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5G NEW RADIO EVOLUTION TOWARDS ENHANCED FEATURES

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ABSTRACT

Smartphones, as well as other smart devices, with the capability of having more than one subscriber identity module (SIM) at once have been on the market for several decades. The support and implementation for these current multi-SIM smart devices has been largely done without radio specifications, meaning that these implementations are completely proprietary.

As the market and use of multi-SIM enabled devices grow, operators and network vendors have identified that there is a need to standardise certain aspects of multi-SIM functionality. This is needed to solve several issues regarding multi-SIM operations between the user equipment (UE) and network (NW).

In this thesis, the NR 3GPP Release 17 is analysed and 5G modem implementations for some of the introduced multi-SIM features are designed. Impact to both UE and NW side are taken into consideration for the introduced multi-SIM features. The designed 5G modem implementations for multi-SIM can not completely validated until the implementation is completed for the 5G enabled networks.

Keywords: 3GPP Release 17, 5G modem implementation, Multi-SIM

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TIIVISTELMÄ

Älypuhelimia, kuten muitakin älykkäitä laitteita, joissa voi olla useampi kuin yksi SIM-kortti yhtäaikaisesti, on ollut markkinoilla jo useita vuosikymmeniä. Tuki ja implementaatiot tällaisille multi-SIM älylaitteille on suurimmaksi osaksi tehty ilman radiospesifikaatioita, joka tarkoittaa, että tällaiset implementaatiot ovat täysin valmistajien omia toteuksia.

Operaattorit ja verkkovalmistajat ovat tunnistaneet tarpeen standardoida tiettyjä osa-alueita multi-SIM toiminnallisuudesta markkinoiden ja multi-SIM-laitteiden käytön kasvamisen myötä. Tämä on tarpeen, jotta multi-SIM toiminnalisuuteen liittyvät ongelmat saadaan ratkaistua käyttäjien laitteiden (UE) ja verkkojen (NW) välillä.

Tässä työssä analysoidaan NR 3GPP Release 17:n määrityksiä ja työn puitteissa 5G modeemi-implementaatiot joillekin esitetyille multi-SIM toiminnallisuuksille on suunniteltu. Vaikutukset sekä UE- että NW-puolelle on otettu huomioon esitetyille multi-SIM-toiminnallisuuksille. Suunniteltua 5G modeemitoteutusta ja vaikutuksia multi-SIM:lle ei voida täysin validoida UE- ja NW- puolella ennen kuin toteukset on tehty 5G verkoille.

Avainsanat: 3GPP Release 17, 5G modeemi-implementaatio, Multi-SIM

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FOREWORD

This thesis was written during my employment at MediaTek Wireless Finland. Writing this thesis has been quite a ordeal and has taken a while to finish this thesis. I would like to thank my colleagues at MediaTek for guidance on this thesis. I want to especially thank Antti Kangas from my team for providing me with technical guidance. Additionally, I want to thank my university supervisors Olli Silvén and Tuomo Hänninen who pushed and motivated me to finish this thesis finally after a long time.

Lastly, I want to thank my family and friends for motivating me to finish my thesis.

Oulu, March 3rd, 2023

Bekim Abazi

LIST OF ABBREVIATIONS AND SYMBOLS

3GPP	3rd Generation Partnership Program
4G	4th Generation Mobile Phone Network
5G	5th Generation Mobile Phone Network
5GC	5G Core Network
5GS	5G System
AMF	Access and Mobility Management Function
CA	Carrier Aggregation
DC	Dual Connectivity
DSDA	Dual-SIM Dual Active
DSDS	Dual-SIM Dual Standby
EPC	Evolved Packet Core
EUTRA	Evolved Universal Terrestrial Radio Access
eSIM	Embedded Subscriber Identification Module
GSMA	GSM Association
IMEI	International Mobile Equipment Identifier
LTE	Long Term Evolution
MAC	Medium Access Control
MUSIM	Multi-SIM
MSMA	Multi-SIM Multi Active
MSMS	Multi-SIM Multi Standby
NAS	Non-Access Stratum
NR	New Radio
NSA	Non-standalone
NTN	Non-Terrestrial Network
NW	Network
UE	User Equipment
UPF	User Plane Function
URLLC	Ultra-Reliable Low Latency Communication
OSI	Open Systems Interconnection
PDCP	Packed Data Convergence Protocol
PHY	Physical
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RF	Radio Frequency
RLC	Radio Link Control
RRC	Radio Resource Control
SA	Standalone
SDAP	Service Data Adaptation Protocol
SFM	Session Management Function
SIM	Subscriber Identification Module
SoC	System on a Chip
TR	Technical Report
TS	Technical Specification

