



O-RAN Next-Generation Fronthaul Conformance Testing

The Move Toward an Open RAN

Radio access network (RAN) deployments for 4G and earlier relied on shared proprietary network equipment from the same vendor or vendors. Traditionally a multi-vendor network had equipment from multiple vendors deployed in different parts of the network. Most often, equipment from various vendors did not mix in a particular part of the multi-vendor network. Many service providers refer to this as a single vendor “region.” As a result, the radio units had to be from the same manufacturer as the baseband unit (BBU). Together, these devices formed what was known as the eNodeB (eNB) in LTE.

Driven mainly by the O-RAN Alliance, service providers worldwide are driving adoption of an open RAN for 5G. The O-RAN Alliance has defined a 5G RAN architecture that breaks down what was once a single-vendor, hardware-centric RAN into several sections. Interoperable standards precisely define the interfaces between these sections.

The O-RAN Alliance brings together mobile network operators, equipment manufacturers, device makers, and chipset suppliers to create standards and recommendations for an open radio access network (RAN). Building a more cost-effective, agile RAN requires openness. Open interfaces are essential to enable small-scale vendors to introduce their own services quickly. Open interfaces facilitate multi-vendor deployments and a more competitive supplier ecosystem.

As a result, service providers can mix and match components from several vendors, which offers the following benefits:

- **Virtualization:** Fronthaul interfaces are moving from proprietary common public radio interface (CPRI) to open Ethernet. Ethernet enables virtualization by allowing fronthaul traffic to switch between physical nodes using common off-the-shelf networking equipment. As a result, traffic directs to nodes with spare capacity and new instances of baseband processing startup.
- **Price:** Competition within the marketplace reduces costs.
- **Innovation:** Previously, small-scale radio vendors could not gain entry to a network because they did not interoperate with an incumbent eNB. Service providers were unable to deploy any breakthrough technology offered by a small-scale vendor unless they also used that vendor’s eNB. Small vendors lack the resources to build a complete RAN. Open interfaces solve this problem.
- **Speed of innovation:** Small-scale companies move faster than large ones. By enabling these companies to participate, carriers hope to accelerate innovation.
- **More control:** Virtualization of new network elements allow for more customization without proprietary interfaces.

The new O-RAN for 5G, and in many cases retroactively for LTE, consists of the following three components:

- O-RAN Central Unit (O-CU) is the component of the RAN that is centralized and virtualized. It is responsible for the packet data convergence protocol (PDCP) layer of the protocol. Its northbound interface is the backhaul network to the core; its southbound interface is the F1 interface.
- O-RAN Distributed Unit (O-DU) is the component responsible for all baseband processing, scheduling, radio link control (RLC), medium access control (MAC), and the upper part of the physical layer (PHY). The F1 is the northbound interface, and the O-RAN fronthaul is the southbound interface. The virtualization of this component is typical but requires some hardware assistance in the form of accelerators such as field-programmable gate arrays (FPGAs) or graphics processing units (GPUs).
- O-RAN Radio Unit (O-RU) is the component responsible for the lower part of the PHY layer processing (for example, fast Fourier transform (FFT) / inverse fast Fourier transform (IFFT), beamforming), including the analog components of the radio transmitter and receiver. There is a remote possibility of virtualization of the O-RU; however, one working group in the O-RAN Alliance plans a “white box” radio implementation using off-the-shelf components. It enables anyone to construct a radio without proprietary components, which differs from virtualization.

Figure 1 shows the O-CU, O-DU, and O-RU integration that 3GPP refers to as the gNodeB (gNB).

