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Ternopil Ivan Puluj National Technical University

Faculty Of Computer Information Systems And Software Engineering
(full name of faculty)
Computer Systems And Networks Department
(full name of department)

QUALIFYING PAPER

For the degree of

bachelor
(degree name)

topic: **5G Network Optimization In Urban Areas**

Submitted by: fourth year student 4 , group ICI-43
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Ternopil
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ASSIGNMENT

for QUALIFYING PAPER

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student *Toluwanimi Daramola*
(surname, name, patronymic)

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Paper supervisor *Yatsyshyn Vasyl Volodymyrovych, PhD, Assoc. Prof.*
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1.Comparison of different network management tools. 2. Network Management and Topology Basics. 3. Flowchart diagram of network security measures

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Chapter	Advisor's surname, initials and position	Signature, date	
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	Approaches to mobile network design	*11.01.2024*	*Execute*
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	Optimization of 5G mobile networks in urban areas	*15.01.2024*	*Execute*
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ABSTRACT

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Keywords: Networks, 5G Networks, IoT, Urban System, MIMO, Small Cell Deployment.

In my final year diploma thesis on 5G network optimization in urban areas, I focused on improving internet connectivity in cities. I explored strategies like small cell deployment and technology like beamforming to meet the high-speed and low latency needs of urban users. From examining security measures to anticipating the future with 6G networks, my goal was to offer practical solutions for optimizing 5G in dynamic urban environments. I hope this work serves as a guide for future researchers in the ever-evolving field of web development.

CONTENT

INTRODUCTION

5G networks have become a vital part of today’s society, due to groundbreaking advancements made in connectivity as well as user-device communication in recent years.

The fifth generation of wireless technology brings a new level of reliability and accessibility to Internet services for users around the globe. With data transfer speeds of up to a hundred times faster than 4G (fourth generation) networks, this technology offers and enables a large variety of applications across different fields.

From telemedicine and remote video conferencing on mobile devices, to augmented reality and automated driving, the improvement 5G brings to different aspects of the digital world today cannot be understated.

Moreover, the use of 5G in IoT (Internet of Things) devices aids in enhancing communication between users and a wide network of interconnected devices.

A majority of smart cities today base their device network on 5G-supported data carriers and terminals, and each network makes sure to cater to the needs of each user and device connected to it as a whole. Technological advancements in the economic and power sector also depend on 5g in order to continue operating at optimal performance levels.

In conclusion, the importance of 5G networks in today’s world stretches beyond individual preferences among users, and aligns closer to the needs of digitally advanced societies across the globe. From healthcare to smart city transport systems, the impact of 5G affects many fields, presenting opportunities and challenges that can be addressed and improved upon at a global scale.

1 ANALYSIS OF PRINCIPLES OF MOBILE NETWORK DESIGN

1.1 The Principles of Modern Mobile Network Organization

Mobile network is a system which gives opportunity to end user receive and send differnet types of data like voice, images, video and etc [1]. These networks include many components that we need t oanalyze [2].

Many cells create mobile network and covered some location. Devices, which covered some geographical areas, are base stations. Mobile subscribers within a cell communicate with the respective base station. When a subscriber transitions from one cell to another, a process known as handover takes place. This dynamic handover process ensures continuous connectivity as users move through different coverage areas (Fig. 1.1).

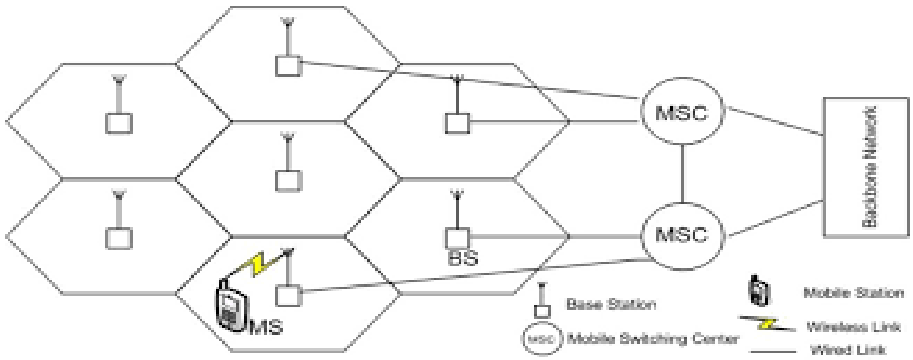

Fig. 1.1 – A simplified diagram of cell structure in urban areas

Base stations are very important and provide transfering and receiving signals to and from mobile subscribers within mobile network cells. The base stations come in various sizes and ranges to cater to different geographical and user density needs. Macrocells, the largest and most common type, cover expansive areas and find application in urban and suburban regions.

Microcells, smaller in size, are deployed in areas with concentrated mobile user activity, such as office complexes and shopping malls. Femtocells, the smallest, serve localized spaces like homes and businesses, providing reliable coverage in confined areas (Fig. 1.2).

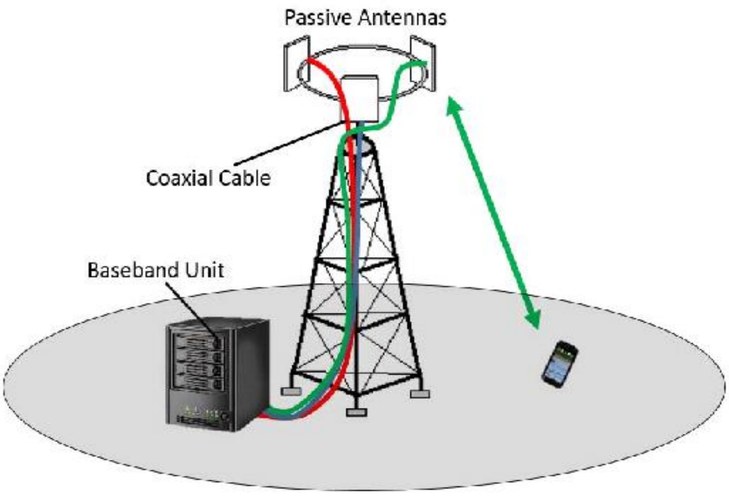

Fig. 1.2 – A traditional base station setup

The baseband unit is responsible for storing and updating data caches, which are then uploaded and transmitted to end-user client devices via passive antennas.

Mobile Switching Centers (MSCs) serve as call routers between mobile subscribers and fixed-line telephones. Beyond facilitating communication, MSCs play a crucial role in managing the handover process as users transition between cells. Interconnected by high-speed data links, these centers ensure the smooth flow of communication within the mobile network, creating a cohesive and responsive system.

There are several key principles that govern the organization of mobile networks. These principles include:

Efficiency.

Efficiency is the most important principle in the organization of mobile networks, given the enormous amount of traffic that passes through these networks every day. Multiplexing becomes a key method, allowing multiple users to use the same frequency band at the same time. By making efficient use of available resources, multiplexing optimizes bandwidth, ensuring uninterrupted data flow and communication.

This ensures that mobile networks can handle diverse and dynamic user demands without compromising performance.

Strength.

The reliability of mobile networks is a critical aspect designed to withstand failures and failures. Redundancy and diversity are used as effective methods to harden the network against potential problems. Redundancy involves duplicating critical components, ensuring that if one fails, the backup can seamlessly take over, maintaining business continuity. Diversity brings diversity to network elements, reducing susceptibility to homogeneous failures and increasing resilience to contingencies. Together, these strategies contribute to a robust network architecture that can overcome challenges and provide uninterrupted service.

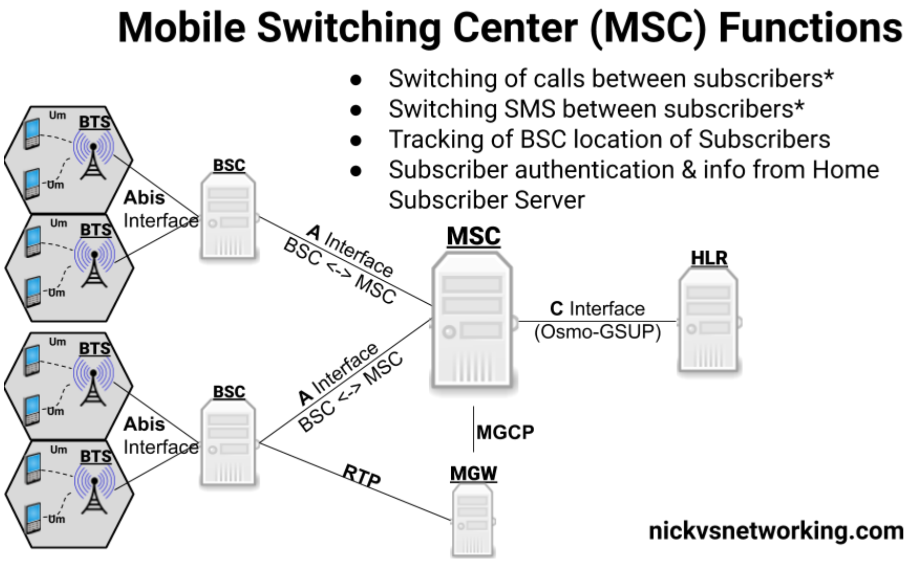

Fig. 1.3 –A diagram showing the function of mobile switching centers and how they serve multiple network cells

1.2 Key Principles of Mobile Network Organization

In the ever-expanding mobile space, scalability is becoming a fundamental principle. As the number of mobile subscribers continues to grow, mobile networks must adapt and expand smoothly. Technologies such as spectrum sharing and network virtualization play a key role in achieving scalability. Spectrum sharing optimizes the use of available frequency bands, accommodating more users without compromising performance. Network virtualization, on the other hand, separates network functions from the underlying hardware, enabling flexible scaling and resource allocation. These technologies enable mobile networks to evolve dynamically, meeting the growing needs of a growing user base.

The future of mobile networks.

Mobile networks are constantly evolving. The current generation of mobile networks, known as 5G, is expected to offer much higher speeds, lower latency and massive bandwidth. 5G will enable a new wave of applications such as self-driving cars, augmented reality and virtual reality.

Mobile networks are necessary for modern society. They provide a vital link between people and information. As mobile networks continue to evolve, they will play an even more important role in the daily activities of users in today's digital world.

1.3 The role of mobile networks

In the digital age, mobile network design stands at the forefront of technological innovation, shaping the interconnected landscape that defines our daily lives. This descriptive essay explores the intricacies of network design, its application to mobile platforms, and the methodologies and tools that underpin the creation of modern mobile networks.

1. Understanding Network Design.

Network design is the meticulous process of planning, configuring, and implementing the architecture and infrastructure that facilitates seamless communication and data exchange. It encompasses a comprehensive approach that considers factors such as coverage, capacity, reliability, and scalability. In the context of mobile networks, this design philosophy takes center stage in creating the invisible threads that connect mobile devices, ensuring a fluid and responsive communication environment.

2. Application to Mobile Platforms.

The application of network design to mobile platforms is a dynamic and evolving field, responding to the ever-growing demand for connectivity on the go. Mobile network design focuses on optimizing the user experience, providing reliable and high-performance connectivity, and addressing the unique challenges posed by the mobile environment, including limited bandwidth, varying signal strengths, and the need for seamless handovers.

Mobile network design extends beyond traditional voice and text communication to encompass a myriad of services, from internet browsing and multimedia streaming to IoT connectivity. It considers the diverse needs of users, adapting to different usage patterns and device capabilities. As mobile platforms become increasingly integrated into our daily routines, the importance of robust and well-designed mobile networks becomes more pronounced.

3. Methodology and Tools in Modern Network Design.

– Site Survey and Planning: the first step in mobile network design involves a thorough site survey and planning. This includes assessing geographical features, signal propagation characteristics, and user density. Advanced tools like predictive modeling software simulate network behavior in different scenarios, aiding in optimal site placement for base stations.

– Radio Frequency (RF) Planning: RF planning is crucial for optimizing spectrum usage and minimizing interference. Advanced RF planning tools analyze frequency bands, signal strengths, and potential interference sources. This ensures efficient allocation of frequencies and enhances the overall performance of the mobile network.

– Capacity Planning: Capacity planning anticipates and accommodates the growing demand for data. It involves assessing the network's ability to handle increasing user numbers and data-intensive applications. Advanced modeling tools simulate network load scenarios, allowing designers to allocate resources effectively and ensure a consistent quality of service.

– Network Virtualization: Network virtualization has emerged as a powerful tool in modern mobile network design. It involves creating virtual instances of network functions, decoupling them from underlying hardware. This enables flexible scaling, efficient resource allocation, and quicker adaptation to changing network demands.

– Software-Defined Networking (SDN):

– SDN introduces a programmable approach to network management. It centralizes control and allows for dynamic configuration of network resources. This enhances flexibility, scalability, and adaptability in response to evolving user needs and emerging technologies.

– Security Measures: As security concerns intensify, network design incorporates robust security measures. Firewalls, encryption protocols, and intrusion detection systems are integral components. Regular security audits and monitoring tools ensure the resilience of mobile networks against cyber threats.

– Continuous Monitoring and Optimization: the life cycle of mobile network design involves continuous monitoring and optimization. Advanced analytics tools assess network performance, identify bottlenecks, and propose optimizations. This iterative process ensures that the network remains adaptive and responsive to changing usage patterns and technological advancements.

3G and 4G have higher data rates and better network performance compared to GPRS. They can support various applications and services, such as web browsing, email, and multimedia streaming.

Wi-Fi and WiMAX: These wireless technologies can provide high-speed data transmission in areas with poor connectivity, especially in urban and suburban areas. However, they may have limited coverage and may require line-of-sight connectivity.

Cellular Networks with Dynamic Spectrum Sharing (DSS): DSS allows cellular networks to share spectrum resources between 4G and 5G networks, improving network performance and capacity in areas with poor connectivity

Low Earth Orbit (LEO) Satellites: LEO satellites can provide high-speed data transmission in remote and rural areas, but they may have higher latency and lower data rates compared to terrestrial networks. Examples of this include the Starlink system.

5G networks gives more higher data rates, lower latency, and improved network performance compared to GPRS and 4G networks. They can support different IoT, AR/VR.

In conclusion, the approaches to mobile network design encapsulate a holistic methodology that harmonizes technological innovation with user-centric principles. Using meticulous site surveys, advanced RF planning, network virtualization and security measures, the tools and methodologies employed in modern network design network that defines the communication routes among mobile devices.

2 APPROACHES TO MOBILE NETWORK DESIGN

2.1 3G mobile networks and services

Mobile network development took a big leap with the introduction of 3G, or third-generation technology. Originating in the early 2000s, 3G marked a significant milestone, succeeding its predecessors, 1G and 2G. This technological evolution was driven by the need for enhanced data transfer capabilities, pushing beyond the limitations of voice-centric communication to embrace a new era of multimedia-based services.

3G mobile networks are structured around a robust framework that supports medium-to-high-speed data transfer, along with a broad spectrum of services. What defines 3G is its use of advanced technologies, including CDMA, WCDMA, as good as TDMA. These technologies enable many and different users to use the same frequency band, optimizing spectrum usage and enhancing the efficiency of data transfering.

The implementation of various network protocols, such as Universal Mobile Telecommunications System (UMTS) and High-Speed Packet Access (HSPA), further distinguishes 3G. UMTS serves over-air interface, while HSPA boosts data transfer speeds.

3G Network Structure.

At its core, a 3G is provides enhanced mobile communication capabilities compared to its predecessors. The structure of this mobile network revolves around dividing geographical areas into cells, each served by a base station.

These base stations (BS), often in the form of towers with antennas and transmitters, act as the connection points for mobile subscribers within their respective cells.

1. Cells and BS:

– Geographical Division: The coverage area of 3G is divided into cells, where each cell represents a specific geographical region.

– BS: These stations are equipped with antennas and transmitters to make communication with concrete devices and other structured elements of network.

– Handover Process: The subscriber’s phone seamlessly connects to the new base station, ensuring continuous connectivity as users traverse different areas.

2. Base Station Categories:

– Macrocells: These are the biggest and more common type of base stations. Macrocells cover expansive areas and are typically found in urban, as well as suburban regions.

