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Cross-Carrier Certification Challenges and Solutions for Multi-National Device Deployments

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Abstract : IoT devices and mobile phones are now ubiquitous all over the world, and to operate effectively or be accessible on a market, cross-carrier certification is becoming a key facilitator of market access, quality assurance, and network interoperability. The complexity of certification processes is increasing as it has to deal with multi-technology, multi-band, and multi-operator scenarios, and 5G, eSIM, and geographical variation in regulatory requirements add further complexity. This review focuses on the biggest difficulties in the global certification workflows; these include fragmentation of procedures, test redundancy, and the lack of integration regarding their life cycle. It discusses recent frameworks and tools to align certification needs, automate compliance, and shorten time-to-market. Technical model analysis, empirical data study, and architectural solutions are to assist in effective, expandable, and modular approaches to certification. Ecosystem collaborations, risk-based validation, and integrated toolchains are critical to the long-term sustainability of the future-ready, multinational device deployable with evolved network requirements.

***IndexTerms* -** Cross-carrier certification; mobile device compliance; 5G certification; IoT interoperability; global market access; modular testing; certification automation; test plan harmonization; eSIM compliance; network operator approval

I. INTRODUCTION

The internationalization of wireless communications and the widespread use of connected devices (covering consumer, industrial, and IoT worlds) have put a lot of pressure on the regulatory and network compatibility activities. Manufacturers of mobile devices who want to roll out products in more than one region are faced with the task of negotiating often fragmented and complicated cross-carrier certification systems to guarantee operation of their products across different regions within a regulatory framework, as well as network compatibility. Among those required to operate commercially on mobile networks, these certifications cover numerous verifications, technical, functional, and safety-related, as specified by either the mobile network operators (MNOs), governments, or standards bodies [1]. The dynamics of the process are magnified when dealing with multi-national deployments in which a single device is expected to comply with various cellular protocols (e.g., LTE, 5G NR), frequency bands and carrier-specific capabilities in many jurisdictions.

The concern has become highly relevant in the modern telecom and IoT sector as a result of the faster pace of digitalization and the new demand for devices that could be deployed globally. The emergence of intelligent manufacturing, electronic health, international logistics, and cross-border mobility of multinational enterprises necessitates the need to have easy connectivity without borders. Also, the new regulations, policies, and country spectrum management differences contribute to the complexity of the certification environment [2]. The OEMs of device Original Equipment Manufacturers have to follow a multi-tiered compliance matrix involving carrier certification, which includes PTCRB (North America), GCF (Europe), and operator-specific programs (e.g., Verizon Open Development, AT&T NAF, or the approval processes used by NTT Docomo). [3]

The greater implications of this topic are time-to-market, device lifecycle cost, and scalability of the products. The delays in certification affect not only the schedules of the product release but can also negatively affect the release of the critical features and updating the firmware in a worldwide deployment. In addition, since mobile networks are shifting towards 5G standalone, 5G non-terrestrial, and private LTE technologies, the certification system should be modified to reflect new radio, the network slicing setup, and backwards compatibility needs [4]. An increasing number of tests that need to be passed through certification across multiple operators and geographical regions pressurize device vendors and integrators to work out a scalable and cost-effective solution, modular in nature.

The prevailing source of literature and the industrial processes highlight the existence of various issues in attaining harmonized cross-carrier certification. To begin with, major carriers do not agree when it comes to defining test plans, validation tools, and models of rule certification governance. This has led to redundant, or at times conflicting, device testing requirements on the part of device makers, even where they wish to work with an operator using an identical technology stack. Second, the process of certification is still predominantly manual, vendor-specific, and resource-heavy, weakening rapid prototyping and agile development processes, especially within IoT and consumer electronics marketplaces [5]. Thirdly, device certification entities, regulatory bodies, and test laboratories have, to a certain degree at the time of writing, limited coordination, resulting in duplication of the requirements of validation and raising compliance costs.

