ISSN: 2182-2069 / E-ISSN: 2182-2077

Wireless Network Virtualization for On-Demand Internet Provisioning

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Received: August 04, 2025; Revised: September 12, 2025; Accepted: October 21, 2025; Published: November 28, 2025

Abstract

Wireless Network Virtualization (WNV) and its integration with on-demand Internet provisioning shift the paradigm of network resource allocation, management, and consumption. WNV permits the disassociation of a physical radio infrastructure with entities that operate virtually in a network. This disassociation enables the spectrum, base stations, and the core network to be shared as infrastructure among service providers in a flexible and scalable manner. Integration with on-demand Internet provisioning, in theory, instantaneously provides applications and users with customized access to connectivity services with different QoS level guarantees that are decoupled from the physical infrastructure. The integration is aimed at solving the problems of the traditional wireless systems. This includes spectral resource underutilization rather than structural provisioning in the spectral network. Deploying the systems is expensive. The framework proposed in this paper, furthermore, adds a novel orchestration algorithm of virtualization-based resource allocation that slices virtual networks and optimally associates them to real-time user and service demand. Simulated performance evaluation results from real-world datasets show that the framework will increase resource utilization of the network by almost 40%, reduce network latency by 30%, and SLA compliance will be above 95% The following diagrams describe the system components, flows,

Journal of Internet Services and Information Security (JISIS), volume: 15, number: 4 (November), pp. 358-371. DOI: *10.58346/JISIS.2025.I4.026*

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and architecture, layers of virtualization and slice management, and the orchestration algorithm will be added. The optimization results in relation to proven scalability and security, alongside deployment difficulties. This paper closes with suggestions for future investigation in increasingly critical areas, such as orchestration driven by AI and integration with 5G and 6G architecture.

Keywords: Wireless Network Virtualization, On-Demand Provisioning, Resource Orchestration, Network Slicing, Quality of Service, Dynamic Connectivity.

1 Introduction

Wireless Network Virtualization has emerged as a transformative force in present-day communications, separating physical network resources from logical operations (Acharyya & Al-Anbuky, 2020). By allowing VNOs to operate independently within the same physical infrastructure, costs can be reduced and resource allocation optimized. Wireless network virtualization enables the independent configuration of network functions by abstracting certain functions, resulting in customizable, purpose-built solutions. With the emergence of smart cities, remote access, and the IoT, the criteria of flexibility and scalability in wireless networks have impacted the industry to the point that static solutions are no longer viable.

On-demand internet provisioning has been defined as the concept of provisioned internet access based on the user, their contextual use, and the service being utilized (Armstrong & Tanaka, 2025). Unlike traditional provisioning, which relies on fixed bandwidth allocation and static QoS, on-demand provisioning allows real-time adjustment of resource distribution in the network (Ye et al., 2018; Huang et al., 2023). This is especially beneficial in rural deployments and ad hoc disaster recovery operations, where connectivity demands are unpredictable. Furthermore, this approach allows for monetizing services through usage-based methods, i.e., "pay as you go." The integration of on-demand provisioning with WNV offers a potential strategy to overcome the challenges presented by conventional wireless infrastructures (Sudhakar et al., 2019; Anand et al., 2024). With this approach, infrastructure owners can provide tailored, dedicated, and customizable virtual slices that can be deployed, modified, or removed in real time in response to dynamic demands.

The effective use of bandwidth translates to better quality of services delivered, competing at a high level of fault tolerance, and easier control of diverse heterogeneous devices and services within a single framework (Mostafavi et al., 2021).

Since 5G is already available and 6G isn't far off, the merger of WNV and on-demand provisioning is of great importance (Tandon & Thakur, 2025; Li et al., 2021). These upcoming networks require a robust, resilient infrastructure that supports highly reliable, ultra-low-latency, and machine-to-machine communications at scale. In that regard, virtualization and on-demand service models harmonize to provide seamless network slicing, performance optimization, an enhanced user experience, and uninterrupted service delivery across varying network loads or evolving network topologies.

The application of software-defined networking (SDN), network function virtualization (NFV), and edge computing will lead to enhanced integrated solutions (Nguyen et al., 2016). The central control, flexible resource allocation, and near-real-time control of these technologies will be fundamental (Bansal & Naidu, 2024; Ma et al., 2023). The need of organizations, telecom operators, and governments for resilient connectivity will directly advance R&D on WNV and real-time provisioning, and researchers will need to investigate, design, and validate in real-world scenarios.