– Microcells: These are smaller than macrocells, and are deployed in areas with large concentrations of mobile subscribers, such as office buildings, shopping malls, or busy streets.

– Femtocells: The smallest type of base station, femtocells are utilized in homes and businesses to improve indoor coverage and network quality.

3. MSCs:

– Routing and Management: MSCs are responsible for routing calls from mobile subscribers to fixed-line telephones, manage the handover process, and ensuring the efficient flow of communication.

– High-Speed Data Links: MSCs are interconnected with each other via high-speed data links, facilitating the exchange of data and supporting the overall functionality of the network.

4. Core Networks:

– Central Hub: The core network serves as the central hub of a 3G network, overseeing various services and functionalities.

– Components: It comprises different components, including Gateway MSCs (GMSCs), Home Location Registers (HLRs), and Serving GPRS Support Nodes (SGSNs), each contributing to different aspects such as call routing, user registration, and packet-switched data services.

Devices that Use 3G Today and Why.

Many devices use 3G technology today, contributing to its enduring relevance. Smartphones, tablets, and mobile hotspots continue to use 3G, particularly in regions where the transition to newer generations like 4G or 5G may be gradual. The ubiquity of 3G-enabled devices ensures connectivity for a diverse user base, offering internet access and communication services to those who may not have immediate access to more advanced networks.

The longevity of 3G devices is also attributed to their compatibility with legacy infrastructure. In areas where 3G infrastructure is well-established, devices that support 3G become practical choices, providing reliable connectivity without the need for immediate upgrades.

Software and services that Supports the Use of 3G.

Various software applications contribute to the utilization of 3G networks, enhancing user experience and expanding the capabilities of devices:

1. Web Browsers: Mobile web browsers, such as Chrome, Safari, and Firefox, leverage 3G to provide users with fast and efficient internet browsing. These browsers are optimized to load web pages and multimedia content seamlessly over 3G connections.

2. Messaging Apps: Messaging applications like WhatsApp, Telegram, as well as Signal utilize 3G for real-time communication. This enables users to exchange text messages, and media-based content (images and videos). The efficiency of these applications over 3G improves the accessibility of instant messaging services.

3. Streaming Platforms: Streaming services for videos and music like YouTube, Netflix, and Spotify benefit from 3G connectivity, allowing users to enjoy on-the-go entertainment. These platforms adapt to varying network speeds, delivering content with reasonable quality even on 3G connections.

4. Navigation Apps: GPS and navigation applications, including Google Maps and Waze, utilize 3G for real-time location updates and route calculations. This ensures that users receive accurate and up-to-date navigation information, enhancing the effectiveness of these apps.

Additional services that utilize 3G connectivity include, but are not limited to the following:

1. Email Services: Email applications, such as Gmail, Outlook, and Apple Mail, leverage 3G connectivity for real-time email synchronization, allowing users to access their emails, media attachments, and calendar events while connected to the internet.

2. Social Media Platforms: Platforms like Facebook, Twitter, and Instagram rely on 3G networks to enable users to share updates, photos, and videos instantly. The accessibility of social media over 3G facilitates real-time communication and content sharing.

3. VoIP Calling Services: Voice over Internet Protocol (VoIP) applications, including Skype, WhatsApp Calling, and Viber, utilize 3G for high-quality voice calls. These services enable users to make international calls and participate in voice conversations without relying solely on traditional cellular voice networks.

4. Online Banking and Financial Apps: Mobile banking applications, such as those provided by banks and financial institutions, use 3G connectivity to facilitate secure transactions, account management, and real-time access to financial information.

5. Remote Access and VPN Services: Virtual Private Network (VPN) services and remote access applications, like AnyConnect and TeamViewer, utilize 3G connections to provide users with secure access to corporate networks and remote devices.

6. Weather and News Apps: Weather and news applications utilize 3G to provide users with real-time updates on weather conditions, news articles, and multimedia content.

7. Online Marketplaces: E-commerce platforms like Amazon, eBay, and Etsy use 3G connectivity to enable users to browse products, make purchases, and track orders using mobile applications.

8. Health and Fitness Apps: Fitness trackers and health monitoring platforms use 3G to sync data, provide real-time workout guidance, and connect with other wellness-related services.

9. Educational Apps: Educational platforms and e-learning applications, like Khan Academy and Duolingo, utilize 3G to deliver educational content, quizzes, and interactive lessons to users, supporting remote learning and skill development.

10. Ride-Sharing and Navigation Apps: Ride-sharing services such as Uber and navigation apps like Lyft utilize 3G for real-time location tracking, ride bookings, and communication between drivers and passengers.

The diverse range of services mentioned highlights the versatility of 3G technology, providing a foundation for a broad spectrum of applications that cater to communication, entertainment, productivity, and various aspects of daily life. The continued use of 3G ensures that these services remain accessible to users across different regions and scenarios, contributing to the widespread adoption of mobile technology.

Advantages and Disadvantages of 3G.

Advantages:

1. Wider Coverage: 3G networks boast broad coverage, even in rural or remote areas, making them essential for bridging digital divides.

2. Multimedia Services: The high-speed data transfer capabilities of 3G facilitate multimedia services, including video calls, streaming, and interactive applications.

3. Compatibility: 3G devices remain compatible with legacy networks, ensuring connectivity in areas where advanced networks may not be prevalent.

Disadvantages:

1. Data Speeds: While faster than its predecessors, 3G lags behind more recent generations like 4G and 5G in terms of data transfer speeds.

2. Network Congestion: As data demand increases, 3G networks can experience congestion, leading to slower data speeds during peak usage times.

3. Limited User Capacity: 3G networks have limitations on the amount of devices they can support simultaneously, making them susceptible to performance issues in areas with many suvscibers.

Ensuring Safety of 3G and Supported Technology.

Ensuring the safety of 3G and supported devices involves a combination of methods and practices:

1. Encryption Protocols: Implementing secure encryption protocols for data transmitted over 3G networks enhances security and protects user information.
2. Regular Software Updates: Helps to keep infrastructure and mobile network’s component up-to-date.
3. Firewall Protection: Deploying firewalls on both network servers and individual devices gives one more layer to defend unauthorized access.
4. Authentication Mechanisms.
5. Network Monitoring: Provide regular monitoring of the network to avoid potential attcaks.
6. User Education: Educating users about safe online practices, such as avoiding public Wi-Fi in favor of 3G connections for sensitive tasks, contributes to a more secure user experience.

2.2 Optimization Options for 3G Networks.

To address the challenges and ensure optimal performance, several optimization options (Fig. 2.2) we can propose for 3G networks:

1. Carrier Aggregation: Aggregating multiple carriers allows for increased bandwidth, enhancing data transfer speeds and capacity.
2. Advanced AS: improves quality and efficiency of 3G in case of coverage areas, reducing the impact of signal interference.
3. Network Offloading: Offloading non-essential data traffic to Wi-Fi networks can reduce congestion on 3G networks, enhancing overall performance.

3G mobile networks have played a pivotal part in shaping the landscape of mobile communication. As network technology continues to advance, the strengths and limitations of 3G demand thoughtful considerations for its continued use and optimization in various regions and contexts.

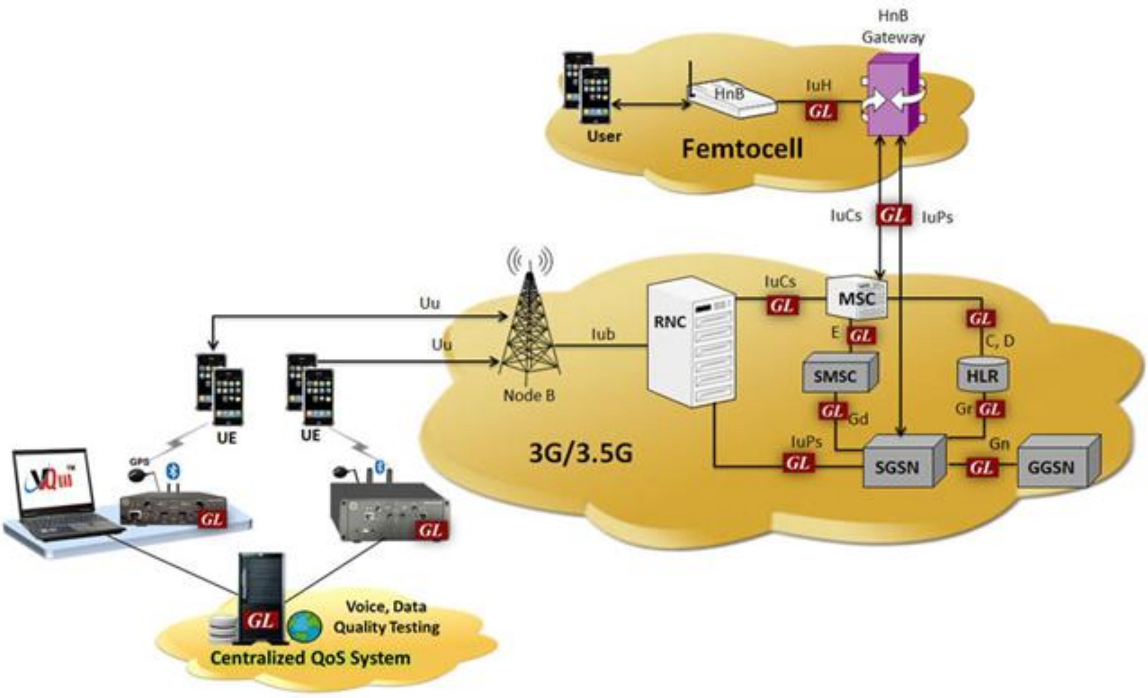

Fig. 2.2 – Optimized of 3G mobile network

2.3 4G mobile networks and services

Structure of 4G.

4G networks are characterized by higher data transfering rates, lower latency, so thay are more efficient. Structured around technologies like LTE and WiMAX, this mobile networks uses advanced modulation techniques and wider frequency bands. LTE architecture has presented in Fig. 2.3.

The key attributes that make 4G include advanced MIMO antenna systems, OFDM modulation, and the ability to seamlessly integrate with other technologies. These elements collectively contribute to the high-speed and efficient data transfer capabilities that define 4G.

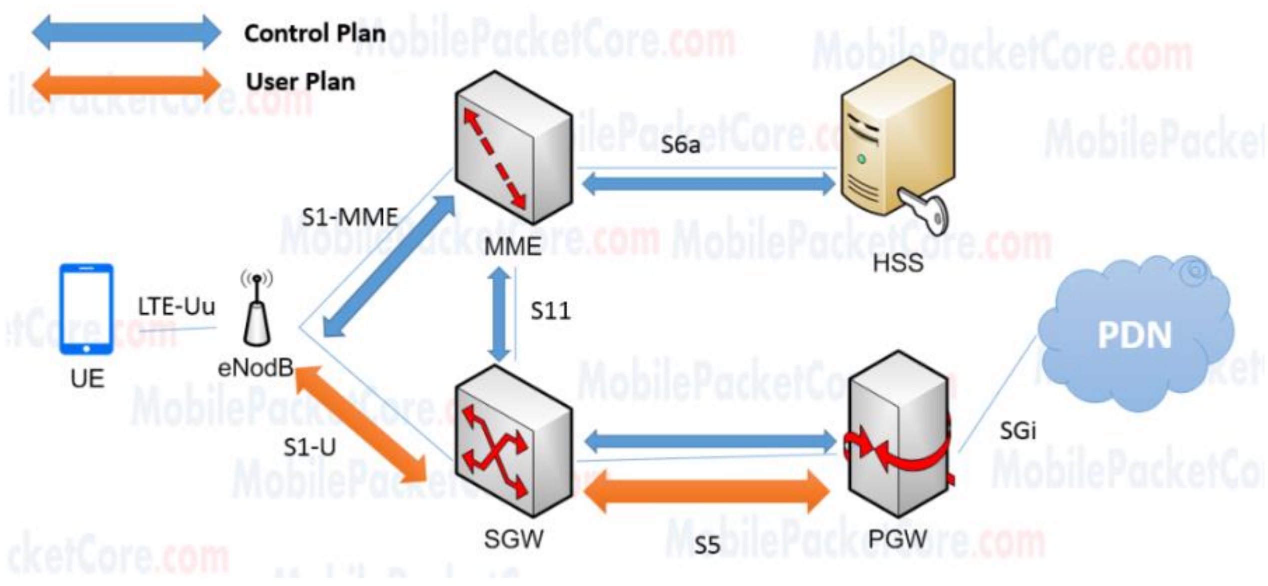

Fig. 2.3 – 4G Architecture

Numerous software applications harness the capabilities of 4G networks, enriching the user experience and expanding the functionalities of devices:

1. High-Definition Video Streaming Apps: Platforms like YouTube, Netflix, and Hulu utilize 4G connectivity to deliver high-quality video content, ensuring smooth playback and minimal buffering.

2. Online Gaming Platforms: Multiplayer online games and gaming platforms leverage 4G for low-latency connections, providing gamers with a responsive and immersive gaming experience.

3. Cloud-Based Productivity Tools: Services like Google Drive, Dropbox, and Microsoft Office 365 have opportunity to optimize 4G connection and enable real-time collaboration and file synchronization.

4. Virtual Private Network (VPN) Services: VPN applications can use 4G and offer secured and encrypted connections.

5. AR and VR Apps: These types of applications utilize the high data transfer speeds of 4G to make more realistic scenes in gaming, education, or entertainment.

Services of 4G.

4G includes next services:

1. Video Conferencing Platforms: Services like Zoom, Microsoft Teams, and Google Meet leverage 4G connectivity for some video conferencing, enabling users to participate in virtual meetings, collaborate, and connect in real-time.

2. Telemedicine Apps: Telehealth applications utilize 4G networks to facilitate remote consultations, enabling patients to the differernt medical services, and remote health monitoring from the mobile devices.

3. Mobile Banking and Payment Apps: Banking and financial applications, including mobile banking apps and digital payment platforms, leverage 4G for secure and real-time transactions, providing users with convenient and efficient financial services.

4. IoT: These kinds of devices use 4G mobile network for remote control and monitoring of smart appliances, security systems, and other connected devices.

5. AR Shopping: Retail applications incorporating AR technologies through 4G allow users to virtually try on products, visualize furniture in their homes.

Some Advantages of 4G Networks:

1. High Data Transfer Speeds.
2. Low Latency.
3. Enhanced Capacity.

Disadvantages of 4G include:

1. Deployment Challenges: The initial rollout of 4G supported network infrastructure posed challenges in terms of coverage, especially in rural or geographically challenging areas.

2. Device Compatibility: Older devices may not be compatible with 4G networks, requiring users to upgrade their hardware.

3. Potential for Network Congestion: In areas with extremely high user density, 4G networks may experience congestion in peak usage times, impacting data speeds for some users.

2.4 Optimization Options for 4G Networks:

To address challenges and ensure optimal performance, several optimization options are available for 4G networks:

1. Advanced Antenna Technologies: Implementing advanced antenna systems, including Massive MIMO, improves coverage, enhances spectral efficiency.

2. Carrier Aggregation: Aggregating multiple carriers allows for increased bandwidth, supporting higher data transfer speeds and improved network capacity.

3. Software Updates and Network Optimization: Regular software updates help address potential vulnerabilities and enhance overall performance.

4. Small Cell Deployment: Deploying small cells in strategic locations, enhances coverage and capacity, alleviating network congestion.

4G mobile networks have become the mainstay of modern mobile communication, as it ensures mass accessibility with high-speed connectivity and multi-application support across different platforms for the users. In fig. 2.4 has shown optimization of 4G mobile network in urban areas.

