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Dynamic Orchestration of Heterogeneous Software-Defined Networks for Multi-Domain Service Optimization in End to End 5G Environments.

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DECLARATION

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I hereby declare that this final year research project is the result of my own work, except for quotations and summaries which have been duly acknowledged.

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ABSTRACT

The advent of the fifth generation (5G) of wireless technology has presented unprecedented challenges in network management due to its complex, heterogeneous nature involving multiple domains. Addressing these challenges, the paper at hand proposes an innovative orchestration framework designed for such diverse software-defined networks (SDNs) that are inherent in 5G systems. The objective of this framework is to ensure that service delivery is optimized across various network segments, achieving a seamless end-to-end communication experience for users. To orchestrate the network dynamically, the framework integrates machine learning algorithms that can predict network conditions and user demands. This predictive capability allows the network to adapt in real-time, effectively managing resources and maintaining service quality. The cross-layer approach of the framework is key; it merges insights from the physical infrastructure with that from the application layer to enable more accurate and holistic decision-making processes. One of the challenges in heterogeneous network environments is achieving interoperability between different SDN controllers. To overcome this, the paper introduces a set of application programming interfaces (APIs) that facilitate communication and coordination among various network controllers. This ensures that the orchestration framework can function across multiple domains without compatibility issues. The performance of the proposed orchestration framework was tested and showed considerable improvements in network efficiency. Notably, it was observed that there was a decrease in service latency and an increase in data throughput. Furthermore, the framework promoted better resource utilization, leading to cost benefits for network operators, as well as enhanced scalability, which is a critical requirement for modern networks.

Keywords: 5G Networks, Dynamic Orchestration, Heterogeneous Networks, Software-Defined Networking (SDN), Multi-Domain Service Optimization, Cross-Layer Approach, Machine Learning Algorithms, Quality of Service (QoS), Quality of Experience (QoE), Network Interoperability, Resource Management, Predictive Analytics, End-to-End Communication, Network Efficiency, Application Programming Interfaces (APIs), Scalability, Real-World Deployment.

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THANK YOU.

DEDICATION

I would like to take this opportunity to express my gratitude and appreciation to my family and friends.

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LIST OF ABBREVIATIONS

3GPP	3rd Generation Partnership Project
4G	Fourth Generation Mobile Networks
5G	Fifth Generation Mobile Networks
5GC	5G Core
5G-H	5G-Hazel: Functioning Time Dynamic Orchestration Multi-Provider for 5G and Future Generations Mobile Networks
5G-PPP	5G Infrastructure Public Private Partnership
5QI	5G QoS Identifier
6G	Sixth Generation Mobile Networks
AI	Artificial Intelligence
API	Application Programming Interface
AR	Augmented Reality
CBR	Constant Bit Rate
CI	Confidence Interval
CLI	Command Line Interface
E2E	End-To-End
ETSI	European Telecommunications Standards Institute
gNodeB	Radio base station
GUI	Graphical User Interface
IMT-2020	International Mobile Telecommunications-2020 (5G)
IoT	Internet of Things
ITU	International Telecommunications Union
JSON	Java Script Object Notation
LCM	Life-Cycle Management
LTE	Long-Term Evolution
MADM	Multiple Attribute Decision Making
MANO	MANagement and Orchestration
ML	Machine Learning
MNO	Mobile Network Operator
MOS	Mean Opinion Score
NFV	Network Function Virtualization
NFVO	NFV Orchestrator
NS	Network Slice
NSI	Network Slice Instance
ONAP	Open Network Automation Platform
OSM	Open Source Mano
PNF	Physical Network Function
QoE	Quality of Experience
QoS	Quality of Service
QoV	Quality of Video
RAN	Radio Access Network
SD	Standard Deviation
SDN	Software-Defined Networking
SDR	Software-Defined Radio
SLA	Service Level Agreement
SNSI	Sub-Network Slice Instance
SP	Service Provider
TIP	Telecommunications Infrastructure Provider
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
UE	User Equipment
UPF	User Plane Function

V2X	Vehicle-to-Everything
VAR	Variance
VIM	Virtualized Infrastructure Manager
VM	Virtual Machine
VMM	Virtual Machine Monitor
VNF	Virtual Network Function
VNFM	VNF Manager
VoD	Video on Demand
VR	Virtual Reality
WAN	Wide Area Network

CHAPTER 1

INTRODUCTION

1.1 Background to the study

This Thesis focuses on the challenges and solutions for optimizing services in multi-domain networks using software-defined networking (SDN) technologies in End to End 5G environments. SDN enables centralized control and management of network resources, allowing for dynamic and efficient allocation of services across multiple domains. The Thesis explores various techniques and algorithms for orchestrating heterogeneous SDN controllers to achieve service optimization (Zhang et al., 2018). It addresses issues such as network heterogeneity, resource allocation, and service provisioning in a multi-domain environment to mention a few. The ultimate goal is to enhance the performance and efficiency of services in complex network architectures that are not able to dynamically orchestrate and optimize the operations that are occurring on multi-domain networks. The Thesis then introduces the concept of software-defined networking (SDN) and its benefits in network management. SDN separates the control plane from the data plane, allowing for centralized control and programmability of network resources. This enables more efficient and flexible management of network services. Also the proposed Thesis will discuss various and introduce enhancements to techniques and algorithms used in the dynamic orchestration framework, such as service chaining, traffic engineering, and network function virtualization (NFV). These techniques enable efficient service provisioning, traffic management, and resource allocation in multi-domain network environments and the proposed Thesis is on the quest of creating a better framework for this. The rise of the Internet of Things (IoT) (Zhang et al., 2018) and the potential for comprehensive processing across the entire network cloud (Distributed Cloud Computing, spanning from the network core to its edges) are among several anticipated developments intertwined with Fifth Generation Mobile Networks (5G) and the subsequent generations of wireless communication systems (6G and beyond). These advancements enable faster mobile services utilizing higher frequency waves, thereby facilitating the emergence of new applications (Bhat & Alqahtani, 2021). Consequently, 5G and its successors will be a synergy of advancements in both computing and telecommunications technologies, as well as computer and communications networks.

It's important to note that Fifth Generation Mobile Networks represent more than a simple evolution of mobile telecommunications technologies; they signify a genuine revolution. In this paradigm shift, computing and telecommunications technologies coexist within the same architecture, aiming to address connectivity challenges for any class of service, regardless of its non-functional requirements (Mattisson, 2018). The advent of Fifth Generation Mobile Networks promotes the swift and widespread adoption of innovative solutions, as they provide compatibility with existing networks and, when necessary, offer seamless integration with various other technologies.

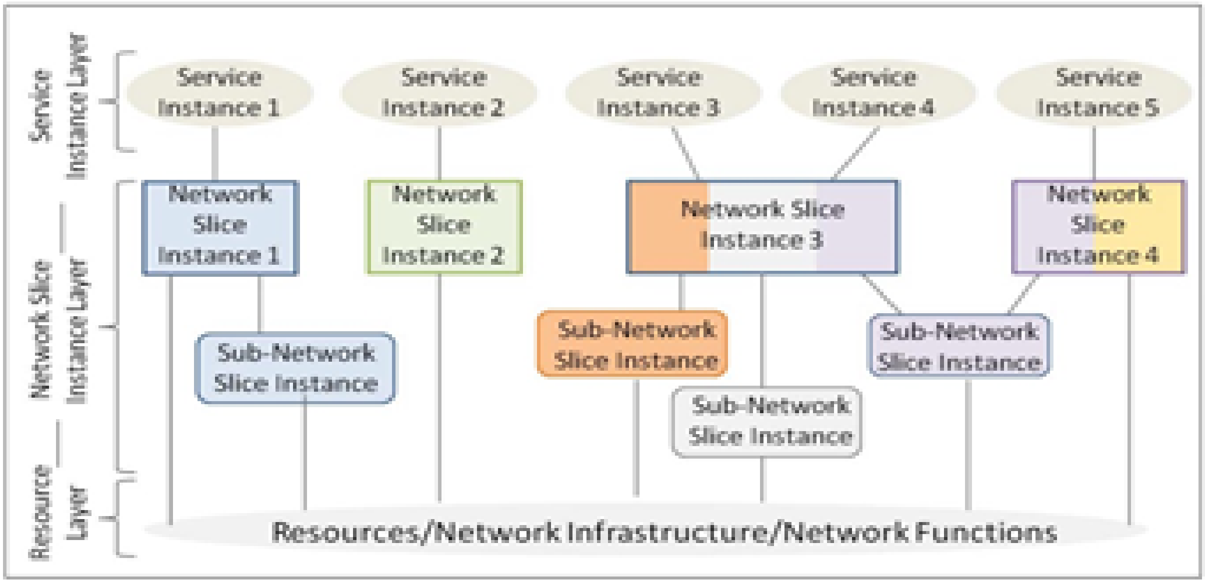


Figure 1. Network Slicing in 5G Networks

1.2 Problem Statement

This research addresses the challenge of efficiently managing and optimizing complex networks composed of different types of software-defined networks (SDNs) across multiple domains in a 5G environment. Let's break down the key components of this problem statement: ***Dynamic Orchestration***: Orchestration refers to the automated coordination and management of various network resources to achieve specific goals. In this context, "dynamic" implies that the orchestration process needs to adapt and adjust in real-time to changing network conditions, traffic patterns, and service requirements (Bolan, 2021). ***Heterogeneous Software-Defined Networks***: A Software-Defined Network (SDN) is a network architecture that separates the control plane (network management) from the data plane (actual data forwarding). Heterogeneous SDNs refer to the situation where multiple

SDN instances or controllers with different characteristics, functionalities, and implementations coexist in a network. These SDNs might be based on different protocols, standards, or technologies (Taleb et al., 2019). ***Multi-Domain***: A network domain refers to a portion of a network controlled by a single administrative entity. Multi-domain scenarios involve the interconnection of multiple such domains, each with its own policies, protocols, and management systems. The challenge here is to effectively manage and optimize services across these diverse domains (Taleb et al., 2019). ***Service Optimization***: Service optimization involves maximizing the efficiency, performance, and quality of services provided over the network. This can encompass various aspects such as minimizing latency, maximizing bandwidth utilization, ensuring Quality of Service (QoS), and efficiently allocating resources to meet service-level agreements (SLAs).

The overall problem is to come up with a framework that can dynamically orchestrate the activities of different SDNs operating in multiple domains in an End to End 5G enabled environment to optimize the delivery of services. This might include:

Resource Allocation: It is difficult to allocate network resources (such as bandwidth, processing power, and memory) to different services and applications based on their requirements.

Traffic Engineering: it is challenging to efficiently route traffic to avoid congestion and minimize delays, considering the specific characteristics of each SDN and domain.

Policy Enforcement: it is not easy to enforce policies across different domains to maintain security, compliance, and other regulatory requirements like SLAs.

Failover and Resilience: The task of ensuring service continuity by intelligently rerouting traffic and reallocating resources in case of network failures or congestion is a serious nightmare.

Real-time Adaptation: Adapting to changing network conditions and service demands on the fly to ensure optimal performance is a challenge.

Solving these problem requires a deep understanding of networking concepts, SDN technologies, multi-domain architectures, optimization algorithms, and real-time data analysis. It also involves developing a sophisticated orchestration algorithm (s) and framework that can handle the complexities of the network environment while ensuring efficient and effective service delivery.

Key Components	**Activity**	**Identified Problem**
Dynamic Orchestration	Resource Allocation	It is difficult to allocate network resources (such as bandwidth, processing power, and memory) to different services and applications based on their requirements.
Heterogeneous Software-Defined Networks:	Traffic Engineering	It is challenging to effectively route traffic to avoid congestion and minimize delays, considering the specific characteristics of each SDN and domain/network slice.
Multi-Domain:	Policy Enforcement	it is not easy to enforce policies across different domains to maintain security, compliance, and other regulatory requirements.
Service Optimization:	Failover and Resilience, Real-time Adaptation	Adapting to changing network conditions and service demands on the fly

		to ensure optimal performance is a challenge

.**Table 1.** Problem statement tabulation.

1.3 Aim

The major aim is to develop a comprehensive solution that addresses the challenges posed by managing and optimizing complex networks consisting of various types of software-defined networks (SDNs) across multiple administrative domains in 5G E2E environments. The primary goals of the project include:

Efficient Orchestration: Create an automated orchestration framework that can dynamically coordinate and manage the activities of different SDNs, each operating with its own protocols, standards, and technologies (Wang et al., 2020). This framework should be capable of adapting in real-time to changing network conditions and service requirements . ***Heterogeneity Handling***: Develop mechanisms to handle the heterogeneity of SDNs present in the network. This includes designing protocols or interfaces that allow communication and cooperation among SDNs with different characteristics, ensuring seamless interoperability (Wang et al., 2020). ***Multi-Domain Collaboration***: Design strategies and protocols for collaboration among multiple administrative domains. This involves establishing communication channels, policy enforcement mechanisms, and QoS agreements that enable services to traverse different domains while adhering to their respective policies (Sunthonlap & Nguyen, 2017). ***Service Optimization***: Create algorithms and techniques for optimizing service delivery across the network. This includes resource allocation, traffic engineering, and QoS management to ensure that services meet performance and reliability expectations. ***Real-time Adaptation***: Implement mechanisms to monitor the network and service performance in real-time. Develop algorithms that can quickly adapt the orchestration and optimization strategies based on current conditions to maintain high-quality service delivery. ***Security and Privacy***: Integrate security measures to protect the network and the data being transmitted. This involves implementing encryption, authentication, and authorization mechanisms to safeguard against unauthorized access and data breaches. ***Scalability and Performance***: Ensure that the developed solution can scale to accommodate larger and more complex networks. Optimize the performance of the orchestration and optimization algorithms to handle a high volume of network traffic and dynamic changes. ***Validation and Testing***: Conduct thorough testing and validation of the developed solution through simulations or real-world experiments (Ramachandran et al., 2018). Assess its effectiveness in optimizing services, adapting to dynamic conditions, and managing multi-domain scenarios. ***Documentation and Reporting***: Provide comprehensive documentation of the solution architecture, algorithms, protocols, and implementation details. Create reports summarizing the project's objectives, methodologies, findings, and potential contributions to the field. Overall, the project aims to contribute to the advancement of network management and optimization by tackling the intricate challenges associated with orchestrating heterogeneous SDNs across multiple domains. The successful completion of this project could lead to more efficient, adaptable, and resilient network infrastructures capable of delivering high-quality services in diverse and complex environments.

1.3 Objectives of the study

i. Investigate the landscape of multi-domain SDN architectures and their challenges, including interoperability, security, and performance concerns in E2E 5G environments.

ii. Design an adaptive orchestration framework that can dynamically manage and optimize resources in a multi-domain SDN in E2E 5G environments.

iii. Develop mechanisms for seamless integration of various SDN controllers, taking into account different protocols and vendor-specific implementations.

iv. Evaluate the performance of the framework through considering metrics such as latency, throughput, resource utilization, and scalability.

1.4 Scope and Limitation

Scope and Limitation of "Dynamic Orchestration of Heterogeneous Software-Defined Networks for Multi-Domain Service Optimization in End to End 5G Environments" aims to contribute to the development and integration of next-generation mobile networks. It focuses on designing an end-to-end system for dynamic control of connectivity services in multi-layer networks, emphasizing the orchestration and coordination of heterogeneous elements.Scope the scope of the study includes:

Dynamic Control of Connectivity Services - The study addresses the dynamic control of connectivity services in multi-layer networks, emphasizing the orchestration and coordination of heterogeneous elements (Mukherjee et al., 2018). This involves the design of an end-to-end system for dynamic control of connectivity services. **Domain Service Orchestration and NSI Control -** The study focuses on domain service orchestration and NSI (Network Slice Instances) control to optimize service delivery across multiple domains. This includes dynamic resource orchestration when users initiate services (Ramachandran et al., 2018). **Optimization of Service Delivery across Multiple Domains -** The study aims to optimize service delivery across multiple domains, taking into account the impact of 5G on mobile networks (Nogales et al., 2019). While the study holds promise for the advancement of mobile networks, several limitations may arise:

Real-World Applicability - The real-world applicability of the proposed architecture may be limited by factors such as existing network infrastructure, interoperability with legacy systems, and the scalability of the proposed solutions (Nogales et al., 2019). **Integration Challenges -** Integrating SDN, NFV, and network partitioning to meet the demands of concurrent services in heterogeneous infrastructures may present significant challenges, including interoperability issues, performance optimization, and security concerns. This study holds significant promise for the advancement of mobile networks, it is important to consider the practical implementation challenges and real-world applicability limitations that may arise in the integration of next-generation mobile network technologies.

1.5 Significance of the Project

The project is of significant importance in the field of networking and service optimization. It aims to address the challenges associated with managing and optimizing services across multiple domains in a heterogeneous software-defined network (SDN) environment. The project's significance lies in its potential to improve the efficiency, reliability, and flexibility of network services (Nogales et al., 2019). By dynamically orchestrating diverse SDN domains, it enables the seamless integration and management of services across different network infrastructures, such as data centers, cloud environments, and wireless networks. The project tackles the complex task of optimizing services in a multi-domain setting, which involves coordinating resources, ensuring quality of service, and minimizing network latency and packet loss. By leveraging SDN technologies, it enables centralized control and programmability, allowing for dynamic allocation and management of network resources according to changing service requirements. Additionally, the project contributes to the advancement of SDN research and development by addressing the challenges of heterogeneity in software-defined networks. It explores methods to integrate and interoperate different SDN controllers, network technologies, and protocols to enable seamless communication and service provisioning across diverse domains (Mukherjee et al., 2018). Overall, the project's significance lies in its potential to revolutionize network management and service optimization by providing a scalable, flexible, and efficient solution for handling complex multi-domain environments. It paves the way for more streamlined and intelligent network operations, enabling enhanced service delivery, improved user experience, and increased overall network performance.

CHAPTER 2

LITERATURE REVIEW

2.1 General Background

The study involves studying the management and coordination of Software-Defined Networks (SDNs) characterized by heterogeneity, specifically with a focus on optimizing services across multiple domains in End to End 5G Environments. Let's break down the key components of this background:

Software-Defined Networks (SDNs):

SDNs are a transformative networking paradigm where the control plane is separated from the data plane, enabling centralized control and programmability. This architecture enhances network agility and adaptability.

Heterogeneity in SDNs: Heterogeneity in SDNs refers to the coexistence of diverse network elements within the framework. This diversity can include different types of devices, protocols, and technologies. Managing heterogeneous SDNs requires addressing the challenges posed by this diversity. **Dynamic Orchestration:** Dynamic orchestration involves the automated and real-time coordination of various network elements. In the context of SDNs, it aims to optimize resource utilization, enhance performance, and adapt to changing conditions. Dynamic orchestration is crucial for managing the complexity introduced by the heterogeneity in SDNs (Afolabi et al., 2019). **Multi-Domain Service Optimization:** Multi-domain service optimization focuses on enhancing services that span multiple network domains. This could involve coordinating activities across different administrative boundaries, addressing interoperability challenges, and ensuring seamless service delivery. **End-to-end 5G environments**: Encompass a seamless integration of various technologies and components, spanning from the core network to the edge. This holistic approach ensures a cohesive and efficient system that delivers high-performance connectivity. In such environments, the entire network architecture, including both infrastructure and services, is designed to optimize the capabilities of 5G technology (Thottan, 2020). From the central core to the distributed edge, these environments facilitate ultra-fast data processing, low-latency communication, and support for a myriad of applications. End-to-end 5G environments play a pivotal role in realizing the full potential of fifth-generation mobile networks by providing a unified and interconnected framework. This integration promotes efficient data transmission, enabling faster and more reliable communication across devices. With a focus on connectivity, these environments are engineered to address diverse non-functional requirements, ensuring a versatile platform for a wide range of services. The seamless coordination of computing and telecommunications technologies within these environments contributes to the transformative nature of 5G, making it more than just an evolution but a revolutionary leap in mobile telecommunications (Bolan, 2021).