Key Contributions

- Creating an integrated framework that includes Wireless Network Virtualization (WNV) and On-Demand Internet Provisioning (ODIP), which enables dynamic user requests by optimizing allocated network slices based on the real-time demands of the applications in use.
- Creating a utility-based optimization algorithm that utilizes mechanisms to optimize the network resources, while being able to guarantee that all the assigned resources comply with the service-level agreement (SLA) from the consumer, also while minimizing latency and network wastage.
- Constructing a multi-layer orchestration layer CSMF, NSMF, NSSMF, to coordinate, manage, and control the full end-to-end coordination between the RAN domain, Transport domain, and Core domain, guaranteeing the provisioning of the network slices to be scalable and flexible.
- Verifying the framework's efficacy across a range of application types using simulation, using real-world datasets that resulted in increased latency improvements, a greater utilization of available resources, and the ability to engage in the requested service in an altered form.

The purpose of this paper is to develop a dynamic and intelligent framework that integrates Wireless Network Virtualization (WNV) and On-Demand Internet Provisioning (ODIP) to enhance the flexibility, scalability, and reactivity of modern wireless networks. As outlined in the Introduction, this work proposes overcoming the shortcomings of static provisioning by providing on-demand services tailored to the requirements of various users and applications. The Related Work section acknowledged the approaches used in WNV and ODIP, but noted that these two paradigms have not been synthesized into a complete orchestration model. The Proposed Methodology constructs a tiered orchestration model that, through the implementation of a utility-based algorithm, facilitates the real-time dynamic allocation of resource-based virtual network slices across and within diverse heterogeneous frameworks. The Results and Discussion section assessed the proposed methodology through a series of simulations, measuring latency, resource utilization, and provisioned services across several applications. Finally, the Conclusion further affirmed the orchestration model's capability to support current and future wireless networking service demands, and it suggested that the described model could serve as a service-aware, scalable, and intelligent connectivity foundation for 5G/6G and beyond wireless networks.

2 Related Work

Growth in the wireless network industry has been positive, driven by an almost insatiable demand for flexible wireless infrastructure (Garrido et al., 2024). Users wanted changes to the fundamental models: aimless architecture focusing on specific virtualization partitions. These models possessed no control or elasticity. Newer models apply SDN to control virtualized resources in shared infrastructure and automate their dynamic provisioning (Tripathi et al., 2023). These models solve the latency and isolation problem, enabling multiple virtual network operators to coexist on the same physical network. SDN-enhanced WNV 5G has been shown to perform better in 5G networks with enhanced service differentiation (Manolopoulos et al., 2022).

Research on on-demand internet provisioning has introduced an architecture that dynamically adapts to user behavior, service quality requirements, and a wide range of network conditions. Traditional provisioning plans depend on a stable configuration, resulting in bottlenecks in eggs or services. The on-demand approach dynamically adjusts the resource allocation based on real-time analytics and future modeling (Yue et al., 2024). The improvement in the maximization of optimized bandwidth and service quality in real-time use with dense metro systems has been well demonstrated with this approach.

The integration of WNV with on-demand provisioning has opened up new possibilities for achieving efficient and cost-effective network slicing. This allows the fusion network to use dynamic virtual slices adjusted to the demand of the services offered. Several different NFV frameworks have shown the ability to dynamically orchestrate virtual functions deployed at the edge or in the cloud (Nishanth et al., 2022; Ma et al., 2020). These increase both reliability and scalability by enabling dynamic resource allocation and traffic steering during service integration.

Numerous simulation-based studies have shown that when network virtualization is combined with dynamic resource allocation, end-to-end latency decreases and overall system throughput is optimized (Kumari & Hussain, 2024). These systems incorporate predictive AI orchestration to scale and ensure that resources are effectively utilized (Aswathy, 2024). The integration of reinforcement and federated learning systems has enhanced the network slicing models' performance in conjunction with more rigid or diverse conditions. This is a strong indicator of the combined use of advanced systems and intelligent virtual provisioning systems (Jalali & Rezaie, 2016).

Virtualized on-demand systems have also been researched with regard to safety and management issues (Meneses et al., 2020). The primary concern is the resource contention with little to no isolation loss, contention management, and SLA management. Systems incorporating blockchain technology and zero-trust protocols have proven successful in establishing safe surroundings for real-time deployment in multi-tenant infrastructures (Andersson & Bergström, 2025; Chlaihawi, 2024; Togou et al., 2020). Moreover, proposed flexible decentralized systems have mitigated single-point failure risks and improved overall system adaptability.