1. INTRODUCTION

The use of mobile telecommunication devices as well as the maximum throughput these devices can achieve have been steadily rising for the past decades. While the fifth generation (5G) of mobile connections has been in commercial use already for years, new features for 5G are continuously being introduced. The newly released 3GPP Release 17 specification brings many new features and enhancements to the 5G system. These changes enable such features as Non-Terrestrial Networks, 5G Multicast and Broadcast Services (MBS), NR sidelink, and coordination of Multi-SIM activities between the UE and the network.

Devices that support multiple SIMs have existed for years. There are many use cases for such devices, for example one SIM can use call functionality while the other SIM only serves mobile data. This gives the user the option for example to have one device that can simultaneously be used for personal and work related activities. With this sort of functionality there is no need to have separate phones, for example when travelling abroad either one of the SIMs can be switched to local operator network SIM to provide data connectivity. This helps to keep data costs lower than what data transfer with roaming would offer. As per 2019, the market for Dual SIM enabled smartphones in several countries in Asia amount for nearly half of all the smartphone sales [1].

Currently there are proprietary solutions implemented in both UEs and networks. These solutions include for example how UE schedules incoming and outgoing data transmission and how paging is handled for MUSIM devices. These can cause problems for the UE and network operations in MUSIM use cases where the status of active SIMs can change due to UE operation which can lead to UE and network not be in sync anymore.

This thesis analyses the 3GPP Release 17 specification and the features presented for Multi-SIM. The analysis and solutions for Multi-SIM features presented in thesis focuses mainly on the 5G user equipment (UE) side and not on the network side. The motivation for this analysis is to provide more detailed information about how the Multi-SIM features can be implemented to the UE. These Multi-SIM features are applicable to both 4G and 5G enabled UEs. Although these features can be implemented for the 5G UE, the verification for these features can not be completed until the support is done also for the network.

Chapter 2 of this thesis provides background for 5G technologies and the connectivity options available for 5G. The 3GPP standardisation groups and 5G NR specifications are discussed in Chapter 3. In Chapter 4, Multi-SIM technology and existing implementations are presented, providing insight on difficulties in Multi-SIM implementations and why standardisation is needed. The Multi-SIM features introduced are presented in Chapter 5 as well as proof of concept solutions for 5G modem. The summary of this thesis and its solutions are presented in Chapter 6.

2. 5TH GENERATION MOBILE COMMUNICATIONS

2.1. 5G New Radio

The 3GPP has defined New Radio (NR) as the fifth generation of mobile communications known as 5G. The first New Radio specification was specified in 3GPP Release-15 which was released in early 2018. The 5G architecture is called the 5G System (5GS) and it consist of the 5G Core Network (5GC), 5G Access Network (5G-AN) and the 5G User Equipment (UE).

