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A Comprehensive Survey of Integrated IP and Optical Network Control in Multi-Grade Virtualized Networks

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Abstract: In the telecommunications industry, the rapid evolution of next-generation systems has created a need for a flexible, scalable, and efficient network infrastructure. The fields of integrated Internet Protocol (IP) and optical networks are growing at a drastic rate to address the demand for dynamic resource allocation, low-latency services, and bandwidth-demanding applications. Network virtualization enables the requirement for multigrade network services that support differential performance requirements, which raises the challenge of network control and management. This survey paper reviews the various IP and Optical network control mechanisms, along with their integration in the context of a multi-grade virtualized network. The different control frameworks, along with support technologies such as network virtualization and software defined networking. The various limitations and challenges of the existing approaches have been identified by focusing on resource allocation, traffic engineering, and quality of service assurance. It also highlights the open research directions for achieving an intelligent and unified IP-optical virtualized network.

Index Terms - 5G, network slice, SDN, multi-layer control, Cellular networks, IoT devices, Virtualization, SDN, NFV, Dynamic allocation of network resources, Network optimization.

I. INTRODUCTION

The fifth generation (5G) network is growing at at faster rate due to its network slicing feature. It can enhance mobile broadband, IoT connectivity, and reliable low-latency communication services enabled by mobile edge computing. To accommodate these heterogeneous service requirements, both the IP and optical networks must be capable of isolation, capacity differentiation and multigrade performance guarantee. These capabilities are essential within each slice for providing quality of service, low latency, and high reliability.

The dynamic nature of the 5G services demands the on-demand provision of bandwidth with the help of the virtualized network. Slicing plays a key role in the applications that are rapidly instantiated, short-lived, and automatically managed by a service agent rather than human intervention. To achieve this, an advanced control mechanism is required across the IP and optical layers, where a multi-layer software-defined network (SDN) plays a key role. With the help of the SDN controllers, a virtualized network enables the service on demand over the IP and optical network. This integrated control enables the seamless delivery of the diverse network services, along with multi-grade virtualization over the common physical infrastructure.

The Open Network Operating System (ONOS) controller incorporates functionalities for IP-Optical integrated resource management within a control framework. When combined with virtualization, it enhances end-to-end service automation and resource utilization. Network slicing improves performance and optimizes resources to unlock the potential of 5G networks. Section II outlines various techniques proposed by researchers, along with their advantages and limitations. Section III discusses the challenges for the integration of IP and Optical networks with Multilayer SDN and virtualization technology to shape the next generation of networks.

II. LITERATURE REVIEW

The different researchers have worked on various systems for the multi-graded virtualized network as follows –

D. Scano et al. [1] propose the hybrid SDN orchestration for SONiC packet–optical nodes with coherent pluggable modules. It integrates SONiC switching with the SDN controller of the optical layer to coordinate IP and optical provisioning. This solution is cost-effective compared to earlier systems with standardized APLs. It faces the challenge of scalability. L. Velasco [2] proposes an optical telemetry architecture based on a wide spread system where the agent collects and analyzes data before sending it to the central manager. It enhances control over the proactive network and increases network availability. It can be extended to include real-time anomaly detection. T. Dicorato et al. [3] present an alternative to SDN architectures by adding pluggable interfaces in the router using the transport API. This research includes routing and network control through the open API. It reduces operational costs and can be extended with open models and automated multi-vendor testing.

D. Sattar and A. Matrawy [4] addressed the challenges in the allocating the slices in optimal way over the 5G core networks. It reviews different techniques based on resource allocation and the Quality of Service (QoS) provided for applications. The author also given the optimal slice allocation algorithm to maximize the no. of slices and ensure QoS requirements. The strength of this algorithm has been evaluated through simulated experiments, which demonstrate that it achieves optimal slice allocation and improves overall performance. Kibeom Park, Sangmo Sung, et al. [5] discuss various ways for the commercial implementation of 5G network slicing. They highlight issues related to end-to-end network slicing and present different experienced use cases. The authors summarize various slicing standards. They propose Radio Access Network (RAN) and Open RAN for network slicing. The SLA manages end to end network slicing. Further, it can be extended to large, scalable networks. Johari Abdul Rahim, Rosdiadee Nordin, et al. [6] compare the various open-source controllers, including Ryu, Floodlight, NOX/POX, ONOS and OpenDayLight. These controllers are compared in terms of language used for programming, support for carrier-grade, and learning curve. The ONOS was created with high availability, scalability and performance. It offers SDN control with APIs. The SDN and ONOS can be deployed in the actual network environment, which makes ONOS a stronger choice in Open SDN. Need to address the centralised controller failure along with several security challenges.

A. Aguado, V. Lopez, et al. [7] aims to provide the solution for the end-to-end quantum encryption using virtual network function. Author provides in-depth survey for the quantum encryption and its survey. It provides the solution for the VNF deployment and automation of the services considering the software defined network. Proposed solution can be further applied to the integration of the networks. Thabo Semong, et al. [8] reviews the various techniques related to the link failure recovery in the software defined networks. It analyses the failure and recovery of link using SDN and OpenFlow technology. It also performs the comparison between the different protocols used for managing the data and control plane. Author also discusses the failure locations and the techniques for handling them. Author proposes different solutions with tools. The hybrid approach can be used for the SDN for controlling. Alcardo Alex Barakabitze, et al. [9] provides the review of the various techniques used for the network slicing using the SDN and NFV. Author also presents the details about the various technologies used in the 5G network slicing including virtual machine and container. Author provides the 5g management for the edge and fog networks. The future challenges include inter-domain service management, security, hardware to software switching need to addressed.

