5G Network Slicing Simulation

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***Abstract*—This paper presents a simulation model for 5G network slicing in a dynamic environment, focusing on resource allocation, traffic patterns, and interference effects. The model simulates different network slices, including enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communications (URLLC), and Massive Machine Type Communications (mMTC), under varying traffic loads and interference conditions. We explore two implementations of the model, highlighting the incorporation of slice priorities, mobility, latency penalties, and resource allocation strategies. The improvements in the second version are discussed to assess its performance in realistic 5G network scenarios.**

***Index Terms*—5G, Network Slicing, Resource Allocation, Interference, Traffic Simulation, Latency Impact**

I. Introduction

The advent of 5G technology marks a significant leap in mobile communication, transforming how we connect and enabling a wide array of applications and services. From high-speed internet to smart cities, 5G is set to revolutionize industries. A key innovation that underpins this transformation is *network slicing*. This technology allows a single physical 5G network to be partitioned into multiple virtual networks, or ”slices,” each tailored to meet the specific needs of diverse applications. Each slice can offer unique combinations of **bandwidth**, **latency**, and **reliability**.

For instance, slices designed for **enhanced Mobile Broadband (eMBB)** provide high data rates, ideal for applications like video streaming and virtual reality. In contrast, **Ultra-Reliable Low-Latency Communication (URLLC)** slices are tailored for mission-critical tasks such as autonomous driving and industrial automation, where minimal delay and high reliability are paramount. Meanwhile, **massive Machine-Type Communication (mMTC)** slices support a vast number of connected devices, such as sensors in IoT ecosystems, with modest data requirements.

This project explores the concept of network slicing through simulation. By modeling different slices (**eMBB**, **URLLC**, and **mMTC**), the project demonstrates dynamic resource allocation under varying traffic loads and interference conditions. The simulation reflects real-world challenges in managing 5G networks, such as traffic fluctuations and external interference. Visualizations of the simulation results provide insights into how network slicing efficiently allocates resources, ensuring **quality of service (QoS)** across slices, even under challenging conditions. This study highlights the potential of network slicing to support a diverse range of 5G-enabled applications.

II. Importance and Advantages of Network Slicing

The introduction of 5G technology has revolutionized the way networks operate, and one of its cornerstone innovations is *network slicing*. This technique allows a single physical network to be divided into multiple virtual slices, each optimized to serve specific applications or industries. Network slicing is critical to fulfilling the diverse requirements of 5G use cases, ranging from high-speed streaming to ultra-reliable low-latency communications. Below are some of the key importance and advantages of this technology:

- **Resource Optimization:** Network slicing ensures efficient resource allocation by dedicating specific network resources, such as bandwidth, latency, and data rate, to each slice based on its unique requirements. This prevents resource wastage and maximizes network utilization.
- **Service Differentiation:** Different industries and applications, such as autonomous vehicles, Internet of Things (IoT), and mobile broadband, have varying performance needs. Network slicing allows for the creation of customized slices, ensuring that each service gets the performance characteristics it requires.
- **Flexibility and Scalability:** The ability to dynamically create, adapt, and scale slices based on real-time demands enables 5G networks to remain agile. This flexibility allows networks to handle diverse and fluctuating workloads effectively.
- **Reduced Latency and Improved QoS:** Critical applications such as autonomous driving and telemedicine require extremely low latency and high reliability. By isolating traffic for these applications, network slicing reduces latency and guarantees a higher **Quality of Service (QoS)** for these mission-critical tasks.

- **Enhanced Security:** Since each slice operates as a logically isolated network, sensitive data in critical applications is more secure. This isolation reduces the risk of cross-slice interference or unauthorized access, improving overall network security.
- **Cost Efficiency:** By enabling multiple services to operate on the same physical infrastructure, network slicing reduces the need for separate networks. This leads to significant cost savings in terms of deployment and operational expenses.

These advantages make network slicing a fundamental component in unlocking the full potential of 5G. It provides the necessary infrastructure for a broad range of applications, ensuring that networks can adapt to the evolving demands of modern industries and consumers.

