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5G Network Deployment

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Abstract

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The objective of this thesis is to cover the implementation of the 5G network at Metropolia University of Applied Sciences that has been deployed by Nokia with the support of Metropolia's staff members. It also involves the scientific theory behind every implementation process.

The study was based on theoretical resources and publications that cover the theoretical part of the study, while the practical part was based on the practical deployment of the 5G network at Metropolia University, including observation and involvement in the process, as well as meetings and investigation with the experts who contribute to the network deployment.

The result of the study illustrates through the first chapters the properties of the fifth-generation (5G) and the reasons for 5G network deployment, the technologies that 5G uses to obtain these properties, and the different ways and strategies of network deployment. while the last chapters illustrate the practicality of 5G network deployments, including network architecture, design, and hardware setup.

In addition, this thesis is meant to be a documentation of the 5G network implementation. As well as it is to be a valuable resource for the academic understanding and practical implementation of 5G networks for Metropolia University of Applied Sciences.

Keywords: 5G, Wireless Communication.

Contents

List of Abbreviations

2G:	Second Generation of cellular networks
3G:	Third Generation of cellular networks
4G:	Fourth Generation of cellular networks
5G:	Fifth Generation of cellular networks
3GPP:	Third Generation Partnership Project
AR:	Augmented Reality
BTS:	Base Transceiver Station
CaaS:	Container as A Service
CMG:	Core Media Gateway
CU:	Central Unit
CPRI:	Common Public Radio Interface
DL:	Down Link
DU:	Distributed Unit
eCPRI:	Enhanced Common Public Radio Interface
eMBB:	Enhanced Mobile Broadband
eNB:	evolved Node B
EPC:	Evolved Packet Core

FDD:	Frequency Division Duplex
Gbps:	Gigabits per second
GHz:	Gigahertz
gNB:	Next Generation Node B
GNSS:	Global Navigation Satellite System
HD:	High definition
IoT:	Internet of Things
IP:	Internet Protocol
LTE:	Long Term Evolution
MEC:	Multi-Access Edge Computing
MHz:	Megahertz
MIMO:	Multiple Input Multiple Output
mmWave:	Millimeter Wave
MPLS:	Multiprotocol Label Switching
NFVI:	Network Function Virtualization Infrastructure
NGC:	Next Generation Core
NSA:	None-Standalone
NSSF:	Network Slice Selection Function

OBSAI:	Open Base Station Architecture Initiative
PPS:	Pulse Per Second
RAN:	Radio Access Network
RIC:	RAN Intelligent Controller
RU:	Radio Unit
SA:	Standalone
SFN:	Single Frequency Network
ToD:	Time of Day
TDD:	Time Division Duplex
UEs:	User Equipments
UL:	Up Link
UPF:	User Plane Function
VR:	Virtual Reality
vCU:	Virtualized Central Unit
vDU:	Virtualized Distributed Unit

1 Introduction

The advantage of the Fifth Generation (5G) technology presented in its enormous transformative potential. In addition to 5G technology core attributes such as low latency, high reliability, and the support for revolutionary concepts such as network slicing and massive Internet of Things (IoT) capabilities. In this thesis, the fundamental principles of the 5G technologies, spectrum, band frequencies, deployment strategies, and network architecture are demonstrated.

The diverse landscape of spectrum within which 5G operates is illustrated, spanning from the millimeter-wave domains of high-band spectrum to nuanced allocations in mid-band and low-band spectrum. That includes explaining frequency allocations, regulations, strategic approaches to spectrum allocation, and licensing processes in 5G implementation.

As part of this thesis, the study was carried out to include several aspects of 5G technologies including duplexing technologies, beamforming, Massive Multiple Input Multiple Output (Massive MIMO), network slicing, and the integration of edge cloud and cloud computing. As well as, the study and evaluation of 5G architecture options, the non-standalone and the standalone, provides insight into the structural foundations of the 5G networks.

The last chapters of this study focus on the deployment of the Non-Standalone (NSA) network. This practical part illustrates the goals, objectives, planning, and preparation phases, followed by the network design, hardware components, and architectural considerations. The traffic flow within the network architecture, both from the user and to the user, unravels the complexities of real-world 5G deployment.

Spectrum allocation is a fundamental aspect of the telecommunication system deployment. Exploring the spectrum allocation strategies and the reason behind the selection of specific frequency bands and bandwidths, and the consideration of the compatibility with the network hardware and meeting the data transmission requirements, contribute not only to the academic understanding of 5G technology but also to shed light on its practical deployment scenarios.

2 The Fifth Generation (5G)

2.1 The Foundation of 5G

5G is the fifth generation of the cellular networks, which is designed to provide fast data transfer rates and peak speeds that can reach up to 20 gigabits per second (Gbps), more than a hundred times faster than the previous 4G networks. 5G utilizes the use of higher frequency radio waves such as the millimeter waves. Higher frequency radio can carry more data compared to the lower frequencies but it covers less ranges. [1]

2.2 Low Latency and High Reliability

The latency is defined as the time taken to send the information and receive a response. 5G latency can reach one millisecond or less compared to 400 milliseconds of 4G. Low delays achieved by the development of 5G mobile networks open the way to new experiences and opportunities, including virtual reality experiences, factory robots, self-driving cars, and other applications for which a fast response and reliability are not optional, but a strong prerequisite. [1]

2.3 Network Slicing and Massive IoT Support

Networks provide the same services to all users in the previous generations. 5G introduced network slicing where operators can divide the same physical network into thousands of virtual networks. Network slicing allows the operators to define the specific characteristics of each slice. For example in the management industry, customers will require different slices for different functions. One customer could require high speed and low latency, whereas another may require high security. [8]

Furthermore, 5G is equipped to support the massive Internet of Things (IoT) ecosystem. Network slicing enables the capacity to connect a vast number of devices at the same time every shared device can be connected to a network slice that owns a specific set of properties. [1]

3 Spectrum

Spectrum is the key asset of the mobile operators; it is responsible to determine the network's capacity, data rates, and converge capabilities. Spectrum options available for 5G, frequency variants, and their properties and characteristics are discussed in this chapter.

5G marks the first mobile radio system designed to exploit the broad-spectrum range spanning approximately 400 MHz to 90 GHz. The 5G system is designed for deployment across licensed, shared, and unlicensed spectrum bands, employing both Frequency Division Duplex (FDD) for paired spectrum and Time Division Duplex (TDD) for unpaired spectrum. The ability to utilize different bands optimally unlocks varied capacity and coverage properties.

The motivations driving 5G deployment across different spectrum bands are multifaceted, as illustrated in figure 1. Frequencies in the high-frequency millimeter wave bands (between 30 and 300 GHz) offer extensive spectrum, enabling high capacity and data rates. Frequencies ranging from 24 to 39 GHz provide operators with up to 800 MHz of spectrum, facilitating user data rates of 5 Gbps. Moreover, frequencies surpassing 50 GHz offer even more spectrum, facilitating user data rates above 10 Gbps. However, challenges arise due to the short propagation of millimeter wave signals, limiting cell range to a few hundred meters. [2, p. 49]

Band	5G use case and motivation	Spectrum per operator
Above 52 GHz	• Very high data rate >10 Gbps • Licensed and unlicensed frequencies	>1000 MHz
24–39 GHz	• High data rate >5 Gbps • Hot spot capacity and fixed wireless	800 MHz
5 GHz unlicensed	• Local solution • No spectrum license needed	Up to 500 MHz shared
3.3–5.0 GHz and 2.6 GHz	• 2 Gbps with100 MHz and 4x4MIMO • Urban capacity with massive MIMO	100 MHz
1.5–2.6 GHz	• 5G brings massive MIMO capability • Gradual refarming from LTE to 5G	Combined 2 × 50 MHz
Sub 1 GHz	• Wide area and deep indoor coverage • Low latency with FDD	Combined 2 × 25 MHz

Figure 1. Motivation for 5G deployment on different spectrum bands [2, p. 49].