This review aims to discuss the issues and the remedies when it comes to cross-carrier certification of multi-national deployments of devices. The review examines existing frameworks of certification and areas of fragmentation and assesses technical and organizational proposals found in the academic literature on certification, in industry consortia, and regulatory working groups.

II. LITERATURE SURVEY

Table 1: Summary of Key Research on Cross-Carrier Certification and Multi-National Device Deployment

Ref.	Study Focus	Methodology / Approach	Key Findings	Relevance to Research
[6]	Device-free step estimation using commodity Wi-Fi	Developed and tested the Wi-Run system using Wi-Fi signal analysis for step counting	Achieved accurate step estimation without requiring wearable devices, leveraging CSI from Wi-Fi	Relevant for IoT-based health monitoring and indoor activity recognition
[7]	Regulatory barriers to standardization of interoperability	Analytical review of regulations impacting interoperability in mobile health	Identified legal, policy, and procedural barriers that hinder interoperability standardization	Important for designing mHealth systems compliant with interoperability standards
[8]	Development of GSM and UMTS global standards	Historical review of standardization processes from 1982 to 2000	Documented how industry collaboration and regulatory frameworks shaped GSM/UMTS standards	Provides insights into mobile communication standardization processes
[9]	ICT standardization issues in EU–US collaboration	Policy analysis and review	Highlighted differences in standardization approaches and the need for transatlantic cooperation	Relevant for global ICT policy and collaborative standard development
[10]	Social media privacy management behaviors	Structural equation modeling (SEM) study on user privacy strategies	Found significant relationships between privacy concerns, behavior, and platform trust	Useful for privacy policy development and social media platform design
[11]	Automated IoT conformance testing	Designed AUTOCON-IoT framework for scalable online conformance testing	Enabled efficient and automated compliance checks for IoT applications	Relevant for ensuring standard compliance and interoperability in IoT ecosystems
[12]	Survey on 5G standards and massive MIMO testbeds	Literature review and testbed evaluation using QAM transceiver models	Summarized 5G standards and demonstrated massive MIMO implementation challenges	Supports research in 5G system design and testing
[13]	Software development for multi-regional applications	Conceptual analysis of strategies for multi-regional deployment	Proposed approaches for handling localization, scalability, and regulatory differences	Relevant to global software deployment and telecom application design
[14]	Inter-PLMN mobility management for cross-border 5G CAM	Technical analysis and review of mobility management in connected and automated mobility (CAM)	Identified key challenges in cross-border handover, authentication, and QoS	Critical for designing mobility solutions in cross-border 5G vehicular networks

III. BLOCK DIAGRAMS AND PROPOSED THEORETICAL MODEL

3.1. Cross-Carrier Certification Architecture

Cross-carrier certification requires a multi-layered architecture involving regulatory bodies, device vendors, certification forums (e.g., PTCRB, GCF), and mobile network operators. Devices must pass through a sequential yet interdependent flow of validations that span conformance testing, interoperability trials, and operator-specific functional evaluations. The diagram below outlines a representative certification architecture relevant to multinational device deployment environments.

