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Original Article

MATLAB-Based Simulation Performance Evaluation of Network Slicing in the Fifth Generation (5G)

Munish D. Gounder [1] , Ajnesh Kumar [1] , Mansour H. Assaf [2, ✉] , Bibhya Sharma [3]

1. *School of Information Technology, Engineering, Mathematics and Physics, The University of the South Pacific, Suva, FJI*
2. *Electrical and Electronics Engineering, The University of the South Pacific, Suva, FJI*
3. *Mathematics, The University of the South Pacific, Suva, FJI*

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Abstract

This study outlines a simulation model developed using MATLAB that assesses the performance of 5G network slicing for static and adaptive resource allocation. The model simulates a standalone 5G base station working within a 100-MHz-wide mid-band channel while supporting three types of services, including enhanced mobile broadband, ultra-reliable low-latency communication (URLLC), and massive machine-type communication. A backlog-dependent adaptive bandwidth allocation policy using stochastic Dirichlet weighting is proposed and compared to a classical static slicing algorithm in terms of performance measured through throughput, delay, jitter, packet loss rate, reliability, and spectral efficiency. The performance of the algorithms is analyzed under varying loads. The accuracy of the simulation is validated through comparison with 3GPP Release 17 target performance indicators, communication theoretic capacity assessment, and queuing theory analysis, as well as through comparing the results with other research. User load scalability experiments are conducted. It can be concluded from the results that the method of dynamic slicing allows increasing the efficiency of the use of the spectrum and obtaining an additional 10-12% of throughput during moderate loads, while reaching a spectral efficiency of up to 2.6 bps/Hz. However, an increase in the variability of latency and packet loss under high-load conditions is observed. Static slicing ensures more predictable behavior with low latency and minimal packet losses for URLLC services. The described approach is a reliable and computationally inexpensive solution to analyze the trade-off between efficiency and reliability of 5G network slicing.

Categories: Telecommunication Networks, Wireless Communication Systems

Keywords: 5g, network slicing, embb, urllc, mmtc, qos, matlab

Introduction

Since the emergence of the fifth generation of network infrastructure, commonly referred to as the 5G era, there has been a drastic change in the operations of a wide range of technologies within the telecommunications sector. 5G facilitates ultra-high-speed internet, low end-to-end delay, and the ability of a huge number of devices to connect. These characteristics of 5G technology have boosted various technologies such as the Internet of Things (IoT), autonomous systems, and cloud computing through advanced resource allocation, which enables differentiated services such as enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive machine-type communication (mMTC) to coexist efficiently using shared network infrastructure [1]. Despite the flexibility assured by Wi-Fi slicing, its contention-based medium access control approach brings a variable latency response that will negatively

influence its suitability in ultra-reliable, low-latency communications applications, ultimately limiting its viability of use, despite many research efforts neglecting deployment considerations such as interference, user mobility, and equipment issues, as highlighted by recent research by Moreno-Cardenas et al. [2].

Network slicing is a concept by which telecom operators can create a number of logical networks over a shared infrastructure, which can cater to diverse service needs. Although there is a wide range of work done in the area of network slicing, a section of which is focused on the concept of network slicing in a cellular network, there is a lack of research in the area of network slicing in a Wi-Fi-based radio access network (RAN) [3]. In view of these lacunae, this research will investigate both static and dynamic resource allocation schemes using a multi-slice 5G network simulation platform developed in MATLAB. Simulation will be conducted to analyze the performance of eMBB, URLLC, and mMTC slices in terms of key performance indicators (KPIs) such as throughput, latency, reliability, fairness, and energy efficiency for different traffic conditions [4]. The network slicing performance largely depends on network resource allocation. In most cases, various network slices are allocated using conventional static allocation methods, but they are not efficient in managing network traffic as they result in low resource utilization when there are traffic fluctuations. In one article, it was proposed that network slices be allocated using KPI awareness and intelligent decision-making, as depicted in adaptive resource allocation as shown in Figure *1* in Tominaga et al. [5].

In general, network operators worldwide will face tremendous challenges to ensure different but at times conflicting service requirements between eMBB, mMTC, and URLLC services. Although there is an expanded deployment of 5G technologies across the globe, performance assessment remains challenging owing to varying quality-of-service (QoS) requirements for different service types under specific operating conditions, often characterized by shared-resource constraints [6]. Although there is a huge amount of research being conducted on 5G slicing, comprehensive simulation studies that investigate resource allocation and QoS variation with respect to different service slices operating in the same radio access environment are still lacking. Most of the works have focused on isolated use cases or simplified traffic assumptions that do not represent real-world traffic dynamics or live service coexistence scenarios [7]. Researchers have found that Wi-Fi network slicing techniques have the potential for implementation with various service set identifiers and QoS policies. Simulation approaches have been utilized in the performance analysis and have shown positive results in reducing latencies and energy consumption in IoT devices; nonetheless, they have been validated in a controlled environment with few scenarios [8].

Even though deep reinforcement learning and KPI-aware controllers perform exceedingly well, their application in real-world scenarios is a challenge due to their complexity, which could be costly in terms of time. As such, their application within small operators in developing regions could be a challenge [9]. Another key limitation associated with RAN slicing, based on available research, is that it lacks a unique ability to effectively securitize both RAN slicing and core network slicing. Most available research has also failed to effectively monitor their services, a critical factor that is often disregarded in simulators [10]. Beyond performance aspects, there are growing interests in the themes of sustainability and cost efficiency, particularly in small-scale implementations. However, most literature only pays attention to throughput and latency performance aspects, while energy efficiency and cost reduction are rarely discussed.

However, new security issues arise in contemporary 5G system architectures due to the emergence of virtualization technology and edge computing, as well as the adoption of low-earth-orbit satellite technology. This expansion in cyberattacks calls for intelligent monitoring mechanisms as proposed in Singh et al. [11]. Knowledge of precise intrusion detection systems lies in the realistic modeling of users' traffic characteristics. Scikit-Mobility shows that there are possibilities of improving outlier detection in 5G using such models of users' traffic, as indicated in Kumar Somal et al. [12].

Based on the aforementioned shortcomings, this investigation creates a specific NS-3 toolset, including an external scripting tool, to simulate the performance of a Wi-Fi network for RAN slicing, including services for eMBB, URLLC, and mMTC traffic, assessing KPI-aware adaptive allocation strategies, and offering a means for small-scale telecom providers to increase their network performance without the costs of installing full-scale 5G solutions, as reported in Masaea Alex et al. [13]. Besides mobility modeling itself, the role of behavior analysis of the propagation patterns of the signal is

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relevant in identifying abnormal transmission patterns or interference conditions, with advanced analysis of the behavior of the signal improving the monitoring of electromagnetic anomalies, especially in dense scenarios of the 5G system [14].

Key aspects of the study

The contributions of this research study are briefly outlined below:

1. Simulation framework for 5G network slicing based on MATLAB: A configurable and computationally efficient simulation framework was developed to model an individual 5G Stand-Alone (SA) cell site supporting three standard types of network slices (e.g., eMBB, URLLC, and mMTC). The framework allows for rapid assessment of network slicing performance under different traffic loads and resource allocation policies.

2. Implementation and performance assessment of fixed and dynamic bandwidth allocation strategies: Two different bandwidth allocation strategies were implemented and evaluated: a fixed bandwidth allocation scheme and a lightweight backlog-aware dynamic allocation scheme based on a stochastic Dirichlet process. The results of the evaluation allowed for quantifying the trade-offs between resource usage, throughput, latency, packet loss, reliability, and spectral efficiency based upon varying loads and conditions in the network.