The spectrum within the range of 3.3–5.0 GHz presents an attractive fusion of high data rates and extensive coverage. With approximately 100 MHz per operator and 4×4 Massive MIMO configurations, this spectrum achieves peak data rates of 2 Gbps. Leveraging TDD technology, this band's coverage can approach that of the 2 GHz band, especially when coupled with high-gain base station antennas and beamforming techniques. Similarly, the widely used Long Term Evolution (LTE) spectrum at 1.5–2.6 GHz, mainly employing FDD technology, serves urban areas, offering capacities up to 2 × 20 MHz per operator. Reframing LTE to 5G in this spectrum range benefits from 5G's inherent support for Massive MIMO, ensuring enhanced performance.

Below the 1 GHz threshold lies the spectrum crucial for wide area coverage and deep indoor penetration. These low bands serve as the backbone for critical communications in wide area networks, including rural areas, boasting ultra-high reliability. Supporting FDD technology and offering 2 × 20–30 MHz on multiple spectrum blocks, these frequencies provide essential coverage while offering latency benefits over TDD, supporting simultaneous transmission and reception [2, p. 50-51].

3.1 Millimeter Wave (High-Band Spectrum)

Millimeter wave spectrum ranges from 24 to 100 GHz, as shown in figure 2. This sufficient range in 5G networks meets the escalating demands for increased capacity and higher data rates. Regulatory bodies across the globe are actively engaged in efforts to open up new bands within this range. These higher frequencies offer significantly broader bandwidth compared to frequencies below 6 GHz. Allocating even a fraction of this spectrum to the mobile industry could yield a substantial 20–30 GHz, markedly surpassing the available spectrum under 6 GHz [2, p. 52, 5].

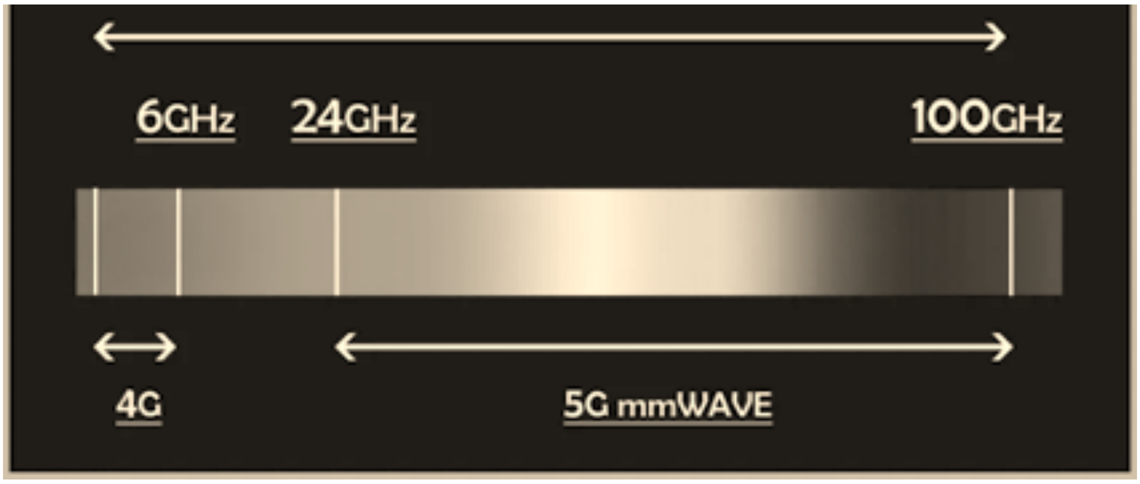

Figure 2. The millimeter Wave spectrum [3].

In practical terms, early-phase access below 40 GHz allows for up to 800 MHz bandwidth per operator, while frequencies exceeding 50 GHz might provide up to 2 GHz. These allocations primarily utilize Time Division Duplex technology. However, the millimeter wave spectrum faces challenges due to its rapid signal attenuation, therefore the deployment of denser infrastructure is required, particularly in urban areas. Despite these challenges, millimeter wave use is highly promising for heavy dense urban environments.

The millimeter wave spectrum is regulated and licensed to manage and distribute it because of its distinctive characteristics. Advancements are continuously aiming to mitigate the propagation challenges inherent in millimeter wave technology. That is resulting potentially to expand its applications across diverse deployment scenarios. It's important to note that the specifics of allocation and regulations can significantly vary based on regional and national frameworks [3].

3.2 Mid-Band Spectrum

The mid-band spectrum ranges between 3.3–5.0 GHz and 2.6 GHz. It is mostly used in high-speed data services that require good capacity to carry plenty of data and coverage over long distances. The 3.3–5.0 GHz range, in most cases, can provide approximately 100 MHz of spectrum and data rates of up to 2 Gbps.

The 2.6 GHz band is part of the mid-band spectrum. It has been extensively used by LTE networks because of its coverage and capacity. With 2 x 20 MHz typically available per band for operators, this spectrum block is mostly associated with Frequency Division Duplexing (FDD) technology, offering reliability in simultaneous transmission and reception.

Both the 3.3–5.0 GHz and 2.6 GHz bands play important roles in the evolution to 5G. They facilitate the delivery of robust, high-speed services and ensure widespread coverage in diverse geographical areas, therefore they are integral components in the spectrum portfolio for 5G deployments. [2, p. 55]

3.3 Low-Band Spectrum

The low-band spectrum operates below 3 GHz. It possess an exceptional propagation characteristic. The frequencies in this range can achieve wide-area coverage and penetrating indoor environments.

Within the sub-1 GHz bands, typically ranging from 600 MHz to 900 MHz, operators can access to spectrum blocks of 2x20–30 MHz across various blocks. The sub-1 GHz bands are known for their ability to provide wide area coverage and reliable communication in challenging environments.

The ability of the low-band spectrum to penetrate buildings and reach remote areas effectively ensures that even in densely populated urban areas or within structures, connectivity remains stable and reliable. Furthermore, FDD technology is used in these bands to contribute to lower latency compared to TDD. [2, p. 58]

In essence, the low-band spectrum below 3 GHz serves as the backbone for establishing broad coverage networks, offering reliable connectivity in both urban and rural landscapes. Its excellent propagation characteristics and capacity to penetrate obstacles make this spectrum an important part for connectivity in 5G deployments.

3.4 Frequency Variants

3GPP has established distinct frequency variants for the bands expected to host 5G deployments. These frequency variants are the result of collaborations between mobile operators and equipment vendors within the 3GPP framework. The process involves by the initiation of work of the mobile operators, followed by its completion by the equipment vendors.

Each frequency variant is released autonomously, enabling vendors to utilize a specific frequency variant from the Release 16 specifications while integrating functionalities from earlier releases, such as Release 15. As the 3GPP specifications evolve, additional frequency variants are continually defined, reflecting the ongoing development and refinement of the 5G ecosystem. This iterative incorporation process of enhanced functionalities and optimizations supports the diverse network requirements and the technological advancements evolvement. [2, p. 64-65]

Table 1 display and list available frequency bands and their operating freuencies and dulexing.