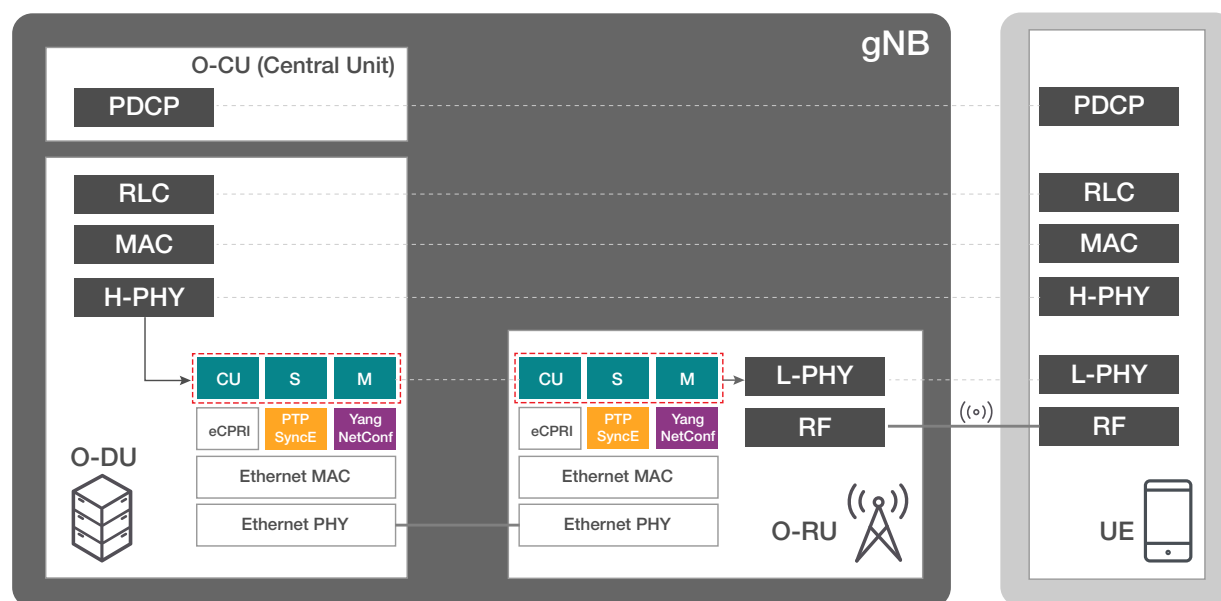


Figure 1. The protocol stack on a gNB

Conformance and Interoperability Testing

Making the new open RAN work demands stringent test requirements. In the past, testing the eNB as a complete entity according to 3GPP requirements was enough. The required test points focused on the UE and backhaul interface. With the introduction of the open RAN and a distributed RAN, it is now necessary to test each component in isolation for conformance to the standards. It is also important to test the components in combinations for interoperability.

Conformance and interoperability testing are both necessary to correct any performance issues. Usually, completion of conformance testing happens first to ensure all elements meet the required interface specifications. Interoperability testing occurs next to ensure all elements work together. Bypassing conformance testing and only relying on interoperability testing is equivalent to a car manufacturer assembling a car from untested parts and only testing whether the car starts and runs.

Conformance testing focuses on each component in isolation. Testing in isolation requires test equipment to emulate the surrounding network element to check all capabilities in the protocol. There are benefits to this approach not attainable with interoperability testing alone. These tests reduce the risk associated with deploying in an open RAN.

Benefits of conformance test

- Stresses the device under test (DUT) to the limits of its stated capabilities.
- Exercises protocol features to test that interfaces and functions are working as expected.
- Ensures your application is functioning properly by performing negative testing, which is not possible in interoperability testing.



Test Challenges

Fronthaul conformance testing

Interoperability testing methodology changed minimally from 4G to 5G O-RAN. In interoperability testing, you simply test a combination of equipment as a gNB, similar to testing an eNB in 4G. Conformance testing is different for O-RAN conformance tests.

Conformance test for the O-DU

The master node for the O-RAN fronthaul protocol is the O-DU. In the O-DU southbound interface, the control and user plane protocol messages come from the O-DU to the O-RU, except license assisted access (LAA) and uplink user plane data. The O-RU does not acknowledge these messages; it merely carries them out in the best feasible way.

The F1 northbound interface is a stream of data sent through the radio to one or more UEs. The F1 interface does not have a mechanism to direct the O-DU to format data, which protocol elements to use, or how to send the data in time. That type of control is necessary to test the O-DU for O-RAN compliance but is only available through a dedicated port. For example, if you need to test non-contiguous resource block allocations (section extension six) because a vendor's radio supports it, it is not possible to force the O-DU to include that section extension in its C-plane messages. For this reason, the O-RAN conformance test specification chose to defer testing the O-DU until a later date.

Conformance test for the O-RU

The O-RU executes C-plane commands without acknowledgment back to the O-DU. These messages transmit at extremely high data rates and a very tight timing tolerance. You can analyze the RF response of the O-RU to determine whether it understood and correctly acted on the O-DU's commands. Also, to test the O-RU, you need an emulator to simulate the O-DU, a vector signal analyzer to receive RF energy emitted by the O-RU, and a signal source to generate an uplink signal to the O-RU for it to process. You need additional equipment such as a chamber and positioning system if this is for an over-the-air (OTA) test.

The O-RU also requires a 5G or LTE formatted waveform since the O-RU understands the resource elements and resource blocks. The O-RU must “zero-fill” unused resource blocks not sent by the O-DU.

The O-RU needs to know the placement of resource blocks in a symbol and where to zero-fill. As a result, it is impossible to test the O-RU in either uplink or downlink with a single-carrier signal as in 4G. As Figure 1 shows, the O-RU is unaware of the protocol layers such as the MAC, RLC, and PDCP layers. Testing an RU with a sophisticated UE emulator and a full-stack DU emulator emulating functions like UE mobility, handovers, and UE attach procedures would essentially be no more than using test equipment to exercise test equipment.