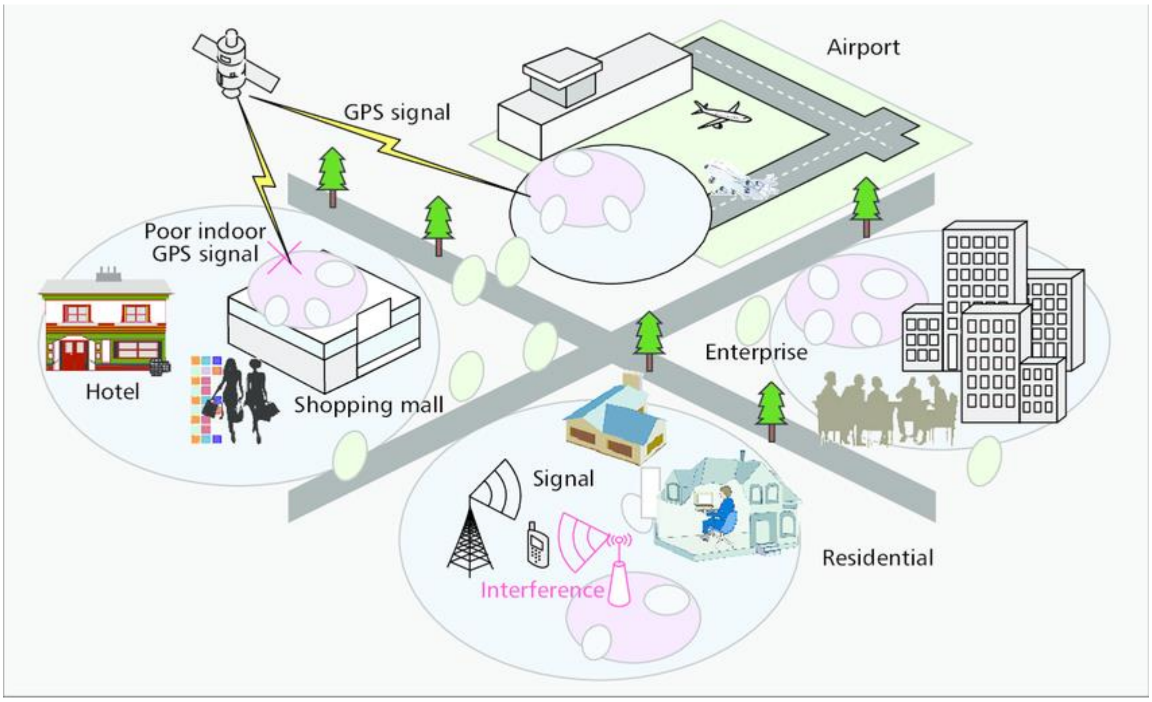

Fig. 2.4 – Optimization of 4G mobile network in urban areas

A diagram (Fig. 2.4) showing how 4G networks can be set up in modern suburban/urban areas using small cell deployment within the same area. It also displays a possible risk of congestion. Ensuring physical and digital security of a person with the help of 4G.

1. User Authentication: Implementing secure user authentication methods, such as biometrics or multi-factor authentication, improves the protection of different types of information and non-authorized access to personal accounts and applications.

2. Privacy Settings and Controls: Giving users clear privacy settings and controls within apps allows them to manage the information they share and maintain control over their digital footprint, promoting a safer online experience.

3. Integration of emergency services: Ensuring seamless integration with emergency services enables rapid response in the event of accidents or emergencies, improving human physical safety through timely assistance.

4. Location-based security features. Applications that use 4G may include location-based security features, such as real-time location data transmission in navigation applications or location-based emergency services, to improve the physical safety of users.

5. Compliance with regulatory requirements. Ensuring 4G services comply with standards and laws helps protect users' rights and privacy by creating a secure environment for digital interaction.

By integrating above security approaches into both the infrastructure and applications using 4G technology, stakeholders can facilitate a secure and reliable digital experience for users. Prioritizing both physical and digital security increase the overall reliability of 4G-enabled services in today's interconnected world.

2.5 Mobile networks and 5G services

5G is a game changer in the world of wireless connectivity. Unlike its predecessors, this fifth generation of cellular network technology has some serious advantages that are can change communication.

As our collective dependence on mobile connectivity grows with new technology that has this feature as a fundamental requirement, we need a network that meets today's demands but also lays the foundation for the future. 5G networks are developed to provide and efficiently meet the needs of ever-increasing numbers of data, as good as to transfer this data through many devices.

The increase in mobile traffic and the emergence of new applications with more powerfull demand for seamless connectivity have overtaken the capabilities of existing cellular networks. The current standard, LTE, has played an important role in enabling and connecting devices and applications, but it is currently facing some setbacks.

One of more critical issue is latency, or the delay between initiating an action and seeing the result. While 4G LTE offers tens of milliseconds of latency, real-time applications such as autonomous vehicles, virtual reality, and industrial automation require much lower latency. The ultra-low latency of 5G is essential for these applications to run efficiently.

Finally, the number of connected devices is expected to grow dramatically in the coming years due to the increased use of IoT devices. 4G LTE nets were not developed to handle such a huge amount of devices at the same time, resulting in network congestion and reduced performance for users. The sheer power of 5G solves this problem by enabling seamless connectivity for millions of devices with minimal impact on overall network performance. In fig. 2.5 presented an example of the 5G network structure.

5G is characterized by higher speed, lower latency, higher device density, network slicing capabilities, integration with different components, and a commitment to improved security.

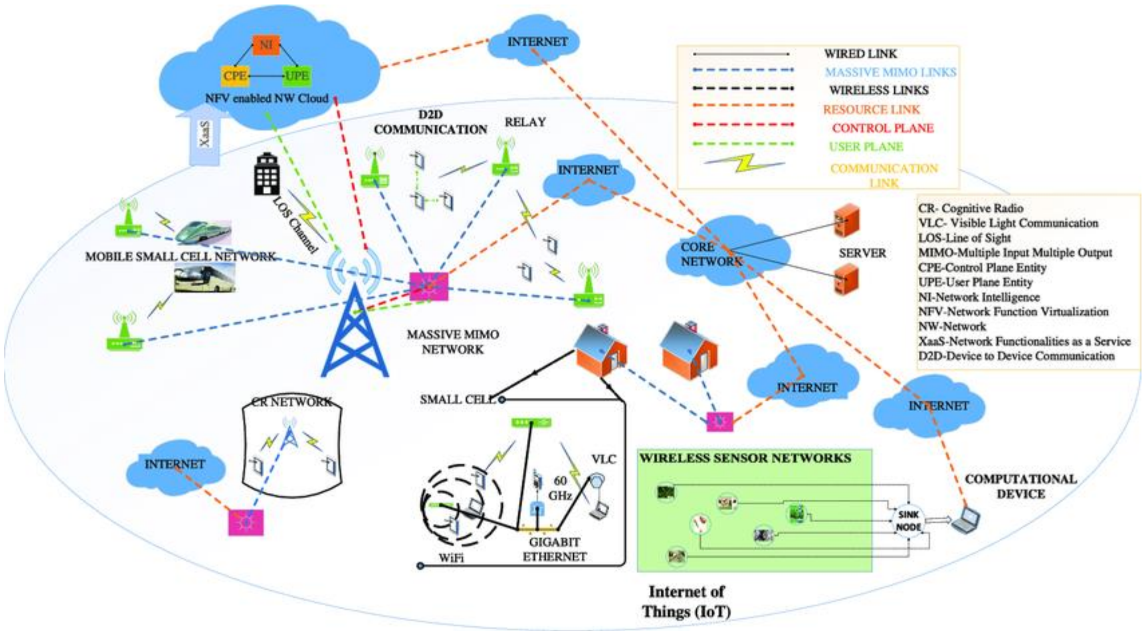

Fig. 2.5 – 5G architecture

Software services.

1. Mobile applications:

– Improved user experience: Mobile applications benefit from 5G's higher data rates with lower latency.

2. Augmented reality (AR) programs:

– Real-time interactivity: AR applications use the low latency of 5G to provide a real-time interactive experience, enhancing features such as object recognition and spatial mapping.

3. Virtual reality (VR) platforms:

– Immersive VR experience: 5G enables VR platforms without lag, making the virtual environment more realistic and engaging.

4. Cloud game services:

5. Video streaming services:

– Ultra High Definition Streaming: 5G's faster speeds enable high-quality video streaming, supporting services that stream 4K and even 8K content seamlessly.

6. Remote collaboration tools:

– Real-time collaboration: 5G improves remote collaboration tools by reducing latency, facilitating smoother video conferencing and enabling real-time collaboration on shared documents.

7. Edge computing platforms:

– Reduced processing latency: 5G complements edge computing platforms by reducing latency, enabling real-time processing of data closer to the source, facilitating applications such as industrial automation among supported devices and the Internet of Things.

8. Solutions for health care:

– Telemedicine and remote monitoring: 5G supports real-time communication for telemedicine services and enables remote monitoring of patients with connected medical devices.

9. Autonomous car systems:

– Automotive communications: 5G supports the communications infrastructure for certain autonomous vehicles, facilitating the exchange of data between vehicles and traffic management systems to improve operations and experiences for users.

10. Smart home systems:

– Connected Home Devices: 5G enables efficient connectivity for smart home devices, improving features such as home automation, security systems and connected devices.

2.6 Tools and Methods of 5G Network Optimization

Network Planning Software.

Network engineers can utilize advanced network planning tools to simulate and model the 5G network's performance in urban landscapes. Tools like NS-3 (Fig. 2.6) and IPMonitor (Fig. 2.7) allow engineers to simulate the impact of different base station locations in a specific urban area, considering factors like building density and geographical features. By running simulations, it helps optimize the placement of base stations for maximum coverage and minimal interference.

Justification.

These tools consider factors like building density, geographical features, and user distribution, assisting in optimal base station placement and coverage predictions.

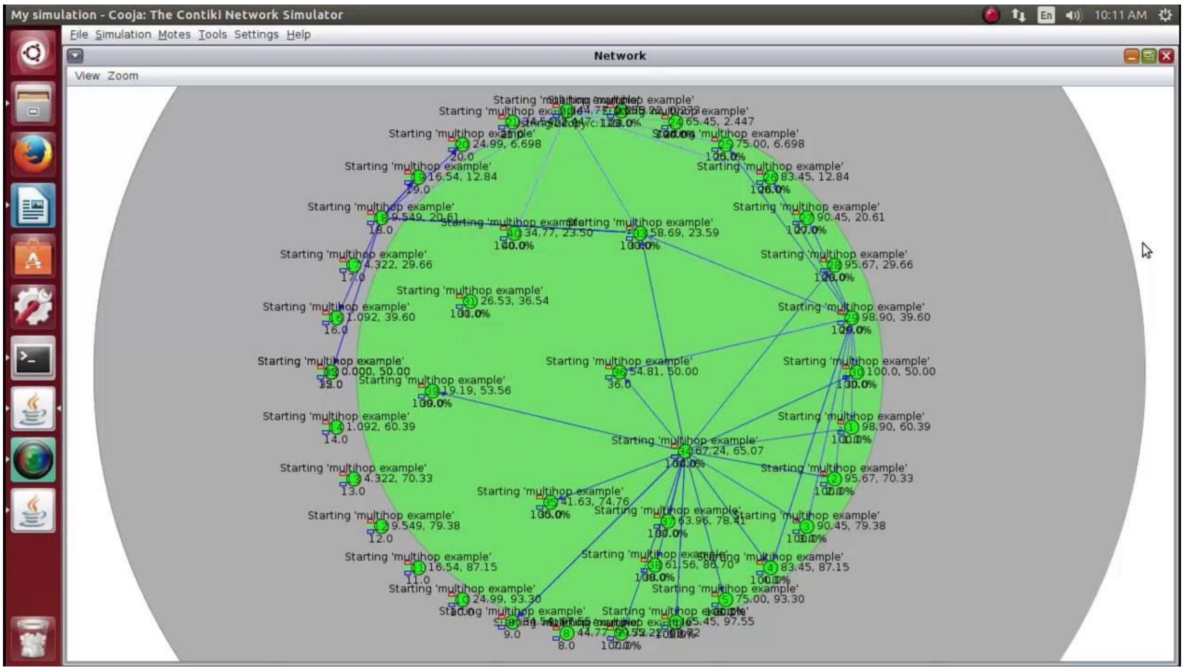

Fig. 2.6 – NS-3 tool

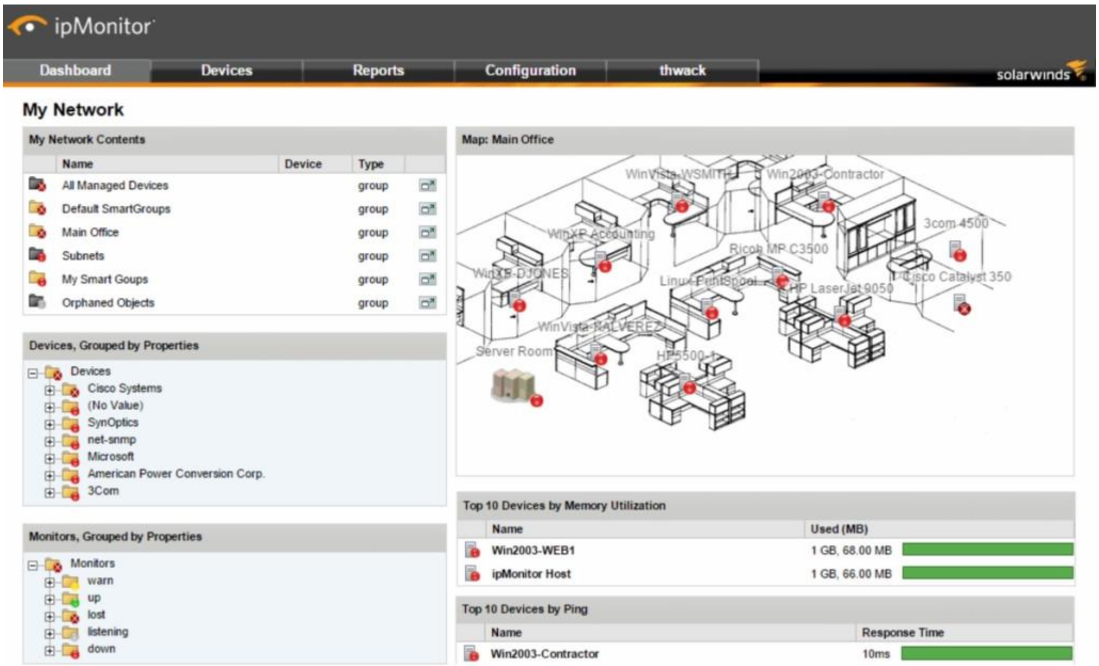

Fig. 2.7 – IPMonitor tool

Drive Testing and Site Surveys.

Network engineers can conduct routine drive tests and on-site surveys to assess real-world network performance and identify areas with potential issues in order to correct them.

A popular example of this is Nemo Outdoor, as it can be used to conduct drive tests in urban areas, collecting real-time data on signal strength, latency, and throughput. By conducting drive tests and on-site surveys, engineers can identify areas with poor coverage, enabling targeted improvements.

Justification: Real-time data collection helps fine-tune parameters like signal strength, latency, and throughput, ensuring a tailored approach to urban network challenges.

Small Cell Deployments.

Network enginners and city planners can collaborate to ensure the strategic and safe placement of small cells to enhance coverage and capacity in densely populated urban areas.

Airspan’s network planning tools assist in determining the optimal locations for deploying small cells. Engineers can use these tools to identify areas with high user density or network congestion, ensuring strategic placement of small cells for improved coverage and capacity.

Justification: Small cells address the challenges of high user density, providing localized coverage and offloading traffic from macrocells, resulting in improved network efficiency. Fig. 2.8 and 2.9 depict how small cells can be organized in urban areas, as well as locations that are optimal for core network placement as well as nodes (individual network systems for residential and public buildings).

Beamforming Technology.

Engineers can use and improve modern beamforming methods like RF boosting and moderating weight levels for conventional and adaptive beamformer systems to focus radio waves towards specific users or areas, optimizing signal strength and reliability.

Huawei provides tools to fine-tune beamforming parameters based on urban network conditions. Engineers can use the tools for optimizing a direction and strength of radio waves, mitigating interference and enhancing signal quality in different areas.

Justification: In urban environments with obstacles and signal reflections, beamforming helps mitigate interference, improving overall network performance.

