- 4) O-RAN Alliance e.V. O-RAN Working Group 4 (Open Fronthaul Interfaces WG) Control, User and Synchronization Plane Specification Management Plane Specification
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- 7) Anritsu Corporation. O-RAN Radio Unit Test Solution product introduction (web), Nov 28 2023. <https://www.anritsu.com/en-us/test-measurement/products/mx772000pc>
- 8) Xilinx Inc. T1 Telco Accelerator Card Data Sheet (DS999)
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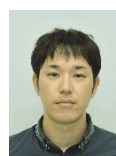
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Table 1 Key MX773000PC Specifications

Communication Functions	U/C-Plane	Frequency Range	FR1 (Frequency Range 1)
		Bandwidth	20, 40, 60, 80, 100 MHz
		Subcarrier Spacing (SCS)	15, 30 kHz (15 kHz only at 20 MHz bandwidth)
		No. of Layers	1
		No. of Component Carriers (CC)	1
		No. of Controlled RF Ports	1
		Supported Protocols	VLAN (Virtual Local Area Network) *Multi-tags not supported O-RAN Split Option 7-2x C-Plane for Downlink Scheduling U-Plane for Downlink IQ U-Plane for Uplink IQ (Decoding not supported) *IP/UDP (User Datagram Protocol) not supported *Supports eCPRI as Transport Header but RoE (Radio over Ethernet) not supported
		Compression Algorithm	Block Floating Point (BFP) 9/12/14 bit
	M-Plane	Supported Protocols	VLAN *Multi-tags not supported Netconf Client IPv4, IPv6 DHCPv4, DHCPv6, Static IP SSHv2 (Secure Shell 2.0), TLS (Transport Layer Security) 1.2
	S-Plane	Supported Protocols	PTPv2, SyncE (ESMC) PTP Profile: G.8257.1
Measurement Functions	U/C-Plane	—	Uplink: TX Power, EVM (Error Vector Magnitude), Frequency Error, Origin Offset, Timing Offset, Descramble results display, EVM/Power/Constellation graph display Downlink: Tx function for IQproducer-created waveform data, Function for regenerating U/C Plane packets saved in pcap
	M-Plane	—	Edit any packet sequence and set any parameters Displays O-RU response to executed sequence Displays M-Plane connection status
	S-Plane	—	Functions for changing PTP and SyncE parameters Function for confirming PTP and SyncE sync status via M-Plane Changeable PTP parameters: Domain, Step Mode, Priority#1/#2, Clock Class, ID, Time Source, Clock Accuracy, Announce Interval, UTC Offset, Sync Interval, Minimum Delay Request Interval Changeable SyncE parameters: QL, Source MAC Address, Event Flag
		Time Error Injection Function	Function for adding time error defined in item 3.3.3 of O-RAN Conformance Test (O-RAN.WG4.CONF.0) to PTP time
		PTP Correction Function	Function for correcting PTP update timing time error in input 1PPS signal and at O-DU Emulator
		Frequency Correction Function	Function for correcting input PPS signal and Ethernet frequency error
	Others		Functions for capturing Ethernet packets and outputting to pcap file

Publicly available