A Sustainable 6G Communication Framework for Reliable D2D and V2X Services via Network Slicing and NFV

Dr. Shubhi Jain[1], Dr. P. K Singhal[2]

[1]Associate Professor, Department of Electronics and Communication Engineering, Swami Keshvanand Institute of Technology & Management & Gramothan, Jaipur, Rajasthan, Pincode 302017, India
Shubhijain19@gmail.com
[2]Professor, Department of Electronics and Communication, Madhav Institute of Technology & Science, Gwalior, Madhya Pradesh, Pincode 474005, India
pks_65@mitsgwalior.in

ABSTRACT

Sixth-generation (6G) communication networks are expected to enable intelligent, ultra-reliable, and energy-efficient wireless connectivity for emerging mission-critical applications. Among these, Device-to-Device (D2D) communication and Vehicle-to-Everything (V2X) services impose stringent requirements in terms of ultra-low latency, high reliability, massive connectivity, and dynamic quality-of-service (QoS) provisioning. Conventional monolithic network architectures are inadequate to support such heterogeneous service demands in a scalable and sustainable manner. This paper presents a sustainable 6G communication framework that integrates network slicing and Network Function Virtualization (NFV) to enhance the reliability, flexibility, and energy efficiency of D2D and V2X communications. The proposed framework enables the logical partitioning of a shared physical infrastructure into multiple service-oriented network slices, each tailored to specific application requirements such as safety-critical vehicular communication, high-throughput infotainment, and proximity-based D2D services. NFV is employed to virtualize core and edge network functions, allowing dynamic deployment, adaptive scaling, and efficient orchestration of network resources while reducing hardware dependency and operational energy consumption. Simulation-based performance evaluation demonstrates that the proposed architecture achieves significant improvements in end-to-end latency, packet delivery reliability, resource utilization, and energy efficiency compared with traditional monolithic network designs. The results confirm that the joint adoption of network slicing and NFV is a key enabler for building sustainable, resilient, and future-ready 6G networks capable of supporting next-generation D2D and V2X services.

KEYWORDS: 6G network, Communication technology, Device-to-Device (D2D), Network slicing, Network Function Virtualization (NFV), Vehicle-to-Everything (V2X).

INTRODUCTION

1.1 Background and Motivation

The development of 6G communication networks is necessitated by the increased need of smart, high-reliability, and extremely low-latency communication to provide new digital services. The use of applications like proximity-based Device-to-Device (D2D) communication and Vehicle-to-Everything (V2X) services is likely to become one of the main aspects of smart cities in the future, autonomous transportation systems, and real-time cyber-physical environment. These applications have very high performance requirements in terms of latency, reliability, scalability and energy efficiency and the operational ability of current network architectures cannot compare to such.

D2D communication allows direct exchange of data between immediate devices and thus minimising transmission delays and congestion in the network and V2X communication allows real time communication between vehicles, infrastructure, and other road users. The co-existence of these heterogeneous services using a common network infrastructure, however, creates significant issues in the QoS differentiation, dynamically allocated resources, and long-term sustainability. The solution to these challenges is necessary in order to facilitate effective and trusted communication in the 6G environments in the future.

1.2 Problem Statement

Although the 6G technologies have great potential, existing network designs still are quite monolithic and hardware-based and cannot be flexibly adapted to support heterogeneous and mission-critical apps, including D2D and V2X communications. The current mechanisms of allocation of the resources available to the system cannot address dynamic traffic patterns, high mobility and service requirements. Furthermore, the growing interconnection of network infrastructure and computing resources contributes to greater energy use and complexity of work, which creates serious sustainability questions. As a result, it is of paramount importance to have an open and versatile, service-conscious and energy-efficient architecture design that can support the dependable D2D and V2X communication in 6G networks.

1.3 Enabling Technologies Network Slicing and NFV.

Network slicing and Network Function Virtualization (NFV) have become the two most important enabling technologies to overcome the constraints of traditional network architecture. Network slicing enables logical separation of a physical infrastructure that is shared by many into many virtual networks each of which is configured to meet certain service specifications. The feature allows the isolation and optimization of resources to latency sensitive and reliability sensitive applications, including V2X and D2D services. NFV supports the concept of network slicing by separating the network functionality and specialized hardware to support the dynamic deployment, scaling, and efficient use of network resources. The joint implementation of both network slicing and NFV offers the flexibility and adaptability needed to run sustainable work in the 6G network.

1.4 Aims of the Proposed Framework.

The main aim of this task is to develop a sustainable 6G communication architecture that will offer effective and dependable support to the D2D and V2X services. The suggested framework would facilitate service-oriented network slicing that has the ability to support heterogeneous QoS requirements, shorten end-to-end latency of mission-critical communications, enhance resource utilization and energy efficiency associated with NFV-based virtualization, and provide scalability and adaptability in case of dynamically changing network conditions.

1.5 Novelty and Contributions

The innovative aspect of this work is that network slicing and NFV are used simultaneously to tackle the reliability, efficiency, and sustainability issues of 6G-enabled D2D and V2X communication. Contrary to the current methodologies, which look at these technologies as stand-alone and independent, the proposed framework looks at coordinated slice and virtualized function orchestration. The key contributions in this paper are design of an integrated and power-efficient 6G architecture to support D2D and V2X services, development of service-conscious slicing strategy to meet the needs of the heterogeneous performance, the design that depends less on hardware and operates less is implemented based on NFV, and the overall performance evaluation that proves the decreased latency, increased reliability, resource usage, and energy consumption.