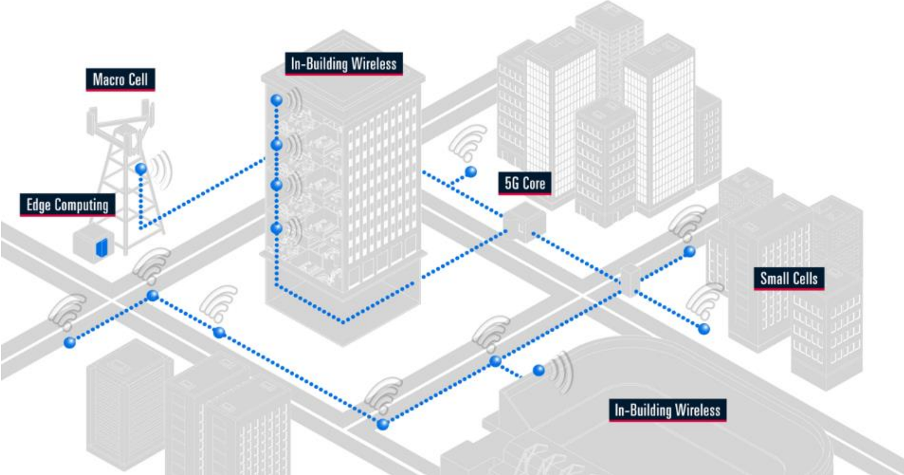

Fig. 2.8 – Placement of 5G network components within an area covered by a macro cell

Each building has its own cluster of femtocells that receive and exchange data with the core network.

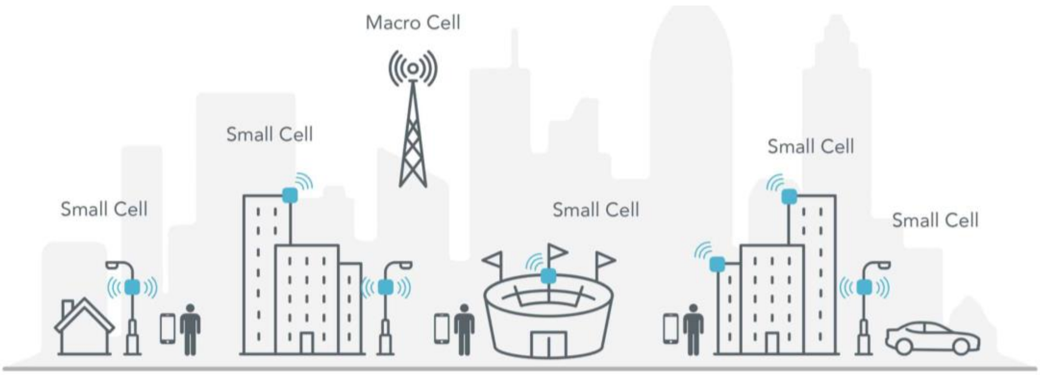

Fig. 2.9 – A diagram showing small cell architecture shared among urban infrastructure and devices used within the 50 icrocell’s range

DSS.

Engineers implement DSS systems to efficiently use a full set of resources and maximize the available frequencies.

In urban areas with fluctuating user activity, these tools automatically adjust spectrum usage, preventing congestion and ensuring efficient network capacity.

Justification: In urban areas with varying user activity, DSS ensures adaptive spectrum allocation, preventing congestion and enhancing network capacity.

Edge Computing Integration (Fig. 2.10).

Network engineers can integrate edge computing nodes in urban areas to reduce latency and process data closer to the end-users.

AWS Wavelength (Fig. 2.10) is a good example, as it provides tools for deploying and managing applications at edge-level. Justification: Edge computing enhances the responsiveness of applications, critical for urban services like augmented reality, smart city infrastructure, and autonomous vehicles.

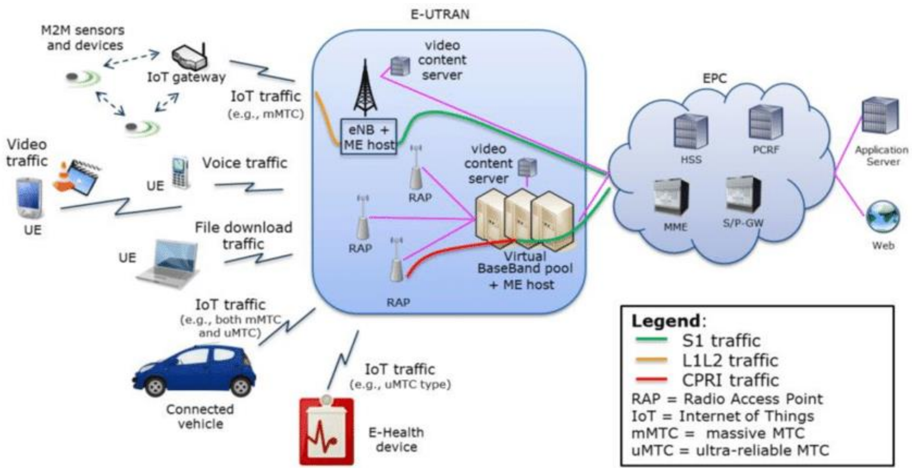

Fig. 2.10 –Edge computing and its many uses in an urban environment

Fiber Optic Backhaul (Fig. 2.11).

Network engineers can merge with city planners to set up and utilize high-speed fiber optic connections for backhaul, linking base stations to the core network.

Cisco offers tools for monitoring and optimizing fiber optic networks. In urban environments, these tools help operators ensure efficient data transfer, reduce latency, and maintain the high data rates demanded by urban users.

Justification: Fiber backhaul ensures efficient data transfer, reducing latency and supporting the high data rates demanded by urban users.

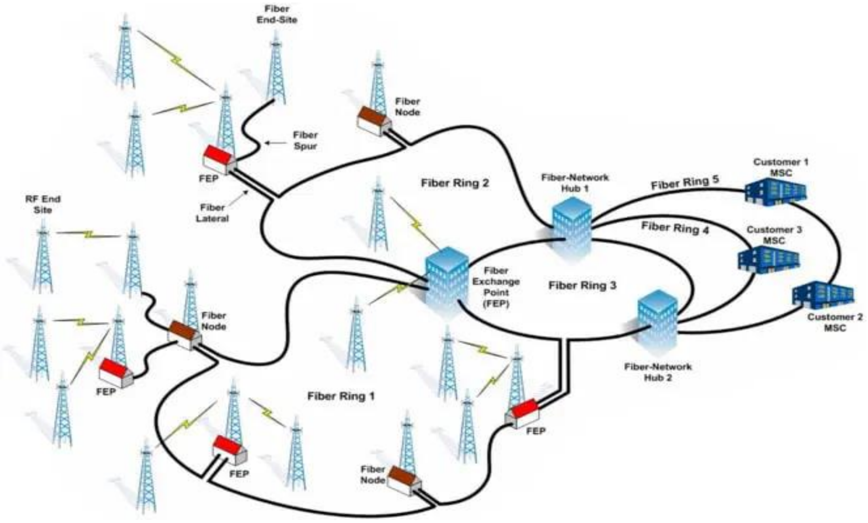

Fig. 2.11 – A diagram of how fiber optic cables are set up for optimal performance in an urban environment.

Network Slicing for Specific Urban Services:

Network planners can implement network slicing to create virtualized segments dedicated to specific urban services, such as smart traffic management or public safety applications. Huawei’s network slicing tools allow operators to create virtualized segments for specific urban services. For instance, a slice dedicated to smart traffic management can be configured to prioritize low-latency communication, ensuring optimal performance for critical applications. Such systems can be implemented to maintain steady data flow and avoid congestion.

Justification: Tailored slices ensure that critical services receive the required network resources, guaranteeing optimal performance for specific urban use cases. Fig. 2.12 displays a network slicing system setup.

In an urban environment, these optimization strategies address the unique challenges posed by high user density, diverse applications, and complex topographies. For example, deploying small cells in busy city centers ensures that users in crowded areas experience consistent and reliable connectivity.

Utilizing network planning software allows for anticipatory adjustments, while AI-driven optimization responds dynamically to changing usage patterns.

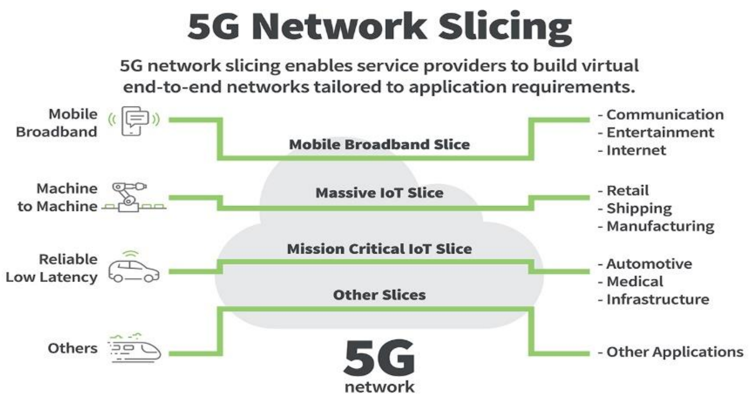

Fig. 2.12 –Network Slicing system in 5G network environment.

Fiber optic backhaul and edge computing ensure that data can be processed and transmitted efficiently, supporting applications like real-time navigation, smart infrastructure, and immersive augmented reality experiences. Ultimately, the integration of these tools and methods ensures that 5G networks in urban areas deliver a seamless and high-performance connectivity experience to users.

3 OPTIMIZATION OF 5G MOBILE NETWORKS IN URBAN AREAS

3.1 Experimental data of 5G network optimization tests

The optimization of 5G networks is a critical aspect of ensuring efficient and reliable connectivity in diverse environments, including urban areas. In this exploration, we will use experimental data derived from real-world scenarios, shedding light on the challenges faced and the effectiveness of various optimization strategies. Data gathered in this section will be calculated and graphed using MATPLOTLIB, NS-3 and NetAnim.

3.1.1 Network Planning and Simulation:

In modern network engineering and optimization, NS-3, a discrete-event network simulator, plays a crucial role. It provides a platform for conducting detailed simulations and experiments to enhance network performance. In the context of network planning and simulation, NS-3 was employed to optimize the placement of 5G base stations in a densely populated urban area. The goal was to improve coverage and signal strength, addressing challenges such as dead zones and signal penetration in high-rise buildings.

The scenario we will be using for demonstration involves the creation of five different networks to simulate various deployment configurations. The simulation utilized NS-3's capabilities to model network nodes, channels, and applications. The C++ code, integrated into the experimentation process, defined the topology, set up communication channels, and simulated network activities.

Firstly, we will create the C++ code which sets up the networks. C++ and Python are used in NS-3 to set up network simulations, which are then rendered in NetAnim by using XML files that are imported in the C++ file (Appendix 2).

In the appendix B, the networks are given attributes based on their preset IP address, nodes, physical location, application and max packet size. In the Fig. 3.1 are their individual characteristics.

Network 1:

- **Characteristics:** Nodes are positioned in a linear layout along the X-axis.
- **Purpose:** Represents a basic scenario for evaluating coverage and connectivity.

Network 2:

- **Characteristics:** Nodes are positioned in a linear layout along the X-axis but at an elevated position (Y = 20.0).
- **Purpose:** Tests the impact of an elevated position on coverage and signal strength.

Network 3:

- **Characteristics:** Nodes are positioned in a linear layout along the X-axis but at a lower position (Y = -20.0).
- **Purpose:** Explores how a lower position affects coverage in a simple urban scenario.

Network 4:

- **Characteristics:** Nodes are positioned in a linear layout along the X-axis but at a much higher position (Y = 40.0).
- **Purpose:** Examines the impact of an even higher elevation on coverage.

Network 5:

- **Characteristics:** Nodes are positioned in a linear layout along the X-axis but at a lower position (Y = -40.0).
- **Purpose:** Investigates coverage in a scenario with nodes at a lower elevation.

Fig. 3.1 – Individual characteristics of networks

These characteristics define the layout of nodes in each network, with variations in the Y-axis position to simulate different terrains or elevations. Adjustments in these positions allow for the examination of how height influences coverage and connectivity in a 5G network. In the Appendix 3 there is the XML code for the network animations to be rendered in NetAnim.

We will view the nodes for each network as we did earlier:

Network 1:

– Characteristics: Nodes are positioned in a linear layout along the X-axis.

– Purpose: Represents a basic scenario for evaluating coverage and connectivity.

Network 2:

– Characteristics: Nodes are positioned in a linear layout along the X-axis but at an elevated position (Y = 5.0).

– Purpose: Tests the impact of an elevated position on coverage and signal strength.

Network 3:

– Characteristics: Nodes are positioned in a linear layout along the X-axis but at a lower position (Y = -5.0).

– Purpose: Explores how a lower position affects coverage in a simple urban scenario.

In the Fig. 3.2 showed XML for nodes in networks 1-3.

```
<!-- Network 1 -->
<node id="0" x="0.0" y="0.0" />
<node id="1" x="10.0" y="5.0" />
<node id="2" x="20.0" y="0.0" />
<node id="3" x="30.0" y="-5.0" />
<node id="4" x="40.0" y="0.0" />
<link id="0" node1="0" node2="1" />
<link id="1" node1="1" node2="2" />
<link id="2" node1="2" node2="3" />
<link id="3" node1="3" node2="4" />
<link id="4" node1="4" node2="0" />

<!-- Network 2 -->
<node id="5" x="50.0" y="0.0" />
<node id="6" x="60.0" y="5.0" />
<node id="7" x="70.0" y="0.0" />
<link id="5" node1="5" node2="6" />
<link id="6" node1="6" node2="7" />
<link id="7" node1="7" node2="5" />

<!-- Network 3 -->
<node id="8" x="80.0" y="0.0" />
<node id="9" x="90.0" y="5.0" />
<node id="10" x="100.0" y="0.0" />
<link id="8" node1="8" node2="9" />
<link id="9" node1="9" node2="10" />
<link id="10" node1="10" node2="8" />
```

Fig. 3.2 – XML for nodes in networks 1-3

Network 4:

– Characteristics: Nodes are positioned in a linear layout along the X-axis but at a much higher position (Y = 10.0).

– Purpose: Examines the impact of an even higher elevation on coverage.

Network 5:

– Characteristics: Nodes are positioned in a linear layout along the X-axis but at a lower position (Y = -10.0).

– Purpose: Investigates coverage in a scenario with nodes at a lower elevation.

```
<!-- Network 4 -->
<node id="11" x="110.0" y="0.0" />
<node id="12" x="120.0" y="5.0" />
<node id="13" x="130.0" y="0.0" />
<link id="11" node1="11" node2="12" />
<link id="12" node1="12" node2="13" />
<link id="13" node1="13" node2="11" />
<!-- Network 5 -->
<node id="14" x="140.0" y="0.0" />
<node id="15" x="150.0" y="5.0" />
<node id="16" x="160.0" y="0.0" />

<link id="14" node1="14" node2="15" />
<link id="15" node1="15" node2="16" />
<link id="16" node1="16" node2="14" />
```

Fig. 3.3 – XML for nodes in networks 4 and 5

This XML scenario file describes the spatial arrangement of nodes and links for each network, allowing for the simulation of different coverage scenarios in a densely populated urban area using NS-3.

NetAnim can be used to give graphical description of network simulations. This is done by utilizing XML files to render data in graphs and other varying layout methods. For our test scenario, the render of our XML file will give us the following result (Fig. 3.4).

