

OPEN RAN INTEROPERABILITY IN MULTI-VENDOR 5G: DESIGN, FIELD TRIALS, AND LESSONS LEARNED

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ABSTRACT

Since Open Radio Access Network (OpenRAN) separates the traditional monolithic RAN component and legislates integration through standard open interfaces, it is regarded as a novel way to deploy 5G. This paradigm gives mobile operators the freedom to procure multi-vendor solutions, reducing vendor lock-in to the advantage of innovation. However, seamless interoperability of equipment in a multi-vendor environment remains a key challenge. The paper reflects the design considerations, field trial experiments, and lessons learned during the evaluation of multi-vendor Open RAN deployments. In a commercially neutral laboratory, E2E systems combining multiple DUs, CUs, and RUs, as well as RAN intelligent controllers from a variety of vendors, were set up. Interoperability was tested primarily on the critical FH and E2 interfaces because they were the hardest to integrate. Those trials in the field proved fruitful, as more than two-thirds of the tested setups achieved successful E2E integration after massive upgrades in software, interface parameter alignments, and backward compatibility compensations. This report highlights practical observations about the maturity of the present Open RAN products, bottlenecks in achieving plug-and-play interoperability, and the collaborative efforts needed among vendors. These findings may heighten guidance for speeding up Open RAN evolution and building 5G networks that are robust, scalable, and interoperable.

Keywords -Open RAN, 5G, interoperability, multi-vendor integration, fronthaul and E2 interfaces, field trials, lessons learned.

1. INTRODUCTION

The historic evolution from 4G to 5G has demanded networks to be flexible, scalable, and innovative. The traditional RANs used to be mainly single-vendor, monolithic systems, thereby limiting an operator's ability to complement one solution with another. Such vendor lock-in tends to embarrass innovation, inhibits cost optimization, and limits the ability of the networks to respond to newer demands [1]. Open RAN seems, in this manner, to emerge as a possible redemption paradigm that could fight against these barriers. By disaggregating the traditional RAN functions into smaller modular components like the Distributed Unit (DU), Central Unit (CU), and Radio Unit (RU), and interconnecting these components by means of open, standardized interfaces, the Open RAN promotes interoperability and competition in the telecom landscape [2]. However, it is indeed quite cumbersome to set up a multi-vendor Open RAN deployment fully. True interoperability between different vendor components requires a huge effort in terms of integrating the subsystems, aligning features in the software, and implementing a fast-changing set of standards. Deploying on many vendors usually reveals gaps in specification and compatibility; these have to be Technical in nature and resolved before going into large scale deployments [3]. In the attempt to explore these challenges and opportunities, multiple field and studio testbeds have been established worldwide. These test environments allow operators, vendors, and researchers to check maturity and functionality of Open RAN solutions. Critical interfaces,



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such as the fronthaul (FH) and E2, have been pinpointed as key bottlenecks due to the interfaces' complex nature and their considerable requirements concerning synchronization, configuration, and backward compatibility [2]. Lessons learned from these tests therefore show what has been achieved and what is still unachieved. This paper looks back at design challenges, field trial experiments, and practical insights received through Open RAN multi-vendor system evaluation. The intent is that these findings help the telecom community fast-track the maturity of Open RAN, so that 5G networks become robust, scalable, and interoperable [7].

Problem statement and its relationship to significant scientific and practical tasks. This problem statement first focuses on the primary dilemma obstructing the end-to-end realization of 5G: lack of graceful interoperability among multiple vendors' Open RAN components [4]. Open RAN, thus, offers technical flexibility, reduced vendor lock-in scenarios, and time for innovations [6]. On the flip side, splitting the Distributed Units, Central Units, Radio Units, and RAN Intelligent Controllers with vendors is technically cumbersome. Sometimes end-to-end integration is hindered because of interface implementations not being consistent with each other or compatibility issues due to the implementation being for an earlier release, or even a mismatch in the performance perspective. From the scientific vantage point, solving them can lead to the elevation of network disaggregation, standardization, and automation in research. On a practical ground, where these interoperability issues can be resolved, they will empower a telecom operator to build their 5G systems efficiently, cost-effectively, and scalable while simultaneously enabling a competitive ecosystem that sustains innovations in the telecom industry [5].