1.6 Organization of the Paper

The rest of the paper is structured in the following way. Section 2 entails a literature review of the related works about 6G communication, D2D and V2X services, network slicing, and NFV. Section 3 provides the proposed system architecture and methodology. The performance evaluation and results are discussed in Section 4. Lastly, Section 5 brings to an end the paper and provides future research directions.

LITERATURE REVIEW

2.1 6G Vision and V2X Communication Evolution.

The shift between 5G and beyond-5G (B5G) and 6G networks has been broadly perceived as one of the major facilitators of intelligent mobility and enhanced vehicular communication services. According to recent research, the 6G architecture will be required to offer ultra-reliable and low-latency communication, massive connectivity, and sustainable operation to meet new V2X requirements [1], [3], [5]. All these works underscore the need to incorporate communication, sensing, and intelligence in order to meet high mobility and safety-critical demands in driving condition. According to surveys devoted to the V2X evolution, such issues as latency sensitivity, reliability limitations, and scalability turn out to be the most prevalent challenges that are not satisfactorily solved by the current architectures [6], [10], [12].

2.2 Network Slicing of Vehicular and D2D Network Services

Network slicing has attracted significant research interest as a key mechanism for supporting heterogeneous service requirements over a shared physical infrastructure. Several studies propose slicing frameworks tailored to vehicular use cases, particularly for platooning and safety-critical services, demonstrating the effectiveness of logical isolation and service differentiation in improving reliability and latency performance [2], [8]. More recent works extend slicing concepts toward B5G and 6G ecosystems, emphasizing end-to-end orchestration, dynamic slice life-cycle management, and intelligent resource allocation strategies [4], [7], [20].

Despite these advancements, most existing slicing solutions primarily focus on vehicular communication scenarios and treat V2X services in isolation. The coexistence of D2D communication within the same sliced infrastructure is often overlooked, and the interaction between D2D and V2X traffic with competing QoS requirements is not explicitly addressed. Moreover, current approaches rarely consider sustainability and energy efficiency as integral objectives of the slicing design. In contrast, the proposed framework jointly supports D2D and V2X services within a unified slicing architecture while explicitly incorporating service differentiation, resource efficiency, and sustainability considerations.

2.3 NFV and Virtualized Network Architectures

Network Function Virtualization (NFV) has emerged as a fundamental enabler of flexibility and scalability in modern communication networks. Prior research highlights the role of NFV in decoupling network functions from proprietary hardware, enabling rapid deployment and efficient utilization of computational resources [9]. NFV-based architectures have been shown to reduce operational overhead and improve adaptability to dynamic traffic conditions in 5G and beyond networks [18].

However, much of the existing NFV-related literature concentrates on generic network optimization or cloud-centric virtualization scenarios, without explicitly addressing the joint requirements of D2D and V2X communication. In particular, the integration of NFV with service-aware network slicing remains underexplored in the context of heterogeneous, latency-

sensitive, and energy-constrained 6G environments. Additionally, sustainability aspects such as energy-aware VNF placement and adaptive resource scaling are often treated as secondary concerns. The proposed work differentiates itself by tightly integrating NFV with service-oriented slicing to support both D2D and V2X services while explicitly targeting reliability, latency reduction, and energy efficiency.

2.4 AI-Delivered and Smart Slicing in 6G

Recent studies increasingly explore the application of artificial intelligence (AI) techniques to enhance network slicing and resource management in 6G networks. Learning-based orchestration, explainable AI, and closed-loop control mechanisms have been proposed to improve reliability, adaptability, and quality-of-service assurance across network slices [11], [15], [20]. Emerging research also investigates the use of large language models and advanced AI-driven orchestration to manage complex communication scenarios, including satellite-assisted and direct-to-device communications [14], [17].

While these approaches demonstrate strong potential for intelligent network management, their application remains largely fragmented and scenario-specific. Most AI-driven slicing solutions focus on individual use cases or isolated network segments, without addressing the simultaneous coexistence of D2D and V2X services within a unified and sustainable 6G framework. Furthermore, the combined impact of AI-assisted slicing, NFV-based virtualization, and sustainability objectives is insufficiently explored. The proposed framework addresses this limitation by providing a holistic architecture that integrates service-aware slicing and NFV, creating a foundation that can be extended with intelligent orchestration mechanisms for future 6G deployments.

2.5 Sustainability and Resource Efficiency in the B5G/6G Networks.

The sustainability has become a key design requirement of the new wireless networks. Some of these research works point to the necessity of energy-conscious architecture, effective resource management, and lower communication cost in dense and heterogeneous systems [1], [13], [16], [19]. Articles on intelligent transportation systems emphasize that a sustainable V2X communication needs to balance between performance and energy consumption and cost of the infrastructure [10]. However, the majority of the available solutions use sustainability as a peripheral goal, as opposed to incorporating it into the network design as a design principle.

2.6 Research Gap and Motivation

Based on the literature reviewed, it is clear that much has been achieved in the 6G V2X communication, network slicing, NFV, and AI-based network management. Nevertheless, the available literature focuses on these aspects individually. It does not exist as a consistent and sustainable 6G architecture that actively combines both network slicing and NFV to deal with both D2D and V2X services with a comprehensive consideration of reliability, latency, scalability, and energy efficiency. The identified gap encourages the creation of the proposed framework that is supposed to offer a holistic, service-conscious, and future-proof solution in respect to the needs of next-generation communication systems.