One possible deployment option of 5G network is shown in Figure 1 below. The 5GC part provides Access and Mobility Management Functions (AMF) and User Plane Functions (UPF) via NG connections to the gNodeB's which are located in the NG-RAN part of the network providing the 5G connectivity. The gNodeB's are connected to each other via Xn interfaces. There is also a possibility to have ng-eNB stations in the NG-RAN that can be used for dual connectivity options towards the UE or the possibility of connecting an LTE device to the 5G network via E-UTRA protocols. UEs are then connected to gNB's or ng-eNB which allows the UE to have connectivity in 5G networks. [2]

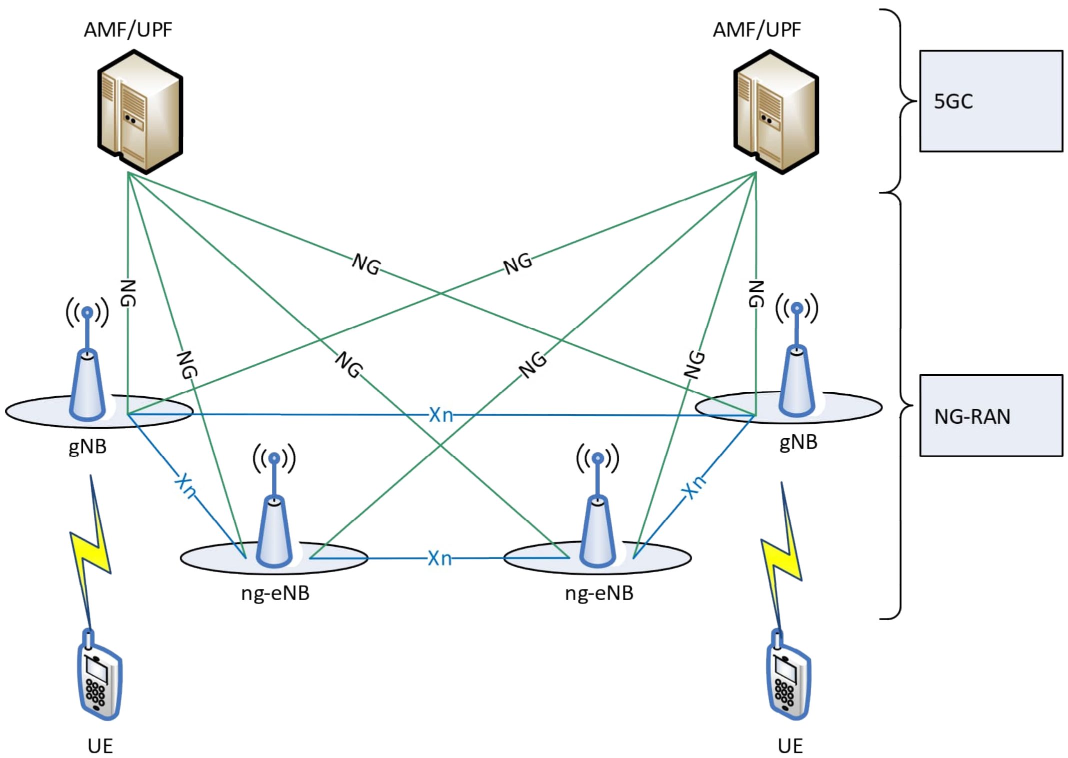

Figure 1. Example 5G network.

2.2. 5G Core Network

One of requirements for 5G core network architecture was the support for Network Function Virtualization and Software Defined Networking. The separation of control plane and the user plane was also done for 5GC. This separation of control and user planes provides the ability for independent function deployment meaning that functions does not need to the same between the planes.

The system split between the 5GC and NG-RAN is shown Figure 2 below. The 5GC provides many functions to the 5G network. The AMF is a part of control plane on the 5G core side. The AMF handles Non-Access Stratum (NAS) signaling between the UE and NW. Functionalities provided by AMF are for example the support for network slicing, NAS signalling and termination and idle state mobility handling for the UE and mobility management. The Session Management Function (SMF) provides functions for allowing UE IP address allocations and for PDU Session Control. These functions are needed for UE to access the internet. The third part of 5GC, the User Plane Function (UPF) covers the user plane processing. The UPF provides functions for packet routing, mobility anchoring and interconnects PDU sessions to the Data Network. [3 p. 70–75]