Table 1. Frequency variants. [2, pp. 64]

Operating band	Uplink	Downlink	Duplex
n1	1920–1980 MHz	2110–2170 MHz	FDD
n2	1850–1910 MHz	1930–1990 MHz	FDD
n3	1710–1785 MHz	1805–1880 MHz	FDD
n5	824–849 MHz	869–894 MHz	FDD
n7	2500–2570 MHz	2620–2690 MHz	FDD
n8	880–915 MHz	925–960 MHz	FDD
n12	699–716 MHz	729–746 MHz	FDD
n14	788–798 MHz	758–768 MHz	FDD
n18	815–830 MHz	860–875 MHz	FDD
n20	832–862 MHz	791–821 MHz	FDD
n25	1850–1915 MHz	1930–1995 MHz	FDD
n28	703–748 MHz	758–803 MHz	FDD
n29	N/A	717–728 MHz	SDL
n30	2305–2315 MHz	2350–2360 MHz	FDD
n34	2010–2025 MHz	2010–2025 MHz	TDD
n38	2570–2620 MHz	2570–2620 MHz	TDD
n39	1880–1920 MHz	1880–1920 MHz	TDD
n40	2300–2400 MHz	2300–2400 MHz	TDD
n41	2496–2690 MHz	2496–2690 MHz	TDD
n48	3550–3700 MHz	3550–3700 MHz	TDD
n50	1432–1517 MHz	1432–1517 MHz	TDD
n51	1427–1432 MHz	1427–1432 MHz	TDD
n66	1710–1780 MHz	2110–2200 MHz	FDD
n70	1695–1710 MHz	1995–2020 MHz	FDD
n71	663–698 MHz	617–652 MHz	FDD
n74	1427–1470 MHz	1475–1518 MHz	FDD
n75	N/A	1432–1517 MHz	SDL

n76	N/A	1427–1432 MHz	SDL
n77	3300–4200 MHz	3300–4200 MHz	TDD
n78	3300–3800 MHz	3300–3800 MHz	TDD
n79	4400–5000 MHz	4400–5000 MHz	TDD
n80	1710–1785 MHz	N/A	SUL
n81	880–915 MHz	N/A	SUL
n82	832–862 MHz	N/A	SUL
n83	703–748 MHz	N/A	SUL
n84	1920–1980 MHz	N/A	SUL
n86	1710–1780 MHz	N/A	SUL
n257	26 500–29 500 MHz	26 500–29 500 MHz	TDD
n258	24 250–27 500 MHz	24 250–27 500 MHz	TDD
n260	37 000–40 000 MHz	37 000–40 000 MHz	TDD
n261	27 500–28 350 MHz	27 500–28 350 MHz	TDD

3.5 Spectrum Allocation and Regulations

3.5.1 Regulatory Framework

The regulatory framework is the cornerstone dictating the utilization and management of the allocated spectrum for 5G networks. Regulatory institutions set up rules that manage spectrum usage to ensure fair and effective distribution among operators. This kind of structured set up aims to fulfill and balance the needs of the operators as well as protecting users' interest and the national security.

3.5.2 Auctions and Licensing

Each country establishes a different set of rules for allocating and licensing spectrum to the operator companies that demanding specific frequency bands to operate. For example, millimeter wave auctions of 37GHz, 39GHz and 47GHz spectrum bands in the United States reached total sale of 558 billion.

Countries still moving forward to plan for allocating more frequency bands in the future. As the Finnish telecoms regulator Traficom has announced that it plans to press on with the auction of 5G spectrum lately. The licensing grants the operators the right to use the specific frequency bands. [3]

4 5G Technologies

5G uses a set of sophisticated and advanced technologies that ensure fast connectivity and effective reliability. These technologies are designated for each section of the 5G network. Beamforming and Massive Multiple Input Multiple Output are designed to improve transforming data transmission and reception as well as duplexing techniques such as Frequency Division Duplex and Time Division Duplex. Network Slicing ensures a tailored network slice for each distinct application and that improves the efficiency of the network. Edge cloud and cloud computing play crucial roles with data processing and network function migration.

4.1 Duplexing Technologies

Duplexing methods enable bidirectional communication between devices in mobile network. FDD and TDD represent two approaches to achieving this two-way data flow. The FDD technique uses two separate frequencies for the uplink (transmit) and downlink (receive). In contrast, TDD uses the same frequency for upstream and downstream traffic at different times. [4]

4.1.1 Frequency Division Duplex (FDD)

Frequency Division Duplex is a communication duplexing method that uses distinct frequency bands for the uplink (transmit) and downlink (receive), as illustrated in figure 3. In FDD systems, simultaneous communication in both directions using separate frequency bands. FDD provides a constant continuous data transmission while it requires more power compared to TDD systems. [4]

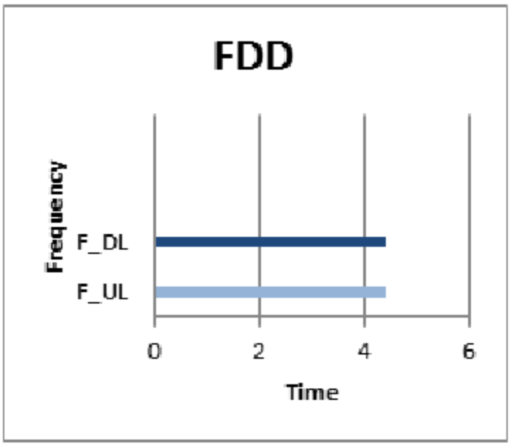

Figure 3. FDD. [5]

4.1.2 Time Division Duplex (TDD)

Time Division Duplex technique uses the same frequency band both uplink (transmit) and downlink (receive) communication at different time intervals, as illustrated in figure 4. TDD systems divide the available time into alternating time slots for transmitting and receiving. TDD is more flexible in allocating resources based on different traffic demands, but it requires more careful synchronization to avoid interference. [4]

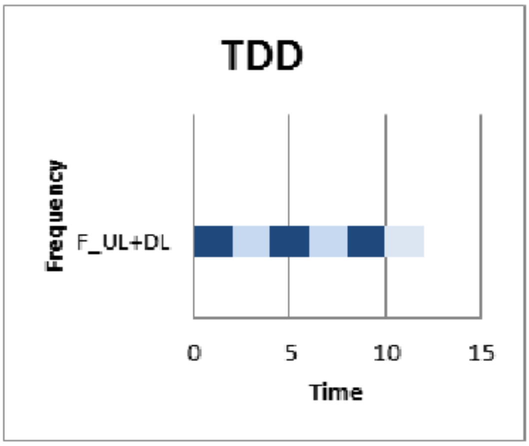

Figure 4. TDD. [5]

4.2 Beamforming

Beamforming simplifies the complexities of signal transmission by shaping and directing signals. Let's explore two scenarios with two antenna systems, transmitting the same total energy, as shown in figure 5.

In the first case, energy is dispersed uniformly in all directions. While the three User Equipments (UEs) around the antenna receive similar energy amounts, a substantial portion is wasted in non-UE directions. This scenario represents a traditional approach where energy is not optimized for targeted reception.

Now, in the second case, we introduce beamforming. Here, the signal strength of the radiation pattern, often referred to as the beam, is meticulously shaped. The energy is concentrated in the direction of the UEs, significantly strengthening the signal in that specific direction. Unlike the first case where energy was dispersed, this focused approach minimizes wastage and ensures that the radiated energy is optimized for enhanced signal strength precisely where it is needed – towards the UEs. [6]

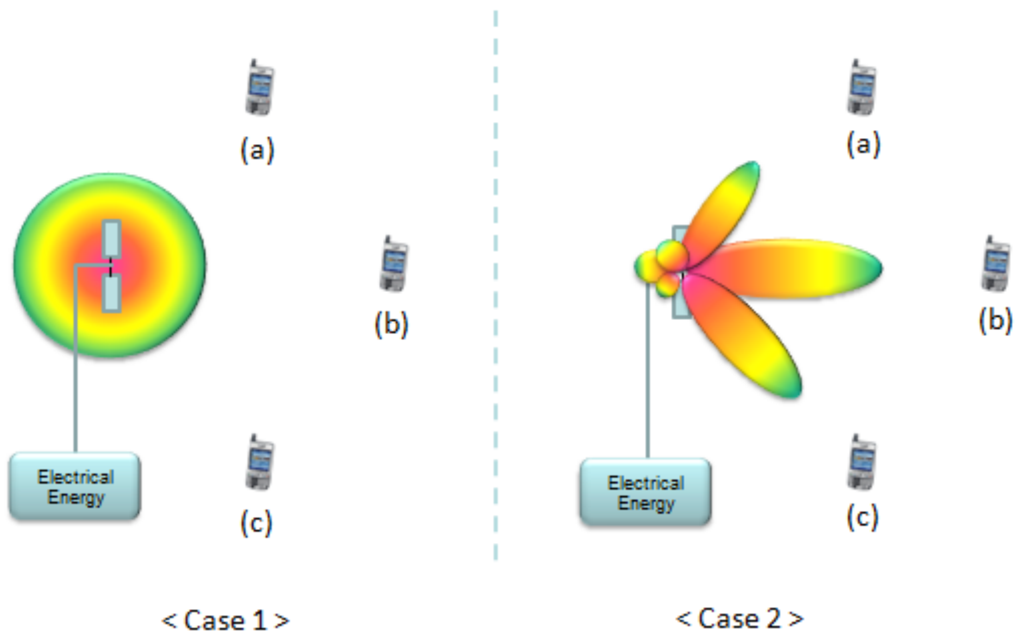

Figure 5. The use of Beamforming. [6]

Beamforming allows for a more efficient and directed use of energy, minimizing waste and maximizing signal strength for specific targets. This technology plays a crucial role in advancing the effectiveness of wireless communication systems, providing targeted and optimized signal transmission.