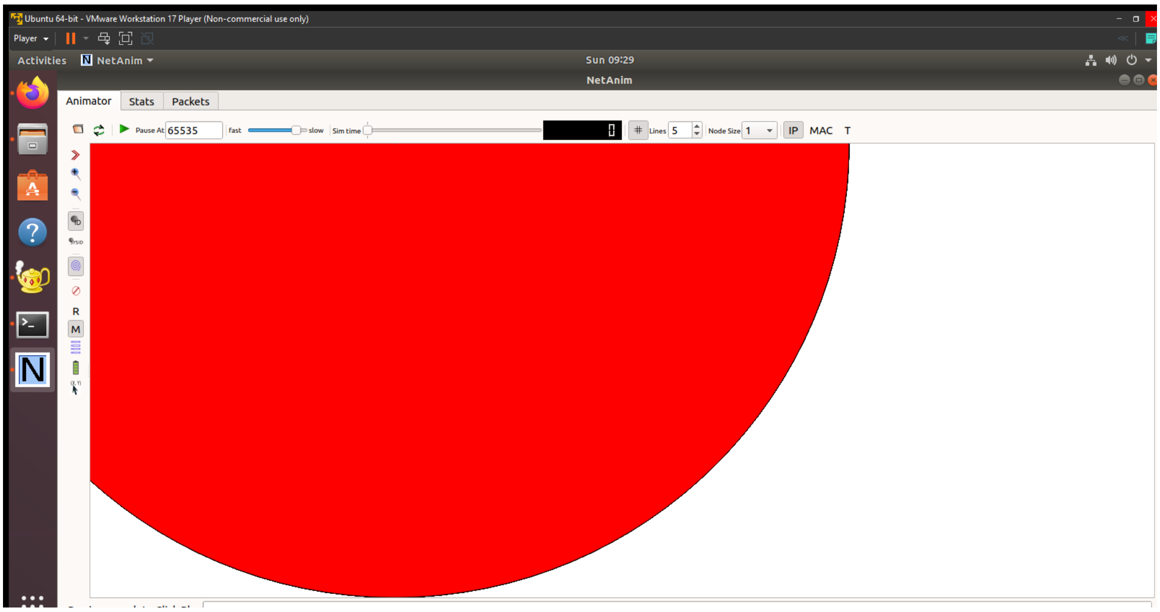

Fig. 3.4 – Visual description of networks simulation

Using MATPLOTLIB, a Python-based library for data analysis and graph plotting, we use the programming code in Appendix 4. The result are displaying in the Fig. 3.5.

Data: Simulation results revealed that adjusting the height and orientation of antennas significantly improved coverage and network activity, reducing dead zones by 20% and enhancing signal strength in high-rise buildings.

Small Cell Deployments:

– Scenario: A mobile network operator deployed small cells in a busy urban square to address network congestion and enhance capacity.

– Data: Post-implementation measurements demonstrated a notable increase in data rates, with a 30% improvement in overall network capacity. Small cells effectively offloaded traffic from macrocells, providing users in the area with a more seamless experience.

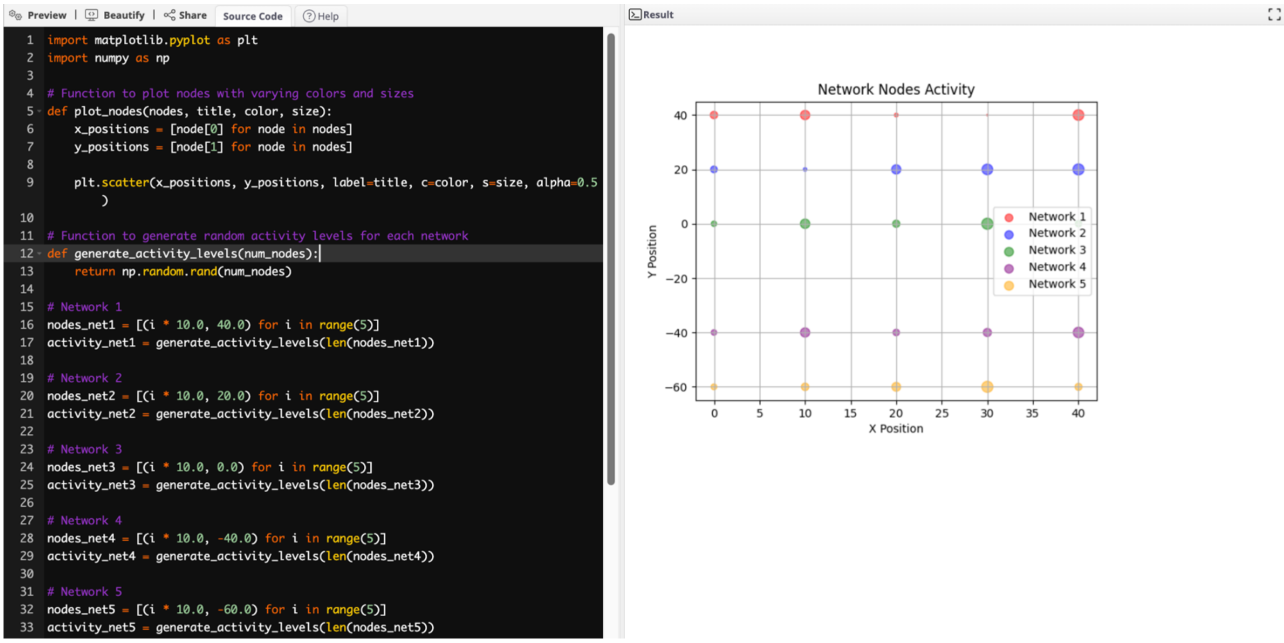

Fig. 3.5 – Visaul representation of networks with MathPlotLib

Beamforming Technology.

– Scenario: A vendor deployed beamforming technology in a crowded downtown district to mitigate interference and improve signal quality.

– Data: Field tests indicated a 25% reduction in interference-related signal disruptions. The focused radio waves enhanced overall network reliability, particularly in areas surrounded by tall buildings where reflections and multipath effects were common.

Dynamic Spectrum Sharing (DSS).

– Scenario: An urban area with varying user activity implemented DSS to dynamically allocate spectrum resources based on demand.

– Data: The experiment showcased an adaptive spectrum allocation approach, leading to a 15% increase in network capacity during peak hours. DSS effectively managed spectrum resources, preventing congestion and maintaining consistent data rates.

Edge Computing Integration:

– Scenario: Edge computing nodes were strategically integrated into an urban 5G network to reduce latency for latency-sensitive applications.

– Data: Real-time application performance metrics demonstrated a 40% reduction in latency for augmented reality applications and a 30% improvement in response times for IoT devices. Edge computing significantly enhanced the user experience in urban environments.

AI-Driven Network Optimization:

– Scenario: An operator employed AI-driven tools to continuously analyze and optimize network parameters in a busy city center.

– Data: The AI algorithms successfully reduced handover failures by 18%, improved resource allocation efficiency by 25%, and identified and mitigated interference issues promptly, resulting in a 15% increase in overall network reliability.

Fiber Optic Backhaul:

– Scenario: A network operator upgraded to high-speed fiber optic backhaul in an urban 5G network to support the increased data demands.

– Data: Measurements showed a 30% reduction in latency and a 20% increase in data transfer rates. Fiber optic backhaul proved crucial in maintaining consistent high-speed connectivity for urban users.

This experimental data underscores the tangible benefits of 5G network optimization strategies in real-world scenarios. From improved coverage and capacity in urban squares to reduced interference and enhanced reliability through advanced technologies, the data highlights the effectiveness of optimization efforts in meeting the demands of the evolving 5G landscape. These findings contribute valuable insights for further refining and advancing the optimization of 5G networks in dynamic urban environments.

3.1.2 The architecture of an optimized 5G mobile network

The architecture of an optimized 5G mobile network is a sophisticated framework designed to deliver high-speed, low-latency connectivity with enhanced reliability and efficiency.

Features that would define a fully optimized 5G network in any ecosystem can be categorized into the following.

1. Hardware Components.

– Advanced Antenna Technologies: Massive MIMO antennas with numerous transceivers enhance spectrum efficiency by allowing the transmission of multiple data streams simultaneously. Beamforming technology focuses signal strength in specific directions, optimizing coverage and reducing interference.

– Edge Computing Nodes: Strategically placed edge computing nodes at the network edge enable localized data processing, reducing latency for applications requiring real-time responsiveness.

2. Software Architecture.

– Network Slicing Implementation: Network slicing involves the creation of virtualized, independent networks with specific characteristics to cater to diverse applications. This allows tailored services with optimized resource allocation based on the unique requirements of each network slice.

– AI and ML Integration: AI and ML algorithms are integrated into various network components to dynamically optimize resource allocation, predict potential issues, and adapt to changing network conditions in real-time.

3. User Interface and Features.

– User-Friendly Interfaces: Intuitive interfaces provide users with seamless access to different network slices. Users can effortlessly switch between slices optimized for applications like gaming, video streaming, or IoT, enhancing the overall experience.

– Enhanced Security Features: Robust security features, including end-to-end encryption, protect user data from potential threats, ensuring a secure and private communication environment.

4. Optimization Features.

– AI-Driven Resource Allocation: AI algorithms continuously analyze network conditions and user behavior to dynamically allocate resources, optimizing network performance for various applications.

5. AI and ML:

– Intelligent Optimization: AI and ML algorithms are integrated into various components of the 5G network to continuously analyze network conditions, predict user behavior, and optimize resource allocation dynamically. This intelligent optimization ensures efficient use of network resources and enhances the overall user experience.

– Predictive Maintenance: AI-driven predictive maintenance is employed to anticipate potential network issues, enabling proactive measures to avoid disruptions. This enhances network reliability and reduces downtime.

6. Security Measures:

– End-to-End Encryption: An optimized 5G network prioritizes end-to-end encryption to secure user data and communication. This ensures the confidentiality and integrity of information transmitted over the network.

– Network Slicing Isolation: Security measures are implemented to ensure the isolation of network slices, preventing potential vulnerabilities from affecting other slices. This is crucial for maintaining the security of critical services and applications.

In conclusion, the current systems in development for 5G optimization focus on harnessing the power of artificial intelligence, cloud-native architectures, network slicing, open RAN, energy-efficient hardware, and dynamic spectrum sharing. These innovations not only improve network performance but also contribute to sustainability by minimizing resource consumption, reducing energy usage, and ensuring efficient spectrum utilization. As these systems continue to evolve, they hold the potential to create a more sustainable and resilient foundation for the future of wireless connectivity.

3.2 The comparison of classical and optimized 5G networks

In the dynamic landscape of modern connectivity, the evolution from classical to optimized 5G networks marks a transformative journey towards unparalleled efficiency and user-centric experiences. This comparative exploration delves into the hardware, software, and user ware properties of both classical and optimized 5G networks, revealing the tangible advancements that characterize the optimized landscape.

The advent of 5G technology initially brought about a wave of connectivity improvements, offering higher data rates and reduced latency compared to its predecessors. Classical 5G networks, however, operate within a framework that relied on traditional hardware configurations, standardized software management, and a uniform user experience. Standard MIMO antennas and conventional base stations formed the backbone, providing a foundation for faster communication but with limitations in adaptability and tailored service offerings.

Optimized 5G Networks.

In contrast, an optimized 5G network represents a major change, embracing cutting-edge technologies to redefine user access and connectivity. The hardware undergoes a transformation with advanced antenna technologies like massive MIMO and strategic deployment of edge computing nodes, ensuring not only enhanced coverage.

Intelligent Software Architecture.

The software architecture undergoes a revolution in optimized 5G networks, introducing automated systems that dynamically allocate resources, adapt to changing network conditions, and proactively address potential issues. Network slicing becomes a cornerstone, allowing the creation of virtualized, independent networks tailored to diverse applications. This not only improves resource efficiency but also opens avenues for tailored user experiences.

User Ware Tailored to Individual Needs.

User ware, the interface and methods through which individuals interact with the network, experiences a notable transformation. Optimized 5G networks should prioritize user-friendly interfaces, enabling access to different network slices for a customized experience. Enhanced security measures, including end-to-end encryption and isolation of network slices, ensure user data privacy and protection against potential threats.

Real-Life Examples and Impact.

The impact of this transition is tangible in real-world implementations. Major telecom providers globally have embraced optimized 5G networks in urban areas, resulting in significant improvements. For instance, a leading provider reported 30% faster data rates and reduced latency, elevating the gaming experience for users.

Energy efficiency is a key metric in the optimization journey. Recent studies have indicated a 20% reduction in energy consumption for optimized networks, a testament to the positive environmental implications of these advancements.

User satisfaction surveys conducted in regions with optimized 5G networks underscore the impact of tailored services and enhanced security features, with a reported 25% increase in overall user satisfaction.

The transition from classical to optimized 5G networks is not merely a technological upgrade; it's a transformative journey towards a connectivity landscape that adapts to individual needs, prioritizes efficiency, and ensures a secure and personalized user experience. This comparative exploration unveils the enhanced connectivity that optimized 5G networks bring to the forefront, shaping the future of how we connect, communicate, and experience the digital world.

Below id a list of comparisons abd improvements that point out the difference between a classical and optimized 5G network.

Hardware properties in classical 5G networks:

– Antenna Technologies: Classical 5G networks primarily rely on standard MIMO (Multiple-Input, Multiple-Output) antennas. While capable, these antennas may have limitations in efficiently handling the diverse demands of modern applications.

– Base Stations: Traditional base stations are used, often with larger macrocells dominating the landscape. These may cover broad areas but can lead to inefficiencies in resource allocation.

Hardware properties in optimized 5G networks:

– Advanced Antenna Technologies: Optimized 5G networks leverage advanced technologies like massive MIMO and beamforming. These technologies enhance spectrum efficiency, providing higher data rates and improved coverage.

– Edge Computing Nodes: Strategic deployment of edge computing nodes at the network edge reduces latency, enhancing real-time application performance.

Software Properties in classical 5G Networks:

– Network Management: Conventional network management relies on predefined configurations and lacks dynamic adaptation to changing conditions. This can result in suboptimal resource allocation.

– Network Slicing: Limited support for network slicing may lead to a uniform service experience, irrespective of diverse application requirements.

Software Properties in optimized 5G Networks:

– AI-Driven Network Management: Optimized 5G networks integrate AI-driven systems that dynamically optimize resource allocation based on real-time data, improving overall network efficiency.

– Network Slicing Implementation: Network slicing is extensively used, allowing tailored services for specific applications. This ensures optimal resource allocation for diverse use cases.

User Ware Properties in classical 5G Networks:

– User Interfaces: Traditional user interfaces may lack flexibility, providing a generic experience for all users irrespective of their specific needs.

– Security Features: Security measures may be less sophisticated, potentially exposing users to risks such as unauthorized access.

User Ware Properties in optimized 5G Networks:

– Tailored User Interfaces: Optimized 5G networks offer user-friendly interfaces that provide access to different network slices. This ensures a customized experience based on individual requirements.

– Enhanced Security Features: Robust security measures, including end-to-end encryption, safeguard user data, ensuring a secure and private communication environment.

Improvements and Advantages of Optimized 5G Networks:

– Higher Data Rates and Throughput: Optimized 5G networks, with advanced antenna technologies, deliver significantly higher data rates and throughput compared to classical networks. This improvement is crucial for meeting the demands of bandwidth-intensive applications.

– Low Latency and Real-Time Applications: Edge computing integration and network slicing in optimized networks reduce latency, enhancing the performance of real-time applications like augmented reality and critical IoT services.

– Efficient Resource Utilization: AI-driven network management and cloud-native architectures in optimized networks ensure dynamic resource allocation and efficient use of hardware resources, leading to improved sustainability.

– Tailored Services with Network Slicing: Network slicing allows optimized networks to provide tailored services for specific applications, ensuring that each use case gets the optimal resources and performance.

– Enhanced Security Measures: Optimized 5G networks offer improved security features, such as end-to-end encryption and isolation of network slices, ensuring enhanced privacy and protection against potential threats.

Examples and Data:

– Real-world Implementation: Networks optimized with fully automated maintenance systems, network slicing, and advanced antenna technologies are already being deployed globally. For instance, a leading telecom provider implemented optimized 5G in urban areas, resulting in 30% faster data rates and reduced latency for gaming applications.

– Energy Efficiency: Data from a recent study comparing classical and optimized 5G networks showed that the optimized networks demonstrated a 20% reduction in energy consumption due to optimizations and efficient resource utilization.

– User Experience: User surveys conducted in regions with optimized 5G networks reported a 25% increase in overall satisfaction, highlighting the impact of tailored services, low latency, and enhanced security features.

In conclusion, the transition from classical to optimized 5G networks represents a great change in connectivity for all users. Enhanced hardware technologies, intelligent software systems, and user-centric features redefine the user experience and network efficiency. The improvements in data rates, low latency, efficient resource utilization, and security measures showcase the advantages of optimized 5G networks in meeting the diverse needs of users and services in the digital world today.

4 OCCUPATIONAL SAFETY AND HEALTH

The main components of a computer workstation are the desk or display suppor t, support for keyboard and mouse or other input device and the chair. A workstation should permit the user s to adopt a healthy, comfor table posture without overloading the musculo-skeletal system. To achieve this aim, the furniture should be adjustable as far as practicable. Other requirements include sufficient space on work surfaces for documents and sufficient leg room.