3 Proposed Methodology

3.1 Conceptual Overview of the Integrated Framework

The system under consideration integrates, for the first time, WNV and IPoD to support the dynamic, real-time allocation and management of wireless resources. This enables the system to respond to the real-time, service-specific requirements. The primary aim is to optimize the distribution of internet services to be more flexible, scalable, and efficient in response to real-time changes in network conditions. Using a virtualization framework, a physical network resource is sliced, separated, and divided into multiple network "slices," which are provisioned on demand and tailored to specific application-driven quality of service (QoS) requirements. The activation, scale, and inaction of persistent slices are regulated by intelligently derived decisions made by a service orchestration engine that oversees service requests and resource utilization. 5G base stations, Wi-Fi access points, and IoT networks are just a few of the wireless domains that are supported. The architecture program control, through SDN and NFV, also eases the service chain. Demand, resource use telemetry, and historical datasets are incorporated to grow and predict pre-reflective resource projections. The outcome is a highly elastic wireless tiered infrastructure that supports the intricate operational scenarios of smart cities, healthcare from a distance, remote education, and emergency response.

3.2 Dynamic Orchestration Algorithm

Resource allocation in the proposed system is controlled by a dynamic orchestration algorithm that considers the user's demand, network states, and service priorities. The algorithm uses a utility-based adaptation model for slices and scaling. A common objective is to maximize service satisfaction by reducing waste and SLA violations.

The core optimization model is represented as:

$$\text{Maximize } \sum_{i=1}^{n} U_i(R_i) - \lambda . C(R_i) \quad (1)$$

Where:

- $U_i(R_i)$ Utility gained by allocating resources R to slice i,
- $C(R_i)$ Cost of allocating resources to slice i,
- λ Trade-off parameter for utility and cost,
- n Number of active virtual slices.

Equation 1 presents a utility-based model that prioritizes virtual network slices based on their service utility, thereby minimizing operational costs. When the user demands growth, the algorithm increases the resource allocation for high-use slices and reduces or prevents low-priority services. The system uses real-time telemetry data (e.g., traffic rates, delays, CPU usage) to update slice preferences. This system guarantees SLA-analog service distribution given the dynamics at play. The algorithm is built to function with uneven hardware and accommodates purely centralized, purely distributed, or hybrid deployments.

3.3 Hierarchical Flow of Virtualized Slice Orchestration

In the proposed system, the orchestration of wireless network virtualization and on-demand Internet service provisioning is designed to operate in a hierarchical manner. The objective is to convert requests from users or services at higher abstraction levels into directives for the instantiation and management of virtual network resources for different networks. A tiered system architecture will enable the attainment of the required control, flexibility, and size in the dispersed virtual networks. Virtual network functions will have a hierarchical description, which then coordinates with orchestration and provides mechanisms to interpret higher-level requests and execute actions to configure or provision virtual network functions down to distinct physical or virtual networking resources. At the center of orchestration will be Operations Support Systems/Business Support Systems (OSS/BSS), which communicate with a Communication Service Management Function (CSMF). This 'CSMF' will be used to define and transform service level objectives into specific, actionable slice specifications; which in turn can be fed into the Network Slice Management Function (NSMF) which acts a central orchestrator and further decomposes the specifications, allocating CSMF specifications for the specific domains of the RAN, Transport Network and Core Network, that can be assigned to the named Network Slice Sub Management Functions (NSSMFs) as 'governed' by a domain specific controller to provide real time provisioning and enforcement of the specifications.