4.3 Massive MIMO

Massive multi-input multi-output (MIMO) stands out as a groundbreaking technology, particularly enhancing the capacity and user experience in the realm of 5G Enhanced Mobile Broadband (eMBB). Departing from the conventional method of broadcasting data across the entire coverage area, massive MIMO concentrates signal energy on specific users, resulting in a remarkable enhancement of throughput and efficiency.

Massive MIMO's distinctive characteristic lies in its ability to boost both downlink (DL) and uplink (UL) signal strength, elevating cell throughput by allocating multiple beams to one or multiple users. In addition, Massive MIMO optimises signals and reduces the overall interferences level in networks towards users and cells. [7]

4.4 Network Slicing

Network slicing is a technology that offers unprecedented advantages a single physical network capable of accommodating diverse service requirements. Operators utilise network slicing for creation of multiple virtual networks or 'slices' each tailored for distinct applications with specific demands. This concept is illustrated in figure 6. [8]

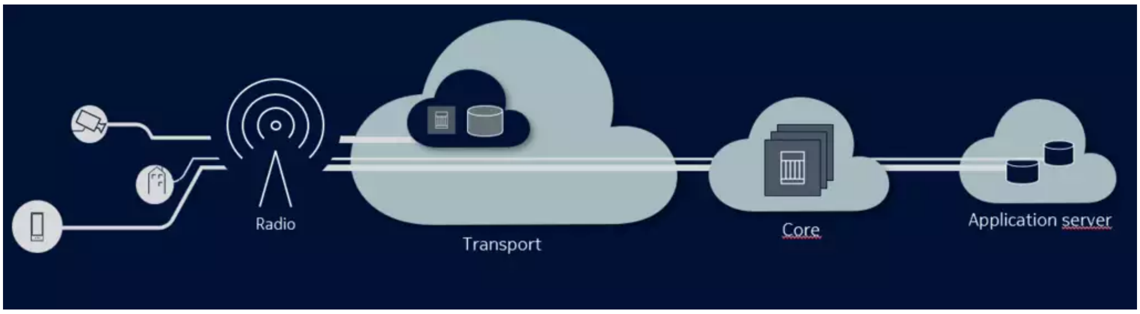

Figure 6. 5G network slicing concept. [8]

Each slice is a unique slice instance, encapsulating dedicated and isolated network functions, bandwidth, latency profiles, and security parameters. Orchestrating this network segmentation is the Network Slice Selection Function (NSSF), determining the appropriate slice type based on service requirements, network conditions, and user context. [2, p. 81-82]

Network slicing supports numerous benefits and applications. It enables the provisioning of services tailored to specific use cases, such as ultra reliable low latency communications for critical applications and massive machine type communications for IoT deployments. Moreover, it is allocating resources dynamically based on specific slice demands to ensure efficient network operation.

However, challenges exist, including the harmonization of slice management across different vendor environments to ensure seamless interoperability. Network Slices have to be isolated to prevent security breaches across different slices. Network slicing advances and unlocks innovation services and user experience across various industries and applications as 5G technology continues evolving.

4.5 Edge cloud and cloud computing

In modern networks the combination of Edge Cloud and traditional cloud computing is changing how data processing and services delivery. Unlike traditional cloud models centralized in distant data centers, Edge Cloud leverages distributed computing resources situated closer to data sources and end-users. Figure 7 illustrates the differnce of a system with and without edge cloud.

Many of network functions migrate towards Edge Cloud in the implementation. Notably, for the mobile core, the Edge now possesses the capability to handle 5G Next Generation Core (NGC) workloads, such as the User Plane Function (UPF). This network functions migration, allows the Edge to execute these critical functions closer to the user, facilitating the low latency for new use cases and innovative solutions.

One of the pivotal network functionalities that gain immense advantage from being hosted at the edge is the virtualized Distributed Unit (vDU) and virtualized Central Unit (vCU) functions. This shift enables the implementation of Cloud RAN and facilitates the RAN Intelligent Controller (RIC). Moreover, the deployment of vDU and vCU at the edge enhances the capabilities of Multi-Access Edge Computing (MEC), opening up possibilities for ultra-responsive, low-latency applications and services. [9]

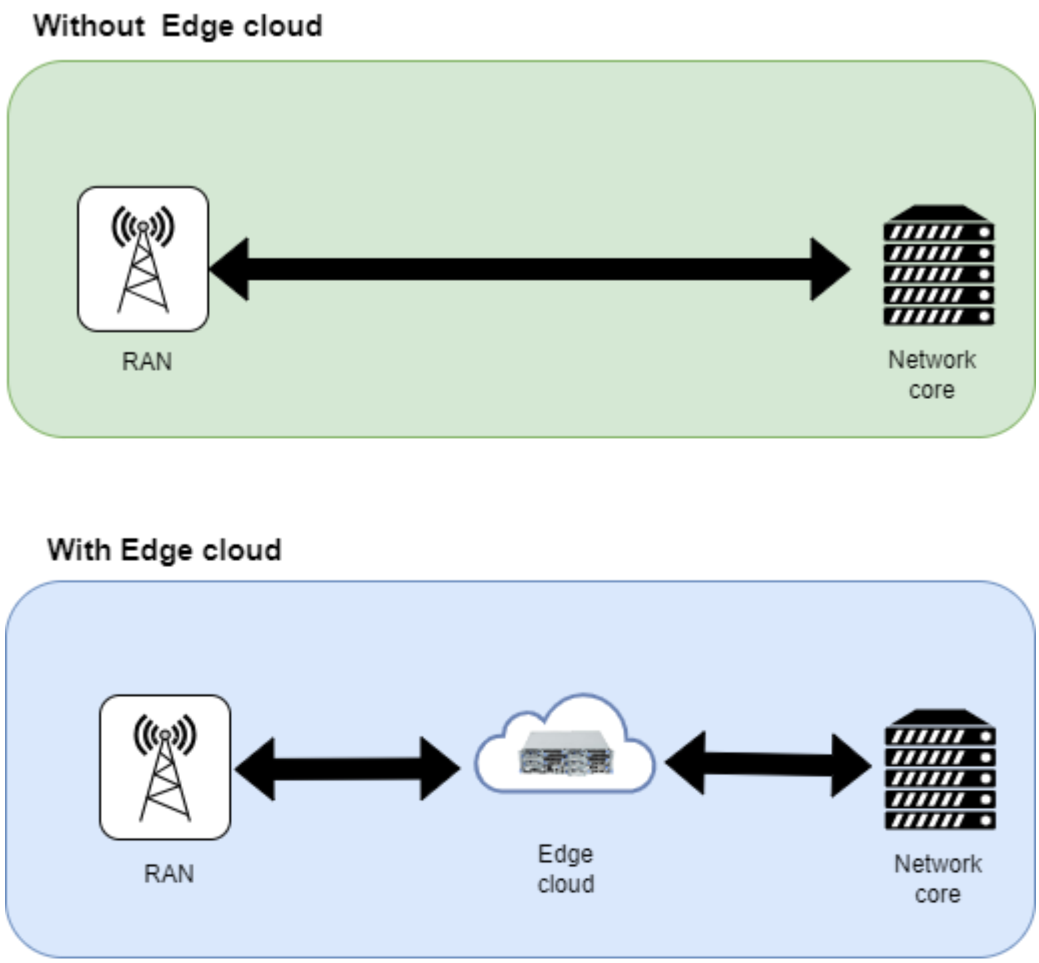

Figure 7. Network architecture with and without edge cloud.

