Dynamic Network Slicing for Enhanced Wi-Fi Performance

Patel Krish
Computer Science
IIIT Vadodara
202151110@iiitvadodara.ac.in

Atharv Barde
Computer Science
IIIT Vadodara
202151184@iiitvadodara.ac.in

Baraiya Poojan
Computer Science
IIIT Vadodara
202151185@iiitvadodara.ac.in

Patel Utkarsh
Information Technology
IIIT Vadodara
202152329@iiitvadodara.ac.in

Sachin Kumar
Information Technology
IIIT Vadodara
202152335@iiitvadodara.ac.in

***Abstract*—The evolution of 5G technology marks a significant advancement in wireless communication. This project explores dynamic network slicing to enhance Wi-Fi performance, focusing on optimizing resource allocation, mobility management, and Quality of Service (QoS). By leveraging the concept of network slicing, multiple logical networks are established over a shared physical infrastructure to cater to diverse application requirements such as Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC), and Massive Machine-Type Communications (mMTC). Using Python-based simulations, the project demonstrates how dynamic slicing improves bandwidth utilization, ensures QoS, and supports seamless mobility across slices. This report provides a comprehensive overview of the project's methodology, results, and implications for next-generation wireless networks.**

***Index Terms*—5G, Network Slicing, Dynamic Resource Allocation, QoS, Python Simulation, Mobility Management**

I. Introduction

The emergence of 5G technology has revolutionized wireless communication by addressing the growing demands for higher data rates, ultra-low latency, and massive device connectivity. Unlike its predecessors, 5G introduces innovative concepts such as network slicing, dynamic resource allocation, and software-defined networking, enabling the creation of flexible and efficient network architectures tailored to diverse use cases.

Traditional Wi-Fi networks often struggle to meet the stringent requirements of modern applications due to static resource allocation and limited adaptability. This results in poor Quality of Service (QoS), especially in dynamic environments with fluctuating user demands. Integrating 5G principles, such as dynamic network slicing, into Wi-Fi networks can significantly enhance their performance and reliability.

Dynamic network slicing allows the creation of multiple logical networks over shared infrastructure, each tailored to specific performance criteria like high bandwidth, low latency, or scalability. By enabling real-time resource allocation, dynamic slicing can address challenges such as user mobility and varying traffic patterns effectively.

This project explores the application of dynamic slicing to Wi-Fi networks using the ns-3 simulator. Simulations evaluate how slicing impacts bandwidth utilization, QoS, and user experience, demonstrating its potential to bridge the gap between 5G capabilities and traditional wireless systems.

II. Project Overview and Objectives

A. Overview

This project investigates the use of dynamic network slicing in Wi-Fi networks, inspired by the principles of 5G technology. By simulating dynamic resource allocation, we aim to optimize Wi-Fi performance and enhance adaptability to varying user demands. The ns-3 simulator is used to create a virtualized network environment, enabling an evaluation of slicing techniques in realistic scenarios.

Building on existing research in 5G slicing, this project adapts its concepts to Wi-Fi systems. Our approach focuses on supporting diverse applications such as high-speed streaming and low-latency communications while providing insights into the technical feasibility and benefits of dynamic slicing.

B. Objectives

The objectives of this project include:

- **Dynamic Network Slicing Simulation:** Use the ns-3 simulator to model dynamic slicing in Wi-Fi networks with real-world scenarios such as eMBB, URLLC, and mMTC.
- **Real-Time Resource Allocation:** Implement algorithms for real-time resource allocation to optimize bandwidth utilization and minimize latency.
- **Mobility Management:** Assess the impact of user movement on slice performance and ensure consistent QoS through seamless handovers.

- **Performance Analysis:** Evaluate throughput, latency, and scalability under various network conditions and compare results with static slicing.
- **Visualization and Insights:** Generate visual outputs to illustrate resource allocation and behavior across slices and provide actionable insights.

III. Project Methodology

A. Simulation Framework

The project utilized the ns-3 simulator to model a Wi-Fi network integrated with 5G slicing principles. The simulated architecture featured a base station configured with three primary slices:

- **eMBB:** Designed to handle high-bandwidth applications like HD video streaming and file downloads.
- **mMTC:** Optimized for IoT applications, ensuring reliable communication for devices with minimal data requirements.
- **URLLC:** Dedicated to ultra-reliable, low-latency tasks, such as autonomous vehicle communication and real-time industrial operations.