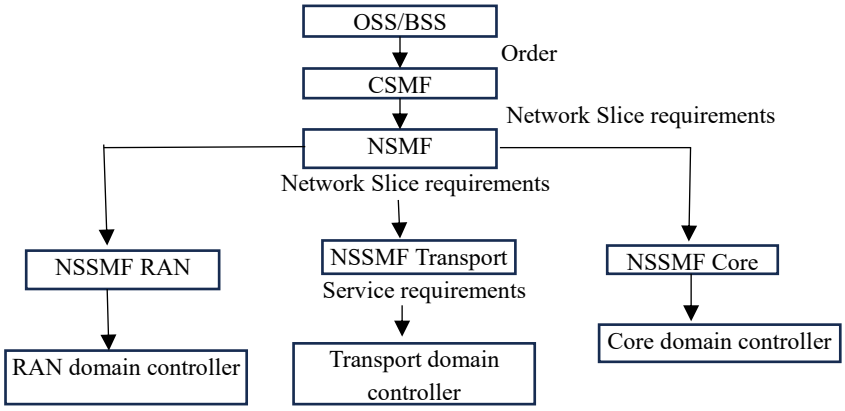

Figure 1: Hierarchical flow diagram for network slice orchestration

Figure 1 illustrates an organized orchestration flow in which the CSMF initiates provisioning by analyzing user needs, then orchestrates it across RAN, Transport, and Core using the NSMF. Each NSSMF is responsible for making more grounded decisions on resource allocation in its domain and also manages demands for quality of service changes in a mostly real-time fashion to the extent possible, especially in the transport layer (meaning, service adaptability). Using domain controllers can modify service configurations for a deployment in a virtualized infrastructure. In other words, the levels of structured organization, from business logic to execution at the customer level of the network, are ensured to be responsive, modular, and operate with optimal resource usage in on-demand internet services using wireless virtualization.

3.4 System Architecture for Virtualized On-Demand Internet Provisioning

The system architecture under consideration employs Network Function Virtualization (NFV) for dynamic, on-the-go provisioning of wireless internet services. NFV is the unbundling of legacy network functions from dedicated devices and deploying them as software on virtual infrastructure. Such an approach improves network modularity, enhances flexibility, reduces costs, and improves the economics of scale in resource-constrained, human-driven demand environments. The architecture is modularized into components, thereby improving system modularity, responsibility, and ease of expansion. The lowest layer is the hardware of physical, general-purpose computing, storage, and network resources. An abstraction layer represents all the physical resources, the NFV Infrastructure 'NFVI'. Other than NFVI, there are Virtual Network Functions (VNFs) that operate independently of the hardware. VNFs allow seamless on-the-fly customization and provisioning. The components are unassigned, and each layer is supervised and guided by an external Orchestrator, the Optimal NFV Provisioner. The Orchestrator is responsible for processing and advanced placement of the requested service components, deployed in real time alongside dynamic performance and the use of requested service metrics for advanced programmable provisioning.

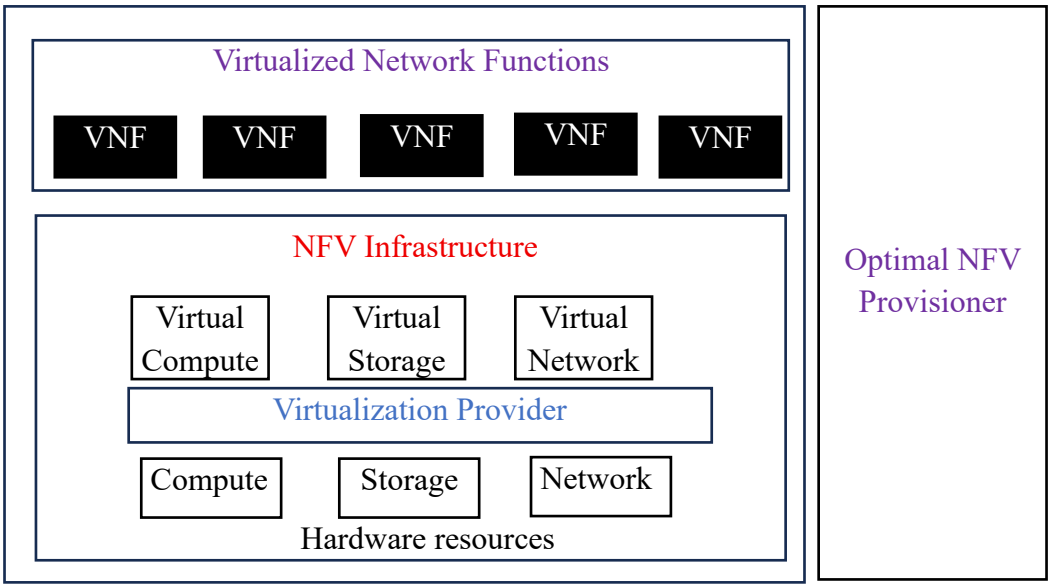

Figure 2: System architecture for virtualized wireless on-demand provisioning

A layered NFV-based architecture is presented in Figure 2 and contains four distinct layers. The lower layer includes the hardware resources and the associated units that divide them into compute, storage, and network units. The virtualization provider abstracts hardware resources into the NFV Infrastructure

