Study On Transition from VNFs to CNFs in 5G Networks

[1]Dhanya M

[1]RV college of engineering/Department of MCA, Bengaluru, Karnataka, India

Abstract -- This paper explores the evolution and implications of transitioning from Virtualized Network Functions (VNFs) to Cloud-Native Network Functions (CNFs) within fifth-generation (5G) networks. As 5G technologies redefine telecommunications, there is a growing need for agile, scalable, and efficient network infrastructures. The study begins by examining Network Function Virtualization (NFV) and its initial deployment through VNFs, highlighting their foundational role in early 5G implementations. It then shifts focus to CNFs, which leverage containerization, microservices architecture, and advanced orchestration to enhance resource utilization, expedite service delivery, and optimize network slicing efficiency compared to VNFs. Drawing on industry case studies and comparative analyses, the paper illustrates how leading telecom providers harness CNFs to boost network performance and support diverse 5G services like ultra-reliable low-latency communications (URLLC), massive machine-type communications (mMTC), and enhanced mobile broadband (eMBB). Key findings underscore CNFs' operational benefits in agility, scalability, and cost efficiency, while addressing challenges such as security and interoperability. The study concludes with a comprehensive analysis of the transformative impact of CNFs on 5G networks, emphasizing the necessity for ongoing innovation, robust standardization efforts, and cross-industry collaboration to address existing challenges. These efforts are essential to fully harness the potential of CNFs, ensuring they meet the diverse and demanding requirements of future 5G services globally.

Keywords : NFV**,** 5G, CNF, VNF**,** Telecommunication.

I. INTRODUCTION

The advent of fifth-generation (5G) networks heralds a transformative era in telecommunications, promising unprecedented speeds, lower latency, and vast connectivity capabilities [1]. Central to these advancements are Network Function Virtualization (NFV) technologies, which have evolved from traditional hardware-based network infrastructures to more flexible and scalable virtualized environments [2]. Initially deployed through Virtualized Network Functions (VNFs), NFV enabled telecom operators to enhance service agility and reduce operational costs by virtualizing network functionalities on standard hardware platforms. However, as 5G demands evolve to support applications like ultra-reliable low-latency communications (URLLC), massive machine-type communications (mMTC), and enhanced mobile broadband (eMBB), the limitations of VNFs in resource efficiency, agility, and scalability have become apparent [3]. This realization has led to the emergence of Cloud-Native Network Functions (CNFs), which represent a paradigm shift towards containerized, microservices-based architectures that leverage cloud-native principles [4].

Architectural Overview

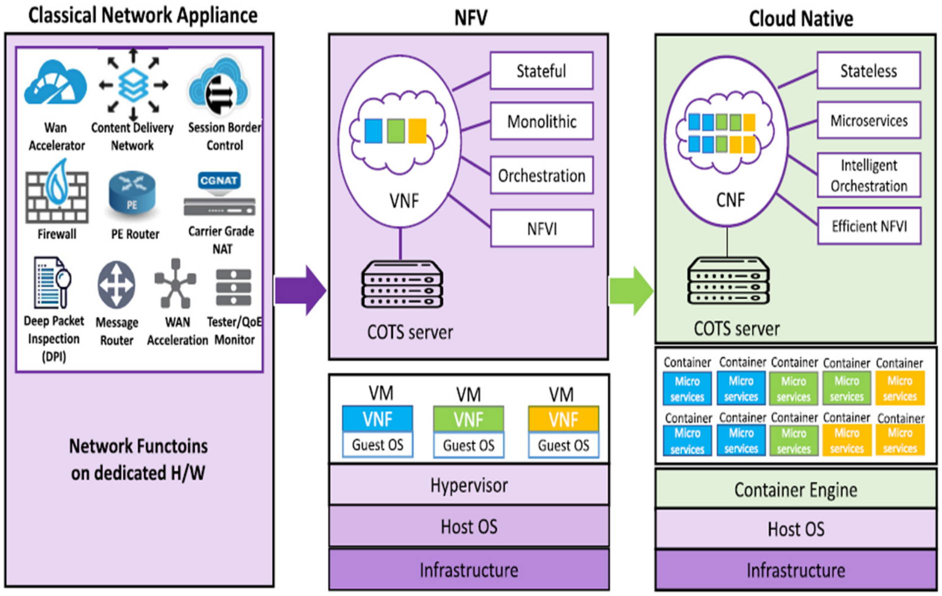

Fig. 1. Monolithic architecture, VNF virtualization architecture and CNF Cloud architecture [3].

