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Test Plans, Results, and Lessons Learned About Open RAN Integration During the NTIA 5G Challenges

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About Open RAN Integration During the NTIA 5G Challenges

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Glossary of Terms

3GPP	3rd Generation Partnership Project
5G	fifth generation wireless technology
CBRS	Citizens Broadband Radio Service
DOCSIS	data-over-cable service interface specification
DoD	U.S. Department of Defense
E2E	end-to-end
ITS	Institute for Telecommunication Sciences
NOI	Notice of Inquiry
NTIA	National Telecommunications and Information Administration
NTN	non-terrestrial network
Open RAN	open radio access network
O-CU	open central unit
O-DU	open distributed unit
O-RU	open radio unit
OTIC	Open Testing and Integration Centre
RAN	radio access network
SA	standalone
SE-RAN	Security-Enhanced RAN
TIP	Telecom Infra Project
UE	user equipment
Wi-Fi®	wireless network protocols based on the IEEE 802.11 family of standards

Test Plans, Results, and Lessons Learned About Open RAN Integration During the NTIA 5G Challenges

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Abstract: The vision of the 5G Challenge competitions was to accelerate adoption of 5G open interfaces, interoperable subsystems, and multi-vendor solutions by fostering a large, vibrant, and growing vendor community dedicated to advancing 5G interoperability towards true plug-and-play operation. This report provides test plans, results, and lessons learned about 5G Open RAN multi-vendor interoperability and compliance during the 2022 and 2023 5G Challenges. Multiple vendors demonstrated O-RAN ALLIANCE subsystem interoperability and performance on a limited timeline with no prior integration or planning. Contestants made significantly faster integration progress when they were open to sharing and working together. Significant integration time was devoted to resolving configuration parameters and compliance mismatches (e.g., which options were selected). Stringently following software development best practices improves the speed and success of multi-vendor interoperability.

Keywords: 5G, interoperability, Open RAN

1. Introduction

The National Telecommunications and Information Administration's Institute for Telecommunication Sciences (NTIA/ITS) and the U.S. Department of Defense's Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E)) partnered to execute prize-based 5G Challenge competitions to foster, accelerate, and expand Open RAN development and adoption. This included a key partnership with CableLabs as the host lab and system integrator to develop and execute the test strategy and activities. This report presents the methodology and results from this research to expand and improve Open RAN

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interoperability testing and thereby accelerate the adoption and development of Open RAN services.

The 5G Challenges implemented an innovative multi-vendor interoperability testing paradigm for fifth generation (5G) cellular open radio access network (Open RAN) standards-based systems. This novel testing approach allowed true ad hoc multi-vendor interoperability testing to encourage new development and entrants into the 5G Open RAN marketplace. The research provides insights and recommendations for future activities that replicate and build on the 5G Challenge's testing framework to further support multi-vendor deployments of O RAN ALLIANCE open central units (O-CU), open distributed units (O-DU) and open radio units (O-RU). The O-CU hosts the control plane and user plane functions and protocols that control radio resources, packet data convergence, and transport layer processing. The O-DU hosts various protocol layers for baseband processing and data transmission. The O-RU converts the radio signals from the antenna to digital signals sent to the O-DU and vice versa.

2. Background

2.1 The Nature of the 5G Open RAN Interoperability Problem

Current cellular deployments and operations are dominated by monolithic, closed, and proprietary systems installed and maintained by a small number of major vendors [1]–[3]. This fosters an environment where the cost of market entry for new and smaller vendors—already at a disadvantage because of low visibility in the field—is prohibitively high and there is little motivation for the major vendors to migrate to an open, disaggregated, modular, and more interoperable architecture. New or smaller 5G market entrants often lack financial resources and need incentives to create open standards products, services, and offerings for 5G Open RAN multi-vendor deployments.

Monolithic, single vendor 5G deployments raise concerns around:

- Vendor lock-in
- Higher costs, especially for new capabilities
- Reduced incentive for innovation
- Potential security risks
- Supply chain resilience

Potential security risk issues include the operator's inability to examine network subsystems for security threats. More information on cellular security is provided by the DoD sponsored Security-Enhanced RAN (SE-RAN) [4] project.

Open RAN is an active area of commercial development designed to build upon 3rd Generation Partnership Program (3GPP) standards and promote the disaggregation of the typically monolithic cellular infrastructure. Open RAN supports the growth and development of open interfaces, so multiple vendors can seamlessly interoperate [1]–[3], [5], [6]. Currently, traditional single-vendor deployments generally outperform multi-vendor Open RAN deployments when examined for performance and feature parity (e.g., operations, service management, and network optimization capabilities).

Initial 5G testbeds consisted of legacy and entrenched operators and vendors partnering to test operator-specific features, use cases, and requirements. These early 5G testbeds typically did not explicitly test multi-vendor interoperability, and they were only available to specific vendors. Small or new entrants to the 5G Open RAN market are often constrained by the availability of experienced staff and budgets for interoperability testing. This creates a barrier to entry and highlights the need for openly available 5G testbeds [1]. Access to 5G testbeds has improved as a result of the establishment of many new Open RAN labs (e.g., the DISH ORCID lab in Wyoming), but the budget concerns remain.