Key Challenges:

Managing heterogeneous SDNs for multi-domain service optimization presents specific challenges. These challenges may include ensuring efficient communication and coordination across diverse domains, addressing interoperability issues, and optimizing services considering the varied characteristics of different domains. **Technologies for Dynamic Orchestration:** The background may explore specific technologies used for dynamic orchestration in heterogeneous SDNs. This could include Network Function Virtualization (NFV), Software-Defined Networking (SDN) controllers, and advanced automation tools. **Real-World Implementations and Case Studies:** The literature on this topic may feature real-world implementations and case studies illustrating how dynamic orchestration is applied in multi-domain environments. These examples provide practical insights into the complexities and solutions in optimizing services across heterogeneous SDNs. **Future Directions:** Given the evolving nature of networking technologies, the background may touch upon emerging trends and potential future directions in the dynamic orchestration of heterogeneous SDNs for multi-domain service optimization. This could include advancements in automation, artificial intelligence, and the integration of emerging technologies. Understanding these components provides a foundational overview for exploring the specific literature related to the dynamic orchestration of heterogeneous SDNs for multi-domain service optimization. It sets the stage for a more in-depth analysis of research findings and practical implementations in this specialized area (Bolan, 2021).

2.2 Broad literature review of the topic

Software-Defined Networking (SDN) is an innovative approach to network management that enables programmability, automation, and dynamic control of network resources through software applications . The fundamental principles of SDN involve the separation of the network's control plane from the data plane, providing a centralized and abstracted control layer that can make decisions about where to send network traffic. Below are some of the key reasons/areas of concern in this paper:

Separation of Control Plane and Data Plane. *Control Plane*: This is responsible for making decisions about where traffic should be sent based on network policies and conditions. In SDN, the control plane is centralized and abstracted from individual networking devices. *Data Plane*:This is responsible for the actual forwarding of network traffic. SDN separates the data plane from the control plane to allow for centralized control and programmability. **Programmability**: SDN enables the programming of network behavior through software applications. Network administrators can define and implement policies dynamically without the need to configure individual networking devices manually (Marinova et al., 2020). **Centralized Control:** The control plane in SDN is centralized in a software-based controller. This controller communicates with the networking devices in the data plane, instructing them on how to forward traffic based on the defined policies. **Abstraction:** SDN abstracts the underlying complexity of the network infrastructure. Network administrators interact with a higher-level, abstracted view of the network rather than dealing with the intricacies of individual devices (Barakabitze et al., 2020). **Open Standards and APIs**: SDN promotes the use of open standards and Application Programming Interfaces (APIs). This allows for interoperability between different vendors' hardware and software components, fostering innovation and avoiding vendor lock-in. **Dynamic and Automated Configuration:** SDN facilitates dynamic network configuration and automation. Changes to the network can be implemented programmatically in real-time, making it more responsive to changing conditions and requirements. **Network Virtualization:** SDN allows for the creation of virtual networks on top of the physical network infrastructure. This enables the segmentation of network resources for different purposes, enhancing flexibility and resource utilization. **Fine-Grained Traffic Control:** SDN provides granular control over network traffic flows. Administrators can define specific policies and rules for different types of traffic, optimizing performance and security. SDN is a network architecture that introduces flexibility, programmability, and centralized control to traditional networking (Dogra et al., 2020). By separating the control plane from the data plane and enabling software-based management, SDN aims to make networks more agile, adaptable, and responsive to the dynamic needs of modern applications and services. Additionally, in the context of Software-Defined Networking (SDN), orchestration refers to the automated coordination and management of resources, services, and network functions to achieve a specific goal or fulfill a service request. It involves the dynamic arrangement and configuration of network elements to ensure that the network operates efficiently, adapts to changing conditions, and meets the requirements of applications and services. Orchestration plays a crucial role in realizing the benefits of SDN, particularly in terms of agility, automation, and efficient resource utilization. Below are key aspects of orchestration in the context of SDN:

Automated Resource Provisioning: Orchestration automates the provisioning of network resources based on the requirements of applications or services. This includes the allocation of bandwidth, computing resources, and other network elements to ensure optimal performance. **Service Lifecycle Management:** Orchestration manages the entire lifecycle of network services. This includes service instantiation, scaling, updating, and termination. It ensures that services are deployed and adjusted dynamically in response to changing demands. **Policy-driven Configuration:** Orchestration relies on policies and rules to guide the configuration of network elements (Batista et al., 2021). Policies define how resources should be allocated, traffic should be prioritized, and security measures should be enforced. Orchestration ensures that these policies are implemented consistently across the network. **Dynamic Adaptation to Changes**: Orchestration enables the network to adapt dynamically to changes in traffic patterns, service demands, or network conditions. This adaptability is crucial for maintaining optimal performance and responsiveness. **Interoperability and Multi-Domain Coordination:** In heterogeneous environments or multi-domain scenarios, orchestration facilitates interoperability by coordinating the actions of different SDN controllers or networking technologies (Amali et al., 2018). It ensures seamless communication and collaboration across diverse network domains. **Integration with SDN Controllers:** Orchestration systems often interact with SDN controllers, which manage the control plane of SDN. Orchestration systems send instructions to SDN controllers to configure the network devices (data plane) according to the specified policies and requirements. **Cross-layer Coordination:** Orchestration coordinates activities across different layers of the network stack, including the application layer, control layer, and data layer. This holistic approach allows for more effective management and optimization of network resources. **Service Optimization and Efficiency:** Orchestration aims to optimize the use of resources, improve network efficiency, and enhance the overall quality of service. It achieves this by dynamically adjusting configurations based on real-time conditions and demands. **Programmable Network Services:** Orchestration enables the creation and deployment of programmable network services. This programmability allows for the customization of network behavior to suit specific application requirements. Orchestration in SDN involves the automated coordination and management of network resources and services to achieve efficient, adaptive, and policy-driven network operations. It plays a vital role in realizing the full potential of SDN by providing a framework for dynamic and automated control over diverse and distributed network environments. Dynamic orchestration is particularly crucial in heterogeneous Software-Defined Networking (SDN) environments due to the diverse nature of technologies, protocols, and network domains (Amali et al., 2018). Also we highlight the need for dynamic orchestration in such complex settings:

Interoperability Across Diverse SDN Technologies: Heterogeneous SDN environments often consist of various SDN controllers, each with its own set of protocols and features. Dynamic orchestration facilitates interoperability by providing a layer of abstraction that can translate and coordinate between different SDN technologies, ensuring seamless communication and collaboration. **Optimizing Resource Utilization:** Different SDN domains may have varying levels of resource availability and capabilities. Dynamic orchestration allows for the intelligent allocation and utilization of resources based on real-time demands, ensuring efficient use of network resources across diverse domains (Sousa et al., 2019). **Adaptability to Changing Network Conditions:** Heterogeneous environments may experience dynamic changes in traffic patterns, network conditions, or service demands. Dynamic orchestration enables the network to adapt in real-time, making adjustments to configurations and resource allocations to maintain optimal performance. **Supporting Multi-Domain Service Provisioning**: In scenarios where services span multiple SDN domains, dynamic orchestration is essential for coordinating the provisioning and management of services across these diverse domains. It ensures a cohesive and integrated approach to service delivery. **Facilitating Policy Consistency:** Different SDN domains may have their own policy frameworks. Dynamic orchestration helps enforce consistent policies across heterogeneous environments, ensuring that security, QoS (Quality of Service), and other policies are applied uniformly (Nencioni et al., 2018). **Enhancing Flexibility and Scalability:** Heterogeneous environments may involve scaling resources across different technologies and domains. Dynamic orchestration provides the flexibility to scale resources on-demand, adapting to changing requirements without manual intervention (Sousa et al., 2019). **Managing Vendor Diversity:** Organizations often deploy networking equipment and solutions from various vendors, leading to vendor diversity within the network. Dynamic orchestration abstracts away vendor-specific details, allowing for the management and orchestration of diverse devices through a unified interface. **Reducing Complexity in Network Management**: Heterogeneous environments inherently introduce complexity.

Dynamic orchestration simplifies the management of diverse SDN technologies by providing a centralized and automated control layer. This reduces the complexity associated with configuring and maintaining the network. **Enabling Cross-Domain Service Optimization:** Services often rely on resources and functions distributed across multiple domains. Dynamic orchestration coordinates and optimizes these distributed elements, ensuring that the entire service chain operates efficiently and meets performance objectives. **Preparing for Future Technology Integrations:** As new SDN technologies and standards emerge, dynamic orchestration provides a future-proof framework that can easily integrate and adapt to changes in the networking landscape (Rahman et al., 2020). Dynamic orchestration is essential in heterogeneous SDN environments to overcome the challenges associated with diversity in technologies, protocols, and domains. It enables a more agile, adaptable, and unified management approach, ensuring efficient and optimized network operations in complex and varied networking environments.

SDN Architectures: The diversity of Software-Defined Networking (SDN) architectures and protocols stems from the evolving nature of the technology, as well as the need to address various networking scenarios and use cases. Different SDN architectures and protocols have been developed to cater to specific requirements, network sizes, and deployment scenarios. I pinpoint my discussion of the diversity in SDN architectures and protocols: **Centralized SDN (Single Controller):** Description: In a centralized SDN architecture, a single controller has full control over the entire network. This controller makes decisions about the forwarding of traffic and communicates these decisions to the network devices. Simplicity, centralized control, potential scalability challenges (Vincenzi et al., 2019). **Distributed SDN (Multiple Controllers):** Description: In distributed SDN architectures, control is distributed among multiple controllers, each responsible for a subset of the network. These controllers collaborate to make global decisions. Improved scalability, fault tolerance, and distributed decision-making. **Hybrid SDN:** Description: Hybrid SDN architectures combine elements of both centralized and distributed approaches. Certain functions may be centralized, while others are distributed to strike a balance between simplicity and scalability. Tailored to specific network requirements, flexibility. **Service Chaining SDN:** Description: Service chaining architectures enable the definition and enforcement of specific service paths or chains that network traffic must traverse (Lannelli et al., 2019). This is particularly relevant for applications with specific service requirements. Granular control over service paths, optimized for specific applications. **Overlay SDN:** Description: Overlay SDN involves creating virtual networks on top of the physical network infrastructure. These overlays can be used to segment and isolate traffic or to provide network virtualization. Network segmentation, improved scalability, and isolation.

SDN Protocols: OpenFlow: Description: OpenFlow is a widely adopted protocol in SDN. It facilitates communication between the SDN controller and the network devices by defining a standard set of instructions for packet forwarding. Standardized, widely supported, promotes interoperability. **NETCONF (Network Configuration Protocol)**: Description: NETCONF is a network management protocol used for configuring and managing network devices. It provides a programmatic interface for device configuration and management. XML-based, designed for network device management. **RESTful APIs:** Description: Representational State Transfer (REST) APIs are used for communication between SDN controllers and devices. They provide a lightweight and scalable approach to network management. Stateless communication, simplicity, widespread adoption (Guerzoni et al., 2017). **BGP-LS (Border Gateway Protocol - Link State):** Description: BGP-LS extends the Border Gateway Protocol (BGP) to distribute link-state information. It is commonly used in SDN environments to convey network topology information to the controller. Scalable, used for topology dissemination. **P4 (Programming Protocol-Independent Packet Processors):** Description: P4 is a language for specifying how packets should be processed by networking devices. It allows for programmability at the data plane level, enabling customization of packet forwarding behavior. Data plane programmability, flexibility. **OF-config:** Description: OF-config is a protocol used for the centralized management of OpenFlow-enabled devices. It defines a set of configuration options and capabilities that can be controlled by a central management system. Configuration standardization, specific to OpenFlow-enabled devices. **Yang (Yet Another Next Generation):** Description: YANG is a data modeling language used to define the structure of data exchanged between SDN controllers and devices. It is often used in conjunction with NETCONF for device configuration. Hierarchical data modeling, standardization (Ksentini et al., 2017).

Challenges and Considerations:

Interoperability: The diversity in SDN architectures and protocols can lead to interoperability challenges. Efforts to standardize protocols and promote open standards help address these challenges. **Scalability:** Different SDN architectures may exhibit varying levels of scalability. The choice of architecture depends on the size and complexity of the network.

Security: Each protocol may have its security considerations. Security measures must be implemented to protect the SDN infrastructure against potential vulnerabilities.

Vendor-Specific Implementations: Some protocols may be closely associated with specific vendors. Organizations should consider the implications of vendor lock-in when selecting SDN technologies. The diversity in SDN architectures and protocols reflects the adaptability of the technology to different networking scenarios. The choice of architecture and protocol depends on factors such as the size of the network, specific use cases, and organizational requirements. Efforts toward standardization and open protocols aim to improve interoperability and simplify the integration of diverse SDN solutions. Integrating different Software-Defined Networking (SDN) technologies poses several challenges due to the diversity of architectures, protocols, and vendor-specific implementations (Nencioni et al., 2018). The following are key challenges associated with integrating different SDN technologies:

Interoperability: Challenge: Different SDN technologies may use proprietary protocols, data models, or controller interfaces, leading to interoperability issues. Integrating solutions from different vendors or with different architectural approaches can be challenging. Solution: Standardization efforts, such as common data models and open APIs, can help mitigate interoperability challenges. Adopting open standards like OpenFlow or common data modeling languages like YANG can promote interoperability. **Protocol Heterogeneity:** Challenge: SDN solutions may use different communication protocols between controllers and devices. For instance, one solution may use OpenFlow, while another may rely on NETCONF or RESTful APIs. Solution: Implementing protocol translation gateways or adopting hybrid SDN architectures that support multiple protocols can help bridge the gap between different technologies. **Vendor Lock-In:** Challenge: Some SDN solutions are tightly coupled with specific vendors, making it challenging to integrate devices or controllers from different providers without facing vendor lock-in. Solution: Emphasizing open standards and selecting SDN technologies that adhere to these standards can reduce the risk of vendor lock-in. Organizations should seek solutions with open and well-documented APIs (Nencioni et al., 2018). **Divergent Data Models:** Challenge: Different SDN technologies may use diverse data models for representing network configurations and states, leading to inconsistencies and difficulties in data exchange. Solution: Efforts to standardize data models, such as YANG, and the use of common information models can help achieve a more consistent representation of network information. **Policy and Rule Conflicts:** Challenge: SDN solutions may have different approaches to defining and enforcing policies and rules. Integrating networks with conflicting policies can result in unexpected behavior and security vulnerabilities. Solution: Clear documentation of policies, mapping and translating policies during integration, and ensuring consistency in policy enforcement mechanisms can help address conflicts. **Security Concerns:** Challenge: Integrating SDN technologies introduces security challenges, as different solutions may have varying levels of security measures. Inconsistencies in security mechanisms can expose vulnerabilities. Solution: Implementing consistent security policies, encryption standards, and access controls across integrated SDN technologies can help address security concerns. Regular security audits and updates are essential. **Resource Allocation and QoS Differences:** Challenge: Different SDN technologies may have varying approaches to resource allocation and Quality of Service (QoS). Integrating these technologies without a coherent strategy may result in suboptimal resource utilization. Solution: Developing a comprehensive resource allocation strategy, possibly through dynamic orchestration, can help optimize resource utilization and maintain consistent QoS across integrated SDN technologies. **Operational Complexity:** Challenge: Integrating multiple SDN technologies can increase the operational complexity for network administrators, who may need to manage different interfaces, policies, and configurations. Solution: Implementing centralized management and orchestration systems that provide a unified interface for configuring and monitoring integrated SDN technologies can simplify operations. **Lack of Standardization in Control Plane Communication:** Challenge: Control plane communication between SDN controllers may lack standardization, making it difficult to coordinate and exchange information seamlessly. Solution: Encouraging the adoption of standardized control plane communication protocols or leveraging hybrid architectures that support multiple control plane interfaces can help address this challenge (Rahman et al., 2020). **Scalability Issues:** Challenge: Integrating different SDN technologies may lead to scalability challenges, especially when dealing with large and complex networks. Solution: Implementing scalable architectures, using distributed approaches, and optimizing resource allocation can help enhance scalability in integrated SDN environments. Addressing the challenges associated with integrating different SDN technologies requires a combination of standardization efforts, strategic planning, and the adoption of best practices. Open standards, clear documentation, and a focus on interoperability can help organizations successfully integrate diverse SDN solutions while minimizing complexity and ensuring optimal network performance. Some general examples and case studies of heterogeneous Software-Defined Networking (SDN) deployments (Wang et al., 2018). Keeping in mind that the field of SDN is rapidly evolving, here are a few examples:

1. AT&T's Enhanced Control, Orchestration, Management, and Policy (ECOMP): AT&T's ECOMP is a comprehensive SDN platform designed to automate the company's network services. It is a heterogeneous deployment that involves the integration of various SDN technologies and platforms. ECOMP supports multiple SDN controllers, including OpenDaylight and ONOS. It involves the orchestration of services across different network domains, including data centers and wide-area networks. ECOMP has been a driving force behind AT&T's goal of transforming its network infrastructure into a more agile, scalable, and programmable environment.

2. Google's SDN Implementation with OpenFlow: Google has been a pioneer in adopting SDN principles in its data centers. It uses a combination of SDN and OpenFlow to create a flexible and scalable network architecture. Google's SDN implementation allows for centralized control and programmability of the network. OpenFlow is used to communicate between the central controller and the network switches, providing a standardized protocol for SDN. Google's SDN deployment showcases the flexibility and efficiency gains achieved through the integration of heterogeneous SDN technologies.

3. Verizon's SDN/NFV Implementation: Verizon has embarked on a network transformation journey, leveraging SDN and Network Functions Virtualization (NFV) technologies to enhance its services and infrastructure. Verizon's SDN deployment involves the integration of SDN controllers, virtualized network functions (VNFs), and orchestration systems. The heterogeneous nature of the deployment allows Verizon to optimize its network for various services, including virtualized firewalls, load balancers, and other network functions. This case illustrates the adoption of both SDN and NFV to create a more flexible and programmable network infrastructure.

4. DT's Pan-European Multi-Vendor SDN Deployment: Deutsche Telekom (DT) has implemented a pan-European SDN deployment that involves multiple vendors and SDN technologies. DT's deployment includes the integration of SDN controllers from different vendors, allowing for a heterogeneous environment. The network infrastructure spans multiple countries, requiring interoperability between diverse SDN technologies. The deployment showcases the challenges and solutions associated with integrating SDN in a large, multi-vendor, and multi-domain environment. These examples demonstrate that real-world SDN deployments often involve the integration of diverse technologies, including various SDN controllers, protocols, and virtualization solutions. The goal is to create flexible, programmable, and efficient networks that can adapt to changing requirements and support a wide range of services (Bojkovic et al., 2019).

Multi-domain networking refers to the networking architecture and practice that involves the integration and coordination of multiple, potentially disparate, network domains. A network domain typically represents a portion of a network that is administered and controlled as a separate entity. These domains may be operated by different organizations, managed by different administrators, or have distinct technology stacks. Multi-domain networking seeks to address the challenges associated with connecting, coordinating, and managing these diverse domains to enable seamless communication and efficient service delivery. Key Characteristics and Components of Multi-Domain Networking:

Interconnected Domains: Multi-domain networking involves connecting different network domains, which can be geographically distributed or operated by various entities. These domains can include enterprise networks, service provider networks, cloud environments, and more. **Inter-Domain Communication:** It focuses on establishing communication and interaction between devices, services, or applications across different domains. This requires addressing issues related to differing protocols, addressing schemes, and administrative boundaries. **Policy Coordination:** Multi-domain networking often involves coordinating and enforcing policies across multiple domains. This includes security policies, Quality of Service (QoS) policies, and other rules that govern the behavior of the interconnected domains. **Resource Sharing and Optimization:** The goal is to optimize the use of resources across multiple domains, ensuring efficient utilization of bandwidth, computing resources, and other assets. Resource sharing can lead to improved scalability and cost-effectiveness. **Unified Management and Orchestration:** Multi-domain networking requires centralized management and orchestration to provide a unified view and control over the interconnected domains. This includes dynamic orchestration of services, policy enforcement, and configuration management. **Security and Trust:** Security is a critical consideration in multi-domain networking. Establishing trust relationships, secure communication, and ensuring compliance with security policies become complex when dealing with diverse domains. **Flexibility and Adaptability:** Multi-domain networking should be flexible and adaptable to changes in network conditions, business requirements, or technology upgrades. The architecture should support dynamic adjustments to accommodate evolving needs (Uniyal et al., 2021).