PROPOSED METHODOLOGY

3.1 Overview of the Proposed Methodology

This section presents the proposed methodology for designing a sustainable 6G communication framework that supports reliable Device-to-Device (D2D) and Vehicle-to-Everything (V2X) services. The methodology adopts an energy-efficient and service-oriented network design that integrates network slicing and Network Function Virtualization (NFV) to address the heterogeneous quality-of-service (QoS) requirements, high mobility, and scalability challenges inherent to next-generation communication environments. Unlike traditional monolithic architectures, the proposed framework follows a virtualization-based approach in which network resources are dynamically provisioned and orchestrated in response to application demands and real-time network conditions.

The overall architecture abstracts the underlying physical infrastructure into virtualized resources that are logically partitioned into customized network slices tailored to the specific requirements of D2D and V2X services. NFV enables flexible deployment and adaptive scaling of network functions across edge and core domains, facilitating efficient resource utilization and reduced operational overhead. Figure 1 illustrates the conceptual architecture of the proposed framework, highlighting the interaction between physical resources, virtualized network functions, and service-specific network slices.
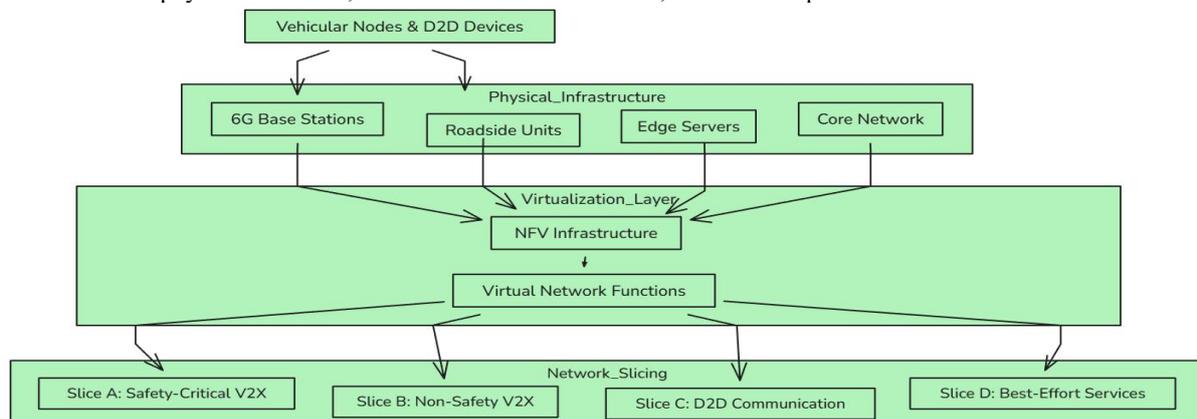
Fig. 1 Proposed sustainable 6G communication framework integrating network slicing and NFV for D2D and V2X services

3.2 System Model and Assumptions

The model system presupposes the 6G-enabled heterogeneous network setting that includes base stations, roadside units, edge servers, vehicular nodes, and user devices that work on a common physical infrastructure. Both D2D and V2X communications requests are embedded on the same network and they have varying performance needs when it comes to latency, reliability, and bandwidth. It is believed that the network will be able to fully virtualize core, access, and edge network functionality to allow the flexibility in the instantiation and migration of services. Moreover, it is also assumed that centralized orchestration bodies possess visibility of network states all around the world to be able to manage slices and allocate resources.

3.3 Service-Aware Network Slicing Strategy

Its methodology uses a service-conscious network slicing approach in order to logically divide the common infrastructure into several virtual slices. Every slice will be tailored to satisfy the requirements of particular QoS relating to each type of application, including safety-critical V2X communication, non-safety car services, and proximity-based D2D communication. Slice isolation is used to ensure that failure of one slice does not impact other slices, and hence increase reliability and predictability.

Each slice resource allocation is dynamically adjusted depending on the demand of traffic and mobility patterns and service priority. Such long-variable slicing policy permits the effective utilization of network resources with high performance guarantees on latency sensitive and reliability sensitive services.

Table 1 highlights the main network slices to be taken into account in the proposed methodology and the related service attributes.

**Table 1: Network slice configuration Service-based.**

Slice Category	Supported Service	Latency Sensitivity	Reliability Requirement
Slice A	Safety-critical V2X	Very High	Very High
Slice B	Non-safety V2X	High	High
Slice C	D2D Communication	Moderate	Medium
Slice D	Best-effort Services	Low	Standard

3.4 NFV-Based Virtualized Function Deployment

NFV is at the center of the suggested methodology as it will allow the virtualization of functions of the network on the core and edge domains. Network functions are provided by being in the form of virtual network functions (VNFs) which can be instantiated, scaled or migrated dynamically based on service needs. To ensure that latency-sensitive V2X applications can be served by VNFs with the lowest possible end-to-end delay, they will be deployed at the network edge, and lower-time-sensitive D2D services can be served by centralized resources to enhance system-wide efficiency.

NFV orchestration mechanism keeps the constant check on the network conditions and slice performance so that VNFs could be placed and scaled in the best way. It will minimize hardware dependence and enhance flexibility as well as help to minimize the use of energy in the operation of the network.