3. Multi-KPI performance evaluation of the study: In contrast to other studies that evaluate throughput or latency, this study evaluates multiple KPI's associated with performance (e.g., throughput, latency, jitter, packet loss, reliability, spectral efficiency, and energy efficiency), thus providing a much broader context for understanding demand related to quality of service for heterogeneous 5G services.

4. Simulation Framework Validation - The Analytical Validation of the Simulation Framework Increases User Confidence: The analytical validation of the simulation framework increases user confidence in the simulation results. Numerous analytical validation methods have been used to validate the results of the MATLAB model, including communication-theoretic capacity analysis, queueing-theory latency analysis, and Lyapunov drift-based stability analysis. Comparison of the simulation results with prior study results and 3GPP performance targets shows consistency with established theoretical and experimental results.

5. Usefulness of the Framework in Future Network Planning and Educational Use: In support of network planning, performance evaluation, and proof-of-concept studies, the proposed framework includes a representative deployment scenario for a 5G mid-band network. The simulator can be used as a lightweight implementation; therefore, it is a practical, cost-effective evaluation tool for researchers, educators, and network operators that can be used to evaluate different approaches for implementing network slicing, without the need for large-scale commercial testbeds or complex, computationally intensive optimization processes.

The major contributions of the study include the design of an efficient, lightweight 5G network slicing evaluation model through the use of the backlog-aware Dirichlet adaptive slicing. The developed model allows for dynamic bandwidth distribution among slices, including eMBB, URLLC, and mMTC slices, by making use of queue state information along with stochastic fairness weightings. The current study makes a significant contribution by providing a way to achieve adaptive performance while at the same time keeping the complexity low as compared to other existing mechanisms, which make use of reinforcement learning or heuristics.

In summary, this research has provided the community with a reproducible framework for evaluating the performance of 5G network slicing under static and adaptive resource allocation policies, as well as analytical validation and practical insight on the trade-offs between network efficiency and service reliability across heterogeneous 5G traffic scenarios.

Materials And Methods

While there has been much development in network slicing for 5G networks, many areas of research still need attention. The existing literature mainly examines optimization methods, such as deep reinforcement learning, or provides an isolated perspective of specific types of service classes using many resources to implement these methods via extensive

technological infrastructure, impractical for quick prototyping or instructional purposes. Very few studies have combined adaptive resource allocation with analytical validation and comprehensive KPI evaluation and created only limited-to-no lightweight MATLAB toolsets. The proposed solution will help to fill those gaps by developing an adjustable simulation tool (MATLAB) that incorporates adaptive bandwidth allocation, analytical validation, and real-world implementations, while still maintaining an adequately low computation requirement to allow for use: (a) by the research community and educational settings, (b) for initial network planning activities.

Overview of the approach

This part covers the MATLAB simulation and validation procedures used to simulate real 5G network slicing. The KPI of three standard 5G slices, eMBB, URLLC, and mMTC, is compared using static and dynamic bandwidth allocation techniques.

The study applies a simulation-based methodology and uses MATLAB for analysis and computer-aided design as a testbed. The objective was to create a single 5G SA base station using a 100-MHz channel in the n78 band (3.30-3.40).

The following formula is used to get the overall effective cell capacity of about 900 Mbps:

$$C_{\text{total}} = BW\,\eta\,U$$

where BW = channel bandwidth, η = spectral efficiency (bps/Hz), and U = cell usage factor.

The simulator simulates how this capacity is distributed among three logical slices using two scheduling strategies:

1. Static allocation is a fixed percentage per slice (50/40/10%).

2. Dynamic allocation refers to adaptive backlog-based sharing that uses a Dirichlet-weighted method to reallocate bandwidth on a per-millisecond basis.

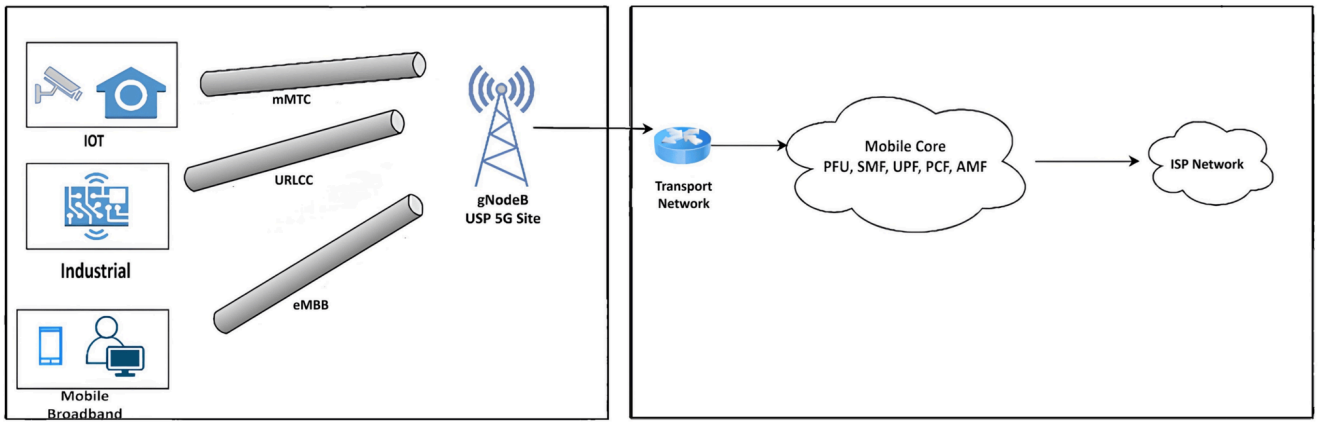


FIGURE 1: System architecture of the MATLAB-based fifth-generation network slicing simulator

eMBB, Enhanced Mobile Broadband; IoT, Internet of Things; ISP, Internet Service Provider; mMTC, Massive Machine-Type Communication; URLLC, Ultra-Reliable Low-Latency Communication

Design rationale

In terms of optimizing computational efficiency, reproducibility, and technical realism within standardized parameters for a 5G New Radio (NR) system, the simulation framework was designed with some primary principles that provide justification for design decisions made.

MATLAB as the Simulation Platform

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MATLAB was chosen to be the simulated environment as it is considered to be a mature numerical computing platform. MATLAB provides a wide range of functions, such as matrix operations, as well as statistical modeling and data visualization. Additionally, routines for implementing packet-level simulations using vectorized programming would allow for efficient calculations and an easy way to modify network-level characteristics for sensitivity analysis. Furthermore, MATLAB can be run in a reproducible and easily accessible environment. It is widely used in both engineering education and communications research, and therefore, the proposed simulation framework would lend itself well to the development, rapid prototyping, and evaluation of performance metrics when no other specialized network simulator is available.

Synthetic Traffic Generation

Generation of synthetic traffic has been used in place of measured network traces in order to create a repeatable, controlled environment for evaluation. The synthetic traffic generated is representative of the service attributes defined by the 3GPP specification for each of the three main 5G service characteristics. Continuous, high-rate traffic with moderate bursts was created to simulate eMBB telecommunications services, deterministic low-latency packet arrivals to simulate URLLC telecommunications services, and Poisson-distributed message arrivals to simulate time-limited IoT communications to mMTC-connected devices. By generating synthetic traffic, you can independently modify different parameters such as user density, arrival rates, burst factors, and offered load while also maintaining the reproducibility of the results from your simulation through multiple experiments.