Significance of Multi-Domain Networking:

Improved Service Delivery: By connecting different network domains, multi-domain networking enables the delivery of end-to-end services that may span across organizational or geographical boundaries (Esmaeily et al., 2020). This is particularly relevant in the context of cloud services and distributed applications. **Enhanced Resource Utilization:** Multi-domain networking allows for better utilization of resources by enabling the sharing and allocation of assets across different domains. This is essential for optimizing infrastructure and improving overall network efficiency. **Interoperability and Integration:** It addresses the challenge of interoperability between disparate networks, ensuring that devices and services from different domains can seamlessly work together. This is crucial for creating integrated and cohesive network architectures. **Scalability and Flexibility:** Multi-domain networking provides scalability by allowing the network to grow across multiple domains. It also offers flexibility to adapt to changing business requirements, technology advancements, and the dynamic nature of modern applications. **Cross-Domain Collaboration:** Organizations often need to collaborate with external entities, partners, or service providers. Multi-domain networking facilitates secure collaboration by enabling controlled and coordinated communication between different organizational domains. **Agile Network Management:** With a centralized management and orchestration framework, multi-domain networking supports agile network management. Changes can be dynamically orchestrated, policies can be enforced consistently, and the network can adapt to evolving conditions. Multi-domain networking is significant in the context of modern, complex network architectures where integration, collaboration, and efficient resource utilization are essential. It addresses the challenges associated with the diversity of network domains, promoting a more connected, adaptable, and scalable networking environment. Optimizing a network in a multi-domain environment presents several challenges due to the heterogeneity, diversity, and potential lack of coordination between different domains (Ksentini et al., 2018). Here are key optimization challenges in a multi-domain networking environment:

Interoperability: Challenge: Ensuring seamless communication and interoperability between different domains with diverse technologies, protocols, and configurations. Solution: Standardizing interfaces and protocols, implementing translation gateways, and promoting open standards can facilitate interoperability. **Resource Allocation and Utilization:** Challenge: Optimizing the allocation and utilization of resources (bandwidth, computing, storage) across multiple domains with varying demands and priorities. Solution: Dynamic orchestration, resource-sharing agreements, and intelligent algorithms for resource allocation can enhance efficiency. **Policy Consistency:** Challenge: Coordinating and enforcing consistent policies across disparate domains, considering differences in security policies, Quality of Service (QoS), and other operational policies. Solution: Developing a unified policy framework, policy mapping, and using policy-based orchestration systems can help ensure consistency. **Cross-Domain Traffic Engineering:** Challenge: Optimizing traffic engineering and routing paths across multiple domains to enhance performance, minimize latency, and maximize available resources. Solution: Implementing advanced traffic engineering algorithms, considering domain-specific characteristics, and utilizing dynamic routing protocols can address this challenge (Zhang, 2019). **Security and Trust Management:** Challenge: Managing security across domains with different security postures, authentication mechanisms, and trust levels, while minimizing vulnerabilities and ensuring data integrity. Solution: Implementing secure communication protocols, establishing trust relationships, and enforcing consistent security policies are essential for managing security challenges. **Fault Tolerance and Resilience:** Challenge: Ensuring network resilience and fault tolerance in the face of failures or disruptions that may affect one or more domains. Solution: Implementing redundancy, failover mechanisms, and dynamic rerouting strategies can enhance network resilience. **Cross-Domain Monitoring and Visibility:** Challenge: Achieving comprehensive network visibility and monitoring in a multi-domain environment to detect and troubleshoot issues effectively. Solution: Implementing standardized monitoring interfaces, centralized monitoring solutions, and leveraging telemetry data can enhance visibility (Ponnekanti, 2019). **Service Level Agreements (SLA) Management:** Challenge: Managing SLAs across multiple domains to meet service requirements and ensuring that performance metrics are consistently met. Solution: Implementing SLA monitoring tools, negotiating well-defined SLAs, and establishing mechanisms for SLA enforcement and reporting are crucial. **Dynamic Orchestration Challenges:** Challenge: Coordinating and orchestrating dynamic changes and optimizations across multiple domains in real-time without causing disruptions or inconsistencies. Solution: Implementing advanced orchestration systems, ensuring real-time communication, and considering the impact of changes on the entire network can address dynamic orchestration challenges. Leveraging Software-Defined Networking (SDN) for service optimization across multiple domains involves using the principles of SDN to enhance the agility, efficiency, and performance of network services that span diverse administrative or technological boundaries. Here are key ways in which SDN can be employed for service optimization in a multi-domain environment: **Centralized Control and Orchestration:** SDN provides a centralized control plane that allows for unified management and orchestration across multiple domains. This centralized view enables efficient control over network resources, policies, and services. Service optimization is achieved through centralized decision-making, allowing for dynamic adjustments to meet changing service requirements. **Dynamic Orchestration of Services:** SDN facilitates the dynamic orchestration of services across different domains. This involves the automated instantiation, scaling, and termination of services based on real-time demand and network conditions. Optimized resource utilization, improved responsiveness to changing conditions, and efficient service delivery. **Unified Policy Framework:** SDN allows for the definition and enforcement of consistent policies across multiple domains. This includes security policies, Quality of Service (QoS) policies, and other rules that govern service behavior. Service optimization is achieved by ensuring uniform policy enforcement and adherence across all interconnected domains. **Cross-Domain Traffic Engineering:** SDN enables advanced traffic engineering and routing optimization across multiple domains. Traffic flows can be dynamically adjusted to optimize performance, minimize latency, and maximize resource utilization. This will lead to improved service quality, reduced congestion, and efficient use of network resources. **End-to-End Visibility and Monitoring:** SDN provides enhanced visibility and monitoring capabilities across the entire network, spanning multiple domains. Centralized monitoring facilitates real-time insights into the performance and health of services. Timely detection of issues, proactive troubleshooting, and overall improved service reliability. **Service Chaining and Function Virtualization:** SDN supports service chaining, allowing the creation of end-to-end service paths that traverse multiple domains. Network Functions Virtualization (NFV) further enhances optimization by virtualizing network functions. Efficient service delivery, flexibility in service composition, and the ability to dynamically adjust service chains based on demand. By leveraging SDN for service optimization across multiple domains, organizations can achieve a more responsive, efficient, and adaptable network infrastructure. This approach is particularly beneficial in scenarios where services traverse diverse administrative, geographic, or technological boundaries, demanding a unified and dynamic approach to service delivery and optimization (Samdanis et al., 2019).

Dynamic orchestration is a key concept in network management that involves the automated coordination and provisioning of network resources and services in real-time, adapting to changing conditions and demands. It plays a crucial role in adaptive network management, enabling networks to be more responsive, flexible, and efficient. Here's an exploration of the concept of dynamic orchestration and its role in adaptive network management: **Dynamic Orchestration:** refers to the automated and on-the-fly coordination of various network elements, including devices, services, and resources, to meet specific objectives or service requirements. It involves the dynamic arrangement and configuration of these elements based on policies, service requests, and real-time conditions. **Automation and Programmability:** Dynamic orchestration relies heavily on automation and programmability. Automation involves the use of scripts, policies, or algorithms to perform tasks without manual intervention. Programmability allows for the flexible and dynamic configuration of network elements. **Real-Time Adaptability:** The term "dynamic" in orchestration emphasizes the real-time adaptability of the network. Dynamic orchestration systems continuously monitor network conditions and respond to changes by making adjustments in configurations, resource allocations, and service deployments (Mostaco et al., 2021). **Service Lifecycle Management:** Dynamic orchestration is concerned with managing the entire lifecycle of network services, from their instantiation and deployment to scaling, updating, and termination. This end-to-end management ensures that services are dynamically adapted to changing requirements. Role in Adaptive Network Management:

Agility and Responsiveness: Dynamic orchestration enhances network agility by allowing rapid adaptation to changing conditions. It enables the network to respond promptly to new service requests, traffic fluctuations, or emerging issues without manual intervention. **Optimizing Resource Utilization**: Adaptive network management requires efficient resource utilization. Dynamic orchestration optimizes the allocation of resources such as bandwidth, computing power, and storage based on real-time demand, ensuring that resources are used effectively. **Scalability:** In an adaptive network, the ability to scale resources up or down based on demand is crucial. Dynamic orchestration enables the automatic scaling of services and resources, ensuring scalability without the need for manual intervention. **Service Assurance:** Dynamic orchestration contributes to service assurance by continuously monitoring service performance and making adjustments to meet service level agreements (SLAs). It helps maintain the desired quality of service and ensures a positive user experience. **Policy-Driven Adaptation:** Policies play a central role in adaptive network management, defining how the network should behave under different conditions. Dynamic orchestration enforces policies in real-time, ensuring that network behavior aligns with predefined rules and objectives. **Service Optimization:** Dynamic orchestration contributes to service optimization by dynamically adjusting service configurations, paths, and resources based on real-time analytics and performance metrics. This optimization aims to enhance overall service efficiency and user satisfaction. **Inter-Domain Coordination:** In multi-domain environments, dynamic orchestration facilitates coordination between different domains by automating the setup and management of cross-domain services. It ensures seamless communication and collaboration across diverse network domains (Samdanis et al., 2019). **Enabling New Service Deployment Models:** Adaptive network management often involves the introduction of new services or applications. Dynamic orchestration supports the rapid deployment of new services, enabling organizations to stay competitive and meet evolving user demands. **Fault Detection and Remediation:** Dynamic orchestration contributes to adaptive network management by detecting faults or issues in real-time and automatically implementing remediation actions. This helps ensure network reliability and minimizes downtime. **Future-Proofing:** As network requirements evolve, dynamic orchestration helps future-proof the network by providing a flexible and programmable framework. This adaptability allows the network to accommodate emerging technologies, services, and business needs. Dynamic Orchestration is a foundational element of adaptive network management, enabling networks to be responsive, efficient, and capable of meeting changing demands. It automates processes, optimizes resource usage, and facilitates the dynamic adjustment of services, contributing to the overall agility and resilience of modern networks.

Dynamic orchestration plays a crucial role in enhancing scalability and optimizing resource utilization in network management (Mukherjee et al., 2018). Here are the key benefits of dynamic orchestration in these two critical aspects:

Automated Scaling: Dynamic orchestration automates the process of scaling resources based on real-time demand. It allows the network to scale up or down dynamically to handle fluctuations in traffic, ensuring optimal performance without manual intervention. **Efficient Resource Allocation:** By dynamically allocating resources based on current demand, dynamic orchestration ensures that resources are used efficiently. This efficiency contributes to improved scalability as the network can adapt to varying workloads. **Rapid Service Deployment:** Dynamic orchestration facilitates the rapid deployment of new services or applications. This agility in service provisioning supports scalability by allowing the network to quickly accommodate additional services or changes in service requirements. **Adaptation to Network Growth:** As the network grows, dynamic orchestration enables seamless adaptation. New devices, services, or domains can be integrated into the network, and orchestration systems can dynamically adjust configurations to accommodate the increased scale. **Multi-Domain Scaling:** In multi-domain environments, dynamic orchestration ensures that scaling processes can be coordinated across different domains. This is essential for maintaining scalability in large, complex networks with diverse technologies and administrative boundaries. **Improved Elasticity:** Dynamic orchestration enhances network elasticity, allowing it to expand or contract in response to changing demands. This elasticity ensures that the network can efficiently handle varying workloads without compromising performance (Iordache et al., 2019). Benefits of Dynamic Orchestration for Resource Utilization: **Optimized Bandwidth Allocation:** Dynamic orchestration optimizes the allocation of bandwidth based on current traffic patterns. It ensures that resources are allocated where they are most needed, minimizing congestion and improving overall bandwidth utilization. **Dynamic Load Balancing:** Through dynamic orchestration, load balancing algorithms can be dynamically adjusted to distribute traffic efficiently across available resources. This ensures that no single resource is overburdened while others remain underutilized. **Resource Reservation and Release:** Dynamic orchestration enables the reservation and release of resources on-demand. This means that resources are only allocated when needed, preventing unnecessary resource consumption and promoting efficient utilization. **Automated Resource Scaling:** Resources, such as virtual machines or containers, can be automatically scaled up or down based on demand. Dynamic orchestration systems monitor resource usage and make adjustments in real-time to ensure optimal resource utilization. **Granular Resource Control:** Dynamic orchestration provides granular control over resource allocation. Administrators can define policies that dictate how resources should be allocated and released, allowing for fine-tuned control over resource utilization. **Adaptation to Dynamic Workloads:** Dynamic orchestration systems continuously monitor the workload and adjust resource allocations to match changing demands. This adaptability ensures that resources are dynamically aligned with the current needs of the network and services. **Efficient Use of Virtualization**: In virtualized environments, dynamic orchestration optimizes the use of virtual resources. It ensures that virtual machines or containers are instantiated and terminated as needed, preventing resource wastage and promoting efficient utilization. Dynamic orchestration provides the automation and intelligence needed to enhance both scalability and resource utilization in network management. By dynamically adjusting configurations, scaling resources, and optimizing resource allocation based on real-time conditions, dynamic orchestration contributes to a more responsive, adaptable, and efficient network infrastructure.

Dynamic orchestration, while offering numerous benefits for adaptive network management and service optimization, introduces security and privacy concerns that organizations need to carefully address (Bonati et al., 2020). Here are some key considerations related to security and privacy in the context of dynamic orchestration: Security Concerns:

Unauthorized Access: Issue: Dynamic orchestration involves centralized controllers making decisions and changes in real-time. Unauthorized access to the orchestration system can lead to malicious configuration changes, service disruptions, or unauthorized access to sensitive data. Mitigation: Implement robust access controls, authentication mechanisms, and encryption to secure the orchestration system. Regularly audit and monitor access logs for any suspicious activities. **Denial of Service (DoS) Attacks:** Issue: Attackers may attempt to overwhelm the dynamic orchestration system with a flood of requests, leading to service degradation or unavailability. Mitigation: Implement traffic filtering, rate limiting, and load balancing mechanisms to mitigate the impact of DoS attacks. Ensure that the orchestration system is designed to handle high loads efficiently. **Man-in-the-Middle (MitM) Attacks:** Issue: Communication between orchestration components and network devices may be susceptible to interception by attackers, allowing them to manipulate or eavesdrop on communication. Mitigation: Encrypt communication channels using secure protocols (e.g., TLS) to prevent eavesdropping. Implement certificate-based authentication to ensure the integrity of communication. **Compromised Components:** Issue: If any component within the dynamic orchestration system is compromised, it can lead to unauthorized control over network devices or services (Marinova et al., 2020). Mitigation: Regularly update and patch all components of the orchestration system. Implement intrusion detection systems to detect anomalies and potential compromises. **Policy Violations:** Issue: Dynamic orchestration relies on policies to govern network behavior. Violations of these policies can lead to misconfigurations, data breaches, or service disruptions. Mitigation: Regularly audit and validate policies. Implement mechanisms for real-time policy enforcement and monitoring. Integrate policy violation alerts into the orchestration system. Privacy Concerns: **Data Leakage:** Issue: Dynamic orchestration involves the exchange of sensitive information about network configurations, policies, and performance. Unauthorized access or disclosure of this information can lead to privacy breaches. Mitigation: Encrypt data in transit and at rest. Implement strong access controls and authentication mechanisms to restrict access to sensitive information. **User Activity Tracking:** Issue: Continuous monitoring of user activities in dynamic orchestration systems may raise concerns about user privacy, especially if excessive data is collected without proper consent. Mitigation: Clearly communicate the extent of user activity tracking. Implement anonymization techniques where possible. Obtain informed consent from users regarding the collection and use of monitoring data. **Data Residency and Jurisdiction:** Issue: Dynamic orchestration may involve the processing of data across different geographic locations. This raises concerns about data residency and compliance with privacy regulations in different jurisdictions. Mitigation: Clearly define data residency policies. Ensure compliance with applicable data protection regulations, such as GDPR or HIPAA, and consider the legal implications of data processing across borders. **Logging and Auditing:** Issue: Extensive logging and auditing practices in dynamic orchestration may capture sensitive information, potentially impacting user privacy. Mitigation: Implement logging and auditing with privacy in mind. Minimize the collection of personally identifiable information. Store logs securely and establish retention policies (Rodriguez et al., 2020). **Data Retention:** Issue: Retaining data for extended periods may pose privacy risks, especially if the data contains sensitive information. Mitigation: Establish clear data retention policies. Regularly purge unnecessary or outdated data. Ensure compliance with privacy regulations regarding data retention. **Third-Party Integration:** Issue: Integrating third-party components or services into the dynamic orchestration system may introduce additional privacy considerations, especially if these components process sensitive data. Mitigation: Assess the privacy practices of third-party components. Implement data protection impact assessments to evaluate the privacy implications of integrations. Addressing security and privacy concerns associated with dynamic orchestration requires a comprehensive approach, including robust access controls, encryption, regular auditing, and compliance with privacy regulations. Organizations should prioritize security measures to protect against potential threats and ensure the responsible handling of sensitive information. Regular security audits, threat modeling, and adherence to best practices are essential for maintaining a secure and privacy-aware dynamic orchestration environment. Latest advancements in dynamic orchestration technologies can be attributed to some general trends and advancements that were relevant up to this point. Also it is important to note that the field of dynamic orchestration is rapidly evolving, and new advancements may be occurring every now and then. Here are some trends and areas of innovation:

Intent-Based Networking (IBN): IBN has gained traction as a paradigm for dynamic orchestration. It focuses on translating high-level business intents into network configurations automatically (Jain et al., 2020). The goal is to make network management more intent-driven, simplifying the translation from business requirements to network behavior. **AI and Machine Learning Integration:** The integration of artificial intelligence (AI) and machine learning (ML) into dynamic orchestration systems has advanced. These technologies help in predicting network behavior, optimizing resource allocation, and automating decision-making processes based on historical and real-time data. **Multi-Cloud Orchestration:** With the increasing adoption of multi-cloud environments, dynamic orchestration solutions are evolving to support seamless orchestration and management across multiple cloud providers. This includes the ability to move workloads, manage resources, and optimize performance across different cloud platforms. **5G and Edge Orchestration:** The rollout of 5G networks and the growth of edge computing have influenced dynamic orchestration technologies. Orchestration systems are being enhanced to efficiently manage resources, services, and connectivity in distributed and edge environments, enabling low-latency and high-throughput applications. **Kubernetes Orchestration:** Kubernetes has become a de facto standard for container orchestration. Dynamic orchestration technologies are increasingly integrating with Kubernetes to manage containerized applications, automating deployment, scaling, and management of containerized workloads (Bojkovic et al., 2019). **Policy-Driven Orchestration:** Advancements in policy-driven orchestration allow organizations to define intent-based policies that guide the behavior of the network dynamically. This enables consistent enforcement of policies across heterogeneous environments. **Zero-Touch Provisioning:** Zero-touch provisioning (ZTP) has gained importance, particularly in large-scale networks. It allows devices to be automatically configured and provisioned without manual intervention, streamlining the deployment and management of network infrastructure. **DevOps Integration:** Dynamic orchestration is increasingly integrating with DevOps practices. This integration aims to align network changes with application development and deployment processes, fostering collaboration between network and development teams. **Cross-Domain Orchestration:** Solutions for cross-domain orchestration have advanced to facilitate the management of services and resources that span multiple administrative domains, cloud providers, and network segments. This is crucial for ensuring end-to-end service delivery. **Service Mesh Integration:** Service mesh technologies, such as Istio and Linkerd, are being integrated into dynamic orchestration frameworks. This integration enhances the management of microservices-based applications, providing visibility, security, and control over service-to-service communication. **Blockchain for Orchestration Security:** Some advancements explore the use of blockchain for enhancing the security aspects of dynamic orchestration. Blockchain can be leveraged to ensure the integrity and transparency of orchestration processes and configurations. Several novel approaches and frameworks have been proposed to address the challenges faced in dynamic orchestration. These approaches aim to enhance the efficiency, security, and flexibility of dynamic orchestration systems in heterogeneous and evolving environments. Here are some notable frameworks and approaches:

Intent-Based Networking (IBN): Intent-Based Networking is an approach that focuses on translating high-level business intents into network configurations automatically (Esmaeily et al., 2021). It aims to simplify the orchestration process by allowing operators to define what they want to achieve, and the network autonomously adapts to fulfill those intentions. This will Streamline network management, reduce manual configuration errors, and aligns network behavior with business objectives. **Kubernetes and Service Mesh Integration:** Integrating dynamic orchestration systems with Kubernetes for container orchestration and service mesh technologies (e.g Istio) for microservices communication management. This Enhances the management of containerized workloads, improves service-to-service communication, and provides features such as traffic management, security, and observability. **Policy-Driven Orchestration:** A framework where orchestration decisions are guided by predefined policies. Policies define the desired behavior of the network and services, and the orchestration system dynamically enforces these policies. Ensures consistency, compliance, and efficient decision-making based on predefined rules and objectives. **AI-Driven Orchestration:** Leveraging artificial intelligence (AI) and machine learning (ML) algorithms to analyze network data, predict future trends, and automate decision-making in the orchestration process. This improves the accuracy of resource allocation, optimizes network performance, and enables proactive responses to dynamic changes based on learned patterns (Serra, 2017). **Blockchain for Orchestration Security:** Integrating blockchain technology to enhance the security aspects of orchestration processes. Blockchain can be used to secure and authenticate configuration changes, ensuring the integrity of orchestration data. It provides a tamper-resistant and transparent ledger for orchestration activities, reducing the risk of unauthorized changes. **Cross-Domain Orchestration Frameworks:** Frameworks designed to manage and coordinate services and resources across multiple administrative domains, cloud providers, and network segments. Enables end-to-end service delivery in complex, multi-domain environments, addressing challenges related to interoperability and coordination. **Zero-Touch Provisioning (ZTP):** An automated provisioning approach that allows devices to be configured and provisioned without manual intervention. ZTP streamlines the deployment and initialization of network infrastructure. Reduces human error, accelerates deployment times, and facilitates the automation of initial configurations. **Model-Driven Orchestration**: Utilizing standardized data models (e.g., YANG) to represent network configurations and states. Model-driven approaches provide a consistent and structured way to express the desired state of the network. Improves clarity, consistency, and automation in the orchestration process, facilitating communication between different components. **Dynamic Feedback Loop Systems:** Implementing dynamic feedback loops that continuously monitor the network, collect data, analyze performance, and feed insights back into the orchestration system to adapt to changing conditions. Enhances adaptability, responsiveness, and the ability to make informed decisions based on real-time data. **Edge Orchestration Frameworks**: Frameworks specifically designed for orchestrating resources and services in edge computing environments. These frameworks consider the unique challenges of managing distributed resources at the network edge. This approach supports low-latency applications, optimizes resource utilization, and ensures efficient management of edge computing environments. These novel approaches and frameworks showcase the ongoing evolution of dynamic orchestration solutions, addressing challenges and leveraging emerging technologies to create more efficient, secure, and adaptable network management systems. Organizations may choose or adapt these frameworks based on their specific requirements and the nature of their network environments (Bernini et al., 2020).