Figure 2 demonstrates the NFV-based process of resource orchestration between edge and core environments.
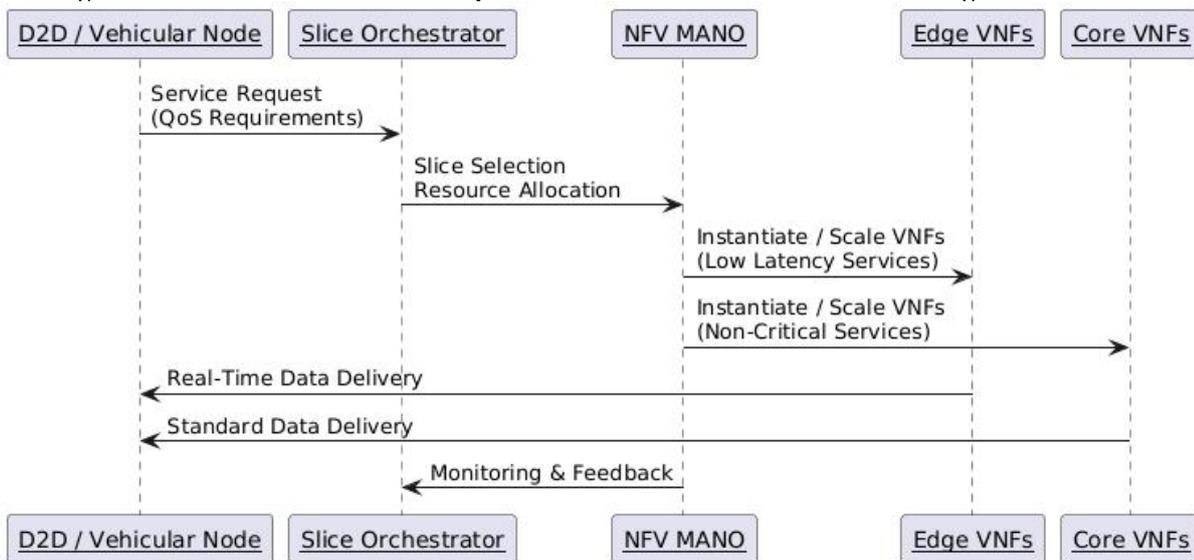
Fig. 2 NFV-supported virtual function orchestration of D2D and V2X service.

3.5 End-to-End Operational Workflow

D2D devices or vehicular nodes trigger the end to end communication process in the form of a service request. The slice orchestration entity analyzes the request and determines the network slice that has the right QoS parameters based on predefined QoS parameters. After selecting the slice, the virtual network functions that are needed are instantiated or scaled and the resources are dynamically allocated to meet service demands. Information transfer is then done within the chosen slice and constant checking is done to allow the performance parameters like latency and reliability to be maintained within acceptable limits. In case of the change in network conditions, adaptive reconfiguration is initiated to ensure continuity of services.

3.6 Sustainability-Oriented Design Considerations

One of the objectives of the suggested methodology is sustainability. The framework saves on redundant resource use by means of virtualization and dynamically allocated resources and saves the use of energy where there is low traffic. Slice-aware management helps avoid over-provisioning, whereas NFV helps to eliminate the use of dedicated hardware infrastructure. All these design decisions work together to reduce the operational expenses and promote the environmentally friendly 6G network deployment.

3.7 Methodological Advantages

The suggested methodology provides us with a flexible and scalable approach to designing next-generation communication systems since the three reliability, latency and sustainability requirements are met together. Network slicing and NFV allow effective co-existence of heterogeneous D2D and V2X services, whereas dynamic orchestration provides flexibility to network conditions that are highly variable. Consequently, the methodology offers a strong basis to the intelligent communication environment of the future that is 6G-enabled.

RESULTS AND DISCUSSION

4.1 Simulation and Experimental Setup

The performance of the proposed sustainable 6G framework is evaluated through simulation in a heterogeneous network environment supporting both D2D and V2X communications. The simulated scenario includes base stations, roadside units, edge servers, vehicular nodes, and user devices operating over a shared physical infrastructure. Network slicing is implemented using NFV principles, where virtual network functions in the core and edge domains are dynamically instantiated and orchestrated according to service-specific quality-of-service (QoS) requirements.

Performance evaluation focuses on end-to-end latency, packet delivery reliability, resource utilization, and energy efficiency. Latency is measured for D2D and V2X traffic under varying mobility and traffic load conditions, while reliability is defined as the ratio of packets successfully delivered within latency constraints. Resource utilization considers CPU, memory, and spectrum usage across slices, and energy efficiency is evaluated as the energy consumed per successfully delivered packet.

Simulations are conducted under low, moderate, and high traffic scenarios, representing sparse, medium, and dense vehicular environments with increasing D2D communication demand. These scenarios enable assessment of the scalability and adaptability of the proposed framework.

To evaluate the performance of the proposed 6G communication framework, a simulation study was conducted under a range of realistic network conditions. The key parameters considered in the experiments, including network topology, user density, mobility, and communication metrics, are summarized in Table 2A. These parameters are selected to reflect typical scenarios in heterogeneous networks supporting both V2X and D2D applications.