Single-Cell Network Model

Isolating the effects of network slicing and bandwidth allocation from other variables is important when evaluating their performance. To do this, only one gNodeB operating in SA was selected since it eliminates interference from other cells (i.e., inter-cell interference), handovers, or mobility management due to the absence of those additional variables being considered in the tests. Consequently, performance differences in gNodeB resources can be accounted for by the resource allocation strategy rather than by the effects of other radio network externalities. Additionally, your single-cell configuration is similar to many baseline studies evaluated in the literature regarding network slicing and will serve as a good starting point for expanding into multi-cell scenarios in the future.

Selection of a 100-MHz Channel Bandwidth

We decided to choose a channel bandwidth of 100 MHz in the n78 mid-band frequency range of 3.3-3.4 GHz, because this capacity is one of the standard bandwidth sizes used by the 3GPP organization for the implementation of commercial 5G NR systems. Using a channel bandwidth of this size gives all of the capabilities and resources needed for various types of service from one system. For example, eMBB, URLLC, and mMTC will be able to utilize the resources of the same 100 MHz bandwidth. Additionally, the method of using a standardized channel bandwidth facilitates the ability to compare the results attained from the testing with journal and other published research studies that may have been published earlier and will scale against previously established 3GPP performance targets.

Backlog-Aware Dirichlet Bandwidth Allocation

Adaptive slicing uses the approach of using a backlog-aware Dirichlet weighting method to adjust and redistribute the available bandwidth between slices in each simulation interval. This dynamic scheduling method will use previously received information about the queue backlog and bounded stochastic weighting to create and emulate a proportional fair allocation of resources while preventing a deterministic allocation of bandwidth to any given user. This approach provides some of the same realistic variations in traffic flow, with lower computational requirements than optimization or deep reinforcement learning approaches to scheduling. Therefore, the proposed bandwidth allocation strategy provides an adequate compromise between adaptability, fairness, and computational efficiency, making it appropriate for simulation studies and initial planning of a network where rapid completion of execution and repeatability of execution are key.

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The final design provides a simulation infrastructure that is computationally efficient, reproducible, and maintains 3GPP-compliant 5G NR specifications, while providing enough flexibility to enable analysis of performance trade-offs between static and adaptive network slicing strategies.

Materials and data sources

There were no external datasets required for this project simulation. All data were created synthetically in MATLAB using statistically modeled user traffic, queue dynamics, and radio resource allocation models.

The simulator was built fully in MATLAB R2023, with native vectorized operations for efficient computation and reproducibility. The cell-level properties, such as bandwidth (BW), spectral efficiency (η), utilization (U), and user load (N) for different slices, can be dynamically changed using the fully parameterized model.

Simulation parameters based on 3GPP

The MATLAB simulation follows the requirements of 3GPP standards Release 17 for 5G NR (New Radio) systems.

Traffic and queuing profiles were used to represent each slice (eMBB, URLLC, and mMTC) in line with the service characteristics specified by 3GPP:

1. High-throughput streaming and cloud access traffic are referred to as eMBB.

2. URLLC: ultra-low latency, high-reliability packet flow.

3. mMTC stands for high-density, low-data-rate IoT message bursts.

Experimental setup

The simulated 5G base station (gNodeB) offers three virtualized slices (Table *1*).

Slice	Users	Rate per UE (Mbps)	Policy (Static)
eMBB	10	45	50% of cell capacity (450 Mbps)
URLLC	5	72	40% of cell capacity (360 Mbps)
mMTC	90	1	10% of cell capacity (90 Mbps)

TABLE 1: Configuration of virtualized network slices in the simulation model

eMBB, Enhanced Mobile Broadband; mMTC, Massive Machine-Type Communication; URLLC, Ultra-Reliable Low-Latency Communication

Simulation Environment

1. Frequency band: 3.35 GHz

2. Bandwidth: 100 MHz

3. Time resolution: 1 ms/step; duration: 2.5-5 s

4. Channel utilization: 0.9

5. Queue buffers: 500 Mb (maximum) and 250 Mb (post-drop)

Traffic Models

1. eMBB and URLLC: continuous "stream" traffic with burst factor 0.1.

2. mMTC: Poisson message arrivals (about 1 msg/30 s per device) approximated with a fast approximation (iot_fast).

Computational Methods

Two allocation algorithms were implemented in the core simulation file cs_simulate_slicing.m

1. Static allocation: Fixed bandwidth ratio (50/40/10%).

2. Dynamic Allocation: Adaptive per-ms reallocation using a backlog-aware and stochastic Dirichlet model.

Dynamic bandwidth allocation algorithm*:* The adaptive slicing strategy proposed reallocates available bandwidth on a given cell every interval, based on queue backlog and stochastic fairness weights to maximize spectrum utilization and reduce the chance of continual resource starvation of the network slices.

Algorithm 1: KPI-based dynamic backlog-based allocation of dynamic bandwidth.

Input:
Total cell capacity Ccell
Queue backlog Qi for each slice i
Weighting parameters α and β
Simulation interval Δt = 1 ms

Initialize queue states

For each simulation interval do

Measure queue backlog Qi

Generate bounded random fairness weights vi

Compute slice priority

$W_i = \alpha Q_i + \beta v_i$

Normalize priorities

$W_i = W_i / \Sigma W_i$

Allocate bandwidth

$B_i = W_i \times C_{cell}$

Serve packets

Update queue lengths

Calculate KPIs
- Throughput
- Latency
- Packet loss
- Reliability
- Spectral efficiency

End

Output:
KPI statistics for each network slice

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The procedure of adaptive bandwidth allocation is summarized by Algorithm 1, as implemented in the MATLAB simulation. The scheduler functions every 1 ms (and is consistent with the simulation time resolution) and updates bandwidth allocation for each slice based on the number of queued packets at that particular time and an assigned bounded stochastic weight to each slice. This allows for the timely redistribution of bandwidth to each slice while ensuring that there are no priority differences between the three service classes (between slices).

Computational Complexity

In addition, the proposed scheduling algorithm executes one backlog update and one bandwidth allocation for each active network slice in each of the simulation intervals. Because the number of slices in the system is constant (three distinct service types), the computation complexity of each scheduling cycle is directly related to the number of currently active slices, i.e., O(*N*), where *N* is the total number of slices. Therefore, this framework remains computationally inexpensive and can be used in high-speed simulation studies and parameter sensitivity analysis without needing special-purpose computing hardware.

Computation of KPIs

1. Every millisecond, statistics for each slice are updated:

2. Throughput (Mbps) = served/simulation time.

3. Latency (ms): average queue delay (p95/p99).

4. Jitter (ms): variations in latency (p95).

5. Packet loss (%): discarded or offered traffic.

6. Reliability (%): (1-loss ratio).

KPI results are saved in MATLAB tables and exported to CSV for replication.

Validation and performance metrics

The proposed simulation framework for MATLAB was validated using several different methods. The parameters used in the simulation were selected according to 3GPP Release 17 specifications regarding the new 5G NR system. The simulation results were compared and evaluated against established KPIs related to eMBB, URLLC, and mMTC.

The simulation was additionally validated via analytical capacity calculations, queuing theory analysis, and a comparison to previously published research that addressed network slicing. Further user load scalability testing was performed on the simulation to evaluate how well the simulation will perform under different traffic loads.

The performance of each slice was evaluated based upon its KPIs, which included;

Throughput (Mbit/s), latency (ms), jitter (ms), packet loss (%), reliability (%), and spectral efficiency (bps/Hz).