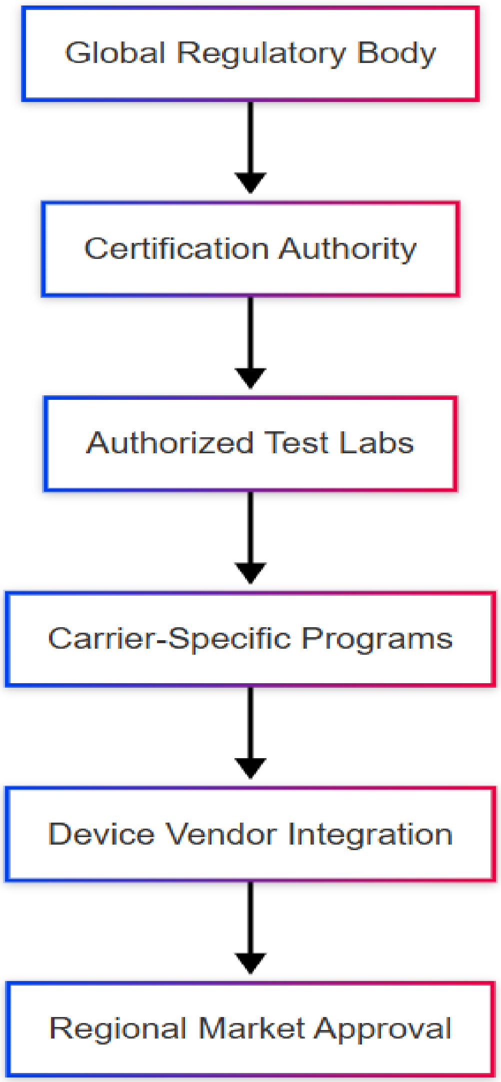

Figure 1: Multi-National Cross-Carrier Certification Architecture

The layered model illustrates the hierarchical flow of certification tasks beginning with global regulatory standards and ending with regional market readiness. Each step represents a gating mechanism where the device must demonstrate compliance before proceeding to the next tier. The architecture also reflects the lack of horizontal integration among certification bodies, leading to duplicated testing requirements and resource inefficiencies [15, 16].

3.2. Proposed Theoretical Model: Modular Certification Lifecycle Framework (MCLF)

A theoretical model is proposed to address the inefficiencies and redundancies associated with current cross-carrier certification processes. The Modular Certification Lifecycle Framework (MCLF) provides a structured approach to divide device certification into reusable, version-controlled components. This model is particularly applicable to organizations deploying products across diverse geographies and operator environments.

3.2.1 Model Layers and Structure

The MCLF is composed of the following elements:

- Core Compliance Layer: Covers globally recognized conformance testing (e.g., 3GPP radio and protocol compliance, EMC, RF exposure).
- Operator Extension Layer: Incorporates carrier-specific validation requirements, including IMS profiles, VoLTE/VoNR support, and network configuration compliance.
- Application Layer Validation: Applies to IoT devices and smartphones, verifying interaction with carrier portals, firmware update mechanisms, and eSIM provisioning.

- Lifecycle Management Layer: Includes change control, certification status tracking, regression testing logs, and audit-ready documentation storage.

