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5G TRAFFIC BALANCING AT THE 2100 MHZ FREQUENCY BAND

Master's Thesis
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ABSTRACT

Odewale Moses Oluwasegun: 5G Traffic Balancing at the 2100 MHz Frequency Band
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This thesis explores the strategic implementation of traffic balancing within the context of NR 2100 MHz frequencies, focusing on its potential to enhance capacity and throughputs in conjunction with existing NR bands and anchor LTE bands. The NR 2100 MHz frequency band is excellent for 5G coverage in sub-urban regions because of its cell range of about 5 km with a bandwidth of 20 MHz, therefore there is a great interest in how it will function after it is fully deployed by network operators.

The study delves into the implications of traffic balancing on network performance, user experience, and overall quality of service within the realm of 5G networks operating at the 2100 MHz frequency band. Through a comprehensive analysis of the intricate interplay between traffic distribution and spectrum allocation, this study investigates the feasibility and efficacy of achieving traffic balancing objectives. The examination of existing NR bands and anchor LTE bands as integral components of the balancing strategy offers a holistic understanding of the intricate network dynamics.

The potential advantages of traffic balancing are shown through empirical analyses of the KPIs post parametrization processes in a designated trial area using network planning and optimization software. The parameters tuning was done in such a way that it could reduce congestion on the NR frequency layers, optimize resource allocation, and subsequently improve network performance by deliberately shifting user traffic loads. The study demonstrates how such optimization enhances user experience by lowering latency, increasing throughput, and improving user experience in 5G networks. All parametrization and measurements were done on the Suomen Yhteisverkko Oy (SYV) network in Finland.

However, the study acknowledges the complexities inherent in implementing traffic balancing mechanisms. Dynamic mobility strategies and advanced algorithms are essential to achieve effective load distribution. Moreover, the introduction of traffic balancing procedures necessitates consideration of network architecture adjustments and potential interoperability challenges.

Ultimately, this study not only contributes to the advancement of network optimization strategies but also holds broader implications for the telecommunications industry. The findings underscore the potential of traffic balancing to reshape network efficiency, sustainability, and user satisfaction in the rapidly evolving landscape of 5G networks operating at the 2100 MHz frequency band. By addressing both technical and operational aspects, this thesis provides valuable insights for network operators, researchers, and stakeholders seeking to unlock the full potential of 5G technology.

Keywords: 5G, 2100 MHz Frequency Band, Traffic balancing, Network performance.

PREFACE

First, I would like to express my gratitude to my supervisors and examiners, Dr. Joonas Säe and Prof. Jukka Lempiäinen, for their impeccable guidance in the topic selection stage and tweaking it into viable research that is applicable in the ever-evolving mobile network world. My appreciation goes to Dr. Joonas Säe for constantly guiding me on the ropes needed to complete this thesis accurately.

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LIST OF ABBREVIATIONS

1G	First Generation of wireless cellular technology
2G	Second Generation of wireless cellular technology
3G	Third Generation of wireless cellular technology
3GPP	3rd Generation Partnership Project
4G	Fourth Generation of wireless cellular technology
5G	Fifth Generation of wireless cellular technology
5GC	Fifth Generation Core Network
5G NR	Fifth Generation New Radio
A1	An interface in Radio Access Network
AP	Application Protocol
AR	Augmented Reality
BLER	Block Error Rate
BS	Base Station
BSC	Base Station Controller
BSS	Base Station Subsystem
BTS	Base Transceiver
CA	Carrier Aggregation
CC	Component Carriers
C-plane	Control plane
CU	Centralised Unit
DC	Dual Connectivity
DL	Downlink
DRB	Data Radio Bearer
DU	Distributed Unit
en-gNB	EN-DC gNB
eMBB	enhanced Mobile BroadBand
eNB	E-UTRAN Node B
EN-DC	E-UTRAN-NR Dual Connectivity
EPC	Enhanced Packet Core
FDD	Frequency Division Duplex
FR1	Frequency Range 1
FR2	Frequency Range 2
gNB	next generation Node B
gNB-CU	next generation Node B – Centralized Unit
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HO	Hand-over
IFHO	Inter and Intra Frequency Hand-over
IoT	Internet-of-Things
IIoT	Industrial Internet-of-Things
IMLB	Integrated Mobility Load Balancing
IMT	International Mobile Telecommunications
ITU-R	International Telecommunications Union-Radiocommunications Sector
KPI	Key Performance Indicator
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
MeNB	Master E-UTRAN Node B
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
mMIMO	massive Multi-Input Multi-Output

MMS	Multimedia Message Service
mMTC	massive Machine Type Communications
N1	Frequency band 2100 MHz
N28	Frequency band 1800 MHz
N78	Frequency band 3500 MHz
NGMN	Next Generation Mobile Network
NR-ARFCN DL	NR Absolute Radio Frequency Channel Number Downlink
NR-ARFCN UL	NR Absolute Radio Frequency Channel Number Uplink
NG-C	Next Generation Control plane
NG-RAN	Next Generation Radio Access Network
NG-U	Next Generation User plane
NPN	Non-Public Networks
NR	New Radio
NSA	Non-Standalone
NTN	Non-Terrestrial Network
OFDM	Orthogonal Frequency-Division Multiplexing
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol layer
PDF	Probability Density Function
PDSCH	Physical Downlink Shared Channel
PDU	Protocol Data Unit
PSCell	Primary Serving Cell
QoE	Quality of Experience
QoS	Quality of Service
Rel-13	Release thirteen
Rel-15	Release fifteen
Rel-17	Release seventeen
RAB	Radio Access Bearer
RAN	Radio Access Network
RAT	Radio Access Technology
RRC	Radio Resource Control
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RU	Radio Unit
Rx	Receiver
SA	Standalone
SBA	Service-Based Architecture
SCG	Secondary Cell Group
SCS	Sub-carrier Spacing
SgNB	Secondary Next Generation Node B
SgNB-CU	Secondary Next Generation Node B Centralized Unit
S-GW	Serving Gateway
SINR	Signal to Interference and Noise Ratio
SMS	Short Message Service
SRB	Signalling Radio Bearer
SSB	Synchronization Signal Block
SS-RSRP	Synchronization Reference Signal Received Power
SS-RSRQ	Synchronization Reference Signal Received Quality
SS-SINR	Synchronization Signal to Interference-Noise Ratio
SYV	Finnish Shared Network Ltd (Finnish: Suomen Yhteisverkko Oy)
TDD	Time Division Duplexing
TSC	Time Sensitive Communication
Tx	Transmitter
UE	User Equipment
UL	Uplink

URLLC	Ultra-Reliable and Low Latency Communications
VR	Virtual Reality
V2X	Vehicle-to-everything
WCDMA	Wideband Code Division Multiple Access
X2 interface	An interface in Radio Access Network

1. INTRODUCTION

The quest to exchange information from one point to another with ease has led to the evolution of mobile technology from the phase of using handbag-sized first generation of wireless cellular technology (1G) phones which involved short conversations between a somewhat small number of professionals, to the era of second generation (2G) where mobile services grew through circuit switch (voice) and short message service (SMS) which birthed the third generation (3G) of mobile services that enable mobile internet access with a compact device.

It transitioned into the era of mobile video consumption, which enabled a higher data speed provided by the fourth generation (4G) services allowing for more design and usage of mobile applications, platforms, and devices like smartphones, Appstore, video and live-streaming content via YouTube and other media.

Consequently, the fourth industrial revolution that anchored its drivers on artificial intelligence, cloud computing, and robotics leverages on fifth generation (5G) mobile network as its enabler because it supports very low latency and high reliability humanistic/machine-centric communication; supports high user density; maintains high quality at high mobility; supports enhanced multimedia services, et cetera. [1].

Deployment of 5G is most popular with the Non-Standalone (NSA) Architecture option, which requires cooperation with a long-term evolution (LTE) network. The 5G next generation node B (gNB) is a Secondary node (SgNB, en-gNB), while the LTE evolved NodeB (eNB) assumes a master role (MeNB) [2] The Master role means the LTE layer will handle the control plane data. The LTE evolved packet core (EPC) is used since all control plane messages are taken within LTE over S1-C (interface between eNB and MME) to MeNB) [2]. The user equipment (UE) connection to the New Radio (NR) component is made with the help of LTE, which implies LTE connectivity always comes first.

The capabilities of UE, eNB, and gNB can help optimize traffic between layers, but most importantly, it can maximize UE peak throughput potential and the user experience. Due to the development of idle mode load balancing (IMLB) feature, UEs are directed to the best suitable targets based on UE and eNB-supported solutions. With this feature, when UE is released and moved to Radio Resource Control (RRC) idle mode, eNB compares UE-supported E-UTRAN NR Dual Connectivity (EN-DC) band combinations, NR bands enabled for EN-DC IMLB, and optionally, handover event (B1) measured NR coverage.[2] Distributing traffic between network resources to avoid overload on a single frequency layer, optimizing resource usage, and maximizing throughputs to improve user experience with 5G network services is crucial. This is done in radio access networks (RAN) by distributing the traffic across different cells, frequency layers, and radio access technologies. [2]

The widely deployed NR bands are N78 TDD (channel bandwidth of 100 MHz and carrier frequency of 3500 MHz) and N28 FDD (channel bandwidth of 10 MHz and carrier frequency of 700 MHz), and load balancing is done between the FR1 and FR2 of these bands in respect to the anchor LTE layer. In other to increase capacity, N1 FDD (channel bandwidth of 20 MHz and the carrier frequency of 2100 MHz) was deployed as it is utilized on 3G and 4G networks. The 3G 2100 MHz (Band 1) are refarmed in other to be re-purposed for NR 2100 MHz.

This thesis investigates how traffic balancing could be achieved in NR 2100 MHz frequencies with respect to the existing NR bands and anchor LTE bands to increase capacity and throughput. It also explains the implications of traffic balancing on network performance, user experience, and overall quality of service in 5G networks operating at the 2100 MHz frequency band.

2. 5G MOBILE COMMUNICATIONS

The fifth generation of mobile networks has had a commendable technology transformational impact on the world as it revolutionizes and connects everyone seamlessly. This fast connectivity has supported a variety of new applications such as the Internet of Things (IoT), Augmented Reality (AR), Virtual Reality (VR), Autonomous Vehicle et cetera. This chapter explains the concepts involved in understanding the fundamentals of this mobile communication generation.

2.1 Evolution of 5G

Over the past few decades, the landscape of cellular mobile communications has undergone continuous evolution, becoming an integral component of our daily routines. It has progressed from its early days of basic functions like voice calls and analog wireless technology to the present state of IP-based digital technology. This modern technology now underpins a wide array of applications that permeate various aspects of our lives, encompassing video, Internet access, the Internet of Things (IoT), and public safety services. Central to these transformative shifts is the Third Generation Partnership Project (3GPP), an organization that has dedicated over two decades to shaping the standards essential for cellular mobile communication.

Since 1998, 3GPP has been at the forefront of establishing the industry standards for cellular mobile communications, covering the evolution from 3G wideband code-division multiple access (WCDMA)/high-speed packet access (HSPA) to 4G LTE/LTE-Advanced, and most recently, 5G New Radio (NR). With the formulation of 5G NR standards within 3GPP Release 15 (Rel-15), the capabilities and features of cellular mobile communications have achieved unparalleled levels. In comparison to LTE/LTE-Advanced, NR boasts the ability to provide faster data rates, reduced latency, improved reliability, and access to new spectrum bands. The fundamental prerequisites for 5G, as outlined by the International Telecommunication Union - Radiocommunication Standardization Sector (ITU-R), have significantly shaped these advancements are summarized in Figure 1 [3].

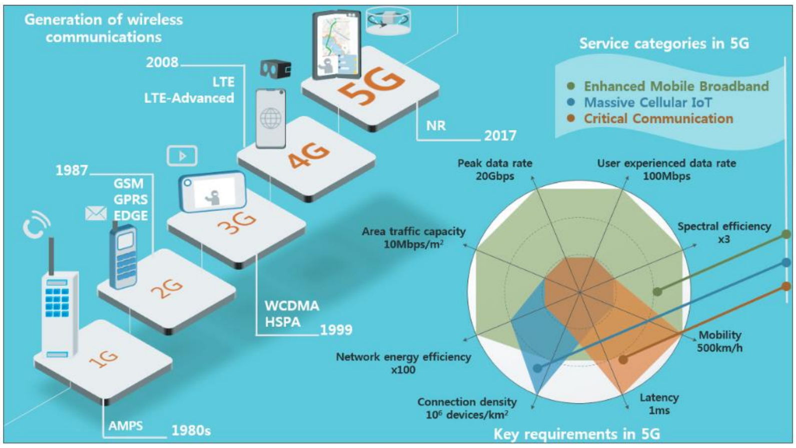

Figure 1. *Key requirements of 5G cellular mobile communications as defined by ITU-R. © 2019, IEEE [3]*

2.2 5G Releases

The initial version of the 5G System, which encompasses the 5G Core (5GC), 5G New Radio (NR), and 5G User Equipment (UE), is presently undergoing global commercial deployment across a wide range of frequency bands, including sub-6 GHz and millimetre wave (mmWave). The 3rd Generation Partnership Project (3GPP) standardized the second phase of 5G in Release 16 (Rel-16) specifications, finalizing it by March 2020. While Release 15 (Rel-15) primarily concentrated on improving mobile broadband services, Release 16 (Rel-16) shifted its focus to introducing new elements for Ultra-Reliable Low Latency Communication (URLLC) and the Industrial Internet of Things (IIoT). This included features such as Time Sensitive Communication (TSC), advanced Location Services, and the provision of support for Non-Public Networks (NPNs).

Furthermore, within Release 16 (Rel-16), essential new functionalities are being introduced, including NR on unlicensed bands (NR-U), Integrated Access & Backhaul (IAB), NR Vehicle-to-X (V2X), improvements to massive Multiple Input Multiple Output (MIMO) technology, the convergence of wireless and wireline communication, the implementation of the Service Based Architecture (SBA), and the introduction of Network Slicing. Consequently, it is anticipated that there will be a significant rise in the variety of use cases, connectivity types, users, and applications operating on 5G networks. This growth serves as a strong incentive for the implementation of additional security measures to address the expected surge in security threats in terms of both quantity, scale, and diversity.

Release 17 (Rel-17) and beyond is expected to include (but not limited to) enhanced support of NPN, enhanced support of wireless and wireline convergence, support for multicast and broadcast architecture, proximity services, enhanced support of multi-access edge computing, and enhanced support of network automation. The evolution of 5G releases can be captured in Figure 2 [4].

The 3GPP community has outlined significant areas of focus for consideration in Release 17 (Rel-17). These areas include NR-Light, with the goal of facilitating lightweight communications for industrial sensors and similar applications. Also, it encompasses improvements for the Industrial Internet of Things (IIoT), enhancements in Multiple Input Multiple Output (MIMO) technology, enhancements for side-link communication in both Vehicle-to-Everything (V2X) and public safety scenarios, support for Non-Terrestrial Networks (NTNs), coverage enhancement techniques, and the initiation of efforts to extend 5G New Radio (NR) to operate in frequencies above 52 GHz. The culmination of these efforts is anticipated to result in specifications within Release 18 (Rel-18).