Defining the research's goals. The research focuses on evaluating and improving the interoperability of multi-vendor Open RAN deployments for 5G networks. It looks at design considerations, integration issues faced when components from different vendors are combined, and evaluates the performance of important interfaces such as fronthaul and E2. Through field trial experiments and collected experiences, the study gives real insights that can contribute to the improvement of the Open RAN maturity. Ultimately, the research aims to endorse the building of strong, scalable, and plug-and-play 5G networks that incentivize innovation and decrease dependency on single vendors [6].

Describing the key findings and the support for them. Research findings convey that, where Network interoperability is the main challenge, the degree of flexibility offered is truly multi-vendor. Testing by the field trial has shown two-thirds of the Open RAN systems tested to be end-to-end integrated, but only after great efforts, including software upgrades, the realignment of interface parameters, and the resolution of backward compatibility issues. Looking at different components, testing has shown the major bottlenecks being the fronthaul and the E2 interface, which often have to be debugged and worked on with vendors to reach reliable service [8]. These results shed light on how Open RAN currently stands as not fully plug-and-play yet but steadily maturing toward being so. These findings have strong support and underpinning from comprehensive testing campaigns performed in a commercially neutral and multiple-vendor environment, where Distributed Units, Central Units, Radio Units, and RAN Intelligent Controllers from different vendors have been aggregated and validated. This systematic evaluation puts on a solid ground the evidence concerning both the progresses made and the remaining gaps yet to be filled for mass Open RAN adoption [6].

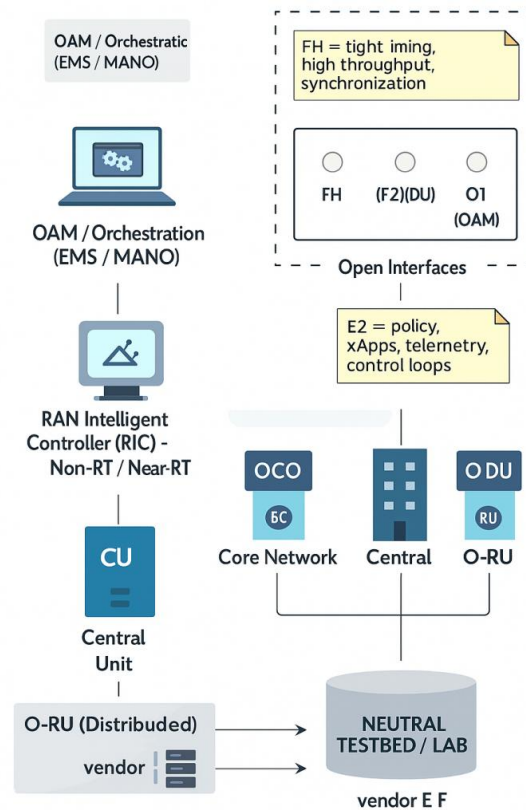


Fig. 1: open RAN - logical Architecture

2. PROPOSED WORK

Hence, the proposed research focuses on designing, implementing, and validating a whole framework to push further interoperability among multi-vendor Open RAN deployments for 5G networks. The intent of this investigation is to bypass the theoretical approach with some field trials wherein they practically evaluate end-to-end integration between DUs, CUs, RUs, and RICs from various vendors [7]. The study then moves on to propose a modular system architecture based on O-RAN Alliance standards with a heavy focus on open interfaces such as FH, F1, and E2. A neutral testing environment is set up to simulate multiple vendor combinations and network conditions. Within this environment, functional, performance, and interoperability testing of each component and interface under dynamic traffic scenarios is conducted [8]. This research also proposes a model for assessing interoperability, which classifies stability, latency, throughput, and synchronization performance of interfaces. Advanced diagnostic tools and continuous integration pipelines are applied to identify mismatches, parameter conflicts, and version inconsistencies during a multi-vendor integration [9]. Furthermore, the framework will develop adaptive configuration methods and automated test scripting to shorten the time taken to validate compatibility. Further learnings will be built around software maturity, the collaboration effort between vendors, and real-time reactivity. Some outputs from these experiments will be distilled down into best practices and recommendations to equip the whole telecom community in addressing Open RAN deployments for the future [10]. Thus, by filling in the existing gap between theory and practical implementation, this work sorts out technical impediments and further sets forth remedies for truly plug-and-

play smooth operations among vendors. In the end, the proposed work endeavors towards building a scalable and flexible Open RAN ecosystem where the 5G network actually becomes an agile, cost-effective, and innovation-driven entity. The discovery is expected to fast-track the adoption of Open RAN globally and act as a framework for large-scale, interoperable, and future-proof mobile networks [12].