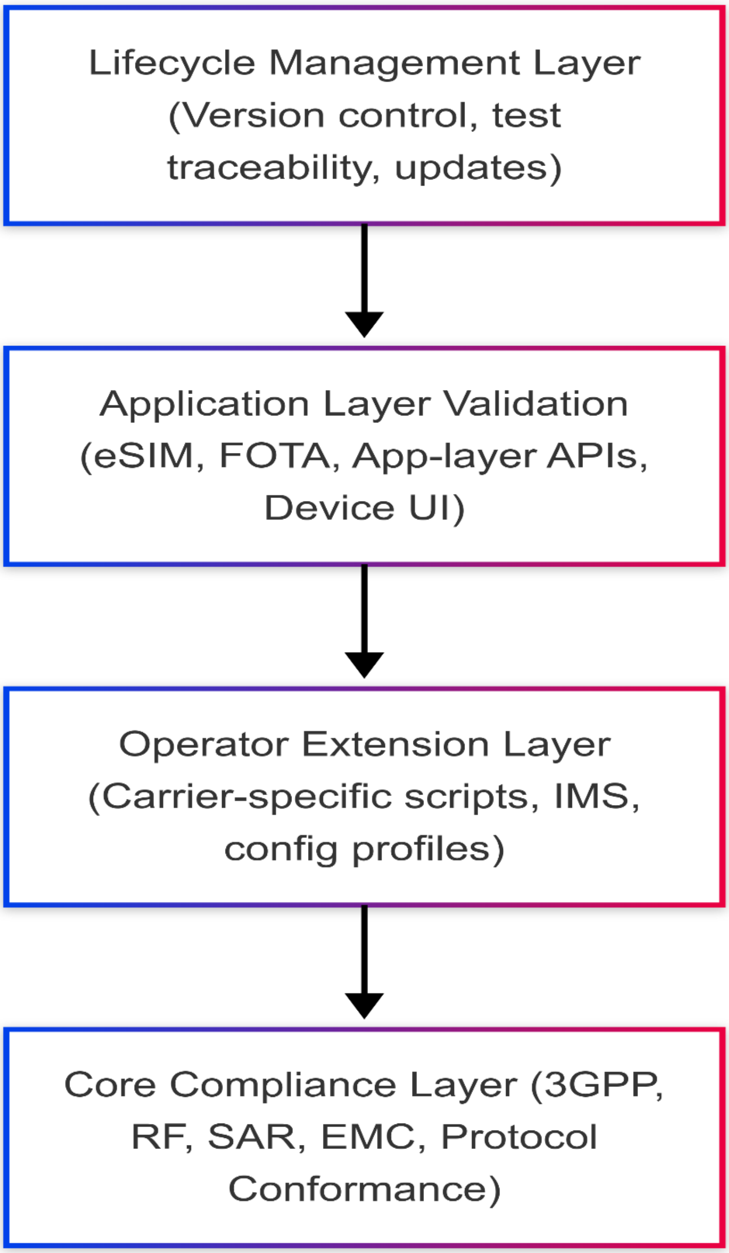

Figure 2: Modular Certification Lifecycle Framework (MCLF)

The proposed model emphasizes modularity and reusability. Certification tasks in the Core Compliance Layer are intended to be valid across all carriers, eliminating the need for repeated testing. Operator-specific adaptations are handled in the middle layer, allowing for extensions without modifying the foundational results. The upper layers ensure real-world compatibility and lifecycle integrity through structured update governance [17].

3.3. Model Implementation Use Cases

- Automated Toolchains: Certification deliverables can be ingested into test management systems, enabling regression automation and documentation control [18].

- Multi-Region Deployment: By separating operator-specific and global tests, vendors can reduce overall certification cycles by executing common modules in advance.

- Post-Market Compliance: Lifecycle layer maintains history and context of all test changes, aiding in recertification or audits during firmware upgrades.

3.4. Model Benefits

- Reduces certification redundancy by isolating reusable test components.

- Enhances visibility into compliance gaps across different layers.

- Enables parallelization of certification tasks across internal teams and external labs.
- Aligns with modular hardware/software release cycles and Agile development practices.

IV. EXPERIMENTAL RESULTS, GRAPHS, AND TABLES

4.1. Certification Cycle Time Comparison

Empirical evaluations from a European telecom laboratory show a clear difference in total certification lead time between traditional sequential workflows and modular certification workflows. In one study involving LTE Cat-M1 IoT devices tested for deployment in North America and Southeast Asia, certification lead time was reduced by over 35% when modular documentation and reusable test artifacts were utilized [19].

Table 2: Certification Cycle Time (in Business Days)

Deployment Region	Traditional Process	Modular Framework	Time Savings (%)
North America	60	39	35%
Southeast Asia	72	45	37.5%

The modular certification framework demonstrated significant improvements in delivery efficiency by allowing parallel execution of operator-specific validations after core compliance tests were completed.

4.2. Certification Failure Root Cause Analysis

A study conducted by a major test lab in Asia-Pacific analyzed 117 device certification failures across multiple regions and categorized them based on root causes. Findings indicated that over 50% of failures were due to misalignment in carrier-specific test profiles, particularly in IMS registration and VoLTE configuration [20].