Daifallah Alotaibi, et al. [10] provides the traffic management solution using the 5G slicing with software defined multiple access technique (SoDeMa). This solution provides he intelligent traffic data management and its services with minimum response time. Author reduces the processing time, cost and complexity with the help of SoDeMa. In the future this can be improved with focus on the energy consumption minimization, security and use of the machine learning. Srija Chakraborty, Ashok Kumar Turuk, et al. [11] proposes the scalable SDN optical network architecture for minimizing the messages transferred from data to control plane. The different mechanisms are proposed for channel reservation, quality and speed improvement along with transmission. The transmission channels are reserved prior to the transmission to avoid the burst collision. Author compares the performance of in simulated environment using various parameters including bust delay, throughput etc. P. Wang, G. Wen, et al. [12] addresses the challenges in the multiple layer networks synchronization. Author proposes the framework for making node-to-node and complete synchronization inside multiple layer network. It considers three steps including designing coupling function, analyzing stability and optimizing the performance over the synchronization process. It increases the performance and functionality of the network.

B. P. R. Killi and S. V. Rao [13] proposed strategies for the hypervisor placement and controller placement called VCPP and JHCP. The placement of the hypervisor over the physical network is done by VCPP along with placement over virtual network. It allows to dynamically add the network operator based on growing requirement. The author aim is to reduce the network latency along with energy consumption. The proposed approach significantly improves the network performance along with resource utilization. Ziran Min, et al. [14] uses 5G slice concept for the IoT related applications. Author applies the PCA and Hellinger distance-based recursive K-Means algorithm. The results show the drastic reduction in the high dimensionality of the dataset. It also makes the provision of network resources using clustering inside 5G slicing. Further it can be improved using the real traffic on large dataset. It can also integrate with other method for supporting dynamic nature of 5G network.

Nicola Andriolli, Alessio Giorgetti, et al. [15] presents the advanced technique on intent-based networking for providing the automatic optical network and zero touch service. It is very much suitable for the data center network. It can be integrated with the other optical network. R. Casellas, R. Martínez, et al. [16] provides the various technique review with inclusion of control and orchestration challenges and trends of Optical network. The various services over the heterogeneous network have been automated. Yet need to reduce the cost and time required to deployment for complex task.

S. Wijethilaka and M. Liyanage [17] presents a review of the network slicing techniques in IoT realization. The author presents the different test cases for different IoT application scenarios. The various challenges have been identified related to the network slicing. The role of the AI in network slicing has been discussed for further improvement. Subedi, et al. [18] presented a comprehensive comparison between the techniques used for network slicing, and its integration with SDN and NFV for creating the flexible and dynamic architecture. This architecture might cover the variety of application support. It is flexible to satisfy the diverse needs of the industry.

R. Zamora and A. K. Srivastava [19] provide the review of the different techniques on the micro grids and their applications. Athor proposes the multilayer system for voltage and frequency control using global network optimization, cluster-level coordination, and local voltage and frequency control layer. The results show the proposed approach is effective in grid management using network. André Perdigão, et al. [20] proposes the network slicing manager design mechanism for automation of the slicing. The proposed system can meet the vertical requirement with the 5G services. The proof-of-concept prototype has been

developed and result are evaluated. The result shows that the solution is best suitable for the industrial use cases where there is a 5G requirements. This system can be extended with the dynamic mechanism for slicing.

III. CHALLENGES

The details review of the different techniques has been carried out in the above section. Following are the challenges addressed for making fully integrated multi-grade virtualized network using Ip and Optical network as follows –

1. Requirement of the standard framework for interoperability over different layers and various vendor system. It currently faces the difficulties in IP and Optical control over heterogeneous network.
2. Current SDN controllers are not able to adapt the scaling requirement over carrier-grade networks due to diverse traffic demands.
3. Need of dynamic and proactive mechanism for the resource allocation, since currently it only relies on the static or reactive mechanisms.
4. Need the assured quality of service ad SLA for dynamic and multi slice environment.
5. Current methods still required human intervention. So, there is a requirement of the fully automated, and self-optimizing system.
6. The cyber-attack challenges need to address for maintaining the trust on the system.
7. Need to do more research on the integration of edge, quantum, and 5G networking.

IV. CONCLUSION

Nowadays, with the fast growing of the fifth-generation network (5G) network, the different applications demand the different bandwidth based on the requirement. The network slicing enables the differential service requirement over the physical network. This paper reviews the various techniques used for the 5G network. This paper also heights the various techniques for the IP control and optical network control. Also presents the integrated techniques of IP and Optical within the multilayer SDN and virtualization environment. Through this review various challenges are identified related to the quality of service, security, scalability, dynamic controller mechanism and use of AI. These challenges need to be addressed for unlocking the potential of the 5G network.

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