PERFORMANCE EVALUATION OF COMPUTER NETWORK TOPOLOGIES USING OPEN 5GS

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Abstract**—** With the rapid advancement of communication technologies, the need for high-performance and scalable network architectures has become critical. This manuscript presents a comprehensive performance evaluation of various computer network topologies using OPEN5GS, an open-source platform designed for simulating 5G network environments. The study models and analyzes point-to-point, star, and mesh topologies to assess key performance indicators such as latency and throughput under diverse traffic conditions and network loads. Through extensive simulation, the results highlight how different topological structures respond to varying performance demands. The core contribution of this work lies in offering practical insights into the comparative efficiency of common network designs, which can assist network engineers in selecting optimal architectures tailored to specific application needs. This evaluation supports data-driven decision-making for designing robust and efficient communication systems in next-generation networks.

Keywords—OPEN5GS , Network topologies , Latency, Throughput.

I. INTRODUCTION

Fifth-generation wireless (5G) is the latest iteration of mobile communication technology, designed to increase the speed and responsiveness of mobile networks in an unprecedented way. In particular, 5G promises to enable sophisticated use cases, such as connected vehicles, remote surgery, remote control of production lines, and retail and medical drone deliveries. [8]

Open5GS is an open-source project that provides a comprehensive and flexible implementation of 4G LTE and 5G core network functions, enabling the development, testing, and deployment of next-generation mobile networks. Designed with modular architecture, it includes essential components such as the Mobility Management Entity (MME), Serving Gateway (SGW), Packet Data Network Gateway (PGW), Home Subscriber Server (HSS), and 5G core elements like the Access and Mobility Management Function (AMF) and User Plane Function (UPF). These components work together to facilitate seamless mobile communication, device connectivity, and service delivery. Developed primarily in the C programming language for high efficiency and performance, Open5GS supports various network protocols and standards, making it adaptable to different deployment scenarios.

Its open-source nature promotes collaborative development, allowing researchers, telecom engineers, and hobbyists to customize and extend functionalities according to their unique requirements. Open5GS can run on standard hardware and virtualized environments, which makes it accessible for academic institutions, startups, and large telecom operators to experiment with network configurations, optimize resource allocation, and simulate real-world network conditions. Additionally, it supports integration with network automation tools and SDN (Software Defined Networking) controllers, enabling automated management and scalability of networks.

Many use cases for Open5GS include testbeds for 5G research, prototyping private LTE/5G networks for industrial IoT applications, and educational purposes to understand core network operations. Its ability to emulate complex network environments without the need for costly physical infrastructure significantly reduces development costs and accelerates innovation. Furthermore, the platform is regularly updated and maintained by an active community, ensuring compliance with evolving standards and compatibility with various network devices. Overall, Open5GS is a critical tool for advancing wireless communication research, supporting the deployment of private networks, and fostering innovation in the rapidly evolving landscape of mobile connectivity.

ARCHITECTURE OF OPEN5GS

A. Overall Architecture

Our 5GS platform is illustrated in Fig. 1. It is installed on a Ryzen Threadripper 3970X with 64 CPUs and 256 GB RAM. The operating system is Ubuntu 22.04. The 5G SA platform consists of a 5G Core network from open5GS (v2.6.4) and an O-RAN Alliance-compliant Radio Access Network (RAN) from srsRAN (v23.10). It connects to the public internet using an Ethernet interface and running a masquerade script.
The radio unit is a USRP B210 connected to the RAN via USB3. The USRP contains a GPS disciplined oscillator (GPSDO) and 5GHz compatible hinged external antennas from Molex. [4]