Due to tight timing tolerances, the O-RU (DUT), O-DU emulator, signal analyzer, and the signal source require synchronization to a common clock. Usually, the O-RU expects to receive its timing from a synchronous Ethernet connection, as well as S-plane messages from the O-DU emulator. The synchronization of the O-DU emulator and the O-RU ensure alignment in the entire system. It is also important that the O-DU emulator triggers the signal generator at the appropriate time to send its RF signal to the O-RU.

All conformance tests in the O-RAN fronthaul conformance test specification begin with exercising the M-plane and synchronizing through the S-plane before starting any CU-plane testing. These functions require testing before any CU-plane tests begin.

Conformance test set up for O-RU

A conformance test solution for an O-RU includes an O-DU emulator, a vector signal analyzer, and a signal source. You can use a test sequencer to automate the testing since a conformance test suite consists of hundreds of tests. Figure 2 shows the test equipment radio (TER) in the O-RAN conformance test specification.

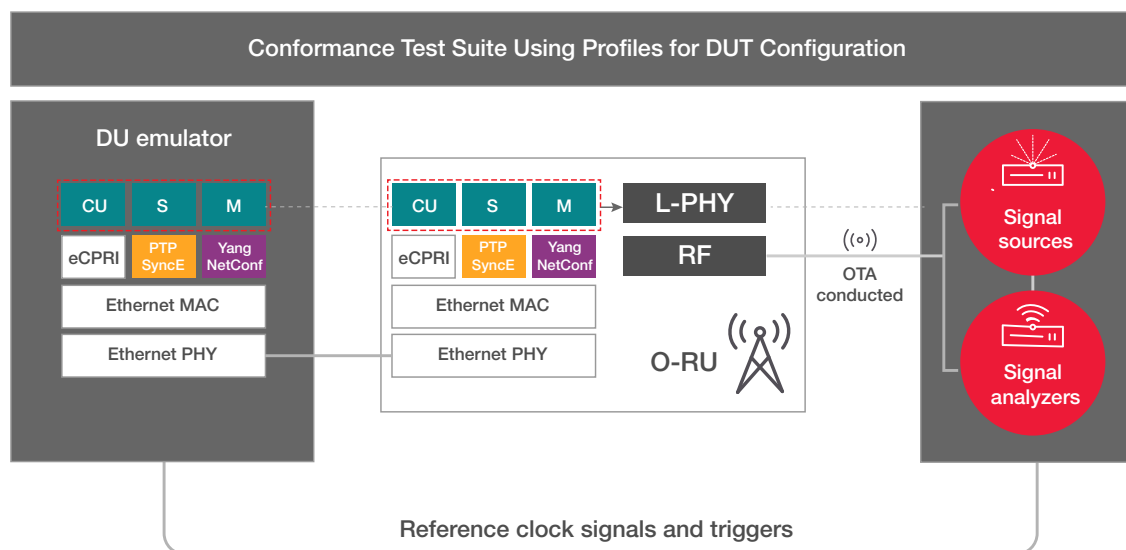


Figure 2. TER equipment radio test

Conducted test considerations

Generally, FR1 radios have conducted test ports available or exposed by the manufacturer. Conducted test ports enable easy and cost-effective testing. The challenge arises when you have large antenna arrays on FR1 radios. In this case, it is expensive to have an analyzer on every port. However, to measure beamforming, you measure the ports at least pairwise because measuring phase and amplitude differences require at least two signals.

It is possible to use an RF switch matrix and switch ports into and out of test equipment; however, that is time-consuming. Another solution is to use a channel emulator with spatial filtering or beamforming capabilities to attach to all ports simultaneously. The result digitally moves the signal analyzer / signal source to measure the beam strength at various points.

OTA testing

FR1 OTA testing is expensive because the chambers are large. It is best to use a conducted test for FR1.

Most FR2 radios require OTA testing because they do not have conducted test ports. The good news is that FR2 chambers are smaller and less expensive than FR1 chambers.

Other than the physical connection to the RF side of the radio, the test configuration is the same for conducted and OTA tests.

How to Choose the Appropriate Test

The conformance test specification contains broad sections to test the M-plane, S-plane, and CU-plane. There are a variety of test categories, and the following are questions to ask to determine the best test for your specific purpose:

- **Generic:** Does the O-RU perform basic resource allocation tasks using symbol number increment commands (symInc), resource blocks (RBs), or non-contiguous RB allocations?
- **Beamforming:** Will the O-RU support basic index-based beamforming and advanced beamforming methods?
- **Compression:** Can the O-RU correctly compress and decompress I/Q data?

- **Delay management:** Does the O-RU work correctly at the limits of its delay windows?
- **LTE:** If the radio is a 4G LTE radio, will it support all required capabilities?
- **LAA:** Can it meet the criteria if the radio supports LAA?