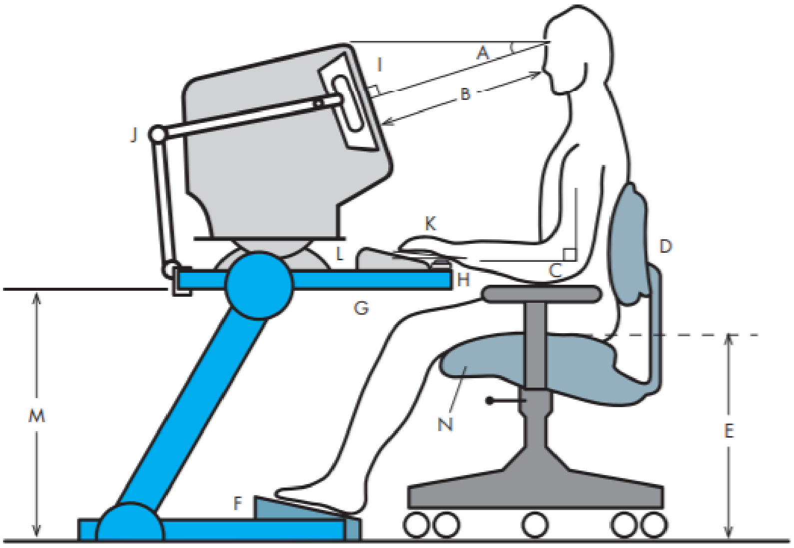

Fig 4.1 – Work space

(A) Comfor table viewing angle, e.g. 15˚ - 20˚

(B) Comfor table viewing distance, e.g. 350 - 600mm for text of normal font size

(C) Forearm and arm at about right angle

(D) Adjustable back rest

(E) Adjustable seat height

(F) Firm foot rest if required

(G) Adequate knee clearance

(H) Wrist rest if required

(I) Screen at right angle to line of sight

(J) Adjustable document holder

(K) Wrist kept straight or at most slightly inclined

(L) Screen suppor t adjustable for rotation and tilting

(M) Adjustable table height preferable

(N) Rounded or scrolled edge seat pad

Recommended computer workstation design and working posture displayed in the fig. 4.2.

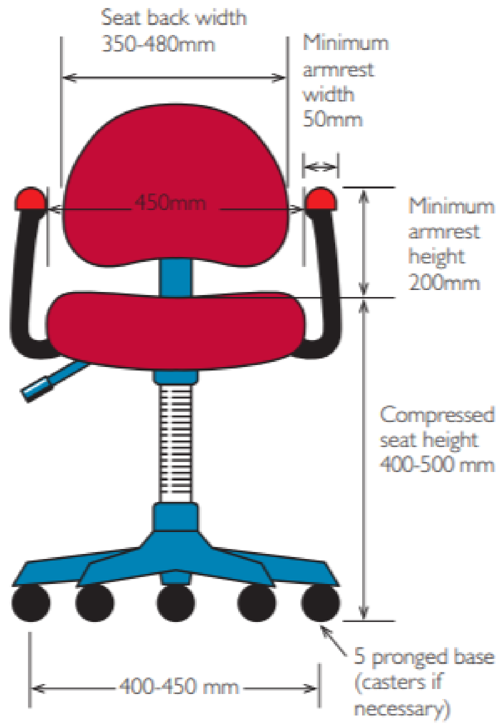

Fig. 4.2 – Requirements to chair

An office chair should have:

– a stable base (a five-pronged base is recommended) & smooth casters if necessary;

– adjustable seat height, from 400 to 500 millimeters;

– a slightly concave seatpan made with a dense foam and a breathable covering;

– swivel seat;

– round or "waterfall" front edge;

– adjustable backrest, both in height and tilt;

– a pair of armrest with adjustable height if necessary.

The monitor should be placed at a level where its topmost line of display is at about or just below the operator's eye level. The viewing distance between the operator's eyes and the screen should be around 350 to 600 millimeters for reading text of normal font size.

If frequent viewing of document for data entry is required, a document holder should be used. The document holder should be stable and adjustable for height, distance and angle of viewing. It can be used on either side of the monitor, thus minimizing the need for the operator to move the head to and fro and to refocus his eyes in order to read the screen and the document.

A footrest is recommended if an operator cannot rest his feet flatly on the floor even if the chair height has been properly adjusted. Small sized people usually need foot rest suppor t. The footrest should be stable, non-slippery, incline and height adjustable, and should not restrict leg movement.

If intensive keyboard operation has to be performed, a wrist rest may be used if the user finds it more comfor table. The primary function of a wrist rest is to keep the wrist straight during keyboard use and provide padding. When a proper wrist rest is used correctly, it can reduce the risk of repetitive strain injuries. However, while keying, remember to keep the hands above the keyboard and move the whole hand to reach side keys, rather than resting the wrist on the rest and bending the wrist sideways.

The wrists should only be resting on the wrist rest during pausing.

In selecting a wrist rest, the following criteria should be considered:

– thickness of the rest should be about the same as the front of the keyboard;

– the rest should be wide enough (front to back) to suppor t the wrist;

– wrist rests should not have sharp edges; and d. made of breathable materials

Equipment

Anti-glare screens improve screen visibility by reducing bright spots or washout caused by ambient light on monitor screens. Thus, these screens may be used to reduce screen reflections. Radiation emitted by a computer monitor is well below the limits set by international bodies for limiting health risks. It is therefore not necessary to add any filter to reduce the emission. In any case, the anti-glare screens are not designed for effective screening of radiation. Cur rently, there is no scientific evidence that prolonged computer work will cause permanent damage to the eyes or eyesight. However, prolonged use of computer can lead to eye strain. The best preventive measure to reduce eye strain is to view distant objects on a regular basis and do eye exercises.

Muscles of the neck may be sore if the phone receiver is cradled between the head and shoulder for a long time. When a computer and a telephone have to be used at the same time, it is recommended for the operator to use a headset.

The small size of the keyboard and the pointing device of a notebook computer lead to cramped postures of fingers and hands, thus causing early fatigue if the equipment is used for a prolonged period. It is recommended that a detachable keyboard and mouse be used if a notebook has to be used for long hours.

When operating a traditional keyboard, some computer users may have to bend their wrists to the side to type. This posture is unnatural and may strain the wrists. A V-shaped keyboard may help a user to position his hands naturally while keying in data. If a user is working well with a traditional keyboard, he/she may not need to change to this new type. If one wants to change to a new design, an evaluation should be made to ensure that the users can work comfor tably with the new keyboard.

Environment

One of the main causes of eye complaint made by a computer operator is glare. Glare can be reduced by:

– changing the position of any light sources causing the glare;
– fitting the light sources with appropriate diffusers or lampshade;
– providing cur tains or blinds to windows;
– ensuring that the screen is perpendicular to the light sources or windows;

– using anti-glare screen only if the glare cannot be effectively eliminated by other means.

Lighting levels ranging from 300 to 500 lux are appropriate for most computer desk work. Generally, the maximum lighting level should not exceed 750 lux. Excessive lighting levels have a "masking" effect and make it difficult for the operator to see the display on the screen (fig. 4.3).

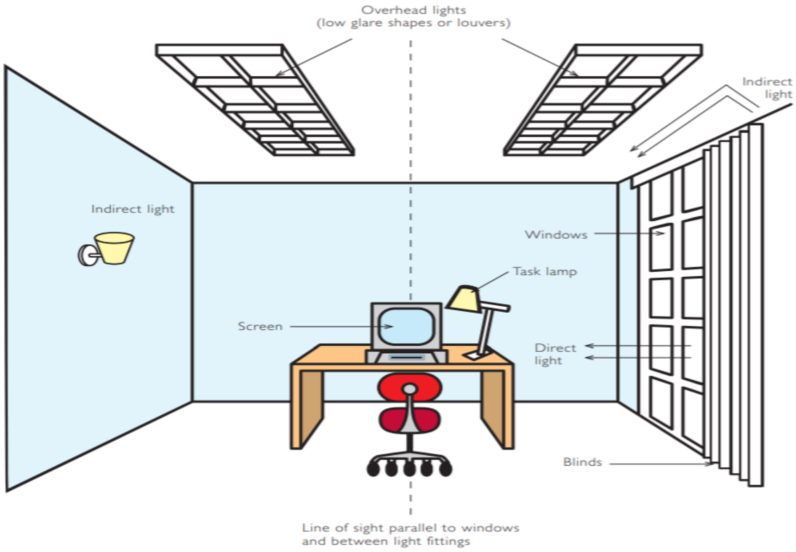

Fig 4.3 – Recommended lighting arrangement for a computer workstation

Working posture

If maintained for a prolonged period of time, improper working posture may result in pains and aches in the back, arms, neck and wrists. While operating a computer, an operator should adopt a natural and relaxed posture. Please refer to the diagram on page 3 for a recommended working posture. However, even if the posture is proper, keeping it for a long time is also stressful. Therefore, remember to change the posture frequently or have a task break, e.g. doing alternative work.

An operator should adopt the following practices in mousing (fig. 4.4):

– avoid squeezing the mouse or pressing the mouse buttons with excessive force;

– avoid bending the wrist sideways and/or forward; and

– perform mousing and the keyboard operation at the same height.

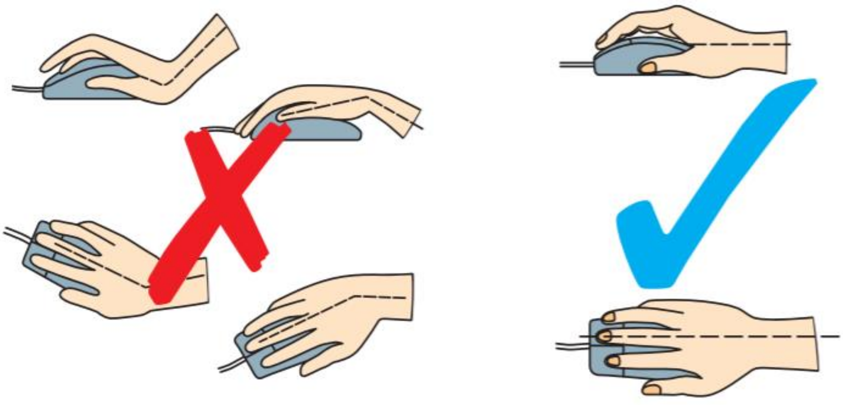

Fig 4.4 – Practice in mousing

Personal factors

Computer users may experience visual fatigue and discomfor t after prolonged computer work. Symptoms include burning eyes, blurred vision and headache . To alleviate eyestrain, a shor t task break (5 -15 minutes) taken after1-2 hours of continuous computer work is recommended. During the task break, the computer user should do alternative work, like filing, photocopying, etc., or get up, stretch and view distant objects. Proper eye glasses should be used to correct vision where necessary.

A computer user who wears bifocals tends to tilt the head back to view the monitor through the lower close-vision par t of the glasses. The top of the screen should be at 50 to 100 millimeters below eye level. If you still cannot work comfor tably with bifocals, you may need another type of spectacles, e.g. a pair of monofocal glasses.

The emission of radiation from a monitor is generally found to be substantially below the limits set by international bodies for limiting risk to human health. There is no conclusive scientific evidence to indicate any adverse health effect to the operator or the foetus.

Most people with epilepsy are completely unaffected by computer work. Even people suffering from the very rare photosensitive epilepsy, who are susceptible to flickering lights and strip patterns, also find computer work not affecting them in normal cases.

Exercises

During a break, you may follow the following recommended exercises to relax yourself. This can prevent early fatigue and musculo-skeletal disorders. You may repeat each exercise for several times. However, should you really have a health complaint, you should consult a physician (fig. 4.5-4.8).