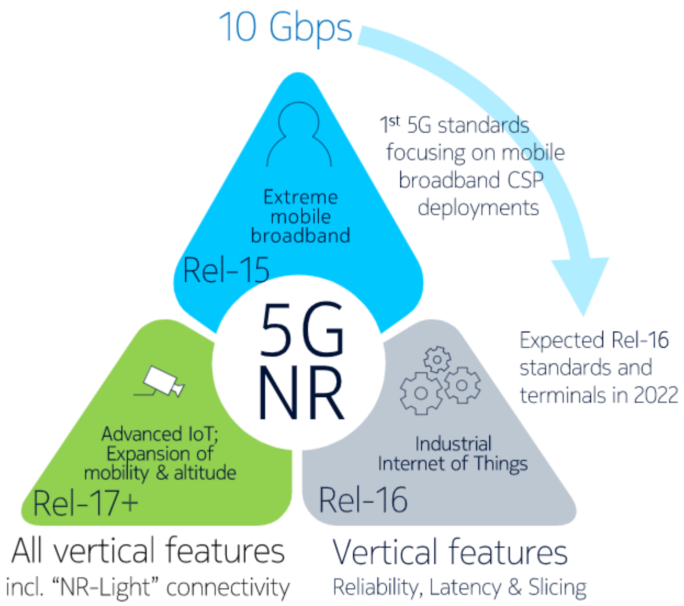

Figure 2. *Evolution of 5G from Rel-15 to Rel-17 [6].*

2.3 5G Use Cases

Following extensive years of research into the upcoming generation of communication systems, there is now a widely accepted understanding of the 5G service environment. Particularly, it is widely acknowledged that 5G represents more than just an incremental evolution of 4G cellular networks. It is not merely about introducing new spectrum bands, enhancing spectral efficiency, or achieving higher peak throughputs. Rather, 5G is poised to address novel services and innovative business models, diverging from the traditional "business-as-usual" evolution seen in previous generations.

These innovations will be cultivated through tight cooperation with various vertical industries, introducing fresh prerequisites and necessitating novel approaches to network design, construction, and administration. The evaluation of these vertical sectors' demands has been instrumental in the METIS-I project's findings, as well as discussions within forums like the Next Generation Mobile Network (NGMN) Alliance and ITU-R. Consequently, this collaborative effort has led to the identification of the three primary 5G service types [5]:

- **Enhanced Mobile BroadBand (eMBB),** often also referred to as extreme MBB (xMBB), which requires both extremely high data rates and low-latency communication in some areas, and reliable broadband access over large coverage areas.
- **Massive Machine-Type Communications (mMTC),** require wireless connectivity for tens of billions of network-enabled devices worldwide. Here, key vital priorities are scalable connectivity for an increasing number of devices, wide area coverage, and deep indoor penetration.
- **Ultra-reliable Low-Latency Communications (uRLLC),** requiring ultra-reliable low-latency and resilient communication links for, e.g., vehicle-to-anything (V2X) communication and industrial control applications.

These used cases are captured in different categories as seen in Figure 3 [6].

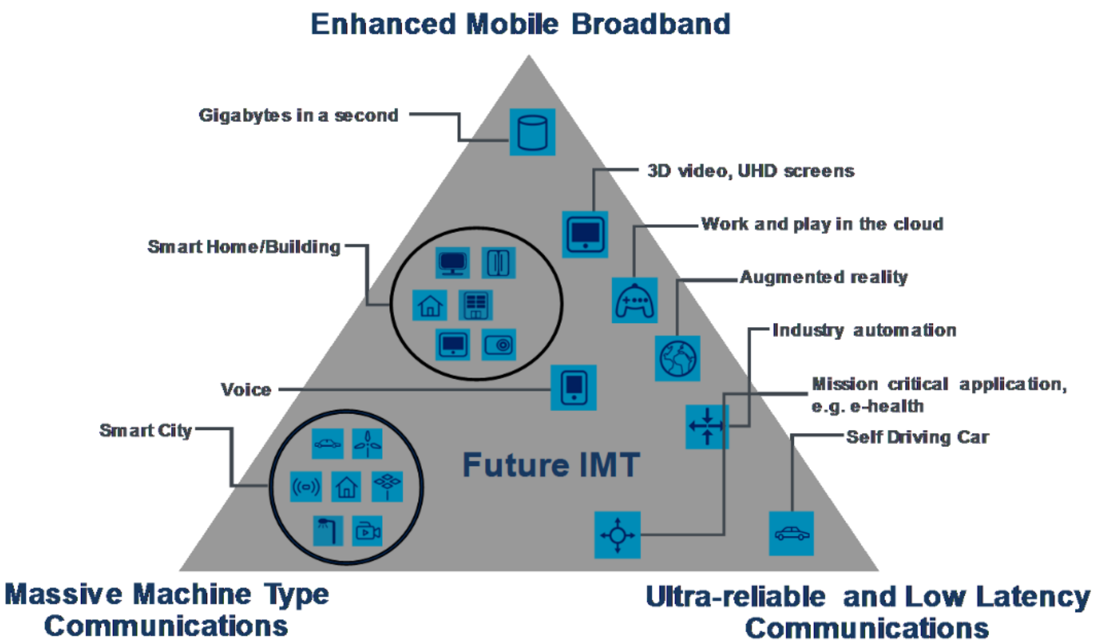

Figure 3. *5G use cases covering different applications [8].*

2.4 5G NR Bands

NR utilizes orthogonal frequency-division multiplexing (OFDM)-based waveform for both downlink and uplink with a subcarrier spacing (SCS) of $2^n \times 15\ kHz$ where 0 ≤ n ≤ 3 for data transmission. The applicable SCS depends on the frequency band and deployment scenarios.

Table 1 [3] below gives a summary of the newly defined NR bands, applicable SCSs, and the maximum bandwidths with respect to component carriers (CC) with and without carrier aggregation (CA), while Table 2 [3] compares NR with LTE-Advanced in terms of performance.

Table 1. *Newly defined NR bands and applicable subcarrier spacings [3].*

	Applicable frequency range	**Newly defined NR bands**	**Applicable SCSs for data transmission**	**Maximum bandwidth**
Frequency range 1 (FR1)	450 MHz - 7.125 GHz	N77 (3.3 - 4.2 GHz) N78 (3.3 - 3.8 GHz) N79 (4.4 - 5 GHz)	15/30/60 kHz	100 MHz per CC 1.6 GHz for CA (16CCs)
Frequency range 2 (FR2)	24.25 GHz - 52.6 GHz	N257 (26.5 - 29.5 GHz) N258 (24.25 - 27.5 GHz) N260 (37 - 40 GHz) N261 (27.5 - 28.35 GHz)	60/120 kHz	400 MHz per CC 6.4 GHz for CA (16CCs)

Table 2. *Performance comparison between release 15 NR and release 10 LTE-Advanced [3].*

	LTE-Advanced (Release 10)	NR (Release 15)
Peak data rate for downlink	Without CA: 600 Mb/s With CA (5 CCs): 3 Gb/s	Without CA: 4.9 Gb/s for FR1, 10.7 Gb/s for FR2 With CA (16 CCs): 78.2 Gb/s for FR1, 171.2 Gb/s for FR2
Peak data rate for uplink	Without CA: 300 Mb/s With CA (5 CCs): 1.5 Gb/s	Without CA: 2.4 Gb/s for FR1, 4.0 Gb/s for FR2 With CA (16 CCs): 38.2 Gb/s for FR1, 64.6 Gb/s for FR2
Average spectral efficiency	Downlink: 3.2 bps/Hz Uplink: 2.5 bps/Hz	Downlink: 13.9 b/s/Hz Uplink: 7.7 b/s/Hz
Achievable minimum air latency	4.8 ms	0.48 ms
Maximum mobility	350 km/h	500 km/h

Also, Table 3 captures some of the NR FR1 bands for duplex modes Frequency-Division Duplexing (FDD) and Time-Division Duplexing (TDD). The highlighted N1, N28, and N78 are frequency bands currently deployed on Telia and DNA network operators for the Suomen Yhteisverkko Oy (SYV) project in Finland.

Table 3. *NR operating bands in FR1 [4].*

NR Operating Band	Uplink (UL) operating band BS Rx UE Tx f_{UL_low} - f_{UL_high}	Downlink (DL) operating band BS Tx UE Rx f_{DL_low} - f_{DL_high}	Duplex Mode
N1	1920 MHz - 1980 MHz	2110 MHz - 2170 MHz	FDD
N2	1850 MHz - 1910 MHz	1930 MHz - 1990 MHz	FDD
N3	1710 MHz - 1785 MHz	1805 MHz - 1880 MHz	FDD
N5	824 MHz - 849 MHz	869 MHz - 894 MHz	FDD
N7	2500 MHz - 2570 MHz	2620 MHz - 2690 MHz	FDD
N8	880 MHz - 915 MHz	925 MHz - 960 MHz	FDD
N20	832 MHz - 862 MHz	791 MHz - 821 MHz	FDD
N28	703 MHz - 748 MHz	758 MHz - 803 MHz	FDD
N38	2570 MHz - 2620 MHz	2570 MHz - 2620 MHz	TDD
N41	2496 MHz - 2690 MHz	2496 MHz - 2690 MHz	TDD
N50	1432 MHz - 1517 MHz	1432 MHz - 1517 MHz	TDD
N51	1427 MHz - 1432 MHz	1427 MHz - 1432 MHz	TDD
N66	1710 MHz - 1780 MHz	2110 MHz - 2200 MHz	FDD
N70	1695 MHz - 1710 MHz	1995 MHz - 2020 MHz	FDD
N71	663 MHz - 698 MHz	617 MHz - 652 MHz	FDD
N74	1427 MHz - 1470 MHz	1475 MHz - 1518 MHz	FDD
N78	3300 MHz - 3800 MHz	3300 MHz - 3800 MHz	TDD
N77	3300 MHz - 4200 MHz	3300 MHz - 4200 MHz	TDD

N79	4400 MHz - 5000 MHz	4400 MHz - 5000 MHz	TDD

2.5 5G NR Architecture

There are two types of 5G architecture which are the Non-Standalone (NSA) and Standalone (SA) options. It is expedient to know some options on how to connect either an LTE core (EPC) network or NR core network (5GCN) with LTE base stations (eNB) and NR base stations (gNB), and two of these options were adopted for NSA (Option 3) and SA (Option 2) architecture as seen in Figure 4.

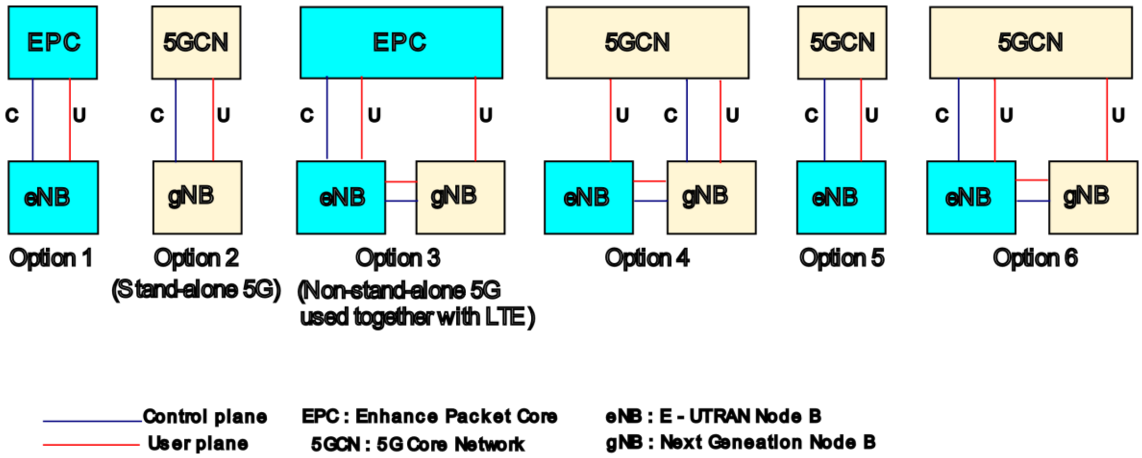

Figure 4. *5G NR Options According to 3GPP Release 15 [5]*

2.5.1 Non-Standalone (NSA) Architecture

In option 3x, an LTE cell takes on the role of an "anchor cell," initiating the RRC connection through the LTE radio link. Subsequently, a 5G user plane connection is overlaid onto the existing LTE user plane connection. This configuration is commonly known as EN-DC. In this specific context, the LTE base station serving as the anchor is termed the Master eNB (MeNB), while the 5G base station is known as the Secondary gNB (SgNB). The 4G core network, known as the Evolved Packet Core (EPC), remains in use with slight adjustments made to the Mobility Management Entity (MME) and the Serving Gateway (SGW). [7]. The LTE cell used as an anchor cell needs significantly enhanced functionality, so the relevant release and features must naturally be loaded. In most cases, the 5G equipment is deployed in areas where there is already an existing LTE network, and this must be taken into account when planning the 5G layers.

The NSA 3x architecture is seen in Figure 5, which captured the control plane and user plane connectivity to the MME and SGW.

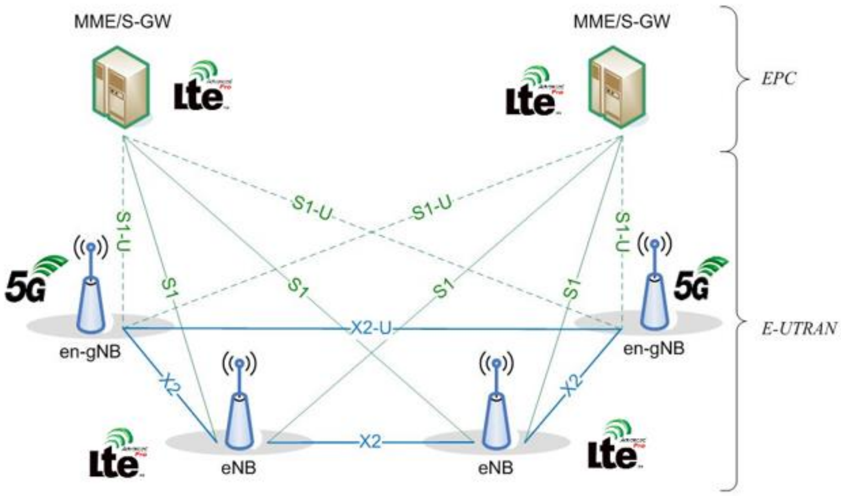

Figure 5. *5G NR NSA Deployment Option 3x Architecture [9].*

The NSA architecture serves as an interim phase in the progression towards a complete 5G deployment, where the 5G Access Network connects to the existing 4G Core Network [7]. Within this NSA configuration, the (5G) New Radio (NR) base station, designated as the en-gNB (enhanced gNB), establishes a connection with the (4G) Long-Term Evolution (LTE) base station, referred to as the eNB, via the X2 interface. It's worth noting that the X2 interface was initially introduced before Release 15 to facilitate communication between two eNBs. Release 15 also extends its support to connecting an eNB and en-gNB, enabling the implementation of the NSA architecture.

