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Certify that this assignment is entirely our own work, except where we have given fully documented references to the work of others, and that the material contained in this assignment has not previously been submitted for

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1.0 Introduction

The continuously growing need for ultra-reliable, high throughput wireless communication in modern urban environments, characterized by high population densities, rapid technological adoption and rising demands for applications that accelerate require communications under harsh conditions and with hard constraints on (i) latency, (ii) reliability and (iii) energy consumption makes providing JamEo a highly useful and likely essential task. Autonomous vehicles cruising through crowded cityscapes, the thousands of interconnected IoT devices powering smart infrastructure, the pain points on existing mobile network architectures are immense. Those narrow streets between tall buildings are also referred to as urban canyons, where traditional radio frequency (RF) propagation in the millimeter wave (mmWave) spectrum are essential in supporting 5G and its eventual 5G-Advanced upgrade become problematic.

mmWave signals have unrivaled bandwidth and data rates, but may suffer from poor penetration, high path loss and being prone to the shielding effects of buildings, vehicles and even the weather. However, this limits the reliability of line of sight (LoS) communication which makes dense urban deployment not a small task. Despite these challenges they are not insurmountable. Recently, introduction of innovative technologies, like Reconfigurable Intelligent Surfaces (RIS), dense small cell networks and Massive MIMO arrays, has restructured the possibilities for urban wireless infrastructure. Besides combating propagation difficulties such solutions allow for highly focused beamforming, as well as spatial multiplexing that results in huge gains in both throughput and spectral efficiency.

Now take 5G-Advanced, the strategic evolution of 5G which aligning these enablers to intelligent network orchestration. It incorporates resources management using AI and ML, network slicing on the fly and edge computing to reduce latency and increase quality of service (QoS) level across disparate applications. In urban environments, 5G-Advanced offers the ability for latency sensitive services like emergency response (URLLC), high bandwidth entertainment (eMBB) and scalable IoT deployments (mMTC) to exist together on shared infrastructure through virtual network slices, each isolated and optimized for its respective need.

These reports' architectural innovations propose not only feasible but strategically positioned and managed network resources. RIS panels on building facades, small cells on lampposts, AI beam steering, the mesh is collaborative and it augments the mmWave system to overcome non-LoS problems. In parallel, compute resources are brought closer to the user with edge computing nodes, reducing latency (round trip time) and achieving real time responsiveness.

5G-Advanced is ultimately not an incremental change, but rather a transformational framework tailored to break physical and operational barriers of urban environments. It deploys intelligent orchestration, dynamic spectrum utilization and advanced antenna systems that will set the foundation for future proof digital cities to be resilient, responsive and resource efficient.

2.0 Literature Review

mmWave Technology in Mobile Computing

Millimeter wave (mmWave) technology starting from 24 to 100 GHz is the key part of 5G and further emerging 6G wireless communication systems. Traditional sub 6 GHz bands are being widely occupied by exponential increase in mobile data consumption, mmWave comes in with very large bandwidth and ultra-low latency communication that is a must for modern use cases like AR, Autonomous vehicles etc. and real time HD streaming. Rappaport notes, though, that mmWave frequencies offer the high throughput and low delay enablement for the forthcoming mobile services, albeit with reduced range and penetration (Rappaport, et al., 2013).

The mmWave frequency range includes bands such as 26 GHz, 28 GHz, 38 GHz, and 60 GHz. Such bands allow transfer rates of the order of gigabits per second. Nevertheless, high frequency signals have peculiar propagation issues. mmWave signals have high path loss and hence the signal strength is rapidly reduced with distance. Moreover, their poor diffraction and limited penetration make them highly obstruction sensitive to walls, foliage, or even atmospheric conditions like rain.

These propagation characteristics are thoroughly analyzed and how they influence 5G deployment strategies are discussed by Vaigandla. Though much bandwidth is available in mmWave bands, they point out that overcoming these limitations through engineering is vital to their usability, as much bandwidth is not utilized (Vaigandla, Sandhya, Srikanth, & Mounika, 2021).

The propagation challenges are managed through beamforming technology that shifts signals through antenna arrays to avoid complete omnidirectional broadcast. The technique provides enhanced signal gain together with decreased interference levels. The main advantage of analog beamforming is simplicity and reduced power requirements yet it lacks flexibility features. The desire to achieve precision involves trading off system complexity together with higher power needs. The hybrid system implements the most beneficial aspects of both approaches.

This paper explains the methods proposed by Niu for building dependable mmWave communication channels in unpredictable radio frequency conditions. The authors emphasize in their conclusion that beam alignment and steering systems are vital for mobile solutions to sustain signal quality (Niu, Li, Jin, Su, & Vasilakos, 2015).

Moreover, Giordani emphasizes the future role of beam training and management procedures in 5G New Radio (NR) standards. This is because they propose that finding accurate beam alignment is crucial to determine the overall performance of the mmWave communications, and in dense urban deployments, the more important the performance of mmWave communications will base on beam alignment (Giordani, Polese, Roy, Castor, & Zorzi, 2019).

mmWave signals have very poor ability to penetrate common building materials (concrete, metal) and therefore have a very poor Indoor Reach and reliability. The solutions to mitigate this problem include the use of several architectural and technological strategies. For example, small cells are low power base stations of high density to guarantee line of sight (LoS) connectivity. The Reduction in signal quality and reliability in urban environments occurs due to distance between the transmitter and the receiver.

Relays and repeaters augment the coverage by retransmitting received signal in cover hardware breaks. The use of device-to-device relays for improving coverage in areas over which mmWave signals are blocked is explored by Wu. They simulate that the D2D relays can have a great signal availability even without adding additional infrastructure (Wu, Atat, Mastronarde, & Liu, 2016).

As a novel approach for mmWave signal paths control, reconfigurable Intelligent surfaces (RIS) are passive or semi passive surfaces that reflect and control the signal paths in real time. With RIS it is possible to dynamically optimize the radio environment, supplying programmable mirrors that improve connectivity without the need for active transmission (Basharat, et al., 2021).

Massive MIMO: Antenna Configurations and Throughput

(Martínez, Carvalho, & Nielsen, 2015) which analyzed the influence of 64x64 antenna arrays on massive MIMO system throughputs. The measurement-based assessment conducted in an indoor setting reveals that expanding antenna numbers results in substantial throughput improvement. Higher data rates and better performance result from the 64x64 array configuration because it does better spatial multiplexing and reduces interference better than smaller array systems.

Throughput optimization depends extensively on how big antenna arrays (apertures) become according to the research. The spatial separation capabilities of the 64x64 array configuration surpasses other array configurations because it separates users better and this separation capability optimizes throughput performance particularly in densely populated environments. The research data indicates that massive MIMO systems benefit from implementing larger antenna arrays.

Spectral efficiency improvement depends heavily on beamforming algorithms within massive MIMO systems across high-frequency mmWave bands as per the article (Althuwayb , et al., 2021) . The paper presents a new beamforming method prepared for phased-array setups that enhances spectral efficiency by directing signal beams precisely toward the desired user. The strategic beamforming method reaches its best spectrum utilization potential while reducing interference.

The research brings forward a fresh beamforming method which searches to optimize spectrum efficiency performance. The algorithm determines spectral efficiency-specific optimization functions that let the least squares approach function effectively track and modify beamforming weights. As a result of this method users obtain exact beam-to-channel alignment which leads to full spectrum exploitation. The designed algorithm features low computational complexity that enables its application in big MIMO systems with multiple antennas. The research shows through simulated results that this methodology reaches almost optimal spectral efficiency while requiring less processing power than advanced algorithms. The article concludes that efficient beamforming algorithms play a crucial role in developing enhanced spectral efficiency and maximizing spectrums utilization.

Network Slicing Use Cases and Quality of Service (QoS) Requirements

(Domeke , Cimoli, & Monroy, 2022) state that network slicing within 5G and beyond networks becomes vital to accept different emerging applications which need unique Quality of Service (QoS) parameters. The smart city sensors and industrial IoT applications under massive machine-type communication (mMTC) need qualities such as high scalability and low energy usage and moderate latency capacities. Emergency services together with remote surgery operations require URLLC to deliver both ultra-fast under-1-millisecond responses and exceptional service dependability. Autonomous driving needs specialized network slices for providing continuous connectivity through strong communication although vehicles move quickly.

eMBB together with AR/VR technologies represent remarkable use cases because they need high throughput combined with low latency and real-time performance excellence. The implementation of Industry 4.0 applications depends on network slices which create reliable enhanced synchronous and energy-efficient conditions for robotic systems and automated procedures. Edgeling and slicing technologies when combined enable 5G networks to provide enhanced service quality through processed and stored data at nearby locations. The differentiated network slices enable service providers to create virtualized infrastructure systems that match QoS requirements of each individual use case thus becoming essential for future mobile and edge computing platforms.