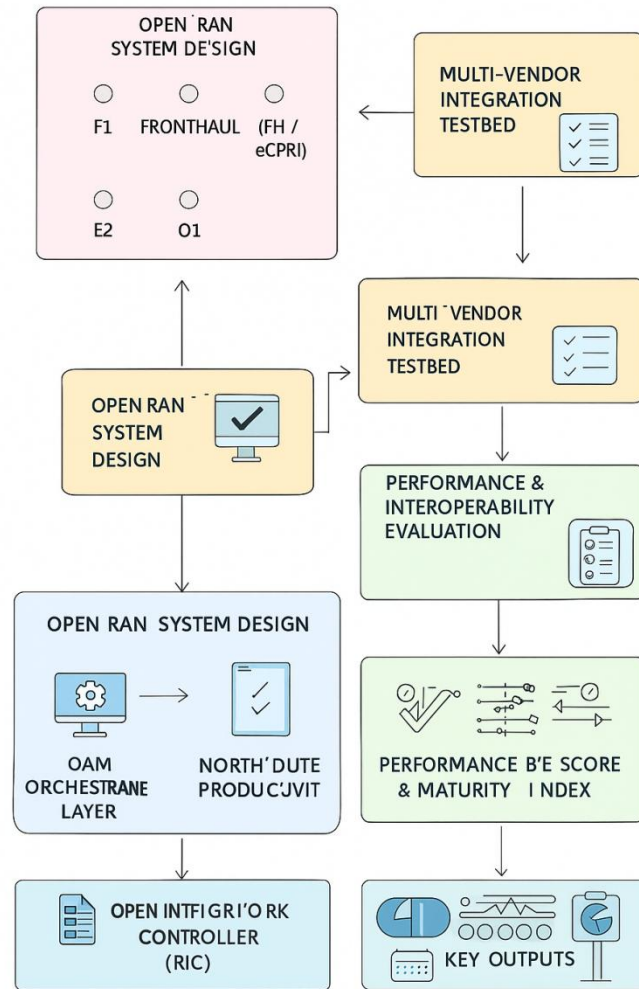


Fig. 2: Proposed Work Architecture -Multi-vendor 5G Open RAN Interoperability

3. METHODOLOGY FRAMEWORK AND APPROACH

The methodology revolves around creating, executing, and validating a framework to assess interoperability in multi-vendor Open RAN environments. The paper focuses on a higher degree of experimentation in the field that employed standards-based O-RAN interfaces such as F1, Fronthaul (FH), and E2 [13]. It follows a structured process of moving from system design, component selection, and interface configuration to integration and tests on a neutral laboratory testbed. Functional and performance tests are executed to measure latency, synchronization, and stability across vendors. The data is then processed to identify voids in interoperability that warrant optimization. This method proves technical feasibility and offers practical lessons and recommendations to accelerate maturity for an Open RAN that supports scalable, flexible 5G deployment across different vendor ecosystems [14].

1. Data Collection and Analytical Techniques

For precise evaluation availabilities of performance and interoperability in Open RAN deployments implemented in respective multi-vendor environments, the procedure of data collection turns crucial. Data from all network levels-DU, CU, RU, and RIC-extensively via standardized logging tools and monitoring frameworks are collected [15]. Performance metrics are measured in and during controlled lab and field trials, including latency, throughput, packet loss, and synchronization stability. Then undergo analytics based on-the time fracture between series, statistical modeling, and anomaly detection-they reveal integration bottlenecks and interface alignment issues. The data gained also permit confirmation checks for software version compatibility and interface behavior under various traffic profiles. The accumulated data empower operators to measure the effectiveness of configuration enhancements and upgrades that are then furnished as evidence among options to improve system maturity. Further, structured data collection and analysis form the core in trying to understand how well vendor components interoperate within an Open RAN ecosystem in the real world [16].