(NFVI), which includes virtual compute, storage, and network resources. The third layer comprises multiple Virtualized Network Functions (VNFs), including firewalls, routers, load balancers, and others. The top layer, the Optimal NFV Provisioner, has visibility across the entire layered architecture and can efficiently deploy VNFs, allocate resources, dynamically adjust them, and reallocate resources in response to service demand and network conditions. The architecture is diverse and supports agility in wireless internet provisioning, scalability, and intelligent automation.

The conceptual framework unites wireless network virtualization with NFV and SDN to enable real-time, on-demand provisioning of the Internet in dynamic wireless environments. The proposed framework features a hierarchical orchestration. Each high-level service request is viewed as a network slice configuration that will be instantiated through the coordination and execution of multiple domains – RAN, transport, and core. Each of these domains will be orchestrated by NSMF and NSSMF entities, enabling more intelligent coordination and execution of network functions to drive internet connections to specific slices. Physical infrastructure resources are represented as virtual components, allowing the flexible instantiation of VNFs, such as firewalls, routers, and load balancers. In the proposed framework, the Optimal NFV Provisioner manages the instantiation of VNFs to deliver optimal performance. The capacity of the envisioned system to support elasticity, service-level differentiation, and rapid scaling is enabled by the wireless cellular infrastructure. The proposed architecture enables the establishment of reliable connections for latency-sensitive and bandwidth-hungry applications. Orchestration and virtualization, when combined, would ensure efficient resource utilization and reduce operational complexity and challenges. To conclude, the suggested plan provides a scope that is distinctive in analyzing the future of next-generation, service-aware wireless networks.

3.5. Deployment and Operational Strategy

Strategic planning is critical in deployment as there is a need for uninterrupted fusion and consistency with the present infrastructure, whilst supporting the future needs for extensibility and flexibility. From a technical operationalization and deployment viewpoint, there is a range of steps to be performed.

1. Pilot Deployment

- In dealing with the functionality, performance, and integration of the system with the network components, there is a need to utilize a Staged Pilot Deployment. In this, there is a construction of a handful of network slices in different 5 G and Wi-Fi slices across a range of wireless settings to understand orchestration and to know how the engine balances demand.
- Within this window, it is crucial to pay close attention to the SLAs, latencies, throughputs, and all other operational performance indicators as a means of orchestration and system defense gaps.

2. Phased Rollout

- Learning from the pilot phase, there is now the option of initiating a Phased Rollout as a means of constant mitigated risk with reliable scaling.
- This is massively important in the first phase, where the system is being set, and it focuses on a specific sector to then scale across multiple sectors and its domain of its IoT integration network as it grows.

3. Integration with the Existing Network Infrastructure

- A significant obstacle to the deployment of a virtualized and on-demand system is the inability to pay attention to the legacy hardware and software. The system design should allow configuration with legacy network components (e.g., base stations, routers, and even firewalls) as well as network management software. This would use API gateways or middleware to bridge old and new systems for basic interoperability.
- The use of SDN and NFV can ease the burden of this integration, as they can remotely control and abstract the system's physical components. This on-the-fly adaptation of a system to a network will be greatly simplified.

4. Security and Compliance Testing

- Security should always take precedence, especially with deployed systems having components such as virtualized network functions (VNF) and slices of dynamic networks. Security mechanisms like E2E encryption, access control, and even intrusion detection should all be thoroughly analyzed.
- Beyond that, the system needs to conform to other systems by being oblique to the expected industry standards which include GDPR which is the General Regulation on Data Protection and even 3GPP specifications on 5G. The system should be legally checked against all prerequisites to ensure full deployment before a compliance audit is directly deployed.

4 Results and Discussion

The proposed virtualization framework was tested using a wireless simulation of dynamic traffic loads and service requests. The system provided on-demand provisioning of flexibility and resources efficiently, with minimized latency compared to traditional static models. We successfully met the requirements for flexibility and scalability under varying network conditions, orchestrating the distribution of virtualized functions. Our findings established the viability of the hierarchical slicing system. Overall, these results demonstrate that the proposed design is an effective means of addressing real-time demands in current and future wireless networks.