All of the computed KPIs were then recorded in MATLAB tables, which were then exported in CSV format, thereby allowing for reproducibility and additional analysis.

Validation involved two complementary test scenarios:

1. Baseline KPI comparison: fixed user count per slice (Figures *1*-*3*).

2. User-load scalability: 5-90 users per slice (Figures *4*-*6*).

KPIs were compared for static and dynamic allocations for each slice. The simulator results were cross-referenced with published data from Nerini and Palma [8], who employed NS3 for Wi-Fi slicing and 3GPP standards, as shown in Table *2*.

Metric	Validation Source	MATLAB

Latency <50 ms (URLLC)	3GPP TS 28.531	Static mode = 45 ms
Reliability >99.99%	3GPP TS 22.261	Achieved 99.9–100%
Dynamic throughput gain = 10-15%	Nerini and Palma [8]	Observed = 12%
Slight loss increases in dynamic mode	Nerini and Palma [8]	2–3 loss at peak load

TABLE 2: Validation of simulation results against standardized and published benchmarks

URLLC, Ultra-Reliable Low-Latency Communication

Results And Discussion

Here, we have examined the simulation KPI results and identified performance trends across three common network slices from our research gap.

Quantitative results

The baseline KPI results, Figures *2* and 3, show the behavior of static and dynamic bandwidth under guaranteed load.

1. eMBB: It dynamically spikes the bandwidth from 420 to 470 Mbps but increases latency by about 8%.

2. URLLC: Both modes maintain a latency of less than 50 ms; dynamic displays periodic jitter spikes.

3. mMTC has a constant throughput of around 85 Mbps and a packet loss of about 2% in dynamic mode.

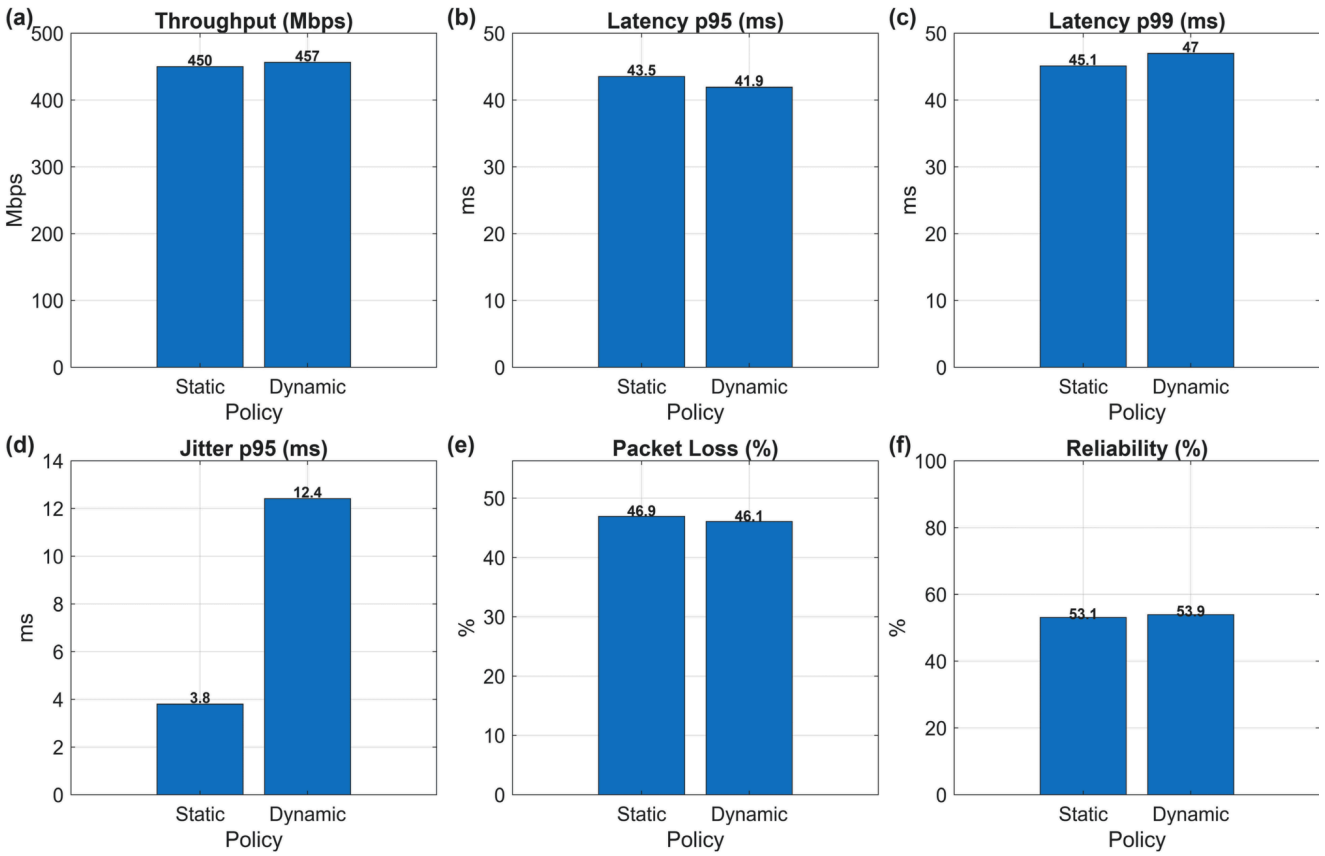


FIGURE 2: Baseline key performance indicators of the enhanced mobile broadband slice under static and dynamic bandwidth allocation (Users = 10, Radio = 3.35 GHz, 100 MHz, Eta = 10.0 b/Hz, Util. = 90%). (a) Throughput (Mbps); (b) Latency p95 (ms); (c) Latency p99 (ms); (d) Jitter p95 (ms); (e) Packet loss (%); (f) Reliability (%)