The simulation framework incorporated realistic mobility scenarios and dynamic traffic loads, reflecting the varying demands of real-world networks. Traffic patterns for each slice were modeled to evaluate the network's adaptability and performance under fluctuating conditions.

B. Dynamic Resource Allocation

Dynamic resource allocation formed the backbone of the simulation, focusing on adjusting resources in real-time based on the following parameters:

- **Network Load:** Resources were reallocated dynamically to meet the varying demands of each slice, ensuring optimal bandwidth usage and preventing congestion.
- **QoS Requirements:** Applications requiring low latency, such as URLLC, were given higher priority to maintain consistent performance.
- **Real-Time Adaptation:** The system continuously monitored key performance indicators (KPIs) such as throughput, latency, and mobility patterns to adapt resource allocation as needed.

This approach ensured efficient utilization of network resources, reducing latency for critical applications and improving overall user experience.

C. Mobility Management

Mobility management mechanisms were implemented to ensure seamless connectivity during user transitions between slices. The simulation modeled various user scenarios, such as:

- **High-Speed Vehicles:** Frequent handovers between access points while maintaining low latency for applications like navigation.
- **Pedestrians:** Moderate mobility requiring consistent QoS with occasional slice transitions.
- **Stationary Users:** Applications like video streaming that demand stable connections with minimal disruptions.

The mobility framework ensured that dynamic slicing maintained robust QoS, even in high-mobility scenarios.

D. Simulation Validation

Simulation results were validated against predefined KPIs, ensuring that the implemented slicing mechanism met the desired objectives. Metrics such as throughput, latency, and scalability were analyzed to evaluate the system's performance across diverse scenarios.

IV. Results and Observations

The simulation results highlighted the advantages of dynamic network slicing in enhancing Wi-Fi performance. Key observations include:

- **Improved Bandwidth Utilization:** Dynamic slicing optimized bandwidth usage by reallocating resources based on real-time network demands, ensuring efficient distribution even under varying traffic conditions.
- **Enhanced Quality of Service (QoS):** The system maintained low latency for URLLC applications, consistent high-quality playback for eMBB traffic, and reliable connectivity for IoT devices in the mMTC slice.
- **Seamless Mobility Management:** Mobility mechanisms ensured smooth handovers with minimal QoS disruption, even in high-speed scenarios, demonstrating adaptability in dynamic environments.
- **Scalability and Adaptability:** The system supported increased user density and adapted efficiently to sudden traffic surges, maintaining high performance and service quality.
- **Energy Efficiency:** By reallocating resources dynamically, the system reduced power consumption while maximizing network performance, particularly during low-demand periods.
- **Visualization of Results:** Graphical outputs illustrated resource allocation, latency, and scalability, emphasizing the adaptability of the slicing mechanism to diverse traffic patterns.

Figures 1, 2, and 3 showcase the simulation results, highlighting improvements in bandwidth allocation, latency reduction, and system scalability.

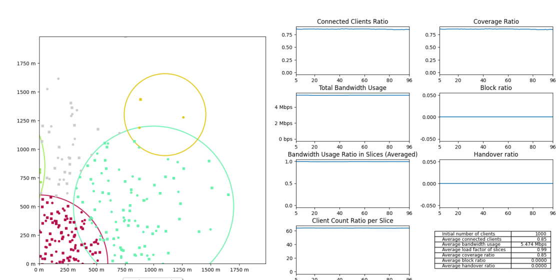

Fig. 1. Resource allocation in high traffic scenarios.

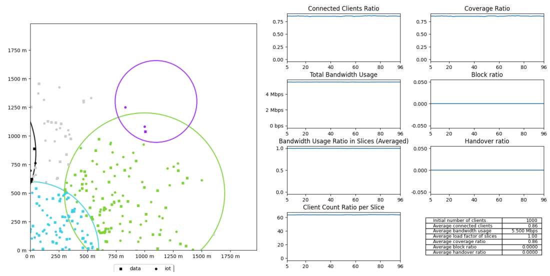

Fig. 2. Latency reduction in URLLC slice.