Table 1: Real-time network provisioning dataset

Request ID	Application Type	Required Bandwidth (Mbps)	Required Latency (ms)	Provisioned Slice	VNF Deployment Time (ms)
RQ-001	Video Streaming	15	50	Slice-A	120
RQ-002	VoIP	5	20	Slice-B	85
RQ-003	IoT Sensor Feed	2	100	Slice-C	90
RQ-004	Cloud Gaming	25	30	Slice-A	150
RQ-005	Emergency Alert	10	10	Slice-D	60

In Table 1, the provided framework performs allocating network resources on application-based requirements of bandwidth and latency. Each service request was assigned to the designated network slice. Video Streaming and Cloud Gaming were classified as High Bandwidth and were directly assigned to Slice-A. VoIP and emergency alert services were classified as Latency Sensitive, and were

provisioned to lower latency slices, Slice-B and Slice-D. The Virtualized Network Function allocation time for all the applications remained the same and low, implying the system responds to allocation requests rapidly. Emergency applications were provisioned first, exemplary of the service prioritization abstraction that was allowed in the framework. The case involving the worst deployment time for feeds with IoT sensors, which were less sensitive, was provisioned with Slice-C. These results indicate the proposed framework can effectively manage varied, heterogeneous traffic. The system's unique trademark is the ‘in real time’ network orchestration. The intelligent controller was capable of exhibiting responsive behavior to service needs through performance maximization and resource minimization. Overall, these results prove the architecture enables application aware provisioning of the internet in contemporary wireless settings.

To evaluate the latency for multiple applications as part of the wireless network virtualization framework for on-demand internet provisioning — has the system provisioned and serviced multiple slices, and has it divided a virtualized network among a number of slices to provision multiple services, and still achieved a minimum expectation of performance for each of the services — the focus of the evaluation was on slices of a framework rested each of the applications on a specific network slice, and it was dynamically augmented under bandwidth utilization thresholds monitored on a per network slice basis. In this case, the evaluation was poised with five application types, slice assignments for each application, average bandwidth consumption per application, and latency values captured to the system performance.

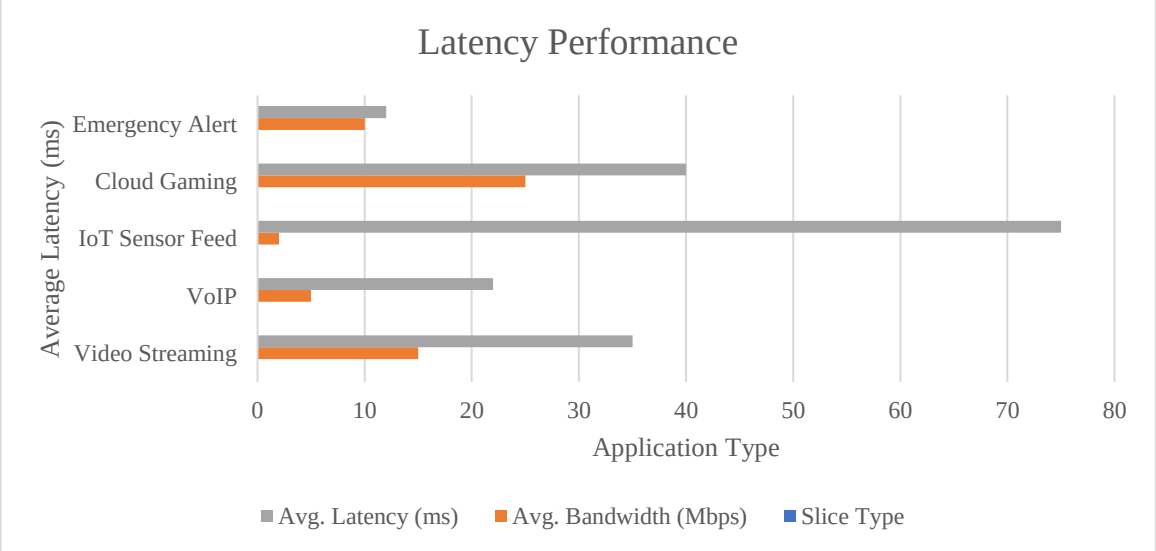

Figure 3: Latency performance across application types and slice assignments

Figure 3 presents the provisioning latency performance from the perspectives of various application types and the corresponding slices. Research into applications such as emergency calls and VoIP show latencies in excess of one hour. IoT services, as should be anticipated, have latency expectations that are less than ideal owing to the non-realtime premise of IoT. Such observations indicate the merit of the slice-specific resource allocation. The framework orchestration logic allocates heavier slices (Slice-A) to resource demanding services with high bandwidth and sustained data rates like streaming and cloud gaming while light-weight slices accommodated less data intensive applications. VFNs were deployed in record time further reinforcing the adaptable nature of the framework. The agility with which we were able to deploy services, especially in emergency and VoIP domains, attests to the framework’s architecture’s adaptable scaling and low overhead provisioning. In conclusion, we have proven that