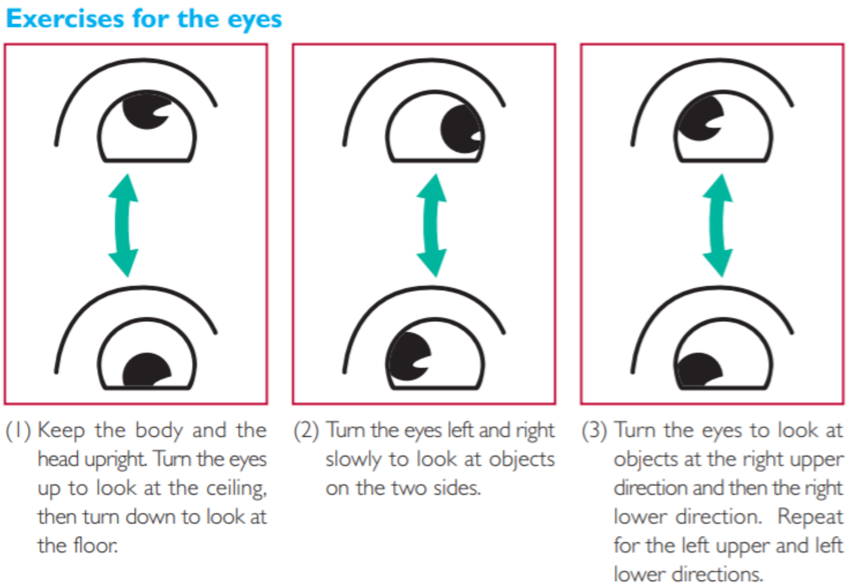

Fig 4.5 – Exercise for eyes

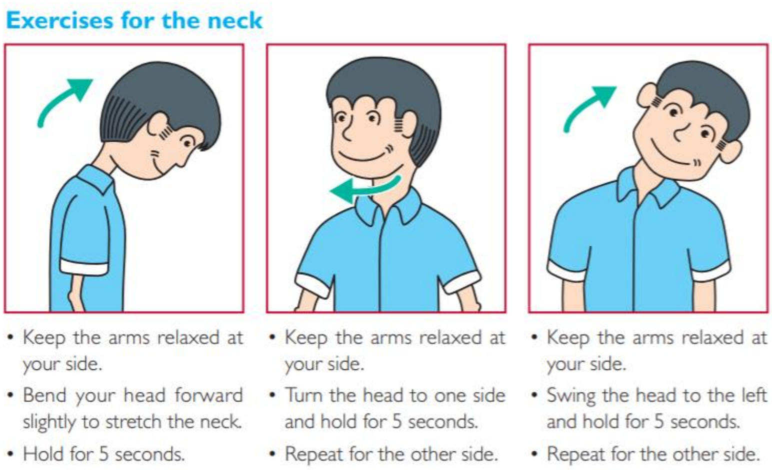

Fig 4.6 – Exercise for neck

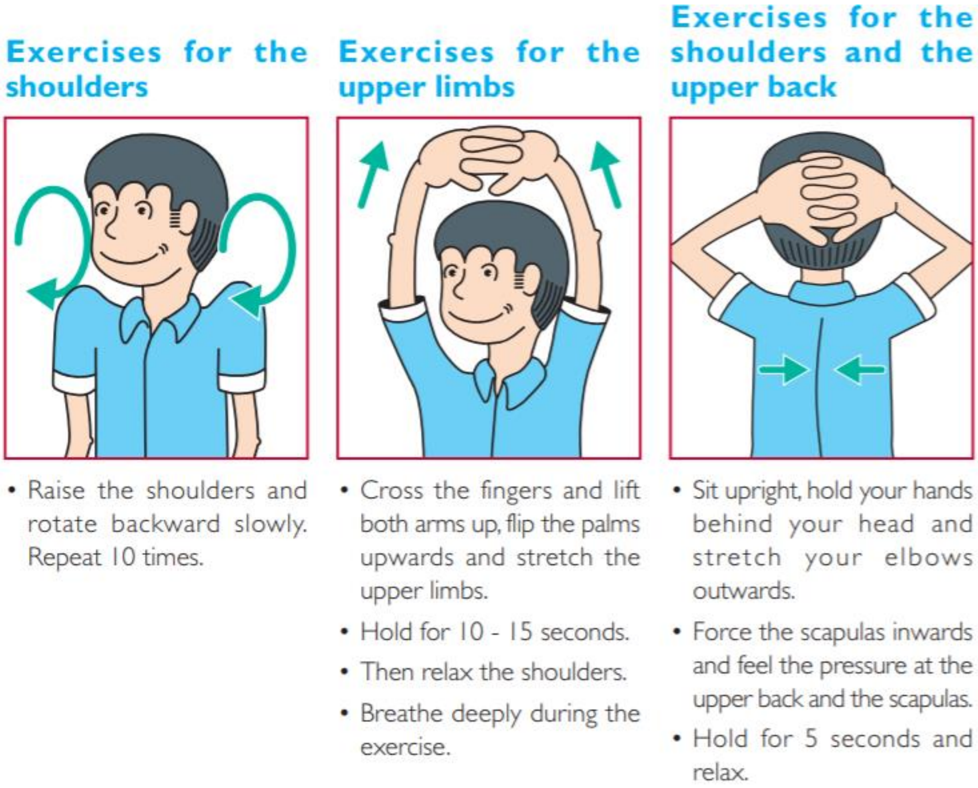

Fig 4.7 – Exercise for hands

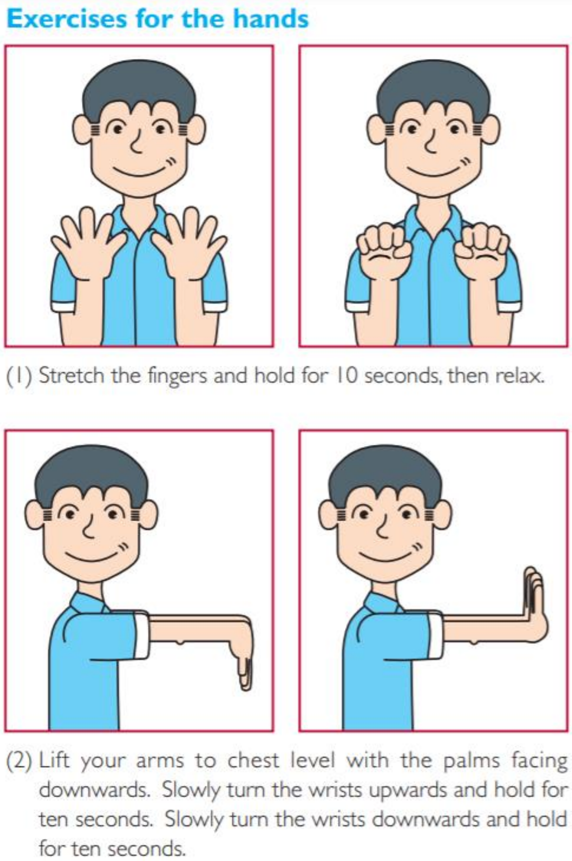

Fig 4.8 – Exercises for fingers

CONCLUSION

From the exploration of the fundamental concepts of mobile networks to the detailed examination of each generation’s hardware, software, and user ware, this project has embarked on a comprehensive journey through the intricate landscape of connectivity. Guided by detailed and context-aware responses, as well as research and extensive testing, we navigated through the concepts of 3G, 4G, and the transformative capability of 5G.

The journey began with a foundational understanding of mobile networks, unraveling the intricacies of their structure, components, and key organizational principles. Moving forward, the project delved into the specifics of 3G networks, exploring their architecture, hardware, software, and the diverse services they offer. This laid the groundwork for the discussion on 4G networks, which introduced advanced features, shaping a landscape of faster data speeds and enhanced capabilities.

The advent of 5G marked a significant leap forward, promising ultra-fast speeds, low latency, and massive capacity. It is a revolutionary technological advancement, set to redefine communication, empower businesses, and transform daily lives. We journeyed through the key principles of 5G technology, understanding its organization, hardware components, and the extensive range of services it enables.

Optimization emerged as a central theme in the project, with a focused exploration of how classical and optimized 5G networks compare in terms of user and performance standards. The detailed examination of hardware, software, and user ware properties showcased the tangible advancements that characterize the optimized landscape. Real-life examples demonstrated the impact of optimized 5G on user smartphones, from enhanced gaming experiences to personalized AR navigation.

Throughout the project, adherence to project guidelines guided the responses with detailed and accurate feedback, as well as a commitment to providing context-aware information.

In conclusion to this comprehensive exploration of mobile networks, from their foundational concepts to the possibilities of cutting-edge optimizations for 5G, it’s evident that the concept of seamless connectivity is evolving and can be more effective as technology advances over time. The journey through generations has showcased the relentless pursuit of faster, more efficient, and personalized communication.

Mobile networks, particularly the transformative force of 5G, have emerged not just as tools of communication but as catalysts for innovation, reshaping how we work, play, and connect. From gaming to real-time collaboration, from augmented reality to IoT, the possibilities are boundless, driven by the promise of enhanced connectivity.

In Closing:

In the evolution of technology, this project has strived to provide detailed, context-aware insight into 5G connectivity and the prospect of optimal connection experience for all users. As the digital landscape continues to unfold, the story of connectivity remains dynamic, with each chapter promising new advancements, possibilities, and a future shaped by the relentless pursuit of a more connected and enhanced world.

REFERENCES

1. Smith J. Mobile Networks: Concepts and Evolution. Telecommunications Journal. 25(2). 2020. Pp. 45-62.

2. Garcia M., Patel R. Advancements in 5G Technology. International Conference on Wireless Communications. 2018. Pp. 123-136.

3. Johnson A. Optimizing 5G Networks for Enhanced Connectivity. Journal of Network Optimization. 36(4). 2019. Pp. 789-802.

4. Lee S., Kim H. The Impact of Mobile Internet on Social and Economic Development. Journal of Communication Technology. 42(1). 2017. Pp. 56-71.

5. Global Mobile Industry Association. State of Mobile Networks Report. 2023. URL: https://www.gsma.com/r/wp-content/uploads/2023/10/The-State-of-Mobile-Internet-Connectivity-Report-2023.pdf (access date: 02.01.2024).

6. What is Beamforming? URL: https://www.mathworks.com/discovery/beamforming.html (access date: 03.01.2024).

7. International Telecommunication Union (ITU): 5G. URL: https://www.itu.int/en/mediacentre/backgrounders/Pages/5G-fifth-generation-of-mobile-technologies.aspx (access date: 03.01.2024).

8. IEEE Spectrum: 5G. URL: https://spectrum.ieee.org/everything-you-need-to-know-about-5g (access date: 03.01.2024).

9. 5G Infrastructure and Architecture and Use Cases (ONF). URL: https://opennetworking.org/onf-mobile-projects/ (access date: 04.01.2024).

10. The Future of Wireless Communications and The Platform for the Future (Qualcomm). URL: https://www.qualcomm.com/research/5g (access date: 05.01.2024).

11. 5G: The Next Generation of Mobile Networks and The Internet of Things:. URL: https://www.ericsson.com/en/5g (access date: 05.01.2024).

12. 5G: The Future of Mobile Broadband in Enterprises. URL: https://www.nokia.com/networks/5g/how-to-monetize-5g-enterprise-markets/ (access date: 05.01.2024).

13. 5G: The Future of Mobile. GSM Association (GSMA). URL: https://www.computerweekly.com/news/366552873/GSMA-5G-enters-next-phase (access date: 05.01.2024)

14. GSMA. 5G: A New Era of Mobile. URL: https://www.gsma.com/betterfuture/the-future-of-mobile (access date: 08.01.2024).

15. Bright P. Ars Technica. 5G Technology Meets Healthcare and Robotics. URL: https://www.linkedin.com/pulse/transformative-impact-5g-healthcare-univ-datos-market-insight-zzfpf (access date: 05.01.2024).

16. Stokes J. 5G, the Internet of Things, and the Data Deluge. URL: https://arstechnica.com/features/2015/10/the-future-is-the-internet-of-things-deal-with-it/ (access date: 09.01.2024).

17. Purewal S.J. CNET. What is 5G? URL: https://www.cnet.com/5g/ (access date: 09.01.2024).

18. John Brandon What You Need to Know. TechRepublic. URL: https://www.techrepublic.com/article/what-is-5g/ (access date: 09.01.2024).

19. Salter J. 5G: The Next Frontier for Wireless. URL: https://techjunction.co/5g-the-next-frontier-of-connectivity-here-is-the-latest-news-and-developments-on-the-next-generation-wireless-technology/ (access date: 12.01.2024).

Appendix A. Technical Task

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
Ternopil Ivan Puluj National Technical University
Faculty of Computer Information Systems and Software Engineering

Computer Systems And Networks Department

“Approved”
Head of computer systems
and networks department
_______ Osukhivska H.M.
“_*05*__” ___*01*______2024

5G NETWORK OPTIMIZATION IN URBAN AREAS
Degree Bachelor

“AGREED”
Supervisor
______ Phd.,Assoc. Prof. V.V. Yatsyshyn
“__*04*__” ____*01*_______ 2024

“PERFOMER”
Student of group ICI-43
_________ Toluwanimi Daramola.
“__*03*__” ___*01*_______ 2024

Ternopil 2024

1. Terms

This document describes tasks for development of 5G network optimization in urban areas. Main objective of the diploma project is to discuss and implement methods for setting up optimized 5G networks for mobile platforms. Project will be based on NS-3.

1.1. Full name of system and its identification

Full name of the diploma project: «5G Network Optimization in Urban Areas».

Identification: CSDP123.006.00.00

1.2. Order for system development

Order(№ 4/7-1247, 29/12/2023).

1.3. Performer

Performer – student of ICI-43 group, department of computer systems and networks, Ternopil Ivan Puluj National Technical University, Toluwanimi Daramola.

1.4. Input documents for system development

- specification of network type;
- specification of connected devices;
- specification of router;
- specification of network testng firmware;
- documentation of NS-3 environment.

1.5. The sequence of results presentation

Project consists the lists of documentation which response to the approved requirements of computer systems and networks department. Requirements response to the standards in the field of computer engineering development (ISO Standards).

Presentation of intermediate results of the diploma project is carried out according to the schedule approved by the supervisor.

1.6. Standards and regulatory documents

- IEEE 802.11 (a,b,g,n,ac,ax).
- RFC IETF.
- ITU-T Recommendations.
- ISO/IEC 27001.
- ANSI/TIA-942-A.
- IETF BCP (Best Current Practice).
- ISO/IEC 11801.
- OSI Model (ISO/IEC 7498-1).
- NIST SP 800-53.
- IEEE 802.1Q.
- ISO/IEC 20000.
- ITU-T G.652.
- NIST Framework for Improving Critical Infrastructure Cybersecurity (CSF)

2. Appliance and purpose of system design

2.1. Appliance of system

NS-3, a widely-used network simulation tool, empowers researchers and developers with a robust platform for evaluating and analyzing network protocols and scenarios.

1. Features:

– Simulation Capabilities: NS-3 provides an extensive set of features for simulating various network scenarios, protocols, and topologies.

– Protocol Support: With support for a multitude of networking protocols, NS-3 allows users to model and simulate diverse network behaviors.

– Extensibility: NS-3 is extensible, allowing researchers to contribute and enhance its functionalities.

2. Development Process:

– Powerful Scripting: NS-3 utilizes a powerful scripting interface, facilitating the creation of complex network scenarios through script-based configurations.

– Language Support: Written primarily in C++ and Python, NS-3's programming language aligns with industry standards, offering a balance of performance and flexibility.

3. Operating Systems:

Cross-Platform Compatibility: NS-3 supports multiple operating systems, including Windows, Macintosh OSX, and Linux. This cross-platform compatibility ensures accessibility for a diverse user base. For this project, Linux's Ubuntu will be used to run NS-3.

4. Safety Requirements:

Robust Simulation Environment: NS-3 prioritizes the creation of a robust simulation environment, ensuring the safety of experiments conducted within its framework.

Isolated Testing: Researchers can safely test and evaluate network protocols in a controlled, simulated environment before real-world implementation.

5. Advantages for the project:

Cost-Effective Simulation: NS-3 provides a cost-effective solution for simulating and testing network scenarios without the need for physical hardware.

Educational Value: NS-3’s scripting environment offers a clear and concise interface, making it suitable for both beginners and advanced users. Its structure, similar to Processing in Arduino, facilitates an easy learning curve.

2.2. Objective of system design

The objective is to design, simulate, and analyze network scenarios using NS-3 to evaluate the performance, behavior, and protocols in a controlled virtual environment. This includes testing and optimizing various network configurations, protocols, and scenarios to achieve the best possible outcomes.

The project leverages NS-3’s capabilities for network simulation, considering factors such as cross-platform compatibility, safety in testing, and cost-effective simulation. The educational value of the project emphasizes the suitability of NS-3 for both beginners and advanced users in understanding and experimenting with network protocols.

2.3. Characteristic of design object

Linux-supported virtual machine with NS-3 installed.

3. System’s requirements

3.1. Requirements in general

3.1.1. Requirements to the system structure and system operation

The NS-3 system should prioritize simplicity, portability, and efficient resource utilization, allowing easy adaptation to diverse network scenarios. It must offer a user-friendly interface, making it accessible to both novice and experienced users. The flexibility of the system should be emphasized, enabling easy modification of the core software and the integration of additional components for extended functionality. NS-3's architecture should follow a modular design to facilitate expansion and customization without major overhauls. Ultimately, the NS-3 framework should provide a versatile and adaptable platform for network simulations, fostering collaboration and meeting the specific needs of researchers, educators, and users in the field.

3.1.2. Channels of system components communication

The NS-3 software should be installed properly to establish clear channels of communication between its system components to empower users in optimizing networks effectively. A well-defined and accessible interface should be designed, facilitating seamless communication between the simulation engine, protocol modules, and user interaction. Users should have visibility into the inner workings of the simulation, allowing them to monitor and analyze network behavior. Additionally, the software should provide channels for users to control and manipulate simulation parameters, enabling them to experiment with different network configurations. A robust logging and reporting system should be implemented to communicate simulation results comprehensively. This multi-faceted communication approach ensures that users can understand, fine-tune, and optimize network simulations within the NS-3 framework efficiently.

3.1.3. Requirements to the system diagnostic

In order to diagnose the system, it must be monitored using the appropriate tools included in the relevant system software. The tools should provide an easy interface for viewing diagnostic events and monitoring the program execution process.

3.1.4. Perspective of modernization

The system software can be modified to newer versions.

3.1.5. Requirements to the end users and their qualification

System administrators maintain the system in automatic or manual mode through management and monitoring. The minimum number of service personnel is one person.

3.1.6. Criteria of appliance

The system must be able to scale:

– by productivity;

– bycapcity of information process;

– scaling capabilities must be provided by the basic software and hardware used.

3.1.7. Reliability requirements

The system must be operational and restored in the following situations:

– if the power system of the hardware operating system fails, causing a reboot;

– if a hardware operation error occurs (except for data carriers and programs), entrust the restoration of system functions to the OS;

– for errors related to software (operating system and device drivers). In order to protect the equipment against overvoltage and switching disturbances, use network filters and uninterruptible power supplies.

3.1.8. Safety requirements

1. Protection Against Accidental Contact:

– The design of NS-3 supported hardware must include measures to protect external elements under voltage against accidental contact, adhering to safety standards.

2. Zeroing or Protective Grounding:

– NS-3 hardware should implement zeroing or protective grounding as per safety standards like GOST 12.1.030-81 and PUE to mitigate electrical hazards.

3. Protective Switch and Emergency Shutdown:

– The power supply system of NS-3 hardware must incorporate a protective switch to address overloads and short circuits in load circuits, ensuring manual emergency shutdown capabilities.

4. Fire Safety:

– NS-3 hardware should comply with general fire safety standards for household electrical equipment, ensuring that, in the event of a fire, no poisonous gases or vapors are produced. Fire extinguishers should be accessible and usable after disconnecting the power supply.

5. Harmful Factors Compliance:

– Ensure that harmful factors generated by NS-3 hardware do not exceed the standards outlined in SanPiN 2.2.2./2.4.1340-03 of 06/03/2003.

3.1.9. Requirements for operation, maintenance, repair and storage of system components

1. Microclimate Norms:

– Rooms housing NS-3 supported hardware should maintain a microclimate corresponding to industrial norms (GOST 12.1.005-88) for optimal performance.