The O-DU emulator

The O-DU emulator requires the test engineer to build a real 5G waveform with one or more frames. The waveform generation capability is similar to software packages used in many signal generators to construct test signals. It enables you to build waveforms that include all the features in a 5G frame. These waveforms include synchronization signals, multi-layer multiple-input / multiple-output (MIMO), demodulation reference signal (DMRS), physical downlink control channel (PDCCH), and physical downlink shared channel (PDSCH) channels. It also has the functionality to control power levels, build uplink and downlink signals, and the ability to automatically make 3GPP compliant frames since the O-RAN conformance test specification uses these as test signals. Waveform generation capability can also generate frequency-domain I/Q data.

When completed, the O-DU emulator takes the signal created and automatically breaks it down into appropriate section types. The tester then needs to adjust the O-RAN specific parameters, such as compression type and method. For example, whether to use static or dynamic, block floating point, beam identification, or weights. This process includes optional section types such as section type O, extended antenna carrier (eAxC) values, mixed numerologies, and any I/Q power scaling.

The O-DU emulator needs to recognize downlink signals and construct U-plane and C-plane messages. It must also recognize uplink signals and only construct correct C-plane messages. The O-DU emulator enables you to specify timing constraints to test the boundaries of the radio's delay windows.

When this process is complete, the O-DU emulator stores the downlink C- and U-plane messages and the uplink C-plane messages as a single test. When you begin the test, the O-DU emulator sends the O-RAN fronthaul packets to the O-RU following the timing constraints set during signal construction. It will also adjust the frame and subframe numbers and check the sums in real time.

Simultaneously, the O-DU emulator triggers the signal source to send uplink RF after an appropriate delay. The delay allows the O-RU to decode and interpret the uplink C-plane messages it just received before recognizing any RF signals. If required, it can also trigger the signal analyzer to begin analyzing downlink RF; the O-DU emulator coordinates the entire test.

Triggering is essential to test time division duplex (TDD) radios. In TDD, the uplink and downlink are on the same frequency band and separated in time. Test coordination is necessary between the O-DU emulator and the rest of the test equipment used in the test.

The O-DU emulator captures the uplink U-plane messages to extract the frequency domain I/Q data from those messages. It will analyze the I/Q data with a software-based vector signal analyzer to assess the data contained in the resource blocks to determine whether they match the ask from the C-plane messages.

The signal source

The signal source generates the uplink RF signal, which must exactly match the uplink C-plane messages generated in the O-DU emulator. For example, the C-plane messages constructed in the O-DU emulator are programmable into the signal generator to ensure accurate user plane (U-plane) data aligns with the resource blocks of its RF signal. Ideally, the O-DU emulator and the signal source waveform software will share that information. Without sharing, the configuration of the signal source equipment is a manual process. It is also important to confirm that the correct data appears in all used resource blocks. This process helps you determine whether the O-RU decoded is the correct resource block as instructed by C-plane commands.

Another important capability of the signal source is whether it can delay its RF output via a set time from the initial trigger signal. This function tests the limits of the delay windows to validate the radio's behavior while adjusting the delay from the last C-plane message to the start of the RF transmission.

The signal analyzer

The signal analyzer receives the RF signal generated by the DUT in the downlink direction. It will decode and demodulate the signal to give you access to the data in the downlink signal. This capability is essential because many tests require the placement of specific data in the specified resource blocks. The output of the analyzer verifies whether the radio accurately read and understood the C-plane commands to place the U-plane data in the right area.

As with the signal source, the signal analyzer shares the configuration data with the O-DU emulator to minimize the amount of manual configuration. Manually configuring the test equipment is very time-consuming when running hundreds of tests.

The test sequencer

The test sequencer engine automates the hundreds of conformance tests required by the O-RAN. The test sequencer can control and coordinate the O-DU emulator, signal source, and signal analyzer through their application programming interfaces (APIs). It also accepts test results from all components. Figure 3 shows the complete test automation platform for the TER.