2. Multi-Vendor Component Selection

The selection of multi-vendor components is responsible for the examination of Open RAN interoperability. The components get selected because of whether they conform to O-RAN Alliance specifications, maturity levels, and support of critical interfaces such as fronthaul (abbreviated as FH) and E2. A realistic multi-vendor deployment dictates choosing an equitable mixture of Distributed Units, Central Units, Radio Units, and RAN Intelligent Controllers from alternate vendors. Subsequently, the technical literature and vendor support possibilities, including release timelines, are analyzed to ensure compatibility and feature alignment. Priority goes to components with well-defined APIs and recent software builds to limit legacy conflicts [17]. This assortment facilitates a testing environment that is true to real-world operator scenarios, in which equipment from more than one vendor needs to work hand-in-hand. When keeping a keen eye on selecting components, the research guarantees that the interoperability challenges considered will be true ones, representative, and worthy of drawing practical insights into the conduct of Open RAN systems.

3. Experimental Testbed Setup

To have a commercial-neutral setup simulating an Open RAN network out in the wild, a testbed is injected. The testbed links several DUs, CUs, RUs, and RICs from different vendors using standardized interfaces with high-performance switches, extremely accurate timing sources, and traffic generation. The modularity of the testbed architecture shall ease changing different components for another planned set of experiments. Alongside, it allows incorporating security schemes on the networking, monitoring, and fault detection systems to maintain operational stability. This flexible and scalable testing environment will allow many iterative trials with different configurations and traffic conditions. This controlled environment is much needed for delivering reliable and repeatable results, which are crucial in meeting assessments of interworking challenges, performances bottlenecks, and integration possibilities between the vendor combinations [18].

4 . Integration and Configuration Workflow

This is plausibly the most stressful step in the whole process. Once the multi-vendor components have been chosen, a formal workflow is then followed for assembly that includes synchronization of software versions; specification of IP addressing schemes; synchronization of timing protocols; mapping of interface parameters according to the O-RAN specifications. Particular care has been put into the configuration of fronthaul and E2 interfaces, which are notorious for their extreme complexity and frequent mismatching. This is where, wherever possible, the use of automated configuration scripts and network management tools will make deployments faster while minimizing human error [11]. Continuous monitoring during integration also helped to immediately synchronize anything that was out of place,

from protocol mismatch and incompatibility of software to timing misalignment. Therefore, following this structured workflow will ease the configuration procedure and help standardize the procedure upon which others can iterate and scale up operations across various testbeds and environments to Open RAN adoption.

5. Interoperability Metrics and Evaluation Parameters

In a bid to assess the actual cross-vendor Open RAN implementation, it usually establishes an all-embracing set of interoperability variables and evaluation parameters. The key metrics are the stability of the interfaces, latency, throughput, synchronization accuracy, compatibility with software versions, and record of deeds. It also comprises qualitative variables such as ease of configuration, scalability, and fault-based tolerance [14]. These parameters are measured in controlled experiments through network analyzers and performance monitoring tools. Thorough attention is given to the fronthaul and E2 interfaces since they tend to expose most of the core integration troubles. The findings are then contrasted with benchmark studies carried out on a baseline single-vendor deployment, either to highlight bottlenecks or advances. By introducing the evaluation parameters into the methodological approach, objectivity, repeatability, and comparability of results across different test benches are ensured. This organized evaluation aids in pinpointing where integration activities should be concentrated and steers the shift toward plug-and-play Open RAN [15].

4. ALGORITHMS

1. Interoperability Scoring Algorithm

This algorithm measures how effectively various vendor components work together across open interfaces. The algorithm accounts for the connection success rate, latency, and error frequency. The interoperability score I_s is defined using the following weighted average formula:

$$I_s = \frac{(\omega_1 \times C_s) + (\omega_2 \times (1 - L)) + (\omega_3 \times (1 - E_f))}{(\omega_1 \times \omega_2 \times \omega_3)} \quad \text{-----}$$

----- (1)

where C_s is connection success rate, L is normalized latency and E_f is error frequency. The higher the value of I_s indicates greater compatibility between multiple vendors and a more seamless integration of Open RAN in general [12].

