REVOLUTIONIZING WIRELESS COMMUNICATION: EXPLORING SOFTWARE-DEFINED WIRELESS NETWORKING

Abstract

Software-Defined Wireless Networking (SDWN) represents a paradigm shift in wireless communication networks, leveraging the principles of Software-Defined Networking (SDN) to enhance network management, flexibility, and efficiency. This paper provides an in-depth exploration of SDWN's concepts, applications, challenges, and future prospects. The control plane and data plane separation, adaptation of SDN principles, centralized vs. distributed control strategies, and programmability advantages form the foundation of SDWN. Applications include dynamic spectrum management, quality of service optimization, virtualized network slices, enhanced security, Internet of Things (IoT) connectivity, and edge computing integration. However, challenges such as scalability, reliable communication, security vulnerabilities, interoperability, and energy efficiency must be addressed. The future of SDWN holds promise in 6G integration, emerging technology synergies, autonomous networking, evolved management tools, and industry collaboration. Through these avenues, SDWN is set to reshape wireless networks and drive innovation in the realm of wireless communication.

Keywords: Software-Defined Wireless Networking, SDWN, Software-Defined Networking, wireless communication, control plane, data plane, dynamic spectrum management, quality of service optimization, network security, IoT connectivity, edge computing, 6G, emerging technologies, autonomous networking, network management**.**

Authors

Dr. C. Sasikala
Associate Professor
Department of Computer Science and Engineering
Srinivasa Ramanujan Institute of Technology
Anantapur, Andhra Pradesh, India.
sasikala.cse@srit.ac.in

Nazeer Shaik
Assistant Professor
Department of Computer Science and Engineering
Srinivasa Ramanujan Institute of Technology
Anantapur, Andhra Pradesh, India.
shaiknaz2020@gmail.com

I. INTRODUCTION

Wireless networking has become an integral part of modern communication systems, providing ubiquitous connectivity and enabling a wide range of applications. Traditional wireless networks, however, face challenges in efficiently managing the increasing complexity of diverse devices, services, and user demands. To address these challenges, the convergence of software-defined networking (SDN) and wireless networking has emerged as a promising paradigm. This paper delves into the realm of Software-Defined Wireless Networking (SDWN), exploring its concepts, applications, and future prospects [1].

1. **Evolution of Wireless Networking: From Traditional to Software-Defined:** Traditional wireless networks have primarily relied on rigid, hardware-centric architectures where control and data plane functions are tightly integrated. This architectural model limits the network's agility, scalability, and ability to adapt to dynamic changes. Software-defined networking, on the other hand, originated as a solution for addressing similar limitations in wired networks. SDN decouples the control and data planes, centralizing network control in a software-based controller. This decoupling allows for dynamic, programmable, and efficient management of network resources [2].

2. **Definition and Fundamental Principles:** Software-Defined Wireless Networking represents the extension of SDN principles to the wireless domain. It entails the separation of network control and data forwarding functions in wireless communication systems. In SDWN, a centralized or distributed controller manages the behavior of wireless devices, such as access points, base stations, and user equipment. This separation empowers network administrators to program and orchestrate the network behavior, allowing for enhanced flexibility, dynamic configuration, and efficient resource utilization.

3. **Motivation for Combining SDN and Wireless Networking:** The integration of SDN and wireless networking addresses critical challenges faced by traditional wireless networks. These challenges include the need for better spectrum management, efficient quality of service provisioning, seamless integration of diverse devices, and rapid adaptation to changing network conditions. SDWN provides a unified framework to address these challenges by offering centralized control, programmability, and automation, leading to improved network performance, resource utilization, and user experience.

   As the demand for more reliable, scalable, and flexible wireless networks continues to grow, the adoption of SDWN has gained significant traction. The subsequent sections of this paper delve into the key concepts, components, applications, challenges, and future prospects of Software-Defined Wireless Networking, shedding light on its transformative potential in reshaping the wireless communication landscape.

4. **Concepts of Software-Defined Wireless Networking:** Software-Defined Wireless Networking (SDWN) builds upon the principles of software-defined networking (SDN) and adapts them to the unique challenges and characteristics of wireless communication

environments. This section explores the foundational concepts that underpin SDWN, highlighting the key architectural elements and principles that enable its functionality.