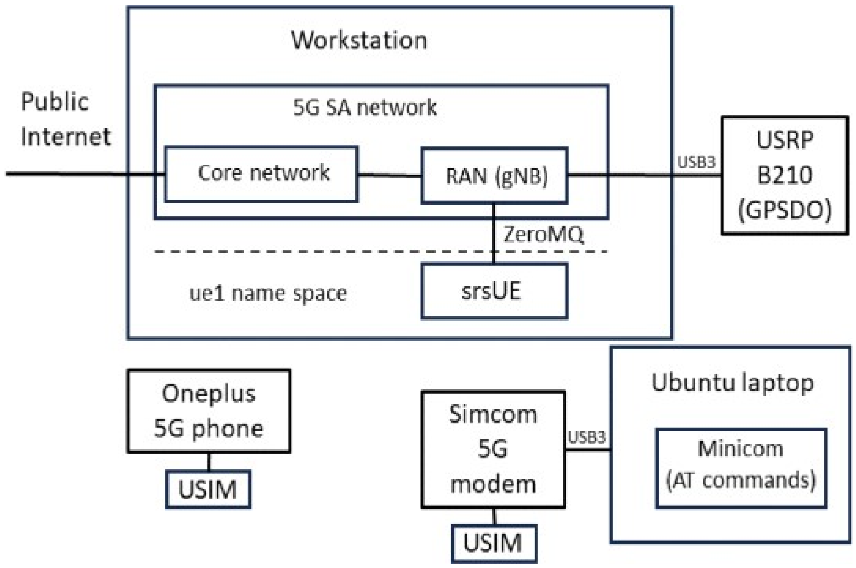

Fig 1. Platform architecture [4]

Three different UEs connect to the 5G SA platform. One UE from srsRAN is installed in a separate namespace within the workstation. This is a 4G UE can be used to test 5G NR but with some difficulty, such as 15 kHz sub- carrier spacing (SCS). It is useful to test the 5G SA platform without being concerned by the air interface and propagation conditions. The second UE is a laptop with a Simcom SIM8262E-M2 5G modem. The modem can be configured and monitored from the laptop using AT commands. It is located close to the 5G SA platform and is useful to test throughput and latency. The last UE is an Oneplus Nord CE 2 Lite 5G phone. It is useful to test coverage and received signal level as a function of distance. Both the modem and the phone have a SIM card installed from Sysmocom. The SIM cards are programmed using a SIM card reader/writer from Omnikey.[4]
The platform operates in the n77 band with a centre frequency of 3.88 GHz. This is a license granted by the Norwegian Communication Authorities (Nkom) for use at specific locations. According to the license conditions, the transmit power is limited to 30 dBm with 0 dB antenna gain, and the maximum bandwidth is 80 MHz. The maximum antenna height above ground
is 10 meters.[4]

B. 5G Core Network

Open5GS is an open-source 5G core network, where the code is made available under the specifications of the
GNU AGPL v3.0 license. In contains both a 5G NSA core and a 5G SA core. The 5G NSA core is essentially a 4G core network, but with some modifications, such as separation between the user plane and the control plane. In the work presented here, only the 5G SA core is used.[4] The 5G SA core contains the following Network Functions (NFs):
AMF; Session Management Function - SMF; User Plane Function - UPF; Authentication Server Function - AUSF; Repository Function - NRF; Unified Data Management - UDM; Unified Data Repository - UDR; Policy and Charging Function - PCF; Network Slice Selection Function - NSSF; and Binding Support Function - BSF [12]. In the control plane, the functions are configured to be registered

in NRF [9]
The three most central NFs are the AMF, SMF and UPF. The AMF is the only NF in the control plane that has interfaces to the gNB and the UEs, so all other control plane NFs communicating with the gNB or the UE do this via the AMF. The AMF also handles authentication of UEs and mobility together with the AUSF, UDM and UDR. The SMF is in charge of managing sessions and, among other tasks, allocates IP addresses to the UEs.
The UPF is the only NF in the user plane, and all user data flows through the UPF to external networks like a public internet. Fig. 2 gives the NFs and the most important interfaces. [4] The red color corresponds to the user plane, and the blue color to the control plane.[4]