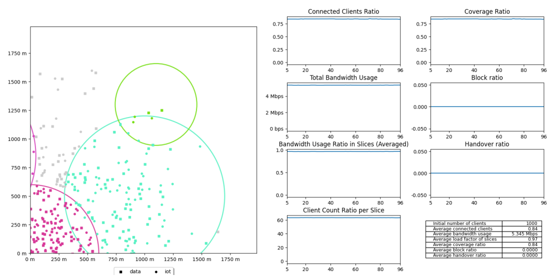

Fig. 3. Scalability under increased user density.

V. Future Work

This project demonstrated the potential of dynamic network slicing but also highlighted areas for future improvement:

- **AI and Machine Learning Integration:** Future work could involve using machine learning algorithms to predict traffic patterns and proactively allocate resources.
- **Advanced Resource Allocation:** Researching more efficient resource allocation strategies that account for energy usage and user priorities can further optimize performance.
- **Real-World Testing:** Expanding the project to real-world environments, such as enterprise networks, would validate its practical application under diverse conditions.
- **Security Enhancements:** Implementing robust security protocols to ensure data integrity and isolate slices from potential cyber threats is essential.
- **Hybrid Network Models:** Exploring models that integrate 5G slicing principles with legacy networks can facilitate a smoother transition to next-generation systems.
- **Customization for Applications:** Tailoring slices for specific use cases, such as healthcare or smart cities, can demonstrate the flexibility of dynamic slicing.
- **Energy Efficiency Optimization:** Further research on energy-efficient slicing mechanisms can support the increasing prevalence of battery-operated IoT devices.

These directions aim to refine the slicing mechanism and expand its application, contributing to the evolution of next-generation network architectures.

VI. Contributions

Each team member contributed significantly to the project's success, leveraging their expertise in specific domains. Below is a detailed summary of individual contributions:

- **Patel Krish:** Led the overall simulation setup in ns-3, configured slice parameters, and analyzed performance metrics. Focused on bandwidth optimization and validated results.
- **Atharv Barde:** Designed and implemented the dynamic resource allocation algorithm. Conducted testing to ensure adaptability to real-time traffic changes and optimized resource distribution.
- **Baraiya Poojan:** Modeled mobility patterns and studied the impact of user transitions on QoS. Generated visualizations to represent simulation outputs and assisted in documenting results.
- **Patel Utkarsh:** Worked on testing different scenarios in the ns-3 simulator and validated system performance under varying network loads. Contributed to preparing graphical representations of results.
- **Sachin Kumar:** Documented the project methodology and findings. Coordinated the team's efforts, managed version control, and ensured timely submission of deliverables.

The project reflects a collective effort where each member utilized their expertise to address different aspects of the simulation, ensuring a comprehensive and successful outcome.

Acknowledgment

We would like to express our sincere gratitude to Dr. Bhupendra Kumar for his invaluable guidance and support throughout the 5G course. His expertise, dedication, and thoughtful insights have greatly enhanced our understanding of the subject. Dr. Bhupendra Kumar's passion for teaching and his ability to break down complex topics into clear and comprehensible concepts has been instrumental in our learning. It has been an honor to learn under his mentorship.

References

[1] M. Nerini and D. Palma, "5G Network Slicing for Wi-Fi Networks," *2021 IFIP/IEEE International Symposium on Integrated Network Management (IM)*, 2021.

[2] J. Ordonez-Lucena, P. Ameigeiras, D. Lopez, J. J. Ramos-Munoz, J. Folgueira, and D. M. Nguyen, "Network Slicing for 5G with SDN/NFV: Concepts, Architectures, and Challenges," *IEEE Communications Magazine*, vol. 55, no. 5, pp. 80–87, 2017.

[3] M. Polese, M. Giordani, A. Roy, D. Castor, and M. Zorzi, "Toward End-to-End, Full-Stack 6G Network Systems: Goals, Enabling Technologies, and Open Challenges," *IEEE Communications Surveys & Tutorials*, vol. 23, no. 4, pp. 2078–2104, 2021.

[4] E. Dahlman, S. Parkvall, and J. Skold, *5G NR: The Next Generation Wireless Access Technology*. Academic Press, 2018.

[5] R. Li, Z. Zhao, X. Zhou, G. Ding, Y. Chen, Z. Wang, and H. Zhang, "Intelligent 5G: When Cellular Networks Meet Artificial Intelligence," *IEEE Wireless Communications*, vol. 24, no. 5, pp. 175–183, 2017.