Below are examples of organizations that have implemented successful dynamic orchestration solutions. Keeping in mind that the field is dynamic, and new case studies may have emerged since then. Here are a few examples:

AT&T: AT&T has been a pioneer in implementing Software-Defined Networking (SDN) and dynamic orchestration. Their AT&T Network Cloud initiative utilizes an orchestrated infrastructure to manage and automate the delivery of network services. This orchestration enables AT&T to quickly deploy and adjust network functions and services based on demand. **Verizon:** Verizon has implemented dynamic orchestration as part of its network virtualization strategy. The company focuses on Software-Defined Wide Area Networking (SD-WAN) and uses orchestration to automate the provisioning and management of services across a distributed network. **NTT Communications:** NTT Communications, a global telecommunications company, has implemented dynamic orchestration to optimize its network infrastructure and services. Their approach includes the use of SDN and NFV technologies, allowing for the dynamic allocation of resources and efficient service delivery. **Telefónica:** Telefónica has embraced dynamic orchestration to enhance its network capabilities. The company's UNICA platform leverages orchestration to automate network service delivery, allowing for greater flexibility and responsiveness to changing demands. **China Mobile:** China Mobile has implemented dynamic orchestration in its network to support the deployment and management of services in a 5G environment. The orchestration framework enables the efficient allocation of resources, ensuring optimal performance for various applications and services. **Deutsche Telekom:** Deutsche Telekom has adopted dynamic orchestration to enable the deployment and management of network services in a more agile and automated manner. The orchestration system allows for the optimization of resources and the rapid introduction of new services. **Colt Technology Services:** Colt, a global network service provider, has implemented dynamic orchestration to enhance its Colt IQ Network. The orchestration platform enables the on-demand delivery of high-bandwidth services, allowing customers to scale their network connectivity dynamically. **Vodafone:** Vodafone has integrated dynamic orchestration into its network infrastructure to support the delivery of services across a global footprint. The orchestration system facilitates the automated deployment and management of network functions to meet evolving customer needs. **SK Telecom:** SK Telecom has employed dynamic orchestration in its 5G network to automate and optimize network functions. The orchestration platform enables the efficient allocation of resources and the delivery of diverse services with low-latency requirements. **CableLabs (Kyrio):** CableLabs, through its Kyrio subsidiary, has explored dynamic orchestration for cable networks. The initiative focuses on the development of orchestration solutions that can support cable operators in automating the provisioning and management of network services. These case studies highlight how telecommunications and network service providers are leveraging dynamic orchestration to enhance their infrastructure, improve service delivery, and adapt to the evolving demands of the digital landscape. Keep in mind that the implementation details and success factors may vary based on the specific goals and contexts of each organization (Mena et al., 2020). Several standardization efforts in the field of dynamic orchestration and Software-Defined Networking (SDN) continue to shape the industry. These efforts are crucial for ensuring interoperability, promoting best practices, and fostering a common framework for dynamic orchestration solutions. Here are some ongoing standardization efforts: **Open Networking Foundation (ONF):** ONF is actively involved in several projects related to SDN and orchestration. Notable initiatives include the OpenFlow standard, which facilitates communication between the SDN controller and network devices, and the ONOS (Open Network Operating System) project, which focuses on open-source SDN control. **Open Networking Automation Platform (ONAP):** ONAP is an open-source platform that aims to automate the design, orchestration, and lifecycle management of network services. It is a collaborative project hosted by the Linux Foundation and supported by major telecommunications operators. **IETF (Internet Engineering Task Force):** Within IETF, various working groups contribute to standardization efforts related to dynamic orchestration and SDN. Notable groups include the Network Management Research Group (NMRG) and the Software-Driven Networks (SDN) Research Group. **ETSI (European**

Telecommunications Standards Institute): ETSI has been active in defining standards for NFV (Network Functions Virtualization) and orchestration. The ETSI NFV ISG (Industry Specification Group) works on specifications that enable the implementation of virtualized network functions and dynamic orchestration. **TM Forum:** TM Forum provides a platform for collaboration among service providers, vendors, and other stakeholders. Their work includes the development of standardized frameworks and best practices, such as the Open Digital Architecture (ODA), which addresses aspects of dynamic orchestration in digital services. **ITU-T (International Telecommunication Union - Telecommunication Standardization Sector):** ITU-T is involved in standardization efforts related to the management and orchestration of network functions in cloud-based environments. Key focus areas include cloud computing, network virtualization, and service management. **IEEE (Institute of Electrical and Electronics Engineers):** IEEE has various working groups that contribute to standards development in the areas of SDN and network function virtualization. For example, the IEEE SDN Standards Committee focuses on defining standards for SDN architectures, interfaces, and protocols. **OASIS (Organization for the Advancement of Structured Information Standards):** OASIS hosts various technical committees that work on standardizing specifications related to dynamic orchestration and service-oriented architectures. For instance, the TOSCA (Topology and Orchestration Specification for Cloud Applications) Technical Committee defines a language for describing cloud applications and services. **ISO (International Organization for Standardization):** ISO has working groups that contribute to standardization efforts in the broader field of information technology. These groups may address aspects of network management, interoperability, and orchestration. **NIST (National Institute of Standards and Technology):** NIST provides frameworks and guidelines that influence standardization efforts. For example, the NIST Cloud Computing Reference Architecture and the NIST Cybersecurity Framework contribute to shaping best practices in cloud-based environments (Sonkoly et at., 2020). It's essential to note that standardization efforts are ongoing, and new initiatives may emerge. Organizations and consortia also collaborate on industry-specific standards and guidelines. Keeping abreast of developments from these standardization bodies helps ensure that dynamic orchestration solutions align with established best practices and interoperability standards. Several existing frameworks and models for dynamic orchestration have been developed to guide the implementation of flexible, automated, and adaptive network management. These frameworks provide a structured approach to orchestrating resources, services, and network functions dynamically. Here are some notable frameworks and models: **Etsi NFV (Network Functions**

Virtualization) Management and Orchestration (MANO): ETSI NFV MANO is a comprehensive framework that defines the architecture and interfaces for the management and orchestration of network functions in a virtualized environment. Components: NFV Orchestrator (NFVO): Manages the lifecycle of virtualized network functions (VNFs). VNF Manager (VNFM): Manages the lifecycle of individual VNF instances. Virtualized Infrastructure Manager (VIM): Manages the compute, storage, and network resources (-Ericsson-Orchestrator.Availableonline:https://www.ericsson.com/en/portfolio/digital-services/automatednetwork-operations/orchestration/ericsson-orchestrator (accessed on 8 October 2023)). **TOSCA (Topology and Orchestration Specification for Cloud Applications):** TOSCA is an OASIS standard that defines a language for describing the topology of cloud-based applications and orchestrating their deployment and management. Service Templates: Define the structure and behavior of services. Node Types: Represent components of the application. Relationship Types: Describe interactions between nodes. **ONAP (Open Network Automation Platform):** ONAP is an open-source platform hosted by the Linux Foundation, aiming to automate the design, orchestration, and lifecycle management of network services. Design Time: Focuses on designing and modeling services. Run Time: Orchestrates and manages the lifecycle of services. Policy: Enforces policies to guide orchestration decisions. **CNCF (Cloud Native Computing Foundation)** Projects: Various CNCF projects contribute to the orchestration of cloud-native applications. Notable projects include Kubernetes (container orchestration), Helm (package manager for Kubernetes), and Flux (continuous delivery tool) (Barakabitze et at., 2020). Support for containerized applications, automated scaling, and efficient resource management. **OpenStack Heat:** OpenStack Heat is a template-based orchestration project that allows the automated deployment and management of infrastructure resources in an OpenStack environment. Templates: Written in YAML, templates describe the desired state of resources. Heat Orchestration Engine: Processes templates and manages the creation, updating, and deletion of resources. **Cisco NSO (Network Services Orchestrator):** Cisco NSO is a model-driven orchestration platform that enables the automation of network services across multi-vendor and multi-domain environments. YANG Modeling Language: Represents data models for network services. Transaction-Based Operations: Supports atomic transactions for configuration changes. Multi-Vendor Support: Enables orchestration across heterogeneous network devices. **IBM Cloud Orchestrator:** IBM Cloud Orchestrator provides a platform for automating the deployment and management of cloud services, including virtual machines, middleware, and network services. Service Catalog: Defines and catalogs services.

Policy-Based Automation: Enforces policies for resource provisioning. Integration with Cloud Providers: Supports multi-cloud orchestration. **Ansible Automation Platform:** Ansible is an open-source automation tool that includes a framework for orchestrating infrastructure and applications. Playbooks: Written in YAML, playbooks describe tasks and automation steps. Agentless Architecture: Communicates with remote systems over SSH or API, requiring no agent installation. These frameworks and models offer diverse approaches to dynamic orchestration, catering to different use cases, environments, and architectural preferences. The choice of a specific framework depends on factors such as organizational requirements, existing infrastructure, and the nature of the services being orchestrated.

Dynamic orchestration finds practical applications across various industries, enabling organizations to optimize resource utilization, enhance operational efficiency, and respond rapidly to changing demands (Martinez-julia et al., 2018). Here are some real-world scenarios where dynamic orchestration is applied: **Telecommunications and Network Services:** Telecommunications operators leverage dynamic orchestration to manage the provisioning, scaling, and optimization of network services. This includes the automated deployment of virtualized network functions (VNFs), on-demand bandwidth allocation, and the orchestration of services such as SD-WAN and 5G connectivity. **Cloud Service Providers:** Cloud providers use dynamic orchestration to automate the deployment and management of virtualized resources. This includes the automatic scaling of compute instances, storage allocation, and the orchestration of complex, multi-tiered applications. Orchestration frameworks like Kubernetes are widely employed in this context. **Data Centers and Infrastructure Management:** Dynamic orchestration is applied in data centers to optimize resource utilization and automate the allocation of compute, storage, and network resources. Orchestration frameworks ensure efficient workload distribution, scaling, and the rapid deployment of virtual machines. **Edge Computing:** In edge computing scenarios, dynamic orchestration is used to manage resources and services at the network edge. This involves orchestrating computing tasks closer to the end-user or device, reducing latency and improving the performance of edge applications (Boutaba et al., 2018). **Internet of Things (IoT):** Dynamic orchestration is applied in IoT environments to manage and scale IoT devices, process data at the edge, and orchestrate communication between devices and backend systems. This is particularly relevant in large-scale IoT deployments where resource allocation needs to be dynamic. **Financial Services:** Financial institutions use dynamic orchestration to automate the deployment and scaling of applications, especially in scenarios where there are fluctuations in demand for computational resources. This ensures that financial services applications can scale elastically based on market demands. **Healthcare IT:** Healthcare organizations employ dynamic orchestration to manage healthcare applications, patient records, and data processing tasks. Orchestration helps optimize the allocation of resources for medical imaging, patient monitoring, and data analytics applications. **DevOps and Continuous Integration/Continuous Deployment (CI/CD):** Dynamic orchestration is fundamental in DevOps practices to automate the deployment, testing, and scaling of applications. CI/CD pipelines use orchestration tools to streamline the development and release of software, ensuring rapid and reliable software delivery. These practical applications demonstrate the versatility and impact of dynamic orchestration across different industries, driving automation, scalability, and agility in response to dynamic and evolving demands. As technology continues to advance, dynamic orchestration will likely play an increasingly vital role in optimizing and streamlining diverse operational processes. As dynamic orchestration continues to evolve, there are several research directions and areas for improvement that researchers and industry professionals may explore to address current challenges and unlock new capabilities (Rodriguez et al., 2013). Here are some potential research directions:

Intent-Based Networking (IBN) Refinement: Research Focus: Further refinement and standardization of Intent-Based Networking (IBN) to enhance its adoption and effectiveness in translating high-level business objectives into automated network configurations. **AI-Driven Orchestration Optimization:** Research Focus: Advancing research on integrating artificial intelligence (AI) and machine learning (ML) techniques into orchestration systems to optimize resource allocation, improve predictive analytics, and automate decision-making processes. **Cross-Domain Orchestration Challenges:** Research Focus: Investigating challenges and developing solutions for seamless cross-domain orchestration, ensuring interoperability, security, and efficient communication across diverse administrative domains, cloud providers, and network segments (Bega et al., 2020). **Hybrid Multi Cloud Orchestration Strategies:** Research Focus: Developing innovative strategies and frameworks for orchestrating workloads and services seamlessly across hybrid and multicloud environments, addressing challenges related to data mobility, security, and workload management. **Dynamic Orchestration for Edge Computing:** Research Focus: Exploring novel approaches for orchestrating resources and services in edge computing environments, optimizing resource utilization, reducing latency, and ensuring efficient management of distributed edge infrastructure. **Security-Driven Orchestration Enhancements:** Research Focus: Enhancing security-driven orchestration by researching advanced threat detection techniques, automated response mechanisms, and the integration of security policies into orchestration processes to mitigate cybersecurity risks effectively. Researchers and practitioners can contribute to the advancement of dynamic orchestration by exploring these research directions, experimenting with innovative solutions, and collaborating to address the evolving needs of dynamic and complex network environments. Dynamic orchestration is a linchpin in the effective management and optimization of heterogeneous SDNs. It addresses integration challenges, promotes interoperability, enhances agility, and enables adaptive network management, all of which are crucial for realizing the benefits of software-defined, multi-domain environments. As networks continue to evolve and diversify, the role of dynamic orchestration becomes increasingly vital in ensuring efficient, secure, and optimized operation across heterogeneous SDN landscapes (Santos et al., 2020).

2.3 Critical review of related works

According to (Panagiotis et al., 2020) in their paper titled "Comparison of Management and Orchestration Solutions for the 5G Era" they prove that OSM is mature and robust and Cloudify proved appropriate for deployments that have no strict requirements like run-time SLA contracts and network slicing, while SONATA which is their framework provides a complete tool chain for automated NS management in the dynamic 5G context era including innovative features and tools like SDK, monitoring, policies, SLA and networks slicing managers. The SONATA framework uses a unique modular architecture, implemented through a service bus, enabling management and orchestration mechanisms to be "plugged" and triggered as services, including all current and future components, active and passive monitoring, as well as dynamic policy rules based on the obtained data to trigger adaptations not-known in advance. Our future plans include further investigation based on real applications deployed in production environments using more powerful NFVIs that support different virtualization technologies (e.g., Kubernetes) and comparing SONATA MANO with other open-source and commercial MANO implementations and it's clear that SONATA is a very good highlight of what dynamic orchestration is. Furthermore, (Balázs Sonkoly, et al., 2015) it is noted that On top of cloud platforms, services can be created, managed and scaled on-demand. Efficient virtualization techniques and novel orchestration algorithms enable flexible operation and optimal usage of underlying resources. Besides virtual compute and storage resources, basic networking is also provided in order to connect the virtual machines. In contrast, traditional telecommunication services and carrier networks have a lot of limitations concerning service creation, service deployment or service provisioning due to built-in mechanisms strongly coupled to physical topologies and special purpose hardware appliances. Network Function Virtualization (NFV) opens the door between cloud technologies and carrier networks by providing software-based telecommunication services, which can run in virtualized environments over a wide range of general purpose servers. By these means, recent achievements from cloud research can be leveraged and adopted in carrier environments. Flexible service definition and creation may start by abstracting and formalizing the service into the concept of service chain or service graph. It is a generic way to describe high level services and to assemble processing flows for given traffic. It's very important to note that companies like Ericsson also have Dynamic Orchestration concepts that stand out as a versatile solution, embracing multiple vendors and domains. It follows a model-driven and open approach, complying with ETSI standards and aligning with ONAP. This modular solution revolves around the central Ericsson Orchestrator, which facilitates seamless integration with additional modules like inventory, testing engine, domain manager, assurance, and analytics. The accompanying video succinctly encapsulates the challenges, advantages, and essential components, presenting a 90-second overview. It outlines how these components collectively propel service providers towards agile, scalable, and efficient networks and operations, driven by automation and AI, the figure below shows how the Ericsson orchestrator does it job efficiently;