5G network management receives revolutionary changes through AI/ML-driven orchestration techniques because they automatically generate real-time decisions that allocate network slicing resources. Modern 5G technology demands exceed traditional rule-based methods because they lack sufficiency in current complex and dynamic conditions. Networks use reinforcement learning (RL) together with deep reinforcement learning (DRL) and multi-agent RL (MARL) to acquire network information automatically and reach maximum throughput speeds and raise performance while maintaining minimal system overhead. The combination of DRL and MARL technology strengthens dynamic resource distribution and traffic handling because they reduce signal interference and boost spectral performance capabilities regarding base stations and user device coordination. The operation of network slicing utilizes AI technology to make dynamic virtual slice configurations that correspond with live traffic data and service performance standards. ML models detect demand changes to predict future usage patterns which allows resources to be predicted before high and low traffic periods ensuring continuous performance levels. The system automatically tracks performance measurements through continuous monitoring to change configurations which enhances self-optimization. The integration between SDN and NFV with orchestration systems improves orchestration functions while providing scalable reliable solutions. AI systems deliver essential support to 5G autonomous vehicles as well as IoT deployments together with telemedicine solutions before establishing key aspects for next-generation 6G networks (Bikkasani & Yerabolu, 2024).

3.0 Comparative Table

5G vs 5G Advanced Comparison:

Feature	5G	5G-Advanced
Speed	Around 1–10 Gbps	Around 10–100 Gbps
Latency	~1 millisecond (ms)	~0.5 millisecond (ms)
Technology	Established on CFDM and massive MIMO	Updated from current 5G technology with beamforming and AI
Bands	Low (Around 600MHz to 2GHz) Mid (Around 3GHz to 6GHz) High (Around 6GHz to 32GHz)	Mid (Around 3GHz to 6GHz) High (Around 6GHz to 38GHz) Possibly mm wave (Around 30GHz to 300GHz)
Use Cases	- Enhanced Mobile Broadband (eMBB) - 4K/8K video streaming - AR/VR experiences - Smart cities - IoT connectivity (e.g., smart homes, sensors)	- Holographic communications - Immersive XR (Extended Reality) - Autonomous vehicles with AI coordination - Real-time industrial automation - Telepresence and remote surgery - High-precision drone operations

Table 1 : 5G vs 5G Advanced Comparison

Enhanced Mobile Broadband (eMBB) in 5G vs Holographic Communications in 5G-Advanced:

Aspect	5G: Enhanced Mobile Broadband (eMBB)	5G-Advanced: Holographic Communications
Definition	Provides high-speed, high-capacity wireless internet for data-heavy applications	Enables real-time, 3D holographic visuals requiring ultra-fast, low-latency networks
Experience	Smooth 4K/8K video streaming, fast downloads, stable mobile internet	Life-like remote presence with interactive 3D visuals and spatial sound
Requirements	Moderate-to-high data speeds (1–10 Gbps), low latency (~1 ms)	Extremely high data rates (10–100 Gbps), ultra-low latency (~0.5 ms), precise sync
Use Cases	- Streaming media - Online gaming - Social media - Remote work	- Remote collaboration with 3D avatars - Virtual events & education - Telepresence in healthcare and business
Impact	Enhances everyday digital life through better mobile broadband	Revolutionizes communication by making virtual presence feel real

Table 2 : Enhanced Mobile Broadband (eMBB) in 5G vs Holographic Communications in 5G-Advanced

4.0 Architecture diagram

4.1 mmWave Deployment in Urban Canyons

Narrow city streets framed by tall buildings, also known as urban canyons, present both an opportunity and challenge for mmWave-based 5G networks. Because of their high frequency, mmWave signals deliver massive bandwidth and gigabit-level data rates but are extremely susceptible to physical obstructions and signal deterioration (Sheikh et al., 2025).

In urban canyons, buildings are present in sharp angles and narrow paths that create unrealizable (non-line of sight, or non-LoS) communication, a requirement for success in mmWave performance. However, buildings can be also leveraged to support deployment. For example: small cells can be mounted on (say) lampposts or streetlights close to every 100-150 m for short LoS paths; Reconfigurable Intelligent Surfaces (RIS) placed on the building facade can reflect signals around corners or into shadowed areas; relay nodes may also be used to assist the forwarding of data through non-LoS paths(Basar et al., 2019).

In order to effectively deploy mmWave smartphone devices in a well-developed urban environment such as an urban canyon, urban design constraints and the precise planning of network design elements have to be accounted for, and also the proficiency of advanced beamforming to adapt to signal-blocking changes resulting from vehicles or people occupies part of the urban space. When successful, mmWave technology can exploit the profound density of urban locations—to provide fiber-fast speeds and ultra-low-latency 5G service, even in the most challenging of environments.

4.1.1 Challenges of mmWave Deployment

mmWave frequencies usually range from 24 GHz to 100 GHz and provide very large bandwidths but also encounter a number of technical constraints - particularly in congested urban environments (Li et al., 2020).

- Severe Blockage: mmWave signals have severe blockage from obstacles like buildings, vehicles, foliage and pedestrians. Sub 6 GHz frequencies have the advantage of being able to diffract or penetrate obstacles unlike mmWave waves which experience repeat loss.
- High Path Loss and Atmospheric Attenuation: Free-space path loss increases with frequency so mmWave signals have higher losses for shorter distances. For example, when it rains, the signal strength is considerably attenuated, and atmospheric humidity may affect it.
- Diffraction and Reflection: mmWave wavelengths are too short to diffract around corners or effectively reflect off of surfaces so coverage flexibility is diminished.
- Line-of-Sight (LoS): To achieve optimal mmWave communication, a LoS or near-LoS path is preferred and is not very feasible in areas with remarkable geometries that obstruct LoS.
- Small Cell Density Required: mmWave coverage ranges are short (~100-200 meters), so to achieve small cell density deployment locations is impossible and relatively complex and costly in infrastructure.
- Interference and Beam Alignment: mmWave transmissions require more directed beamforming for the wireless signal, therefore precise beam alignment is required, and changes in mobility or environment can also change the alignment.

4.1.2 Solutions to mmWave Challenges:

A comprehensive solution to the aforementioned concerns will involve a combinatorial approach that integrates designs of both hardware and networks that empower mmWave:

- Dense Small Cell Deployment: small cells with mmWave transceivers will be densified and deployed on different urban structures (e.g., lampposts, building face). Having small cells close together mitigates link distances and the high path loss.
- Relays: Relay nodes will be installed so that they can receive and forward mmWave signals to mitigate gaps for the mmWave streamline/nodes/operator, as barriers exist that prevent direct coverage due to blocked line of sight. Relays can bridge the coverage gap without requiring direct or line of sight from the base station.
- Reconfigurable Intelligent Surfaces (RIS): RIS are material surfaces, composed of many planar surface areas with networks of tunable reflective elements deployed outdoors, that can be reacted to redirect and reshape reflected electromagnetic waves. For instance, RIS could be deployed on vertical walls of buildings to bounce signals into shadowed areas that require coverage which drastically improve NLOS coverage (Basar et al., 2019).
- Advanced Beamforming and Beam Steering: Massive MIMO arrays with advanced beamforming algorithms will allow signal beams to be dynamically pointed (i.e., steer directional beams) to maximize signal strength while reducing interference in 3D space.
- Adaptive Resource Management: Artificial intelligence integrated into a network management system will adjust power levels, beam directions, and scheduling in real-time while accounting for environmental changes or changes in the traffic load to optimize coverage and capacity.
- Hybrid Deployment Strategies: Hybrid Deployment Strategies - a flexible use of sub-6 GHz frequencies and mmWave would allow for fallback solutions, as well as reliable coverage in challenging situations (Li et al., 2020).

4.1.3 Placement Strategies for Dense Urban Environments:

The successful placement of network elements in urban canyons is to provide coverage and capacity, minimal deployment costs:

- Small Cells on Lampposts and Street Furniture: Lampposts have the advantage of being reasonably centrally located, providing an elevated mounting capable of providing coverage along with power and backhaul connectivity. When small cells (or antennas) can be deployed every 100-150 meters with considerable overlapping coverage areas, the shadow zones are minimized.
- RIS Placement on Building Facades: In most cases, RIS panels are attached to the building's surface that faces streets or other open public spaces or to reflect signals into areas that aren't otherwise blocked. RIS placement is enhanced by ray-tracing simulations, which help develop an optimized placement.
- Relays at Important Intersections: Relays often deploy at street intersections, on street corners, and sometimes on the inside of urban canyons if there are no direct-links available. Relays act as repeaters of signals and add to the coverage area.
- Height Dynamics: To create good relative height for small cells, RIS, and relays to optimize a clean signal path, while protecting from vehicles and other street level obstacles.
- Backhaul Voice/Wireless: Small cells and relays ideally have backhaul connections (fiber/wireless) to the core network and needs to be designed into the network with capacity needed to connect back to the core without creating latency through the overall design.

4.1.4 Deployment Strategy Explanation

The suggested deployment captures the many facets and elements in developing a resilient urban, mmWave network:

- Small cells act as the initial access points using multiple lighthouses (lampposts and street furniture), placing small cells in close proximity ensuring continual mmWave signal footprint.
- Reconfigurable Intelligent surfaces(RIS) can be put on building facades, consciously reflecting mmWave into areas that are protected behind urban canyon geometry, extending coverage without excess power.
- Relays also extend coverage by taking the signals around corners or bridging non-LoS gaps which can bias seamless coverage supplies.
- Massive MIMO beamforming under "some conditions" allows for dynamic re-configurations to adapt link quality with user movement and changing conditions.
- This hybrid approach allows the mmWave limitations to be balanced by providing the highest rates and reliability in a dense urban environment.