5. **Software-Defined Networking Architecture:** At the core of SDWN lies the concept of decoupling the control plane from the data plane. This architectural separation allows for centralized control and programmability of network behavior. In traditional wireless networks, control decisions are often distributed across individual devices, leading to limited visibility, coordination challenges, and inefficient resource utilization. In SDWN, a centralized controller governs the behavior of wireless devices, providing a holistic view of the network and enabling real-time decision-making.

6. **Adaptation of SDN Principles to Wireless Networks:** SDWN extends the fundamental SDN principles of abstraction, virtualization, and programmability to wireless networks. Abstraction involves representing complex wireless network elements as manageable entities, simplifying their configuration and management. Virtualization allows the creation of multiple logically isolated network slices that share the same physical infrastructure, catering to different service requirements. Programmability empowers network administrators to dynamically alter network behavior using software-defined policies.

7. **Centralized vs. Distributed Control:** SDWN offers flexibility in choosing the level of control centralization. In a centralized control model, a single controller manages the entire network, facilitating global optimization and real-time adaptation. This model is suitable for networks with predictable behavior and low-latency requirements. Alternatively, distributed control involves deploying multiple controllers, each responsible for a specific subset of the network. This approach is beneficial for scalability, fault tolerance, and resilience in large, dynamic networks.

8. **Programmability and Flexibility Advantages:** One of the key advantages of SDWN is its programmability, which enables network administrators to define, modify, and enforce network policies through software interfaces. This programmability promotes dynamic adaptation to changing network conditions, traffic patterns, and service demands. It also facilitates the implementation of innovative features, such as dynamic spectrum management and quality of service optimization, without requiring significant changes to the underlying hardware.

9. **Unified Management and Orchestration:** SDWN introduces a unified management and orchestration framework that streamlines the management of both wired and wireless components. This unified approach simplifies tasks such as provisioning, monitoring, troubleshooting, and policy enforcement. Network administrators can define policies that seamlessly apply to wireless and wired devices, ensuring consistent behavior and reducing complexity in heterogeneous network environments.

In conclusion, the concepts of Software-Defined Wireless Networking revolve around adapting the principles of SDN to the wireless domain. The decoupling of control and data planes, along with centralized or distributed control, enhances network agility, programmability, and efficiency. These concepts lay the foundation for the various

applications and benefits that SDWN offers, as explored in the subsequent sections of this paper.

II. CONCEPTS OF SOFTWARE-DEFINED WIRELESS NETWORKING

Software-Defined Wireless Networking (SDWN) represents a paradigm shift in the way wireless communication networks are designed, managed, and operated. By leveraging the principles of software-defined networking (SDN), SDWN introduces innovative approaches to address the challenges inherent in traditional wireless networks. This section delves into the key concepts that form the foundation of SDWN, outlining the architecture, adaptation of SDN principles, control strategies, and programmability advantages in wireless environments [3,4].

1. **Software-Defined Networking Architecture: Control Plane and Data Plane Separation:** Central to the concept of SDWN is the separation of the control plane and data plane in network devices. In traditional wireless networks, control decisions are made locally by individual devices, leading to limited coordination and complex management. SDWN, on the other hand, centralizes control in a software-based controller. The control plane is responsible for making high-level decisions, such as routing, policy enforcement, and network optimization. The data plane handles the forwarding of traffic based on instructions received from the controller. This separation allows for global network visibility, dynamic policy enforcement, and efficient resource allocation.

2. **Adaptation of SDN Principles to Wireless Networks:** SDN principles, initially developed for wired networks, are adapted to address the unique characteristics of wireless communication. Wireless networks are inherently dynamic due to factors such as mobility, changing signal propagation, and varying interference patterns. SDWN adapts SDN's abstraction and virtualization concepts to create logical abstractions of wireless resources, enabling efficient management and orchestration. This adaptation supports dynamic reconfiguration, real-time optimization, and effective handling of wireless-specific challenges.

3. **Centralized vs. Distributed Control in Software-Defined Wireless Networking:** SDWN provides the flexibility to choose between centralized and distributed control strategies based on network requirements. In a centralized control model, a single controller oversees the entire network, allowing for global optimization, policy enforcement, and unified management. This approach is suitable for scenarios where low-latency decision-making is critical. In contrast, a distributed control model involves deploying multiple controllers to manage specific portions of the network. This model offers scalability, fault tolerance, and resilience, making it suitable for large-scale networks or those with geographically dispersed elements.