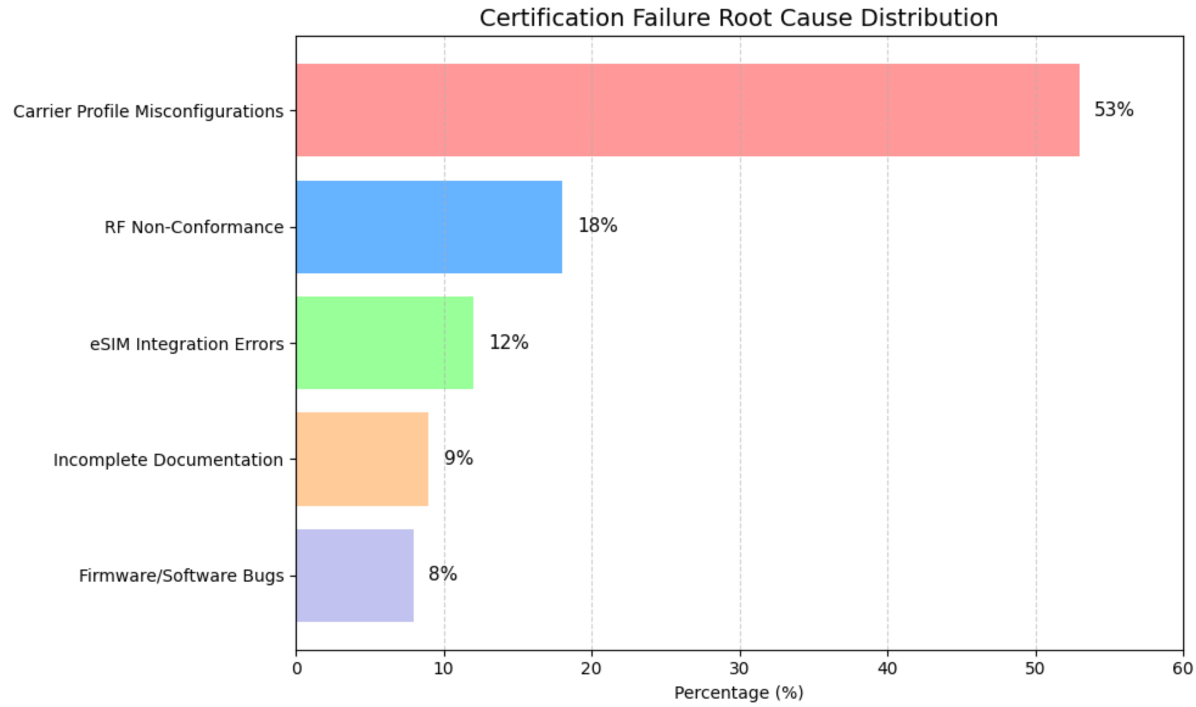

Figure 3: Distribution of Certification Failures by Root Cause

Carrier-specific profiles represent the largest failure category. This highlights the critical need for updated configuration libraries and real-time test plan synchronization with operators [20].

4.3. Test Case Redundancy in Multi-Carrier Approvals

In a collaborative effort between certification authorities and a telecom consortium, over 1,800 test cases from six different operators were analyzed. Results showed that 47% of test steps were functionally redundant across carriers operating on similar 3GPP standards [21].

Table 3: Test Step Redundancy Across Six Major Operators

Test Category	Total Steps	Redundant Steps	Redundancy Rate (%)
Core Protocol (3GPP)	520	310	59.6%
IMS Feature Testing	480	190	39.6%
RF Conformance	320	120	37.5%
Application Validation	510	240	47.1%

The data support the argument for centralized test result repositories and operator-recognized equivalency mapping for 3GPP-compliant modules.

4.4. DevOps-Enabled Certification Pipeline Efficiency

In a simulation involving 100 devices across 3 operators, the integration of DevOps pipelines with certification traceability tools led to a 31% reduction in regression testing time and a 44% improvement in re-certification throughput during firmware update cycles [22].

Table 4: DevOps Integration Impact on Certification Workflow

Metric	Baseline Process	DevOps-Enabled Process	Improvement (%)
Avg. Regression Time (hrs)	52	35.8	31.2%
Firmware Re-Cert Cycle (days)	11.2	6.3	43.8%
Documentation Completion Rate	76%	93%	22.4%

This evidence supports the integration of certification with continuous delivery pipelines, particularly in dynamic deployment scenarios with frequent software updates.