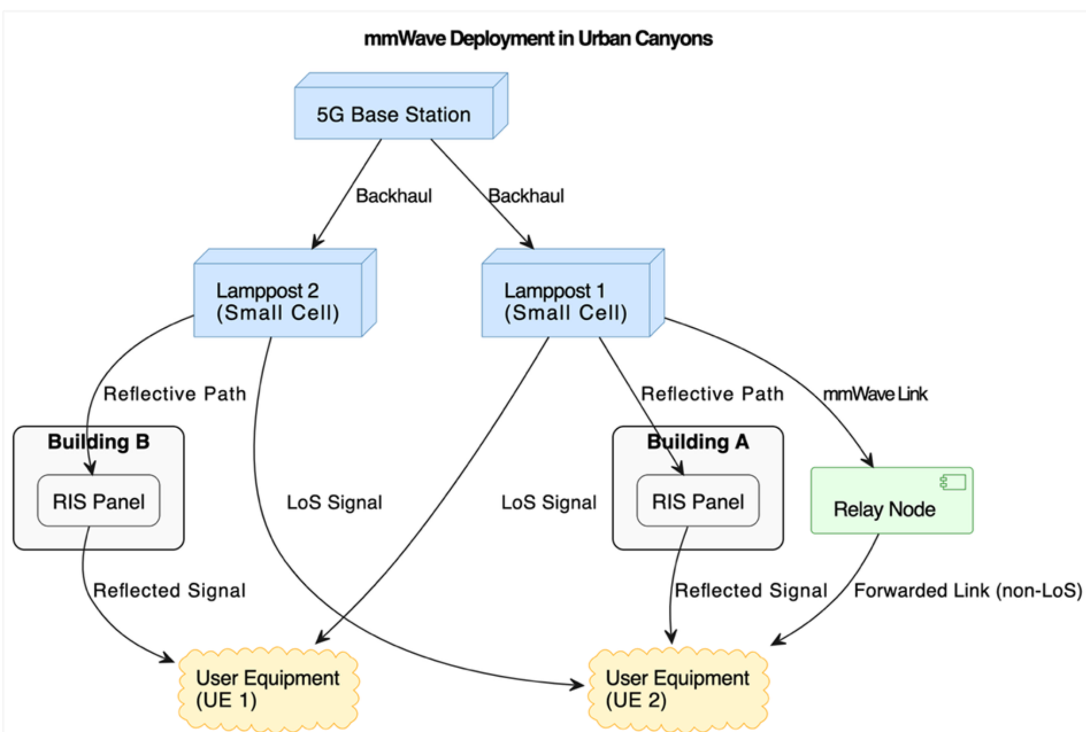

Figure 1: mmWave deployment in urban canyons

The **Figure 1** demonstrates a use-case scenario of mmWave 5G in an urban canyon environment, where a street is narrow and buildings are tall and create major signal propagation issues. A 5G base station to provide back haul connections for multiple small cells mounted on lampposts that are the transmission points in a local vicinity. The small cells provide Line-of-sight (LoS) mmWave signal to nearby user equipment (UE1 and UE2), but in an urban environment a lot of times the signal is blocked, and we need to find other routes. In this case, the Reconfigurable Intelligent Surfaces (RIS) were deployed having been attached to the building facades, Building A and Building B (Basar et al., 2019). The RIS panels facilitate the reflection of mmWave signals, whether at line of sight (LOS) or secondarily by reflection for transmissions that would allow coverage where the user would be unable to receive a direct LOS signal. A relay node was used to retransmit the signal by non line-of-sight (non-LOS) pathway to get the signals to UE2 that were located behind an obstruction. In summary, there were LOS transmission, direct reflection with the RIS, and relayed signals to obtain robust higher rates of connections in difficult use-case scenarios considering urban environments with mmWave transmission, and if we were unable to get reliable connections it would be less efficient to deploy mmWave.

4.2 Massive Multiple Input Multiple Output (MIMO)

Massive Multiple Input Multiple Output (MIMO) is a new and exciting way to wireless communicate. Massive MIMO allows base stations to transmit and receive at the same time and use a lot of antennas (most are dozens of antennas and some higher-order antennas would use hundreds) at a time. Not only is it associated with more antennas, but also with being able to transmit one or more data streams at the same time. It increases the number of users by spatial multiplexing, to send individual beams to individual devices to be used back by the base station. This is most useful in urban areas, where network congestion and interference have a large decline in performance. instead of the traditional "tower" that lumps all of the users together and manages the random sounds, Massive MIMO turns beams in real time to accurate locations instead of lumping everyone together and throwing the big signal everyone got the crappy capacity back, resulting improved quality of signal through less interference, which is most valued in urban settings that are filled with buildings that reflect and absorb signals. Because of all this, it will improve data speed, the ability to handle more capacity, and of course improve connection time, especially in high traffic mobile network settings.

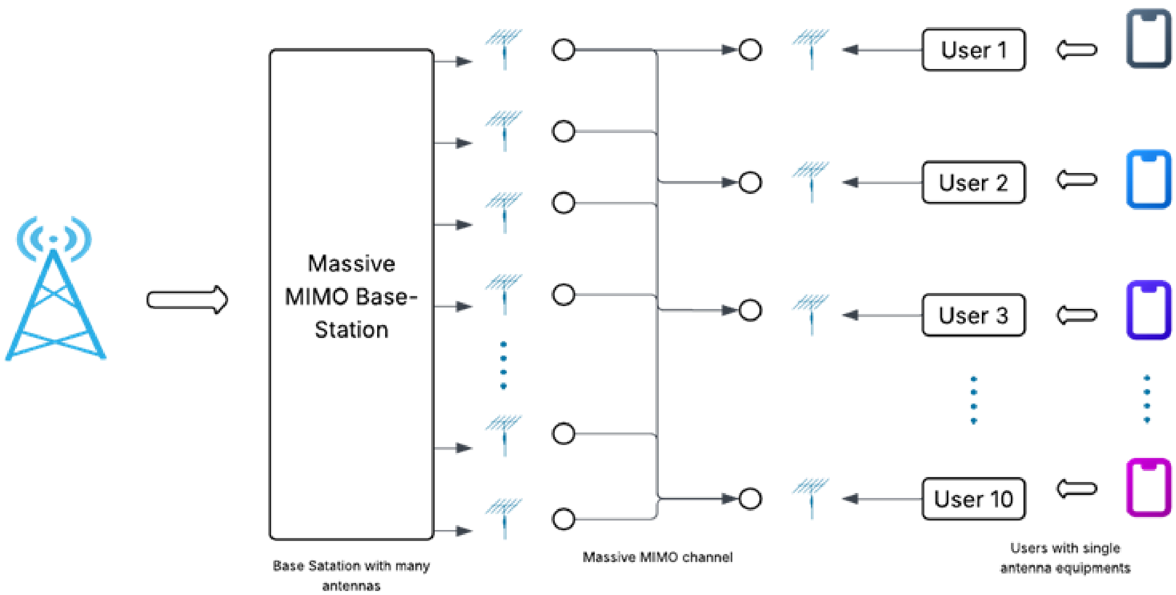

Figure 2 : MIMO Architecture Diagram

Figure 2 represents the fundamental structure of a Massive MIMO communication system which is a key technology in modern and next-generation (5G/6G) wireless networks.

On the left, a traditional base station connects to a Massive MIMO base station, equipped with a large number of antennas (typically from several tens to hundreds), capable of simultaneously transmitting and receiving multiple data streams between the base station and user devices. With the use of spatial multiplexing, spatial diversity and/or space-time processing means that multiple users at the same time and on the same frequency band can be served, increasing the capacity, spectral efficiency, and energy efficiency of the overall network.

The middle of the diagram labelled "Massive MIMO channel" illustrates the intricate network of connections between the base station antennas and the user devices. Each black dot represents a multi-user communication link (a communication link to a user device from a base station antenna). It depicts a complex multi-user channel.

On the right, User 1 through to User K represents the individual users and their single antenna devices, e.g., Smartphones). Each user will have only one antenna, but the base station is able to control interference and deliver high data rates using techniques not limited to beamforming, channel estimation, and precoding.

Not only this race system supports dozens to hundreds of users simultaneously, with improved reliability, throughput, and robustness to interference, Massive MIMO systems will support these advantages with the emergence of high-capacity wireless communication systems.

4.2.1 Antenna Configurations in Massive MIMO

In Layout of Massive MIMO systems, the spatial configuration of antennas can have an effect on the overall system performance. In the literature, the most common configuration of antennas is a 64x64 antenna array; meaning, that the base station has 64 transmit antennas and 64 receive antennas. The use of large arrays gives base stations the capacity to produce much focused beams, where each user can be assigned a beam for communication with the base station. This allows for user separation, reduced interference from other users, and the station can support communication for many users simultaneously, which a smaller antenna configuration cannot achieve.

The physical layout and which aperture size of these arrays really does matter. Large configurations will provide superior spatial resolution, which enables the system to better distinguish between users that are closer together is a beneficial feature in high density and urban areas. For example, studies like that done by Martínez, Carvalho, and Nielsen (2015) identify that larger antenna arrays give statistically significant gains in capacity of the network particularly when used in densely deployed indoor environments. These configurations improve signal coverage of users by improving signal strength when users are either behind obstacles or in areas that suffer heavy scattering.