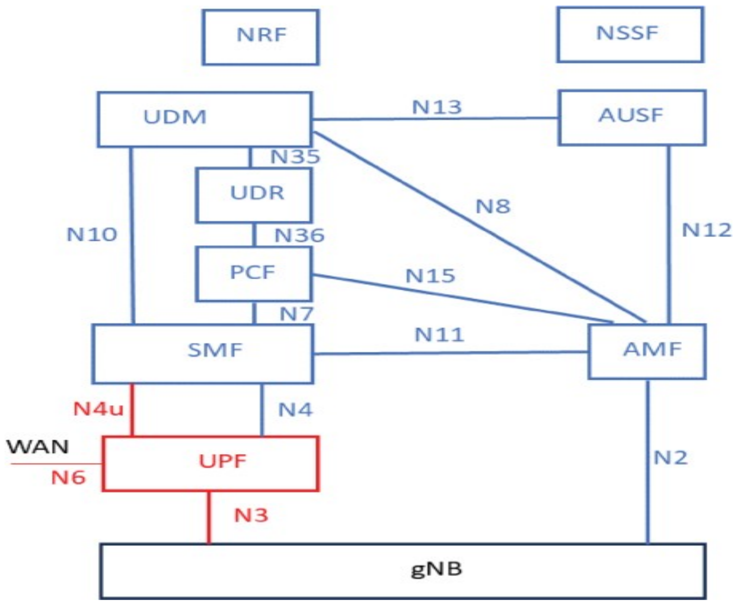

Fig 2. Open5GS core network .[4]

The user credentials are entered using a web interface and stored in the AUSF. The credentials consist of the Subscription Permanent Identifier (SUPI) (same as the IMSI in 4G), the operator code OPc and the subscriber authentication key Ki . These must be same as those stored on the SIM card.Addition to this, it specifies which Data Network Name (DNN) the subscriber can connect to. The DNN is analogous to the Access Point Name (APN) in 4G, but in 5G it is related to network slicing, which is a key feature of 5G networks.[4]

II. LITERATURE REVIEW

A. *"Computer Network Topologies", Author: Ms. Pratiksha Vijay Chinchwade, Ms. K. N. Rode, Ms. Mrunali Nagesh Sankpal, Ms. Rutuja Rajkumar Kognole, 2022 IEEE.*

This paper[1] offers a comprehensive analysis of various physical network topologies, such as bus, ring, tree, mesh, star, and hybrid configurations. These topologies are essential components of network design, each having unique attributes that affect network performance, scalability, and reliability.
The paper explains how different topologies address specific challenges in communication systems, helping to optimize network operations for various use cases. Each topology's characteristics—such as cost, ease of management, fault tolerance, and scalability— specifies its suitability for the particular network sizes and applications. This study serves as a foundational reference for knowing how to select the most effective topology based on the particular needs and goals of a network.

B. ***"Open 5G campus networks: Key drivers for 6G Innovations", Author: Ms Marc Emmelmann, Marcius Corici, Fabian Eichhorn, Manfred Hauswrith, Thomas Magedanz, 2022 IEEE.***

This paper[2] explores the global landscape of 5G campus and private networks, examining their current role and future potential in driving 6G innovations. The authors discuss the evolution of campus networks from early 5G deployments to the development of fully open, customizable networks that cater to specific enterprise and industrial needs.

The paper highlights the key drivers for the growth of Open 5G campus networks, including the demand for ultra-low latency, high reliability, and tailored connectivity solutions for industries such as manufacturing, healthcare, and logistics. These private networks are seen as essential for providing secure, dedicated communication channels, supporting upcoming technologies like AI, Iot, and augmented reality.Additionally, the paper outlines the transition from current 5G networks to future 6G infrastructures, emphasizing the role of open, flexible campus networks in this evolution. It suggests that Open 5G campus networks will serve as a testbed for developing and deploying the innovations required for 6G, including new network architectures, automation, and advanced service capabilities. The paper positions Open 5G campus networks as critical enablers of the next-generation communication systems that will support a wide variety of applications, shaping the future of global connectivity.