The slow progress of multi-vendor interoperability hinders the U.S. Government's desires to support new entrants into the 5G market and to leverage Open RAN networks for specialized use cases. Large cellular infrastructure vendors mainly focus on the commercial cellular operator market. Small companies and new entrants are more likely to be interested in developing customized services and products for smaller markets, like the Department of Defense's (DoD) unique use cases. The success of these small market opportunities relies on Open RAN.

These considerations led DoD and NTIA/ITS to partner and sponsor prized-based 5G Challenges to incentivize the industry to stimulate new entrants focused on true ad hoc multi-vendor 5G Open RAN interoperability based on Open RAN and 3GPP standards. Military information exchange requirements are increasingly outpacing the capacity to build DoD-focused custom wireless communication systems. Open RAN provides the potential for faster-paced development of customized networks that leverage commercial investments and technology. NTIA's mission aligns with the potential of Open RAN to lower the barriers to entry, increase the number of trustworthy suppliers in the market, improve security, and allow operators to choose a wider range of solutions for their particular network characteristics. The 5G Challenges goals and activities are a suitable fit for CableLabs' long history of independent arbitration and neutral host lab interoperability testing for the cable and wireless industries (e.g., DOCSIS®, CBRS, Wi-Fi®). Leading such efforts to drive Open RAN goals of creating vendor interoperability, open interfaces, and a vibrant multi-vendor ecosystem to promote an innovative ecosystem is in the best interests of the industry.

2.2 PlugFests

The O-RAN ALLIANCE develops Open RAN specifications and sponsors Open RAN interoperability events called PlugFests. These PlugFests are the most often used platform to foster and showcase interoperability between 5G Open RAN services and products.

While useful, PlugFests have limited applicability for establishing ad hoc multi-vendor interoperability. PlugFests focus on pre-planned interoperability demonstrations. The PlugFest timeline spans several months, during which the partners establish interoperability, choose test cases, and rehearse a performance demonstration, culminating in testing at an Open Test and Integration Center (OTIC) Lab and a presentation of the results. Because the vendors involved have a high level of control over their partners and test cases, other ways to accelerate advancement of true plug-and-play interoperability should be pursued in addition to PlugFests.

The 5G Challenges differed from the typical Open RAN plugfests because the Challenges:

- Implemented unanticipated pairings between vendors
- Included "stretch" goals in multi-vendor end-to-end (E2E) performance, loading, stress, and mobility
- Offered participants monetary incentives and free lab time

- Stipulated a several-week timeline to demonstrate interoperability
- Paired vendors who in the marketplace would not necessarily have worked together on interoperability before (e.g., a big vendor with a small, specialized vendor)
- Evaluated vendors against a common, pre-defined set of test cases

During a post-Challenge interview, one of the contestants explained the difference between PlugFests and the 2023 5G Challenge: "In a normal course of action, when we show up to O-RAN challenges, you typically show up with partners you've worked with in the past. In this challenge, it's a cold play. You are actually mixing and matching industry leaders that never work together."

2.3 5G Challenge Background and Purpose

DoD and NTIA/ITS partnered with CableLabs to create two 5G Challenge competitions to accelerate adoption of 5G open interfaces, interoperable subsystems, and multi-vendor solutions by fostering a vendor community dedicated to advancing 5G interoperability towards true plug-and-play operation.

The 5G Challenges were informed by a Notice of Inquiry (NOI) [7] that requested information on how to use Prize Challenges to accelerate the development of an open 5G ecosystem and to support DoD missions. The NOI responses identified potential benefits of Open RAN (e.g., better opportunities for innovation, increased diversity of RAN vendors), potential obstacles to Open RAN (e.g., more complex maintenance, including faultfinding and remediation, and the lack of end-to-end coordination), and potential advantages of single-vendor solutions (e.g., better support and access to 5G testbeds).

NTIA/ITS executed two 5G Challenge competitions in subsequent years (2022 and 2023).[5] The 5G Challenges created and introduced a novel prized-based testing approach to encourage, support, and evaluate ad hoc open standards-based interoperability between multiple vendors. The 5G Challenge engaged CableLabs to be the host lab, due to its prior experience as an independent host lab for certification and network equipment testing and its 5G system integration expertise. CableLabs, whose Kyrio subsidiary was the first O-RAN ALLIANCE–approved OTIC lab in the Americas, was the sole lab that met the needs of the project. It was a vital partner in the development and execution of test strategy and activities. The 5G Challenges created an open, collaborative, and supportive environment and encouraged and facilitated new and smaller participants by providing:

- A suite of test cases based on 3GPP standards and O-RAN ALLIANCE specifications
- Equal access to Open RAN test equipment and support
- Short-term test windows

[5] This document refers to the 2022 and 2023 5G Challenges, which in [12] are referred to as the *5G Challenge Preliminary Event: RAN Interoperability Event* (2022) and the *5G Challenge Final Event* (2023).