4.2.2 Throughput Enhancements

Throughput - the successful transmission of data over a network - can be vastly improved due to the effectiveness of Massive MIMO systems. By able to transmit multiple users on the exact same time and frequency resource, the throughput can be measured in orders of magnitude greater than conventional configurations. For example, using a 64x64 antenna configuration allows for more spatial multiplexing, which translates into more simultaneous data streams overhead without interference. This would maximize the number of users catered to, and raise the throughput for each user, resulting in increases of aggregate throughput rate, particularly when users are demanding bandwidth in a crowded area.

The simulation results published in a variety of research papers report throughput increases of several times over conventional MIMO systems, especially when operating in mmWave bands. This is attributed to Massive MIMO systems' ability to focus beam energy into tightly focused beams, ensuring high throughput is still possible even when greatly affected by environmental degradation or interference.

4.2.3 Spectral Efficiency Improvements

Simply stated, spectral efficiency refers to how effectively a finite bandwidth is being used to deliver information. Mass MIMO systems, particularly configurations such as a 64x64 array will present a dramatic improvement in spectral efficiency. The main contributors to this improvement in spectral efficiency are the sophisticated beamforming algorithms. Essentially, these beamforming techniques allow signal energy directed to selected users, without wasting power on adjacent users, while keeping adjacent channel interference to a minimum.

Althuwayb et al. (2021) argue that, new beamforming methods planned for phased-array in massive MIMO will almost get the same spectral efficiency as optimal & a lower complexity. The variables in the new algorithms are the beamforming directions and weights which are dynamically computed to align exactly to the communication channels/paths, hence the system can use the maximum spectral efficiency of the allowed bandwidth to allow the mobile systems to have the fullest signals possible within the confines of using the regulations of their allocated bandwidth.

This ultimately allows a network to handle more data traffic free of any additional spectrum, this is avalanche efficient and cost-effective.

In conclusion, the new massive 64x64 antenna arrays in Massive MIMO systems provide the baseline for each level of gain in throughput and spectral efficiency to manage in an MIMO environment. By separating users extremely well, and providing spatial multiplexing of such high levels of user independence will suffice in dense urban environments. With intelligent beam forming and channel estimation techniques supported by academic research and developments, systems can satisfy 5G's increasing data use & requirements, and ultimately be a power user of spectra.

4.2.4 Beamforming in Massive MIMO

Beamforming is a core technology used in Massive MIMO systems to steer wireless signals to individual users instead of broadcasting a signal in every direction. You can think of this like using a flashlight as oppose to a light bulb; the light (signal) is directed in a narrow beam exactly where it is needed. This means it transmits stronger signals with better signal quality for the intended user, while also lowering interference for those nearby.

In practice, beamforming, (done in real-time) includes controlling the phase and amplitude of the signals transmitted from each antenna in the array, so that they constructively combine at the user's spatial location. With this ability, the system dynamically steers the powerful directed signals towards the users, while allowing for changing environments and movements of the users, ensuring strong connectivity even in crowded environments while avoiding obstacles. This control is especially beneficial at the high frequency bands like millimeter wave (mmWave), where signal suffers from high path loss and poor penetration; thus, the mobility within the space – discrete beams, helps to overcome the high path loss and allows for still super great signals for mobile users.

4.2.5 Multiplexing Explained

Spatial multiplexing is the technique allowing Massive MIMO systems to send multiple independent data streams at one time in the same frequency band.Instead of serving a user at a time spatial multiplexing exploits the fact that the users are at different spatial locations; spatial multiplexing enables the base station to send two (or more) separate streams to two (or more) separate devices/users, simultaneously.

This allows the network to further increase its capacity (and throughput) without needing more spectrum. With its multi-antenna and advanced signal processing, it is possible to separate these streams in space to eliminate interference, so it can send unique data streams to multiple users concurrently in a burst fashion, thus maximizing the bits of data transmission to multiple users regardless of medium. In congested urban environments of limited qualified wireless resources, spatial multiplexing enables the use of limited wireless resources efficiently, allowing the maximum number of users to be served simultaneously, even when very close to each other.

4.2.6 How Beamforming and Spatial Multiplexing Work Together

In Massive MIMO, beamforming and spatial multiplexing are complementary techniques. Beamforming focuses the energy of each data stream towards a specific user while spatial multiplexing allows multiple streams to occupy the same frequency channel without interference. Beamforming and spatial multiplexing work together to allow a base station to know there are many users, enable many users to consume high data rates (or throughputs) with much reliability.

For instance, consider a busy city street with the BS being able to beamform and send signal A to User A, while also transmitting signal B to User B. The BS is signaling to both users simultaneously using spatial multiplexing, meaning that both signals A and B are transmitted from the BS to a user at the same time and in the same spectrum, yet spatially separated. The BS is using beamforming and spatial multiplexing simultaneously to limit interference and simultaneously and provide both users with fast and reliable wireless connectivity.

In summary, beamforming and spatial multiplexing are the two pillars of Massive MIMO technologies. Beamforming provides stronger, higher quality signals with less interference by directing signals in directions where they are intended for a targeted user. Spatial multiplexing enables greater capacity in a network by allowing multiple independent data streams to be sent simultaneously on the same frequency. In concert, beamforming and spatial multiplexing enable operation within a dense, high-volume mobile ecosystem.

4.3 NETWORK SLICING IN 5G-ADVANCED

Network slicing is one of the basic tenorions of 5G-Advanced which enables service providers to cut a single physical infrastructure into a number of end-to-end virtual networks (or "slices") vied to service the specifically different requirements of different applications. With AI slash ML-enabled orchestration, 5G-Advanced integrates important enablers--mmWave spectrum for multi-Gbps data rates, Massive MIMO for spatial multiplexing, and edge computing for localized processing--to rapidly provision, scale, and optimize slices in real time.

In smart cities, network slicing enables latency-sensitive autonomous vehicle control (URLLC), ultrahigh-definition video surveillance (eMBB), and massive IoT deployments (mMTC) to coexist on the same physical infrastructure while avoiding mutual interference. Every slice guarantees its Service Level Agreement (SLA), which translates to keeping strict resource isolation and priority queuing (for instance, for URLLC, SLA $\leq$ 1 ms end-to-end latency; for eMBB, SLA $\geq$ 1 Gbps throughput); furthermore, slicing also allows the creation of network-as-a-service business models, offering vertical industries (like healthcare, transportation, and utilities) customized slices for on-demand lease, thus downsizing operational expenditure (OPEX) (Domeke et al., 2022; Foukas et al., 2017).

The advancement of 5G enhances slicing by Network Function Virtualization (NFV) and Software Defined Network (SDN) decoupling network functions from hardware and allowing the programmatic control of compute, storage, and transport resources. AI/ML engines analyze telemetry data like traffic patterns, QoS deviations, and fault indicators to predict demand spikes, auto-scale slices, and perform self-healing capabilities to ensure resilience and optimization in operation, even in densely packed urban environments.