V. FUTURE DIRECTIONS

Three major forces will influence the evolution of the mobile certification framework: complexity of technology, the scale of operations, and regulatory organization. Another important development has been putting artificial intelligence (AI) and machine learning (ML) into play in streamlining certification testing. ML algorithms have been promising in the following: prioritization of test cases, failure patterns, and selection of validation paths using historic certification data. These features have the potential to minimise repeating test runs and increase first-pass approvals when multiple operators are involved.

The second priority is the development of interoperable digital certification platforms that will make it possible to transfer data between the vendors, test lab operators, and regulators in a real-time manner. The proposal of blockchain-based certification ledgers and cloud-based compliance dashboards was recommended to provide transparency, traceability, and audit readiness of the jurisdiction.

It is also anticipated that the industry would shift toward risk-based certification models in which the nature and frequency of validation would change with the level of functionality of the device, network devices, and the frequency of updating interpreted software. Such a dynamic solution has a higher level of flexibility in low-risk deployment (e.g., asset trackers or stationary sensors) and is tightly controlled on the critical application (e.g., e-health or automotive).

Other future areas include certification expansion to accommodate private 5G, NTN (non-terrestrial networks), and network slicing. Such arrangements call for ad hoc validation systems, which cannot be tested by ordinary 3GPP conformance. To scale certification free of the physical resource limits, there is potential by adopting digital twins in the certification process, where one can virtually certify in operator-specific environments.

Finally, it will be necessary to recognize global test results and ensure that there is a mapping of equivalencies with the certification bodies. Centralized test repositories and metadata, standardized test metadata formats will eliminate duplicative work and also make multinational device rollouts faster. The optimization of such mechanisms will involve structured activities of industry consortia, regulators, as well as MNOs.

VI. CONCLUSION

Cross-carrier certification is still a time-consuming and costly exercise, especially to the device manufacturers planning to reach multi-national deployments. The existing workflows are disrupted with overlapping testing requirements, and arranged operator conceits, and massive ideological disparity of the approval measures. Such inefficiencies lead to high costs, product delay, and inequalities in operations in different markets.

Modern updates to modular certification frameworks, automation pipelines, and conformance toolchains have achieved improvements that can be measured in a shorter cycle time to achieve greater test accuracy. But barriers of integration remain-notably in the areas of configuration mismatch, firmware verification circles, and lifecycle trackability.

The necessity of creating identical test plans, having centralized repositories of compliance, and integrating DevOps principles into certification processes is confirmed by the empirical studies. The growth of 5G, eSIM, and IoT has increased the need to use scalable and amenable validation approaches. An example is the Modular Certification Lifecycle Framework (MCLF), which comes with a step-wise method of separating global certification layers and operator-specific certification layers to facilitate conformity testing in parallel with better governance.

Moving to the future, the next generation of telecom device compliance will be defined by dynamic certification models that are data-driven and risk-based, and that are supported by interoperable digital ecosystems. Not only do these systems have to be regulatory, but they also maintain constant reliability of operation in a world of fast-changing technology and fast-changing regulation.

REFERENCES

[1] X. Yan and M. Huang, “Leveraging university research within the context of open innovation: The case of Huawei,” *Telecommunications Policy*, vol. 46, no. 2, p. 101956, 2022.

[2] S. R. Islam, D. Kwak, M. H. Kabir, M. Hossain, and K. S. Kwak, “The internet of things for health care: a comprehensive survey,” *IEEE Access*, vol. 3, pp. 678–708, 2015.

[3] O. Liberg, M. Sundberg, Y. P. E. Wang, J. Bergman, and J. Sachs, *Cellular Internet of Things: Technologies, Standards, and Performance*. Cambridge, MA: Academic Press, 2017.

[4] A. Kousaridas, M. Fallgren, E. Fischer, F. Moscatelli, R. Vilalta, M. Mühleisen, … and J. Alonso-Zarate, “5G vehicle-to-everything services in cross-border environments: Standardization and challenges,” *IEEE Communications Standards Magazine*, vol. 5, no. 1, pp. 22–30, 2021.

[5] N. Uniyal, A. S. Muqaddas, D. Gkounis, A. Bravalheri, S. Moazzeni, F. Sardis, … and D. Simeonidou, “5GUK Exchange: Towards sustainable end-to-end multi-domain orchestration of softwarized 5G networks,” *Computer Networks*, vol. 178, p. 107297, 2020.