- Unanticipated contestant pairings

The 5G Challenges yielded many successes. Specifically, the 5G Challenges:

- Demonstrated ad hoc multi-vendor interoperability
- Established a cooperative testing environment
- Validated the testing methodology and environment
- Increased emphasis on open and interoperable interfaces in the industry
- Laid the groundwork for true plug-and-play operation

3. Technical Approach

Both the 2022 and 2023 5G Challenges used the same host lab, technical infrastructure, and approach, which aligned with research by Lacava [5]. The host lab provided 5G RAN test systems, 5G UE emulators, and a 5G standalone (SA) baseline system into which competing contestants integrated their subsystems. The 5G SA system is defined as a 5G core with a 5G RAN, as defined by 3GPP Release 15. The 5G Challenges tested only 5G SA configurations.

The 2022 5G Challenge focused on basic Open RAN standards compliance and RAN subsystem interoperability. The 2023 5G Challenge improved on the 2022 5G Challenge by adding performance and mobility testing. The host lab's capabilities more than doubled over this time period, which allowed the 2023 5G Challenge to accept more contestants and to offer longer testing windows. Both 5G Challenges referenced O-RAN ALLIANCE standards and 3GPP specifications for interface specifications and terminology.

3.1 Comparison Between 2022 and 2023 5G Challenge Structures

The O-RAN ALLIANCE Open RAN architecture, shown in Figure 1, provided the foundation for the 5G Challenges' laboratory environment. The Open RAN architecture [8] responds to the limitations of closed, integrated virtual RAN solutions offered by major mobile network infrastructure vendors and supporting efforts to realize an open, interoperable, and intelligent RAN [1]–[3], [5], [6], [9].

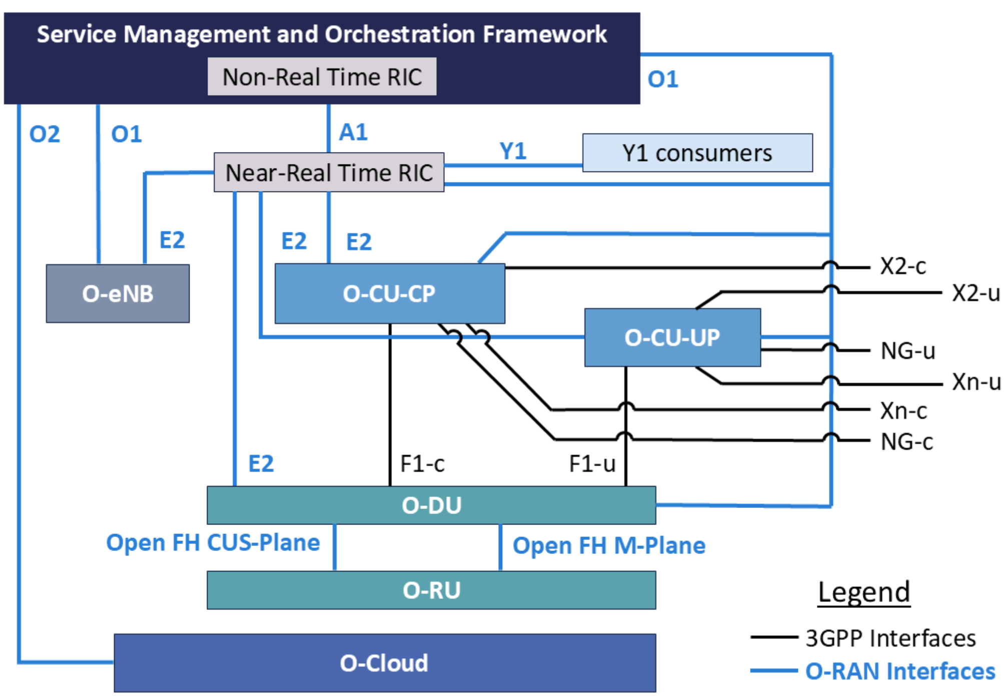

Figure 1. Open RAN architecture.

The 2022 5G Challenge [10] consisted of three stages (see Figure 2):

- Stage One: Application
- Stage Two: Wrap-around emulation testing on each contestant subsystem individually
- Stage Three: E2E integration testing, to establish and test an E2E data session

During Stage One (not shown in Figure 2), organizations applied to participate by submitting white papers. The most qualified contestants were accepted from the applicant pool. During Stage Two, each contestant subsystem was evaluated individually against Open RAN conformance requirements. During Stage Three, a baseline E2E integration of O-CU, O-DU, and O-RU was evaluated with basic performance testing.

The 2023 5G Challenge [11] had the same basic structure, except that a fourth stage of testing was added:

- Stage Four: Mobility testing between two E2E sessions

In addition, the O-CU and O-DU were combined into a single submission (O-CU+O-DU), and advanced performance testing was added to Stage Three stages (see Figure 2).