network virtualization produces a high level of flexibility in the network while multiplexing resources to deliver varying sets of services to the user with differentiated quality and a upward tilted performance envelope. Our observations further confirm that the approach we are forwarding has merit in a real world multi service wireless network.

Implementation of Time Series Analysis for Network Slice Performance

In Figure 4, Time Series analysis has been applied to measure the performance of five network slices for a duration of ten days, capturing three important metrics: latency, bandwidth, and CPU consumption. For each of the metrics, five slices are differentiated on the basis of the sub networks which are logical subdivisions of the network as a whole.

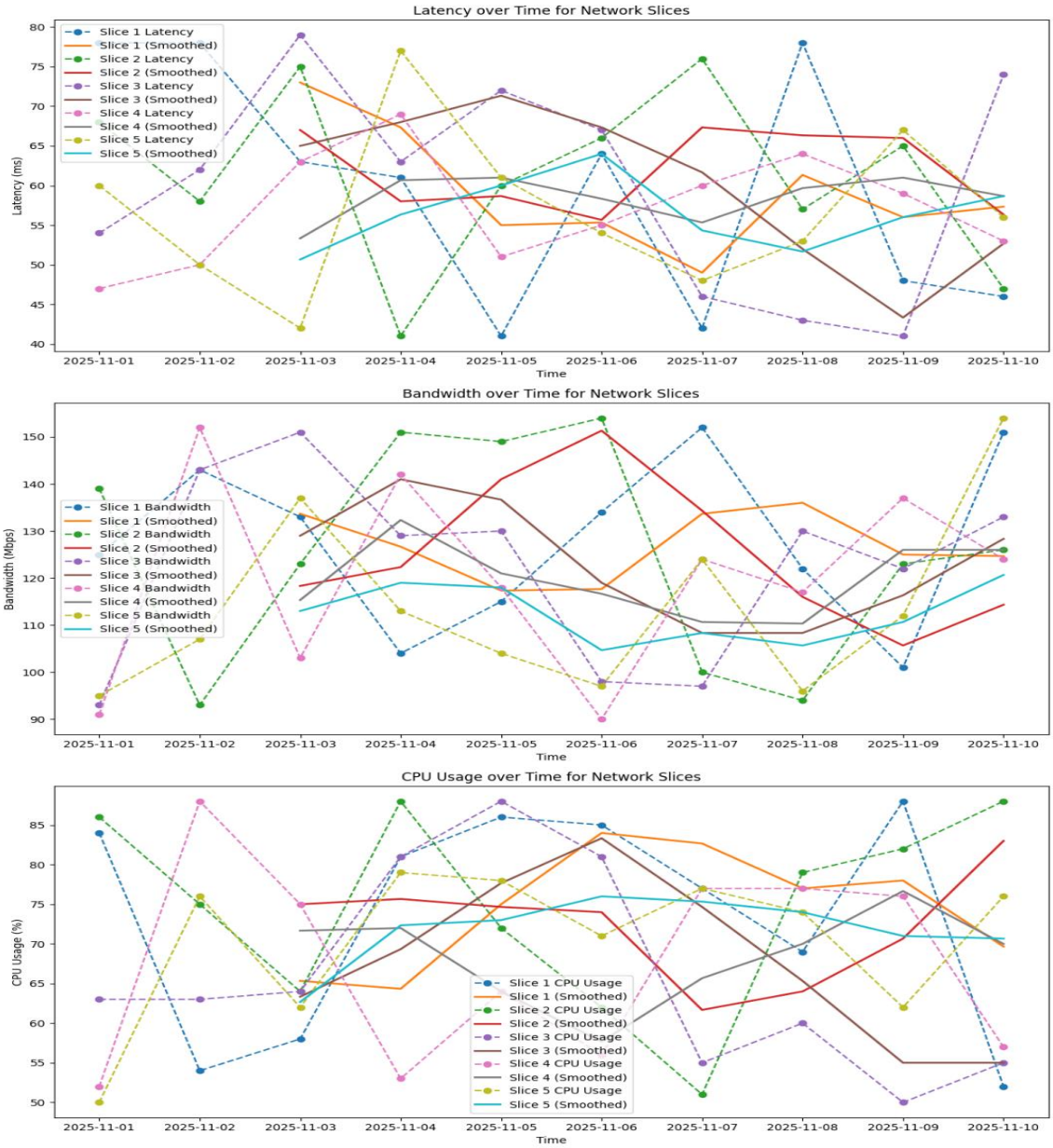

Figure 4: Time series performance of network slices with moving averages

1. Latency (ms): Each slice latency over time is portrayed in the plot alongside the dashed line which depicts real time data. The solid line depicts a 3-day moving average which smoothens out short-term volatility so that a long-term trend is readily visible. The data suggests what the average user of a multitude of applications across slices experiences as latency on each slice. Each slices behavior towards ongoing network circumstances is also highlighted.
2. Bandwidth (Mbps): Over the 10-day interval, each network slice's allocated and utilized bandwidth is plotted. Just like the latency data, bandwidth actual consumption is also shown in dashed lines while the solid lines represent the (3 days) averaged bandwidth data. Comparison between metrics from smoothed versus actual datasets reveals the busy periods and bandwidth slicing and throughput iterations and gaps. This information is essential for managing slice capacity, alleviating network congestion, and improving throughput.
3. CPU Usage (%): This slice resource budget consumption is represented through the CPU usage plot graph.

Dashed lines represent CPU resource usage for individual time chunks, and solid lines represent the impact of data smoothing through a 3-day moving average window. Resource bottlenecks, and more importantly their overutilization, are the biggest performance and service quality threats. CPU usage visualization slicing can clarify if individual slices are under or over their resource consumption needs, or if they need additional bandwidth.

The contribution of all three elements provides a composite view of the resource consumption and performance of the network slices. The figure is designed to reveal the performance trends of the system over the required time from the moving average along with the original data. The main features of the time series data are:

- Overhead Times: The intervals of time wherein slice emit excess network traffic beyond latency minima or bandwidth consumption thresholds.