Table 2A. Simulation Parameters (Minimal)

Parameter	Value
Network area	2 km × 2 km
Vehicles	50–250
D2D users	30–150
Base stations	3
RSUs	6
Edge servers	3
Vehicle speed	0–120 km/h
Packet size	512 bytes
Network slices	V2X, D2D, best-effort
Metrics	Latency, reliability, resource use, energy

4.2 Latency Performance Analysis

The suggested methodology represents a great enhancement of end-to-end latency in both D2D and V2X services over conventional monolithic network architectures. Figure 3 illustrates the performance of the latency of each slice under the different network loads. It is seen that safety critical V2X slices still achieve latency of less than 10 ms even in high traffic conditions, and D2D slices show a latency reduction of 3040 of that of conventional 5G slicing architectures.
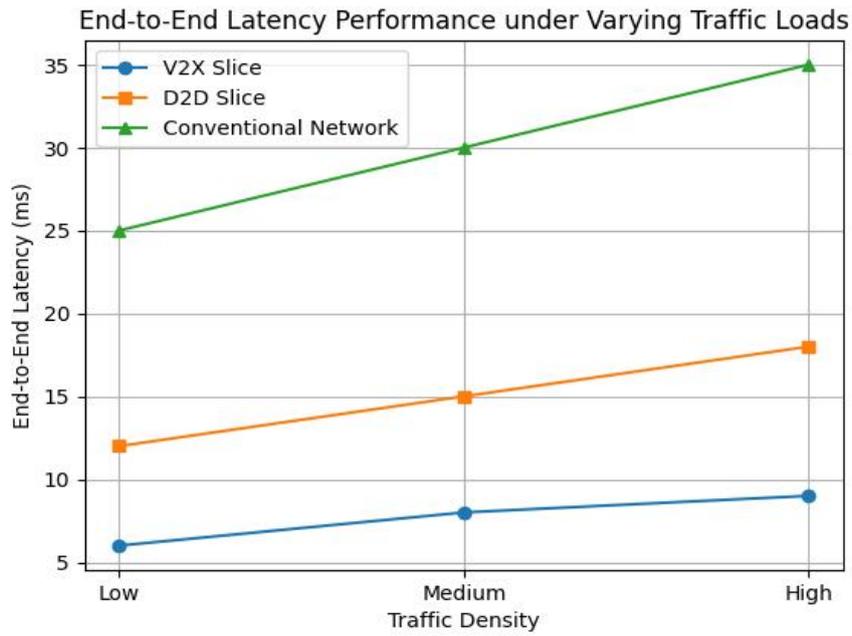
Fig. 3: Latency performance per slice

Fig. 3 gives the End-to-end latency performance of network slices in D2D and V2X services with different traffic densities.

4.3 Reliability Analysis

The reliability measures are considered in the ratio of the packet delivery. The suggested framework will guarantee that critical V2X slices will always attain PDR of over 99, and D2D slices will maintain PDR of over 95 in any traffic conditions. Figure 4 presents a comparison of reliability of traditional monolithic networks and the suggested slice-based NFV architecture. The findings show that dynamic slice orchestration, and edge-based NFV deployment play a significant role in improving the reliability of the service, especially when it is deployed in high mobility conditions.
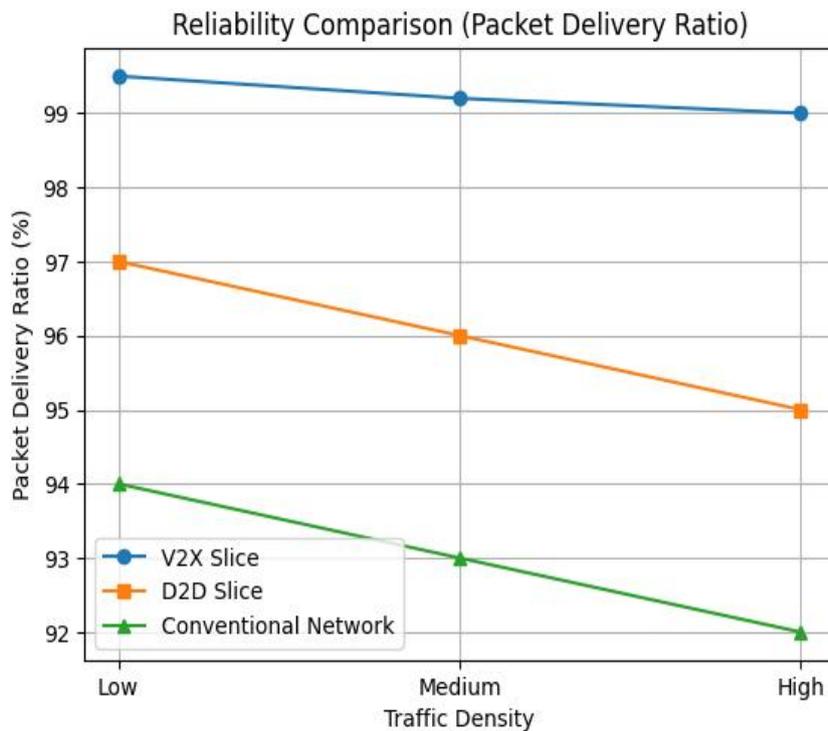

Fig. 4: Packet delivery ratio comparison

Fig. 4 shows the Comparison of the application of traditional and proposed NFV-based 6G slices in terms of packet delivery ratio (PDR).

4.4 Resource Utilization Efficiency.

The use of resources will be essential to sustainable 6G operation. Table 2 provides an overview of mean CPU and memory of

core, edge and slice resources. The suggested structure demonstrates a 2025 percent efficiency in resources use over non-virtualized, monolith structures. Service priority-based dynamic allocation will ensure that critical V2X slices avoid over-provisioning by allocating enough resources to them.