Fig. 1 illustrates the architectural evolution from monolithic architectures to VNF virtualization and finally to CNF cloud architectures. VNFs, rooted in virtual machine technology, run on hypervisors that virtualize the hardware resources of a physical server, allowing multiple VNFs to share the same infrastructure. Each VNF runs within its own virtual machine (VM), containing its own operating system, network functions, and dependencies. This isolation ensures VNFs do not interfere with each other but adds overhead due to the need to manage multiple OS instances. The orchestration layer, often using platforms like OpenStack and ETSI MANO, manages the lifecycle of VNFs, including deployment, scaling, and updating [1][2][6].

In contrast, CNFs leverage modern cloud-native technologies such as containers and microservices to overcome the limitations of VNFs. CNFs are designed to run in containerized environments orchestrated by platforms like Kubernetes. Unlike VMs, containers share the host system's kernel but run isolated user space instances, reducing overhead and allowing for faster startup times and better resource utilization. Kubernetes, specifically designed for managing containerized applications, automates the deployment, scaling, and operation of these containers, providing robust tools for ensuring high availability and scalability. CNFs are typically decomposed into smaller, loosely-coupled microservices that can be developed, deployed, and scaled independently, enhancing flexibility and allowing for more granular updates and maintenance [4][5][7][9].

Further the study examines how CNFs address the shortcomings of VNFs and contribute to next-generation network infrastructures. Drawing on industry case studies, comparative analyses, and insights into operational benefits and challenges, this study provides a comprehensive understanding of the strategic implications and technical advancements driving the adoption of CNFs in modern telecommunications. CNFs offer several advantages over VNFs, including improved resource utilization, faster deployment times, and enhanced support for network slicing—a critical capability in 5G networks for isolating and allocating resources based on application requirements [5]. By decoupling network functions into smaller, independently deployable units, CNFs enable telecom operators to achieve greater operational efficiency and flexibility in managing network services [6].

II. RELATED WORK

Network Functions Virtualization (NFV) has significantly transformed telecommunications by virtualizing network services that were traditionally implemented on proprietary hardware appliances. Initially deployed through Virtualized Network Functions (VNFs), NFV aimed to enhance operational flexibility and reduce hardware dependency in network deployments [1][11]. VNFs have played a crucial role in early 5G implementations, enabling dynamic scaling and efficient resource utilization across various network environments. The transition to Cloud-Native Network Functions (CNFs) represents a major advancement in 5G network architectures. CNFs leverage containerization, microservices architecture, and advanced orchestration frameworks to improve scalability, agility, and operational efficiency [2][3][4]. Recent advancements in CNF placement strategies have demonstrated their ability to optimize network performance and support critical 5G use cases such as ultra-reliable low-latency communications (URLLC) and massive machine-type communications (mMTC). Comparative studies and industry case analyses reveal the transformative impact of CNFs on telecom networks, showing significant improvements in service agility and deployment flexibility compared to VNFs [5][6]. Case studies from leading telecommunications providers highlight the operational benefits of CNFs, including reduced time-to-market for new services and enhanced network efficiency. Validation and benchmarking efforts underscore the performance and scalability of CNFs in real-world deployments, particularly in Open Source MANO (OSM) environments, and in cloud-native 5G orchestration initiatives that streamline network management processes [7][8]. Despite their advantages, CNFs face challenges such as interoperability issues and security concerns. Ongoing efforts to enhance CNF performance, including technologies like SR-IOV in Kubernetes, aim to address these challenges and optimize CNF deployment in 5G core networks [9][10]. Future research will focus on standardization and continued innovation to fully leverage the potential of CNFs in global 5G networks.

From the reviewed papers, it is evident that while VNFs have laid the groundwork for network virtualization in early 5G deployments, the evolution to CNFs offers substantial benefits in terms of scalability, agility, and efficiency. The continued advancement in CNFs promises to address existing limitations and meet the demanding requirements of modern and future telecom services.