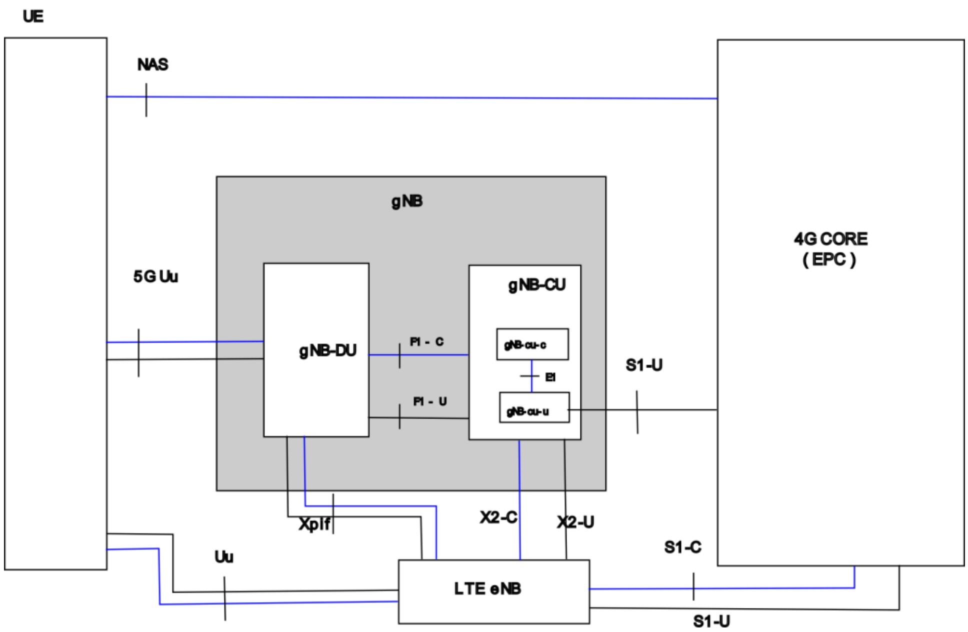

Figure 6. *5G NR NSA RAN Architecture [9].*

2.5.2 Standalone (SA) Architecture

In SA, both C-Plane signalling and information data transfer are done from UE to gNB. In gNB, DU should be connected to CU via 3GPP provided F1 AP Protocol only for both the control and user plane. The gNB is connected via next generation control plane (NG-C) and next generation user plane (NG-U) to a 5G Core Network. 5G Radio control parameters will get exchanged only via 5G NR RAT, as seen in Figure 9. With this approach, the concept of Micro-services offers a viable approach for developing and scaling a 5G System. One of the key goals when employing microservices is to break down system components into highly granular, function-based elements, resulting in lightweight services with ample capacity for resource sharing. This objective aligns seamlessly with the requirements for defining communication scenarios such as enhanced Mobile Broadband (eMBB), massive Machine-Type Communication (mMTC), and Ultra-Reliable Low Latency Communication (URLLC).

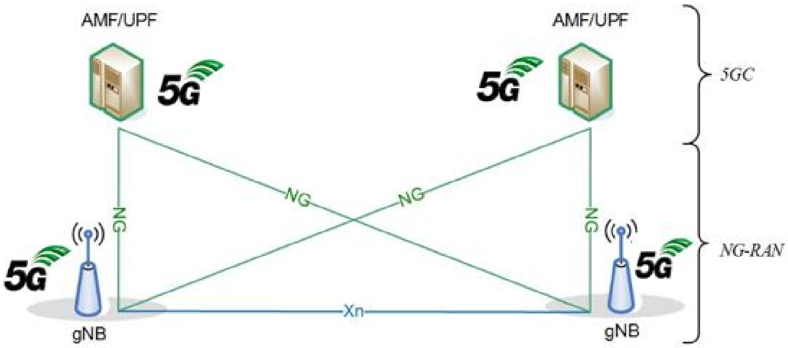

Figure 7. *5G NR SA Deployment Option 2 Architecture [9].*

Figure 7 above shows that the SA architecture can be seen as the pure 5G deployment, not needing any part of a 4G network to operate.

The NR base station (logical node gNB) in Figure 7 connects with each other via the Xn interface, and the Access Network (called the NG-RAN for SA architecture) connects to the 5GC network using the NG interface.

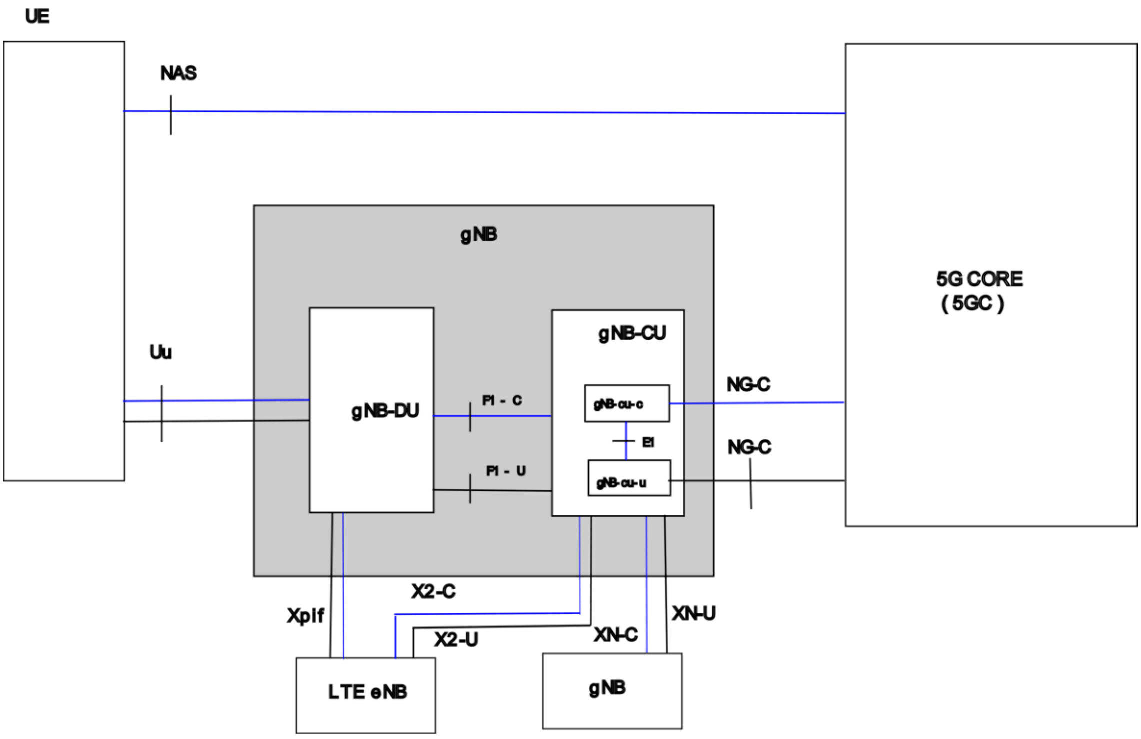

Figure 8. *5G NR SA RAN Architecture [9].*

3. 5G MOBILITY

In a 5G wireless network, the mobility state when a UE is travelling across different sites can either be in a Connected mode or Idle mode. In these mobility scenarios, i.e., in Connected mode mobility UE does perform handover (HO) and in Idle mode mobility UE does cell selection/reselection. The HO procedure is done in such a way that the UE reports measurement report with neighbour cell PCI and signal strength to source cell while source cell takes the decision to start handover procedure to best target cell and target cell completes the HO procedure. The 5G frequency HO is either network controlled or UE controlled. The network-controlled HO is implemented in the 5G NR UEs in RRC_CONNECTED mode and are categorized into cell level and beam level. This chapter explains different handover types in a Connected mode mobility.

3.1 Intra-NR Intra-gNB Mobility

The intra-frequency handover is based on downlink measurements carried out by the UE. The gNB provides the measurement configurations to the UE via RRC signalling once the UE capabilities are known. A3 and/or A5 measurement event are used for handover purpose.

There is a feature that supports a network based intra-frequency of the serving primary serving cell (PSCell) within a gNB (the same CU but different DUs). The SgNB triggers and manages PSCell change and also configures Intra-frequency measurements on UE by tunnelling RRC signalling via MeNB over X2 AP messages (or directly via SRB3) while pre-defined neighbour's HO threshold (A3/A5) event is triggered based on Synchronization Reference Signal Received Power (SS-RSRP) and Synchronization Reference Signal Received Quality (SS-RSRQ) measurements and the neighbour relations are operator configurable per PSCell. The workflow is as shown in Figure 9 below.

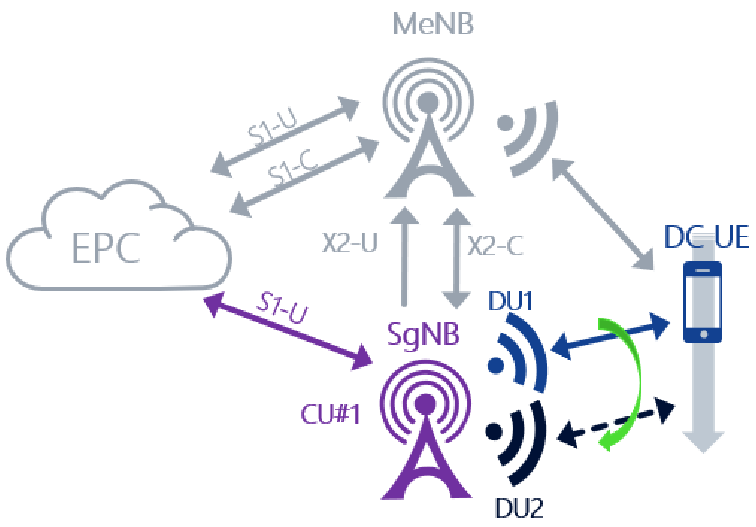

Figure 9. *Workflow between CU and different DUs [12].*

It is important to note that the intra-frequency PSCell change is based on downlink measurements carried out by the UE and it is done through measurement configuration and measurement report.

3.1.1 Intra-NR Intra-gNB Measurement Configuration and Report

The gNB provides NR measurement configurations to the UE indirectly over MeNB (in EN-DC signalling on air interface is possible only over LTE) as seen in Figure 10 and the measurement profile captures the reported events from A3 and A5; hysteresis, thresholds, time to trigger and trigger quantity for SS-RSRP and SS-RSRQ.

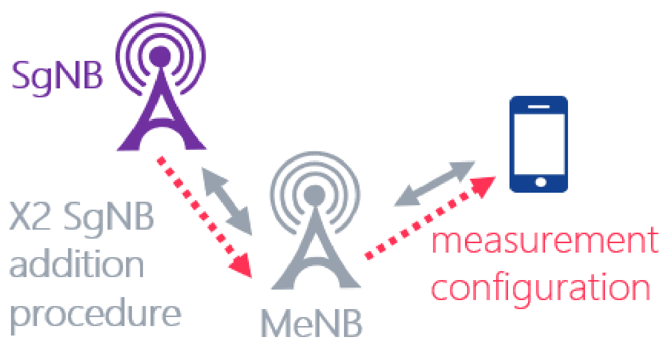

Figure 10. *Measurement configuration workflow [12].*

The UE can directly send NR measurement report to SgNB with Secondary Cell Group (SCG) SRB3 depending on the features in use or indirectly over MeNB via X2AP RRC transfer message as seen in Figure 11.

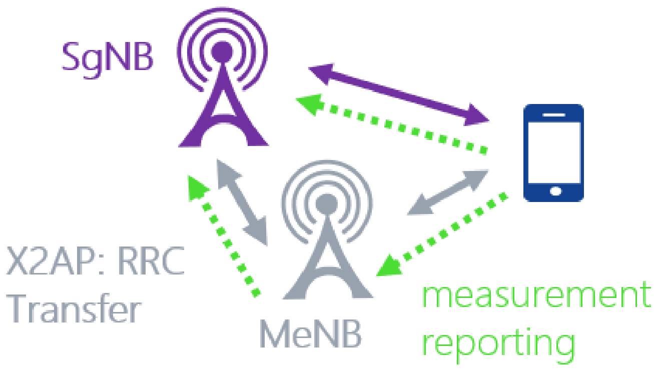

Figure 11. *Measurement report workflow [12].*

When the feature for Intra-Frequency Intra gNB mobility is activated, UE measurement can be configured either during SgNB Addition Preparation procedure (within the X2AP: SgNB Addition Request Acknowledge message) or PSCell change procedure (within X2AP: SgNB Modification Required). This is performed via RRC: RRC Connection Reconfiguration message containing a measConfig IE where the measurement object is serving carrier frequency with A3 or A5 event-based measurement been configured on the UE. The UE then confirms to MeNB via RRC: RRC Connection Reconfiguration Complete that measurement configuration is applied – delivered to SgNB inside the X2AP: SgNB Reconfiguration Complete message as seen in the extended measurement configuration workflow in Figure 12.

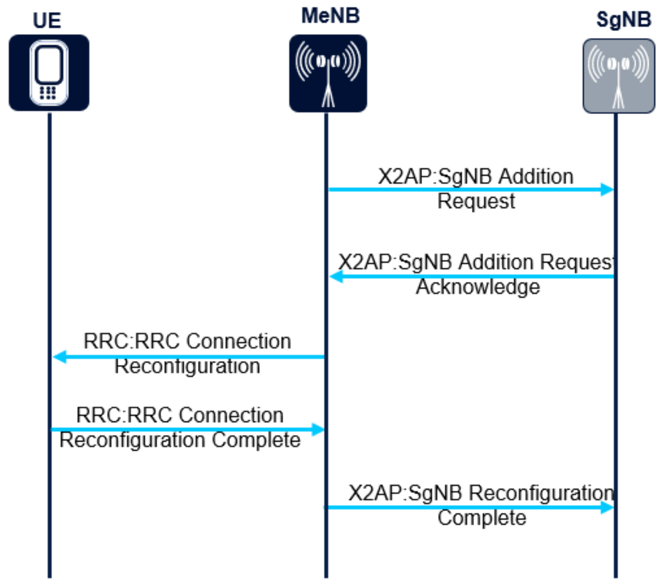

Figure 12. *Measurement configuration extended workflow [12].*

3.1.2 Intra-NR Intra-gNB Handover Process

The HO processes involve different stages with the aim to have RRC signalling towards UE to be done through MeNB over X2-C interface or directly via SRB3 over NR and these processes are [12]:

- NR Handover Decision: SgNB-CU receives RRC NR measurement report from MeNB via X2 AP RRC Transfer message.
- NR Handover Preparation: SgNB-CU selects the target PSCell (based on A3 and/or A5 measurement report) and prepares target cell for PSCell change via F1 UE Context Setup procedure. If CA feature is active in the SgNB, new Serving Cells (SCells) are assigned to the UE during PSCell change while the SCells are implicitly activated when SCells are configured.
- NR Handover Execution: SgNB-CU requests the source gNB-DU to stop scheduling UL/DL data via F1 UE Context Modification while Bearer is suspended. SgNB-CU initiates NR RRC Reconfiguration to UE over MeNB via X2 SgNB Modification procedure to execute the PSCell change and when the UE accesses the target PSCell, target SgNB-DU resumes DL/UL data transfer.
- NR Handover Completion: SgNB-CU releases the UE context at source gNB-DU via F1 UE Context Release procedure.