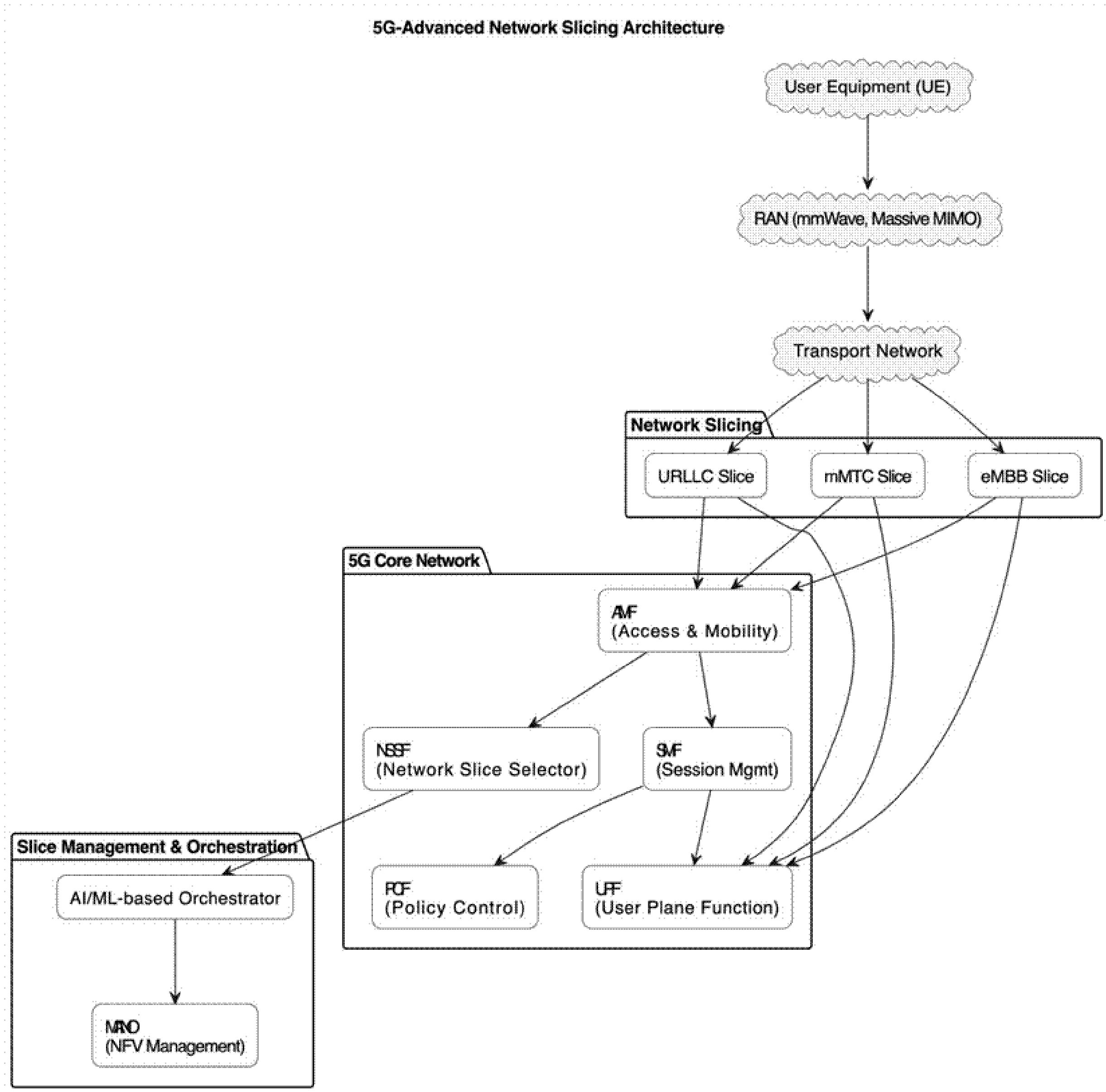

Figure 3 : 5G Advanced Network Slicing Architecture Diagram

4.3.1 Key Features and Advantages of Network Slicing:

- Customization and Optimization:Each slice is tailored to the requirements of its use cases. This means that different services can use the same network to obtain resources such as bandwidth, latency, security, and reliability according to those specific needs. **For Examples:**
    - **Autonomous Vehicles (URLLC slice)** are required for communication through their networks with extremely low latency and much better reliability to be fully capable in real-time scenario situations.
    - For the **eMBB slice of Smart Cities,** streaming of video and exchange of data from the sensors will require high bandwidth.
    - The requirements of **IoT networks** are as follows: High device density and low energy consumption for mMTC.

- **Resource Isolation and Efficiency:** Slices are logically isolated from one another so that high-priority services are not affected by lowerpriority ones. For instance, in a smart city, emergency services slice will remain unaffected by excessive traffic on other slices used for general communications.

- **Dynamic Resource Allocation:** Dynamic allocation based on real-time needs brings slices specific resources such as bandwidth, CPU power, and storage. This dynamic resource allocation is needed and will be proved very effective with changing demand, especially in high-traffic urban environments.
  For example, there will be an emergency in a smart city during which resources can be allocated to public safety slices to ensure that it will not be interrupted from further access.

- **Service Level Agreement (SLA) Enforcement:** Network slicing allows for the precise definition of the Service Level Agreement (SLAs)applicable to a slice, and the SLA requirements for such services include latency, throughput, and reliability metrics, which can be very important for mission-critical services where very low latency is needed, like in autonomous driving or remote surgery.

- **Scalability and Flexibility:** The scaled services afforded by the listen-now-into-nothing-nice-and-nifty concept on network slicing truly set it apart. It may thus be very easy to spawn slices or scale them up or down based on demand. Network slicing serves this purpose in cities, where users and connected devices fluctuate: it ensures that all services keep operating in the spirit of efficiency.

4.3.2 Role of AI/ML In Network Slicing

Artificial Intelligence for managing and optimizing network slices goes together with orchestration for an efficient application. AI/ML provides dynamic slice management by analyzing real-time traffic data and adjusting the resource accordingly.

- **Predictive Analytics:** Reduces the load on existing resources. AI can learn from hundreds of historical data points about previous network demands, traffic patterns, and service requirements regarding a certain predefined service or class of services and deduce what the future network demand is. For example, consider a smart city with an analytical setup for traffic patterns: AI can thus determine which zones are expected to see lots of traffic and preemptively allocate resources to those slices.

- **Dynamic Slice Configuration:** AI/ML-driven orchestration systems dynamically configure network slices based on real-time traffic conditions and objective performance metrics. In a smart city environment, more resources may be allocated to the eMBB slice for high-speed data transfer applications, such as video streaming or connected vehicle communications, during peak hours, while less resources are allocated to not-so-vital slices.

- **Fault Detection and Optimization:** Fault detection is a major function that AI/ML perform at the slice level and subsequently also perform on the automatic corrective actions facility. For instance, if a certain slice is impacted by deteriorated performance (such as increased latency in an autonomous vehicle slice), it can lead to an automatic rerouting of traffic or a resource adjustment by AI to restore peak performance.

- **Security Enhancements:** AI/ML can monitor the behavior of network traffic such that it can detect anomalies in the performance of the network which could trigger security intrusion. In networks associated with 5G and beyond, AIpowered security deployed in the different slices of the network can detect a malicious activity occurring in the real-time slice without disrupting the collection of traffic from the rest of the network.

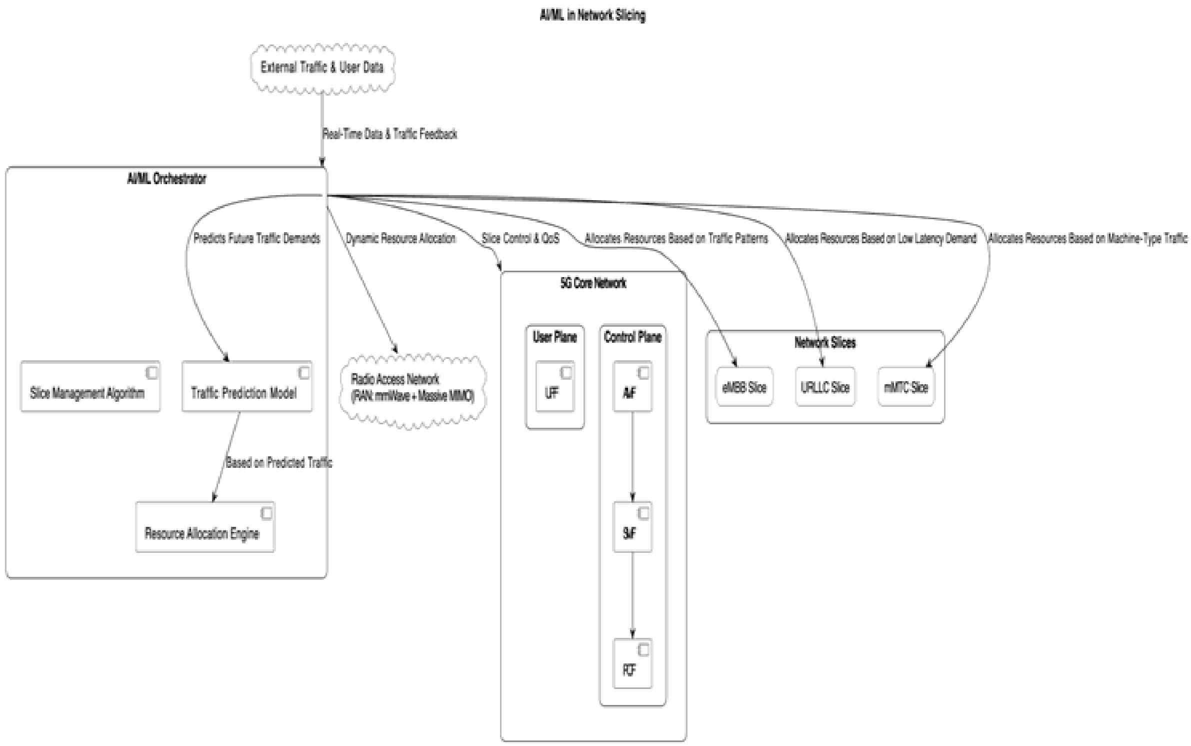

Figure 4 : AI/ML in Networking

4.3.3 Network Slicing in 5G for IoT, Emergency Services, and Autonomous Vehicles

In 5G, network slicing enables various virtual networks to be created on a common physical infrastructure, each optimized for a specific use case. This specialization is critical in urban or metropolitan deployments of 5G, since many of these applications (e.g. IoT, emergency services, autonomous vehicles) can operate with very divergent performance or reliability expectations (Foukas et al., 2017).

Concept of Network Slicing: 5G includes a powerful capability called network slicing, which allows a single physical network to become multiple, virtual networks or "slices". Each slice can be developed to meet the performance, availability, and latency needs of different applications or services, allowing efficient resource utilization and confidence that the service can be performed for different use cases with quality assurance. Network slicing uses the 5G network architecture to develop and manage slices dynamically and to scale slices, providing flexible network capabilities ideal in heterogeneous environments such as smart cities.

Slice Requirements for IoT: The Internet of Things (IoT) is comprised of billions of connected sensors and devices that usually use low power, low bandwidth and enable a large number of devices to connect. A network slice for IoT focuses on massively connected devices, energy-efficient devices, and cost-effective data delivery. We are looking at applications such as smart meters, environmental monitoring, and connected street infrastructure where latency is not the most important factor for operation, but reliability and scalability are the most important requirements.