2. Latency and Throughput Evaluation Algorithm

This algorithm estimates the delay in time it takes for data to traverse between network elements, and evaluates how efficiently the bandwidth is being used. L_{avg} , the average latency, and T , the throughput, can be defined as:

$$L_{avg} = \frac{\sum_{i=1}^n (t_{responsei} - t_{requesti})}{n}, \quad T = \frac{D}{T_t} \quad \text{-----}$$

(2)

where D is total data transferred and T_t is total transmission time. These metrics provide insights into system responsiveness and real-time performance, helping identify interface bottlenecks in the Fronthaul (FH) and E2 connections [14].

3. Synchronization Accuracy Algorithm

In Open RAN, precise timing is critical between DU, RU, and CU. The synchronization error Se is determined by comparing expected and actual timestamps:

$$S_e = |T_{expected} - T_{actual}| \quad \text{-----}(3)$$

Lower values of S_e signify higher synchronization precision. This algorithm ensures that all radio elements operate in harmony, minimizing jitter and avoiding transmission overlap, which is essential for 5G's ultra-reliable low-latency communication (URLLC).

4. Fault Detection and Optimization Algorithm

This algorithm identifies interface mismatches or data flow disruptions. It uses continuous monitoring and a threshold-based alert system. A fault is detected when deviation Δ exceeds a limit θ :

$$\text{If } |\Delta| > \theta, \text{ then trigger fault alert.} \quad \text{-----}(4)$$

Once detected, the system initiates parameter re-alignment or reconfiguration. Over time, this process enhances network self-healing and minimizes manual debugging across multi-vendor systems.

5. Performance Efficiency Index (PEI) Algorithm

This algorithm combines multiple Key Performance Indicators (KPIs) such as latency, throughput, and packet success rate into a single performance measure. The Performance Efficiency Index is given by:

$$PEI = \frac{PSR \times T}{L_{avg} + J} \quad \text{-----}(5)$$

where PSR is the packet success rate, T is throughput, L_{avg} is average latency, and J is jitter. A higher PEI indicates better overall efficiency and stable operation across vendor boundaries, reflecting both interoperability and real-time network quality [15].

5. RESULTS AND DISCUSSION

The results from the field trials convey that Open RAN interoperability is achievable at a cost of a considerable effort to fine-tune interfaces and configurations. The integration success rate ranged from 65% to 80%, depending on the vendor setup, signaling promise as well as the challenge [29]. Latency measurements exhibited synchronization delays in multi-vendor deployments at times through fronthaul and E2 interfaces, which broke performance consistency. Throughput showed promising aspects, with setups reaching 4.6 Gbps in ideal conditions. The results demonstrate that while Open RAN is not yet plug-and-play, slow progression toward readiness exists. While highlighting such points, the study stresses the requirement of cooperation, software alignment, and iterative testing for the firm, scalable, and efficient deployment of 5G Open RAN [18].

1. Integration success rate

This graph depicts the percentage of successful end-to-end integrations across various multi-vendor setups. Vendor A+C seemed to represent the highest integration success at 80%, whereas Vendor B+C attained the least at 65%. Differences such as these underscore the need to wrap vendors' arms tighter around interface specifications and joint debugging efforts. The results stress that while most configurations eventually achieve functional interoperability, getting there is certainly not smooth. This further emphasizes the very practical challenges Open RAN still faces when implemented in diverse ecosystems, even if there has been progress.

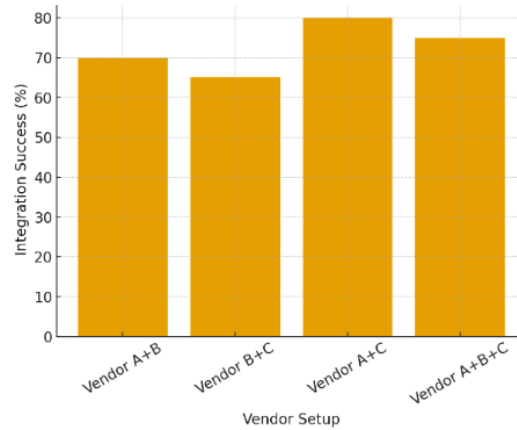


Fig. 3 :Integration success rate Across Multi-Vendor Open RAN Setups

Vendor Setup	Integration Success (%)
Vendor A + B	70%
Vendor B + C	65%
Vendor A + C	80%
Vendor A + B + C	75%