3.1.3 Intra-CU Inter-DU 5G Cell Change

This is an intra-frequency Inter en-gNB PSCell change and the mobility occurs within the same en-gNB (Intra CU) but between different DUs (Inter DU). The HO procedure is initiated by SN and direct SCG SRB3 is used to receive NR measurement report. Also, the PSCell change is supported for NSA calls with at least one established SCG split Data Radio Bearer (DRB) and en-gNB configures (indirectly) the Synchronization Signal Block (SSB) based Intra-frequency measurements at UE (SS-RSRP / SS-RSRQ based A3 / A5 measurements) as seen in Figure 13.

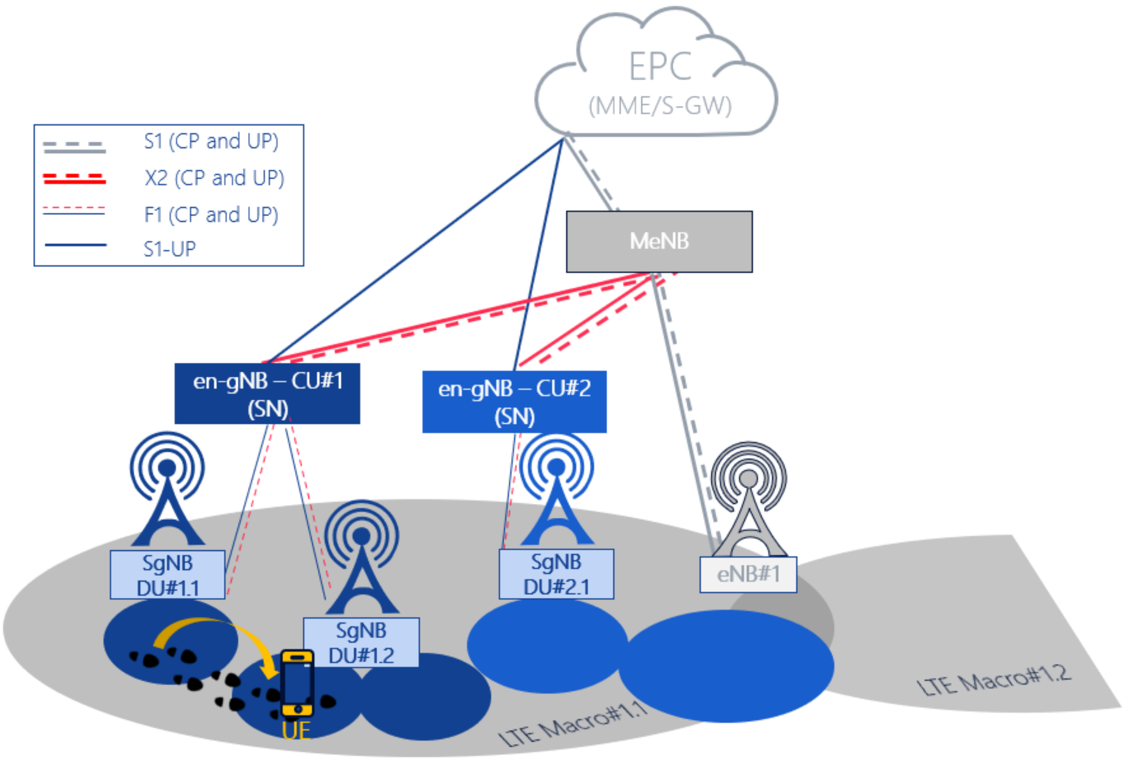

Figure 13. *Intra-CU Inter-DU 5G cell change [12].*

3.2 Inter-NR Inter-gNB Mobility

Inter frequency handover procedure is based on solutions already implemented for intra frequency mobility. The difference is measurement gaps support and PSCell change impact on EN-DC band combinations. The functionality applies to UEs in RRC Connected state with at least one SCG-split DRB established. UE mobility can be triggered from FR1 to FR2 carriers or between carriers within FR2 and for both cases per-FR capable UE is required which means MeNB coordination is not needed. It should be that per-FR capable UE means the UE can measure each FR independently thereby developing into an FR1 to FR2 mobility or an FR2-to-FR2 mobility. The feature responsible for this type of mobility is network controlled and it is applicable to classical or cloud gNB for all: inter-en-gNB and intra-en-gNB (Intra DU or Inter DU) cases. The SgNB triggers PSCell change and configures Inter-frequency measurements on UE by tunnelling RRC signalling via MeNB over X2 AP messages (SRB1) or directly with SRB3 as seen in Figure 14.

A1, A2 and A3/A5 events are triggered based on SS-RSRP/SS-RSRQ measurements (combined decision is supported as well) and the neighbour relations are operator-configurable per PSCell.

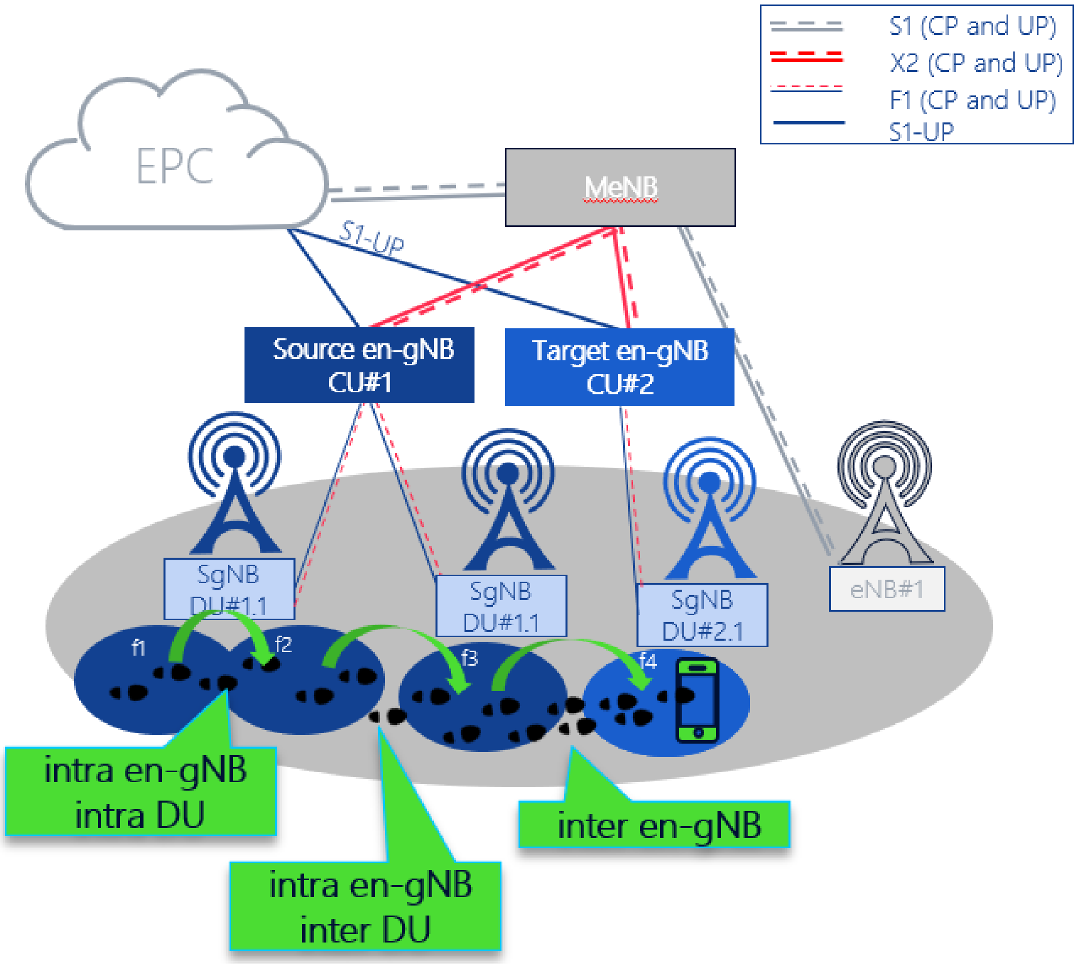

Figure 14. *Inter-CU Inter-DU 5G cell change [13].*

3.2.1 Inter-Frequency Measurements Lifecycle

All events are triggered based on SS-RSRP/SS-RSRQ (or combined) measurements and the trigger point to start inter frequency measurement is A2 event and when A2 event is reported, the UE is being configured with inter frequency A3/A5/A3&A5 and A1 measurements according to the configuration. The A1 measurement is done together with the A3 and/or A5 and it is used for terminating inter frequency A3/A5 measurements and when radio conditions become better and UE reports A1 event, it is reconfigured with A2 measurement again. If event A3 or A5 or A3&A5 (depending on a configuration) is reported, HO procedure is triggered and after HO execution, the UE is attached to a new (target) cell and reconfigured with A2 measurement again. The Inter frequency measurements lifecycle is as captured in Figure 15 below.

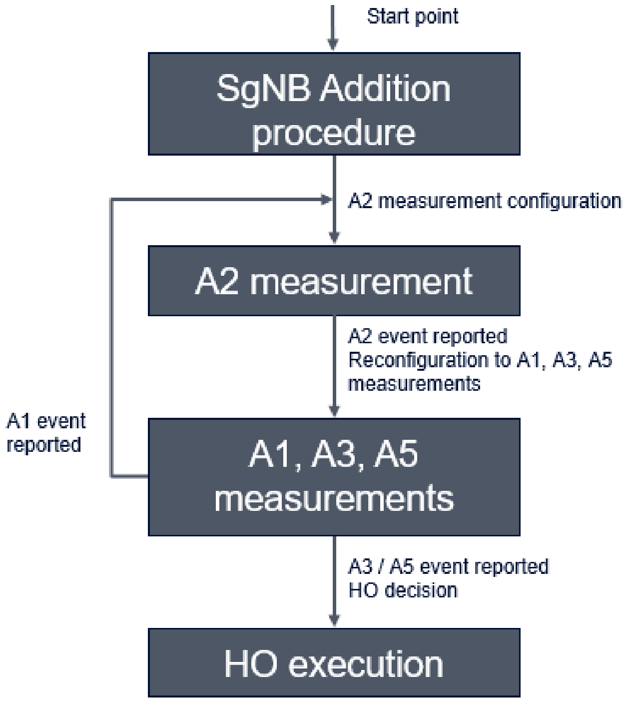

Figure 15. *Inter-Frequency Measurements Lifecycle [13].*

Below in table 4 are also some of the possible NR measurement handover events.

Table 4. *NR Handover Events [11].*

Event Type	Description
Event A1	Serving becomes better than threshold
Event A2	Serving becomes worse than threshold
Event A3	Neighbor becomes offset better than serving
Event A4	Neighbor becomes better than threshold
Event A5	Serving becomes worse than threshold1 and neighbor becomes better than threshold2
Event A6	Neighbor becomes offset better than S Cell
Event B1	Inter-RAT neighbor becomes better than threshold
Event B2	Serving becomes worse than threshold1 and inter RAT neighbor better than threshold2

3.2.2 Inter-NR Inter-gNB Measurement Configuration and Report

The measurement configuration and report involve different layers of events and messaging from the inter frequency measurement configuration; the A1 measurement received; A2 measurement; HO preparation; intra-DU HO execution.

Inter frequency measurement configuration [13]

- The initial step 1: NSA 3x Call establishment. After call establishment procedure, the UE is the DC UE in EN-DC architecture: connected to one LTE cell and one 5G cell. After SgNB addition procedure, the UE is configured with A2 measurement.
- Step 2: When A2 event conditions are fulfilled (PSCell quality goes below the threshold for the defined time) UE sends measurement report to the SgNB.
- Step 3: SgNB decides to reconfigure UE with A1 measurement together with inter frequency A3 or A5 or A3&A5 measurements depending on SgNB configuration and following UE capabilities: inter frequency measurement and report support; per-FR measurement support; and target frequency band support (defined in NRHOIF).

The inter-frequency measurement configuration steps are depicted in figure 16 below:

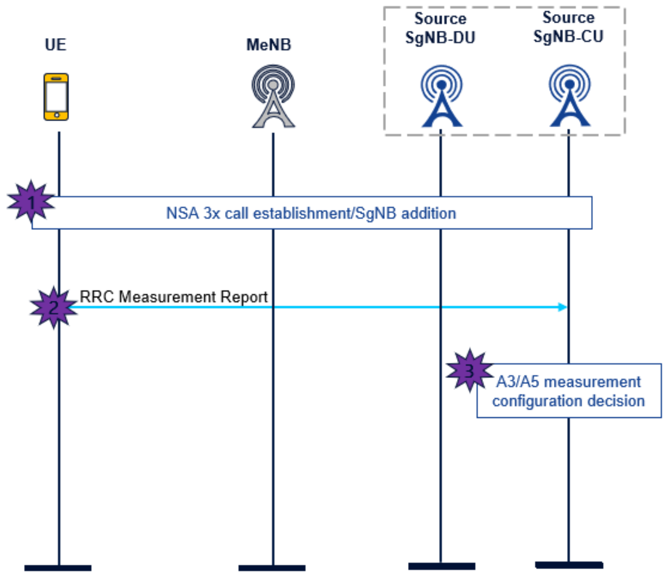

Figure 16. *Inter-Frequency Measurements Configuration Steps 1,2 and 3. [13].*

- Step 4: If PSCell frequency is FR1 and UE will be configured with measurement of frequency from FR2, then no MG is needed. SgNB-CU configures the UE with proper measurements with measConfig IE in RRC Reconfiguration message.