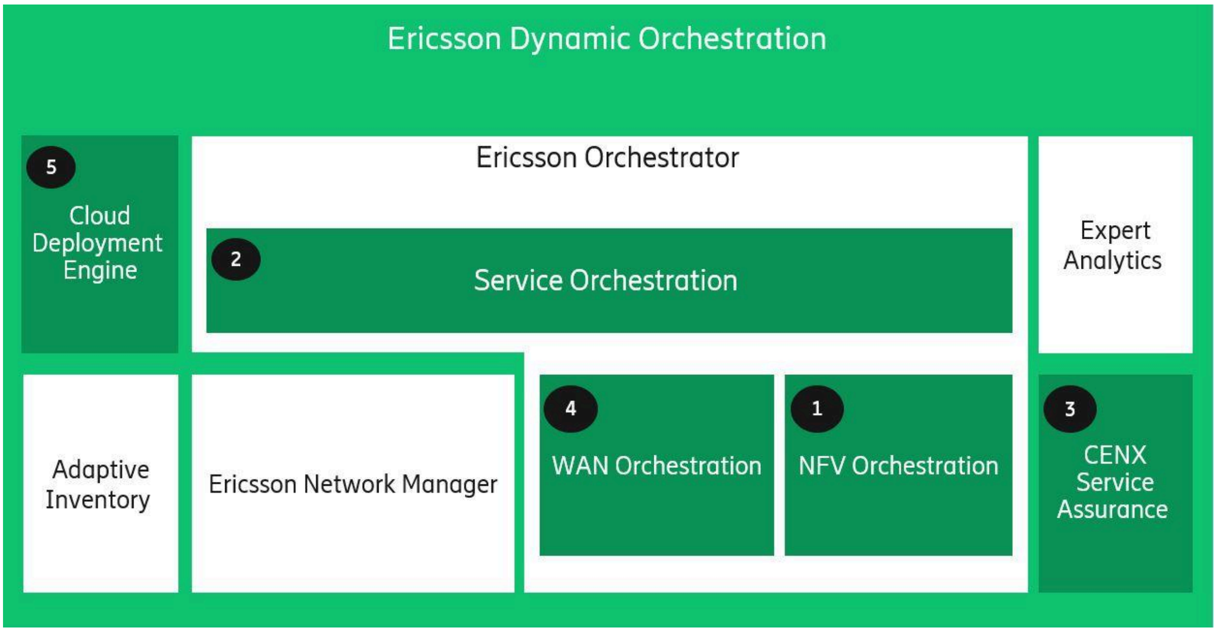


Figure 2- Ericsson Dynamic Orchestration

2.4 Comparison with related works

This section presents an overview of the development of dynamic orchestration in 5G network services. Currently, various entities, including the International Telecommunications Union (ITU), 5G-PPP, 3rd Generation Partnership Project (3GPP), European

Telecommunications Standards Institute (ETSI), and 5G Brasil, are contributing to the standardization of 5G, collaborating with international research projects (5GinFire. Deliverables—5GinFIRE. Available online: https://5ginfire.eu/deliverables/ (accessed on 7 October 2023). Several companies and entities are engaged in testing projects to address challenges in mobile communications coverage. However, conclusive studies on 5G technology are still underway, and researchers, particularly in Asia, Europe, and the USA, are exploring aspects beyond the network layer of the 5G architecture (5G-PPP. View on 5G Architecture (Version 1.0) (Jul.) (2016); 2016. Avaliable online: https://www.trust-itservices.com/resources/white-papers/view-5g-architecture-5g-ppp-architecture-working-group (accessed on 7 December 2023). Considering the presented elements, a 5G network's performance evaluation model and Orchestrator, responsible for implementing Network Slices (NSs) and ensuring end-to-end Quality of Service (QoS), must simultaneously address and fulfill all frequency bands, including those below 1 GHz, between 1 GHz and 6 GHz, and above 6 GHz. An emerging issue in some countries pertains to whether slicing the 5G network aligns with network neutrality regulations. The practical implications for existing open Internet rules regarding 5G are considered speculative at this stage. This uncertainty arises from the evolving nature of 5G elements like network slicing, which depends on technological capabilities, market demand, competition levels, and commercial strategies (Mukherjee et al., 2018). The design of a 5G Orchestrator needs to account for vertical applications with service requirements tailored to 5G use cases and indicators defined by regulators. The International Telecommunication Union (ITU) has outlined various challenges for IMT-2020, specifying that performance indicators must be obtained for each 5G use case. Globally, studies and developments are underway for vertical (single-domain) Orchestrators catering to specific Telecommunications Infrastructure Providers (TIPs) or Mobile Network Operators (MNOs). Companies and entities like Ericsson, Nokia, ETSI, and others are actively involved in this domain. TIPs and MNOs are providers of wireless communications infrastructures and services, respectively. The 3rd Generation Partnership Project (3GPP) has introduced an orchestration and management architecture that focuses on analyzing incoming slice requests, converting service requirements into networking ones, and managing the Life-Cycle Management (LCM) of Network Slices (NSIs) deployed and managed by a single administrative entity. While several promising proposals exist, aggregating diverse features into a unified and fully functional approach for managing and operating each slice, supporting scalability, orchestration, and decision-making across domains with heterogeneous technologies and access methods (e.g., 5G, LTE, Wi-Fi, Wireline) remains a challenge. A

preliminary framework for virtualization in a multi-domain environment has been proposed, emphasizing concepts like isolation, programmability, and performance maintenance. Additionally, a multi-domain orchestration and management framework has been explored to address NS service challenges when utilizing federated resources (NGMN Alliance, 2019).
Other federated slicing solutions have been introduced, such as a multi-domain Orchestrator that handles slice requests for resources beyond its domain and coordinates with neighboring domains. Hierarchical multi-domain orchestration architectures have been proposed based on recursive abstraction and resource aggregation, stitching NSI heterogeneous resources across federated domains (Ksentini et al., 2017). Another concept involves an Inter-slice Resource Broker to manage and orchestrate resources for end-to-end slices across multiple technology domains. Several research projects worldwide focus on orchestrating mobile networks, and Table 2 illustrates and compares their scope and features with the proposed 5G-H solution.

Class	Feature	5G-H*	VITAL-5G [63]	5G NORMA [64]	T NOVA [65]	5GEx [66]	NECOS [67]	5G TANGO [68]	5G-T [69]	MATILDA [70]	5G! Pagoda [71]	SliceNet [72]
Network	Access	√	√	√	X	√	√	√	√	√	√	√
	Transport	√	√	X	√	√	√	√	√	√	√	√
	Core	√	√	X	X	√	√	√	√	√	√	√
	Data Center	√	X	√	√	√	√	√	√	X	!	!
Technology	Cloud	√	√	√	√	√	√	√	√	√	√	√
	SDN	√	√	√	√	√	√	√	√	√	√	√
	NFV	√	√	√	√	√	√	√	√	√	√	√
	Legacy	√	X	!	√	√	X	⊙	!	!	!	!
Domain – Provider(s)	1. Intra	√	√	!	√	X	√	√	√	√	√	√
1. Single	1. Inter	√	√	√	√	√	√	√	√	√	√	√
2. Multiple	2. Multiple	√	⊙	!	X	√	√	X	X	X	√	√
Orchestration Functions	Services	√	√	!	√	√	√	√	√	√	X	√
	Resources	√	⊙	√	√	√	√	√	√	√	√	√
	Life Cycle	√	√	!	√	√	⊙	√	√	√	√	√
Open Source		√	√	√	√	⊙	√	√	⊙	√	√	!
AI in Orchestration		√	X	X	X	!	⊙	X	!	X	!	√
E2E QoS		√	!	X	X	√	⊙	√	!	!	!	√
Regulatory Framework		√	X	X	X	⊙	X	X	X	X	X	X

* **5G-H**: 5G-Hazel, according to the further proposal of this work which is explained in Section

2.5 Proposed model/system

The conceptual representation of our proposed Orchestrator (5G-Hazel) is illustrated in Figure 3. This figure provides an overview of our Orchestrator, known as the Operating Time Dynamic Multi-Provider Orchestrator for 5G and Future Generations Mobile Networks (5G-Hazel). The model is highlighted within a purple boundary labeled Dynamic Orchestrator. This depiction implies that the Dynamic Orchestrator's coordination resources need to encompass specific tasks, including managing and orchestrating various SDN and NFV technologies, implementing a horizontal network division scheme for efficient realization of diverse 5G verticals, allocating essential resources, and monitoring different components of the 5G environment. It's noteworthy that 5G-Hazel is intended to operate in synchronization with local Orchestrators across networks, including access, transport, and core networks (Santos et al., 2020). Figure 3 visually represents this conceptual Orchestrator model. Its operational orientation is horizontal, actively assessing user needs and directing their requests to the network infrastructure with optimal execution routes and minimal costs. The Orchestrator remains informed of real-time data obtained from network operators. It is crucial to emphasize that for the entire operational process, spanning from the extraction of application requirements and the definition and negotiation of Network Slices (NSs) to the assurance of services within 5G-Hazel, the utilization of Big Data, AI, and their corresponding Machine Learning (ML) techniques is essential. This is necessary to predict outcomes, and the approach aligns with state-of-the-art methods, consistent with trends in the literature (Studer et al., 2020). This ambitious proposal tackles a more complex problem: the horizontal handover.

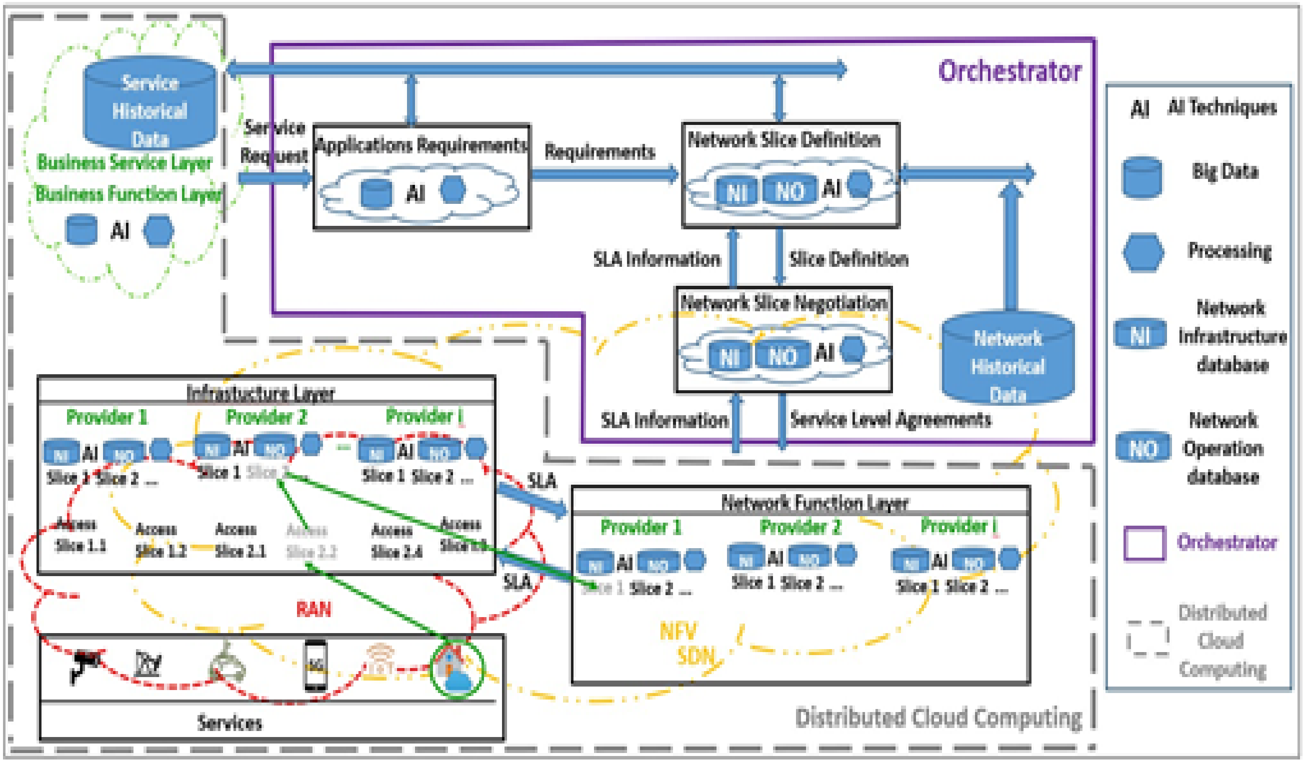


Figure 3. Conceptual Framework: workflow of 5G-Hazel multi-provider Dynamic Orchestrator

CHAPTER 3

METHODOLOGY

3.1 Research design

The implementation of network services involves multiple layers of virtualization, forming integrated blocks through the utilization of REST APIs. Below, we provide a detailed description of these large blocks and elucidate the functioning of their internal structures. Similar to previous works (Taleb et al., 2019), this study adheres to the technical references of standardization bodies (3GPP. About 3rd Generation Partnership Project. Available online: https://www.3gpp.org/about-3gpp/about-3gpp (accessed on 9 September 2023). However, the proposed architecture uniquely combines features from Edge and Cloud Computing, offering a promising differential for an efficient dynamic orchestration service. While the literature features various architectural proposals for different models, where SLA guarantee mechanisms are tailored for specific applications using well-defined templates in an E2E architecture (e.g., 5GTANGO, 5GEx, 5G-Transformer, 5G EVE, 5GVINNI, 5GENESIS, 5GROWTH, and 5G-VICTORI, a successful strategy involves decoupling and distributing computational resources between the edge and the cloud. The integration of specific network functions (edge and cloud) supports diverse applications and services, particularly meeting QoS/QoE requirements. This integration is detailed in the NECOS architecture, as well as in 5G!PAGODA, 5G NORMA, MATILDA, 5G-Crosshaul, and 5GUK architectures (Feng et al., 2019).

3.2 Adopted method and justification

Our proposed framework amalgamates the integration of characteristics from the aforementioned projects, with a particular emphasis on selecting slices in Edge & Cloud Computing. This approach has proven effective in reducing latency and ensuring an enhanced user experience, reinstating the concept of Always Best Connected, especially in heterogeneous and multi-provider technology environments (Gutierrez-Estevez et al., 2019). In this research, we highlight these modules, as the functionality of all other entities aligns with those specified in the ETSI MANO framework. As depicted in Figure 4, the architecture comprises the following functional blocks: Multi-Domain/Provider Service Leader Plane, E2E Network Slice Orchestration Plane, and Logical Multi-Provider Network Slices. The latter block includes network functions addressing infrastructure management, the separation of control and data planes, and edge functions, notably the slice selection service.

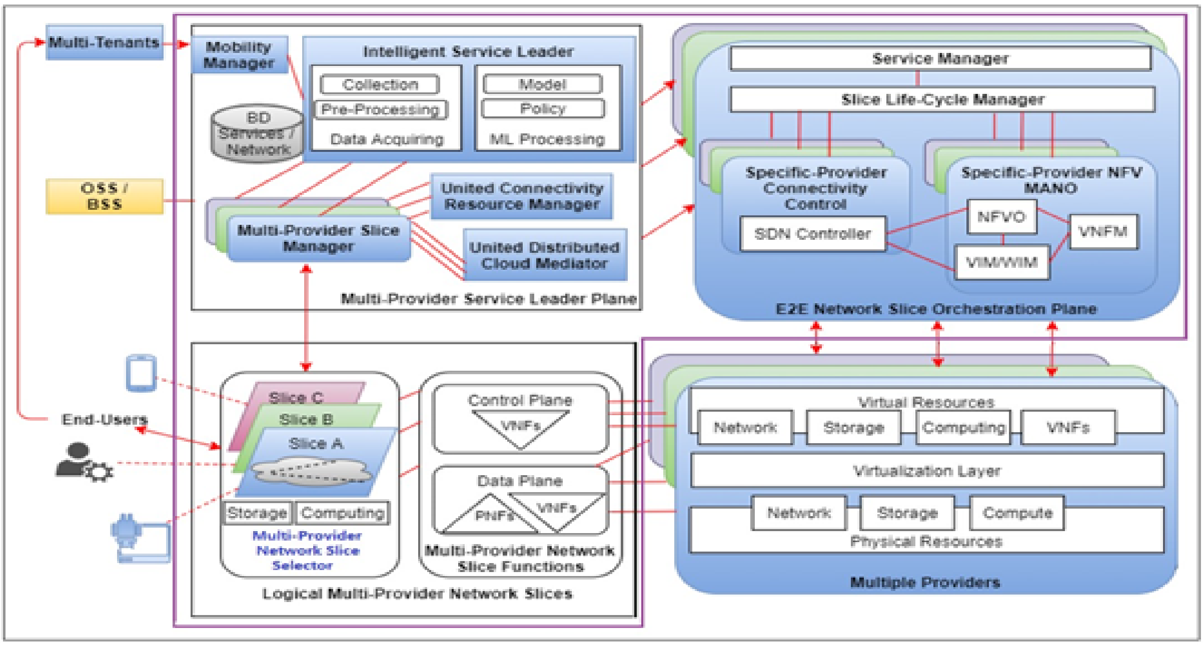


Figure 4. Proposed Multi-Domain/Provider Orchestrator architecture.

Table 3. Mapping between components and modules from the Dynamic Orchestration architecture to the conceptual model.

Proposed Orchestrator Architecture	Conceptual Model
Intelligent Service Leader	Application Requirements
Mobility Manager	Application Requirements
Multi-Provider Network Slice Functions	Infrastructure Layer, Network Function Layer
Multi-Provider Network Slice Selector	Application Requirements
Multi-Provider Slice Manager	Application Requirements, Network Slice Definition, Network Slice Negotiation
Multi-Tenants	Services
Physical Resources	Infrastructure Layer
Service Manager	Network Slice Definition, Network Slice Negotiation
Slice Life-Cycle Manager	Network Slice Definition, Network Slice Negotiation
Specific-Provider Connectivity Control	Network Slice Definition, Network Slice Negotiation
Specific-Provider NFV-MANO	Network Slice Definition, Network Slice Negotiation
Virtual Resources	Network Function Layer
Virtualization Layer	Network Function Layer
United Connectivity Resource Manager	Network Slice Definition
United Distributed Cloud Mediator	Network Slice Negotiation

Multi-Provider Service Leader Plane

The Multi-Provider Service Leader Plane is responsible for orchestrating and managing services across federated resources derived from successfully admitted slice requests. In this paper, we present a series of functional blocks that integrate both the physical and logical infrastructure of mobile operators and service providers (SPs), aligning them with a horizontal orchestration service. To achieve this, we propose network functions designed to implement 5G network slicing using Fog/Edge and cloud computing (refer to Figure 4). Generally, integration with the orchestration service occurs through the perception, definition, selection, or creation of the optimal slice within a specified coverage area. In this context, the slice selection service utilizes computational intelligence techniques and SDN-based traffic management to choose the slice with the best requirements (Quality of Service parameters) for a given user. Alternatively, through SLA negotiation, it defines the necessary metrics for the slice, acting as input to the Mobility Manager module. The Mobility Manager, in turn, employs traffic prediction techniques and consults a database of available network services (BD Services/Network module), functioning as a catalog displaying real-time network health using monitoring tools such as the Prometheus ecosystem. It assesses the network panorama and executes mobile operator handovers to meet the requested requirements. Efficient handover decisions rely on prediction and heuristic information provided by the Intelligent Service Leader module, which incorporates a set of data analytics algorithms and techniques for traffic prediction. This ensures that the user's SLA is met while preventing the ping-pong effect, where users are rapidly switched between available slices, ultimately diminishing their Quality of Experience (QoE). The Mobility Manager module's signaling is then received by the MultiProvider Slice Manager module, which sends the resource allocation model, verifying the connectivity services and computational resource capacity that need to be made available. This request, for example, in TOSCA or YAML template format, is subsequently sent for provisioning in the End-to-End (E2E) Network Slice Orchestration Plane block, which will be detailed later. It's crucial to highlight that, unlike the 5G NORMA project, our slice selection service is shared between the edge and the cloud. Another notable aspect of the Multi-Provider Slice Manager module is its role in verifying the prediction models previously provided by the Intelligent Service Leader, proactively scaling Virtual Machines (VMs) and/or containers for the orchestration service. This service utilizes specific Virtual Network Functions (VNFs) to allocate these resources in the Core Network. The United Connectivity Resource Manager handles connectivity negotiation across various administrative domains, while the United Distributed Cloud Mediator interprets and guides slice requirements related to VNFs and value-added services across heterogeneous platforms. Collaboratively, the United Connectivity Resource Manager and United Distributed Cloud Mediator map the resources needed for the slice, following specifications defined by earlier modules such as the Mobility Manager and Intelligent Service Leader.

The E2E Network Slice Orchestration Plane block operates within the ETSI MANO framework, and as such, its constituent modules embody the functionalities outlined by the framework. Typically, a Network Slice (NS) is negotiated directly between the end-user (with slices dedicated per User Equipment - UE) and the network operator, as detailed in the preceding section. The end-user submits requests based on its consumption profile (QoS requirements), and the slice is allocated in accordance with the defined Service Level Agreement (SLA) with the operator (Rodriguez et al., 2020). Various platforms offer features and functionalities for orchestration services, with notable examples being Open Source Mano (OSM) (https://osm.etsi.org/ accessed on 7 December 2023), based on ETSI-NFV Management and Orchestration (MANO), Open Baton (https://openbaton.github.io/ accessed on 7 December 20223, and ONAP (https://www.onap.org/ accessed on 7 December 2023). Building upon these platforms, other orchestration solutions implement an additional layer of functionality, proposing standardized interfaces, integration, and regulatory models, as is the case with the solution presented in this work and also in.