III. Evolution of NFV

The main objective of Network Functions Virtualization (NFV) is to virtualize network functions such as proxies, load balancers, firewalls, and routers, which traditionally ran on fixed hardware, moving them onto virtual machines (VMs). These virtual network functions (VNFs) can operate on servers, with hardware resources like computing, storage, and networking devices monitored as a common resource pool. This flexibility allows VNFs to be migrated or instantiated in various network locations based on functionality. Implementing these functions in software that can operate on industry-standard servers eliminates the need for new hardware installation, thus enhancing operational flexibility and reducing hardware dependency in network deployments [1][11].

An example of the NFV model is shown in Fig. 2, illustrating how network functions are decoupled from proprietary hardware and run on virtualized infrastructure. This diagram highlights the transition from traditional hardware-based network functions to a virtualized environment, showcasing the foundational role of NFV in modern telecom infrastructure. The NFV model allows for flexible and scalable deployment of network functions across a shared resource pool, enhancing efficiency and reducing costs [1]. Key components in the diagram include the virtualized infrastructure layer, which consists of virtual machines running on industry-standard servers, and the NFV management and orchestration layer, which oversees the lifecycle management, deployment, and operation of VNFs.

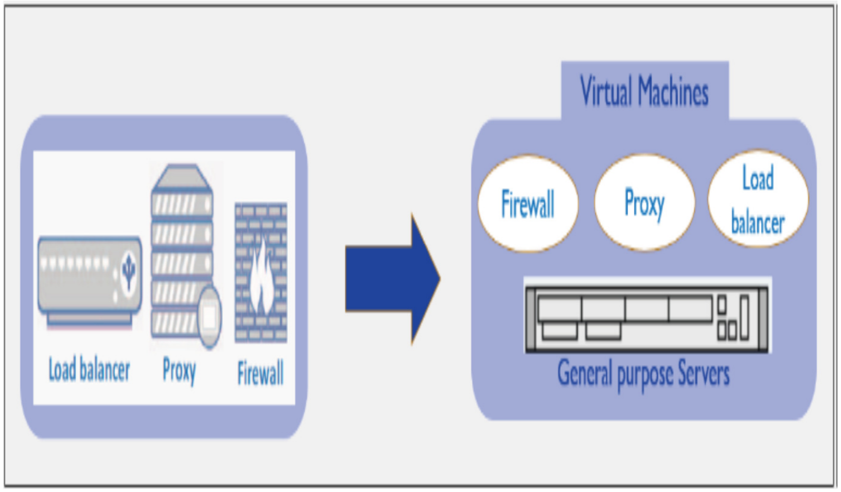

Fig.2. NFV Model [1]

Virtualized Network Functions (VNFs) were the initial realization of NFV principles, providing a way to run network functions as software instances on virtualized infrastructure [2][3][4]. VNFs enabled telecom operators to deploy and manage network services more flexibly and cost-effectively compared to traditional hardware-based solutions. The transition to VNFs brought several key benefits, including improved resource utilization, as operators could optimize the use of their hardware resources by running multiple VNFs on the same physical server; operational flexibility, allowing for dynamic scaling and quick adaptation to changing network demands without the need for physical hardware changes; and reduced capital expenditure, as the shift to software-based functions reduced the need for costly proprietary hardware, lowering the overall capital investment required for network expansion. However, despite these advantages, VNFs also introduced new complexities related to performance management, interoperability between different vendors' solutions, and the need for robust orchestration systems.

While VNFs addressed many issues of traditional network functions, they also brought their own set of challenges. Ensuring VNFs operated with the same efficiency and reliability as their hardware counterparts was a significant hurdle, with performance varying depending on the underlying virtualization layer and hardware used [5][6].

VNFs from different vendors often required bespoke integration efforts, leading to increased complexity and potential vendor lock-in. Additionally, the introduction of VNFs necessitated sophisticated orchestration and management tools to handle deployment, scaling, and lifecycle management effectively, as existing management systems were often not designed to handle the dynamic nature of VNFs. These challenges highlighted the need for further advancements to fully realize the potential of NFV in supporting the next generation of telecom networks.

Cloud-Native Network Functions (CNFs) represent the next evolution in network virtualization, overcoming VNFs' limitations by leveraging cloud-native principles like containerization, microservices architecture, and advanced orchestration frameworks [7][8][9]. CNFs offer several advantages: they use lightweight containers for quick instantiation, scaling, and management, leading to faster deployment times and better resource efficiency; employ a microservices architecture, breaking down network functions into smaller, independent services for easier updates and maintenance; and benefit from advanced orchestration tools like Kubernetes, which provide robust management mechanisms, including automated scaling, self-healing, and rolling updates. By adopting these cloud-native principles, CNFs improve resource utilization, accelerate service delivery, and enhance network slicing efficiency, making them well-suited for 5G networks. Additionally, CNFs promote greater interoperability and integration with existing IT and cloud infrastructures, fostering a more unified and efficient telecom ecosystem.