- Step 5: If PSCell frequency is FR2 and UE will be configured with measurement of frequency from FR2 also, MG configuration is required. At F1AP: UE Context Modification Request message with measConfig IE is sent to the DU and the DU configures MG parameters at the user plane and send them to the CU with F1AP: UE Context Modification Response message with meaGapconfig IE and the UE is then scheduled on the configured MG pattern. The SgNB-CU configures the UE with proper measurements using measConfig IE together with meaGapConfig IE in RRC Reconfiguration message. Then after receiving RRC Reconfiguration Completed, SgNB-CU sends F1AP: UE Context Modification Request with RRC Reconfiguration Complete indicator. These steps are captured in figure 17 as seen below:

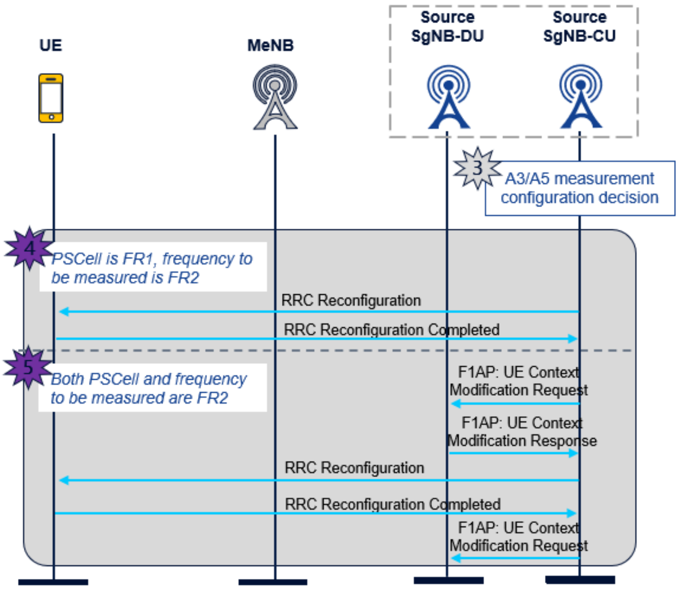

Figure 17. *Inter-Frequency Measurements Configuration Steps 4 and 5. [13].*

A1 measurement received [13]

- Step 6: A measurement report has been sent by the UE.
- Step 7a: SgNB-CU receives A1 measurement report. The UE would be reconfigured to A2 measurement.
- Step 8a: If Measurement Gaps for A3/A5 measurements were not configured, SgNB-CU just reconfigures the UE to A2 measurement with measConfig IE in RRC Reconfiguration message as seen in Figure 18 below:

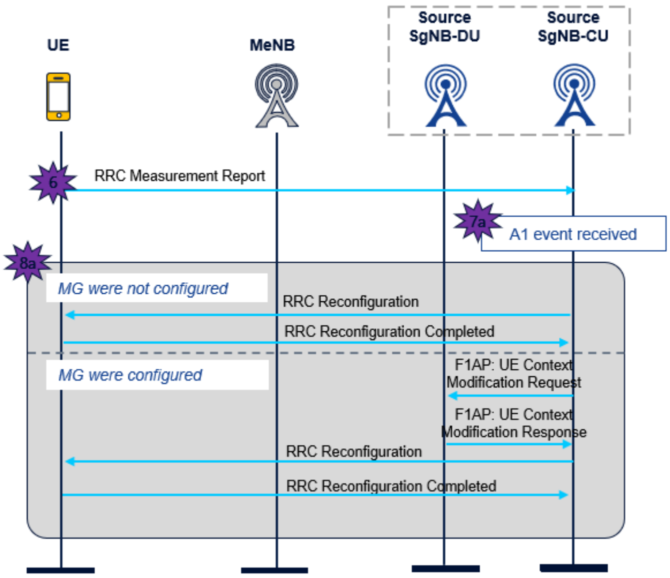

Figure 18. *A1 Measurement Received Steps 6, 7a and 8a. [13].*

A2 measurement received, HO preparation [13]

- Step 7b: SgNB-CU receives A3 / A5 measurement report, which is the trigger for the Handover decision.
- Step 8b: Depending on target cell location, further procedure is based on already implemented intra-frequency solutions as seen in Figure 19 below:

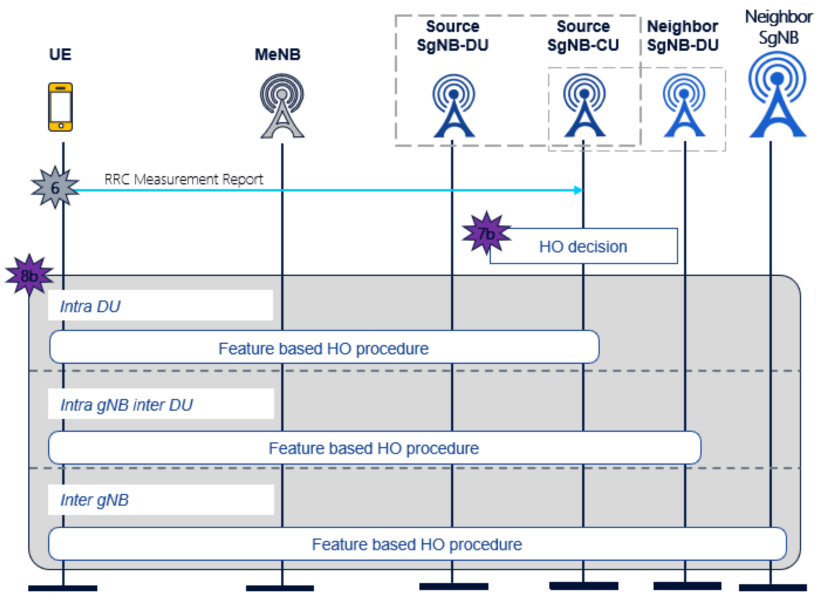

Figure 19. *A2 Measurement Received with HO Preparation Steps 7b and 8b. [13].*

Message flow Intra DU HO execution [13]

- Step 1: gNB-CU performs Admission control for target cell.

- Step 2: gNB-CU sends F1AP: UE Context Modification Request to the gNB-DU to suspend scheduling and to allocate new RLC and MAC resources for the target cell.
- Step 3: Source cell RLC layer suspends DL data transmission.
- Step 4: gNB-CU triggers the network based inter-frequency intra-DU PSCell change towards the target cell by sending RRC Reconfiguration message to command the UE to move to the target cell.
- Step 5: UE performs random access procedure to the new PSCell.
- Step 6: UE sends RRC Reconfiguration Complete message to the SgNB-CU.
- Step 7: After successful handover to target cell gNB-CU switches the data path towards the target cell. These workflows are captured in figure 20 below:

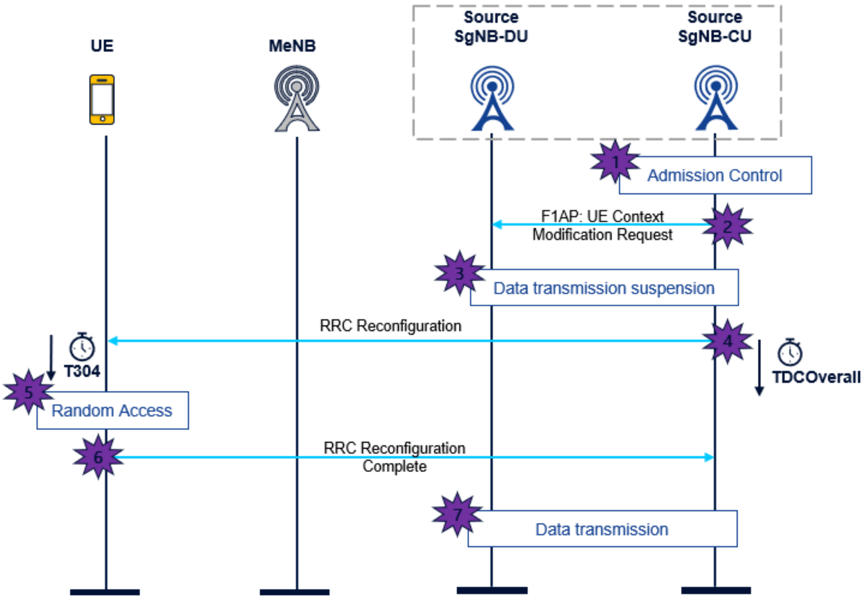

Figure 20. *Intra-DU HO Execution Workflow [13].*

Message flow Inter-DU Intra-gNB HO execution [13]

- Step 1: gNB-CU performs Admission control for target cell.
- Step 2: gNB-CU sends F1AP: UE Context Setup Request to the target SgNB-DU to perform UE context and DRB establishment. Target gNB-DU confirms with F1AP: UE Context Setup Response.

- Step 3: gNB-CU sends F1AP: UE Context Modification Request to source gNB-DU to stop UE data transmission and UE scheduling.
- Step 4: gNB-CU triggers the network based inter-frequency intra-gNB inter-DU PSCell change towards the target cell by sending RRC Reconfiguration message to command the UE to move to the target cell.
- Step 5: UE performs random access procedure to the new PSCell.
- Step 6: After successful handover on target cell gNB-CU switches the data path towards the target cell.
- Step 7: SgNB-CU requests Source gNB-DU to release the old UE context with F1AP: UE Context Release procedure. All these steps are as captured in figure 21 below:

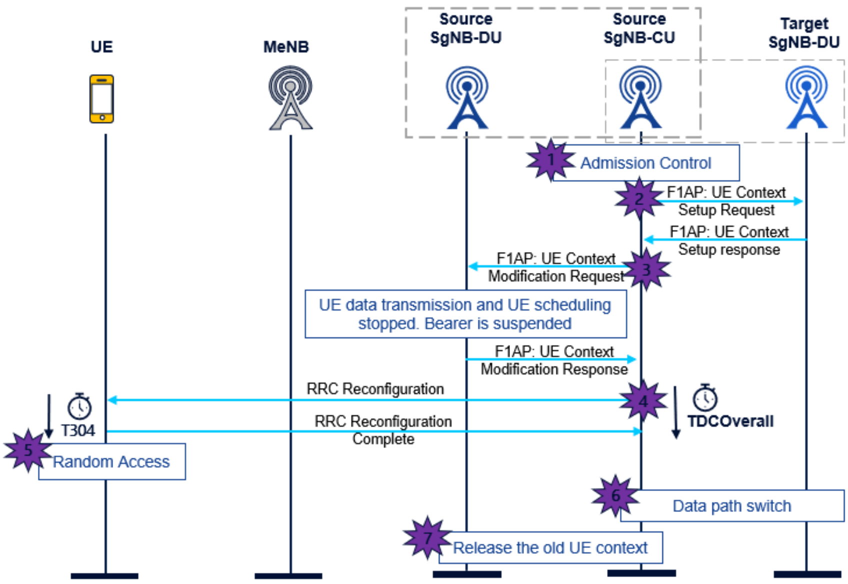

Figure 21. *Message flow Inter DU intra gNB HO execution [13].*

4. 5G TRAFFIC STEERING AND BALANCING

In 5G networks, traffic steering and load balancing are techniques used to optimize network performance, manage resources efficiently, and enhance the user experience. Despite apparent similarities, they have distinct functions which they exhibit and both have an inter-working relationship in other to achieve network's desired goals of improved QoS and QoE.

4.1 Traffic steering in EN-DC

Traffic steering provides balancing of EN-DC capable UEs across suitable frequency layers to optimize load on cells and provide targeted experience for defined group of UEs. It is driven from the policy information and QoS/QoE or any possible criteria for defined group of users and it uses the underlying capabilities of RAN to achieve the desired throughput and goals. The technicality involved for these functionalities to be seamless are discussed below.

4.1.1 EN-DC Aware Idle Mode Steering

It is of utmost importance to steer EN-DC UEs to dedicated LTE layers in other for the eNB to calculate a simplified theoretical maximum throughput for the UEs. The throughput calculation takes into account eNB CA configuration, UE capabilities and PSCell contribution from NR with the LTE frequencies sharing the highest peak throughput get highest idle camping priority. Optionally, B1 measurements are used to check NR layer coverage before adding NR throughput contribution and the results serve as input to which LTE layer EN-DC UE should camp on. Figure 22 below shows the UE capability assumption for LTE frequency layer to initiate an En-DC session on:

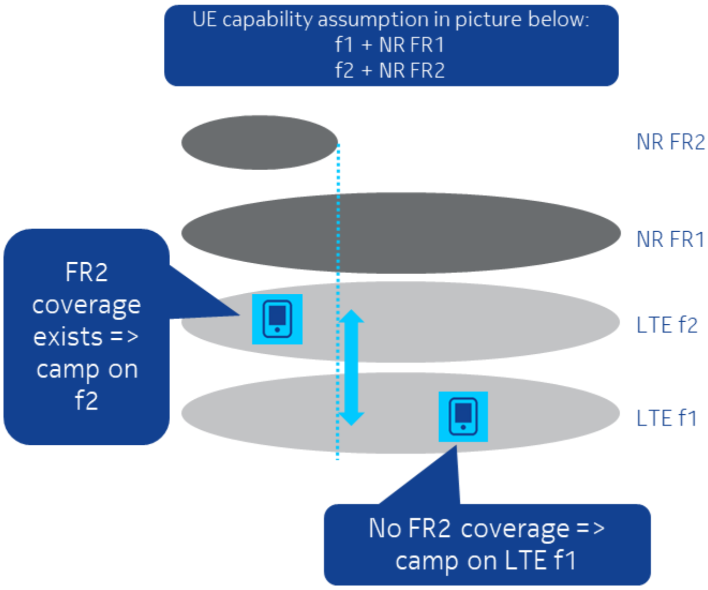

Figure 22. *UE Capability Assumption[13].*

4.1.2 NR frequency-based layering at EN-DC setup

In the event of multiple measurement results been included in SgNB addition, the gNB sorts the measurement results by descending frequency from the highest frequency (highest priority) down to the lowest frequency (lowest priority). The measurement results are sorted by their frequency (represented by NR-ARFCN) where the gNB considers the measurement results from the highest frequency at first and If all reported cells from that frequency are overloaded, measurement results from the next lower layer frequency are taken into account.

The measurement results on a given frequency are kept in the same order in which they are received from eNB (order reported by the UE), sorted from highest to lowest reported measurement quantity, which may be RSRP or RSRQ. The gNB selects the best reported PSCell with available resources and in case of FR2, there is a feature (if enabled) which allows load balancing in NR Cell group (FR2 cells within a sector) in such a way that the best reported PSCell is selected among NR Cell group cells with load below a configured load threshold and if all cells are above the load threshold, the best cell with a load below the first chosen PSCell is selected. These sequences are described in Figure 23 below:

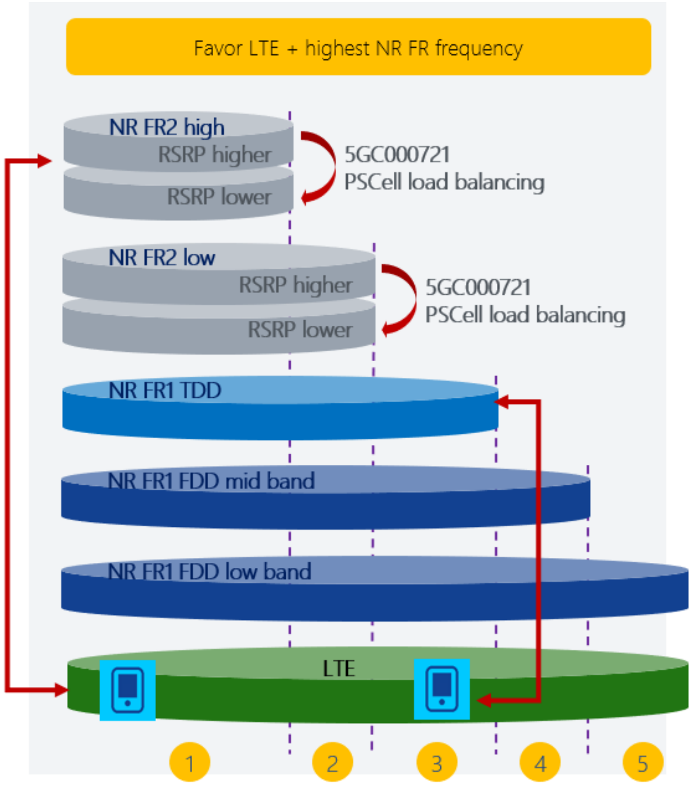

Figure 23. *NR frequency-based layering at EN-DC setup [13].*

4.1.3 A1 based traffic steering to preferred NR layer

There is a feature for traffic steering to a higher capacity layer for co-located sites based on coverage layer signal strength and the steering is done only for selected UEs in a good radio condition assuming these are the UEs in a serving cell center and also under a coverage of higher capacity neighbor cell (co-located sites). This decrease the time the UE has measurement gaps activated in comparison to the time the UE is with measurement gaps. On reception of the A1 Measurement Report, gNB activates periodical inter-frequency A4 measurements according to an enabled feature and the configuration of the A4 measurements is configurable via O&M parameters which is iterated in Figure 24 below:

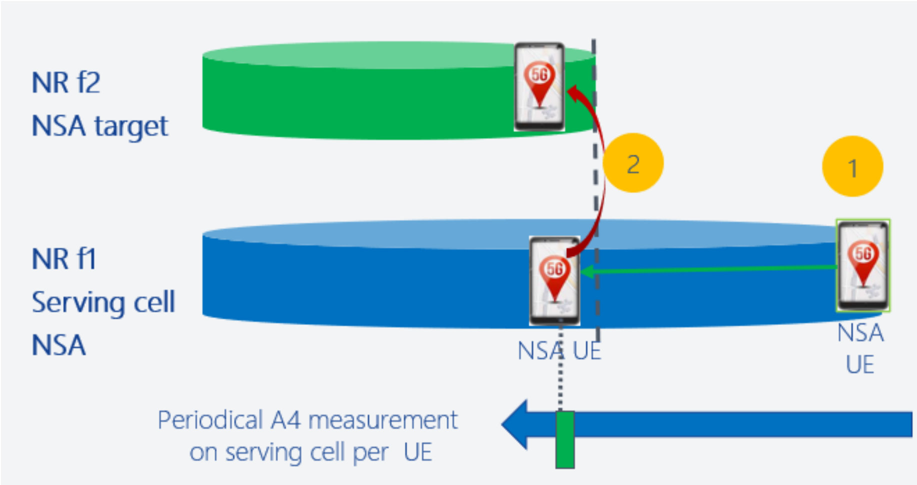

Figure 24. *A1 Based Traffic Steering [13].*

- The event 1 has the UEs connect on NR f1 allowing mixed NSA traffic and gNB configures periodic A1 measurement to eligible UEs.
- At the event 2 upon reception of A1 Measurement Report from the UE, the gNB activates A4 measurements. On reception of A4 Mesurement Report gNB selects the best target cell within the A4 measurements of the highest frequency priority and triggers the handover (NSA) or PSCell change (NSA) to that cell.