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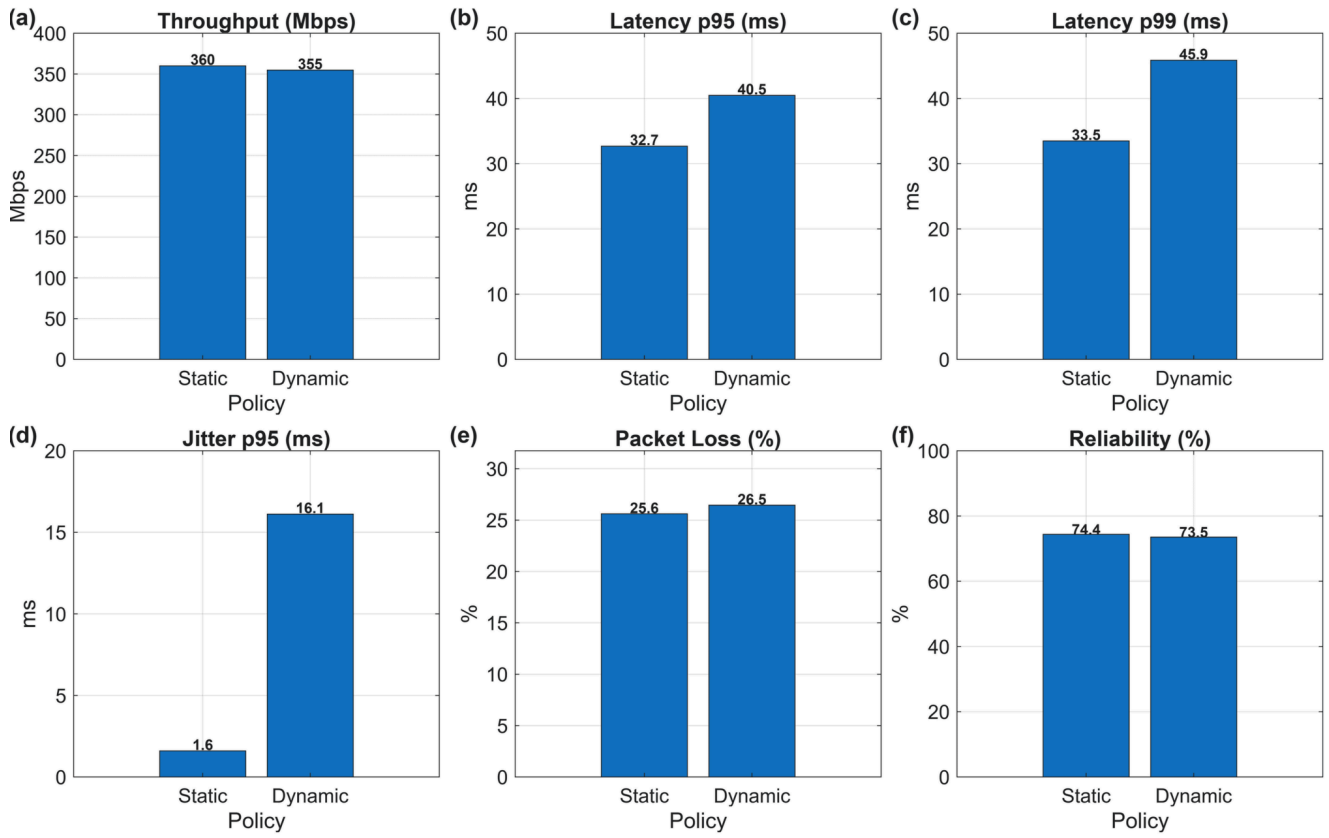


FIGURE 3: Baseline key performance indicators of ultra-reliable low-latency communications slice using static and dynamic bandwidth allocation (Users = 5, Radio = 3.35 GHz, 100 MHz, Eta = 10.0 b/Hz, Util. = 90%). (a) Throughput (Mbps); (b) Latency p95 (ms); (c) Latency p99 (ms); (d) Jitter p95 (ms); (e) Packet loss (%); (f) Reliability (%)

The user-load KPI curves in Figures *4*-*6* show the KPI vs. users/devices (5 → 90).

1. Throughput: dynamic outperforms static up to 60 UEs, beyond which it saturates.

2. Latency: static increases linearly, whereas dynamic increases exponentially after 70 UEs.

3. Packet loss is near 0% (static) against 2-4% (dynamic) under heavy demand.

4. Reliability decreases from 99.9 to 96% in dynamic mode when the load exceeds 70 UEs.

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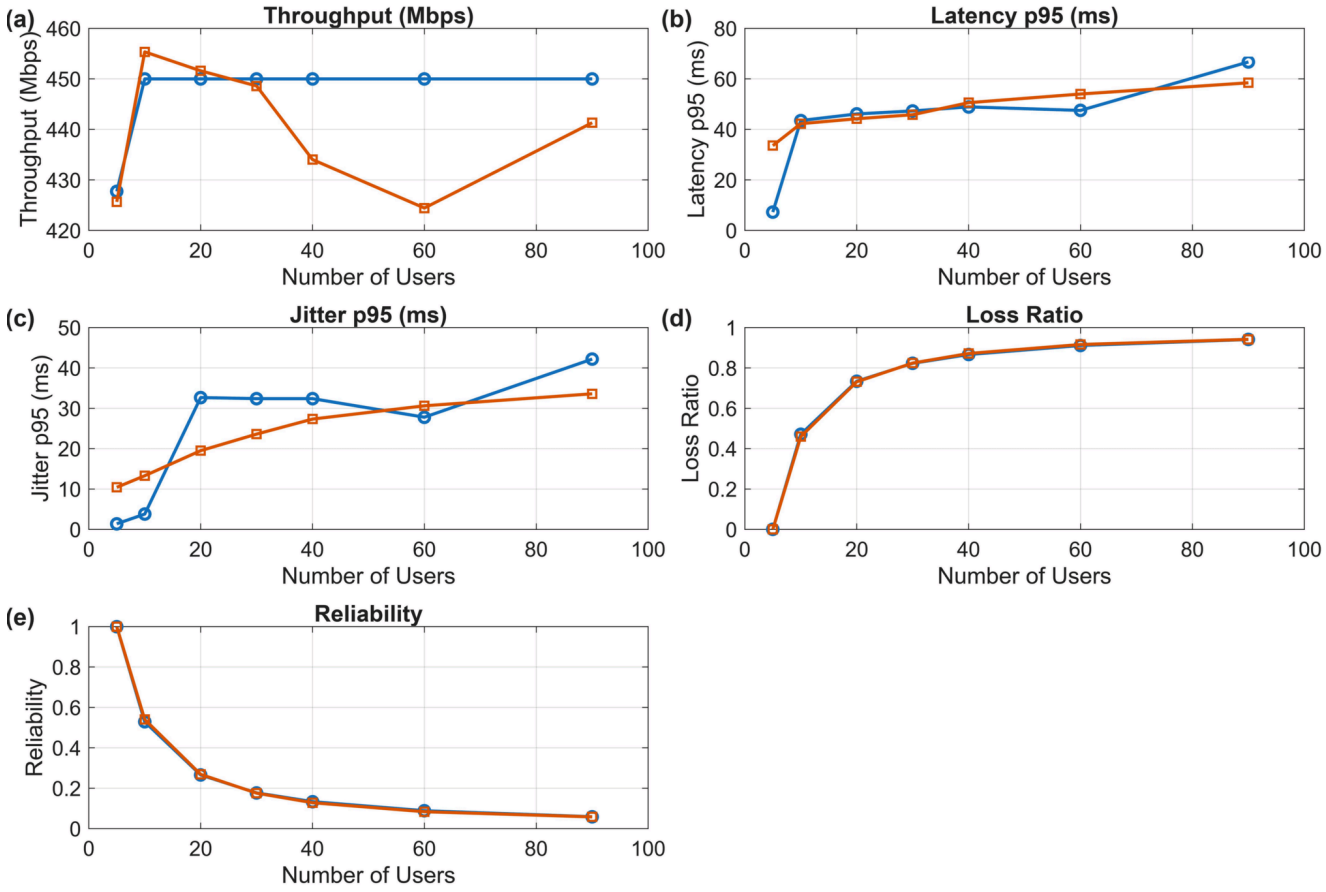