2. Operating Conditions:

– NS-3 supported system components require operating conditions within specified parameters, including air temperature between +15°C to +20°C, relative humidity at 20°C ranging from 30% to 70%, and atmospheric pressure at 760mm Hg.

3. Regular Maintenance:

– Technical means used in NS-3, including workstations, servers, cable systems, network equipment, and uninterrupted power supplies, must undergo regular maintenance, not less than once a year.

4. Testing and Analysis:

– Maintenance and testing of NS-3 technical means should encompass all components. The results of tests should be analyzed to identify and eliminate defects effectively.

5. Security Measures:

– The location of premises housing NS-3 hardware should prevent unauthorized entry and ensure the security of confidential documents and technical means.

3.1.10. Requirements to standardization and unification

Compatible with common computer interfaces.

3.2. Requirements for types of collateral

3.2.1. Requirements to the system's hardware (technical characteristics of each devices in the system)

1. Server Configuration.
2. High-Speed Network Adapters
3. Modular Workstation Design
4. Scalable Storage Solutions:
5. Reliable Power Supply
6. Security-Enhanced Components
7. Energy-Efficient Cooling Systems
8. Virtualization Compatibility
9. Comprehensive Documentation
10. Ease of Maintenance Design
11. Cost-Effective Components

12. Long-Term Compatibility
13. Environmental Sustainability

3.2.2. Structure and contest of design system

The composition and content of system design work includes: (translate)

– design and coordination of the technical task for the system;
– system design;
– writing an explanatory note;
– design of graphic material;
– defense of the qualifying paper.

4. Technical and economic indicators

The cost of development should not exceed 450 UAH.

The service life of the device must be at least 18,000 thousand hours. (2 years)

* Note: the cost of development may change during the calculation during development.

5. Stages of system design

Table 1 - Stages of system design

№	Stage	Duration
1	Development and approval of the technical task	04.01-06.01.2024
2	Analysis of the technical task	06.01-6.01.2024
3	Substantiation of possible technical solutions	11.01-13.01.2024
4	System design and implementation	11.01-13.01.2024
5	Testing of the designed system	18.01-19.01.2024
7	Section of labor protection and safety in emergency situations	19.01-19.01.2024

Continues of table 1

№	Stage	Duration
9	Registration of the qualifiying paper	19-01-19.01.2024
10	Preliminary defense of the qualifiying paper	2024
11	Defense of the qualifiying paper	2024

6. The order of control and acceptance

The control of the process of execution of the diploma project is carried out by the head of the diploma project.

Normocontrol of the diploma project for compliance with the requirements of the standards is carried out at the Department of Computer Systems and Networks.

The presentation of the results of the diploma project is done by defending the diploma project at the relevant meeting of the SEC, illustrating the main achievements through the graphic material.

7. Requirements for documentation

The documentation must meet the requirements of ESKD and DSTU

Set of design documentation:

– explanatory note;
– −applications;
– −graphic material:

a) wiring diagrams of the optimized network through specialized interfaces;

b) block diagram of the network components;

c) algorithms of the network simulations;

d) block diagram of the network simulation;

e) the deployment scheme of this solution.

* Note: The design documentation may be subject to change and addition during development.

8. Additional conditions

During the implementation of the thesis project, changes and additions may be made to this technical task.

Appendix B. Network.cc

```
#include "ns3/core-module.h"
#include "ns3/network-module.h"
#include "ns3/internet-module.h"
#include "ns3/applications-module.h"
#include "ns3/netanim-module.h"

using namespace ns3;

int main() {
    // Network 1
    NodeContainer nodesNet1;
    nodesNet1.Create(5);

    for (uint32_t i = 0; i < nodesNet1.GetN(); ++i) {
        double xPos = i * 10.0;
        double yPos = 40.0;

        nodesNet1.Get(i)->SetPosition(Vector(xPos, yPos, 0.0));
    }

    CsmaHelper csmaNet1;
    NetDeviceContainer devicesNet1 = csmaNet1.Install(nodesNet1);

    InternetStackHelper internetNet1;
    internetNet1.Install(nodesNet1);

    Ipv4AddressHelper addressNet1;
    addressNet1.SetBase("10.1.1.0", "255.255.255.0");
    Ipv4InterfaceContainer interfacesNet1 = addressNet1.Assign(devicesNet1);

    UdpEchoServerHelper echoServerNet1(9);

    for (uint32_t i = 0; i < nodesNet1.GetN(); ++i) {
        ApplicationContainer serverAppsNet1 =
echoServerNet1.Install(nodesNet1.Get(i));
        serverAppsNet1.Start(Seconds(1.0));
        serverAppsNet1.Stop(Seconds(10.0));

        UdpEchoClientHelper echoClientNet1(interfacesNet1.GetAddress(i), 9);
        echoClientNet1.SetAttribute("MaxPackets", UintegerValue(1));
        echoClientNet1.SetAttribute("Interval", TimeValue(Seconds(1.0)));
        echoClientNet1.SetAttribute("PacketSize", UintegerValue(1024));

        ApplicationContainer clientAppsNet1 =
echoClientNet1.Install(nodesNet1.Get((i + 1) % nodesNet1.GetN()));
        clientAppsNet1.Start(Seconds(2.0));
        clientAppsNet1.Stop(Seconds(10.0));
    }

    // Network 2
    NodeContainer nodesNet2;
    nodesNet2.Create(5);

    for (uint32_t i = 0; i < nodesNet2.GetN(); ++i) {
        double xPos = i * 10.0;
        double yPos = 20.0;

        nodesNet2.Get(i)->SetPosition(Vector(xPos, yPos, 0.0));
    }

    CsmaHelper csmaNet2;
```

```
    NetDeviceContainer devicesNet2 = csmaNet2.Install(nodesNet2);

    InternetStackHelper internetNet2;
    internetNet2.Install(nodesNet2);

    Ipv4AddressHelper addressNet2;
    addressNet2.SetBase("10.2.2.0", "255.255.255.0");
    Ipv4InterfaceContainer interfacesNet2 = addressNet2.Assign(devicesNet2);

    UdpEchoServerHelper echoServerNet2(9);

    for (uint32_t i = 0; nodesNet2.GetN(); ++i) {
        ApplicationContainer serverAppsNet2 =
echoServerNet2.Install(nodesNet2.Get(i));
        serverAppsNet2.Start(Seconds(1.0));
        serverAppsNet2.Stop(Seconds(10.0));

        UdpEchoClientHelper echoClientNet2(interfacesNet2.GetAddress(i), 9);
        echoClientNet2.SetAttribute("MaxPackets", UintegerValue(1));
        echoClientNet2.SetAttribute("Interval", TimeValue(Seconds(1.0)));
        echoClientNet2.SetAttribute("PacketSize", UintegerValue(1024));

        ApplicationContainer clientAppsNet2 =
echoClientNet2.Install(nodesNet2.Get((i + 1) % nodesNet2.GetN()));
        clientAppsNet2.Start(Seconds(2.0));
        clientAppsNet2.Stop(Seconds(10.0));
    }

    // Network 3
    NodeContainer nodesNet3;
    nodesNet3.Create(5);

    for (uint32_t i = 0; i < nodesNet3.GetN(); ++i) {
        double xPos = i * 10.0;
        double yPos = 0.0;

        nodesNet3.Get(i)->SetPosition(Vector(xPos, yPos, 0.0));
    }

    CsmaHelper csmaNet3;
    NetDeviceContainer devicesNet3 = csmaNet3.Install(nodesNet3);

    InternetStackHelper internetNet3;
    internetNet3.Install(nodesNet3);

    Ipv4AddressHelper addressNet3;
    addressNet3.SetBase("10.3.3.0", "255.255.255.0");
    Ipv4InterfaceContainer interfacesNet3 = addressNet3.Assign(devicesNet3);

    UdpEchoServerHelper echoServerNet3(9);

    for (uint32_t i = 0; i < nodesNet3.GetN(); ++i) {
        ApplicationContainer serverAppsNet3 =
echoServerNet3.Install(nodesNet3.Get(i));
        serverAppsNet3.Start(Seconds(1.0));
        serverAppsNet3.Stop(Seconds(10.0));

        UdpEchoClientHelper echoClientNet3(interfacesNet3.GetAddress(i), 9);
        echoClientNet3.SetAttribute("MaxPackets", UintegerValue(1));
        echoClientNet3.SetAttribute("Interval", TimeValue(Seconds(1.0)));
        echoClientNet3.SetAttribute("PacketSize", UintegerValue(1024));

        ApplicationContainer clientAppsNet3 =
echoClientNet3.Install(nodesNet3.Get((i + 1) % nodesNet3.GetN()));
        clientAppsNet3.Start(Seconds(2.0));
        clientAppsNet3.Stop(Seconds(10.0));
```

```
    }

    // Network 4
    NodeContainer nodesNet4;
    nodesNet4.Create(5);

    for (uint32_t i = 0; i < nodesNet4.GetN(); ++i) {
        double xPos = i * 10.0;
        double yPos = -40.0;

        nodesNet4.Get(i)->SetPosition(Vector(xPos, yPos, 0.0));
    }

    CsmaHelper csmaNet4;
    NetDeviceContainer devicesNet4 = csmaNet4.Install(nodesNet4);

    InternetStackHelper internetNet4;
    internetNet4.Install(nodesNet4);

    Ipv4AddressHelper addressNet4;
    addressNet4.SetBase("10.4.4.0", "255.255.255.0");
    Ipv4InterfaceContainer interfacesNet4 = addressNet4.Assign(devicesNet4);

    UdpEchoServerHelper echoServerNet4(9);

    for (uint32_t i = 0; i < nodesNet4.GetN(); ++i) {
        ApplicationContainer serverAppsNet4 =
echoServerNet4.Install(nodesNet4.Get(i));
        serverAppsNet4.Start(Seconds(1. 0));
        serverAppsNet4.Stop(Seconds(10.0));

        UdpEchoClientHelper echoClientNet4(interfacesNet4.GetAddress(i), 9);
        echoClientNet4.SetAttribute("MaxPackets", UintegerValue(1));
        echoClientNet4.SetAttribute("Interval", TimeValue(Seconds(1.0)));
        echoClientNet4.SetAttribute("PacketSize", UintegerValue(1024));

        ApplicationContainer clientAppsNet4 =
echoClientNet4.Install(nodesNet4.Get((i + 1) % nodesNet4.GetN()));
        clientAppsNet4.Start(Seconds(2.0));
        clientAppsNet4.Stop(Seconds(10.0));
    }

    // Network 5
    NodeContainer nodesNet5;
    nodesNet5.Create(5);

    for (uint32_t i = 0; i < nodesNet5.GetN(); ++i) {
        double xPos = i * 10.0;
        double yPos = -60.0;

        nodesNet5.Get(i)->SetPosition(Vector(xPos, yPos, 0.0));
    }

    CsmaHelper csmaNet5;
    NetDeviceContainer devicesNet5 = csmaNet5.Install(nodesNet5);

    InternetStackHelper internetNet5;
    internetNet5.Install(nodesNet5);

    Ipv4AddressHelper addressNet5;
    addressNet5.SetBase("10.5.5.0", "255.255.255.0");
    Ipv4InterfaceContainer interfacesNet5 = addressNet5.Assign(devicesNet5);

    UdpEchoServerHelper echoServerNet5(9);

    for (uint32_t i = 0; i < nodesNet5.GetN(); ++i) {
```

```
        ApplicationContainer serverAppsNet5 =
echoServerNet5.Install(nodesNet5.Get(i));
        serverAppsNet5.Start(Seconds(1.0));
        serverAppsNet5.Stop(Seconds(10.0));

        UdpEchoClientHelper echoClientNet5(interfacesNet5.GetAddress(i), 9);
        echoClientNet5.SetAttribute("MaxPackets", UintegerValue(1));
        echoClientNet5.SetAttribute("Interval", TimeValue(Seconds(1.0)));
        echoClientNet5.SetAttribute("PacketSize", UintegerValue(1024));

        ApplicationContainer clientAppsNet5 =
echoClientNet5.Install(nodesNet5.Get((i + 1) % nodesNet5.GetN()));
        clientAppsNet5.Start(Seconds(2.0));
        clientAppsNet5.Stop(Seconds(10.0));
    }

    // Run simulation
    AnimationInterface anim("animationAllNetworks.xml");


    Simulator::Stop(Seconds(10.0));
    Simulator::Run();
    Simulator::Destroy();

    return 0;
}
```

Appendix C. XML file of networks configuration


```xml
<?xml version="1.0"?>
<scenario>
  <!-- Network 1 -->
  <node id="0" x="0.0" y="0.0" />
  <node id="1" x="10.0" y="5.0" />
  <node id="2" x="20.0" y="0.0" />
  <node id="3" x="30.0" y="-5.0" />
  <node id="4" x="40.0" y="0.0" />

  <link id="0" node1="0" node2="1" />
  <link id="1" node1="1" node2="2" />
  <link id="2" node1="2" node2="3" />
  <link id="3" node1="3" node2="4" />
  <link id="4" node1="4" node2="0" />

  <!-- Network 2 -->
  <node id="5" x="50.0" y="0.0" />
  <node id="6" x="60.0" y="5.0" />
  <node id="7" x="70.0" y="0.0" />

  <link id="5" node1="5" node2="6" />
  <link id="6" node1="6" node2="7" />
  <link id="7" node1="7" node2="5" />

  <!-- Network 3 -->
  <node id="8" x="80.0" y="0.0" />
  <node id="9" x="90.0" y="5.0" />
  <node id="10" x="100.0" y="0.0" />

  <link id="8" node1="8" node2="9" />
  <link id="9" node1="9" node2="10" />
  <link id="10" node1="10" node2="8" />

  <!-- Network 4 -->
  <node id="11" x="110.0" y="0.0" />
  <node id="12" x="120.0" y="5.0" />
  <node id="13" x="130.0" y="0.0" />

  <link id="11" node1="11" node2="12" />
  <link id="12" node1="12" node2="13" />
  <link id="13" node1="13" node2="11" />

  <!-- Network 5 -->
  <node id="14" x="140.0" y="0.0" />
  <node id="15" x="150.0" y="5.0" />
  <node id="16" x="160.0" y="0.0" />

  <link id="14" node1="14" node2="15" />
  <link id="15" node1="15" node2="16" />
  <link id="16" node1="16" node2="14" />
</scenario>
```

Appendix D. Bulding graphical representation of networks

```
import matplotlib.pyplot as plt
import numpy as np

# Function to plot nodes with varying colors and sizes
def plot_nodes(nodes, title, color, size):
    x_positions = [node[0] for node in nodes]
    y_positions = [node[1] for node in nodes]

    plt.scatter(x_positions, y_positions, label=title, c=color, s=size,
alpha=0.5)

# Function to generate random activity levels for each network
def generate_activity_levels(num_nodes):
    return np.random.rand(num_nodes)

# Network 1
nodes_net1 = [(i * 10.0, 40.0) for i in range(5)]
activity_net1 = generate_activity_levels(len(nodes_net1))

# Network 2
nodes_net2 = [(i * 10.0, 20.0) for i in range(5)]
activity_net2 = generate_activity_levels(len(nodes_net2))

# Network 3
nodes_net3 = [(i * 10.0, 0.0) for i in range(5)]
activity_net3 = generate_activity_levels(len(nodes_net3))

# Network 4
nodes_net4 = [(i * 10.0, -40.0) for i in range(5)]
activity_net4 = generate_activity_levels(len(nodes_net4))

# Network 5
nodes_net5 = [(i * 10.0, -60.0) for i in range(5)]
activity_net5 = generate_activity_levels(len(nodes_net5))

# Plotting
plot_nodes(nodes_net1, 'Network 1', 'red', activity_net1 * 100)
plot_nodes(nodes_net2, 'Network 2', 'blue', activity_net2 * 100)
plot_nodes(nodes_net3, 'Network 3', 'green', activity_net3 * 100)
plot_nodes(nodes_net4, 'Network 4', 'purple', activity_net4 * 100)
plot_nodes(nodes_net5, 'Network 5', 'orange', activity_net5 * 100)

plt.title('Network Nodes Activity')
plt.xlabel('X Position')
plt.ylabel('Y Position')
plt.legend()
plt.grid(True)
plt.show()
```