C. ***"Open Source Core Network Implementation". Author: Rekha Reddy, Michael Gundall, R. Christoph Lipps, Hans Dieter Schotten ,2020***

This paper [3] discusses the implementation of open-source solutions for core networks, focusing on the flexibility, cost-effectiveness, and scalability that open-source platforms bring to next-generation communication systems, particularly for 5G and beyond.

The authors examine the architecture and components of open-source core network platforms, such as the control and user planes, and the key network functions (e.g., Session Management Function (SMF), Access and Mobility Management Function (AMF), and User Plane Function (UPF)). They highlight the advantages of open-source solutions, including customization, ease of integration with existing infrastructure, and the ability to quickly adapt to emerging technologies and use cases.The paper also provides a qualitative analysis of the open-source approach, looking at factors like community-driven development, interoperability with legacy systems, and the potential for innovation. The authors argue that open-source core networks can drive innovation, reduce operational costs, and empower network Operators benefit from increased control and management of their infrastructure.The paper conducts a quantitative analysis of open-source core network platforms, assessing performance metrics such as throughput, latency, scalability, and fault tolerance. This comparison with proprietary systems sheds light on the potential of open-source solutions to meet the demands of contemporary mobile networks.

D. ***"Performance Evaluation of an OpenSource Implementation of a 5G Standalone Platform" Author: Jan Erik Hakegard (Senior Member, IEEE), Henrik Lundkvist, Ashish Rauniyar (Member, IEEE), Peter Morris, 2024 IEEE***

This paper [4] presents an in-depth evaluation of an open- source 5G standalone (SA) platform.

The study focuses on assessing the platform's performance based on key metrics such as throughput, latency, scalability, and reliability. The authors compare the open-source implementation to proprietary 5G solutions, demonstrating its competitiveness in areas like throughput and latency, while highlighting areas for improvement, especially in fault tolerance and resource management under high load conditions.The platform's cost-effectiveness and flexibility make it an appealing choice for customized and scalable 5G deployments. However, further optimization is necessary to match the robustness of proprietary systems, especially in large-scale and industrial settings. Ultimately, the paper suggests that open-source 5G platforms can foster innovation in 5G and future 6G networks, pending additional development for peak performance.

E. ***"A Study and Analysis on Computer Network Topology For the Data Communication" Author: Santanu Santra, Pinakai Pratim Acharjya, 2022.***

This paper [5] provides a comprehensive analysis of various physical network topologies used in data communication. The authors explore several common topologies, including point-to-point, bus, star, tree, ring, hybrid, and daisy chain. Each topology is examined in terms of its structure, advantages, and limitations, offering a detailed understanding of how they impact network performance, scalability, and fault tolerance.The paper first discusses the point-to-point topology, which connects two devices directly, providing a simple and efficient setup for small-scale networks. However, it is not scalable and this only suitable for scenarios where only two devices need to communicate. The bus topology, which uses a single backbone to connect multiple devices, is cost-effective but prone to congestion and performance degradation as more devices are added.Next, the authors analyze star topology, where all other devices connect to a central hub. This configuration offers easy network management and fault isolation, but the network's performance is heavily dependent on the central hub. The tree topology, a hybrid bus and star topologies, is suitable for large networks due to its scalability, but it can encounter bottlenecks in the central backbone. Similarly, the ring topology connects devices in a circular manner, offering predictable performance but suffering from single-point failures that can interput the entire network.

F. **"5G Campus Networks: A First Measurement Study",** ***Author: Justus Rischke, Peter Sosasalla, Sebastian Itting, Frank H. P. Fitzek (Senior Member, IEEE), Martin Reisselein (Fellow,IEEE) , 2021*** .

This paper[6] presents an depth analysis of the real- world performance of 5G campus networks, focusing on private, localized 5G networks deployed in specific environments such as industrial sites or academic campuses. The authors aim to assess how 5G performs in these private networks, designed for specific applications like smart manufacturing, research, and industrial IoT applications. Through measurements and field tests, the study evaluates key performance parameters such as throughput, latency, signal strength, and network reliability.The study highlights that 5G campus networks demonstrate high throughput and low latency, which are crucial for real-time applications. However, the authors also identify challenges in maintaining consistent performance, such as signal degradation caused by physical obstructions and interference from other wireless systems. While 5G networks performed well in terms of reliability, occasional disruptions were observed in areas with high traffic or complex environments. The results show that effective network design and careful planning of base station placements are essential for optimal coverage and performance.