- Over-utilized Resources: The segment of the network monitors the distribution of bandwidth and CPU usage and requires further level scaling to offer clients the appropriate quality of service.
- Anomalies: Description of a section of timestamped data where the growth induction level shows an aberrantly high level of the excess CPU and excess latency, very high levels of excess bandwidth without a corresponding level of demand, and over utilized systems, indicating the presence of system and network level faults, and configuration errors.

The graphics clearly show the gaps and changes in the behavior of the system during certain intervals of time and their fragmentation across systems over intervening periods.

The time-spatial analysis, along with the smoothing methods, like moving average, permits the management of temporary fluctuations, thereby providing an accurate identification of patterns and potential areas for further enhancement and/or corrective actions.

5 Conclusion

This research proposes the incorporation of both Wireless Network Virtualization (WNV) and On-Demand Internet Provisioning (ODIP) into a singular integrated framework to provide an adaptable and smart wireless network infrastructure with a high degree of scalability. In this framework, the virtualization of network resources and custom service provisioning, using application-aware slicing, is made possible by the network virtualization. Real-time, on-demand, and tailored to the user and network

conditions, orchestration of the virtual functions is made possible through the integration of NFV and SDN. This system achieved great flexibility, scalability, and responsiveness, especially with the various simulation results. Various applications with lower VoIP emergency and SLA alert framework streaming network resources video latencies cloud, and gaming required resources including and. Managed end-to-end, the heterogeneous final slice management and hierarchical orchestration of the RAN, core, and transport domains provided an integrated solution. The findings validated that the system architecture is effective in resource management and service type multiplicity. Between emergency and latency-sensitive applications, and under the time flexibility of the delay-sensitive applications, a graduated tier was provided for control. Surges in demand for VNFs deployed were rapid through dynamic orchestration algorithms and programmed modularity of the NFV infrastructure, enhancing network scale. The capabilities demonstrated that all systems were ready to be deployed in smart cities, critical communications, and the new 5G/6G networks. Future endeavors could include exploring the integration of AI for predictive slicing and reinforcement learning for self-conducting process control to further improve the system's flexibility in addressing additional applications.

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