III. 5G Service Categories: eMBB, URLLC, and mMTC

The 5G network is designed to support a wide range of applications, each with unique performance requirements. To achieve this, 5G leverages *network slicing*, which divides the network into virtual layers tailored to specific use cases. These layers are categorized into three primary service types: **Enhanced Mobile Broadband (eMBB)**, **Ultra-Reliable Low-Latency Communications (URLLC)**, and **Massive Machine-Type Communications (mMTC)**. Together, these categories enable 5G to serve diverse industries and applications efficiently.

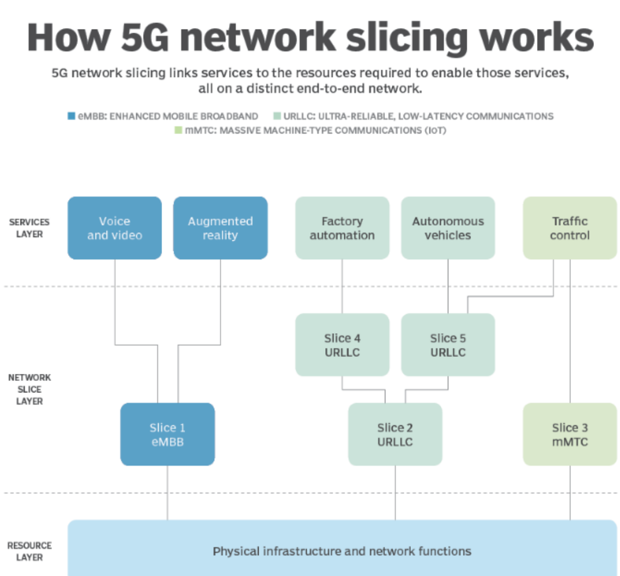

Fig. 1. How does network slicing works

A. eMBB (Enhanced Mobile Broadband)

eMBB is designed to provide high-speed internet and seamless connectivity for applications requiring large data rates. This layer is optimized for data-intensive tasks such as:

- High-definition video streaming
- Virtual reality (VR) and augmented reality (AR) applications
- High-speed downloads and cloud-based gaming

eMBB leverages the high throughput and low latency of 5G, offering speeds exceeding 100 Mbps and ensuring smooth, uninterrupted user experiences even in densely populated areas.

B. URLLC (Ultra-Reliable Low-Latency Communications)

URLLC is designed for mission-critical applications where reliability and ultra-low latency are essential. These use cases include:

- Autonomous vehicles, where real-time communication is crucial for safety
- Industrial automation and robotics in smart factories
- Remote surgery and telemedicine, requiring near-instantaneous feedback

URLLC delivers latencies as low as 1 millisecond and reliability levels of 99.999% to ensure uninterrupted, real-time performance for these critical applications.

C. mMTC (Massive Machine-Type Communications)

mMTC focuses on supporting a massive number of connected devices, often with low data rates and intermittent communication needs. This layer is particularly relevant for the *Internet of Things (IoT)* and includes applications such as:

- Smart meters and environmental sensors
- Connected home devices and appliances
- Low-power devices requiring extended battery life, such as wearables

mMTC is optimized for scalability, enabling millions of devices to communicate efficiently within a single network slice while minimizing energy consumption.

D. Conclusion

These three service categories—eMBB, URLLC, and mMTC—demonstrate the versatility of 5G technology. By catering to the unique requirements of different applications, 5G ensures that industries ranging from entertainment to healthcare and industrial automation can leverage tailored network performance. This capability positions 5G as a transformative force in the evolution of global communication systems.

IV. Simulation Setup

The simulation environment is designed to emulate a realistic 5G network slicing scenario, focusing on the three primary slices: **eMBB**, **URLLC**, and **mMTC**. Each slice is configured with distinct performance requirements, allowing for detailed analysis of resource allocation and traffic management under dynamic network conditions.

A. Network Slicing and Resources

The simulation begins by defining the key parameters for each slice, reflecting their specific use-case requirements:

- **Bandwidth:**
  - eMBB: 50 MHz
  - URLLC: 10 MHz
  - mMTC: 5 MHz
- **Latency:**
  - eMBB: 20 ms
  - URLLC: 1 ms
  - mMTC: 50 ms
- **Data Rate:**
  - eMBB: 100 Mbps
  - URLLC: 1 Mbps
  - mMTC: 500 Kbps

To simulate real-world conditions, each slice is initialized with resource grids that include interference. The interference is modeled as random noise, generated by multiplying a predefined noise level with a random variable. This approach mimics unpredictable network environments.