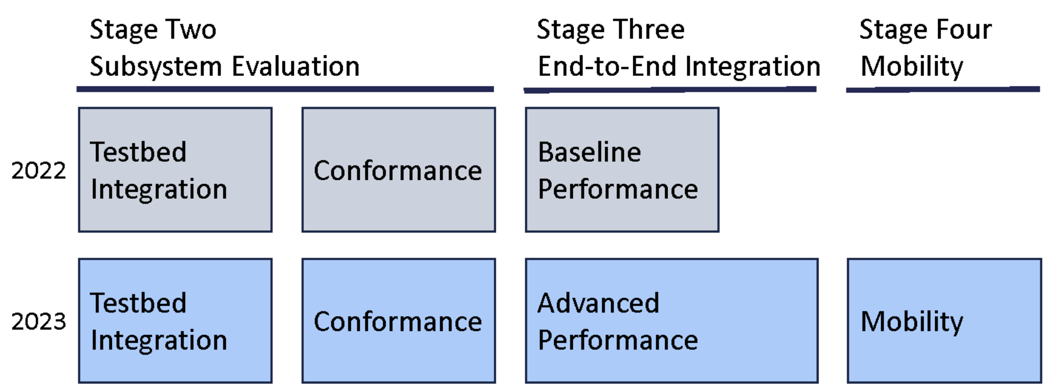

Figure 2. Comparison of testing performed for the 2022 and 2023 5G Challenges.

Analyses of the 2022 5G Challenge motivated the decision to move in 2023 from separate O-CU and O-DU submissions to a joint O-CU+O-DU submission. Many Open RAN vendor subsystems do not expose the F1 interface between O-CU and O-DUs, nor do they comply with O-RAN standards for the F1 interface. Small companies and new entrants are more likely to be interested in developing customized services and products for small markets, like the DoD’s unique use cases. Large cellular infrastructure vendors mainly focus on the commercial cellular operator market. In private communications, mobile network operators (MNOs) expressed interest in adding third-party RUs into their networks—because RUs are deployed across large geographic areas with diverse challenges that could benefit from vendor innovation.

The 2022 and 2023 5G Challenges tested slightly different interfaces, due to the changes noted above (i.e., adding mobility and combining O-CU and O-DU into a single contestant subsystem). The 2022 5G Challenge tested the F1, NG, and Uu interfaces from 3GPP and the Open Fronthaul (FH) interface from the O-RAN ALLIANCE. The 2023 5G Challenge tested the

NG, Xn, and Uu interfaces from 3GPP and the Open Fronthaul interface from the O-RAN ALLIANCE. Masur [6] identifies these as important interfaces for multi-vendor interoperability.

3.2 Host Lab Testing Environment

The 2023 5G Challenge testing environment consisted of two simultaneous test lanes that supported each incremental level of Open RAN subsystem testing from standalone, through paired, to fully integrated E2E testing. Each test lane included a complete set of features from two different Open RAN test emulator vendors, which provided flexibility and capacity for simultaneous testing. The 2022 5G Challenge had a simpler environment, with one test lane and one test vendor.

Figure 3 shows the 2022 and 2023 5G Challenges' reference architectures and the specific interfaces tested for the contestant subsystems under test. The 2022 5G Challenge split the O-CU and O-DU into separate subsystems to better test and assess Open RAN standards compliance (Figure 3, left). The 2023 5G Challenge combined the O-CU and O-DU into a single contestant subsystem (Figure 3, middle).