IV. Difference of VNFs and CNFs

Aspect	**VNFs (Virtualized Network Functions)**	**CNFs (Cloud-Native Network Functions)**
Enhancing Network Performance	VNFs virtualize functions but can be slow due to VM overhead, affecting performance. [1]	CNFs use lightweight containers for faster, more efficient performance, essential for 5G. [3]
Facilitating Network Slicing	VNFs support network slicing but can be complex and less flexible.	CNFs enable quicker, more efficient network slicing with Kubernetes, adapting easily to demand. [4]
Supporting Diverse 5G Services	VNFs are more rigid, which can limit their support for varied 5G services.	CNFs are more agile, better supporting diverse 5G services like mMTC, eMBB, and uRLLC. [5]
Operational Efficiency and Cost Savings	VNFs reduce costs compared to hardware but still incur overhead due to VMs.	CNFs cut costs further by avoiding VM overhead, with automation improving operational efficiency. [7]

Security and Interoperability	VNFs need robust security and integration frameworks due to their diverse nature.	CNFs also face security and integration challenges but require advanced solutions for smooth operation. [11]
Resource Utilization	VNFs are resource-heavy due to VM overhead.	CNFs are more efficient, sharing resources better among containers.
Scalability	Scaling VNFs involves adding new VMs, which can be slow and costly.	CNFs scale faster with containers, requiring less overhead.
Deployment Speed	VNFs have slower deployment times due to VM setup.	CNFs deploy quickly due to fast container startup.
Performance	VNFs can suffer from performance inefficiencies due to the virtualization overhead.	CNFs, utilizing lightweight containers, demonstrate improved latency and throughput, as evidenced by studies on SR-IOV in CNFs [9] and Kubernetes-based CNF deployments [4].

Table 1 : Difference of VNFs and CNFs related to 5G

This comparison highlights that CNFs offer notable advantages over VNFs in the context of 5G networks. While VNFs provide foundational virtualization benefits, they often face performance and cost inefficiencies due to VM overhead. CNFs, leveraging lightweight containers, enhance network performance, scalability, and deployment speed. They also facilitate more agile network slicing and support for diverse 5G services, all while reducing operational costs. However, CNFs come with their own set of challenges, particularly in security and interoperability. Overall, CNFs are better suited to meet the high demands of 5G, offering greater efficiency and flexibility.

V. Benefits of CNFs in 5G Networks

Cloud-Native Network Functions (CNFs) provide substantial benefits over traditional Virtualized Network Functions (VNFs) in 5G networks. CNFs enhance performance and scalability through containerization and microservices architecture, which minimizes overhead and optimizes resource utilization compared to VNFs that rely on virtual machines [2]. This leads to faster instantiation and scaling of network functions, accommodating dynamic network demands effectively. Additionally, CNFs accelerate service delivery by integrating with DevOps practices and automating lifecycle management, enabling rapid deployment of new services and compliance with stringent service level agreements (SLAs) for ultra-reliable low-latency communications (uRLLC) and enhanced mobile broadband (eMBB) [8]. Cost efficiency is another advantage, as CNFs reduce hardware and operational costs by utilizing shared resources more efficiently and streamlining network operations, thereby lowering total cost of ownership (TCO) [11]. Furthermore, CNFs support network slicing and edge computing, allowing for the dynamic management of network slices and extending computing capabilities closer to end-users. This enhances latency-sensitive applications and overall network performance [7]. Looking forward, CNFs are expected to drive innovation by integrating with emerging technologies like artificial intelligence (AI) and machine learning (ML), shaping the future of telecommunications, and addressing the evolving demands of digital transformation [10].

VI. Challenges and Considerations

Cloud-Native Network Functions (CNFs) offer significant benefits for 5G networks, but their adoption presents several challenges.

Complexity of Orchestration and Management: Transitioning to CNFs adds complexity due to reliance on container orchestration platforms like Kubernetes. Managing microservices within CNFs demands robust orchestration frameworks for dynamic scaling, service discovery, and fault tolerance [4]. Integration with existing OSS/BSS systems is also challenging [1].