Cloud computing continues to improve how data is processed, stored, and accessed both at the edge and traditional cloud data centers. However, the Edge Cloud's placing closer to end-users allows for enhanced real-time processing, and reduced latency. Figure 8 shows some of the use cases that require a very short latency, which can only be achieved by applying edge cloud.

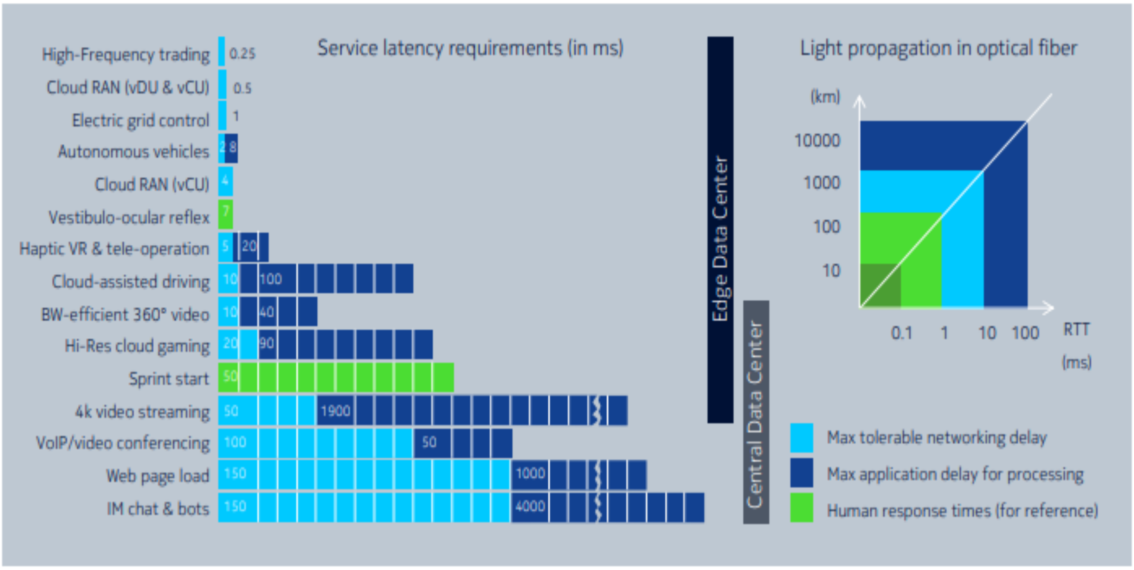

Figure 8. Different use cases demand different latencies. [10 p. 5]

Using the combination of Edge Cloud and cloud computing empowers for innovative applications. This combination can be a suitable use case for Internet of Things (IoT), AR, and VR applications because it enhances scalability, agility, and efficiency to handle big data workloads.

5 5G Architecture

The 5G network architecture evolves from a confluence of various influences and necessities. The preparations for cloud-based implementations, anticipation of accommodating larger data rates, and necessitating lower latencies compared to preceding generations were crucial factors shaping its development. These innovations aimed at enabling a spectrum of new services while ensuring seamless interworking with LTE, particularly in its initial phases. The impact of these elements is intrinsic to the framework of the 5G architecture.

In addition to advancements in radio technology, the inception of 5G introduced a novel core network infrastructure, fostering the integration of new service elements. This encompasses both local and global services, alongside pioneering concepts such as flow-based quality of service, support for network slicing, and many other functionalities. These innovations significantly enhance the efficiency of cloud-based implementations, distinguishing it from its LTE precursor, the Evolved Packet Core (EPC). [2, p. 67]

This chapter presents an overarching view of diverse 5G architectures, encapsulating the nuances of radio access network architecture, interfaces, and the 5G Core network. It explores key elements and functionalities and illustrates the complicated aspects of this advanced network architecture.

5.1 Architecture Options

The 5G network architecture unfolds in diverse configurations, initially presenting a spectrum of eight potential architecture options during 3GPP discussions. However, as the deliberations evolved and considerations encompassed various aggregation and core network combinations, two predominant architecture options emerged as pivotal configurations.

In the culmination of discussions, the finalized architecture options primarily revolved around two distinct paradigms, each showcasing nuanced operational variations. The foremost approach anchored LTE as the connection base, leveraging the existing LTE core while incorporating the 5G radio as the secondary cell (Architecture Option 3x). Following this was the completion of the standalone 5G radio deployment, entailing the integration with the 5G core (Architecture Option 2).

The architectural choices in figure 9 present two models. These configurations evolved in the sequence of their finalization within the 3GPP framework, eventually establishing the bedrock for the standardized implementation of 5G architecture options: [11]

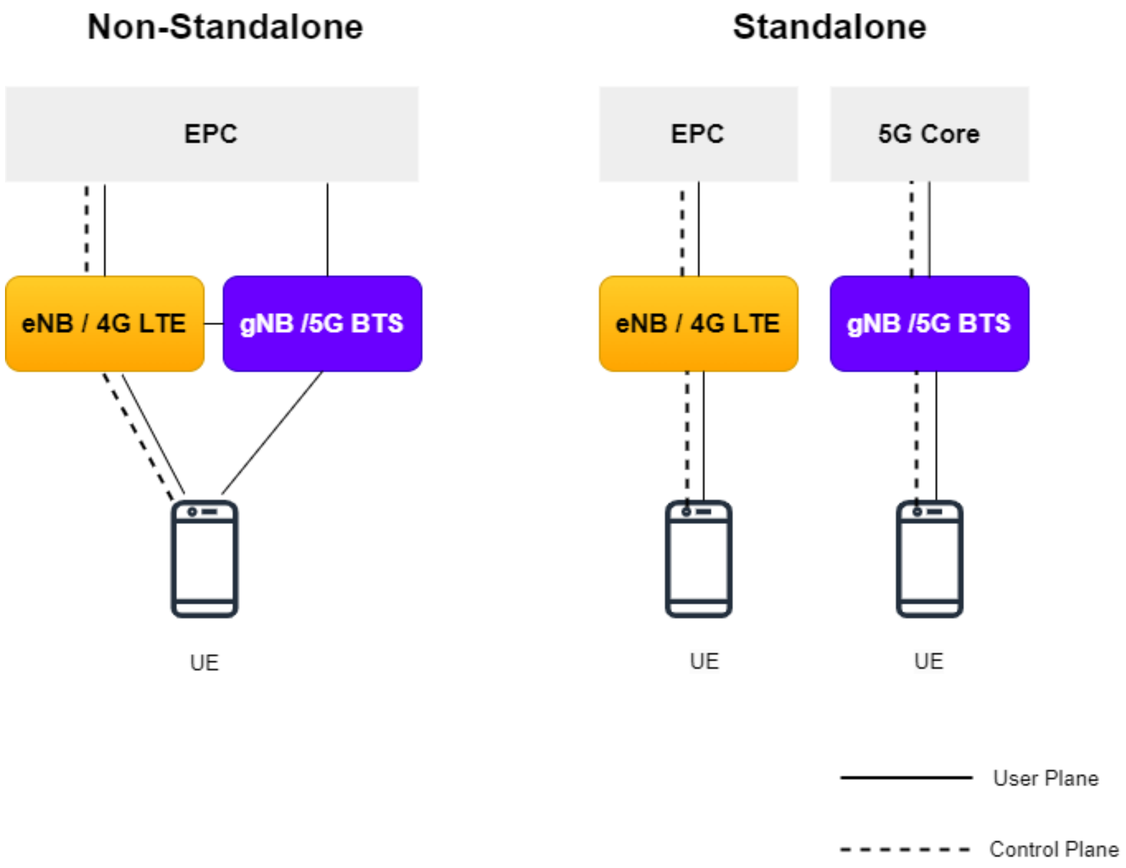

Figure 9. 5G NSA and SA architecture options.