III. DESIGN METHODOLOGY

TOPOLOGY1:POINT-TO-POINT

The most basic and commonly in POTS (Plain Old Telephone Systems) systems used topology is a permanent link between two endpoints. Its switched point-to-point topology is the basic model of conventional telephony systems. Point-to-point network is designed to give direct and dedicated communications between the two endpoints.[7]
Here's a step-by-step guide to setting up a Point- to-Point network topology as shown in Fig 3 with

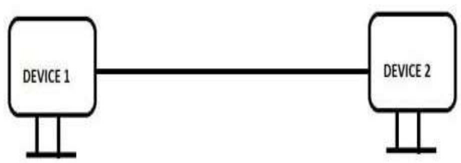

Fig 3 . Point-to-point topology

Open5GS on Ubuntu. This tutorial demonstrates how to connect two devices (such as a User Equipment and a server) using the Open5GS core network to facilitate communication over a dedicated link

Simulation procédure:
To set up a Point-to-Point topology using OPEN5GS, Ubuntu 22.04 or a newer version must be installed on the system. OPEN5GS should be properly configured to simulate 5G core elements like AMF, SMF, and UPF. A basic understanding of networking concepts such as IP addressing and routing is essential. Administrative (root) privileges are required to install packages and modify system settings. Lastly, two IP addresses must be configured to enable the Point-to-Point connection between devices.

TOPOLOGY2: STAR

In the star topology, all the devices are connected to a central device called a hub or a switch.
The hub or switch acts as a central point for all the data communication. In the star topology, each device has its own dedicated connection to the hub. The main advantage of the star topology is that if one cable fails, the other devices will still be operational. The main disadvantage of the star topology is its cost, as it requires more cabling and a central device[10].

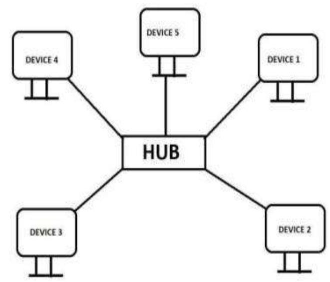

Fig 4. Star topology

In the context of Open5GS, a star network topology shown in Fig 4 would typically involve multiple UEs (User Equipment) communicating with a central 5G core network. The Open5GS core network will handle communication between the UEs and external networks.

Simulation procédure:

To implement a Star topology using OPEN5GS, Ubuntu 22.04 or a newer version must be installed on the system. OPEN5GS should be properly set up to support 5G core components such as AMF, SMF, and UPF. A basic understanding of networking concepts like IP addressing and routing is essential for configuration. Root (administrative) privileges are required to install necessary packages and manage system-level settings. Additionally, appropriate IP addresses must be configured for all nodes participating in the star connection, with a central hub node acting as the main communication point.

TOPOLOGY 3:MESH

In the mesh topology, each device is connected to every other device in the network. The mesh topology is the most fault topology, as it allows for multiple paths for data transfer.

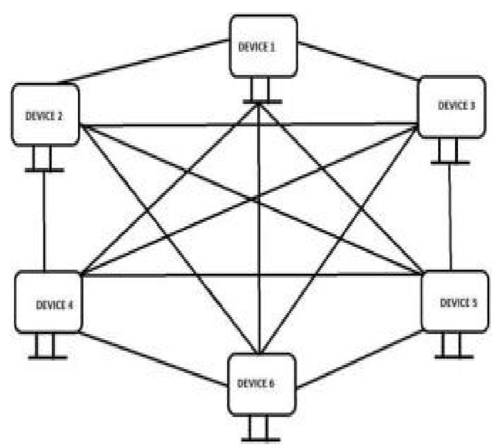

Fig 5 . Mesh topology

The main advantage of the mesh topology is its main disadvantage of the mesh topology is its cost, as it requires more cabling and more devices [10]. In the context of Open5GS, implementing a Mesh Network as shown in Fig 5 involves configuring multiple core network elements (such as AMF, SMF, and UPF) in a way that allows intercommunication between them, and the UEs can connect to different nodes.