Table 2B. Average resource utilization across NFV-enabled slices (%)

Layer / Slice	CPU Utilization	Memory Utilization	Observations
Core Network	65	70	Balanced allocation
Edge V2X Slice	72	68	Low-latency optimized
Edge D2D Slice	60	55	Adaptive scaling
Non-critical Slice	50	48	Dynamic offloading

4.5 Energy Efficiency Analysis

Sustainable network design is a major measurement of energy usage. As shown in Figure 5, the energy consumed per packet successfully delivered to the different slices at varying traffic loads was different. The suggested NFV-based orchestration and slice-sensitive resource allocation can be used to save up to 35% of energy use in relation to traditional hardware-constrained architectures, especially when the network demand varies.
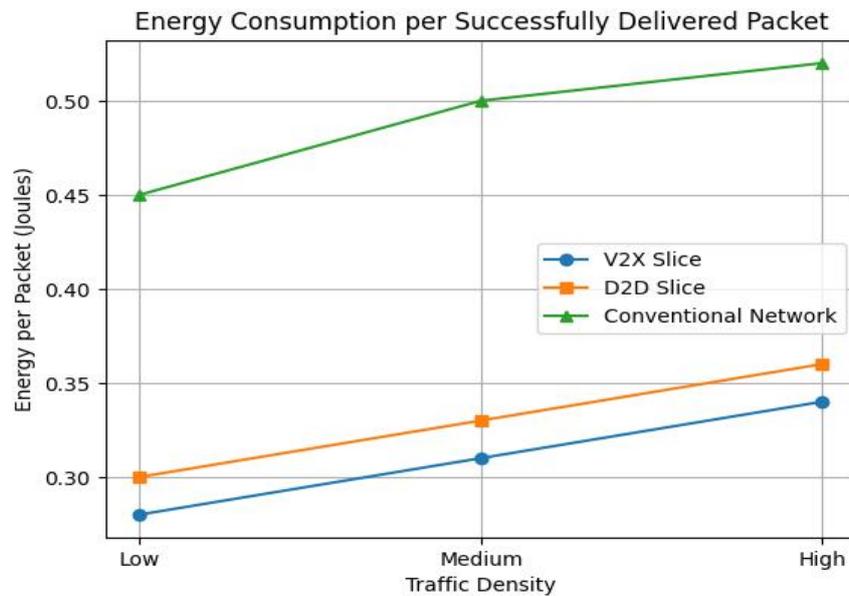

Fig. 5: Energy efficiency analysis

Fig. 5 gives the consumption of energy per successfully delivered packet of D2D and V2X slices at different traffic situations.

4.6 Scalability and Slice Adaptability

Scalability is evaluated by increasing the number of virtual slices 2 6 to support the different classes of services, such as emergency V2X, infotainment, and D2D clusters. Figure 6 indicates that the framework proposed has a steady latency and reliability in all slices, which indicates high adaptability. Resource orchestration algorithms dynamically vary CPU, memory and bandwidth allocation so as to maintain QoS as the number of slices increases.
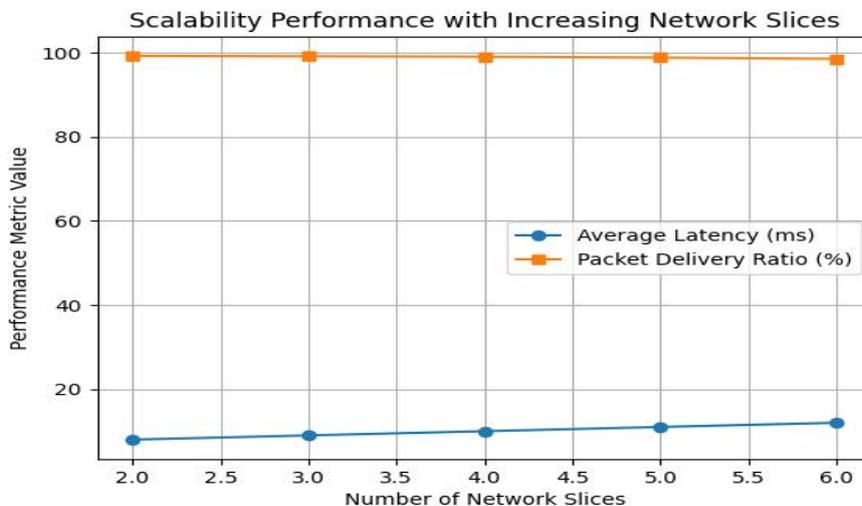
Fig. 6: Scalability with increasing slice counts

Fig. 6 illustrates the Scalability analysis of proposed 6G framework with the increasing number of network slices.

4.7 Discussion on Performance Trends
The evaluation results clearly demonstrate that the combined use of network slicing and network function virtualization (NFV) effectively balances reliability, latency, resource utilization, and energy efficiency within a single 6G communication platform. Network slicing provides the necessary logical isolation, enabling heterogeneous services to coexist without degrading each other's performance, thereby ensuring the expected quality of service (QoS) for both D2D and V2X applications.