4.2 Traffic Balancing in EN-DC

Traffic balancing involves distributing traffic across multiple network resources or components to ensure balanced utilization and prevent congestion. The goal is to optimize resource usage, improve network performance, and avoid overloading any specific network element. Figure 25 shows how an overloaded layer can have its load shared to other frequency layer in other to have a balanced load.

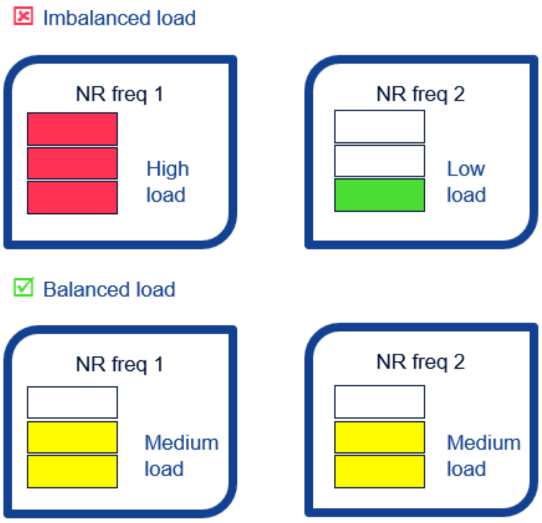

Figure 25. *Imbalanced to Balanced Load [14].*

There are different technicalities involved in the quest of balancing load within carrier frequencies and these are done in such a way that eNB compares UE supported EN-DC band combinations with EN-DC band combinations sets which are configured within Idle Mode Mobility Profiles for EN-DC aware load balancing and then eNB removes any layers on which UE capability does not allow EN-DC from the Primary Target candidates list.

4.2.1 PSCell load balancing in FR1

FR1 cells from the cell list received from the MeNB in SgNB Addition request are ordered based on the following criteria:

- Cells offering Carrier Aggregation (CA) and matching UE CA capabilities are preferred over non-CA ones, if CA aware algorithm is selected for those cells.
- Cells are ordered by the configured priority of their corresponding carrier
- Cells are ordered by the measured RSRP/RSRQ

A load threshold can also be configured, and if best ranked cell exceeds the threshold, gNB tries to select one of the configured FR1 neighbors for load balancing and a replacement cell must also meet load and RF criteria, and optionally a CA criterion. If that fails, gNB tries with second ranked cell, and so on but if no cell meets the load criterion, the least loaded cell may be selected. This is illustrated in figure 26 on how PSCell load balancing is done on FR1.

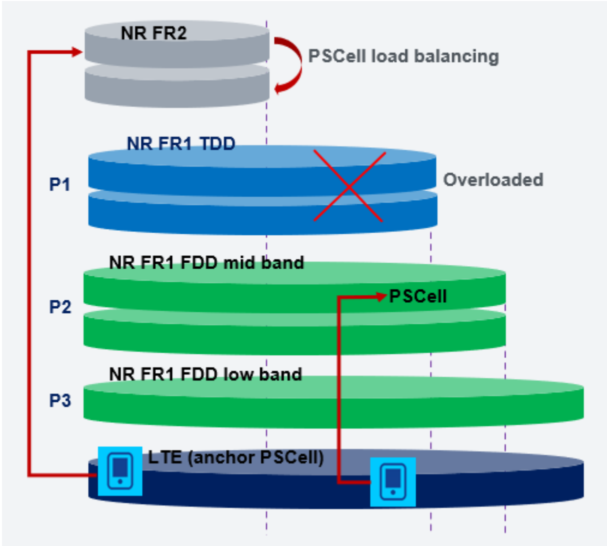

Figure 26. *PSCell load balancing in FR1 [13].*

4.2.2 Traffic balance between N1 F1 and N1 F2

The table 5 below give the details of the N1 frequencies F1 and F2 capturing the carrier frequencies and channel bandwidth.

Table 5. *N1 Frequencies Details*

N1 Frequencies Details		
	F1	**F2**
NR-ARFCN DL	427950	431790
NR-ARFCN UL	389980	393940
DL Carrier Frequency	2139.9 MHz	2159.7 MHz
UL Carrier Frequency	1949.9 MHz	1969.7 MHz
DL Channel Bandwidth	20 MHz	20 MHz
UL Channel Bandwidth	20 MHz	20 MHz
Expected cell range	5 km	5 km

Recall from chapter 3 on the inter-frequency mobility between NR layers specifically between N1 and N28. Parameters are set with respect to RSRP and RSRQ for N1 in order to trigger the A5 and A3 events that efficiently allows Intra-frequency HO (N1 F1 to N1 F2) and Inter-frequency HO (N1 to N28). The major reason for the inter-frequency HO is to allow continuous NR coverage. Figure 27 describes the parameters and processes involved for the Inter-frequency and Intra-frequency HO to occur with their corresponding values.

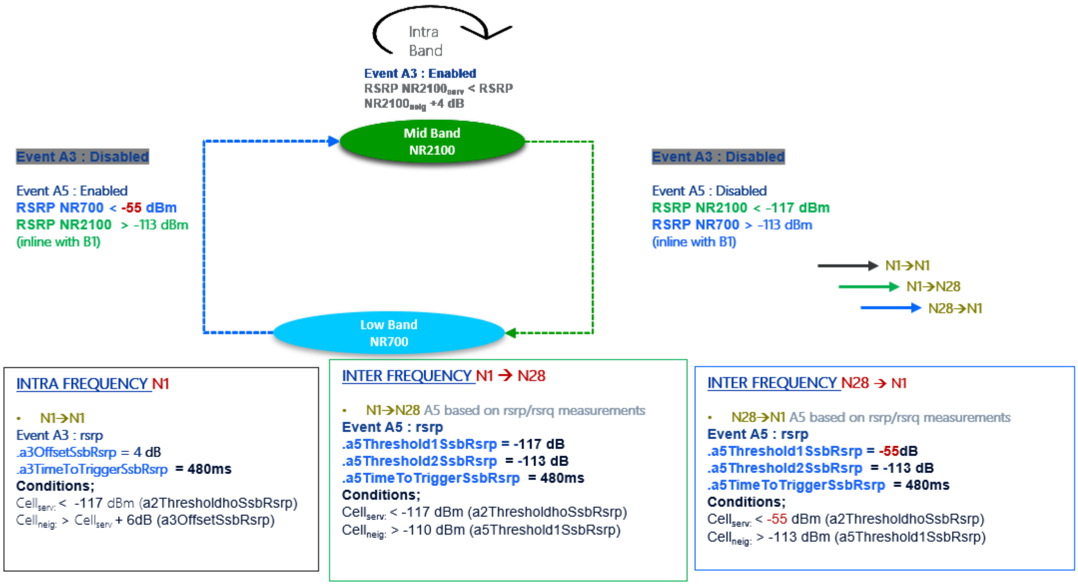

Figure 27. *Inter & Intra Frequency Mobility between N1(F1&F2) and N28 [13].*

The following processes took place in other to ensure the efficient inter and intra frequency mobility between N1 (F1 and F2) and N28 as seen from figure 27:

- Intra band HO occurs when RSRP NR2100 serving is less than RSRP NR2100 neighbor with power of +4 dB while event A3 is enabled.
- Inter band HO from NR2100 to NR700 occurs when events A3 and A5 are disabled and RSRP NR2100 is less than -117 dBm while RSRP NR700 is greater than -113 dBm.
- Inter band HO from NR700 to NR2100 occurs when event A3 is disabled while event A5 is enabled at RSRP NR700 less than -55 dBm and RSRP NR2100 greater than -113 dBm.

The NR layers are designed in such a way that they are interleaved among LTE anchoring layers to balance traffic between F1 & F2 of N1 and 2nd position in B1 measurement control is always given to N28 to ensure 5G coverage. This is as described in Figure 28 showing the parameters value set with the corresponding priorities.

Table 6. *Parameters setting for 2*N1 and 1*N28 Traffic Balancing [13].*

2xN1 + 1xN28				
NRDCPR-0	lcrId	41, 42, 43, 61, 62, 63, 81, 82, 83, 101, 102, 103 L900, L1800F2, L2100F2, L2600F2		
		carrierFreqNrCell	nrCarPrio	mrWaitTimer
	ENDCMEASCONF-0	427950	5	300ms
	ENDCMEASCONF-1	152690	1	300ms
	ENDCMEASCONF-2	431790	4	300ms
NRDCPR-1	lcrId	21,22,23 L700		
		carrierFreqNrCell	nrCarPrio	mrWaitTimer
	ENDCMEASCONF-0	427950	5	300ms
	ENDCMEASCONF-1	431790	4	300ms
NRDC**D**PR-0	lcrId	31, 32, 33, 51, 52, 53, 71, 72, 73, 91, 92, 93 L800, L1800F1, L2100F1, L2600F1		
		carrierFreqNrCell	nrCarPrio	mrWaitTimer
	ENDCMEASCONF-0	431790	5	300ms
	ENDCMEASCONF-1	152690	1	300ms
	ENDCMEASCONF-2	427950	4	300ms

Furthermore, Figure 28 shows how the priorities of NR frequency layers are interleaved with the anchor LTE layers.

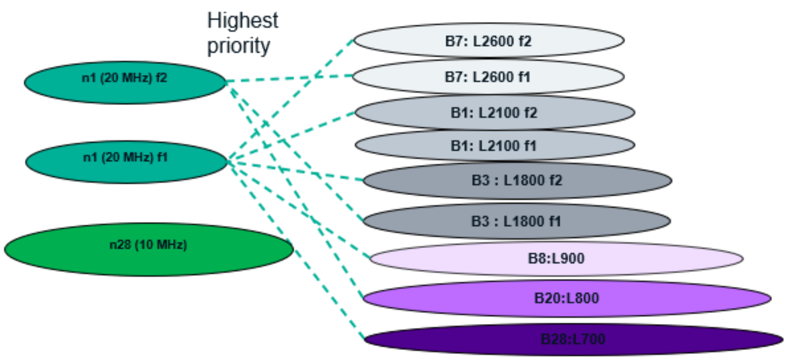

Figure 28. *Interleaved Priority Set Between NR and LTE layers [13].*

5. TRAFFIC BALANCE MEASUREMENTS

The parametrization for the traffic balancing features was done on carefully selected trial area sites with the needed configuration that would aid the expected results. These parametrizations were done using the NetAct software which is a Nokia proprietary tool for network configuration, tunning and optimization. The following parametrization processes were followed using NetAct:

- Pre-requisite feature measurement gap coordination was ‘Enabled’ for 5G FDD-FDD IFHO in trial sites
- Measurement support gap coordination support ‘Enabled’ in meshed gNB sites outside of the trial area.
- 5G IFHO mobility threshold tuning in NR2100 and NR700 cells in trial sites
- Traffic balancing feature ‘Enabled’ between N1F1 and N1F2 in trial sites
- Drive test was performed in other to verify the 5G IFHO FDD-FDD behaviour.
- KPI monitoring and trends for SgNB Addition Success Rate; 5G IFHO FDD-FDD HO performance; 5G data volume and 5G data throughput.

5.1 Trial Area

The trial area comprises of 20 sites around Ruokolahti town in Lappeenranta with different LTE layers, NR2100 and NR700 configuration with EN-DC for NR2100 been setup using the L1800 as the anchor LTE layer. The sites with NR2100 do not have L2100 as the 2100 MHz has been re-purposed to be used for N1 band. Table 7 below shows the LTE and NR details in the trial area with the corresponding cells. The numbers represent the number of cells available per layer and it ranges from no cell (0) to three cells (3) and four cells (4).

Table 7. *Trial area sites configuration*

Site ID	L700 F2	L800	L900	L1800 F1	L1800 F2	L2100 F1	L2100 F2	L2600 F1	L2600 F2	NR700	NR2100 F1	NR2100 F2
	B	C	D	E	F	G	H	I	J	A	G	H
1001192	**3**	**0**	**3**	**3**	**3**	**0**	**0**	**0**	**0**	**3**	**3**	**3**
1001050	3	0	4	3	3	0	0	3	3	3	3	3
1001085	3	0	3	3	3	0	0	0	0	3	0	0
1001088	3	0	3	3	3	3	3	0	0	3	0	0
1001093	3	3	3	0	0	0	0	0	0	3	0	0
1001098	3	3	0	0	0	0	0	0	0	3	0	0
1001101	3	0	3	3	3	0	0	0	0	3	0	0
1001112	3	3	3	3	3	0	0	3	3	3	3	3
1001134	3	3	3	0	0	0	0	0	0	3	0	0
1001137	3	0	3	3	3	0	0	3	3	3	3	3
1001150	3	0	3	3	3	0	0	0	0	3	3	3
1001187	3	0	3	3	3	0	0	0	0	3	0	0
1001195	3	0	3	3	3	0	0	3	3	3	3	3
1001196	3	0	3	3	3	0	0	3	3	3	3	3
1001198	3	0	3	3	3	0	0	3	3	3	3	3
1001221	3	0	3	3	3	0	0	3	3	3	3	3
1001228	3	3	3	0	0	0	0	0	0	3	0	0
1001231	3	3	3	0	0	0	0	0	0	3	0	0
1001233	3	0	3	3	3	0	0	0	0	3	0	0
1002700	4	0	4	4	4	4	4	0	0	4	0	0

The drive test route covers a total distance of 20 km and it was designed in such a way to capture N1 F1 to N1 F2 HO triggering an A3 event and N1 F1 or F2 to N28 HO while triggering an A5 event as seen in Figure 29.