Security and Compliance Concerns: CNF deployments introduce new security vulnerabilities that require stringent measures such as container image scanning, runtime protection, and secure access controls. Incorporating security-by-design principles into CNF architectures is crucial [9].

Interoperability and Standardization: Seamless interoperability between CNFs from different vendors is difficult due to variations in container runtimes and APIs. Standardization efforts by ETSI and 3GPP are essential for defining common interfaces to enable vendor-neutral integration [3].

Performance Optimization and Resource Efficiency: Optimizing CNF performance while maintaining resource efficiency is vital in 5G networks. Techniques like hardware acceleration, resource isolation, and efficient workload scheduling are necessary to meet service requirements [6].

Cultural and Organizational Shifts: Adopting CNFs requires cultural and organizational changes, including the adoption of DevOps practices and collaboration between NetOps and development teams. Fostering a culture of continuous innovation is key [8].

VII. Future Directions and Emerging Trends

CNFs in 5G networks opens up new possibilities for future innovations. This section explores key trends shaping the future landscape of CNFs in telecommunications

Edge Computing and Distributed CNFs: The demand for low-latency applications is driving the adoption of edge computing and distributed CNFs, reducing latency and enhancing real-time responsiveness. Advances in Kubernetes edge computing frameworks support this trend [10].

AI/ML Integration for Autonomous Network Management: AI and ML integration in CNF management enables autonomous network operations. AI-driven analytics optimize resource allocation, predict traffic patterns, and mitigate performance bottlenecks, enhancing efficiency in 5G environments [11].

Hybrid Cloud Deployments and Multi-Cloud Orchestration: Hybrid and multi-cloud strategies are increasingly popular, offering flexibility in workload placement. Standardization in multi-cloud CNF orchestration simplifies management and ensures seamless workload portability [7].

Security-Driven Design and Zero-Trust Architecture: The evolving threat landscape necessitates a security-first approach in CNF design, with Zero-Trust architectures and secure containerization practices to safeguard 5G networks [9].

Green and Sustainable Network Operations: Sustainability in CNF deployments is becoming critical, with energy-efficient designs and practices reducing carbon footprints and operational costs. Green network initiatives align CNF deployments with global sustainability goals [8].

VIII. Conclusion

The shift from Virtualized Network Functions (VNFs) to Cloud-Native Network Functions (CNFs) represents a significant advancement in 5G network architecture, driving improvements in agility, efficiency, and scalability. CNFs leverage containerization and microservices to enhance performance, support a diverse range of 5G services such as URLLC, mMTC, and eMBB, and streamline network management. These innovations enable telecom operators to deploy and scale services more effectively, aligning with the dynamic demands of modern telecommunications.

However, the transition to CNFs is not without its challenges. Issues related to security, interoperability, and orchestration complexity must be addressed to fully harness the benefits of CNFs. Future advancements will likely focus on integrating edge computing, AI-driven management, hybrid cloud strategies, and robust security measures to further enhance network performance and resilience. Continued research, collaboration, and strategic investments will be essential in overcoming these challenges and realizing the full potential of CNFs in global 5G networks.

IX. References

[1] Pitta Vineel Anvith, Dr. B. Malarkodi, Dr. N. Gunavathi, Dr. B. Rebekka, "A Survey on Network Functions Virtualization for Telecom Paradigm," *IEEE*, 2019, pp.302-304.

[2] Nithya Ganesan, Hrithik Sharma, Sahaj Vaghasiya, Prajwal Agarwal, Dev Patel, and B. Thangaraju, "Performance Evaluation of Virtual Network Service Function Deployment in Docker Containers," in *2023 2nd International Conference on Computer Technologies (ICCTech) | 978-1-6654-5582-4/23/$31.00 ©2023 IEEE | DOI: 10.1109/ICCTECH57499.2023.00022*, pp.75-79.

[3] W. Attaoui, E. Sabir, H. Elbiaze, and M. Guizani, "VNF and CNF Placement in 5G: Recent Advances and Future Trends," IEEE Transactions on Network and Service Management, vol. 20, no. 4, Dec. 2023, pp. 4699-4714.