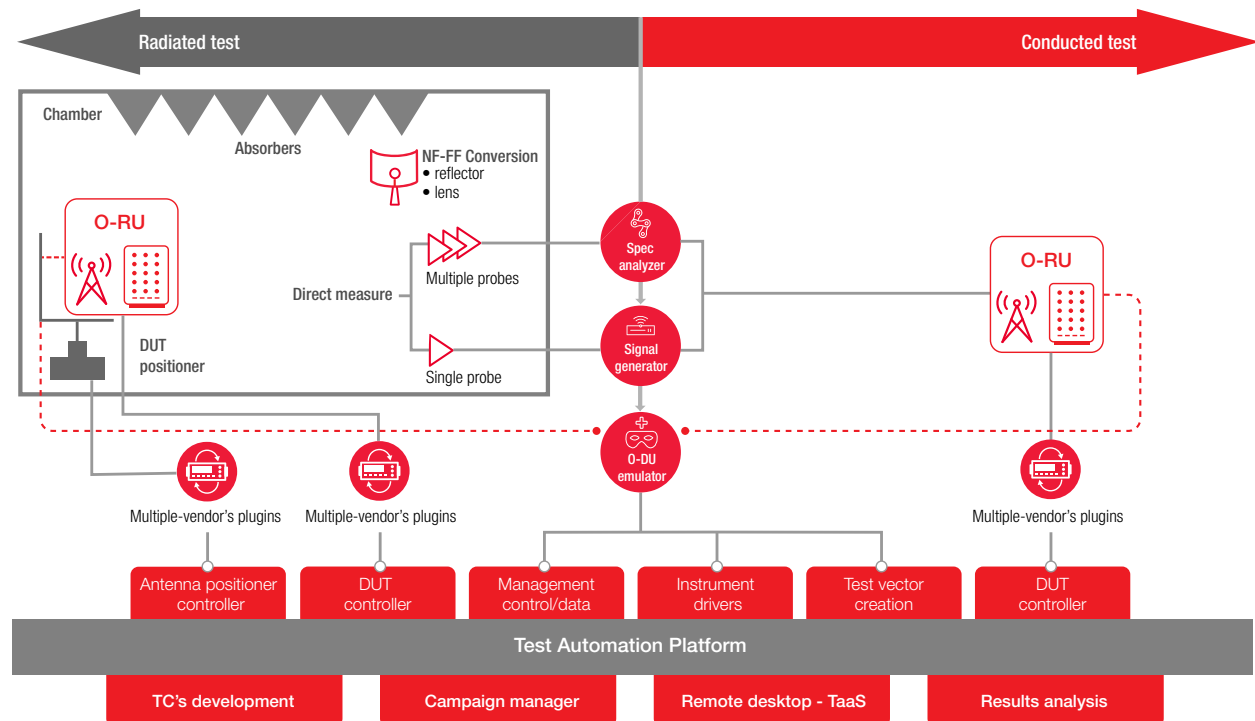


Figure 3. An example of the test automation platform managing, through drivers, the entire test system for either OTA testing (left) or conducted testing (right)

Relationship to 3GPP Testing

Conducting tests specified in 3GPP specifications 38.141-1 and 38.141-2 requires a full gNB since 3GPP does not recognize the open nature of O-RAN. 3GPP does not separate the radio from the baseband processing unit as required by O-RAN. However, it is possible to leverage the 3GPP transmitter and receiver tests (Chapters 6 and 7 of 3GPP 38.141-1/2) when validating the O-RAN fronthaul. All test waveforms specified by the O-RAN conformance test specification use the same test waveforms used in 3GPP tests. Payload data is the only modification. This data is usually a pseudorandom sequence rather than all zeros as specified by 3GPP. The non-zero data ensures the correct data migrates to the right resource blocks. Figure 4 shows the 3GPP test sequences for uplink and downlink.