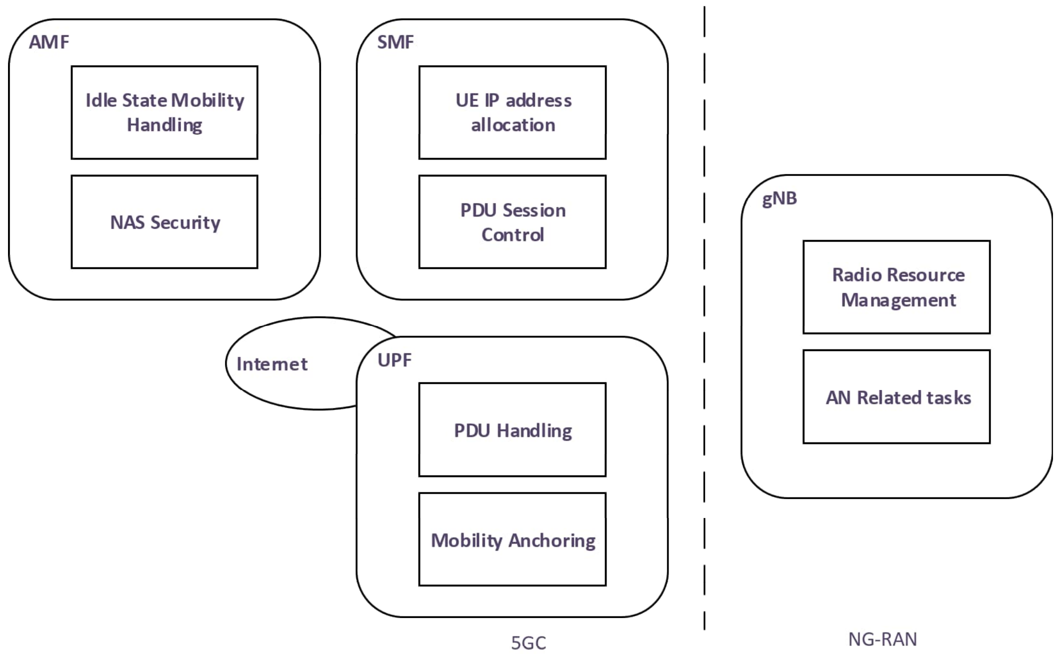

Figure 2. 5G system split between 5GC and NG-RAN.

The OSI model for user and control plane protocol stacks is shown in Figure 3. The protocol stacks consist of several layers and the main difference between these protocol stacks is that in user plane there is no NAS layer as the user plane does not perform any signalling in AMF [3 p. 150]. The physical (PHY) layer is the transmission layer and both uplink and downlink transmission are performed here.

The so called Layer 2 contains the following sub layers: Medium Access Control (MAC), Radio Link Control (RLC), Packet Data Convergence Protocol (PDCP) and

Service Data Adaptation Protocol (SDAP). The MAC sublayer provides services for mapping logical channels and transport channels, scheduling information reporting and priority handling. The RLC sublayer is responsible for error correction, duplication detection, segmentation and protocol error detections. The PDCP sublayer provides services and functions for data transfer, ciphering and deciphering, and integrity protection and integrity verification. SDAP handles mapping of QoS flow and data radio bearer(s).

The Layer 3 consists of RRC and NAS sublayers. This layer is only used in the control plane. NAS handles the communication between the UE and 5GC via AMF signalling. The RRC layer provides services to broadcast system information to NAS, paging, and establishment, maintenance and release of RRC connection between the UE and NG-RAN. [2]