B. Traffic Simulation and Resource Allocation

Traffic patterns are dynamically generated to represent varying network loads over time. For each slice, the traffic load fluctuates between 80% to 120% of its base data rate, reflecting real-world usage variability. The simulation calculates the impact of interference on resource allocation, dynamically adjusting the allocated resources by subtracting interference from the traffic load.

C. Priority-Based Resource Allocation

In the enhanced simulation model, slices are assigned priority levels to reflect their importance in network traffic management:

- **URLLC**: Highest priority
- **mMTC**: Medium priority
- **eMBB**: Lowest priority

The resource allocation process prioritizes higher-priority slices, ensuring that critical applications (like URLLC) receive sufficient resources even under high interference or traffic conditions. This priority-based approach allows for a more realistic simulation of how 5G networks manage resources.

D. Latency Impact Calculation

The simulation also incorporates latency penalties to measure performance degradation. If the traffic load for a slice exceeds its latency threshold, a penalty is applied, reflecting delays or quality degradation. In the second version of the simulation, these penalties are accumulated for each slice and visualized to show their impact on overall network performance. This analysis helps evaluate the effectiveness of resource allocation strategies in maintaining low latency for high-priority slices like URLLC.

E. Visualization and Analysis

The simulation results are visualized, highlighting:

- Resource allocation over time for each slice
- The impact of interference on resource distribution
- Accumulated latency penalties for each slice

These visualizations provide insights into the performance of the 5G network slicing model and its ability to manage diverse traffic and interference scenarios efficiently.

V. Results and Discussion

This section presents the simulation results from both versions of the code and provides a comparative analysis. The focus is on the impact of interference and priority-based resource allocation on network performance.

A. First Code Results

The first version of the code simulates dynamic traffic patterns for the eMBB, URLLC, and mMTC slices while incorporating interference. The primary goal is to assess how interference affects resource allocation across slices.

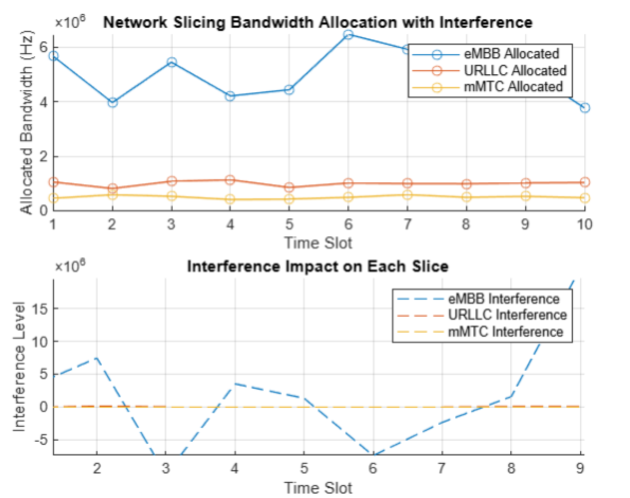

Fig. 2. Resource allocation and interference impact across eMBB, URLLC, and mMTC slices.

In Figure 2, the results illustrate the effect of interference on each slice. The inclusion of interference helps simulate real-world conditions where external factors impact resource distribution. Without considering priority, all slices are treated equally in terms of resource allocation, highlighting how interference affects each slice uniformly.

B. Second Code Results and Improvements

The second version introduces several enhancements, making the simulation more realistic:

- **Slice Priority:** Higher-priority slices, such as URLLC, receive preferential resource allocation.
- **User Mobility:** Users are distributed randomly across base stations, simulating a more dynamic network environment.

- **Latency Penalty:** Latency penalties are calculated to measure performance degradation when traffic exceeds latency thresholds.

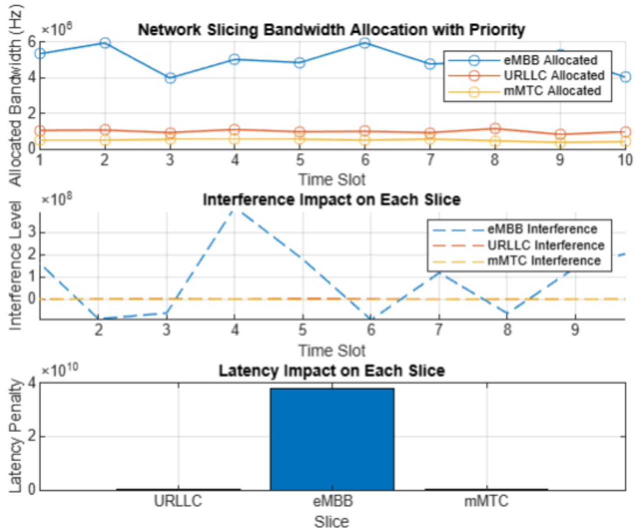

Fig. 3. Priority-based resource allocation and latency penalties across slices.