Slice Requirements for Emergency Services: The emergency services sector demands ultra-reliable, low-latency communication (URLLC). Network slices supporting this sector will be specifically designed to ensure there is no interruption in communication regardless of physical congestion or as a result of an event (such as a disaster). Sustainable features of the slices include bandwidth for guarantee, prioritized traffic, faster provisioning times on the virtualized slice, and isolation from public networks that are congested. Additionally, the slices could provide services for real-time coordination emergencies, video streaming from body cameras or drones to an incident control room or headquarters, or allowing emergency officers to have instant access to information that is essential to response.

Slice Requirements for Autonomous Vehicles: Autonomous vehicles (AVs) necessitate extremely low latency (typically for latency less than 1ms), high reliability, and high-speed data transfer to other vehicles and infrastructures (known as V2X communication). A dedicated network Slice that serves AVs enables real-time sharing of sensors data, route optimizations, collision avoidance, and over-the-air updates. Such slices inherent the ability to support continuation and maintenance of the highest speed to provide safe and consistent performance during changing traffic environments.

Benefits and Real-World Applications: Network slicing boosts 5G's capability to support multiple use cases concurrently with no performance trade-offs by allowing for dedicated virtual networks for different services. Many telecommunications operators are currently conducting real-world testing of slices for a variety of uses, for example, in smart city services, connected emergency ambulance services, automated transport systems, and industrial IoT. Network slicing supports agility and personalization to facilitate delivery of the best network service, while providing security and efficiency.

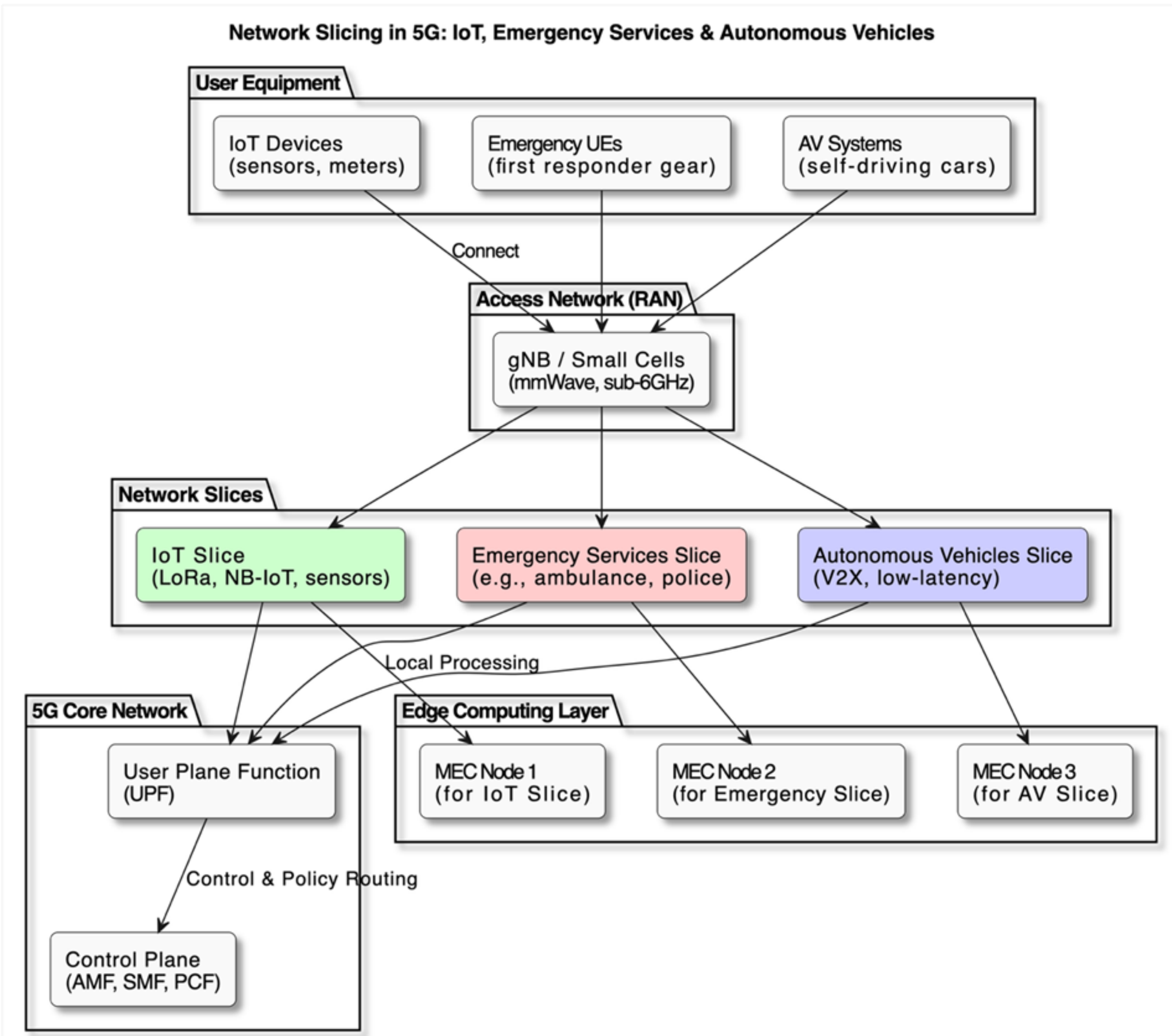

Figure 5 : Network Slicing in 5G for IoT, Emergency Services, and Autonomous Vehicles

4.3.4 Challenges In Network Slicing Implementation:

Despite its advantages, network slicing also brings challenges:

- **Complexity in Management:** One of the major complexities in managing network slicing is configuring, monitoring, and optimizing each slice per se and for specific performance requirements on latency, bandwidth, and security for every individual entity slice. For instance, in a smart city, some of the slices might include traffic control systems (short latency), public safety communications (high reliability), and surveillance (high bandwidth). All of these slices must be orchestrated seamlessly, which requires high-end tools that are automated. Otherwise, it becomes extremely inefficient, error-prone, and non-scalable without AIpowered orchestration environments for managing manually.

- **Inter-Slice Interference:**While slices are logically isolated, they share many of the physical network resources-such as spectrum, antennas, and base stations-that form part of the infrastructure. This shared use may lead to some resource contention and performance degradation. For instance, a live event requiring a high-bandwidth eMBB slice would probably consume most of the network-associated resources and indirectly affect the performance of a URLLC slice for an autonomous vehicle communication. Therefore, even with logical separation, it becomes pertinent to ensure an efficient resource allocation and interference mitigation scheme to ensure all slices are stable and reliable.

- **Security Risks:** All slices are isolated and even a single security vulnerability in one slice may lead to an overall risk to the network. A breach in any one of the slices could propagate or otherwise affect other slices due to insecure APIs, misconfiguration, or malware. This scenario is all the more important to control when dealing with sectors such as healthcare, emergency services, or transportation, where data integrity and availability are critical. AI/ML-powered security solutions can help detect in real-time anomalies, unauthorized access, and threats. However, the added complexity and operational cost associated with implementing these systems will increase.

- **Infrastructure Requirements:** Network slicing will call for huge investments into infrastructures. Massive MIMO, mmWave, and edge computing are necessary to implement some of the more advanced features of 5G. Lots of present existing infrastructures are not conducive to being virtualized and are not able to dynamically allocate resources needed for slicing. In addition, it becomes expensive and logistically tough to modernize legacy infrastructure in urban areas. Network operators must also upgrade their core networks to cloudnative and SDN capabilities to really pull slicing off.

- **Standardization and Interoperability:** Standardization among vendors and telecom providers forms a paramount point upon which the effectiveness of network slicing hinges. And where the unification of protocols and APIs does not exist, achieving this process across regions or networks becomes an impossible task. As such, a situation may happen, for instance, though, where an autonomous vehicle traverses areas governed by different operators; because of heterogeneous slice configurations, the vehicle might experience performance issues. While common standards are in work by bodies such as 3GPP and ETSI, their progress towards widespread adoption presents hindrances towards seamless interoperability(Foukas et al., 2017).

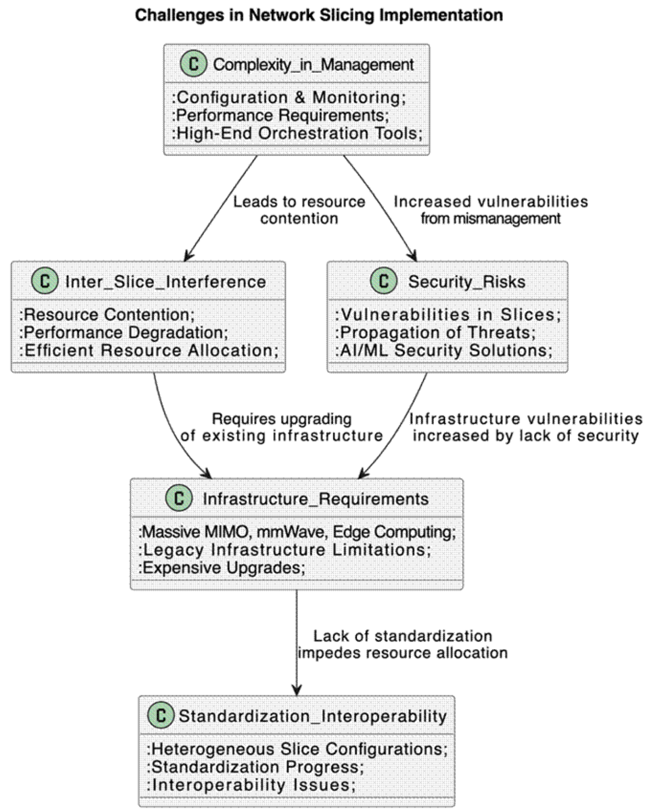

Figure 6 : Challenges in Network Slicing Implementation

Network slicing is a key feature of the architecture of 5G-Advanced networks, allowing flexibility, scalability, and adaptability in support of various applications all within an extremely condensed urban environment. With tailored solutions for autonomous vehicles, smart cities and healthcare, network slicing ensures that specific use cases get the required resources and performance characteristics. In addition to that, application of AI/ML for dynamic orchestration and resource allocation also contributes to the betterment of overall efficiency, reliability and security of the entire system to allow millions of devices to connect and yet optimum performance across each slice.