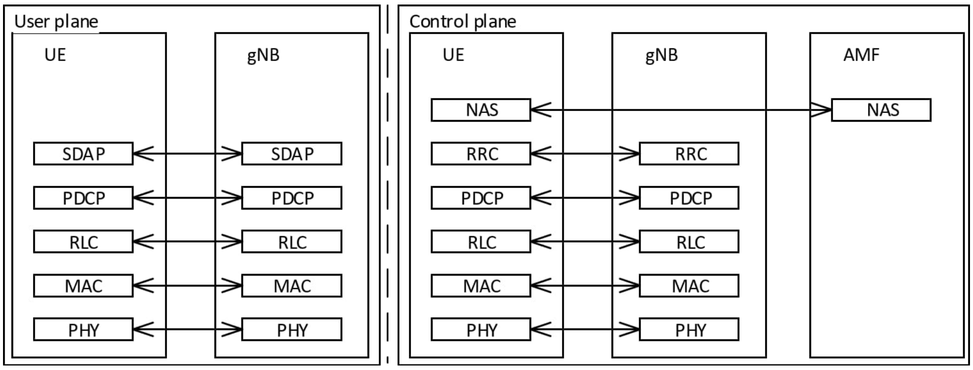

Figure 3. User and Control plane protocol stacks.

2.2.1. RRC Protocol

The Radio Resource Control (RRC) is a part of the NR control plane protocol stack. The RRC is responsible for configuring the UE with the parameters needed by other protocol layers and maintaining connectivity between the UE and NW. Depending of the RRC state, the RRC performs actions related, for example, to connection control, broadcasting of system information (SI), and measurement configuration. [3 p. 168–169]

The RRC has three states in NR. These states are RRC_CONNECTED, RRC_IDLE and RRC_INACTIVE. The states and possible state transitions between RRC states are shown in Figure 4 below. The UE can only be in one of these NR RRC states at a time [4]. When connection between UE and NW is established the UE is in either RRC_CONNECTED or RRC_INACTIVE state. If connection is not yet established, the UE is in RRC_IDLE state. To transition between these states RRC procedures need to be performed. These can be for RRC establishment, RRC release and RRC resume.

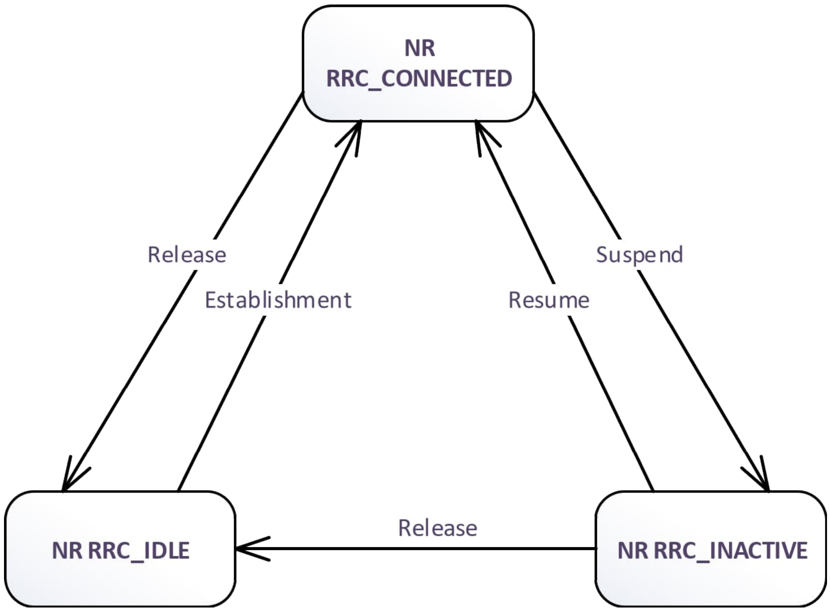

Figure 4. State transitions between NR RRC states

The state transitions between NR and EUTRA dual connectivity is shown in Figure 5. These state transitions are possible when EN-DC, NE-DC, or NGEN-DC connectivity options are used. To change between NR and EUTRA states either handover or reselections procedures need to be performed. The RRC states are identical between NR and EUTRA operation. [4]