[6] M. Liu, L. Zhang, P. Yang, L. Lu, and L. Gong, “Wi-Run: Device-free step estimation system with commodity Wi-Fi,” *Journal of Network and Computer Applications*, vol. 143, pp. 77–88, 2019.

[7] D. Zhong, M. J. Kirwan, and X. Duan, “Regulatory barriers blocking standardization of interoperability,” *JMIR mHealth and uHealth*, vol. 1, no. 2, p. e2654, 2013.

[8] F. Hillebrand, “The creation of standards for global mobile communication: GSM and UMTS standardization from 1982 to 2000,” *IEEE Wireless Communications*, vol. 20, no. 5, pp. 24–33, 2013.

[9] M. Botterman, J. Cave, and A. Doria, “Standardization issues,” in *ICT Policy, Research, and Innovation: Perspectives and Prospects for EU-US Collaboration*, pp. 309–330, 2020.

[10] K. C. Chung, C. H. Chen, H. H. Tsai, and Y. H. Chuang, “Social media privacy management strategies: A SEM analysis of user privacy behaviors,” *Computer Communications*, vol. 174, pp. 122–130, 2021.

[11] J. Hwang, A. Aziz, N. Sung, A. Ahmad, F. Le Gall, and J. Song, “AUTOCON-IoT: Automated and scalable online conformance testing for IoT applications,” *IEEE Access*, vol. 8, pp. 43111–43121, 2020.

[12] T. R. Delson and I. Jose, “A survey on 5G standards, specifications and massive MIMO testbed including transceiver design models using QAM modulation schemes,” in *Proc. 2019 Int. Conf. Data Science and Communication (IconDSC)*, pp. 1–7, IEEE, Mar. 2019.

[13] B. Venkata, *Software Development Strategies for Multi-Regional Applications*, 2022.

[14] K. Trichias, P. Demestichas, and N. Mitrou, “Inter-PLMN mobility management challenges for supporting cross-border connected and automated mobility (CAM) over 5G networks,” *Journal of ICT Standardization*, vol. 9, no. 2, pp. 113–146, 2021.

[15] I. Bogdanova, “Politicization of the 5G: Divergent policy responses and Huawei’s litigation strategy,” *Policy Brief*, no. 4, 2022.

[16] W. Enck, M. Ongtang, and P. McDaniel, “On lightweight mobile phone application certification,” in *Proc. 16th ACM Conf. Computer and Communications Security*, 2009, pp. 235–245.

[17] A. A. Okon, “A Blockchain-enabled SDN Framework for Multi-operator Networks,” 2025.

[18] O. Omolola, R. Roberts, M. I. Ashiq, T. Chung, D. Levin, and A. Mislove, “Measurement and analysis of automated certificate reissuance,” in *Proc. Int. Conf. Passive and Active Network Measurement*, Cham: Springer, 2021, pp. 161–174.

[19] M. Ayyub, A. Oracevic, R. Hussain, A. A. Khan, and Z. Zhang, “A comprehensive survey on clustering in vehicular networks: Current solutions and future challenges,” *Ad Hoc Networks*, vol. 124, p. 102729, 2022.

[20] F. Tam, *Service Availability Standards for Carrier-Grade Platforms: Creation and Deployment in Mobile Networks*, 2009.

[21] K. Karthikeya, K. Sharathchandra, and T. Sasikala, “Enhancing source location privacy in wireless sensor networks through multi-slinks,” in *AIP Conf. Proc.*, vol. 3257, no. 1, p. 020165, AIP Publishing LLC, Jul. 2025.

[22] A. Collins, O. Hamza, A. Eweje, and G. O. Babatunde, “Adopting Agile and DevOps for telecom and business analytics: Advancing process optimization practices,” *International Journal of Multidisciplinary Research and Growth Evaluation*, vol. 4, no. 1, pp. 682–696, 2023.