[4] S. Sekigawa, C. Sasaki, and A. Tagami, "Toward a Cloud-Native Telecom Infrastructure: Analysis and Evaluations of Kubernetes Networking," in Globecom Workshops (GC Wkshps) | 978-1-6654-5975-4/22/$31.00 ©2022 IEEE | DOI: 10.1109/GCWkshps56602.2022.10008579, pp. 838-842.

[5] A. Bittar, Z. Wang, and C. Huang, "Service Function Chaining Implementation using VNFs and CNFs," 2023 IEEE International Conference on Cloud Engineering (IC2E) | 979-8-3503-4394-6/23/$31.00 ©2023 IEEE | DOI: 10.1109/IC2E59103.2023.00029.

[6] L. Yala, S. Cherrared, G. Panek, S. Imadali, and A. Bousselmi, "5G Experimentation Framework: Architecture Specifications, Design and Deployment," in IEEE International Conference on Innovations in Clouds, Internet and Networks (ICIN), 2020 , pp. 159-161.

[7] A. Pino, P. Khodashenas, X. Hesselbach, E. Coronado, and S. Siddiqui, "Validation and Benchmarking of CNFs in OSM for pure Cloud Native applications in 5G and beyond," i2CAT Foundation, Barcelona, Spain; Department of Network Engineering, Universitat Politècnica de Catalunya (UPC), Barcelona, Spain. IEEE International Conference on Computer Communications and Networks (ICCCN), 2021, doi: 10.1109/ICCCN52240.2021.9522356, pp. 1-10.

[8] Authors, A. Khichane, I. Fajjari, N. Aitsaadi, and M. Gueroui, "Cloud Native 5G: an Efficient Orchestration of Cloud Native 5G System," Orange Labs, F-92320, Châtillon, France; Universités Paris-Saclay, UVSQ, DAVID, F-78035, Versailles, In *Proceedings of NOMS 2022-2022 IEEE/IFIP Network Operations and Management Symposium*. IEEE, 2022. DOI: 10.1109/NOMS54207.2022.9789856.

[9] D. T. Nguyen, N. L. Dao, V. T. Tran, K. T. Lang, T. T. Pham, P. H. Nguyen, C. D. Pham, T. A. Pham, D. H. Nguyen, H. T. Nguyen, "Enhancing CNF performance for 5G core network using SR-IOV in Kubernetes," In *Proceedings of International Conference on Advanced Communications Technology (ICACT)*. IEEE, 2022. DOI: 10.1109/ICACT.2022.979112948090, pp. 501-504 .

[10] M. Ungureanu and C. Vlădeanu, "Leveraging the cloud-native approach for the design of 5G NextGen Core Functions," University Politehnica of Bucharest, Bucharest, Romania.In *Proceedings of 2022 14th International Conference on Communications (COMM)*. IEEE, 2022. DOI:10.1109/COMM54429.2022.9817268.

[11] AT&T, BT, CenturyLink, China Mobile, Colt, Deutsche Telekom, KDDI, NTT, Orange, Telecom Italia, Telefonica, Telstra, Verizon. "Network Functions Virtualisation – Introductory White Paper Issue 1." Published October 22-24, 2012 at the SDN and OpenFlow World Congress, Darmstadt, Germany.

[12] A. Khichane, I. Fajjari, N. Aitsaadi, and M. Gueroui, "5GC-Observer: A Non-intrusive Observability Framework for Cloud Native 5G System," in 2023 IEEE/IFIP Network Operations and Management Symposium (NOMS), 2023, pp. 1-6, doi: 10.1109/NOMS56928.2023.10154433.

[13] O. Arouk and N. Nikaein, "Kube5G: A Cloud-Native 5G Service Platform," in 2020 IEEE Global Communications Conference (GLOBECOM), 2020, pp. 1-6, doi: 10.1109/GLOBECOM42002.2020.9348073.

[14] Z. Wang, A. Bittar, C. Huang, C.-H. Lung, and G. Shami, "A Web-based Orchestrator for Dynamic Service Function Chaining Development with Kubernetes," in 2022 IEEE 8th International Conference on Network Softwarization (NetSoft), 2022, pp. 234-239, doi: 10.1109/NetSoft54395.2022.9844086.

[15] H. Lim and Y. Kim, "A Design of Service Function Chaining with VNF and CNF on Cloud Native Environment," in 2022 IEEE 8th International Conference on Network Softwarization (NetSoft), 2022, pp. 240-245, doi: 10.1109/NetSoft54395.2022.9844087.