Figure 3 demonstrates how the introduction of priority alters resource allocation. URLLC, being the highest-priority slice, receives sufficient resources even under heavy traffic and interference, while lower-priority slices such as eMBB are more impacted by resource constraints.

C. Comparison of Results

The comparison between the two versions highlights the benefits of introducing slice priority and user mobility:

- **Interference in Figure 2:** In the first code, interference impacts all slices equally. This visualization underscores the need for prioritization in resource allocation to better manage critical applications under varying interference levels.
- **Priority in Figure 3:** The second code shows how priority-based allocation ensures critical slices like URLLC maintain performance despite adverse conditions. This prioritization leads to better overall network efficiency and ensures that latency-sensitive applications meet their performance requirements.

D. Discussion

The improvements in the second version of the simulation provide a more comprehensive view of 5G network slicing performance. By incorporating priority-based allocation and mobility, the simulation mirrors real-world scenarios more closely. This approach ensures that critical applications receive the resources they need, even under challenging network conditions. The latency penalty visualization further highlights the trade-offs between resource allocation and slice performance, emphasizing the importance of dynamic, priority-driven resource management.

E. Comparison of Results

The second version of the code offers a more detailed analysis of 5G network slicing by incorporating slice priorities and mobility, which are crucial aspects of real-life 5G networks. Additionally, latency penalties are considered, providing more comprehensive insights into network performance. The results indicate that higher-priority slices (e.g., URLLC) are allocated more resources, while lower-priority slices (e.g., eMBB) experience greater latency penalties.

VI. Conclusion

This paper presented two iterations of a 5G network slicing simulation, emphasizing the critical role of efficient resource allocation, interference management, and latency optimization in modern 5G networks. The first version of the simulation provided a foundational understanding of resource distribution under dynamic traffic and interference conditions, offering insights into how interference affects network slices.

However, the second version significantly enhanced the model by introducing priority-based resource allocation, user mobility, and latency penalties. These improvements better reflect the complexities of real-world 5G environments, where different slices cater to diverse applications such as high-speed internet (eMBB), ultra-reliable communications (URLLC), and massive IoT (mMTC). By prioritizing critical slices like URLLC, the second simulation ensures that latency-sensitive and mission-critical applications maintain performance even under high traffic and interference.

The results demonstrate that incorporating slice priorities and dynamic user distribution not only improves resource allocation efficiency but also ensures a balanced network performance. The latency penalty analysis provides a quantitative measure of performance degradation, highlighting the trade-offs between resource constraints and quality of service.

These findings offer valuable insights for network designers and operators, guiding the development of more efficient and resilient 5G networks. Future work could extend this simulation by exploring advanced techniques such as machine learning for predictive resource management and further enhancing mobility models to simulate urban-scale 5G deployments. Ultimately, this study underscores the importance of adaptive and intelligent resource management in realizing the full potential of 5G technology.

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CONTRIBUTIONS OF THE GROUP MEMBERS

1) **Arya Bhatt (202151028):** Researched network slicing fundamentals, including eMBB, URLLC, and mMTC, and developed the initial resource allocation simulation while documenting its results.
2) **Divyanshu Sethiya (202151052):** Worked on traffic simulation with fluctuating loads, interference modeling, and creating accurate visualizations for the first version.
3) **Ujjwal Singh (202151158):** Refined algorithms, researched mobility and latency impacts, and created advanced visualizations, aiding comparative analysis.
4) **Swetha Balamurugan (202151168):** Contributed to network slicing research, by studying the working of network slicing and led result analysis, prepared visuals, and compiled findings.
5) **Hitt Bahal (202151194):** Implemented priority-based allocation, user mobility, and latency penalty calculations, enhancing the realism of the second simulation and worked on interference modeling in first simulation.

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