Simulation procédure:

To set up a Mesh topology using OPEN5GS, the system must have Ubuntu 22.04 or a newer version installed. OPEN5GS should be fully configured to emulate core 5G network functions such as AMF, SMF, and UPF. A basic understanding of networking principles, including IP addressing and routing, is necessary for effective setup and troubleshooting. Root (administrative) access is required to install dependencies and configure network settings. Additionally, each node in the mesh must have IP addresses properly configured to enable direct communication with multiple other nodes in the network, ensuring full mesh connectivity.

IV. PACKET LOSS, LATENCY, THROUGHPUT OF COMPUTER NETWORK TOPOLOGIES.

In any computer network, packet loss, latency, and throughput is important performance metrics, this effect the overall quality of the network.

*Packet Loss:*It refers to the percentage of packets that ared ropped during transmission from source to destination. This happens when network is congested, when there are faulty routers or switches, or when there are issues with the physical medium (such as cables or wireless connections).

Factors Influencing Packet Loss:

i.Network Congestion: High traffic can lead to buffer overflows, causing packet drops.

ii.Faulty Hardware: Malfunctions in network devices like routers, switches, and cables.

iii.Link Quality: Poor quality links, such as wireless signals with interference, can result in packet loss.

iv. Routing Issues: If the routing algorithm isn't optimal, packets may take suboptimal routes leading to loss.

1.Packet Loss Rate (PLR):

The packet loss rate should be calculated using the following formula:

Packet Loss % = (Number of Lost Packets / Total Packets Sent) x 100

Where:Number of Lost Packets is the count of packets that didn't reach the destination.

Total Number of Sent Packets is the count of packets sent from the source.

2. Latency

Latency is the time, takes for a packet to travel from the source to destination. Latency is typically measured in milliseconds (ms) and is an important factor in the responsiveness of a network, especially in the real-time applications like VoIP, video streaming, or online gaming.

Ltrans is the transmission delay and is given by:

$$Ltrans=P/R$$

Where, P is the packet size in bits.

R is the transmission rate of the link in bits per second (bps).

3. Throughput

Throughput is the rate at which data is successfully transmitted from the source to the destination over the network. It is typically measured in bits per second (bps) or megabits per second (Mbps). High throughput is useful for tasks like file transfer, video streaming, or large data applications.

Factors Influencing Throughput:

1. Bandwidth: The maximum data rate supported by the network connection.
2. Network Congestion: High traffic leads to lower throughput as the network becomes congested.
3. Packet Loss: When packets are lost, retransmissions may occur, reducing the overall throughput.
4. Latency: High latency can reduce throughput, especially for protocols that require multiple round-trip communications, such as TCP.

The T hroughput can be calculated using the following equation: $T=S/Ttotal$

Where:T is the throughput in bits per second (bps),S is the size of the transmitted data in bits.Ttotal_is the total transmission time for the data to reach transmissions.

V. IMPACT OF NETWORK TOPOLOGY PERFORMANCE METRICES

The type of network topology directly influences packet loss, latency, and throughput.

Bus Topology:

Packet Loss: High, as there is a single shared communication medium, leading to potential collisions.

Latency: May be higher due to the shared medium.

Throughput: Lower, as multiple devices compete for the same bandwidth.

Star Topology:

Packet Loss: Relatively low, as every device has their own dedicated connection to the central node (hub or switch).

Latency: Generally low, except for the delay introduced the central node.