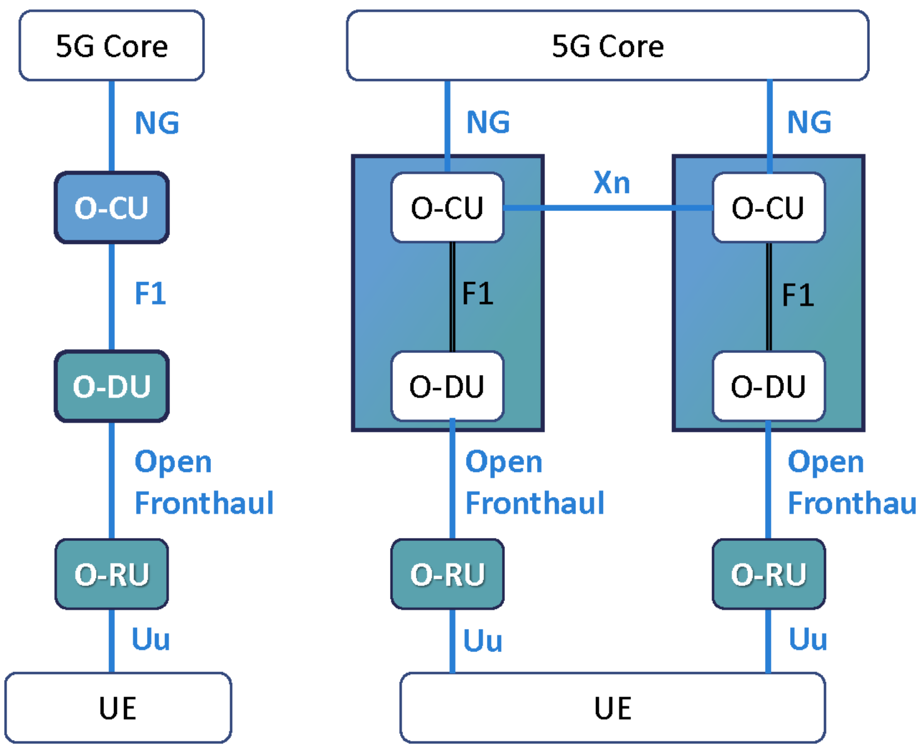

Figure 3. Stage Three in 2022 integrated three subsystems (O-CU, O-DU, and O-RU, left) and in 2023 two subsystems (O-CU+O-DU and O-RU, middle). Stage Four in 2023 integrated two E2E data sessions to test mobility (middle and right). The interfaces under test are blue. Each blue or green box contains a different vendor's subsystem.

During Stage One, applicants submitted white papers. On the basis of these, a panel of judges selected contestants (see Section 3.1).

During Stage Two, wrap-around emulators tested each subsystem in isolation. Stage Two was designed to evaluate compliance of the contestants' standalone Open RAN subsystems (i.e., O-CU, O-DU, O CU+O DU, or O-RU) against 3GPP standards and O-RAN ALLIANCE specifications. Subsystems that passed all the test cases in Stage Two were eligible for participation in Stage Three.

Stage Three tested contestants' abilities to establish an E2E data session across a multi-vendor Open RAN system with emulated UE and a commercial 5G SA core. Each contestant provided an Open RAN subsystem, and CableLabs provided the remainder of the 5G system, as shown in Figure 4. Most of these were cold integrations (e.g., O-RU and O-CU+O-DU vendors that had no prior integration experience with one another). Stage Three tests evaluated functionality and characterized the performance of the integrated system.

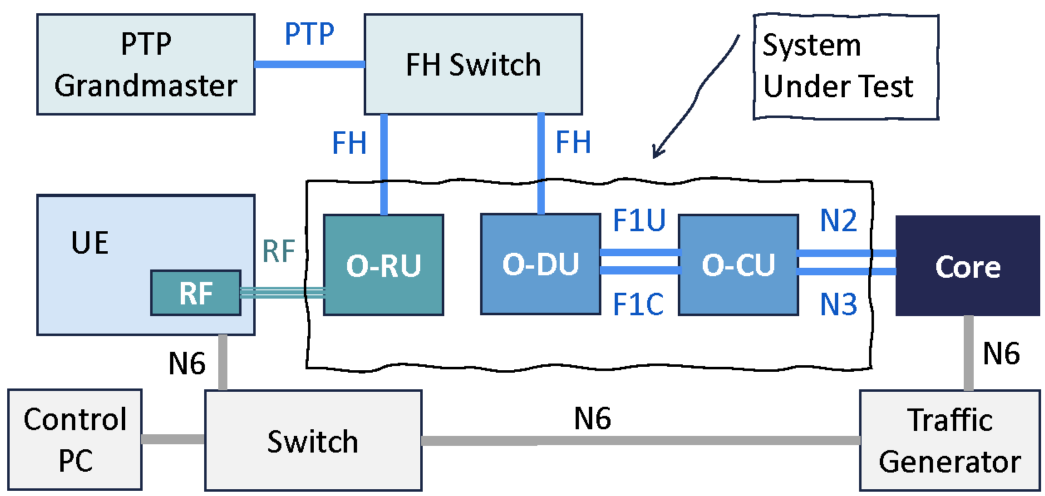

Figure 4. 2023 5G Challenge Stage Three E2E test setup. PTP is the Precision Time Protocol.

The Stage Three test cases assessed the RAN subsystem capability at increasing levels of complexity, using test cases from 3GPP standards and O-RAN ALLIANCE specifications. The four levels of test cases included operational, functional, performance, and stress.

Stage Four tested mobility across two multi-vendor RAN E2E systems with emulated UEs and an emulated 5G SA core (see in Figure 3, middle and right). The same core and UE were connected to two E2E RAN systems from Stage Three, each consisting of O-CU+O-DU and O-RU subsystems from different vendors. Handovers were conducted in both connected and idle modes across the NG and Xn interfaces. Figure 5 shows the equipment configuration.