Figure 29. *Measurements route for trial area.*

5.2 Measurements tools

The data collection tool used was a Nemo Outdoor software installed on a PC and connected to a Samsung S21+ as the UE. It was important for the UE to have the capability to perform 5G IFHO FDD-FDD for N1 band and N28 band. A measurement script is created for downlink session in such a way that a pre-uploaded file of size 50 Gigabytes on an open-source http server (Tele2) is downloaded for 300 seconds to the PC. This is to ensure that events A3 and A5 are triggered and properly captured in the logfiles. Below in Figures 30 and 31 are the PC and UE connection setup with the corresponding data session script used in the measurements.

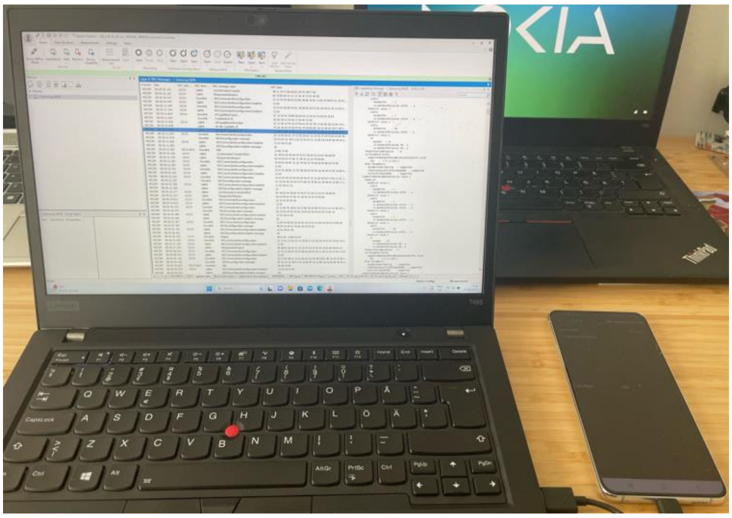

Figure 30. *Measurement PC with Nemo Oudoor and smart phone.*

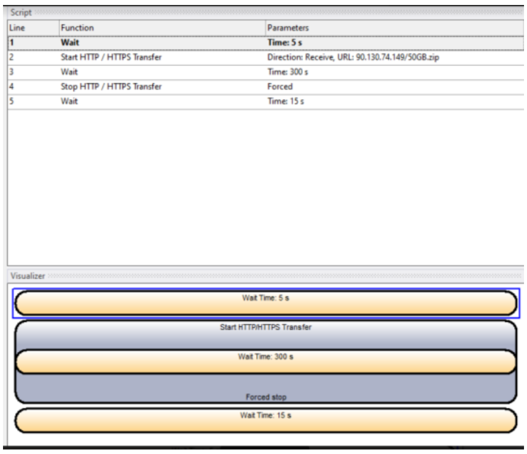

Figure 31. *Measurement script on Nemo Outdoor.*

The ENDC for N1 F1 and N1 F2 where setup using L1800 FDD band as an anchor layer and the figures 31 and 32 below shows the band and system information as captured by the UE for NR-ARFCN 429750 and 431790 respectively.

Band and System Information

Parameter	1. Samsung
Band	LTE FDD 1800 band 3
Packet technology	EN-DC
Serving system	LTE FDD
Network operator	DNA Oy
Mobile country code	244
Mobile network code	12
Cell identification	10524723
Channel number	1351
NR-ARFCN (NR serving cell)	427950, 427950
NR-ARFCN (NR neighbor)	n/a
SCell carrier aggregation mode	DL

Figure 32. *Band and system information for N1 F1.*

Band and System Information

Parameter	1. Samsung
Band	LTE FDD 1800 band 3
Packet technology	EN-DC
Serving system	LTE FDD
Network operator	DNA Oy
Mobile country code	244
Mobile network code	12
Cell identification	10524724
Channel number	1351
NR-ARFCN (NR serving cell)	431790, 431790
NR-ARFCN (NR neighbor)	431790
SCell carrier aggregation mode	DL

Figure 33. *Band and system information for N1 F2.*

6. RESULTS AND ANALYSIS

The KPIs data were generated through the monitoring interface of NetAct for 25 days in other to capture and trend the impact of all the stages of parametrization done on the NR cells in the trial area. These phases where Pre-requisite feature measurement gap co-ordination been 'Enabled' for 5G FDD-FDD IFHO in trial sites; measurement support gap coordination support 'Enabled' in meshed gNB sites outside of the trial area; 5G IFHO mobility threshold tuning in NR2100 and NR700 cells in trial sites and traffic balancing feature 'Enabled' between N1F1 and N1F2 in trial sites.

6.1 SgNB Addition Success Rate

The SgNB Addition Success rate (%) was trended for 5G IFHO FDD – FDD LNCEL for 25 days capturing different stages of parameterization and it could be seen from figure 34 below that:

- SgNB Addition Success rate significantly degraded from 100% stability to about 92% for the 1st 24 hours after 5g IFHO was enabled in the trial area. This further degraded to 90% for the next 4 days.
- After closely looking into performance on site basis, it was noticed the issue hits several individual sites. Some sites like N1192 and N1187 had no impact while others had severe degradation.
- SgNB Addition Success rate recovered back to about 100% after the affected cells were tuned and enabling of support measurement gap coordination in all meshed gNB.

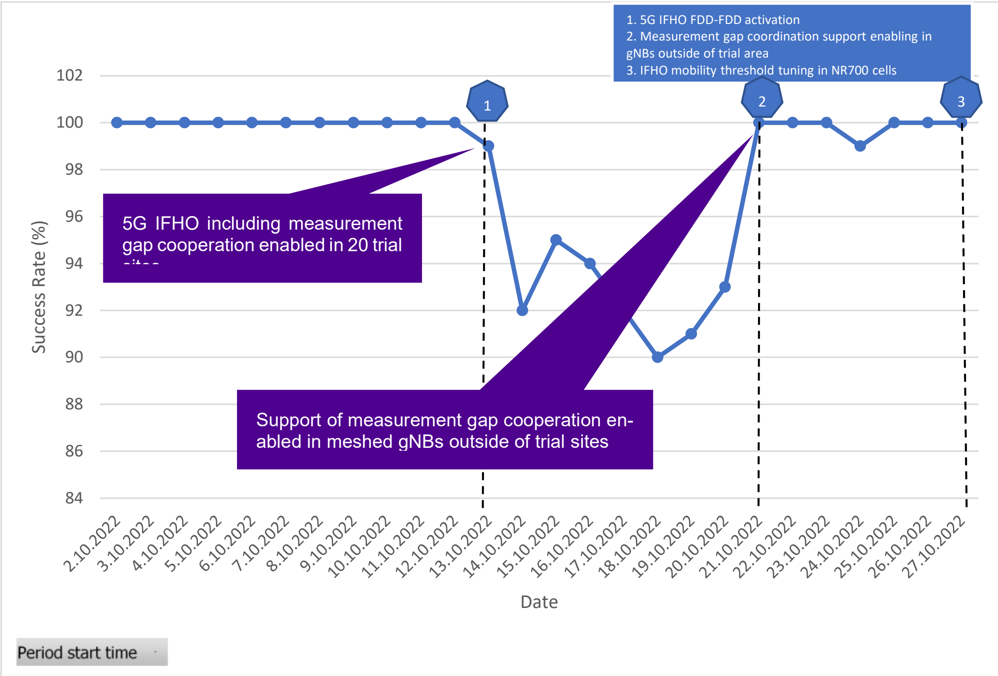

Figure 34. *SgNB Addition Success Rate (%).*

6.2 5G IFHO Performance

The performance of all the 5G IFHO FDD-FDD present in the network with respect to each other is displayed in figure 35 for all of the parametrization process with emphasis on the behaviour of the NR700 and NR2100 post mobility threshold tuning.

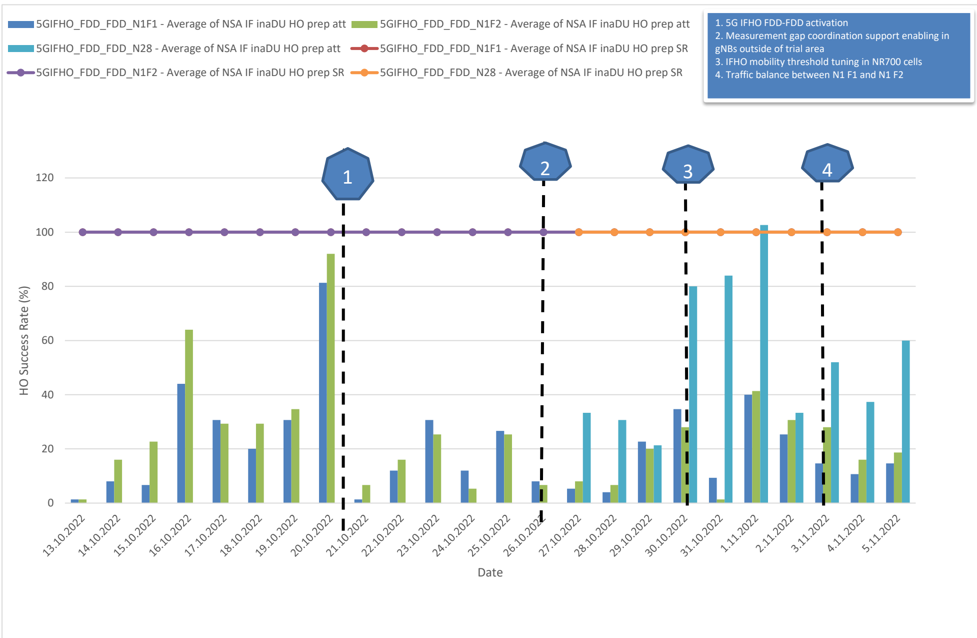

Figure 35. *5G IFHO FDD-FDD Performance.*

- The 5G IFHO FDD-FDD N1F1 HO Preparation Attempts peaked at 82% with a stable HO Success Ratio of 100% when 5G IFHO FDD-FDD activation was completed while the 5G IFHO FDD-FDD N1F2 HO Preparation Attempts peaked at 90% with a stable HO Success Ratio of 100%. The event 5G IFHO FDD-FDD N28 wasn't occurring as IFHO mobility threshold tunning wasn't done yet for NR700 cells.
- 5G IFHO FDD-FDD N1F1 HO Preparation Attempts dropped to a peaked of 30% with a stable HO total Success Rate of 100% when Measurement gap coordination support was enabled in gNBs outside of trial while the 5G IFHO FDD-FDD N1F2 HO Preparation Attempts dropped to a peak of 22% with a stable HO Success Ratio of 100%.
- IFHO Mobility tunning in NR700 cells was done and the 5G IFHO FDD-FDD N28 HO Preparation Attempts started pegging with a peak of 100% and a stable HO Success Ratio of 100%.
- The 5G IFHO FDD-FDD N1F1 HO Preparation Attempts peaked at 18% with a stable HO Success Ratio of 100% when traffic balance between N1F1 and N1F2 was completed while the 5G IFHO FDD-FDD N1F2 HO Preparation Attempts peaked at 19% with a stable HO total Success Rate of 100% and 5G IFHO FDD-FDD N28 HO Preparation Attempts peaked at 60% with a stable HO total Success Rate of 100%.

6.3 5G Data Volume

This is the amount of users traffic been captured for N1 F1, N1 F2 and N28 while depicting their responses to the different stages of parameterization process with much emphasis on the mobility threshold tuning and it's been captured in figure 36 and 37 below for both downlink and uplink data volume.

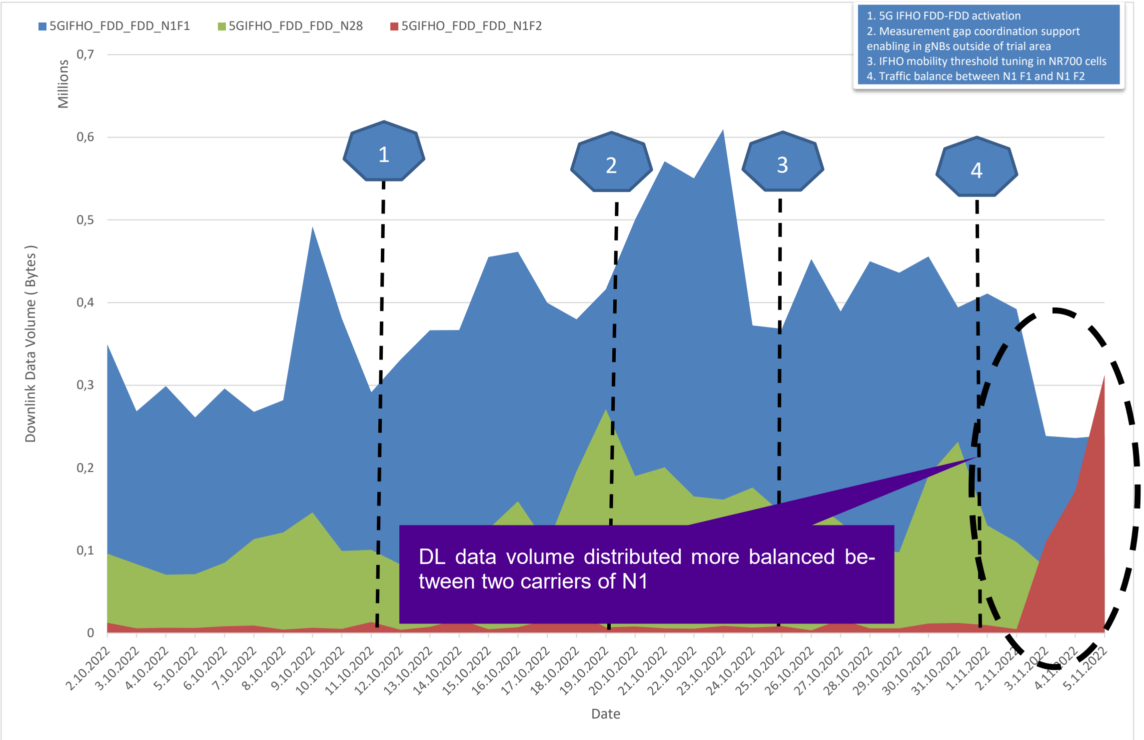

Figure 36. *Downlink data volume for N1F1, N1F2 and N28.*

- The 5G IFHO FDD-FDD N1F1 downlink data volume decreases from 0.6 million bytes Pre traffic balance to about 0.25 million Bytes Post traffic balancing between N1F1 and N1F2.
- 5G IFHO FDD-FDD N1F2 downlink data volume increases from 0.01 million bytes Pre traffic balance to about 0.31 million bytes Post traffic balancing between N1F1 and N1F2.
- 5G IFHO FDD-FDD N28 downlink data volume decreases from 0.25 million bytes Pre traffic balance to about 0.11 million bytes Post traffic balancing between N1F1 and N1F2.