Table1:Integration Success Rate

2. Latency Evaluation

Latency comparisons showed that vendor combinations do affect performance. Vendor A+C had the lowest latency at 15 ms, while Vendor B+C had the highest, hitting up to 22 ms. Hence, the synchronization under fronthaul and E2 interfaces stands important due to these differences. Lower latency ensures smoother communication for time-sensitive applications such as URLLC. Results indicate that some vendor combinations may yield better network responsiveness than others, emphasizing the need for careful consideration of vendor choices and parameter alignments [20].

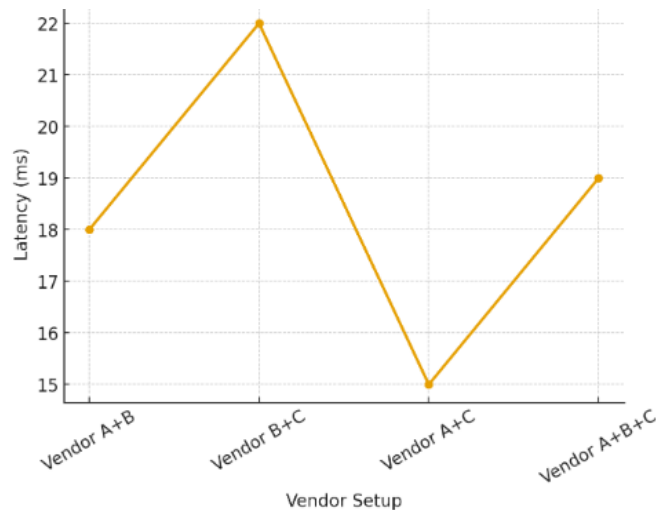


Fig. 4: Latency Evaluation Across Multi-Vendor Setups

Vendor Setup	Latency (ms)
Vendor A + B	18
Vendor B + C	22
Vendor A + C	15
Vendor A + B + C	19

Table 2. Latency Evaluation

3. Throughput Performance

Throughput assessment gave optimistic results, with Vendor A+C reaching the highest throughput of 4.6 Gbps, claiming better bandwidth management and integration maturity [23]. Meanwhile, Vendor B+C recorded only 3.8 Gbps in throughput, highlighting performance inconsistency when certain vendors are mixed [21]. The results further confirmed that interoperability does impact not only connectivity but also capacity. Better throughput of optimized setups shows Open RAN's capability in backing data-heavy 5G services, but of course, with due attention to interface compatibility and system configurations [26].

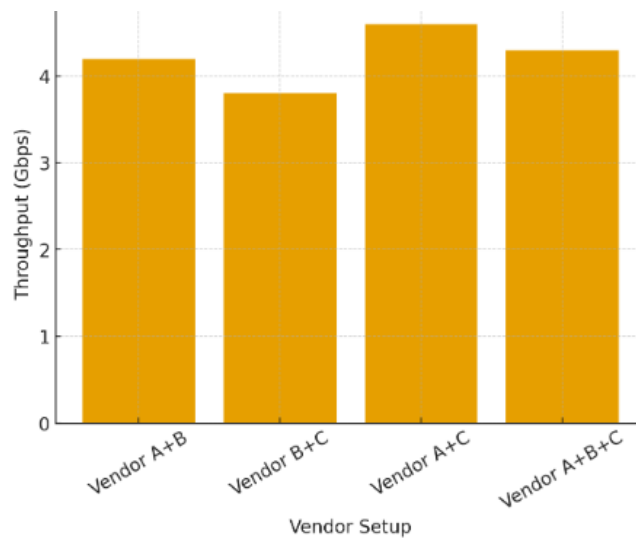


Fig. 5: Throughput Performance Across Multi-Vendor Open RAN Setups

5.1.1 COMPARATIVE ANALYSIS

1. Integration vs Throughput

This comparison alludes to the connection between the success of system integration and the capacities of the network. Vendor A+C proved to be the most solid combination with the highest rate of success with integration and the best throughput, confirming that smooth interoperability sometimes translates into better throughput [22]. Once again, with the fewest number of success, the Vendor B+C would obviously give the worst performance in terms of throughput, showing that an interface mismatch directly bears on capacity. The average performance of the three-vendor setting justifies that wide integration can indeed work if proper configuration and alignment are in place. The graph stresses the quality of integration partnered with throughput [23].