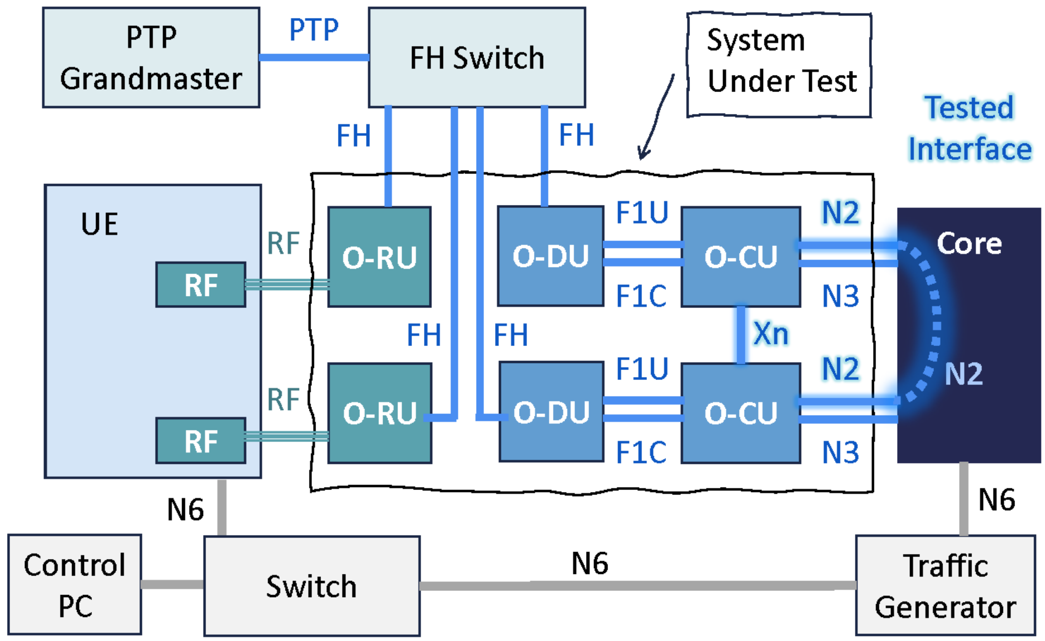

Figure 5. 2023 5G Challenge Stage Four mobility test setup.

3.3 Test Plans

The 5G Challenge team developed a rigorous test plan for each stage of testing. The test plans, testing laboratory environment (part of the Host Lab Configuration), and 5G Challenge rules are publicly available at [11].

The test plans were designed to allow rapid testing for equipment integration and initial functionality, thereby moving successful units to the more advanced testing that can provide guidance for future testing. Each test plan has up to four levels of increasingly demanding test cases. Level 0 contains operations and integration tests to verify basic operations. Level 1 contains functional and protocol conformance tests to verify compliance with 3GPP standards and O-RAN ALLIANCE specifications. Level 2 contains performance tests. Level 3 contains stress, reliability, and stability test cases using pre-defined traffic models for multiple UEs at varying RF conditions.

4. 5G Challenge Results

4.1 2022 Challenge Test Results

The 2022 5G Challenge Stage Two testing results [12] showed different levels of design maturity for the O-CU, O-DU, and O-RU. The O-CUs demonstrated the greatest compliance with 3GPP standards and O-RAN ALLIANCE specifications; O-RUs demonstrated modest compliance; and O-DUs demonstrated very low levels of compliance. These differences may have been caused by the complexity of RAN subsystem functionality and interface requirements, with the O-CU the least complex and the O-DU the most complex. Several applicants withdrew during Stage Two or were not qualified to participate because of the difficulty of separating their combined O-CU+O-DU into separate O-CU and O-DU subsystems. By contrast, all of the O-RU applicant systems had been designed as separate subsystems. Only one contestant team attempted Stage Three, and it demonstrated successful interoperability across a multi-vendor Open RAN using E2E bi-directional data sessions with multiple protocols with a commercial 5G core and UE emulator in the allocated testing time frame.

4.2 2023 Challenge Test Results

The 2023 5G Challenge received 18 O-CU+O-DU and 19 O-RU subsystem applications, as compared to the four O-CU, four O-DU, and three O-RU subsystem applications received for the 2022 5G Challenge. This increase indicates that Open RAN interest and activity is on the rise, which supports the supposition that Open RAN will provide better opportunities for innovation and increased diversity of RAN suppliers. Due to the increased maturity of the Open RAN market, the criteria to pass Stage Two and Stage Three testing were more stringent in 2023 than 2022.

Compared to 2022's, the 2023 5G Challenge test results indicated a major improvement in design maturity of Open RAN subsystems. All 10 contestant subsystems passed 100% of the Stage Two conformance tests. Of the six teams selected for Stage Three, four of six passed the mandatory E2E integration conformance tests (52 tests in total) and various numbers of the conditional mandatory and optional E2E conformance tests. Two teams of four vendors each were selected for Stage Four. Both mobility teams passed 100% of the mobility conformance tests.

Figure 6 graphically shows the increase in participants and pass rates from the 2022 5G Challenge to the 2023 one.