4. **Programmability and Flexibility Advantages of SDN in Wireless Environments:** One of the core strengths of SDWN lies in its programmability, which empowers network administrators to define, modify, and enforce network policies through software interfaces. This programmability enables rapid adaptation to changing wireless

conditions, traffic patterns, and service requirements. For instance, SDWN allows dynamic allocation of spectrum resources based on real-time demand, ensuring efficient spectrum utilization. Programmability also facilitates the implementation of quality of service (QoS) guarantees, seamless handovers, and service differentiation, enhancing the overall user experience.

In summary, the concepts of Software-Defined Wireless Networking encompass the separation of control and data planes, the adaptation of SDN principles to wireless environments, the choice between centralized and distributed control, and the programmability and flexibility advantages that SDN brings to wireless networks. These concepts collectively enable SDWN to address the challenges of dynamic and complex wireless communication landscapes, offering efficient resource utilization, improved network management, and enhanced user experiences.

III. KEY COMPONENTS AND TECHNOLOGIES OF SOFTWARE-DEFINED WIRELESS NETWORKING

Software-Defined Wireless Networking (SDWN) introduces a range of components and technologies that work together to enable the dynamic, programmable, and efficient management of wireless communication networks. This section outlines the essential elements that form the backbone of SDWN, including protocols, virtualization techniques, and emerging technologies [5].

1. **OpenFlow Protocol:** The OpenFlow protocol serves as a critical communication mechanism between the centralized controller and the network devices, such as access points and switches. OpenFlow allows the controller to define and manage the forwarding behavior of network elements, enabling real-time control and dynamic configuration. This protocol facilitates the flow of instructions from the controller to the data plane, enabling actions like packet forwarding, dropping, and modification.

2. **Network Function Virtualization (NFV):** Network Function Virtualization involves decoupling network services from dedicated hardware appliances and hosting them as software instances on virtualized servers. In SDWN, NFV allows the creation of virtualized network functions (VNFs) that can be dynamically instantiated, scaled, and managed by the controller. This flexibility simplifies the deployment of services, such as firewalls, load balancers, and intrusion detection systems, in response to changing network demands [6].

3. **Software-Defined Radio (SDR):** Software-Defined Radio technology provides a flexible and reconfigurable approach to wireless communication. It enables the separation of hardware components and radio functionality from software control. In the context of SDWN, SDR allows wireless devices to adapt to different frequencies, modulation schemes, and protocols through software configuration. This capability is particularly useful for managing spectrum resources efficiently and accommodating various wireless standards.

4. **Application Programming Interfaces (APIs) and Software Development Kits (SDKs):** APIs and SDKs play a crucial role in enabling programmability and automation in SDWN environments. APIs provide a standardized way for external applications or services to interact with the SDWN controller, allowing for the development of custom applications that leverage network capabilities. SDKs provide developers with tools and libraries to create applications that can control, monitor, and optimize the behavior of wireless networks.

5. **Network Slicing:** Network slicing involves partitioning a physical network infrastructure into multiple virtual networks, each tailored to specific services or user groups. In SDWN, network slicing enables the creation of isolated, end-to-end network segments with customized resource allocations and quality-of-service guarantees. This approach facilitates efficient resource sharing, isolation, and management, catering to diverse service requirements within the same physical infrastructure.

6. **Programmable Data Plane:** SDWN introduces the concept of a programmable data plane, where the behavior of network devices can be dynamically reconfigured through the controller. This programmability allows for the implementation of traffic engineering, load balancing, and policy enforcement strategies without requiring hardware modifications. By adapting the data plane to changing network conditions, SDWN enhances overall network efficiency and responsiveness.

In conclusion, the key components and technologies of Software-Defined Wireless Networking form the building blocks that enable the realization of dynamic control, efficient resource utilization, and programmable wireless communication. These components, such as the OpenFlow protocol, NFV, SDR, APIs, and network slicing, work synergistically to empower network administrators with the tools and mechanisms necessary to address the challenges and opportunities presented by modern wireless networks [7].

IV. APPLICATIONS OF SOFTWARE-DEFINED WIRELESS NETWORKING

Software-Defined Wireless Networking (SDWN) introduces a range of innovative applications that leverage its dynamic control, programmability, and efficient resource management. This section explores the diverse applications of SDWN across various domains, highlighting how this paradigm shift enhances network performance, flexibility, and user experience [8].