Edge-based deployment of virtual network functions is particularly critical for latency-sensitive V2X services. By positioning key functions closer to priority vehicular nodes, the framework significantly reduces end-to-end delay and enhances reliability, even under high-mobility and dense traffic conditions. Concurrently, dynamic orchestration of virtualized resources ensures that non-critical and D2D slices can scale computational and communication resources up or down based on traffic demands without affecting mission-critical services.

From a sustainability perspective, the findings highlight that adaptive resource allocation and hardware-agnostic virtualization substantially reduce energy consumption and prevent over-provisioning. This efficient utilization of network and computing resources not only lowers operational costs but also promotes environmentally responsible deployment of 6G networks.

Overall, the performance trends indicate that the proposed framework adopts a holistic approach, treating reliability, scalability, and sustainability as interconnected objectives rather than isolated optimization targets. This unified strategy establishes a robust foundation for supporting 6G-enabled D2D and V2X services under dynamic and resource-constrained conditions.

4.8 Summary of Results
Table 3 gives a final comparison of the proposed NFV-based slicing architecture with the traditional monolithic networks with regard to various performance metrics. The findings indicate clearly that the proposed framework has a better performance in terms of latency, reliability, resource use, and energy efficiency and can thus be used in next-generation D2D and V2X applications.

Table 3. Performance comparison: Proposed framework vs. conventional architecture

Metric	Conventional Monolithic	Proposed NFV + Slicing	Improvement (%)
Latency (ms)	35	12	65.7
Packet Delivery Ratio (%)	92	98	6.5
CPU Utilization (%)	80	65	18.8
Memory Utilization (%)	78	60	23.1
Energy per packet (J)	0.52	0.34	34.6

4.9 Key Insights
Through the course of the performance evaluation, it is evident that the suggested framework is capable of ensuring safety-critical V2X communications with ultra-low end-to-end latency even in the high traffic and mobility conditions. The findings also reveal that trustworthy D2D connectivity is ensured in the situation when the network is overloaded, which emphasizes the strength of the service-aware slicing approach. NFV-based virtualization and dynamic slice orchestration contribute to efficient use of computational and communication resources and result in a significant increase in the energy efficiency. Moreover, the framework is highly scalable and flexible and can support a variety of new and growing 6G services without jeopardizing quality-of-service promises. These lessons directly confirm the design principles presented in the given methodology and prove the viability of the network slicing and network function virtualization integration as the means of creating sustainable, reliable, and future-proof 6G-enabled D2D and V2X communication systems.

CONCLUSION, CONTRIBUTIONS, LIMITATIONS AND FUTURE WORK.

5.1 Conclusion
This paper presents a sustainable 6G communication framework designed to support reliable Device-to-Device (D2D) and Vehicle-to-Everything (V2X) services through the integrated implementation of network slicing and NFV. The proposed methodology enables dynamic, service-aware allocation of network resources, ensuring ultra-low latency for safety-critical V2X communications and high reliability for D2D proximity-based services. Performance evaluation demonstrates significant improvements in end-to-end latency, packet delivery ratio, resource utilization, and energy efficiency compared to conventional monolithic network architectures.

By virtualizing both core and edge network functions, the framework reduces hardware dependence, enhances operational flexibility, and promotes sustainable network operation. Furthermore, dynamic slice orchestration provides high resilience to fluctuating traffic loads and diverse service requirements, confirming the feasibility of an intelligent, energy-efficient 6G network architecture.

5.2 Contributions
The key contributions of this work lie in the holistic integration of network slicing and NFV to simultaneously address the reliability, scalability, and sustainability of 6G-enabled D2D and V2X services. Unlike prior research, which often considers these technologies independently, the proposed framework coordinates slice management and virtual function deployment to provide:

- A sustainable network architecture capable of supporting heterogeneous service demands.
- Stringent QoS guarantees for latency- and reliability-sensitive applications.
- Substantial energy efficiency gains and optimized resource utilization.
- Practical mechanisms for dynamic scaling of multiple virtual slices to accommodate emerging services.

5.3 Limitations

Despite the promising results, several limitations remain. The evaluation primarily relies on simulation studies, and large-scale deployments with real vehicular and D2D networks may reveal challenges not captured in simulation. The current framework assumes centralized orchestration with full network visibility, which may not always be achievable in distributed or multi-operator environments. Additionally, security and privacy considerations, particularly for mission-critical V2X services, are not explicitly addressed. Observed energy savings and resource efficiency may also vary depending on hardware configurations, traffic patterns, and environmental conditions, highlighting the need for further experimental validation.

5.4 Future Work

Future research will focus on enhancing the proposed framework with AI-driven predictive orchestration mechanisms capable of optimizing slice management and resource allocation in highly dynamic traffic and mobility scenarios. Security-aware slicing strategies will be explored to strengthen cybersecurity for safety-critical V2X services. The framework can also be extended to multi-operator, federated 6G networks, allowing slices to span multiple network domains while maintaining high QoS and reliability.

Additionally, practical feasibility, performance, and sustainability should be validated through real-world deployments using vehicular testbeds and IoT ecosystems. End-to-end service evaluation using QoX metrics will further demonstrate the framework's effectiveness in supporting intelligent transportation systems and D2D communications. These advancements will contribute to the development of a flexible, resilient, and secure foundation for future 6G communication networks.