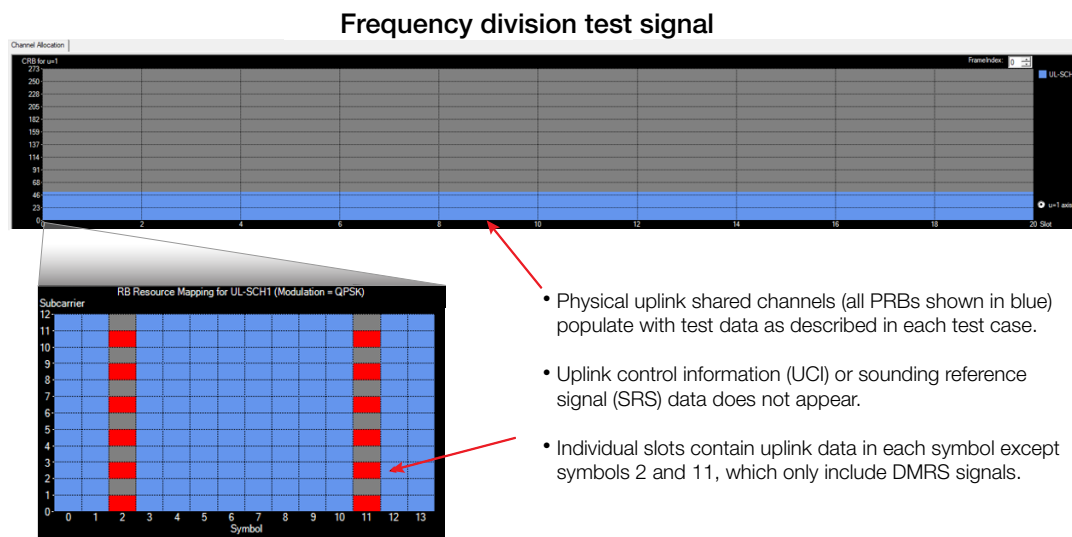


Figure 4. Uplink test signal

3GPP NR-FR1-TM1.1 FDD test signal

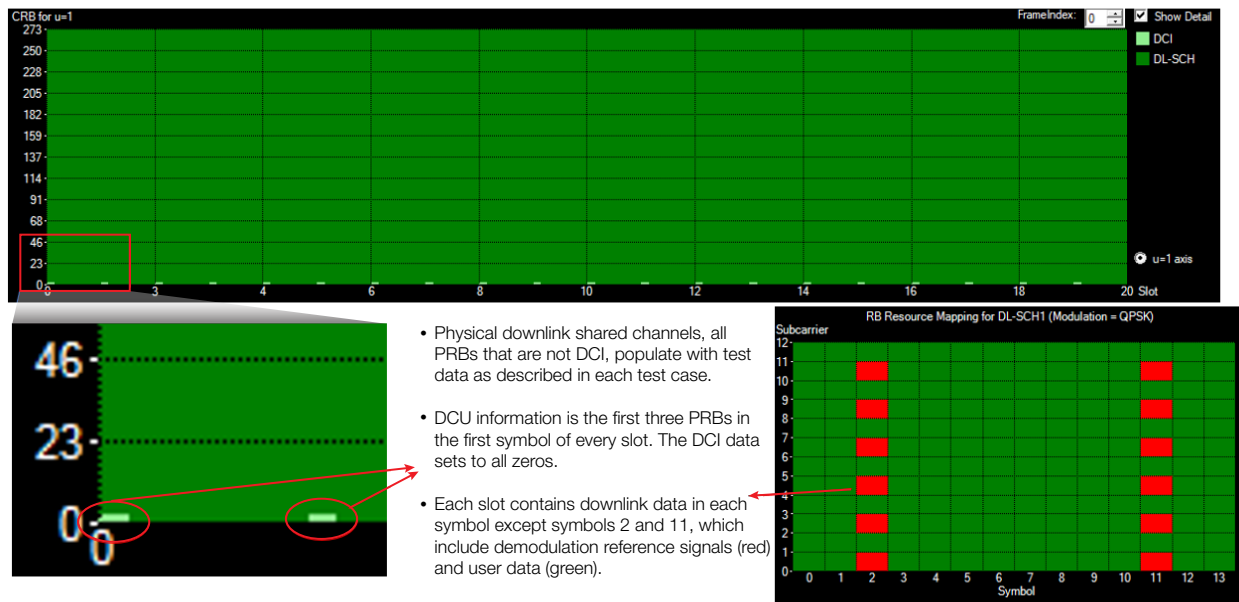


Figure 5. Downlink test signal

The O-RAN WG4 conformance test specification ensures the O-RU's compliance with the O-RAN fronthaul standards. The test setup can test a radio for 3GPP transmitter and receiver performance and O-RAN conformance. The only difference is that 3GPP expects the tests to run on a gNB that is in test mode. The O-RAN tests the radio using an O-DU emulator and does not require a test mode. It is not possible to perform 3GPP Chapter 8 conformance tests using the O-DU emulator because it requires MAC layer processing, which is not present in the O-DU emulator.

Solution

The Keysight O-RAN fronthaul test solution offers a full O-RU test and conformance certification system. The hardware solution has one or more Keysight PXI VXT-II transceivers to generate and receive RF signals from the DUT. The PXI chassis accepts additional transceivers for multiport testing; upconverters are also available for FR2 OTA testing. The O-DU emulation FPGA player provides timing to the O-RU to trigger a pulse per second (PPS) signal to the transceivers.