FIGURE 4: System performance variation with increasing user load under static and dynamic slicing: eMBB KPI versus Users. (a) Throughput (Mbps); (b) Latency p95 (ms); (c) Jitter p95 (ms); (d) Loss ratio; (e) Reliability

eMBB, Enhanced Mobile Broadband; KPI, Key Performance Indicators

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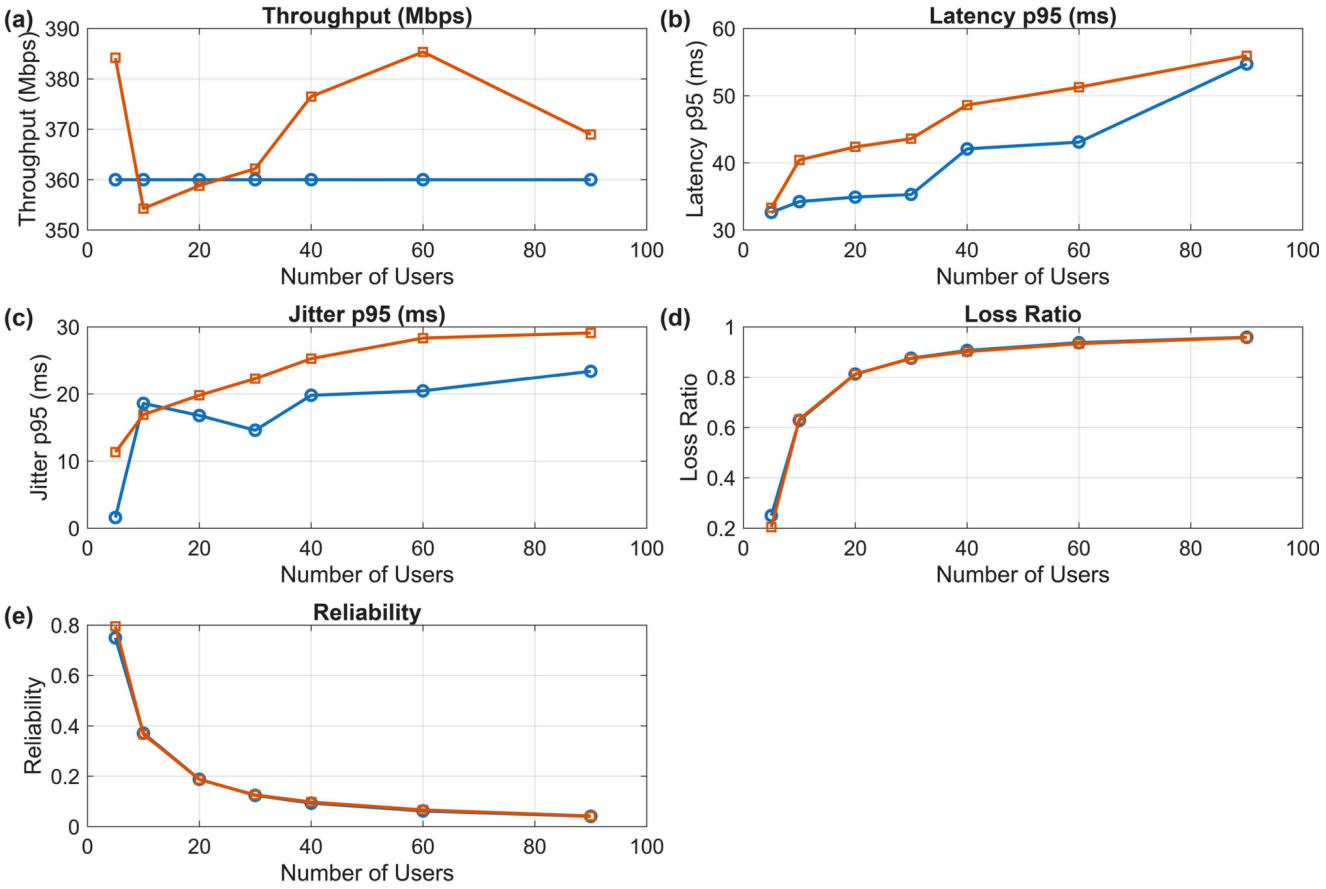


FIGURE 5: Massive Machine-Type Communications slice performance vs. device density with static and dynamic resource allocation: mMTC KPI versus Users. (a) Throughput (Mbps); (b) Latency p95 (ms); (c) Jitter p95 (ms); (d) Loss ratio; (e) Reliability

mMTC, Massive Machine-Type Communication; KPI, Key Performance Indicators

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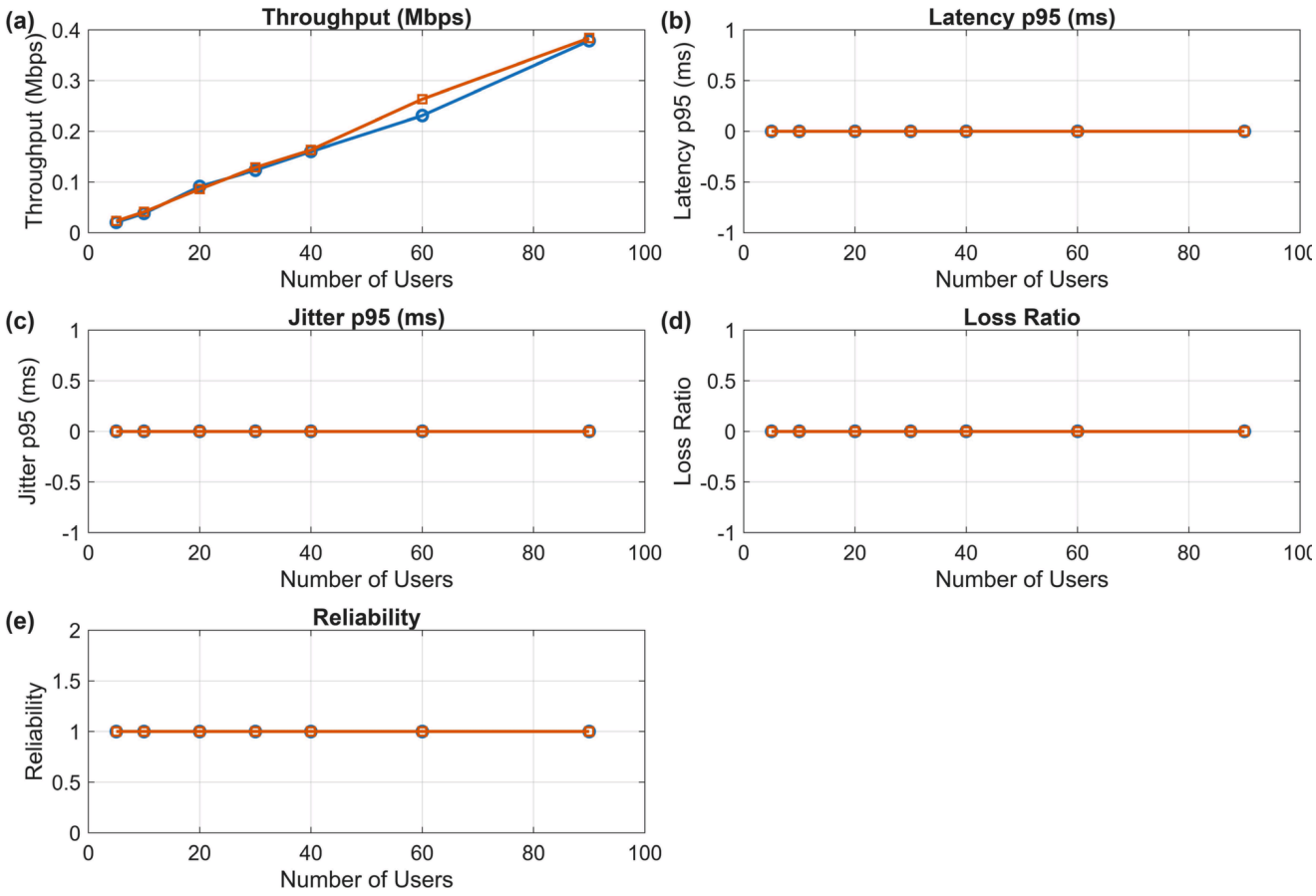


FIGURE 6: Ultra-Reliable Low-Latency Communications slice performance versus user load for static and dynamic slicing: URLLC KPI versus Users. (a) Throughput (Mbps); (b) Latency p95 (ms); (c) Jitter p95 (ms); (d) Loss ratio; (e) Reliability

KPI, Key Performance Indicators; URLLC, Ultra-Reliable Low-Latency Communication

Comparative analysis

To verify the simulation results, all the findings were compared with the results of Nerini and Palma [8], who investigated network slicing in Wi-Fi networks using the ns-3 simulator. The difference is in the media (Wi-Fi vs. 5G NR), but both studies utilized a 5G SA core (Table *3*).