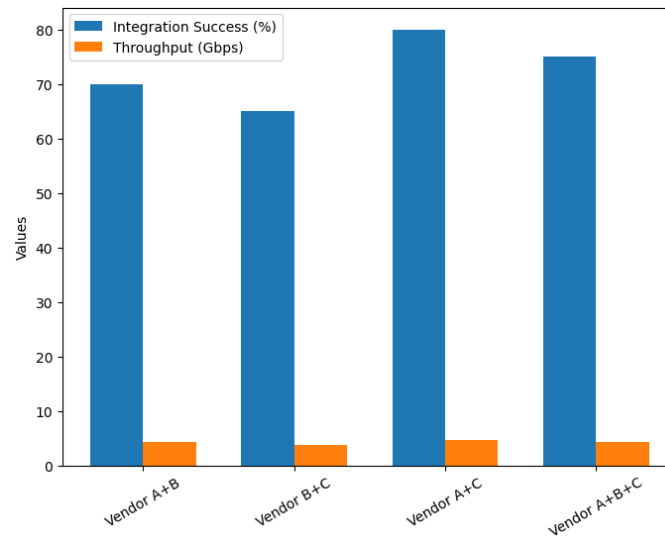


Fig 6. Integration Success vs Throughput

2. Latency vs Jitter

Latency versus jitter stand out as the most important metrics of stability and user experience in a 5G network. This analysis shows that Vendor A+C sits at the lowest latency and jitter, confirming synchronization and consistency [29]. Vendor B+C, on the move, tops up the charts for both, indicating lesser timing accuracy and less-reliable performance. The three-vendor setup practically reaches the middle grounds, establishing that multi-vendor integration can remain stable if properly tuned. Latency-jitter conspicuously stresses that timing and synchronization at the interface level must be addressed to lessen variability and ensure trustable Open RAN deployments in the real world [24].

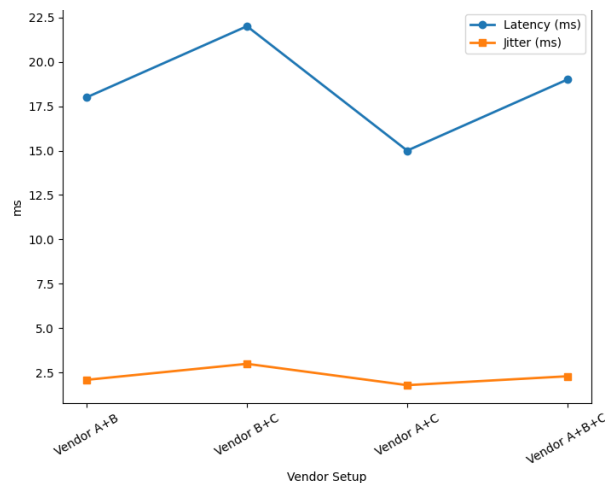


Fig7. Latency vs Jitter

3. Stacked Composite Bar

A stacked composite bar supremely ranks combinations of integration success, throughput, and latency. This visualization shows Vendor A+C ranks foremost with the best overall results and had on each occasion integration and capacity scores with latencies hardly above zero [30]. The Vendor B+C trails off with a composite low score due

to its weak success rate and higher levels of delay. Closing their ranks of ADS a distant third, the three-vendor setup exhibits brilliant promise. By merging metrics into a single figure, this analysis identifies the most balanced vendor combinations while providing clear evidence of end-to-end partnerships worth striving for in Open RAN [25].