5.1.1 Non-standalone (NSA)

In the option 3x deployment, which involves the interworking of 5G and LTE, an evolved Node B (eNB) assumes the primary node role, while the next-generation Node B (gNB) operates as a secondary node. These two nodes establish connectivity between the LTE and emerging 5G infrastructure via the X2 interface.

Within this architecture, the eNB serves as the master node, maintaining a control plane (C-plane) connection to the core network. Conversely, the gNB, functioning as the secondary node, solely facilitates the user plane (U-plane) path to the core network. Data traverses between the network and user equipment through the gNB and the LTE Evolved Packet Core.

The architecture option 3x encapsulates a symbiotic relationship between the eNB and gNB, orchestrating a streamlined transmission pathway leveraging LTE and 5G elements for comprehensive connectivity. [11]

5.1.2 Standalone (SA)

Within the 5G Standalone (SA) Option 2 architecture, the 5G radio cells and the core network operate autonomously, without reliance on the existing LTE network infrastructure.

In this architecture, a gNB is responsible for establishing both control plane (C-plane) and user plane (U-plane) connections to the core network. Unlike the Non-standalone architecture, the SA mode avoids the requirement for the LTE Evolved Packet Core for relying on the novel architecture of the 5G Core Network. [11]

The SA Option 2 deployment delineates a paradigm where the 5G radio cells and the core network operate independently, marking a departure from LTE interdependence and fostering a new realm of standalone 5G functionality.

5.2 Open Radio Access Network (RAN)

The mobile network consists of two primary domains: the Radio Access Network and the Core Network. RAN and Network Core are essential for enabling seamless connectivity and communication.

The RAN serves as a link between the network infrastructure and end-user devices, including visible components such as antennas. Antennas, alongside base stations, facilitate the transmission and reception of signals to and from mobile devices. When users initiate calls or access online content, these antennas transmit and receive signals, which are subsequently digitalized within the RAN's base stations before integration into the broader network.

On the other hand, the Core Network oversees multiple functionalities critical to network operations. It handles access control to verify users for different services and coordinates the routing of phone calls over the telephone network. As well as, it enables operators to monitor and regulate charges, and establish connections between users and the global Internet infrastructure. Additionally, the Core Network plays a key role in network control the handovers as users transition between coverage areas provided by different RAN towers. [12]

Open RAN promotes a significant change for service providers. It is promoting diversity in choosing vendors. Historically, service providers faced limitations imposed by a singular vendor supplying equipment and software, making transitions to alternative suppliers cumbersome. Currently, the direction is moving towards supporting open, multi-vendor networks, emphasizing flexibility and control. [13]

5.2.1 5G RAN Architecture

5G Radio Access Network architecture consists of three elements:

Radio Unit (RU)
The RU serves as the core unit responsible for transmitting, receiving, amplifying, and digitizing radio frequency signals. Positioned in proximity or integrated with the antenna, the RU manages wireless signals.

Distributed Unit (DU)
The DU serves as a computational component of the base station, the DU collaborates closely with the RU. Physically located at or in the vicinity of the RU, the DU contributes to digitalize radio signals before routing them into the network.

Central Unit (CU)
The CU Operates as another computational part of the base station, the CU interfaces between the DU and the 5G core network. The CU’s placement in the architecture can vary, often positioned closer to the Core for streamlined connectivity.

Each element in the 5G RAN Architecture serves specific functions:
The RU is where radio frequency signals are transmitted, received, amplified, and digitized. It is located near or integrated into the antenna, serving as the primary unit for wireless signal management.

Both the DU and CU contribute to the computation aspects of the base station, handling digitalized radio signals within the network. The DU, physically located at or near the RU, aids in digital signal processing, while the CU acts as an interface between the DU and the 5G core network, often positioned closer to the Core for optimized connectivity as shown in figure 10 below. [12]

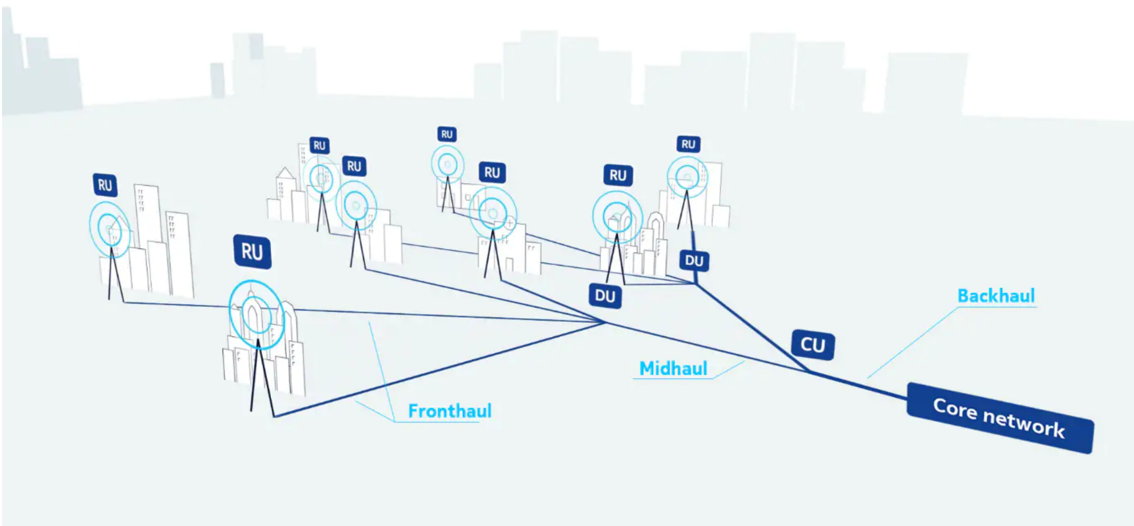

Figure 10. 5G RAN. [12]

6 5G NSA Network Deployment

6.1 Goals and Objectives

The deployment of a 5G Non-Standalone network at Myyrmäki Campus aimed at advancing educational innovation and embracing most recent technology. The goals are to enhance the learning environment, and encourage technological exploration.

The selection of 5G Non-Standalone over Standalone architecture attributed to the fact that only Non-Standalone deployment is commercially available at the time of procurement from Nokia. The deployment of 5G network at Metropolia University of Applied Sciences was the result of a successful partnership between Nokia and Metropolia. This partnership will continue in the future to contribute to the improvement of the educational experience.

Objectives:

- Innovative Learning Environment: Create an innovative learning environment that leverages high-speed connectivity for enriched educational experiences.
- Research and Development Hub: Establish a hub for research and development in 5G technology.
- Collaboration Opportunities: Encourage collaborations with industry partners and technology providers or other educational institutions for collaborative research and development initiatives.

6.2 Planning and Preparation

In the planning and preparation phase for the 5G NSA network deployment, the base station and antenna placement are important to ensure a safe and efficient communication system.

- Avoidance of high-traffic zones when deploying base stations, especially given their potential to generate a high level of noise.
- Selection of areas for the antennas conducive to effective frequency transmission. Adherence to safety distance regulations associated with higher frequencies ensures compliance with safety standards.
- Identifying locations with convenient access to electrical power.
- Conducting an analysis of the local climate informs the selection of locations within acceptable temperature and humidity ranges.

6.3 Network Design and Architecture

The design and components selection are part of Nokia's small cells solution. Small cells solution suitable for indoor scenarios, with improving capacity and coverage.

6.3.1 Hardware Components

The NSA Network components:

1. 7250 IXR-e Interconnect Router
The Interconnect Router 7250 IXR-e, as shown in figure 11, epitomizes adaptability and high-performance networking Internet Protocol (IP) and Multiprotocol Label Switching (MPLS) routing with a variety of interfaces.