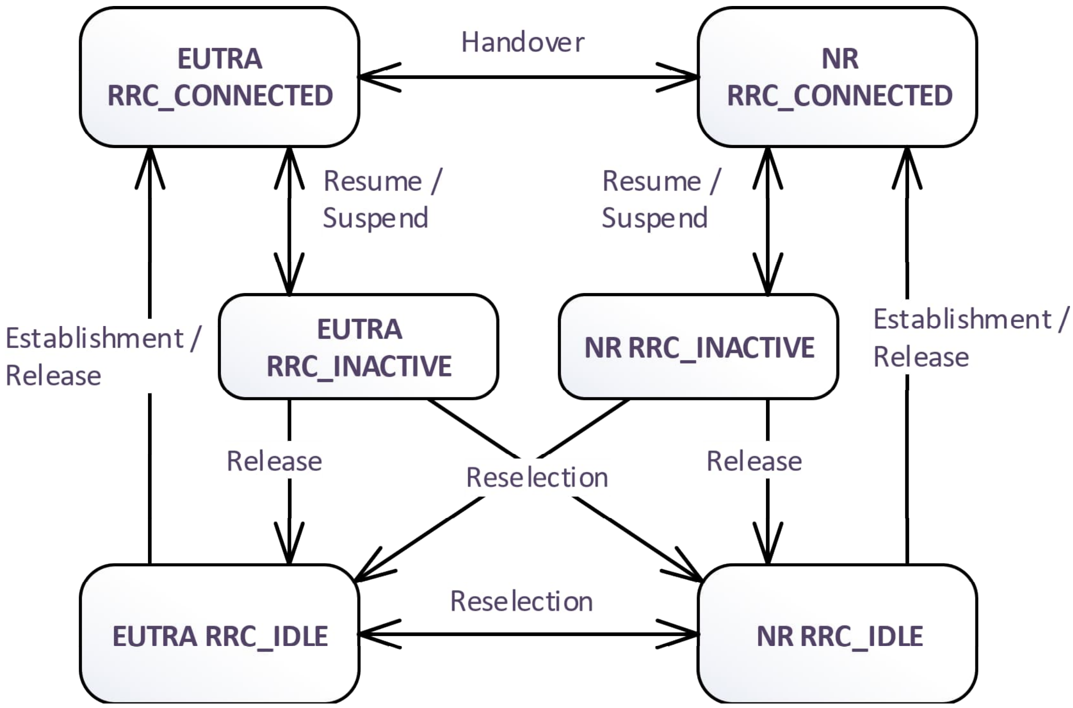

Figure 5. State transitions between NR and EUTRA RRC states

2.3. 5G Architecture Options

The 3GPP provides five architecture options for 5G connectivity as shown in Table 1. These architecture options are divided to two categories, standalone (SA) and non-standalone (NSA). In SA options only one generation of radio access technology is used and in NSA options two generations of radio access technologies are used [5]. If an connectivity option has two RATs in use, master RAT and secondary RAT, the connectivity is considered to be dual connectivity (DC). Current industry focus for 5G is on connectivity options 2 and 3 though other connectivity options could be supported if there is a market for them [5] [6]. The purpose for keeping two architecture options in focus is to simplify the rollout of 5G networks. This helps to keep the time and monetary investment lower for initial 5G deployment.

Table 1. 5G connectivity options

Connectivity Options	**Core Network**	**Master RAT**	**Secondary RAT**	**3GPP Term**	**3GPP Release**
Option 1	EPC	LTE	n/a	LTE	Release 8
Option 2	5GC	NR	n/a	NR SA	Release 15
Option 3	EPC	LTE	NR	EN-DC	Release 15
Option 4	5GC	NR	eLTE	NE-DC	Release 15
Option 5	5GC	eLTE	n/a	eLTE	Release 15
Option 7	5GC	eLTE	NR	NGEN-DC	Release 15

2.3.1. Option 2 (NR SA)

Option 2 architecture is shown in Figure 6. Option 2 is the SA option for 5G networks similarly as option 1 is SA option for LTE. In this option no legacy networks are needed. This solution requires 5GC and NR RATs to be deployed and can fully support the new 5G services and features such as network slicing and Ultra-Reliable Low Latency Communication (URLLC) [7].

Figure 6. Option 2, SA.