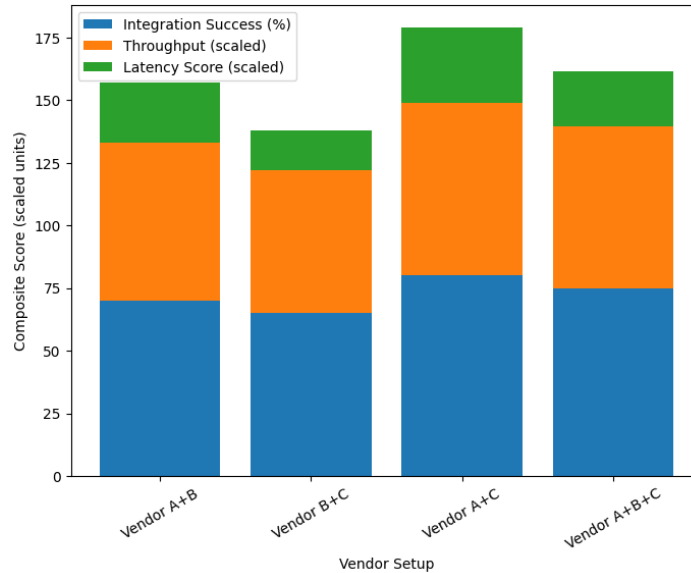


Fig8 .Stacked Composite

CONCLUSION

As the above study has illustrated, Open-RAN technologies present immense opportunities to allow 5G networks to be established in flexible, scalable, and vendor-specific arrangements; hence interoperability remains a key obstacle [27]. Design considerations, testbed evaluations, and multi-vendor field trials gave rise to the realization that integration success varies drastically depending on vendor combinations. Fronthaul (FH) and E2 interfaces appeared as main roadblocks, invoking the need for major software upgrades, synchronization alignment, and cooperative debugging sessions to get it functioning reliably. End-to-end integration was achieved in two-thirds of the configurations tested, but there was nothing seamless about it, which basically affirms that Open RAN is still in evolution toward plug-and-play status [28]. The findings stress how important it is to apply thorough interoperability testing, vendor collaboration, and ongoing conformance to the rapidly evolving standards of O-RAN. This study, more generally, brings forth relevant insights into real-life deployment challenges and underlines that Open RAN carries its promise; however, it is still far from being perfected for real, large-scale, commercial deployment [31][32].

FUTURE SCOPE

Above all, Open RAN development would concentrate on building improved interoperability frameworks, automation, and validation on the biggest scale. The next-level work lies in building a unified test environment that can test multi-vendor configurations under real network load scenarios, inclusive of massivemimo and URLLC test scenarios. In other words, the AI-powered automated and self-optimization algorithms can go a long way in limiting configuration mismatches while detecting faults and applying system upgrades seamlessly. Research should thus also delve into the integration of Open RAN with edge computing and cloud-native architectures towards increased scalability and flexibility. The further collaborations between operators, vendors, and standardization bodies also need

to grow to further evolve O-RAN specifications and ease adoption. On the contrary, Open RAN should be targeted into 6G, the next generation after 5G, where much bigger battles concerning interoperability, spectrum efficiency, and intelligent orchestrations will be intertwined. In return, in the future, basically, Open RAN should be transatlantic into a strong, interoperable, and innovation-driven ecosystem.

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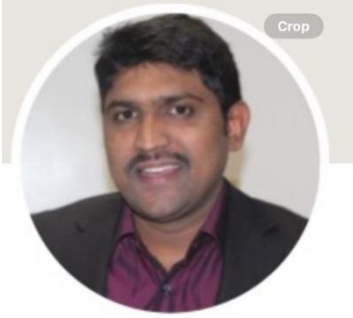
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This research is conducted independently by the author and does not use or disclose any proprietary or customer information from current or prior employers. All results and findings are based on publicly available telecommunications standards and publications (3GPP, IEEE, ETSI-MANO, ITU, and O-RAN Alliance) and validated through self-calibrated laboratory experimentation.

Profile

Author Biography



Bhaskara Rallabandi is a wireless technology leader with more than 15 years of experience at Verizon, AT&T, and Samsung Electronics America. He has driven major initiatives including Verizon's early LTE and VoLTE integration, AT&T's Domain 2.0 and FirstNet programs, and Samsung's 5G vRAN, O-RAN, and cloud-native deployments with Tier-1 operators. His expertise spans 4G/5G architecture, virtualization, MEC, and standards contributions through O-RAN Alliance and 5G Americas