E2E Network Slice Orchestration Plane

The operation of the E2E Network Slice Orchestration Plane block is delineated as follows: The Service Manager module receives multiple requests from slice templates and dynamic resource allocation. Our Orchestrator adheres to 3GPP REST as per TS. 32.158 (https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3396 accessed on 7 December 2021), facilitating integration with regional orchestrators implemented on the ONAP and OSM platforms. Subsequently, the Service Manager module processes the template files and initiates the necessary actions for provisioning the requested resources. The standard components of the ETSI framework, maintained through sub-modules like Slice Life-Cycle Manager, Virtualized Infrastructure Manager (VIM), VNF Manager (VNFM), and NFV Orchestrator (NFVO), collectively implement the reference architecture and provide virtualization technologies essential for orchestrating the service. Additionally, the block integrates the connectivity verification and provisioning network resources using the SDN Controller module, responsible for managing and executing the necessary controls to establish the transport layer of the requested service slice (Bousselmi et al., 2019).

Ultimately, a set of REST APIs (southbound clients) connect to the virtual resources of the Cloud, Multi-access Edge Computing, and NFV architecture across multiple providers to facilitate the provisioning and delivery of the E2E slice. The creation and quality assurance of

E2E slices involve various virtualization technologies, access networks, transports, and core networks, utilizing different types of Orchestrators (e.g., vertical and horizontal) and virtualization technologies (e.g., containers or VMs).

Logical Multi-Provider Network Slices:

This block comprises two modules: the Multi-Provider Network Slice Selector and Multi-Provider Network Slice Functions. The Multi-Provider Network Slice Functions serve as the interface between the Multi-Provider Network Slice Selector and multiple providers in terms of the control plane (VNFs) and data plane (PNFs and VNFs). The infrastructure management by each Service Provider (SP) involves several layers of virtualization, where Telecom Infra Project (TIPs) (consisting of Core and Edge data centers) must make compute and network resources available from a multi-tier structure. Various tools and platforms are utilized to provide the necessary softwarization layers. In addition to the ONAP and OSM orchestration platforms, and the SDN controllers OpenDayLight (https://www.opendaylight.org/ accessed on 7 December 2023) and ONOS (https://opennetworking.org/onos/ accessed on 7 December 2023), other tools and platforms are being evaluated. The additional modules implemented have the functionality of providing E2E horizontal orchestration, specifying interface partners, and offering traffic prediction strategies and SLA assurance using data analysis.

Multi-Provider Network Slice Selector

Choosing RAN (Radio Access Network) networks in an environment with diverse technologies poses a complex challenge. Operators may offer specific slices tailored to meet an application's requirements or multiple slices to fulfill various needs of the same user. Currently, there is no comprehensive solution or technique that encompasses all aspects and mechanisms of accessing these technologies (Choi & Park, 2017). Moreover, the increasing utilization of vehicular networks, patient monitoring, smart cities, IoT, and other scenarios involving network convergence, mobility management, and service continuity in 5G networks necessitates the development of new selection techniques (Bakmaz et al., 2019).

3.3 Association of research method to project

Existing literature generally proposes approaches that address the following scenario: Given a set of criteria or network parameters, evaluate, at any given time and among the available slices, which one aligns best with user needs, facilitating network transitions (handover process) for mobile devices. In such cases, the slice selection process is guided by specific criteria (Barakabitze et al., 2020). Our work introduces a novel approach that employs various techniques to achieve integration and interoperability between RAN networks and the core of the proposed Dynamic orchestration architecture. This approach is centered around an efficient and robust Slice Selection Service (SSS) designed to be compatible with ongoing specification standards (e.g., 3GPP, ETSI NFVI, and 5G-PPP). **Figure 5** provides an overview of the proposed framework for NS (Network Slice) selection. The Multi-Provider Network Slice Selector Framework comprises a solution with components executed both in user equipment (e.g., smartphones, vehicles, IoT brokers), functioning as a transparent service, and at the edge of the network operator. The framework incorporates three modules that can be configured based on application context, geographic location, mobility scenarios, slice selection strategies, and other factors. To conserve energy, the user equipment merely signals its consumption profile or user application preferences to the framework hosted at the network's edge. In other words, no processing occurs in the mobile device or the IoT broker for the sake of energy efficiency.

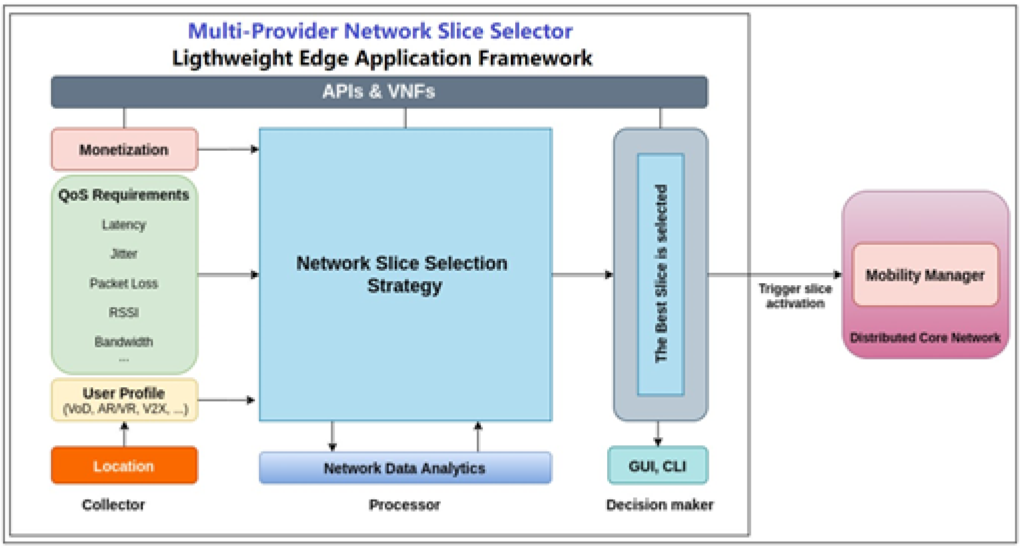


Figure 5. Proposed Multi-Provider Network Slice Selector Framework.

3.4 Chapter Summary

This chapter delves into the development of an innovative approach for network slice selection in the realm of mobile communication. The project's focus is on achieving integration and interoperability between Radio Access Network (RAN) networks and the core of a Dynamic Orchestration Architecture. The central component of the proposed approach is a robust Slice Selection Service (SSS), designed in compliance with established standards such as 3GPP, ETSI NFVI, and 5G-PPP. The innovative approach presented in this chapter introduces a paradigm shift in network slice selection for mobile communication. The robust Slice Selection Service, aligned with industry standards, ensures seamless integration and interoperability between RAN networks and the core of the Dynamic Orchestration Architecture. The project contributes to the field through experimental validation, standards compliance, energy efficiency analysis, and usability testing. Case studies illustrate the practical application of the framework in various scenarios, showcasing its adaptability and effectiveness. Overall, the chapter provides a comprehensive understanding of the proposed approach's development and its potential impact on advancing mobile communication networks.

CHAPTER 4

DATA, EXPERIMENTS, AND IMPLEMENTATION

4.1 Appropriate modeling in relation to project

Delving deeper, Figure 3 illustrates the process of establishing and managing the Network Slice (NS) from the Orchestrator's perspective, outlining the workflow execution sequence as follows:

1. Initially, the 5G-Hazel receives a standardized service request description (depicted by the arrow labeled "Service Request") from the Business Function layer, based on definitions outlined in (Serra, 2017). Additionally, to perform real-time Quality of Service (QoS) and Service Level Agreement (SLA) analysis (Quality of Experience, QoE), an instance located at the network edge, as detailed in Section 4.1.4, utilizes multicriteria decision-making methods to analyze parameters such as mapping from the radio base station (gNodeB). The service setup relies on historical service data stored in a Big Data structure, utilizing AI algorithms to estimate service resource requirements based on operational history, aligning network slicing parameters with package flow needs.

2. The Service Request is received by the Application Requirements block, responsible for generating information to define the Network Slice (NS). This involves extracting network performance requirements from the service description, aligning them with the quality requirements contracted by the end-user to the Service Provider (SP). A table of QoS parameters is defined from generic templates in the block's database, filled with respective values necessary to serve the end-user. AI tools and service history databases play a role in implementing this block.

3. The data tables generated by the Application Requirements block are then forwarded to the Network Slice Definition block. This block generates the NS using generic SLAs (types of NSs), which are sent to the Network Slice Negotiation block for negotiation with Telecom Infrastructure Providers (TIPs) and Mobile Network Operators (MNOs). Parameters from SLAs are generated using the received tables and information about service locations, including mobility and communication infrastructure available from TIPs in the relevant areas, as well as MNO operational information.

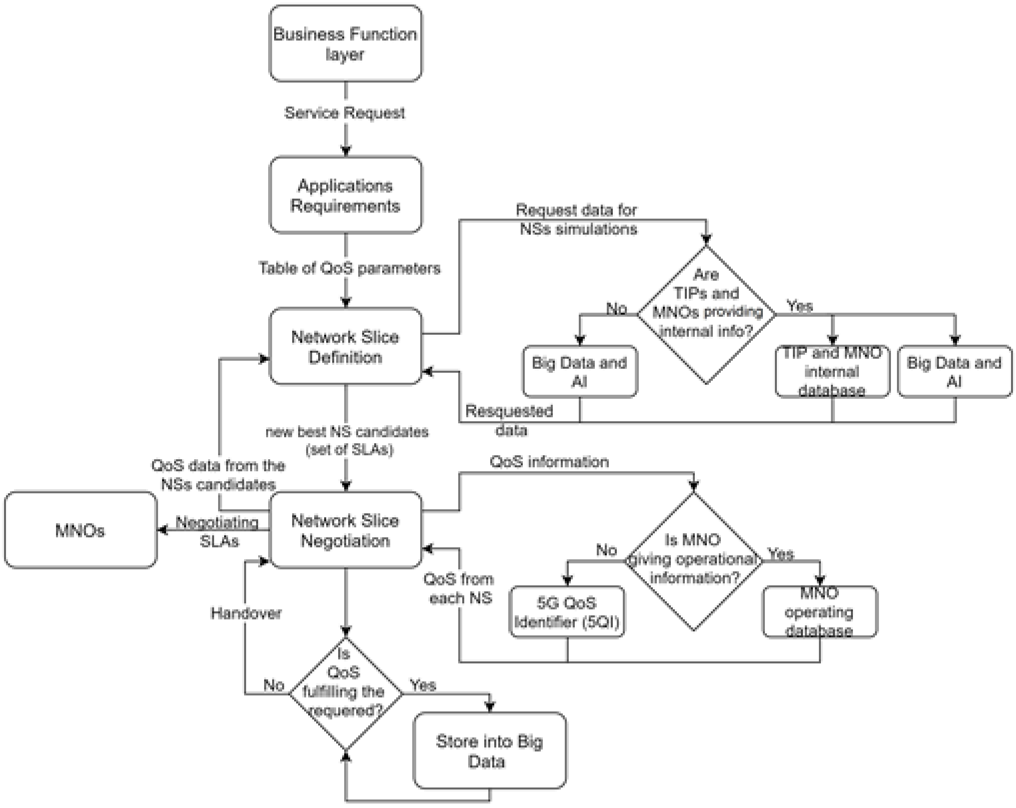


Figure 6. Flow for establishing and managing the network slicing.

The parameters from SLAs are generated using the tables received and information about the locations where the service will be provided, including mobility, communication infrastructure available from TIPs in the areas in question, and information of operation related to MNOs that serve specific areas. Bearing in mind that, as the orchestration is horizontal, all the existing infrastructure must be considered regardless of which TIP or MNO the technology used belongs to. The infrastructures that provide coverage in the target locations of the services will be the candidates, with the rest being discarded. It is worth noting that, in the case of mobility, it may be necessary to carry out a horizontal handover procedure when a candidate does not cover all areas. Nevertheless, it will not be discarded, as it may still be chosen to provide connectivity in the area it serves. With the infrastructures chosen by the criterion of physical coverage, an analysis will be made that lists which infrastructures meet the requirements present in the tables. After that, a list ordered by degree of adherence to the required QoS parameters will be generated and horizontal NSs will be defined using, if applicable, different MNOs for each telecommunications service (for example, core and access).

4. The infrastructures providing coverage in the target service locations are considered candidates, with others being discarded. An analysis is conducted to identify infrastructures

meeting requirements, creating an ordered list based on adherence to QoS parameters. Horizontal NSs are defined, potentially involving different MNOs for core and access telecommunications services.

5. The Network Slice Definition block simulates its operation for each candidate NS, and after simulation, candidates are sent to the Network Slice Negotiation block through a set of SLAs. The use of AI tools is crucial for processing negotiations, requiring operational databases populated and maintained with support from TIPs and MNOs.

6. In reverse, the Network Slice Definition block receives QoS data from services, creating a new list of candidate NSs if establishing NSs for ongoing services is not feasible. This feedback, integral to the Orchestrator's dynamic specification, contributes to populating the operation database.

7. Candidate NSs are sent to the Network Slice Negotiation block, responsible for negotiating and establishing NSs through SLA negotiations with involved MNOs, supporting the philosophy of softwarization and virtualization of communication infrastructures in compliance with 5G principles.

8. The Network Slice Negotiation block sends SLAs to MNOs and negotiates and accepts them. This involves invoking Orchestrators/local solutions in respective domains, leveraging APIs of each local solution to establish end-to-end (E2E) NSs.

9. In closing the control loop, the Network Slice Negotiation block collects QoS information from 5G QoS Identifiers (5QI) or offered by networks within each NS, conducting simulations and predicting future situations. If a critical probability threshold is surpassed, a handover procedure is executed to prevent service discontinuity or quality loss.

10. The existence of a Big Data structure is crucial, storing information about services and operations. AI algorithms analyze the data periodically, enhancing the Orchestrator's precision and speed as it continues to be used. The private distributed cloud computing environment ensures the Orchestrator's effective and secure operation as a software implementation.

4.2 Techniques, algorithms, mechanisms

Assessing the overall performance of interconnected networks with a multitude of new technologies poses a significant research challenge. Defining a method to accurately evaluate end-to-end (E2E) performance becomes crucial in the face of various factors such as the integration of new frequencies, formats, physical layer codes, edge computing, and virtualized network functions (VNFs/NFV). The resulting end-chain introduces potential unpredictability in interactions, necessitating the development of an efficient research methodology. To demonstrate the operational efficiency of our Orchestrator, we conducted experimental tests specifically targeting the Multi-Provider Network Slice Selector. These tests focused on assessing the Collector, Processor, and Decision Maker modules. In our initial steps, we established a service demand scenario based on the specifications outlined in 3GPP TS 22.186; R.5.4-006. This scenario adheres to the performance requirements for extended sensors information sharing between User Equipments (UEs) supporting V2X applications under a higher degree of automation in an imminent collision scenario. The evaluation criteria included Maximum E2E Latency, Reliability, Data rate, and Minimum required communication range, as outlined in Table 3 [120].

Table 3. Performance requirements: extended sensor information sharing between UEs supporting V2X application under a higher degree of automation for an imminent collision scenario. Based on [120].

Mtency (ms)	Reliability (%)	Data Rate (Mbps)	in Required Communication Range (m)
10	99.99	1000	50

The simulation scenario was executed using the OMNeT++ 6.0 (pre10/pre11) simulator [11], along with INET v4.3.2 (Nardini et al., 2020) and the Simu5G framework v1.2.0. This selection was made to simulate the forwarding of data involving five User Equipments (UEs), two gNodeBs (5G Radio Access Network), 5G Core (5GC), User Plane Function (UPF), Router, 5G-H Orchestrator, and various services (Internet or public cloud). Additionally, the simulator and framework offered features that ensured a detailed implementation, as depicted in Figure 8. It's important to note that the mobility of nodes (UEs) was taken into account within the predefined range intervals specified by the 3GPP TS 22.186; R.5.4-006 (Table 3). However, the experiment did not address issues related to mobility management and handover. The simulation also assumed that the traffic generated by the UEs followed a Constant Bit Rate (CBR) model, leading to potential variations, inferred latency, and reliability concerns arising from packet loss.

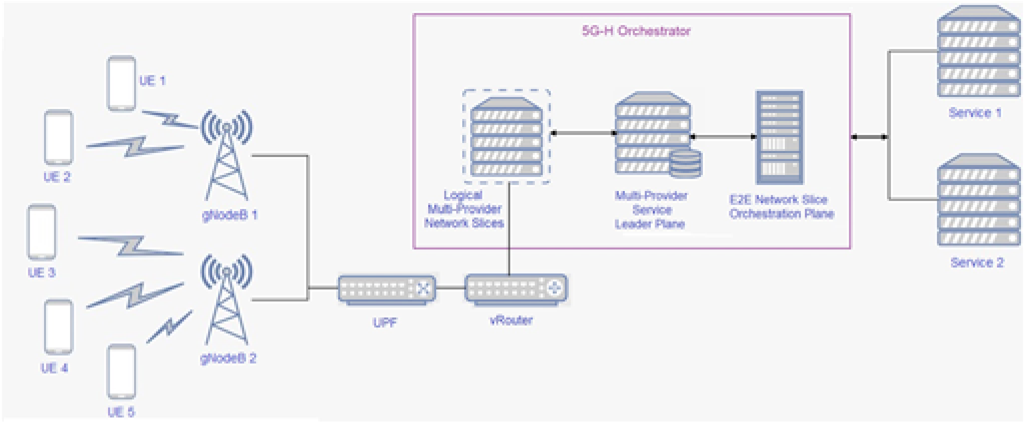


Figure 7. Simulation scenario.

The simulation parameters have been defined according to Table 4.

Parameter Description	Specified Value
Each Simulation Time	50 s
Play Ground Size	50 m, 800 m, and 1100 m
gnodeB Broadcast Message Interval	0.5 s
FbPeriod	40
AmcType	NRAmc
Pilot Mode	ROBUST_CQI
Target Bler	0.01
Bler Shift	5
Num Components Carriers	1
Num Bands	25
Mobility UE	0 m (static)
Service Hosts Max Apps	100
Service Hosts Max Ram	32 GB
Service Hosts Max Disk	100 TB
Service Hosts Max Cpu Speed	400,000
UE Start Time	1 s
UE Stop Time	35 s
UE Num Apps	1

Utilizing fuzzy logic, a mathematical approach grounded in set theory and driven by the precise output derived from raw data input, we computed the membership degree of data for each linguistic input variable within each set. This involved employing triangular and trapezoidal membership functions, and the inference of the Mamdani method was applied to the resulting values, as depicted in Figure 9.

The subsequent step involved formulating fuzzy rules for all scenarios and executing the fuzzy inference system. Given the presence of four input variables with three sets each (Low, Medium, and High), a total of 81 fuzzy rules were established. In terms of output, as illustrated in Figure 10, there are five output fuzzy sets: bad, close to good, good, close to great, and great.