5. Latency Reduction

5.1 Edge Computing Integration

Edge computing is critical in reducing the latency from next generation communications systems. The distributed computing resources of edge computing are located close to the end-users. For edge computing it is not just the latency of distance that matters but rather moving data closer to the end-users, which limits the amount of distance the data must travel between users and the central data center as one design firm developing edge computing applications stressed. The architectural design of edge computing can accommodate ultra-responsive use cases such as autonomous driving, remote surgery, and real-time gaming. What the (Domeke et al., 2022)described was analogous to their operating model of embedding cloud functions within the telecommunications networks they operate with edge, and made the additional point that geographic closeness to the end user allows low latency applications to be realized (autonomous driving and gaming). Relating back to ML, combining edge computing with ML would represent the next stage of intelligent networks with real-time adaptation to real-world conditions. The edge computing algorithms examine usage patterns all the way to nebulously detecting potential congestion, and, chronically predicting future resource consumption and demand based on those historical patterns allowing the network to deliver a stable low-latency performance across workloads. In addition, edge computing and ML enables local processing at the source, enabling systems to interpret their data in-time, and act on the decision based the data by not incurring latency of re-routing data back to a central cloud. This architectural model supports ultra-reliable low-latency communication (URLLC) architectures that underpin advanced 5G and beyond communication systems.

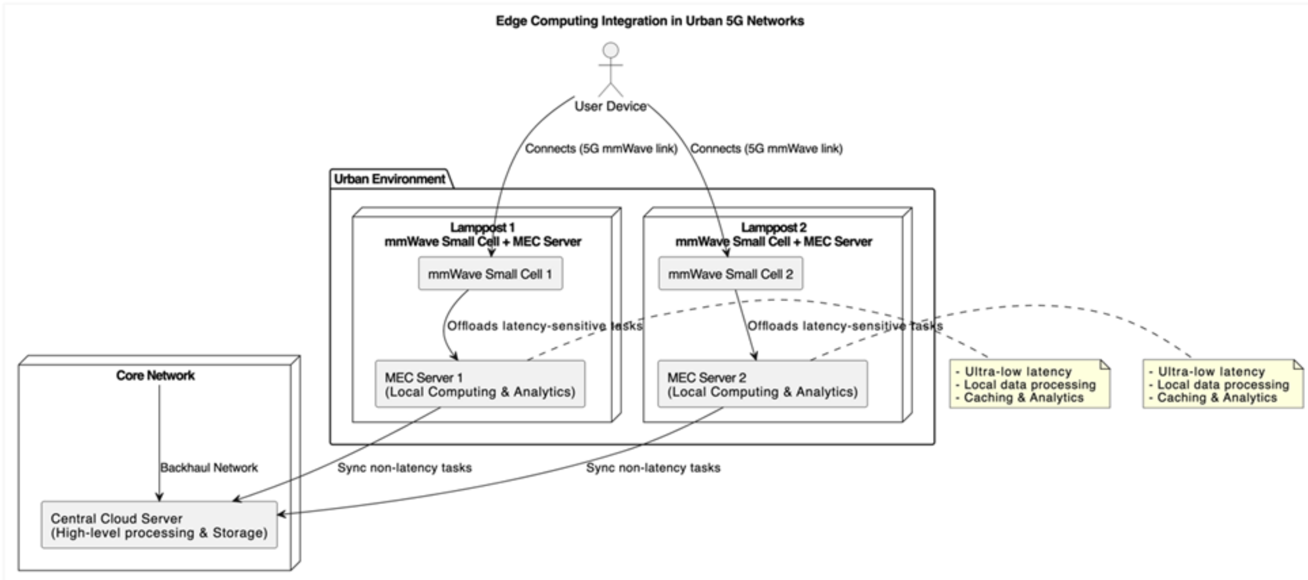

Figure 7 : Edge computing can be integrated into urban 5G infrastructure

The illustration above demonstrates how edge computing can be integrated into urban 5G infrastructure to enable ultra-low latency and real-time data processing. User devices communicate with the nearest small cell via 5G mmWave links. These small cells are co-sited with MEC (Multi-access Edge Computing) servers, which allows for local computing and analytics.

Latency-sensitive tasks (e.g., augmented reality, autonomous driving, and smart city services) are offloaded to the nearest MEC server rather than sent on the backhaul to a remotely located central cloud. This allows edge computing to be able to meet rigorous response time standards while reducing backhaul strain. The remaining less time-sensitive data can be synchronized with a central cloud server via a backhaul network for more extensive processing and storage.

Edge computing enables ultra-low latency, local data processing, and effective caching and analytics by bringing the computation nearer to the user. This could allow for provision of latency-sensitive services to users while also providing a 5G network capable of handling the demands of urban density.

5.2 AI-driven RAN Optimization (dynamic scheduling, AI driven load balancing)

Artificial Intelligence (AI) has become an important enabler of Radio Access Network (RAN) optimization particularly with 5G complexity and dynamically evolving infrastructures (*AI-Driven 5G Network Optimization*, 2024.). A recent review indicates that AI methodologies, including reinforcement learning (RL) and deep learning, are utilized for operating dynamic scheduling and load balancing in the RAN. These AI systems dynamically adapt within the RAN environment to maintain user-based loads while allocating available spectral and computation resources. To illustrate, dynamic scheduling supported by AI-based RL enables transmission timing and frequency allocations to adjust based on current conditions, defining reduced latency. AI load balancing systems predict queuing traffic congestions and pre-allocate workloads across base stations or slices prior to user service disruption, enhancing availability and reliability. Both forms of dynamic orchestration support latency persistence, while allocating computational resources efficiently for innovative slices such as industrial automation, smart cities (IoT), and augmented reality. AI load balancing allows user traffic to be optimally distributed to base stations or slices by processing real-time metrics such as signal strength, user density, and interference. This avoids bottlenecks and maintains a consistent Quality of Service (QoS) for different types of applications. These intelligent networks are typically called Self-Optimizing Networks (SONs), being able to adapt continuously to become optimally resolved without human involvement at all. This adaptive action becomes important when low latency and high reliability are priorities, such as for remote industrial automation, drone fleets, and telehealth applications. Essentially, AI gives the 5G RAN the capability to transform into a self-aware intelligent system capable of ultra-reliable low-latency communication serving consumer and enterprise-grade applications.

5.3 Real World Latency Stats From Case Studies

Nokia's application of latency-reducing strategies in 5G networks, specifically in their 5G-Advanced initiative, are excellent examples of its real-world application, as 5G-Advanced is the natural successor to the initial 5G rollouts. Nokia states that (NOKIA) 5G-Advanced leverages AI and ML-based tools across RAN and core network layers, enabling smarter scheduling, predictive resource allocations, and efficient traffic management. According to Nokia, 5G-Advanced should be viewed as the next evolutionary stage of 5G highlighting latency reduction, improved energy efficiency and the user experience. Using partnerships with telecom operators globally, Nokia put to practical use AI/ML based network automation and realized latency improvements in live conditions. For example, AI-native frameworks automatically modify RAN configurations using real-time updates to optimize both uplink and downlink means that the end-user experience in demanding applications (i.e., AR, VR, cloud gaming) can be improved. The development of accurate timing mechanisms provide, in part, low-latency (end-to-end) times of under five seconds. For certain ultra-reliable low-latency communication (URLLC) scenarios latency can reach as low as five milliseconds. In addition to this, Nokia's advances in sub-10 cm precision positioning are critical for many location-sensitive areas, notably logistics, autonomous navigation, and smart manufacturing. These practical measurements support that through intelligent RAN and core network designs and predictive AI models, it is possible to deliver commercially-consistent value (not just theoretical aspirations) from standardised technologies to actual business outcomes(*5G-Advanced Explained | Nokia.Com*, n.d.).

Nokia's case studies also quantify their improvements in improved energy efficiency and service reliability (state that improved reliability helps address variable load), which strongly supports that 5G Advanced systems are already in a position to tackle the unprecedented demands we expect from digitalisation. We see these benchmarked outcomes as further confirmation of the merits of investing in AI-enabled infrastructure that will have a substantial role in supporting next-gen applications dependent on ultra-low latency connectivity.