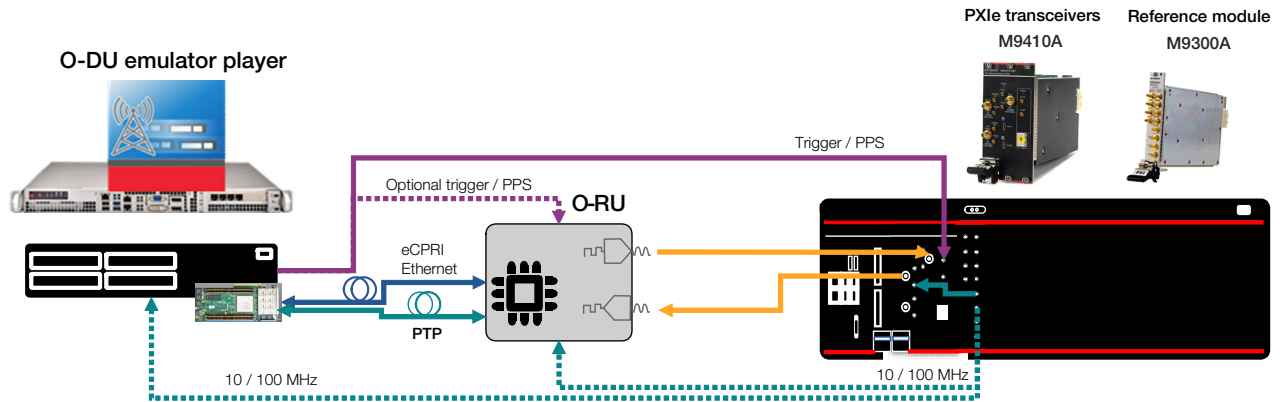


Figure 6. Keysight O-RU test solution

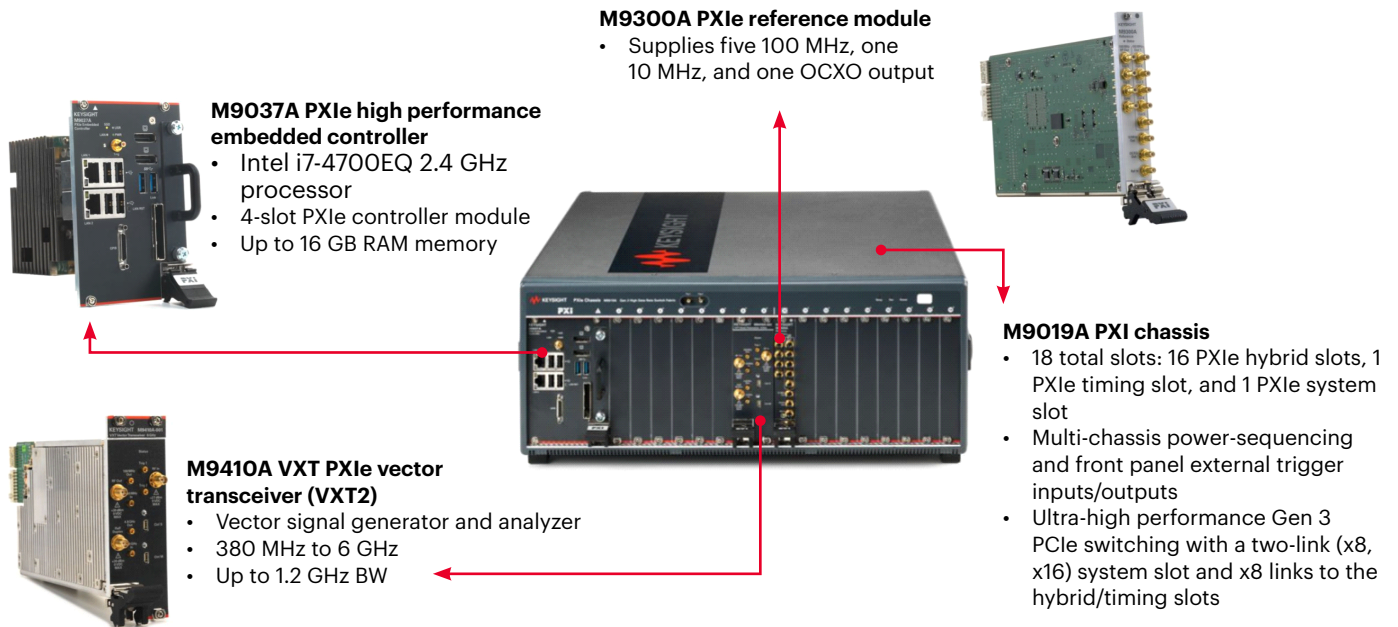


Figure 7. Keysight modular transceiver platform for O-RU test

The solution consists of Keysight's

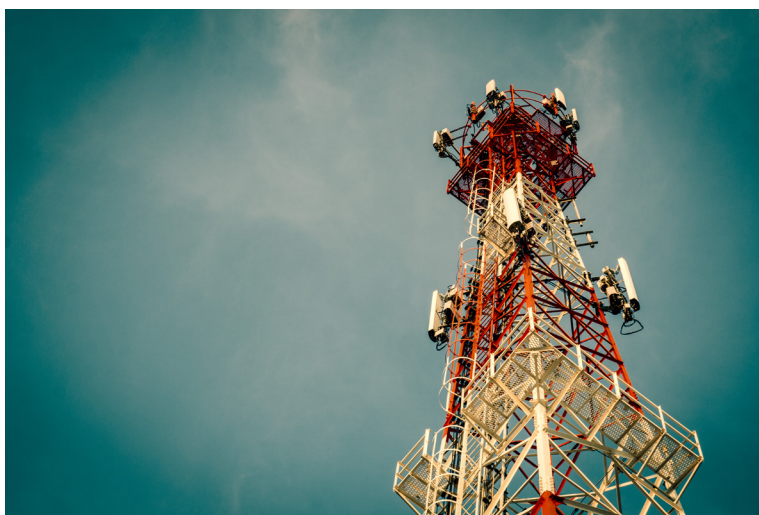
- PathWave Signal Generation software for 5G NR
- Open RAN Studio, Keysight 89600 VSA software for 5G NR
- Keysight KS8400 test automation platform

PathWave Signal Generation creates 5G waveforms for Open RAN Studio as well as for transmission by the Keysight M9410A vector transceiver.