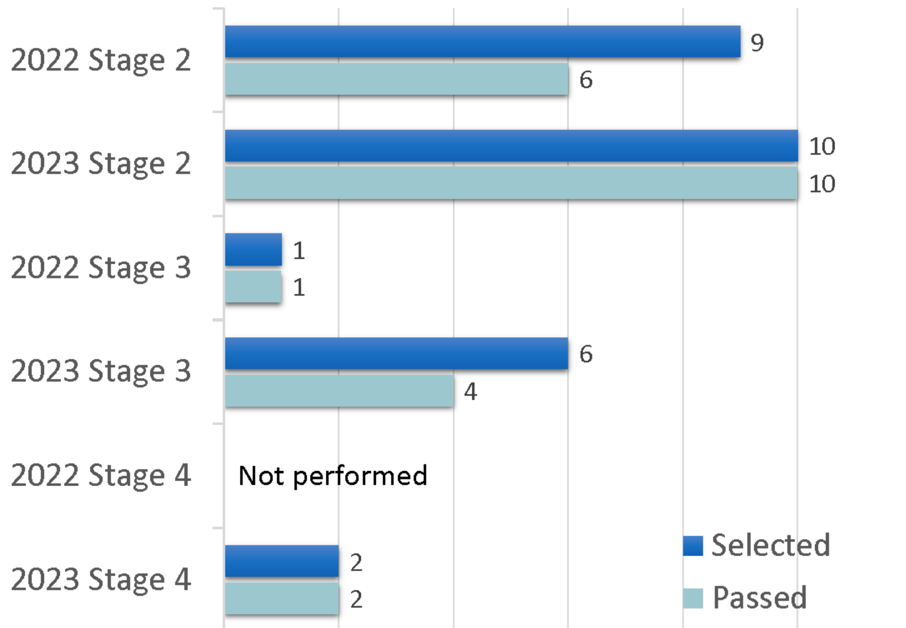

*Figure 6. This chart compares 2022 and 2023 participation rates and stage pass/fail rates and makes clear the increase from one year to the next. The statistics for Stages Three and Four count the number of **teams**, each of which included two to four contestant subsystems (see Figure 3).*

Stage Three was a very complex activity that involved the integration of two contestant RAN subsystems (i.e., O-CU+O-DU and O-RU) with the host lab's commercial 5G core and UE emulator to build a fully operational Open RAN mobile network with no integration history. The conformance test results, time taken, and contestant feedback all indicated that E2E integration was significantly more difficult than mobility.

The 2023 5G Challenge yielded impactful, first-of-their kind results. The Stage Three E2E integration testing results illustrate the evolution of the Open RAN marketplace and the ability of vendors to establish data sessions across a multi-vendor RAN environment comprising O-CU+O-DU and O-RU subsystems. The Stage Four results, which included the first known successful mobility tests between multiple vendors systems, were the most noteworthy and impactful of all 5G Challenge testing. Two different sets of two vendors (four vendors total) were able to connect an O-CU+O-DU from one vendor and an O-RU from a second vendor and then successfully hand over a call, using the Xn interface, from two different Open RAN systems. In other words, a system using Open RAN components from four different vendors could successfully interoperate to complete both N2 and Xn handovers.

4.3 Compliance and Configuration Parameters

Simply complying with 3GPP standards and O-RAN ALLIANCE specifications does not guarantee interoperability. The variations in mandatory and optional features and settings can inhibit or prevent interoperability and, in the current environment, must be addressed on a case-by-case basis.

During Stage Two of 2022 and 2023, contestants spent significant test time resolving configuration issues between their subsystems and the wrap-around tester and emulator including, by example, resolving compliance mismatches of 3GPP standards and O-RAN ALLIANCE specifications. These differences mostly revolved around implementation of different release versions, inclusion of optional features or requirements, and differing interpretations of a specific requirement of a 3GPP standard or O-RAN ALLIANCE specification. The 3GPP standards and O-RAN ALLIANCE specifications offer hundreds of configuration parameters, depending upon unique operator needs. Contestants spent extensive time capturing and reviewing log files and configuration settings to ensure successful integration and messaging, and to ensure that data session establishment met industry standards.

During Stage Three of 2022 and 2023, achieving the required throughput for each protocol type (e.g., TCP, UDP, RDP) in each of the different radio conditions (i.e., good, fair, poor) required optimization of configuration parameters (e.g., frame length, Reference Signal Received Power levels). This was different for each contestant and required close collaboration between the host lab, test equipment vendor, and contestant.

A potential solution to the variability in 3GPP standards and O-RAN ALLIANCE specifications is to create a minimum viable profile (MVP) with a standard configuration and test cases to simplify multi-vendor interoperability. These parameters could be set to accommodate specific implementations or use cases. An MVP would nurture increased and faster multi-vendor interoperability.

4.4 Lessons Learned from the 5G Challenges

Collaboration among diverse vendors is critical for successful integration. Contestants made significantly faster integration progress when they stopped attributing faults to other contestants' systems and resolved to start working together. Hinderances to cooperation include lack of dedicated funding to fix software discrepancies, lack of trust, insufficient software support in third-party module contracts, inflexible subsystems (e.g., designed for a specific customer), and differing interpretations of a specific requirement. Inter-vendor cooperation and coordination play a critical role in mitigating operator concerns around Open RAN deployment, maintenance, faultfinding, and remediation.