2.3.2. Option 3 (EN-DC)

The NSA option 3 uses Evolved Packet Core (EPC) as the core network. LTE RAT is used as master RAT and NR RAT is used as secondary RAT. This connectivity option leverages the existing LTE deployments. As EPC and LTE RATs are widely used in networks and phones, adding the NR secondary RAT is considered as a minor modification to existing networks. 5GC is not used in this options so 5G use cases may not be optimised for 5G capable UEs [5]. The architecture for this option is shown in Figure 7.

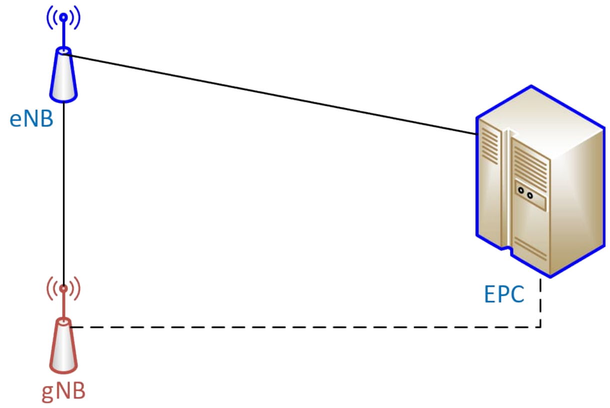

Figure 7. Option 3, EN-DC.

2.3.3. Other NR Connectivity Options

Option 4 architecture is presented in Figure 8 below. NE-DC is an addition to option 2 where 5GC is core network and NR is the master RAT. In NE-DC, dual connectivity is achieved by adding ng-eNB as secondary RAT that provides E-UTRA connectivity. This option would provide better throughput when NR capacity is not optimal by using available LTE bands. [6]

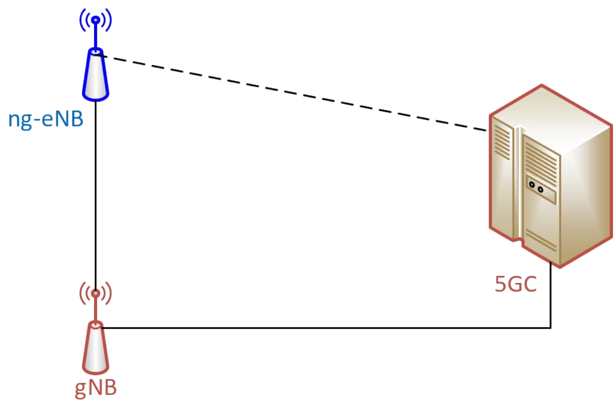

Figure 8. Option 4, NE-DC.

In option 5, 5GC is used as the core network and eLTE is the master RAT as shown in Figure 9. While this option sounds good for leveraging already existing eLTE network coverage, using 5GC for LTE enabled devices would require massive changes for the UEs to support the 5GC non-access stratum. Interfacing with 5GC instead of EPC, as well as handling the 5G-specific security aspects and the new bearer concept, requires large changes in eNBs, which have already been deployed in large quantities with different hardware and software platforms. Upgrade to eLTE would thus be very costly and likely would also require replacing a large quantity of eNBs altogether.

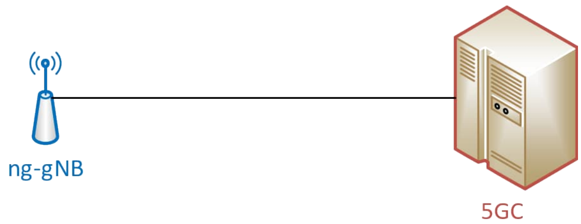

Figure 9. Option 5, eLTE.

In option 7, 5GC is used as the core network. The master RAT used in this option is eLTE and the secondary RAT is NR. The connectivity is shown in Figure 10. This option is an extension to option 5, with NR added as secondary RAT.