Throughput: Can be high, but depends on the capacity of the central hub.
Mesh Topology:
Packet Loss: Very low, as many paths exist for data transmission, allowing for alternate routes in case of failure.
Latency: Generally low, as there are multiple paths, but may increase if the routing algorithm is suboptimal.
Throughput: High, as there are multiple routes for data to travel.

VI. COMPARATIVE ANALYSIS OF METRICES WITH INCREASING THE NODES

The Table 1 compares the performance of three different network topologie such as point-to-point, star, and mesh in terms of latency and throughput as the number of nodes increases.

Table 1 comparison of the performance of three different network topologies

NETWORK TOPOLOGY	NO.OF NODES	LATENCY	THROUGHPUT (bits/sec)
Point-Point	2	0.6325ms	0.0820
	3	0.6315ms	0.1251
	5	0.6319ms	0.1706
	10	0.6291ms	0.2865
	20	2.38µs	0.6308
	30	3.57µs	0.9715
	40	4.67µs	1.2756
Star	3	0.1149ms	1.1767
	6	0.1290ms	1.2574
	9	0.1421ms	1.2689
	10	0.1865ms	1.2766
	20	4.23µs	1.3447
	30	7.56µs	1.4507
	40	13.13µs	1.7439
Mesh	5	0.0426ms	0.525
	8	0.0609ms	0.8976
	10	0.0860ms	1.1095
	12	0.1112ms	1.2776
	20	2.64µs	1.2754
	30	3.68µs	1.276
	40	7.33µs	1.2817

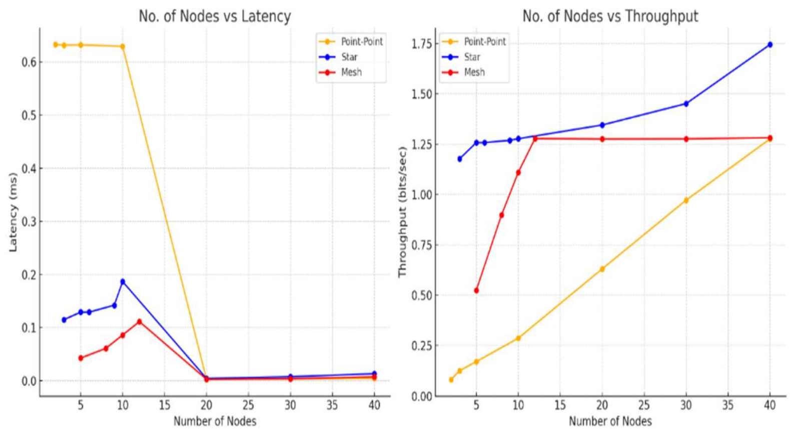

Fig 6 Graph of No of Nodes vs Latency and Throughput of three different network topologies

The point-to-point topology maintains the lowest latency across all node counts, with values remaining in the microsecond range, but only achieves modest throughput. The star topology exhibits slightly higher latency but delivers higher throughput levels, improving as the number of nodes increases as shown in Fig 6. In contrast, the mesh topology consistently offers the lowest latency overall, especially for higher node counts, and demonstrates a steady increase in throughput with more nodes.

CONCLUSION

The implementation and evolution of network topologies using Open5GS showcase the significant potential of open-source 5G core networks in advancing modern telecommunications. Open5GS, as a flexible and scalable platform, facilitates the rapid deployment and testing of various network topologies, from simple LTE systems to complex 5G architectures.
By experimenting with Point-to-Point, Star, Mesh Topologies, users can optimize for performance like throughput, latency and Packet loss, all while adhering to the evolving standards set by 3GPP.

Future Scope

This study focused on Point-to-Point, Star, and Mesh topologies, future work can explore the implementation and performance analysis of other complex and hybrid topologies, such as Tree, Ring, and Bus architectures. Evaluating these additional configurations in Open5GS can further enrich the understanding of topology-specific behavior under diverse network loads and traffic conditions. Additionally, integrating advanced features like network slicing, QoS management, and mobility scenarios in these topologies could extend the scope of simulation and help optimize next-generation network designs for smart cities, IoT ecosystems, and mission-critical applications.

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