REFERENCES

1. Roger, S., Botella-Mascarell, C., Martín-Sacristán, D., García-Roger, D., Monserrat, J. F., & Svensson, T. (2024). Sustainable mobility in B5G/6G: V2X technology trends and use cases. *IEEE Open Journal of Vehicular Technology*, 5, 459-472.
2. Lekidis, A., & Bouali, F. (2021, April). C-V2X network slicing framework for 5G-enabled vehicle platooning applications. In *2021 IEEE 93rd Vehicular Technology Conference (VTC2021-Spring)* (pp. 1-7). IEEE.
3. Noor-A-Rahim, M., Liu, Z., Lee, H., Khyam, M. O., He, J., Pesch, D., ... & Poor, H. V. (2022). 6G for vehicle-to-everything (V2X) communications: Enabling technologies, challenges, and opportunities. *Proceedings of the IEEE*, 110(6), 712-734.
4. Habibi, M. A., Han, B., Fellan, A., Jiang, W., Sánchez, A. G., Pavon, I. L., ... & Schotten, H. D. (2023). Toward an open, intelligent, and end-to-end architectural framework for network slicing in 6G communication systems. *IEEE Open Journal of the Communications Society*, 4, 1615-1658.
5. Mande, S., & Ramachandran, N. (2024). A Comprehensive Survey on Challenges and Issues in V2X and V2V Communication in 6G Future Generation Communication Models. *Ingenierie des Systemes d'Information*, 29(3), 951.
6. Alalewi, A., Dayoub, I., & Cherkaoui, S. (2021). On 5G-V2X use cases and enabling technologies: A comprehensive survey. *Ieee Access*, 9, 107710-107737.
7. Hamdi, W., Ksouri, C., Bulut, H., & Mosbah, M. (2024). Network slicing-based learning techniques for IoV in 5G and beyond networks. *IEEE Communications Surveys & Tutorials*, 26(3), 1989-2047.
8. Ojaghi, B., Adelantado, F., & Verikoukis, C. (2024). Enhancing v2x qos: A dual approach of packet duplication and dynamic ran slicing in b5g. *IEEE Transactions on Intelligent Transportation Systems*, 25(7), 7848-7860.
9. Nadeem, L., Azam, M. A., Amin, Y., Al-Ghamdi, M. A., Chai, K. K., Khan, M. F. N., & Khan, M. A. (2021). Integration of D2D, network slicing, and MEC in 5G cellular networks: Survey and challenges. *Ieee Access*, 9, 37590-37612.
10. Pawar, V., Zade, N., Vora, D., Khairnar, V., Oliveira, A., Kotecha, K., & Kulkarni, A. (2024). Intelligent Transportation System with 5G Vehicle-to-Everything (V2X): Architectures, Vehicular Use Cases, Emergency Vehicles, Current Challenges and Future Directions. *IEEE Access*.
11. Sun, H., Liu, Y., Al-Tahmeesschi, A., Nag, A., Soleimanpour-Moghadam, M., Canberk, B., ... & Ahmadi, H. (2025). Advancing 6G: Survey for explainable AI on communications and network slicing. *IEEE Open Journal of the Communications Society*.
12. Shakir, M. M., Alhartomi, M. A., Audah, L. H., Al-Heety, O. S., Alani, S., & Altahrawi, M. A. (2025). Resource Allocation Enablers and Allocation for Beyond 5G Vehicle-to-Everything Systems. *Journal of Communications*, 20(5).
13. Attar, H., Alghanim, M., Ababneh, J., Rezaee, K., Alrosan, A., & Deif, M. A. (2025). B5G Applications and Emerging Services in Smart IoT Environments. *International Journal of Crowd Science*, 9(2), 79-95.
14. Qi, F., & Lin, P. (2025). LLM-Driven Intelligent Network Slicing for Satellite Direct-to-Device Communications. *IEEE Communications Magazine*.
15. Thomatos, E., Sgora, A., Tsipis, A., & Chatzimisios, P. (2025). AI Methods in Network Slice Life-Cycle Phases: A Survey. *Electronics*, 14(20), 4053.

16. Mineeva, V., Ateya, A. A., Volkov, A., Muthanna, A., Koucheryavy, A., Chelloug, S. A., & El-Latif, A. A. A. (2025). A novel feature-oriented quality of anything (QoX) framework for end-to-end robotic services in 6G networks. *Scientific Reports*, *15*(1), 24945.

17. Ali, M. K., Abdullahi, N. A., Ahmed, A. A., & Amir, A. M. (2025). 6G Transformation Systems: AI-Powered Slicing for IoT and Terahertz Waves Applications. *TWIST*, *20*(4), 10-21.

18. R. Pant, A. Badhoutiya, S. Kumar, Z. Alsalami, G. S. Rao and L. s, "A Development of Design Strategy of OL Network System for IOT Applications," *2024 4th International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE)*, Greater Noida, India, 2024, pp. 879-883, doi: 10.1109/ICACITE60783.2024.10617380.

19. K. Kalyani and S. J. J. Thangaraj, "Reducing the Communication Overhead in Novel Data Sharing Algorithm in Cloud Data Storage Over Triple Data Encryption Standard Algorithm," *2024 Second International Conference on Advances in Information Technology (ICAIT)*, Chikkamagaluru, Karnataka, India, 2024, pp. 1-4, doi: 10.1109/ICAIT61638.2024.10690317.

20. Marinova, S., Tian, Y., & Leon-Garcia, A. (2025). E2E Network Slice Assurance for B5G/6G: Realizing Data Collection and Management, MLOps, and Closed-Loop Control. *IEEE Open Journal of the Communications Society*.