400GE and 100GE ports used for high speed uplinks enable cost-effective network architecture suitable for access and aggregation. The native 25GE ports of the 7250 IXR-e series offer exceptional flexibility and support 1GE, 10GE, or 25GE transceivers, ensuring seamless transitions between different transmission rates without necessitating a complete router replacement. [14]

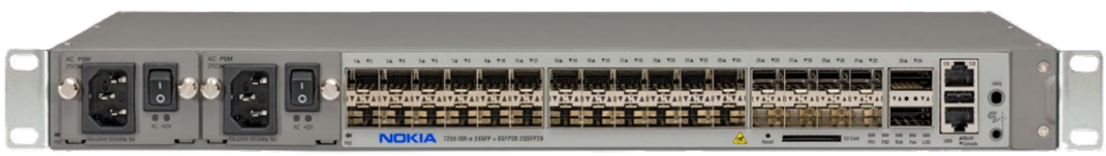

Figure 11. 7250 IXR-e Interconnect router. [14]

2. AirFrame Open Edge Server
The Nokia AirFrame Open Edge Server, as shown in figure 12, is a compact, robust, and openly architected x86 server platform designed for high-performance edge computing. It supports diverse environments including telecom, enterprise, and IT sectors, and is optimized for the integration with

Container as a Service (CaaS) and Network Functions Virtualization Infrastructure (NFVI) software providers.

Available in two chassis variants, 2RU and 3RU, the server accommodates up to 5 server sleds to ensure scalability while housing AC or DC power supplies.

Nokia AirFrame Open Edge features include:

- High-performance server nodes supporting the latest generation Intel® Xeon® Scalable processor family.
- Optimized hardware accelerators specifically for complex workloads.
- Compact NVMe EDSFF E1.S storage that boasts the fastest bandwidth, and higher IOPS for reducing latency and optimizing data handling.

Nokia AirFrame Open Edge solution is certified across various software platforms including major operating systems and cloud stacks. Notable certifications include Canonical/Ubuntu, RedHat Enterprise Linux & RHEL for Realtime, RedHat OpenStack Platform & OSP for Realtime, and RedHat OpenShift Container Platform, VMware ESXi. [15]

Figure 12. AirFrame Open Edge Server. [15]

3. AirScale Baseband Unit

The baseband is responsible for baseband processing across all mobile radio access technologies and frequency bands, low, mid, and high frequencies, including mmWave. It efficiently manages and processes the data that is coming or going to the radios.

The baseband unit, as shown in figure 13, features two sides, the right side housing ABIO 5G TDD and ASIL 5G components, while the left side accommodates ABIO 4G and ASIB 4G elements, as illustrated in figure 13.

Figure 13. Baseband Unit. [16]

1- 5G units

- ABIO 5G TDD

  The AirScale capacity plug-in units, as shown in figure 14, provide cell-specific baseband processing and optical interfaces to radio units.

  Connectivity via RF Module. 9 ports supporting Ethernet/ enhanced Common Public Radio Interface (eCPRI), Common Public Radio Interface (CPRI), or Open Base Station Architecture Initiative (OBSAI), reaching speeds of up to 9.83Gbps.

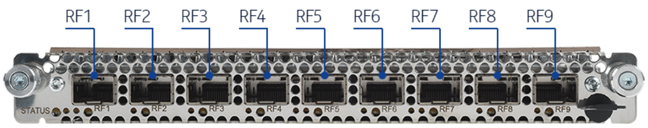

Figure 14. ABIO interfaces.

- ASIL 5G

  The AirScale control plug-in units, as shown in figure 15, provide transport, central antenna data routing, and centralized control for supported radio access technologies.

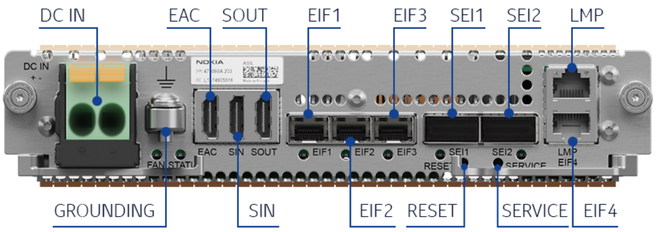

Figure 15. ASIL AirScale control plug-in unit interfaces.

2- 4G units

- ABIO 4G

  The AirScale capacity plug-in units, as shown in figure 16, provide cell-specific baseband processing and optical interfaces to radio units.

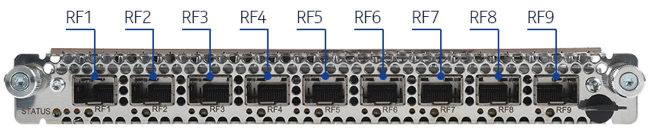

Figure 16. ABIO interfaces.

- ASIB 4G

  The AirScale control plug-in units, as shown in figure 17, provide transport, central antenna data routing, and centralized control for supported radio access technologies.

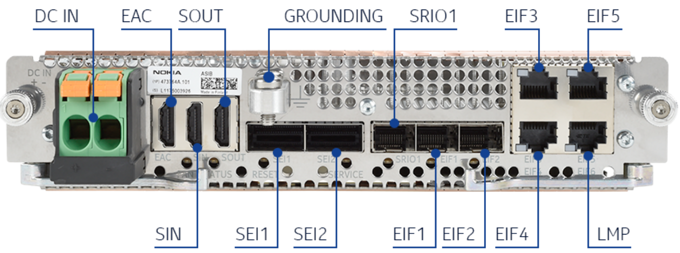

Figure 17. ASIB AirScale control plug-in unit interfaces.

ABIO 5G TDD and ASIL 5G: These components form the 5G baseband infrastructure, enabling TDD functionality and ensuring the efficient handling of uplink and downlink traffic in the 5G spectrum.

ABIO 4G and ASIB 4G: The 4G baseband components are integral for backward compatibility, allowing seamless integration with existing 4G networks.

4. AirScale Indoor Radio ASiR-sHUB APHA

APHA benefits:

- It facilitates seamless connectivity for 2G, 3G, 4G, and 5G CPRI interfaces, ensuring compatibility across various radio technologies.
- It offers twelve ASiR-pRRH ports for adaptable SFN setups that optimize network coverage and performance.
- It supplies power to the radios.
- It supports star and daisy-chain ASiR network configurations with four SFP ports that enhances network adaptability, as shown in figure 18.

Figure 18. APHA Smart Hub. [17]

5. AirScale mmWave Radio AWEUC

The AirScale mmWave Radio, as shown in figure 19, operates within the mmWave spectrum from 24 GHz to 27 GHz. Purpose-built for high capacity 5G connectivity, it targets busy areas requiring extensive coverage and capacity enhancement. AWGUC variants are high-power units providing a substantial 90° coverage in small cell deployments. It is based on Massive MIMO antenna with analog signal beamforming, connecting seamlessly with distributed units via eCPRI. [18]

Figure 19. AWEUC. [19]

6. AirScale Indoor Radio ASiR-pRRHs AHGEHA

Specifically designed for indoor deployment, the AHGEHA 4G AirScale Indoor Radio, as shown in figure 20, optimizes coverage and capacity within confined spaces, supporting many different frequency bands, ensuring a seamless transition between indoor and outdoor network environments. [16]

Figure 20. AHGEHA. [17]

7. AYGE GNSS Antenna

The AYGE GNSS antenna functions as a dual-band receiver with an integrated design, offering highly precise Pulse Per Second (PPS) and Global Navigation Satellite System (GNSS) time of day (ToD) data. It is responsible for the synchronization in the AirScale system modules (NR/SRAN).

AYGE is an integrated receiver antenna unit that combines both the receiver and antenna within a single device, as shown in figure 21. Its design eliminates the need for a separate antenna, enabling direct connection to a system module using an interface cable.

Figure 21. AYGE GNSS Antenna

6.3.2 Architecture

The physical network infrastructure is intricately connected in an NSA configuration, where the 5G system depends on the existing 4G infrastructure. The 4G infrastructure is used for anchoring and controlling the network authentication, while the 5G's used for data transmission.