6. Security Implementation:

6.1 STRIDE THREAT MODEL For Urban 5G Advance Networks

Threat Type	Violated Security Property	Definition	Smart City Example	Recommended Mitigations
Spoofing	Authentication	Pretending to be something or someone other than yourself	A rogue node masquerades as a Roadside Unit (RSU) to inject false traffic-control commands to autonomous vehicles	• 5G-AKA mutual authentication and SUPI/SUCI protection • Certificate-based device attestation
Tampering	Integrity	Unauthorized modification of transmitted or stored information	Compromise of an edge server to alter V2X signaling or control-plane messages, causing unsafe routing in smart traffic systems	• Secure boot and Trusted Execution Environments (TEE) • Cryptographic checksums and end-to-end integrity checks
Repudiation	Non-Repudiation	Claiming that you didn't do something or were not responsible, without supporting evidence	After a collision, a vehicle denies having run a red light; network logs are unverifiable or absent	• Immutable, blockchain-backed event logs • Digital signatures on all V2X messages
Information Disclosure	Confidentiality	Unauthorized leakage of sensitive information	Leakage of pedestrian location data or AV route histories via a misconfigured network slice	• TLS/IPsec for all slice traffic • Data-minimization and anonymization policies
Denial of Service (DoS)	Availability	Exhausting resources needed to provide service	IoT sensor botnet floods a MEC node, disrupting URLLC for emergency responders in a smart city	• AI-driven rate limiting and anomaly detection • Redundant MEC deployment and slice isolation with dynamic load balancing
Elevation of Privilege	Authorization	Allowing someone to do something they are not authorized to do	A compromised pedestrian-safety app exploits orchestration APIs to commandeer the emergency-services slice	• Role-Based Access Control (RBAC) and least-privilege enforcement • Zero-Trust with continuous authorization checks and MFA on critical APIs

Table 3: Stride Threat Model for urban 5G Networks

6.2 AI Driven Security Measures

Unsupervised anomaly detection models, such as autoencoders and Isolation Forests, can be trained on normal-operation telemetry (i.e., throughput, signaling metrics, slice-level KPIs) producing very high detection performance, and without labelled attack data (Madison et al., 2024). These unsupervised specifications have been validated in edge environments against both volumetric anomalies as well as more subtle protocol abuses (Taleb et al., 2017).

A reinforcement learning mitigation engine can consume anomaly alerts and autonomously select the most appropriate remediation action (e.g., quarantine suspect flows, autoscale MEC instances, or reallocate slice resources) in order to reduce both service interruption and collateral impact

(Sheikh et al., 2025). As episodes continue the RL agent refines their policy as a function of both rapid recovery time and efficient resource usage. Federated threat intelligence at the edge allows each MEC node to train arrays of local anomaly models on raw telemetry and share only encrypted model updates to protect user privacy as well as share collective intelligence at a city-wide scale . In addition, this collective learning process increases the likelihood of detecting distributed, or low-and-slow attacks, which span multiple cells .Using LSTM and GRU networks, it is possible to analyze previous fault logs and link-quality information to forecast when, where and how the network is most likely to be overloaded or jammed.

6.3 Examination of Attack Vectors

Jamming (Availability): Directional mmWave jammers can interfere with street-canyon links by saturating the sidelobes of a beam. A direction-finding user's detection algorithm will identify the jammer's angle of arrival and can use AI assisted beam-steering to null the interferer while the RL controllers can ripple elements into neighboring small-cell for sufficient coverage . Anti-jamming hybrid beamforming methods like AO-AJHBF work to jointly determine transmit and receive beams taking into account statistical models of the jammer to make it robust to downlink performance degradation (Wang et al., 2024).

Spoofing (Authentication): A rogue gNodeB or UE can impersonate a legitimate node during the initial access. Enforcing 5G-AKA mutual authentication, and utilizing and AI-based RF fingerprinting to investigate hardware related signal attributes identifying the possibility of imposters that have different physical-layer signatures from the trained model .

Unauthorized Network Slicing Access (Authorization): An attacker can jump between slices as a result of poorly configured APIs or stolen credentials. Continuous AI analysis of slice-to-slice traffic patterns and SLA reporting will detect abnormal flows towards previously isolated slices and automatically re-validate the RBAC and revoke the token and fully isolate from that slice

7.0 Conclusion

Intelligent and adaptive deployment of 5G-Advanced technologies represent future of urban communication infrastructure. With 5G-Advanced, traditional one-size-fits-all deployments of mobile networks simply isn't realistic, given the unprecedented data demand, dynamic traffic patterns and diverse service requirements of ever more digital and automated urban life. Urban areas need to cater to these conditions and 5G-Advanced brings a paradigm shift by deploying AI driven orchestration, high frequency (mmWave and sub-6 GHz) transmission, edge computing and customizable network slicing.

Real world success with cities involves layering and modularity. It also entails how to overcome the short transmission ranges along with high frequency band propagation losses by deploying this mmWave small cells with high spatial density. Strategic deployment of small cells using population density, user behavior heat maps and urban topology constraints is suggested. Reconfigurable Intelligent Surfaces (RIS) are good candidates for augmentation of coverage in areas that are hard to reach and where it would be expensive and power inefficient to add active transmission equipment, like certain urban zones such as alleys, building corners or underground areas of the transit.

But the Massive MIMO and advanced beamforming systems should have a corresponding parallel investment. These are absolutely essential in congested situations for high capacity and efficient spectral usage. By performing adaptive beamforming it increases the beam directionality and the beam quality and reduces the inter user interference; thereby allowing reliable connectivity in a very dense scale, as many as several thousands of users, with compressed footprint (e.g. stadium, smart intersection or any event zone). By integrating spatial multiplexing, each user device receives independent streams and aggregate throughput is increased, to support these future data intensive applications including holographic communications and immersive media.

Latency sensitive service delivery must be built on edge computing. To provide critical data processing and the application of the result close to the end user where it is required, Multi-access Edge Computing (MEC) nodes need to be co-located with small cells for applications such as autonomous vehicle coordination, remote healthcare and real time surveillance. With edge computing, backhaul congestion is reduced and a more predictable and stable service quality is assured which is important, for example in bandwidth strained or emergency cases.

AI/ML based orchestration is the linchpin for operational efficiencies, service differentiation and is enabled by network slicing. In order for smart cities to be architected, smart cities need to be architected in a manner which allows them to create and manage slices in real time supporting creation of emergency services, public safety systems, entertainment platforms and IoT ecosystems working together in sync with different SLAs. A dynamic slice configuration and healing is performed, based on network demand such that performance and security are provided even in environments experiencing failure or congestion.

Collaboration among public agencies, network operators and urban planners is from a policy and infrastructure standpoint. Small cell zoning should be supported by enabling regulatory frameworks, pole access should be facilitated and investment in shared or neutral host infrastructure should be incentivized. City governments must as well incorporate telecom needs in their urban design and planning (s); e.g. enabling of pre permitted small cell sites or embedding connectivity infrastructure in new developments.

Finally, cyber-resilience cannot be an afterthought since 5G-Advanced’s complex virtualization layers, APIs and AI based control planes offer gigantic attack areas. Zero trust architectures, continuous anomaly detection and AI based threat intelligence sharing and analytics between the MEC and core networks must therefore be part of any deployment strategy. The core, slice and edge level should all include security enforcement, so threats such as jamming, spoofing and unauthorized access can be well protected.

Consequently, real world 5G-Advanced deployment is not just a technical challenge but an entire ecosystem transformation. Intelligent placement strategies need to be used by cities, buildings have to leverage AI and edge computing, frequency needs to be utilized flexibly and secure, adaptive and dynamic networks of last mile connectivity need to be built to address the dynamic needs of the cities. Municipalities and operators can then use this to create smart, resilient and inclusive urban environments that leverage the power of technology in service to all citizens at speed, safety and sustainability.

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Signed Meeting Minutes and Assigned Roles

Weekly Meeting & Minute Record

Frequency: Weekly
Week: 4 | **Date:** [28/05/2025]
Group Name: 6

Member Names:

1. Smriti Bhattarai
2. Binesh Shrestha
3. Rebica Shrestha
4. Dev Mani Maharjan
5. Romik Shrestha

Progress:

- Drafted the stakeholder pitch structure (15-slide template created in Google Slides).
- Selected three industrial references (Nokia, Ericsson, and Huawei whitepapers).
- Started integration of architectural diagrams into the final report (Visio-based designs).
- Identified relevant regulatory considerations for Australian spectrum allocation (ACMA).
- Assigned writing sections for the final report among all group members.

Challenges:

- Translating technical content into accessible language for city planners.
- Coordinating diagram revisions and report formatting between sub-groups.
- Verifying accuracy and credibility of industrial case study metrics.
- Integrating all prior phases (1 & 2) cohesively into the final report without duplication.

Next Steps:

- Finalise and rehearse 20-minute live presentation, ensuring simplified and visually engaging delivery for stakeholders.
- Complete and polish all slides with consistent formatting, visuals, and regulatory commentary.
- Integrate Phase 3 content into the final technical report ensuring smooth narrative flow.

- Complete synthesis of all research data (lit review, case studies, design diagrams) into a cohesive final document.

Roles and Responsibilities:

Group Members	Assigned Tasks
Smriti Bhattarai	Visual layout and explanation of edge computing & urban architecture in slides.
Binesh Shrestha	Technical details on Massive MIMO and associated threat model visuals in slides.
Rebica Shrestha	Integration of AI/ML in security slides, consistency checking, formatting, and references in slides.
Dev Mani Maharjan	mmWave deployment security threats section in report, alignment with architectural diagrams.
Romik Shrestha	Network slicing design and latency performance integration into the report.

Signatures:

Group Leader: Dev Mani Maharjan

Module Leader:______________