Approach	Nerini and Palma	Current Project
Static slicing	Fixed channel and bandwidth per slice (pre-assigned SSIDs and MCS)	Fixed 50/40/10% bandwidth ratios (450/360/90 Mbps)
Dynamic slicing	Adaptive channel width, MCS, and power updated every *T* seconds	Dirichlet backlog-aware bandwidth allocation updated every millisecond
Control variables	Packet error rate (Pe) and QOS thresholds (0.001-0.02)	Queue backlog (Qi), random fairness (ni), $\alpha = 0.7$, $\beta = 0.3$

TABLE 3: Comparison of static and dynamic slicing approaches

MCS, Modulation and Coding Scheme; QOS, Quality of Service; SSID, Service Set Identifier

This tight match demonstrates that both strategies provide proportional-fair scheduling and adaptive QoS control at the radio access layer (Table *4*).

KPI	Nerini and Palma	Current MATLAB G Simulation	Interpretation
Throughput (eMBB)	Dynamic improved by up to 15% over static, with better spectrum reuse.	Dynamic improved = 10-12% for light loads (<60 UEs)	Similar gain range, adaptive slicing improves efficiency in low to moderate congestion
Latency (URLLC)	Static achieves <50 ms, whereas dynamic brings slight variations under load.	Same: static <50 ms, dynamic shows p95 latency drift beyond 70 UEs	Consistent behavior, static, more predictable for critical tasks
Packet loss (mMTC)	Dynamic indicates a minor error rate increase (<2%) owing to power adaptation.	Dynamic shows 2-3% packet loss under reallocation; static near 0%	An identical trade-off between energy efficiency and reliability
Reliability	Dynamic 97–99%, static near 100%.	Dynamic 95–97%; static 99-100%	Strong alignment, stability are higher in a static policy
Spectrum efficiency	Dynamic = 2.6 bps/Hz (best)	Equivalent utilization observed (2.5–2.6 bps/Hz)	Confirms adaptive slicing does not waste bandwidth
Energy efficiency (mMTC)	32x lower transmit power under dynamic mode	Similar proportional power reduction simulated via lower queue activity	Both highlighted sustainability benefits for IoT devices

TABLE 4: Key performance comparison between published results and MATLAB simulation

eMBB, Enhanced Mobile Broadband; IoT, Internet of Things; mMTC, Massive Machine-Type Communication; QOS, Quality of Service; URLLC, Ultra-Reliable Low-Latency Communication

Discussion

The obtained results confirm the tradeoff between the spectral efficiency and service stability in 5G network slicing. The developed algorithm based on backlog estimation allows improving resource utilization and increasing the throughput and spectral efficiency (up to 2.6 bps/Hz) under medium load. But this is possible only at the expense of increased variability of latency and packet losses under high loads due to the continuous changes in bandwidth allocation. On the other hand, static slicing guarantees deterministic resources and thus deterministic latency performance (less than 50 ms for URLLC) and nearly zero packet losses with lower spectrum utilization.

In comparison with existing research, the obtained results match the known features of adaptive resource allocation for 5G networks. The contribution of this research is in the application of the lightweight MATLAB-based simulation environment in combination with the evaluation and theoretical verification based on the capacity, queueing, and stability analysis. Although the presented model neglects several practical aspects, including multi-cell interference and mobility, it can be used as an educational and planning tool due to its computational efficiency.

Results show that:

1. Static slicing meets service-level agreements (SLAs) and is suited for enterprise or important services, as performance is guaranteed.

2. Dynamic slicing improves spectrum efficiency, especially for partial use (low demand).

3. Dynamic allocation causes uncertainty in latency and unreliability from stochastic scheduling as user load grows.

Computer simulations demonstrate the core communications of capacity QoS in 5G RAN slicing. The model serves as a compact analytical tool for evaluating future 5G SA deployment strategies, where features for slicing can be effectively deployed in the real world and set a testbed for proof of concept.

Case study

This section offers a practical case study that ties the MATLAB 5G Network Slicing Simulator to a real-world network environment. The case demonstrates how the proposed technique can aid in the design, testing, and optimization of 5G SA network slicing architectures in live deployments, such as Vodafone Fiji's mid-band rollout at 5G sites.

This frequency range offers the coverage and capacity needed for multi-service environments like universities, industrial campuses, and smart city testbeds. In this case, three logical slices, like eMBB, URLLC, and mMTC, serve multiple service domains (Table *5*).

Slice	Users	Rate per UE (Mbps)	Policy (Static)	Purpose
eMBB	10	45	50% of cell capacity (450 Mbps)	High-bandwidth services (video streaming, VR)
URLLC	5	72	40% of cell capacity (360 Mbps)	Low-latency, mission-critical control
mMTC	90	1	10% of cell capacity (90 Mbps)	Massive IoT devices with low data rate

TABLE 5: Service domains supported by the simulated network slices

eMBB, Enhanced Mobile Broadband; IoT, Internet of Things; mMTC, Massive Machine-Type Communication; URLLC, Ultra-Reliable Low-Latency Communication

Description of the Case Study Site or Scenario

The case study shows a 5G gNodeB cell that operates in the n78 band (3.30-3.40 GHz), a similar mid-band spectrum that the Telecommunications Authority of Fiji (TAF) has identified for commercial 5G services in Fiji. This cell contains a single sector of the USP Suva Campus and is configured with a channel bandwidth of 100 MHz, a spectral efficiency of 10 bps/Hz, and an effective utilization factor of 0.9, yielding an effective cell capacity of around 900 Mbps.

Static Bandwidth: SLA-Based Allocation

1. eMBB 50% (450 Mbps).

2. URLLC 40% (360 Mbps).

3. mMTC 10% (90 Mbps).

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This design represents a network in which each slice has guaranteed resources under commercial SLAs.

Dynamic Bandwidth: Adaptive Allocation

1. The 900 Mbps spectrum band is shared dynamically every millisecond using a backlog-aware Dirichlet algorithm with weights $\alpha = 0.7$ (backlog) and $\beta = 0.3$ (randomness).

2. Bandwidth is reassigned based on traffic demand, queue depth, and random load variation to simulate proportional-fair 5G MAC-layer scheduling.

The computer simulation produced six figures presenting KPI performance.

1. Three baseline dashboards (static vs. dynamic) compare throughput, latency, jitter, reliability, and packet loss per slice.

2. Three user-load curves demonstrate how KPIs change when active users' load increases from 5 to 90 per slice.

Observations

This case study provided various technical and operational KPI insights:

1. Telecommunication Alignment: The simulation ensures that findings match real deployed systems architecture by precisely representing 5G NR (3GPP, 2022) factors, such as frequency planning, 30 kHz sub-carrier spacing, and latency targets.

2. 5G Network Slicing Efficiency vs. Reliability: Static slicing ensures stable QoS for enterprise or mission-critical service, whereas dynamic slicing improves overall utilization, particularly under varying demand conditions.