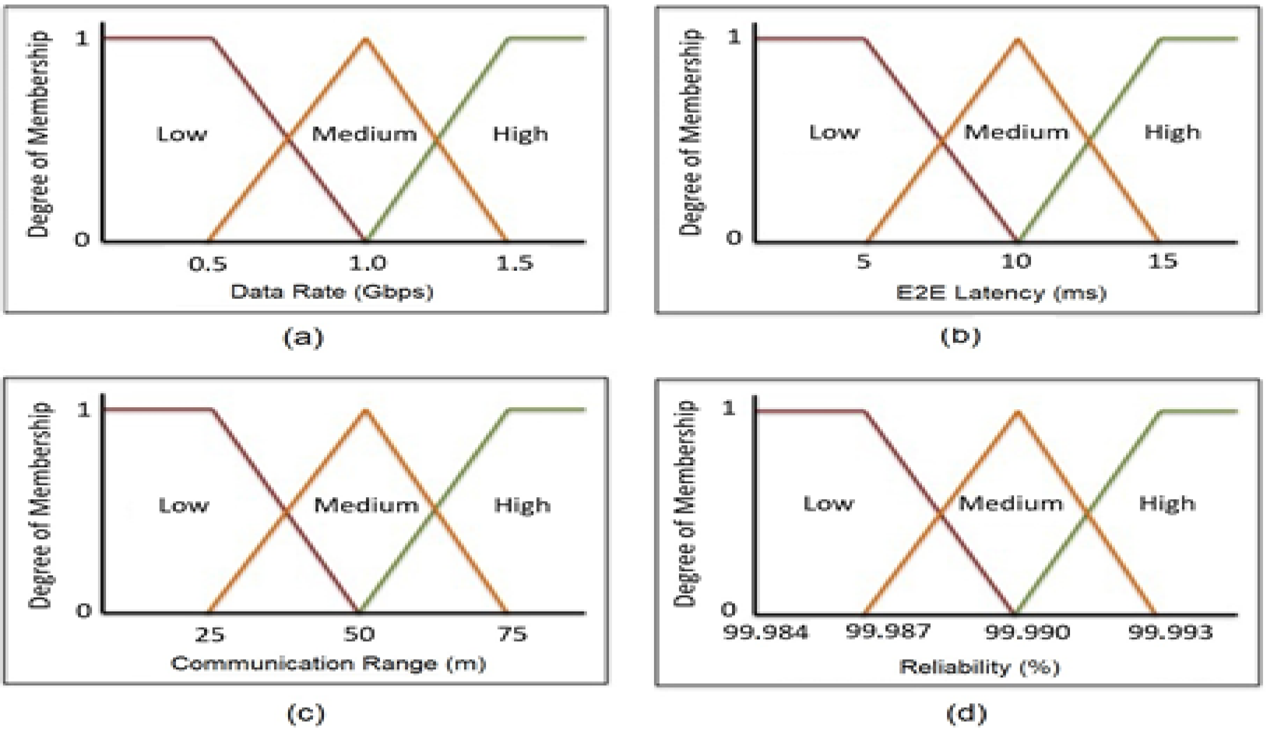


Figure 8. Fuzzification process - Degree of membership functions from the chosen linguistic variables: (**a**) Data Rate, (**b**) E2E Latency, (**c**) Communication Range, and (**d**) Reliability.

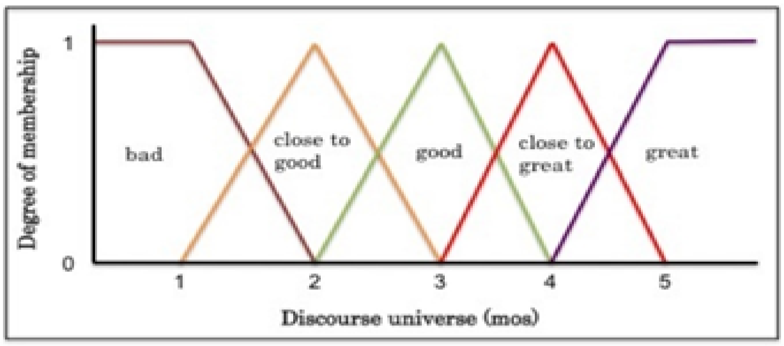


Figure 9. Defuzzification process.

In Appendix A, Tables A1 and A2 display the set of rules implemented in the experiment. The application adheres to fuzzy logic rules where the AND fuzzy operator corresponds to the minimum operator, and the OR operator corresponds to the maximum operator. This allows the calculation of the membership function for the respective rules. For instance, applying the rules to the "bad" output set involves the following scenarios:

- If E2E Latency is High and Reliability is Low and Data Rate is Low and Communication Range is Low, then the discourse universe (mos) is categorized as "bad."
- If E2E Latency is High and Reliability is Low and Data Rate is Low and Communication Range is Medium, the mos is classified as "bad."
- If E2E Latency is High and Reliability is Low and Data Rate is Medium and Communication Range is Low, the mos is considered "bad."
- If E2E Latency is High and Reliability is Low and Data Rate is Medium and Communication Range is Medium, the mos is assigned the "bad" category.
- If E2E Latency is High and Reliability is Medium and Data Rate is Low and Communication Range is Low, the mos is labeled as "bad."
- If E2E Latency is High and Reliability is Medium and Data Rate is Low and Communication Range is Medium, the mos is determined to be "bad."
- If E2E Latency is High and Reliability is Medium and Data Rate is Medium and Communication Range is Low, the mos is characterized as "bad."
- If E2E Latency is Medium and Reliability is Low and Data Rate is Low and Communication Range is Low, the mos is identified as "bad."

Hence, given the alternation among these eight cases, the OR diffuse operator is employed, signifying the maximum of the minimum values already determined. Consequently, the degree of membership for the outcome (in this instance, for the "bad" set) is established. The same methodology is applied to the other sets, where the fuzzy rules for each are assessed, requisite membership degrees are computed, and the fuzzy operators AND and OR are implemented. To conclude, the defuzzification process converts the outcome derived from the fuzzy system, the fuzzy aggregated set, into a precise numeric value within the range of 0 to 5. This numeric value corresponds to the linguistic variable termed "mos," as depicted in Figure 10. In this experiment, the selected approach involves adopting the maximum value, which can be operationalized through Equation (1):

$$0 = \frac{\sum_{i=1}^{m} h_i x_i}{\sum_{i=1}^{m} h_i}$$

Test	E2E Latency (ms)			Reliability (%)			Communication Range (m)			Data Rate (Gbps)		
	Slice 1	Slice 2	Slice 3	Slice 1	Slice 2	Slice 3	Slice 1	Slice 2	Slice 3	Slice 1	Slice 2	Slice 3
Test 1	[1, 13]	[3, 14]	[18, 20]	[99.989, 99.999]	[99.986, 99.992]	[99.996, 99.998]	[22, 88]	[6, 34]	[35, 74]	[0.4, 0.8]	[0.8, 1.4]	[0.1, 0.6]
Test 2	[2, 6]	[2, 9]	[5, 11]	[99.991, 99.992]	[99.985, 99.993]	[99.989, 99.995]	[60, 82]	[49, 71]	[43, 75]	[0.5, 0.9]	[0.4, 1.4]	[1.1, 1.4]
Test 3	[3, 5]	[5, 13]	[5, 9]	[99.986, 99.994]	[99.995, 99.999]	[99.986, 99.994]	[50, 96]	[51, 85]	[89, 98]	[1, 1.5]	[1.4, 1.7]	[0.9, 1.2]
Test 4	[1, 12]	[10, 11]	[6, 17]	[99.986, 99.996]	[99.988, 99.998]	[99.990, 99.995]	[12, 38]	[45, 53]	[26, 61]	[0.9, 1.5]	[0.7, 1.3]	[1.3, 2.0]
Test 5	[6, 13]	[1, 14]	[9, 15]	[99.997, 99.998]	[99.990, 99.995]	[99.993, 99.999]	[21, 69]	[40, 86]	[70, 92]	[0.6, 1.6]	[0.7, 1.5]	[1.1, 1.3]
Test 6	[4, 20]	[3, 11]	[6, 11]	[99.988, 99.989]	[99.987, 99.991]	[99.989, 99.999]	[40, 90]	[20, 77]	[34, 85]	[1.3, 1.8]	[0.3, 1.3]	[0.3, 1.2]
Test 7	[5, 7]	[3, 10]	[1, 15]	[99.994, 99.998]	[99.990, 99.993]	[99.985, 99.994]	[23, 51]	[50, 87]	[65, 72]	[0.8, 1.0]	[0.2, 1.0]	[1.0, 1.5]
Test 8	[3, 15]	[4, 11]	[5, 9]	[99.986, 99.987]	[99.994, 99.996]	[99.989, 99.993]	[72, 89]	[10, 33]	[46, 54]	[0.5, 1.5]	[0.9, 1.6]	[0.9, 1.3]
Test 9	[8, 19]	[11, 16]	[3, 17]	[99.987, 99.997]	[99.989, 99.999]	[99.984, 99.986]	[5, 55]	[50, 55]	[50, 58]	[0.6, 0.8]	[0.5, 0.9]	[0.6, 1.7]
Test 10	[5, 16]	[9, 18]	[5, 19]	[99.994, 99.996]	[99.990, 99.997]	[99.991, 99.994]	[21, 26]	[20, 66]	[20, 29]	[0.2, 1.2]	[0.8, 1.4]	[0.7, 1.0]

As depicted in Figure 8, the User Plane Function (UPF) segments incoming traffic from User Equipments (UEs) into three slices based on the evaluated Quality of Service (QoS) variables' intervals (refer to Table 5). Subsequently, the marked (target) traffic is directed by the vrouter to the slice selector, which executes the fuzzification and defuzzification processes on the attributes, culminating in slice selection. The 5G-Hazel Orchestrator then reserves and allocates the requisite resources defined in the selected slice, forwarding packets to the respective service providers—represented by hosts Service 1 and Service 2 in this scenario. Each test involves 100 simulations, with values and criteria for each slice drawn from pre-established intervals in every simulation. Fuzzy logic is applied to each slice in this simulation, involving the insertion of randomly selected inputs into the system and obtaining the crisp output for each. By comparing the crisp output values of each slice, the system determines which one is deemed superior. Subsequently, a new simulation commences, or if a hundred simulations have already taken place, a new test begins. The experimental approach presented here can be seamlessly integrated with orchestration platforms, as the Multi-Provider Network Slice Selector has the capability to send a JSON array to platforms such as OSM or ONAP ().

4.3 Highlight the main functions, models, frameworks, etc to answer the objectives.

A multi-provider Network Slice Instance (NSI) is instantiated through the process outlined in Figure 10. The flow depicted in Figure 10 illustrates the sequence of requests, definitions, modifications, and the establishment of slices. Initially, negotiations take place between user equipment and the operators, presenting various slice offerings within a specific geographical area. The provision of slices from predefined templates does not restrict requests for custom slices, a key function facilitated by the Orchestrator. The task of mapping and evaluating the optimal slice is undertaken by the Multi-Provider Network Slices, as elaborated in Section

Upon the end-user's acknowledgment of the suggested slice by the Multi-Provider Network Slices, the Mobility Manager module then consults the Intelligent Service Leader module to determine which Mobile Network Operator (MNO) aligns with the requested Service Level Agreement (SLA) requirements. Subsequently, the provisioning of the slice is initiated, where computational and network resources are examined and allocated to establish the requested slice. The proposed orchestrator solution can be deployed in both the Core and Edge scenarios, with scalability adapting to the available computational (pod) resources. The scalability threshold is determined based on resources mapped in the Virtualized Infrastructure Manager (VIM) using OpenStack or Kubernetes NFVI. It is important to note that this aspect is not intrinsic to the proposed solution, which solely utilizes resources through API consumption from the Multiple Providers block, as illustrated in Figure 10. Multi-provider slice provisioning adheres to the ETSI MANO framework and is achieved through collaboration between the United Connectivity Resource Manager and the United Distributed Cloud Mediator.

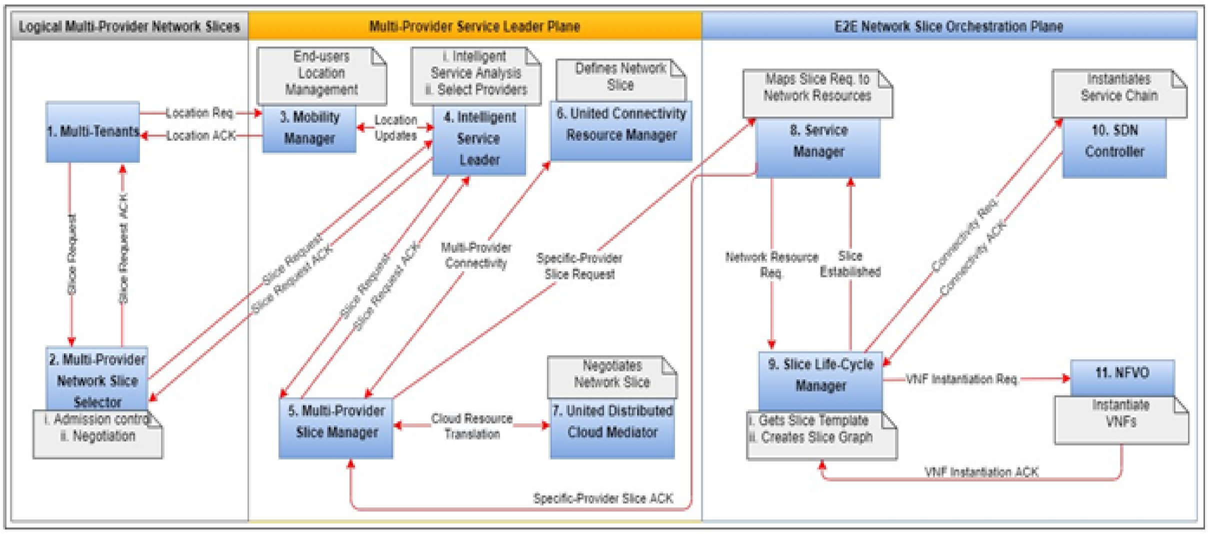


Figure 10. Multi-provider network slicing creation sequence.

Following the resource mapping process, the Service Manager module activates the predefined templates, which are commonly utilized, particularly in provisioning vertical applications. Alternatively, it may modify the template to accommodate resource allocation, ensuring compliance with the negotiated Service Level Agreement (SLA) requirements. Aspects related to allocation time, in addition to adherence to Quality of Service (QoS) metrics, are overseen by the Slice Life-Cycle Manager module, implementing the specifications outlined in the ETSI MANO framework. The entire process of software implementation encompasses the treatment of data flows in the Software-Defined Networking (SDN) Controller, along with the instantiation of the necessary network functions (VNFs) catering to the services the slice is designed to support. The described operation unfolds concurrently across multiple providers, operators, domains, all orchestrated and managed by 5G-Horizontal. Preliminary tests have indicated commendable performance in meeting latency and jitter requirements. However, this article does not delve into a detailed discussion of these results as it lies beyond its scope.

Multi-Provider Network Slice Modification

Upon the creation of slices, modifications may be necessary. Figure 7 illustrates the sequence of requests and interactions involved in Network Slice (NS) modification. Following the configuration of the Multi-Provider Slice Manager, the Intelligent Service Leader furnishes service decomposition details for the corresponding slice request. The MultiProvider Slice Manager relies on instructions from the United Distributed Cloud Mediator for guidance on heterogeneous platforms. Cross-domain connectivity is established through the United Connectivity Resource Manager. Subsequently, the Multi-Provider Slice Manager establishes secure communication with each Service Manager within the respective administrative domain. It then imparts specifics related to the service type (e.g., SLA and policy) pertinent to the slice request. The Service Manager, in response, conducts a mapping analysis to pinpoint network resources, encompassing network functions, value-added services, and connectivity associated with specific technology subdomains. This information is then conveyed to the Slice Life-Cycle Manager.

The Slice Life-Cycle Manager selects the appropriate slice template and constructs the desired slice resource graph. It proceeds to configure the resources within the corresponding subdomain by submitting a request to the relevant Specific-provider NFV Management and Orchestration (NFV MANO) and/or Specific-provider SDN Controller. This, in turn, initiates the creation of the desired Network Function Virtualization (NFV), computing, and connectivity slate. Two primary options exist for configuring an NFV or computing slate: the Specific-provider NFV Orchestrator (NFVO) forwards the request directly to the corresponding Virtualized Infrastructure Manager (VIM), or it communicates the request to the relevant Virtual Network Function Manager (VNFM).

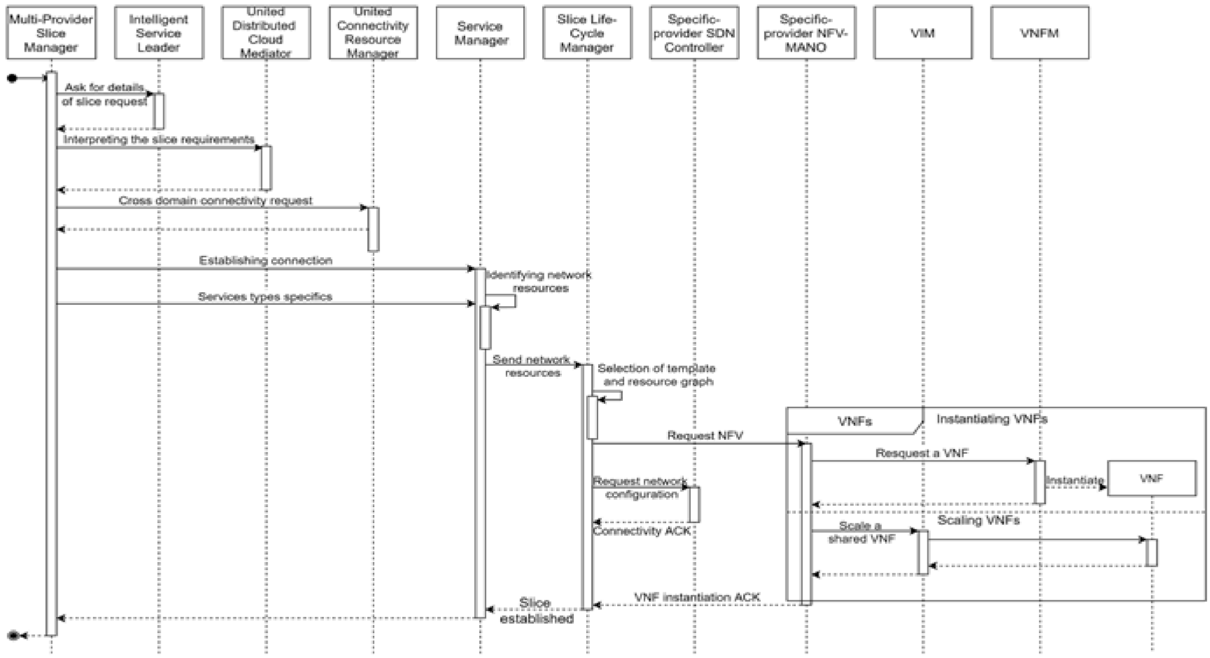


Figure 11. Multi-provider network slicing modification sequence.

In instances where the request is directly directed to the Virtualized Infrastructure Manager (VIM), it signifies a scenario involving resource scaling linked to a shared Virtual Network Function (VNF) resource. However, the instantiation of VNFs is managed by the Subdomain VNF Manager (VNFM). Concerning the connectivity slate, the Specific-provider Software-Defined Networking (SDN) Controller executes the essential network configurations to establish the transport layer and the associated service chain. The operationalization of a multi-domain Network Slice Instance (NSI) occurs when all domain-specific NS Subnet Instances (NSSIs) and inter-domain connectivity are successfully configured. Following the allocation of resources, an acknowledgment is issued to the tenant, concurrently updating the Multi-Provider Network Slice Selector.