Accessible testbeds support multi-vendor Open RAN integration and lower the cost of entry for new and smaller entrants. The testbed ecosystem includes O-RAN ALLIANCE OTICs, as well as academic, industry, and consortia labs (e.g., Telecom Infra Project (TIP)). Contestant feedback suggested that those who benefit the most from wrap-around emulation testing are the smaller vendors, as they often do not have access to expensive Open RAN test equipment, licenses, and comprehensive test suites.

CableLabs and NTIA/ITS engineers devoted significant resources to the development of carefully designed test plans [11]. The individual test cases were categorized as Mandatory, Conditional Mandatory, and Optional. Open RAN manufacturers developing products are encouraged to use these available test plans as a basis for developing their own test plans.

Stringently following software development best practices markedly improves the speed and success of multi-vendor interoperability.

- Hard-coded parameter values halt integration until the software can be modified, recompiled, and debugged.
- Moving from hard-coded parameters to reading parameters from setting files avoids this roadblock.
- Systems that can produce log files are easier to troubleshoot.
- Using third-party modules that cannot be examined or modified hinders troubleshooting.
- Automation can aid the discovery and alignment of configuration differences prior to integration.
- Automated test scripts and software updates (patching) enable continuous integration (CI), continuous deployment (CD), and continuous testing (CT) while maintaining error-free deployment.

Adequate staffing and resources are critical to integration success. Systems-level engineers, network engineers, 5G Open RAN specialists, test system engineers, and independent system integrators all contribute to faster troubleshooting, faster resolution of integration issues, and overall interoperability success. On-site support and on-call support are critical. Virtual support from engineering staff can supplement, but not replace, in-person support.

Test system vendors support E2E integration by providing specialized knowledge about Open RAN system testing and by enabling software updates for the test system (e.g., new features, bug fixes). Test system vendors can resolve differences in interpretation or implementation among engineers, vendor subsystems, and the test systems. Each update to 3GPP standards and O-RAN ALLIANCE specifications triggers a race to update the test system before subsystem vendors need to start testing. Support from test system vendors is particularly important for endeavors, like the 5G Challenges, that push the envelope.

Test labs can act as system integrators. They provide independent arbitration, which makes disagreements less serious and easier to solve. Drawing on their experience with prior integration efforts, the test labs provide insights during faultfinding and remediation.

The 5G Challenge encouraged softwarization-software solutions that can be run on white-box hardware. Based on the subsystems submitted to the 5G Challenges, white-box hardware is rarely sufficient for 5G Open RAN subsystems. Several contestants tried to install and run their subsystem on the host lab’s server, but only one succeeded.

5. Future Challenges for Open RAN

The deployment of truly open, modular, and interoperable 5G Open RAN is a complex problem. This report contributes to addressing this complexity by sharing the lessons learned and test plans used in the 5G Challenge. The 5G Challenges separated reality from hype by demonstrating multi-vendor Open RAN solutions. The results of the 5G Challenges indicate that although Open RAN products are less mature than single-vendor solutions, they are rapidly advancing to the maturity level of single vendor solutions.

The Open RAN movement has many dimensions, with only some of them addressed by the 5G Challenge and, consequently, this report. Going beyond the needs addressed in this report, DoD and NTIA/ITS identified the following additional key challenges to advancing Open RAN:

- Virtualization of high-performance hardware
- Performance parity with traditional RAN
- Spectrum agility for deconfliction in nomadic deployments
- xApp and rApp conflict management
- Integrated sensing and communications at network scale
- Non-terrestrial networks (NTN) for ubiquitous, resilient, and secure services at global scale

The future success of Open RAN depends on the development of consistent, repeatable, worldwide testing to enable trusted performance analyses and dependable deployment strategies. Future efforts towards this end include the development and maturation of test plans, test configurations, a minimum viable profile for integration, and automated test scripts. Collaboration and information sharing are critical to the success of Open RAN.

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14. ABSTRACT
The vision of the 5G Challenge competitions was to accelerate adoption of 5G open interfaces, interoperable subsystems, and multi-vendor solutions by fostering a large, vibrant, and growing vendor community dedicated to advancing 5G interoperability towards true plug-and-play operation. This report provides test plans, results, and lessons learned about 5G Open RAN multi-vendor interoperability and compliance during the 2022 and 2023 5G Challenges. Multiple vendors demonstrated O-RAN ALLIANCE subsystem interoperability and performance on a limited timeline with no prior integration or planning. Contestants made significantly faster integration progress when they were open to sharing and working together. Significant integration time was devoted to resolving configuration parameters and compliance mismatches (e.g., which options were selected). Stringently following software development best practices improves the speed and success of multi-vendor interoperability.

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