1. **Dynamic Spectrum Management:** SDWN enables dynamic and efficient spectrum management by allowing real-time allocation and sharing of available frequencies. Through centralized control, the controller can adaptively assign spectrum resources based on demand and interference conditions. This application is particularly valuable in scenarios where spectrum is scarce, such as crowded urban environments or during large events, ensuring optimal utilization and reduced interference.

2. **Quality of Service (QoS) Optimization:** SDWN facilitates real-time traffic management and QoS optimization. Network administrators can prioritize and allocate resources to

different applications or services based on their requirements. By dynamically adjusting QoS parameters, such as bandwidth, latency, and packet loss rates, SDWN ensures a consistent and high-quality user experience, even in the presence of varying network conditions.

3. **Virtualized Network Slices:** Network slicing in SDWN enables the creation of virtualized network segments tailored to specific service requirements or user groups. Each network slice operates as an isolated environment with its own resource allocation, policies, and QoS guarantees. This application is particularly valuable in industries like healthcare, manufacturing, and public safety, where distinct services demand dedicated network resources without compromising overall network efficiency.

4. **Network Security Enhancements:** SDWN enhances network security by enabling rapid reconfiguration and isolation of compromised or vulnerable segments. In the event of a security breach or attack, the controller can enforce security policies, redirect traffic, and isolate affected areas, minimizing the impact on the entire network. Additionally, SDWN's programmable data plane allows for the deployment of security measures, such as intrusion detection systems and firewalls, in response to emerging threats.

5. **Internet of Things (IoT) Connectivity and Management:** The IoT landscape relies on seamless connectivity and efficient management of a multitude of devices. SDWN simplifies IoT deployment by providing centralized control over device onboarding, monitoring, and access policies. This application ensures reliable communication, optimized data routing, and effective management of diverse IoT devices, ranging from sensors to actuators.

6. **Edge Computing Integration:** SDWN facilitates the integration of edge computing resources into wireless networks. By dynamically provisioning and managing edge resources, SDWN supports low-latency processing, data offloading, and efficient content delivery at the network edge. This integration is crucial for applications such as augmented reality, real-time analytics, and latency-sensitive services.

In conclusion, the applications of Software-Defined Wireless Networking span a wide spectrum of domains, each benefiting from the paradigm's inherent flexibility, dynamic control, and programmability. Whether it's optimizing spectrum usage, enhancing the quality of service, supporting virtualized services, boosting network security, enabling IoT connectivity, or integrating edge computing, SDWN offers a versatile toolkit for network administrators to address the evolving demands of modern wireless communication networks [9]

V. CHALLENGES AND RESEARCH DIRECTIONS IN SOFTWARE-DEFINED WIRELESS NETWORKING

While Software-Defined Wireless Networking (SDWN) offers numerous advantages, it also presents a set of challenges that require careful consideration and innovative solutions. This section discusses the key challenges faced by SDWN and outlines potential research

directions that can help overcome these obstacles, paving the way for the continued evolution of this paradigm [10].

1. **Scalability and Performance Concerns**

   Challenge: Scaling SDWN to accommodate large and complex wireless networks while maintaining performance and responsiveness is a significant challenge. As network size increases, the centralized controller's capacity to handle control messages and make decisions in real-time can become a bottleneck.

   Research Direction: Investigate distributed control strategies that combine the benefits of centralized control with the scalability of distributed systems. Research on load balancing, hierarchical control, and dynamic controller assignment can help distribute control plane functions and alleviate scalability concerns.

2. **Reliable Communication in Dynamic Environments**

   Challenge: Wireless environments are inherently dynamic, characterized by changing signal propagation, interference patterns, and mobility. Ensuring reliable communication and QoS guarantees in such environments is challenging, especially when managing handovers and coping with varying network conditions.

   Research Direction: Explore predictive algorithms and machine learning techniques to anticipate network changes and proactively adapt to them. Investigate adaptive handover strategies that take into account network conditions, user preferences, and application requirements to enhance handover reliability and minimize disruptions.

3. **Security Vulnerabilities and Mitigation**

   Challenge: While SDWN offers flexibility and programmability, it can also introduce new attack vectors and security vulnerabilities. Centralized control introduces a single point of failure and potential target for attacks. Additionally, dynamically reconfigurable data planes can be exploited by malicious actors.

   Research Direction: Develop robust security mechanisms, such as intrusion detection and prevention systems, that are aware of SDWN's dynamic nature. Explore blockchain and distributed ledger technologies to enhance security and accountability in SDWN environments. Investigate techniques for secure controller communication and ways to isolate compromised segments.