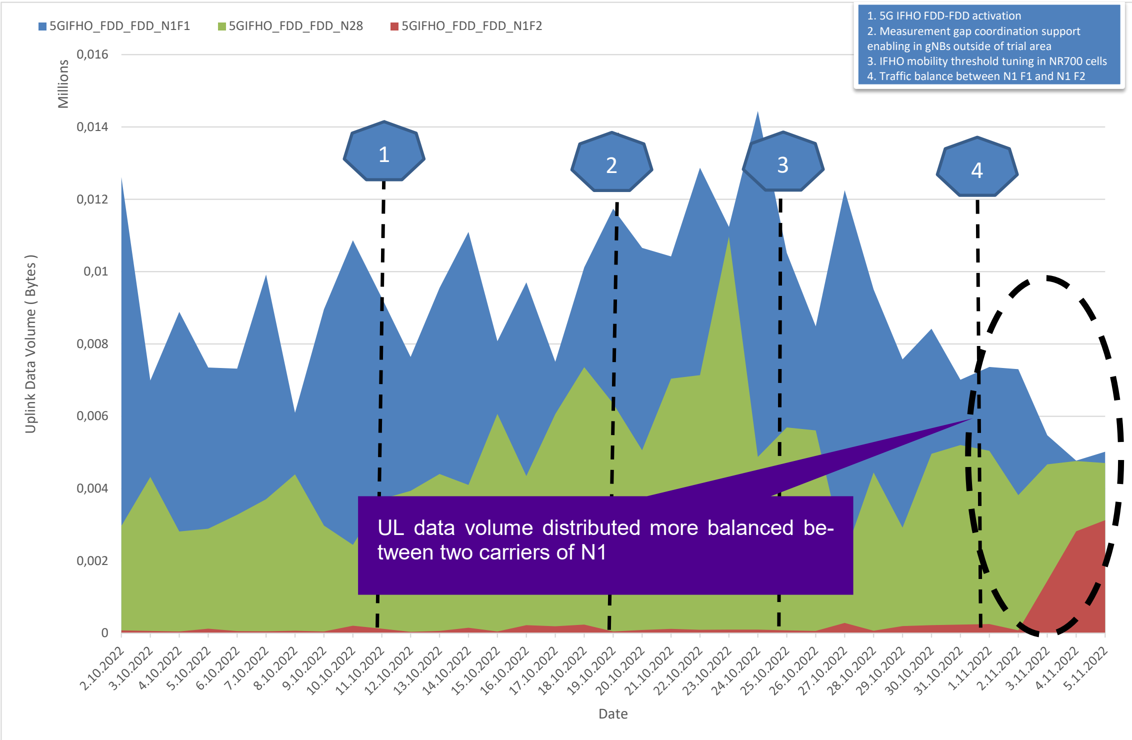

Figure 37. *Uplink data volume for N1F1, N1F2 and N28.*

- The 5G IFHO FDD-FDD N1F1 uplink data volume decreases from 0.014 million bytes Pre traffic balance to about 0.005 million bytes Post traffic balancing between N1F1 and N1F2.
- 5G IFHO FDD-FDD N1F2 uplink data volume increases from 0 million bytes Pre traffic balance to about 0.003 million bytes Post traffic balancing between N1F1 and N1F2.
- 5G IFHO FDD-FDD N28 downlink data volume decreases from 0.011 million Bytes Pre traffic balance to about 0.004 million Bytes Post traffic balancing between N1F1 and N1F2.

6.4 SgNB Addition Request

The MeNB requests that the en-gNB prepare resources for EN-DC operation for a specific UE by sending them SgNB Addition Request message [14] and this request is been trended capturing that for N1F1, N1F2 and N28 in Figure 38 for all the parameterization stages and it depicted a significant increase after the traffic balancing was completed.

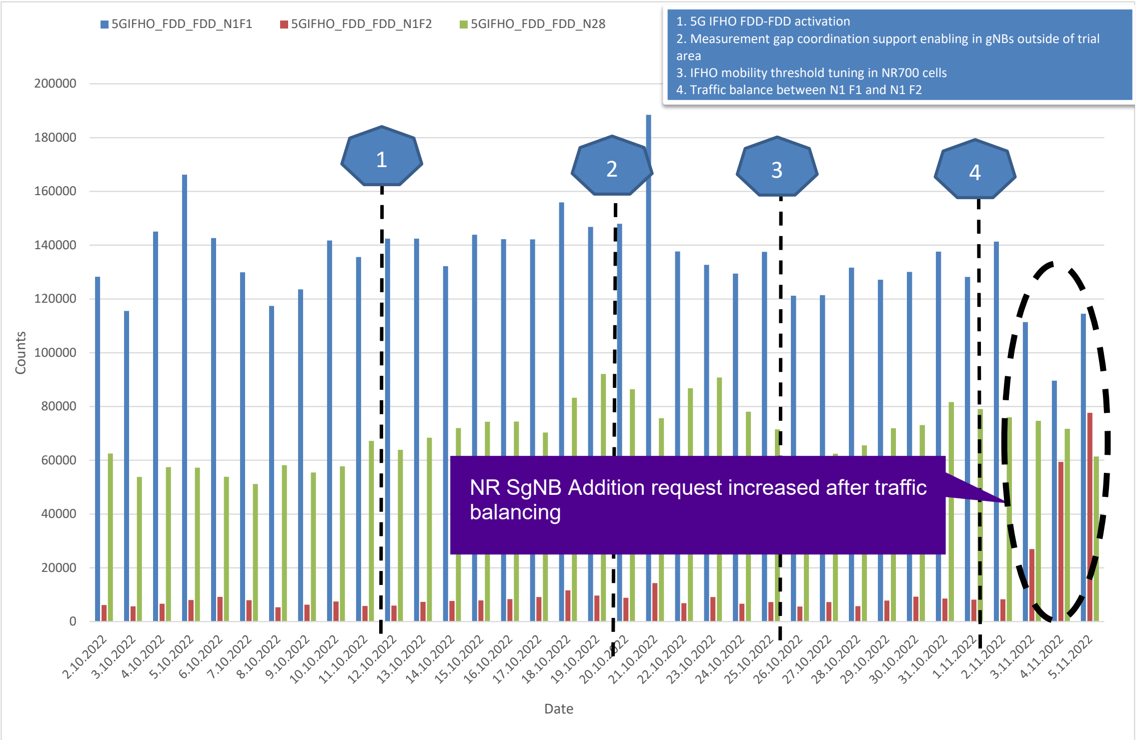

Figure 38. *SgNB Addition Request.*

It is important to note that there could be a possible draw back following the below scenarios:

- When a SgNB addition is triggered, the measurement gaps that have already been set-up in the UE by the MeNB prior to the SgNB addition are set-up in the SgNB.
- If the gaps for these measurements are not configured in SgNB, the MeNB sends the measurement gap configuration in the X2AP: SgNB ADDITION REQUEST.
- If SgNB-DU is not able to apply Measurement Gap configuration prepared by MeNB, UE Context Modification procedure fails.
- SgNB Addition Request Reject is sent to the MeNB.

6.5 5G DL and UL Throughputs

The downlink and uplink throughputs captured from all the active cells of different NR layers of different stages of the parameterization was captured and it could be seen that there was a significantly increase in the downlink throughput on N1 F2 post traffic balancing as seen in Figure 39 below.

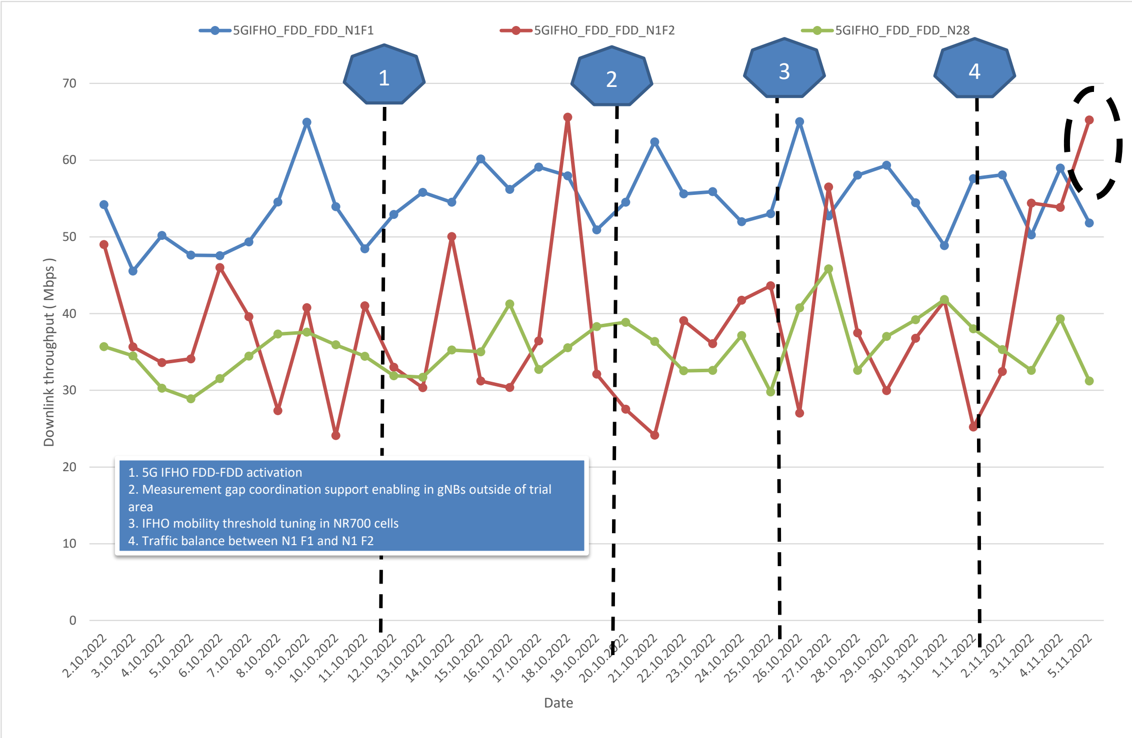

Figure 39. *Downlink throughput (Mbps) post traffic balancing.*

- The 5G IFHO FDD-FDD N1F2 downlink throughput increases significantly Post traffic balancing from about 25 Mbps to 65 Mbps.
- The 5G IFHO FDD-FDD N1F1 downlink throughput maintains a steady trend of about 59 Mbps while the 5G IFHO FDD-FDD N28 downlink throughput maintains a steady trend of about 39 Mbps post traffic balancing.

The corresponding uplink throughput was also captured for the different NR layers and there was significant increase in the N1F2 throughput post traffic balancing parameterization with a slight decline after some hours due to user preferences or activities as seen in Figure 40 below.

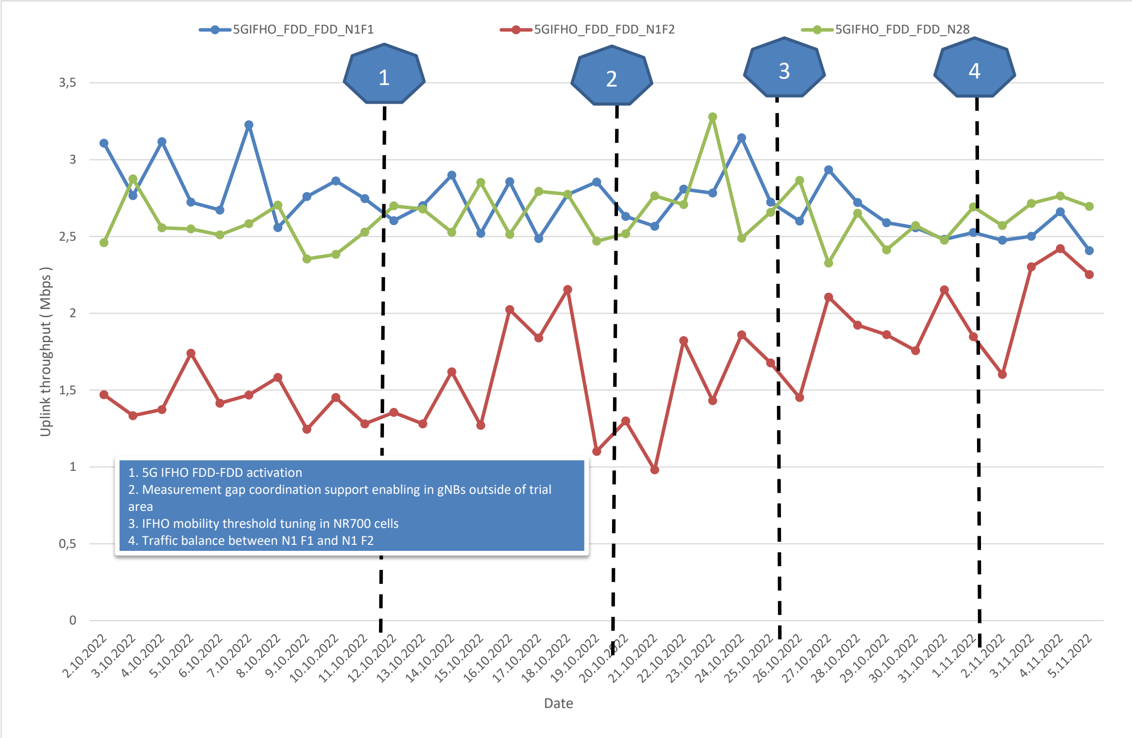

Figure 40. *Uplink throughput (Mbps) post traffic balancing.*

- The 5G IFHO FDD-FDD N1F2 uplink throughput increases slightly Post traffic balancing from about 1 Mbps to 2.3 Mbps.
- The 5G IFHO FDD-FDD N1F1 uplink throughput maintains a steady trend of about 2.5 Mbps while the 5G IFHO FDD-FDD N28 uplink throughput maintains a steady trend of about 2.7 Mbps post traffic balancing.

7. CONCLUSIONS

This thesis has investigated the viability and results of traffic balancing within the framework of NR 2100 MHz frequencies, delving into a crucial area of 5G network optimization. The main goal was to intelligently distribute traffic loads over the NR and anchor LTE bands in order to increase capacity and throughput. This study has shed important light on the possible advantages and difficulties of traffic balancing in 5G networks using the 2100 MHz frequency band.

The study also highlighted the importance of traffic balancing as a practical method for improving network performance. Operators can reduce congestion, eliminate bottlenecks, and ultimately improve the quality of service by efficiently shifting user traffic over several bands. With careful traffic balancing, throughput can be increased, latency can be decreased, and user experiences can be improved, according to the empirical analysis used in this study.

The effects of traffic balancing go beyond simple technical improvements as the investigation has revealed more information about the wider effects on the entire network structure. User satisfaction is anticipated to rise as network performance improves, improving subscriber retention and maybe luring in new clients. Additionally, traffic balancing helps optimize resource allocation, which is in line with modern telecommunication systems' sustainable objectives for resource management and energy efficiency.

However, it is important to acknowledge the challenges and potential drawbacks associated with traffic balancing. The thesis has highlighted the necessity for a dynamic mobility strategy to achieve effective load distribution. Additionally, the introduction of traffic balancing mechanisms may require alterations to existing network architectures and protocols, which could entail deployment complexities and potential interoperability issues.

In conclusion, this study has advanced the understanding of intricate relationship between traffic balancing, network performance, user experience, and overall quality of service in 5G networks operating at the 2100 MHz frequency band. The findings underscore the potential benefits of implementing traffic balancing strategies and provide a foundation for further exploration in the field of network optimization. As the telecommunications industry continues to evolve and adapt to growing demands, the insights gained from this study offer valuable guidance for operators, researchers, and stakeholders striving to enhance the efficiency and effectiveness of 5G networks.

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