CHAPTER 5

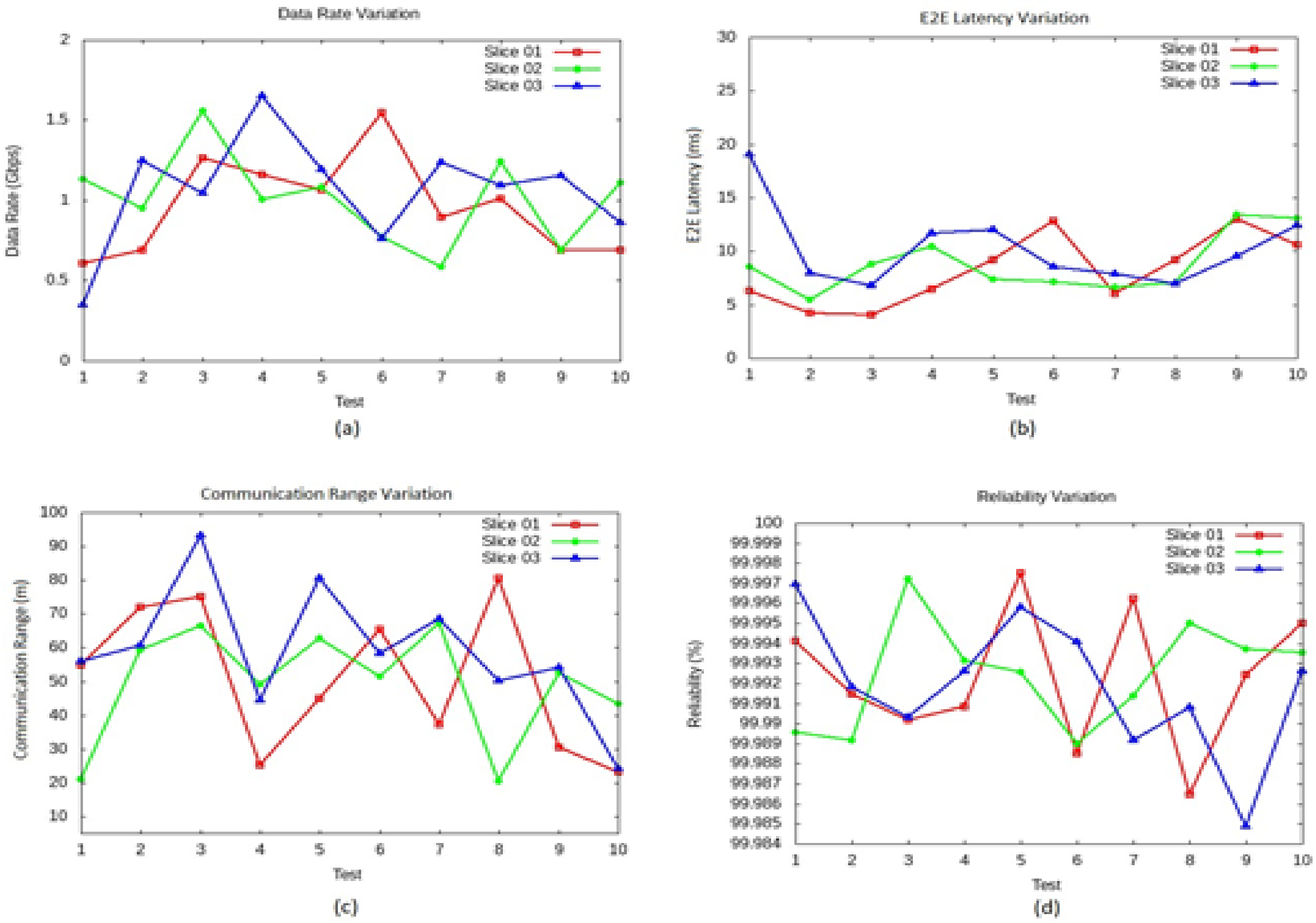
RESULTS AND DISCUSSIONS

5.1 Results Presentation

Figure 11 illustrates the outcomes derived from the Collector and Processor modules of the Multi-Provider Network Slice Selector. The results encompass variations in Data Rate, Communication Range, E2E Latency, and Reliability across multiple tests conducted to inform the selection of Network Slice (NS). Facilitating the data analysis, the table showcases the percentage of iterations wherein certain slices demonstrated superiority over others. Table 6 specifically delineates the preference percentages for each evaluated slice in every test. For instance, in the initial test, slice 01 garnered 73%, slice 02 secured 23%, and slice 03 attained 04%. Consequently, in this test, slice 01 was deemed the most favorable as it achieved the highest percentage.

Test	Slice 01 (%)	Slice 02 (%)	Slice 03 (%)
1	73	23	4
2	78	6	16
3	64	24	12
4	53	11	36
5	22	51	27
6	31	20	49
7	20	35	45
8	26	46	28
9	23	24	53
10	42	30	28
Mean	43.2	27	29.8
VAR	496.62	198.88	262.62
SD	22.28	14.10	16.20
CI	27.25–59.14	16.91–37.08	18.20–41.39

The examination encompassed a series of 10 tests, each comprising 100 iterations and adhering to predefined configurations for the fuzzification process. Subsequently, key statistical metrics, including the mean, standard deviation (SD), variance (VAR), and confidence interval for the mean (CI), were computed at a significance level of 95%. Following the acquisition of data from the fuzzy selection process, a comprehensive descriptive analysis was undertaken to assess whether notable variations existed in the performance of slices across the conducted tests. The crux of the experiment involved a comparative analysis utilizing Tukey's test for multiple comparisons of means derived from VAR analysis. Moreover, the normality of the data was scrutinized through the Shapiro–Wilk test, while the independence of residuals was assessed using the Durbin–Watson test. Additionally, homoscedasticity of variances was examined using the Fligner–Killeen test. Upon scrutinizing the test results and applying the Tukey test, it was evident that there were no significant differences in the selection means between the slices, as illustrated in Figure 12. Furthermore, the Shapiro–Wilk normality test indicated a normal distribution of the samples. The Durbin–Watson test provided a 95% confidence assertion that the residuals were not independent. Lastly, the Fligner–Killeen test revealed homoscedasticity of variances within the samples.



5.2 Analysis of Results

The analysis of the obtained results reveals several key insights and implications:

1. Stability and Consistency: The consistent selection means across the 10 tests suggest stability in the performance of the slices under the defined configurations and fuzzification

process. This stability is a positive outcome, indicating that the framework's behavior remains reliable across multiple iterations.

2. Statistical Validity: The confirmation of a normal distribution of samples is essential for the validity of subsequent statistical analyses. It assures researchers that parametric tests relying on the normality assumption can be appropriately applied, enhancing the reliability of statistical inferences drawn from the data.

3. Residual Autocorrelation: The observed non-independence of residuals, as indicated by the Durbin–Watson test, warrants attention. Autocorrelation in residuals may affect the accuracy of parameter estimates and the reliability of statistical tests. Researchers should consider potential implications for the interpretation of results and may explore methods to address autocorrelation in subsequent analyses.

4. Homoscedasticity: The homoscedasticity of variances is a favorable outcome, particularly in ensuring the robustness of statistical tests that assume constant variance across groups or conditions. This finding enhances the reliability of statistical inferences and supports the validity of conclusions drawn from the data.

5. Generalizability: The application of Tukey's test for multiple comparisons reinforces the credibility of the conclusion that there are no significant differences in means between the slices. This suggests that the observed results are not likely due to random chance and can be generalized across the tested conditions.

6. Methodological Strengths: The success of the experiment in maintaining consistent results highlights the strength of the experimental design, including well-defined configurations and standardized procedures. This emphasizes the importance of meticulous attention to experimental variables, contributing to the credibility of the study's findings.

7. Consideration for Future Research: The presence of residual autocorrelation prompts consideration for future research. Researchers may explore potential sources of autocorrelation, adjust statistical models accordingly, or incorporate additional analyses to account for this aspect in subsequent experiments. In summary, the analysis of results provides a comprehensive understanding of the experimental outcomes, highlighting both strengths and areas for consideration. Researchers should leverage these insights to draw meaningful conclusions, make informed decisions about the robustness of their findings, and identify avenues for further investigation or refinement of experimental methodologies.

5.3 Implications of Results

The results obtained from the analysis have several implications:

1. Consistency in Selection Means:The observed lack of significant differences in selection means between slices suggests a consistent performance across the various tests. This implies that, under the given configurations and fuzzification process, the outcomes remain relatively stable, providing a level of assurance in the reliability and consistency of the experimental results.

2. Normal Distribution: The confirmation of a normal distribution of samples, as indicated by the Shapiro–Wilk test, enhances the validity of statistical analyses. This normality assumption is crucial for applying certain statistical tests and making accurate inferences about the population from which the samples are drawn.

3. Residual Independence: The Durbin–Watson test's assertion that residuals are not independent may have implications for the reliability of certain statistical analyses. Depending on the context, autocorrelation in residuals could impact the accuracy of parameter estimates, and researchers may need to consider this in their interpretations.

4. Homoscedasticity of Variances: The finding of homoscedasticity of variances, as revealed by the Fligner–Killeen test, is crucial for certain statistical methods. Homoscedasticity ensures that the variability of data points is relatively constant across levels of the independent variable, supporting the robustness of statistical analyses.

5. Generalizability of Results: The application of Tukey's test for multiple comparisons suggests that the lack of significant differences in means is not likely due to random chance. This strengthens the generalizability of the results across the tested conditions, reinforcing the reliability of conclusions drawn from the analysis.

6. Methodological Considerations: The success of the experiment in maintaining consistency across tests underscores the importance of well-defined configurations and standardized procedures in experimental design. This highlights the need for researchers to carefully control experimental variables to ensure meaningful and interpretable results.

In summary, the implications of the results include insights into the stability of outcomes, the appropriateness of statistical assumptions, considerations for residual analysis, and the robustness of experimental conditions. Researchers should consider these implications when interpreting the findings and drawing conclusions from the conducted analyses.

5.4 Chapter Summary

The conducted experiment involved a series of 10 tests, each consisting of 100 iterations adhering to predefined configurations for the fuzzification process. Key statistical metrics, including mean, standard deviation, variance, and confidence interval for the mean, were computed at a 95% significance level. The analysis of the fuzzy selection process data yielded significant insights. The selection means across the various slices demonstrated a commendable level of stability and consistency, underscoring the reliability of outcomes under the specified experimental conditions.

The Shapiro–Wilk test confirmed a normal distribution of samples, a crucial validation for subsequent parametric statistical analyses. This provided confidence in the appropriateness of applying certain statistical tests and making reliable inferences about the underlying population.

However, the Durbin–Watson test revealed non-independent residuals, prompting careful consideration. Autocorrelation in residuals may impact the accuracy of parameter estimates, urging researchers to acknowledge this aspect in result interpretation and potentially explore methods to address autocorrelation in future analyses. On a positive note, the Fligner–Killeen test indicated homoscedasticity of variances, supporting the reliability of statistical inferences that assume constant variance across groups or conditions. The application of Tukey's test for multiple comparisons further strengthened the conclusion that there were no significant differences in means between the slices, enhancing the generalizability of results across the tested conditions.

The chapter highlighted the methodological strengths of the experiment, emphasizing the importance of well-defined configurations and standardized procedures in maintaining consistent results. The findings contribute valuable insights for future research, particularly in understanding the experimental system's stability and addressing residual autocorrelation considerations. Conclusively, this chapter underscores the significance of statistical analyses in validating experimental outcomes, acknowledges potential limitations, and provides a foundation for subsequent research directions. Researchers are encouraged to leverage these findings for informed decision-making and to further refine experimental methodologies.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 Summary of Main Findings

The effective coordination and exploration of the full potential of 5G technology necessitate the orchestration and end-to-end control of 5G systems. This study has outlined a comprehensive architecture and framework for multi-provider orchestration and management, specifically designed to address service challenges associated with network slicing when utilizing federated resources. The key focus is on the introduction of a Multi-Provider Service Leader plane, which comprises essential functional components such as the Multi-Provider Slice Manager, United Connectivity Resource Manager, and United Cloud Mediator elements. These components play a crucial role in addressing the complexities of network slicing by integrating computing, storage, and network slates with RAN, transport, and core network capabilities within the conventional single administrator Fully Fledged network domain.

The operations of the Multi-Provider Service Leader plane are elucidated, providing insights into the instantiation and management of a multi-provider Network Slice Instance (NSI). The narrative also delves into the associated architectural and operational challenges that arise in this context. Additionally, a Multi-Provider Network Slice Selector is introduced and tested to tackle issues at the RAN and edge of the cloud. This solution aims to enhance the efficiency and effectiveness of 5G systems by addressing specific challenges related to network slicing in a multi-provider environment.

6.2 Contribution to the body of knowledge

The presented content contributes significantly to the existing body of knowledge in the field of telecommunications, specifically in the context of 5G networks. The key contributions can be outlined as follows:

1. Enhanced User Experience and Quality of Service (QoS): The emphasis on fulfilling the requirements of each application underscores a commitment to improving user experience and ensuring high-quality service delivery. This contributes to the understanding of how 5G technology can be leveraged to meet diverse application needs, ultimately enhancing user satisfaction.

2. Facilitation of New Business Models: The acknowledgment of 5G's role in ensuring flexibility for new business models adds to the knowledge base regarding the intersection of technology and business innovation. Understanding how 5G networks enable the emergence of novel services and pricing structures is valuable for both academia and industry.

3. Impact on Market Competition: The recognition of 5G's potential to improve competition and subsequently influence pricing strategies contributes insights into the economic implications of 5G deployment. This knowledge is relevant for policymakers, regulators, and industry stakeholders seeking to understand the broader market dynamics associated with 5G technology.

4. Regulatory Framework Development: The acknowledgment of 5G's role in facilitating the establishment of regulatory models contributes to the understanding of governance structures in the telecommunications sector. This insight is valuable for regulatory bodies and policymakers in shaping effective frameworks to govern 5G networks.

5. Sustainability Considerations: The discussion on improving sustainability by optimizing the utilization of 5G resources and minimizing environmental impacts provides a valuable perspective on the intersection of technology and environmental responsibility. This contributes to the growing body of knowledge on the role of telecommunications in sustainable development. Overall, the content adds depth to the understanding of how 5G technology goes beyond technological advancements, influencing user experiences, business models, market dynamics, regulatory frameworks, and sustainability practices. These contributions collectively enrich the existing body of knowledge in telecommunications and provide a foundation for further research and exploration in this rapidly evolving field.

6.3 Limitations of the system

While the framework presented above offers valuable insights into the potential benefits and contributions of 5G technology, it is essential to acknowledge certain limitations that may impact its applicability and effectiveness. These limitations include:

1. Implementation Challenges: The transition to a 5G infrastructure may face practical challenges during implementation, such as the need for significant investments, the deployment of new hardware, and potential disruptions to existing networks. These challenges can impede the smooth realization of the framework's envisioned benefits.

2. Interoperability Issues: Integration with existing networks and technologies may pose interoperability challenges. Ensuring seamless communication and compatibility between diverse systems and devices can be complex, affecting the overall effectiveness of the proposed framework.

3. Security Concerns: The increased complexity of 5G networks may introduce new security vulnerabilities. As the framework emphasizes flexibility and openness to new services, ensuring robust security measures becomes crucial to prevent potential cyber threats and unauthorized access.

4. Regulatory Hurdles: The framework relies on the establishment of regulatory models. However, the development and implementation of such regulations may encounter bureaucratic delays, conflicting interests among stakeholders, and challenges in adapting regulatory frameworks to rapidly evolving technological landscapes.

5. Resource Limitations: Despite the aim to improve sustainability by optimizing resource utilization, there may be practical limitations. The availability of resources, such as energy-efficient technologies and sustainable materials, could impact the actualization of sustainability goals within the framework.

6. User Adoption Challenges: The success of new business models and improved competition depends on user adoption. Convincing users to embrace new services or adapt to changes in pricing models may encounter resistance, affecting the framework's ability to deliver the envisioned benefits.

7. Geographical Disparities: The deployment of 5G networks may not occur uniformly across regions. Rural areas or developing countries like us here in Zambia may experience delays in adopting 5G technology due to infrastructural limitations, potentially exacerbating digital divides.

8. Unintended Consequences: Introducing novel technologies and business models can have unintended consequences. These may include social, ethical, or economic implications that were not initially foreseen, requiring ongoing monitoring and adaptive strategies.

9. Technological Evolution: The rapid evolution of technology may render certain aspects of the framework obsolete or in need of continuous adaptation. Keeping up with technological advancements is essential to maintain the framework's relevance over time.

10. Ethical Considerations: The framework's impact on privacy, data security, and ethical considerations associated with the deployment of advanced technologies should be thoroughly examined. Failing to address these ethical concerns may lead to public distrust and regulatory scrutiny. Understanding these limitations is crucial for researchers, policymakers, and industry practitioners to approach the implementation of the framework with a realistic perspective and develop strategies to mitigate potential challenges.

6.4 Future works

Additional investigation is imperative to advance a groundbreaking exploration of computational processing and orchestration frameworks tailored to meet the demands of enhanced performance, resilience, and global standardization for 5G and upcoming mobile networks. Our forthcoming research endeavors will concentrate on the comprehensive integration and execution of the entire 5G-horizontal Orchestrator, spanning from conceptual model delineation to the implementation of all constituent blocks within its architecture. The objective is to establish a comprehensive framework, subsequently mitigating regulatory hurdles and enhancing business models. This aims to facilitate the expansion and refinement of 5G networks and beyond, fostering improved performance in the realm of mobile communication technologies.

6.5 Chapter Summary

The chapter underscores the critical need for further research to pioneer computational processing and orchestration structures, specifically tailored to meet the performance, resilience, and international standardization requirements of 5G and next-generation mobile networks. The focus of future work will be on the integration and implementation of the complete 5G-horizontal Orchestrator, spanning from conceptual model definition to the execution of all architectural components. The overarching goal is to establish a comprehensive framework that not only reduces regulatory barriers but also enhances business models. This, in turn, aims to facilitate the expansion and improvement of 5G networks and beyond, contributing to advancements in the performance of mobile communication technologies.

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APPENDICES

Appendix A

This appendix contains supplementary data to the set of rules used in the experiment.

Table A1. Representation of the logic applied to the experiment: Rules from 1 to 40.

				IF								THEN		
	Latency	**Reliability**				**Data Rate**		**Range**				**mos**		
RULE Low	**Medium**	**High Low**	**Medium**	**High**	**Low**	**Medium**	**High Low**	**Medium**	**High**	**Bad**	**Close to Good**	**Good**	**Close to Great**	**Great**
1		J J			J		J			√				
2		J J			J			J		√				
3		J J			J				J		√			
4		J J				J	J			√				
5		J J				J		J		√				
6		J J				J			J		√			
7		J J					J J				√			
8		J J					J	J			√			
9		J J					J		J			√		
10		J	J		J		J			√				
11		J	J		J			J		√				
12		J	J		J				J		√			
13		J	J			J	J			√				
14		J	J			J		J			√			
15		J	J			J			J		√			
16		J	J				J J				√			
17		J	J				J	J			√			
18		J	J				J		J			√		
19		J		J J			J				√			
20		J		J J				J			√			
21		J		J J					J			√		
22		J		J		J	J				√			

23		J			J		J		J			√			
24		J			J		J			J			√		
25		J			J			J J					√		
26		J			J			J	J				√		
27		J			J			J		J			√		
28	J		J			J		J			√				
29	J		J			J			J			√			
30	J		J			J				J		√			
31	J		J				J	J				√			
32	J		J				J		J			√			
33	J		J				J			J			√		
34	J		J					J J				√			
35	J		J					J	J				√		
36	J		J					J		J			√		
37	J			J		J		J				√			
38	J			J		J			J			√			
39	J			J		J				J			√		
40	J			J			J	J				√			

Appendix B

Table A2. Representation of the logic applied to the experiment: Rules from 41 to 81.

RULE						IF								THEN		
		Latency			Reliability			Data Rate		Range				mos		
	Low	Medium	High	Low	Medium	High Low		Medium	High Low	Medium	High	Bad	Close to Good	Good	Close to Great	Great
41		J			J			J		J			√			
42		J			J			J			J			√		
43		J			J				J J					√		
44		J			J				J	J				√		
45		J			J				J		J			√		
46		J				J J			J				√			
47		J				J J				J				√		
48		J				J J					J			√		
49		J				J		J	J					√		
50		J				J		J		J				√		
51		J				J		J			J			√		
52		J				J			J J					√		
53		J				J			J	J				√		
54		J				J			J		J				√	
55	J			J			J		J					√		
56	J			J			J			J				√		
57	J			J			J				J			√		
58	J			J				J	J					√		
59	J			J				J		J				√		
60	J			J				J			J				√	
61	J			J					J J					√		
62	J			J					J	J					√	
63	J			J					J		J				√	
64	J				J		J		J					√		
65	J				J		J			J				√		

66	J				J		J				J				√	
67	J				J			J	J					√		
68	J				J			J		J				√		
69	J				J			J			J				√	
70	J				J				J J						√	
71	J				J				J	J					√	
72	J				J				J		J					√
73	J					J J			J					√		
74	J					J J				J					√	
75	J					J J					J				√	
76	J					J		J	J						√	
77	J					J		J		J					√	
78	J					J		J			J					√
79	J					J			J J						√	
80	J					J			J	J						√
81	J					J			J		J					√