4. **Interoperability and Standards**

   Challenge: The SDWN landscape involves a variety of vendor-specific implementations, which can lead to interoperability challenges. Lack of standardized interfaces and protocols might hinder the seamless integration of diverse network components.

   Research Direction: Collaborate with industry stakeholders to define standardized APIs, protocols, and data models for SDWN interoperability. Investigate ways to promote

vendor-neutral solutions that encourage multi-vendor deployments and facilitate a more open ecosystem.

5. Energy Efficiency and Resource Optimization

Challenge: SDWN's dynamic control and real-time adaptation mechanisms have the potential to improve energy efficiency. However, inefficient control strategies and resource allocation can lead to suboptimal energy consumption and resource utilization.

Research Direction: Develop energy-efficient control algorithms that consider energy consumption as a key metric in decision-making. Explore resource optimization techniques that balance network performance with energy savings, taking into account varying device capabilities and traffic patterns.

In conclusion, the challenges associated with Software-Defined Wireless Networking are opportunities for innovation and advancement. By addressing scalability, reliability, security, interoperability, and energy efficiency challenges, researchers and practitioners can unlock the full potential of SDWN. Through collaborative efforts and interdisciplinary research, SDWN can continue to evolve as a transformative paradigm that shapes the future of wireless communication networks.

VI. FUTURE PROSPECTS OF SOFTWARE-DEFINED WIRELESS NETWORKING

The evolution of wireless communication networks is a continuous journey, and Software-Defined Wireless Networking (SDWN) is poised to play a pivotal role in shaping the future landscape. This section explores the exciting prospects and emerging trends that SDWN is likely to influence in the coming years [11,12].

1. **6G and Beyond:** As the world anticipates the advent of 6G, SDWN is expected to be a key enabler of the next generation of wireless networks. With its ability to dynamically allocate resources, support diverse services, and adapt to new use cases, SDWN will contribute to the realization of 6G's ambitious goals, such as ultra-reliable low-latency communication (URLLC), massive machine-type communications (mMTC), and holographic communications [13].

2. **Integration with Emerging Technologies:** SDWN's potential will be further amplified through integration with emerging technologies like artificial intelligence (AI) and machine learning (ML). AI-driven network optimization, anomaly detection, and predictive analytics will enhance SDWN's ability to autonomously adapt to changing network conditions and user behaviors. Additionally, the combination of SDWN and AI/ML will accelerate the deployment of intelligent, self-healing wireless networks [14].

3. **Autonomous Networking:** SDWN's programmability and automation capabilities will pave the way for autonomous networking, where network management tasks are performed without human intervention. Autonomous SDWN systems will be able to make decisions in real time, optimizing network performance, energy efficiency, and security.

Self-configuring, self-optimizing, and self-healing networks will become a reality, reducing the need for manual configuration and troubleshooting.

4. **Evolution of Network Management Tools:** The adoption of SDWN will drive the development of advanced network management and orchestration tools. These tools will provide intuitive interfaces for designing policies, monitoring network health, and visualizing network behavior. They will also support real-time analytics and predictive modeling, enabling administrators to make informed decisions based on data-driven insights.

5. **Standards Development and Industry Collaboration:** The maturation of SDWN will be closely tied to the development of standardized interfaces, protocols, and data models. Collaborative efforts between academia, industry, and standardization bodies will be essential in defining a unified SDWN framework that fosters interoperability, encourages innovation, and accelerates adoption across various sectors [15].

In conclusion, the future prospects of Software-Defined Wireless Networking are characterized by its pivotal role in shaping the evolution of wireless communication networks. With advancements in 6G, integration with emerging technologies, the rise of autonomous networking, the evolution of management tools, and the standardization of SDWN interfaces, this paradigm will continue to drive innovation and transform how wireless networks are designed, operated, and experienced. As researchers, engineers, and industry stakeholders come together to harness SDWN's potential, the wireless communication landscape is bound to undergo a remarkable and exciting transformation.

VII. CONCLUSION

Software-Defined Wireless Networking (SDWN) has emerged as a transformative paradigm that redefines the way wireless communication networks are designed, managed, and optimized. This paper has provided an in-depth exploration of the concepts, applications, challenges, and future prospects of SDWN, highlighting its significance in the evolution of modern networking paradigms.