The central hub of this interconnected system is the IXR router, serving as a pivotal point for routing data within both the 4G and 5G networks as shown in figure 22. The gNB (ABIO+ASIL) and eNB (ABIO+ASIB) are physically connected to the IXR router, creating a coordinated link for data exchange.

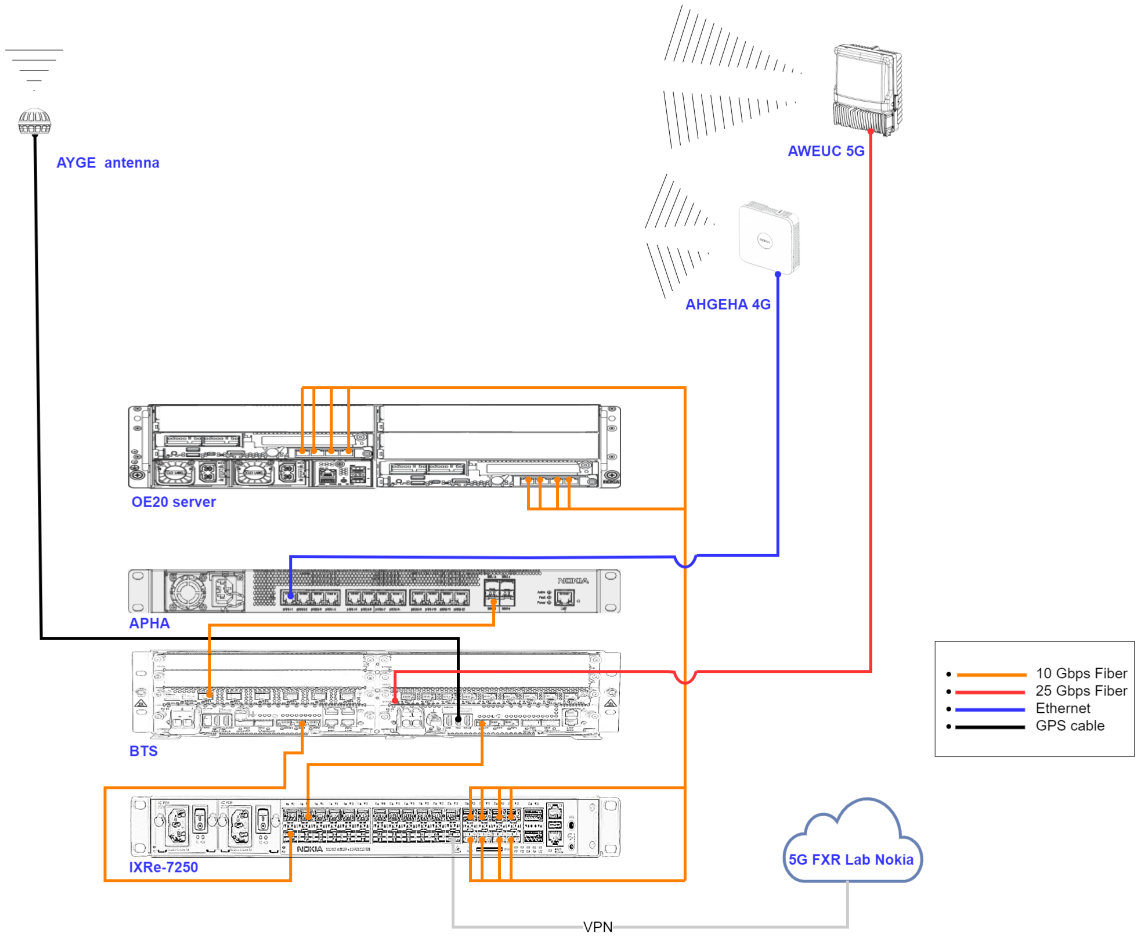

Figure 22. Network Architecture.

The integration of the 5G system involves connecting the gNB to the AYGE GPS for precise synchronization, In the 4G infrastructure, the eNB (ABIO+ASIB) is directly connected to the APHA smart hub, serving as an interface for the 4G radio (AHGEHA).

6.4 Traffic Flow

6.4.1 Traffic from The User

The data that originated from the user's device is transmitted to the radio and then passed to the Base Transceiver Station (BTS). The data is then directed to the IXR Router and then to the server for processing and management. After processing the data passes again to the IXR once again to be routed to its destination.

6.4.2 Traffic to The User

Conversely, the data that originated from a sender enters the network through the IXR and is then routed to the server for processing. After processing the data returns to the IXR and is then passed to the BTS. The BTS sends the data to the radio, ultimately reaching its intended recipient.

6.5 Spectrum Allocation

The allocation of spectrum and bandwidth is crucial for shaping the capabilities of both LTE (4G) and 5G technologies. The 5G radio is designed to accommodate a wide range of bandwidth options because of the need for narrowband carriers at lower frequency bands and the benefits of wideband carriers at higher frequency bands.

In LTE, the maximum bandwidth is capped at 20 MHz, a prudent choice given the typical spectrum allocation per operator, which is usually 20 MHz or less in deployed frequencies. While 5G supports up to 100 MHz for sub-6 GHz scenarios and an impressive 400 MHz for millimeter waves. 5G meets the demands of diverse applications because of the wide range of bandwidth.

The licensing to use these frequencies in Finland must follow TRAFICOM (Finnish Transport and Communication Agency) agency regulations. There are frequencies available for local use, such as frequency bands 2300-2320 MHz and 24.25-25.1 GHz, and n258 band included within this range. While outside these frequencies are owned by mobile network operators and require their permission to use. B7 band is owned by Telia Finland (Mobile Network Operator) and their permission is needed to use this band.

6.5.1 B7 band for LTE(4G)

The LTE (4G) network is allocated within the B7 band, utilizing the 2600 MHz frequency range with a bandwidth of 5 MHz. This allocation ensures a harmonious balance between coverage and capacity, making it well-suited for LTE technology. The 2600 MHz frequency range is capable of supporting various applications within the 4G infrastructure. Notably, AirScale Indoor Radio ASiR-pRRHs AHGEHA is compatible with the B7 band.

6.5.2 n258 band for 5G

The n258 band is characterized by its transformative capabilities. Positioned within the higher frequency spectrum, the n358 band is instrumental in delivering high data rates and low-latency communication—core attributes of 5G technology. The allocated bandwidth is 400 MHz, capable of supporting diverse applications. AirScale mmWave Radio AWEUC, or compatible devices, are adept at operating within the expansive bandwidth of the n258 band.

7 Conclusion

In conclusion, this thesis presented an introduction to 5G technology by demonstrating 5G principles, spectrum, technologies, architecture, and deployment. The thesis started with the foundation of the 5G and its characteristics, such as low latency, and high reliability. Spectrum is very important in wireless communication because it determines network coverage, capacity, and speed. Spectrum in 5G contain a wide range of frequencies across millimeter wave, mid-band, and low-band spectrums, each possess its own properties and challenges.

Duplexing techniques, Beamforming, Massive MIMO, and network slicing contribute to the capabilities of 5G. Duplexing techniques such as TDD and FDD enable simultaneous two-way communication between devices and the network, resulting in more efficient spectrum utilization, higher data rates, and lower latency. Beamforming is used for precise targeting of signals to the users. It enhances network spectral efficiency and coverage, throughput, and capacity. Massive MIMO technology involves deploying a large number of antennas at both the base station and user device sides and that improves spectral efficiency and capacity.

The practical application of these concepts was showcased through a detailed examination of the 5G NSA network deployment at Metropolia University. The goals, planning, preparation phases, spectrum allocation, network design, architecture, and hardware components involved were demonstrated. Traffic flow within this architecture, both from and to the user, was dissected to underscore the intricate pathways data traverses.

In summary, this thesis contributes to the understanding of 5G technology from theoretical foundations to practical deployment. As well as it offered documentation of the 5G network deployment at Metropolia University of Applied Sciences. The combination of theory and practicality of 5G provides a valuable foundation to students who are interested in 5G and wireless communication.

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