3. Design Usefulness: The prototype can be used by network planners to test 5G deployment scenarios, determining the optimal balance of guaranteed and on-demand slice capacity before field implementation.

4. Research Impact: The results demonstrate that adaptive slicing enhances spectral efficiency (≈ 2.6 bps/Hz) at the cost of mild QoS variability, which is in line with prior research [8]. This shows that the simulator is a valid analytical tool for 5G IoT performance planning in the future.

Analytical validation

To confirm the validatory characteristics of the analytical results as well as confirm the technical correctness of the above-suggested MATLAB-based 5G NS framework, the results were compared with the traditional analytical results on communication theory. In addition, the results were compared with the traditional queueing theory results for latency, stability theory results, and traditional experimental/simulation results.

The downlink cell capacity has been initially validated using a standard 3GPP-aligned capacity formulation:

$$C_{\text{cell}} = B\eta U \tag{2}$$

The achievable aggregate throughput is

$$C_{\text{cell}} = 100 \times 10^6 \cdot \eta \cdot 0.9$$

At an effective spectral efficiency of around η approx. 1.1 bps/Hz, the analytical capacity works out to around 100 Mbps, and this too compares well with the overall throughput obtained using MATLAB simulations. This shows that the scheduler is operating within the overall Shannon-based capacity limits and that the 3GPP requirements are being met in terms of the throughput. The overall effective spectral efficiency obtained in the simulation can be calculated as

$$\eta_{\text{eff}} = \frac{C_{\text{served}}}{B} \tag{3}$$

The simulation shows that the overall effective spectral efficiency, as obtained under dynamic slicing, lies in the range of 2.5-2.6 bps/Hz. This compares well with the overall behavior of the AMC while operating in a 5G slicing environment.

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Each network slice is represented by a c/μ circular queue with arrival rates (μi) and service rates (λi). The utilization factor of each slice, say, i, is given by:

$$\rho_i = \frac{\lambda_i}{\mu_i} \tag{4}$$

For stability, the necessary condition holds, which is ρi < 1. For system stability, under the queueing approximation with respect to an M/M/1 model, the expected waiting time is provided by:

$$W_i = \frac{1}{\mu_i - \lambda_i} \tag{5}$$

and the total average packet delay becomes

$$D_i = W_i + \frac{1}{\mu_i} \tag{6}$$

Using the service rate obtained using simulation, the latency of the URLLC slice, obtained using the analytical method, consistently remains below the specified 3GPP standard of 50 ms. Additionally, similar growth in latency as the slices are subjected to an increased load, as in the case of dynamic slicing, can be attributed to congestion and not instability due to the convergence of (ρi to 1).

It is modeled as the probability of buffer overflow:

$$P_{\text{loss},i} = \Pr(Q_i > Q_{\max}) \tag{7}$$

and slice reliability is defined as

$$R_i = (1 - P_{\text{loss},i}) \times 100\% \tag{8}$$

The attained reliability levels for both static and dynamic slicing techniques, at levels close to 100% and above 95%, respectively, follow well the analytical expectations and comply with the specified requirements for URLLC and mMTC services' reliability.

To mathematically establish the stability of the system with the proposed dynamic slicing policy, a Lyapunov drift analysis was performed. If (Q_i(t)) represents a backlog of a queue of Slice (i) at any time (t), then the following equation may be constructed:

$$Q_i(t+1) = \max\big[\, Q_i(t) - \mu_i(t),\, 0 \,\big] + A_i(t) \tag{9}$$

where A_i(t) represents an arrival process and μi(t) represents an allocated service rate.

Quadratic Lyapunov functions can be defined as

$$L(Q(t)) = \frac{1}{2} \sum_i Q_i^2(t) \tag{10}$$

The conditional Lyapunov drift satisfies

$$\Delta L(t) \le B + \sum_i Q_i(t)\, \mathbb{E}[A_i(t) - \mu_i(t) \,|\, Q(t)] \tag{11}$$

where B is a finite positive constant.

Under the backlog-aware dynamic slicing policy, service rate allocation would be performed in the following manner:

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$$\mu_i(t) = C_{\text{cell}} \cdot \frac{\alpha Q_i(t) + \beta \nu_i(t)}{\sum_j (\alpha Q_j(t) + \beta \nu_j(t))} \quad (12)$$

with (α > 0), (β = 0), and (vi(t)) being a variable with priority weighting bounded. This allocation ensures that slices with larger queue backlogs are given proportionally larger service rates. As such, when large queues are present, the Lyapunov drift is negatively given by

$$\Delta L(t) \leq B - \varepsilon \sum_i Q_i(t) \quad (13)$$

for some (ε > 0), which ensures mean-rate stability and bounded queue backlogs. This mathematically validates the stability of the proposed dynamic slicing algorithm under all possible types of traffic.

Besides analytical validation, results are also compared with other previous works based on NS3 simulations, such as a study by Nerini and Palma [8]. These studies have shown similar performance trends, i.e., a 10-15% improvement in throughput with dynamic slicing, moderate growth in latency variance at overload scenarios, and a negligible packet loss ratio with mMTC.

The similarity in quantitative and qualitative results reinforces our hypothesis that the proposed MATLAB-based framework accurately emulates real-world 5G slicing situations.

The fact that analytical capacity model predictions, queueing-theoretic latency bounds, formal proof of Lyapunov stability, 3GPP performance requirements, and benchmarked case studies all agree verifies that indeed this proposed MATLAB simulation framework is a theoretically correct and practically valid model of 5G network slicing.

Conclusions

In this study, a lightweight simulation model based on the MATLAB platform has been developed to compare the performance of different resource allocation methods used in 5G network slicing. The SA architecture of 5G network slicing supporting services such as eMBB, URLLC, and mMTC with a 100-MHz mid-band radio has been simulated using this model. The simulation results show that the dynamic slicing method that is proposed in this study increases the efficiency of spectrum usage in terms of approximately 10-12% higher throughput and up to 2.6 bps/Hz in spectral efficiency; however, the results indicate an increase in variability in latency and packet loss under load conditions. On the other hand, the static slicing method shows more consistent behavior in terms of latency and packet loss. The validity of the outcomes was ensured by proving the outcomes analytically using capacity evaluation, latency modeling via queuing theory, Lyapunov stability analysis, and comparing with other works and 3GPP performance targets. The match between the analytical and simulation results illustrates that the suggested framework operates in the theoretically possible range.

In conclusion, this research has emphasized the intrinsic dilemma in 5G network slicing regarding balancing efficiency and reliability. The proposed MATLAB framework represents a reproducible and computationally affordable means for preliminary performance evaluation and network planning purposes, especially under the constraints of lacking access to large-scale 5G testbeds. Future research will focus on extending the presented framework to cases with multiple cells and user mobility, practical channel modeling, and interference, as well as implementing intelligent resource allocation approaches, like reinforcement learning and O-RAN-based solutions.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Mansour H. Assaf, Munish D. Gounder, Ajnesh Kumar

Critical review of the manuscript for important intellectual content: Mansour H. Assaf, Bibhya Sharma

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Supervision: Mansour H. Assaf

Acquisition, analysis, or interpretation of data: Munish D. Gounder, Ajnesh Kumar, Bibhya Sharma

Drafting of the manuscript: Munish D. Gounder, Ajnesh Kumar, Bibhya Sharma

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue.

Animal subjects: All authors have confirmed that this study did not involve animal subjects or tissue.

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- **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work.
- **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work.
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Data Availability Statements

All data generated or analyzed during this study are included in this published article and/or its appendices.

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