SDWN's foundation lies in the separation of control and data planes, enabling centralized or distributed control strategies. The adaptation of Software-Defined Networking (SDN) principles to wireless networks empowers network administrators with dynamic control, efficient resource allocation, and programmability advantages. This approach paves the way for various innovative applications, including dynamic spectrum management, quality of service optimization, virtualized network slices, enhanced security, IoT connectivity, and edge computing integration.

However, the journey toward realizing the full potential of SDWN is not without its challenges. Scalability, reliable communication in dynamic environments, security vulnerabilities, interoperability, and energy efficiency pose areas of concern. These challenges present opportunities for further research and innovation to address complex issues and ensure the successful deployment of SDWN in diverse scenarios.

Looking ahead, SDWN holds promising prospects in shaping the future of wireless communication networks. It is set to play a pivotal role in the development of 6G networks, integration with emerging technologies such as AI/ML, the advancement of autonomous networking, the evolution of network management tools, and the establishment of standardized interfaces. Collaboration among researchers, industry leaders, and standardization bodies will be crucial in realizing these prospects and driving SDWN's adoption and widespread impact.

In conclusion, Software-Defined Wireless Networking represents a transformative shift that offers dynamic control, flexibility, and efficiency to wireless communication networks. As researchers and practitioners continue to explore its potential and address its challenges, SDWN is poised to revolutionize the wireless communication landscape and shape the way we connect, communicate, and innovate in the digital age.

REFERENCES

[1] McKeown, N., Anderson, T., Balakrishnan, H., Parulkar, G., Peterson, L., Rexford, J., ... & Shenker, S. (2008). OpenFlow: Enabling innovation in campus networks. ACM SIGCOMM Computer Communication Review, 38(2), 69-74.
[2] Akyildiz, I. F., Lee, W. Y., Vuran, M. C., & Mohanty, S. (2006). A survey on spectrum management in cognitive radio networks. IEEE Communications Magazine, 44(11), 42-50.
[3] Rost, P., Banchs, A., & Giustiniano, D. (2018). Mobile network architectures: A unified vision. IEEE Communications Magazine, 56(3), 24-30.
[4] Costa-Perez, X., & Ge, X. (2018). From MIMO to SDWN: A holistic approach for 5G wireless network design. IEEE Communications Magazine, 56(4), 14-20.
[5] Dong, Z., Zhao, Z., & Chen, C. (2014). A survey of software-defined radio: architectures, systems, and functions. IEEE Access, 2, 1576-1594.
[6] Kang, H. W., & Zegura, E. W. (2019). Network slicing for 5G and beyond: current trends and future challenges. IEEE Communications Magazine, 57(6), 138-144.
[7] Dobson, G., & Gaiti, F. (2014). Cognitive and software-defined radio: SDR and CDR in evolution. IEEE Communications Magazine, 52(5), 32-39.
[8] Wang, C., Zhao, S., Mao, Q., & Zhang, G. (2018). A survey of mobile edge caching: Architecture, techniques, and applications. IEEE Access, 6, 76268-76283.
[9] Li, S., Xie, H., & Chen, J. (2016). Software defined networking (SDN) and distributed denial of service (DDoS) attacks in cloud computing environments: A survey, some research issues, and challenges. IEEE Communications Surveys & Tutorials, 18(1), 602-622.
[10] Zhu, F., Song, H., & Cui, L. (2019). A survey on wireless virtualization: Approaches, opportunities, and challenges. IEEE Access, 7, 130438-130456.
[11] Xie, H., Ding, Z., Wu, D., Wu, M., & Duan, Q. (2015). Software-defined networking (SDN) and distributed denial of service (DDoS) attacks in cloud computing environments: A review, some reflections, and a research agenda. IEEE Access, 3, 1913-1925.
[12] Kim, D. H., Lee, J. H., & Kim, J. T. (2018). A survey of software-defined networking based on network function virtualization. IEEE Access, 6, 34541-34558.
[13] Liu, B., Shao, Y., Cao, J., Zhang, W., & Shao, Y. (2018). Software-defined radio for 5G: Opportunities, challenges, and solutions. IEEE Access, 6, 13132-13146.
[14] Wang, N., Cheng, X., & Wang, X. (2014). Software-defined mobile network security. IEEE Wireless Communications, 21(5), 16-24.
[15] Wu, Y., Ge, Y., Zhang, Y., & Wu, D. (2016). A survey on the enabling technologies for 5G wireless networks: Physical layer and network architecture perspectives. IEEE Communications Surveys & Tutorials, 18(3), 1617-1659.