The automatic configurations create C-plane messages for the uplink while the Keysight M9410A VXT PXIe vector transceiver (VXT) uses the same PathWave Signal Generation configuration to generate the uplink RF. The captured uplink I/Q data is extracted from the O-RAN messages and passed to the vector signal analyzer for analysis. The PathWave Signal Generation software configuration file automatically sets up the vector signal analyzer with the necessary configuration parameters. The analyzer measures the RF specific parameters such as error vector magnitude (EVM). It also decodes and demodulates the signal to determine if the U-plane data matches the VXT data.

In the downlink, PathWave Signal Generation creates 5G NR waveforms encapsulated by the Keysight Open RAN Studio Builder. Open RAN Studio Builder adds O-RAN specific parameters to the set of stimulus packets before the Keysight Open RAN Studio Player transfers the packets to the DUT. The PathWave Signal Generation software automatically creates configuration files for the running vector signal analyzer configuring the downlink VXT.

Keysight's Open RAN Studio Explorer examines O-RAN packets captured during the test. It features complete decode capability and allows the user to see packet data as well as timing. It can also display frequency domain I/Q and constellation diagrams.



The Open RAN Studio Builder gives you control over the player while it sends packets. Since the player timestamps all received and transmitted packets in the captured file, you can verify the edges of the timing windows. It also enables you to specify when to send triggers to the VXT for uplink transmission. The VXT allows configurable delays upon receiving triggers before sending its signal.

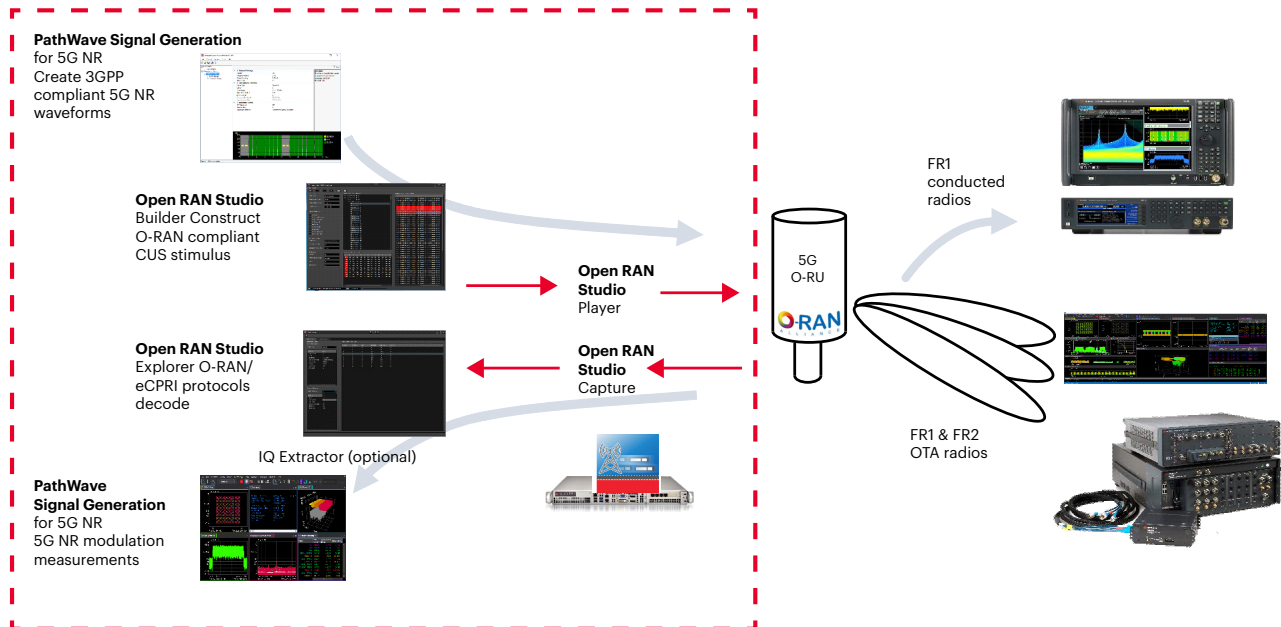


Figure 8. Automate tests with Open RAN Studio for O-RU testing and validation

Summary

To ensure a multi-vendor RAN works properly, it takes more than merely placing multiple instruments together and running through a few calls. Testing each section individually to the maximum of its capabilities is particularly important for O-RUs. The right test tools ensure that you test the radio unit thoroughly. When testing O-RAN compliant radios, you need to go beyond the test protocol because the radio does not return any status messages. Easily simulate the radio with the correct protocol messages containing valid 5G waveforms. Then, measure and coordinate what occurs on the RF side of the radio with the protocol side. Proper testing ensures you choose the right network equipment for your requirements.

For more information on open RAN and 5G, please review the following resources:

- [Keysight 5G Solutions – Online](#)
- [U504BSCA Open RAN Studio – Online](#)
- [Open RAN Studio – Data sheet](#)
- [5G O-RAN Software Solutions – Online](#)