[16] M. Verma, D. Behl, P. Jayachandran, A. Singh, and M. Thomas, "A Reliability Assurance Framework for Cloud-Native Telco Workloads," in 2023 15th International Conference on Communication Systems and Networks (COMSNETS), 2023, pp. 201-206, doi: 10.1109/COMSNETS56262.2023.10041285.

[17] Q. Meng, W. Zhu, D. Li, C. Shi, Q. Wang, and Z. Huang, "An Automatic Integration Deployment Framework for Telecom Cloud Network," in 2022 15th International Congress on Image and Signal Processing, BioMedical Engineering and Informatics (CISP-BMEI), 2022, pp. 1-5, doi: 10.1109/CISP-BMEI56279.2022.9980205.

[18] Y. Wu, X. Wang, and Z. Zhu, "Analysis and Empirical Study of Cloud Native Network Functions," in 2022 International Conference on Education, Network and Information Technology (ICENIT), 2022, pp. 346-350, doi: 10.1109/ICENIT57306.2022.00085.

[19] S. Hirai, T. Tojo, S. Seto, and S. Yasukawa, "Automated Provisioning of Cloud-Native Network Functions in Multi-Cloud Environments," in 2022 International Conference on Education, Network and Information Technology (ICENIT), 2022, pp. 351-355, doi: 10.1109/ICENIT57306.2022.00086.

[20] Q. Jiao, B. Xu, and Y. Fan, "Design of Cloud Native Application Architecture Based on Kubernetes," in 2021 IEEE International Conference on Dependable, Autonomic and Secure Computing, International Conference on Pervasive Intelligence and Computing, International Conference on Cloud and Big Data Computing, International Conference on Cyber Science and Technology Congress (DASC/PiCom/CBDCom/CyberSciTech), 2021, pp. 494-498, doi: 10.1109/DASC-PICOM-CBDCOM-CYBERSCITECH52372.2021.00088.

[21] P. Hegyi, N. Varga, and L. Bokor, "An Advanced Telco Cloud Simulator and its usage on modelling multi-cloud and 5G multi-access environments," in 2021 IEEE International Conference on Dependable, Autonomic and Secure Computing, International Conference on Pervasive Intelligence and Computing, International Conference on Cloud and Big Data Computing, International Conference on Cyber Science and Technology Congress (DASC/PiCom/CBDCom/CyberSciTech), 2021, pp. 1-8, doi: 10.1109/DASC-PICOM-CBDCOM-CYBERSCITECH52372.2021.00088.

[22] B. Dab, I. Fajjari, M. Rohon, C. Auboin, and A. Diquélou, "An Efficient Traffic Steering for Cloud-Native Service Function Chaining," in *Proceedings of the 23rd Conference on Innovations in Clouds, Internet and Networks (ICIN 2020)*, Paris, France, 2020, pp. 71-78, doi: 10.1109/ICIN48450.2020.9071605.

[23] S. Hall, "Evolution of Telco Services utilising Infrastructure-as-a-Service (IaaS)," in *Proceedings of the 2011 15th International Conference on Intelligence in Next Generation Networks*, Berlin, Germany, 2011, pp. 247-251, doi: 10.1109/ICIN.2011.6081093.

[24] F. H. Grings, L. B. D. Silveira, K. V. Cardoso, S. Correa, L. R. Prade, and C. B. Both, "Full dynamic orchestration in 5G core network slicing over a cloud-native platform," in *Proceedings of the 2022 IEEE Global Communications Conference: Next-Generation Networking and Internet*, Rio de Janeiro, Brazil, 2022, pp. 2885-2890, doi: 10.1109/GLOBECOM48099.2022.10000663.

[25] Y. Cao, P. Lv, X. Zhou, Y. Wu, S. Quan, Z. Zhu, and S. Gao, "Research on 5GC Cloud-Native Deployment Mechanism Based on Cloud-Edge Collaboration," in *Proceedings of the 2022 IEEE Conference on Telecommunications, Optics and Computer Science (TOCS)*, Dalian, China, 2022, pp. 24-30, doi: 10.1109/TOCS56154.2022.10016065.

[26] B. Ravichandran, "Securing Virtual Network Function (VNF) in Telco Cloud," *Journal of ICT*, vol. 8, no. 3, pp. 235-246, Jul. 2020, doi: 10.13052/jicts2245-800X.834.