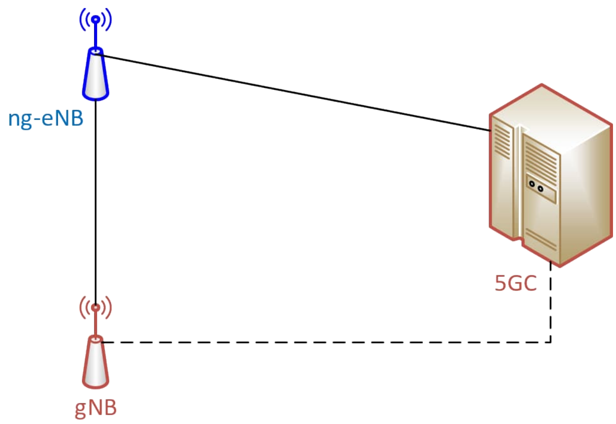

Figure 10. Option 7, NGEN-DC.

2.3.4. 5G Connectivity Pitfalls

The previous sections explains the different 5G connectivity options for the UE and NW. While some of the 5G connectivity options leverage the usage of existing LTE deployments the use of these might not be optimal for 5G performance and might impact user experience. For achieving NR SA connectivity, no existing LTE deployments can be used and as such will require massive investments from both NR modem and network vendors. [8].

This also poses issues for MUSIM UEs regarding the 5G connectivity. All 5G connectivity options might not be supported for MUSIM. This depends on how modem vendors implement their NR modems and what sort of MUSIM connectivity for 5G is supported. For example it might be possible that only 5G NSA and 4G dual SIM connectivity is possible.

The simplest and most beneficial migration path for 5G is to first implement support for NR NSA as existing LTE architecture can be leveraged. After NSA support has been achieved, the modem and network vendors can use the existing 5G architecture for 5G SA development.

3. 5G STANDARDISATION

The first 5G New Radio (NR) standard was released by the 3rd Generation Partnership Project (3GPP) in late 2017. The first 5G NR specification is the 3GPP Release 15 and the later released Release 16 and Release 17 for 5G bring new features and enhancements to existing features. This chapter discusses 5G standardisation and specification releases in more detail.

3.1. 3GPP

The 3rd Generation Partnership Project was founded in December 1998 and it covers telecommunications standard development and unites several standardisation organizations (ARIB, ATIS, ETSI, CCSA, TSDSI, TTA and TTC), and provides the members the means to define the 3GPP technologies. The standardisation in 3GPP is done by work groups as can be seen in Figure 11. The highest decision body in 3GPP is the Project Co-ordination Group (PCG) and is responsible for overall time-frame for releases and work progress as well as management of technical work [9]. The PCG allocates work to three Technical Specification Groups (TSG). These groups are Radio Access Network (RAN), Service & System Aspects (SA) and Core Network & Terminals (CT).

The TSG RAN is responsible for UTRAN, E-UTRAN, and NG-RAN network architectures and for the related network interfaces. The group is also responsible for specifications to Layer 1, Layer 2 and Layer 3 details and interfaces. Radio performance and testing are also specified by TSG RAN. [10]

The overall system architecture and services is the responsibility for TSG SA. TSG SA also handles specifications for security aspects, network management, charging and accounting. The group also co-ordinates with other TSGs to define required services.

The third group is TSG CT and is responsible for the interface (physical and logical) and protocol aspects for User Equipment (UE) and Core Network. These include for example SIM/USIM/ISIM and its interface specifications, and Mobile Terminal interface and functionality.

3.2. Functionality of SIM

The SIM is an integrated circuit card (ICC) that provides UE the means to identify and authenticate subscribers to mobile networks [11]. Once authenticated, the UE is able to establish connection to the network enabling user to make calls and connect to the Internet. The form factor of physical SIMs has been getting smaller and physically can be the size of the ICC. The SIM stores small amounts of information that contains network authentication and user details for connecting to mobile networks [12]. These include information such as personal identification number (PIN), unique serial number (ICCID) and authentication keys (KI). If the UE does not have a SIM, the UE can not authenticate to mobile networks and only emergency services are allowed.

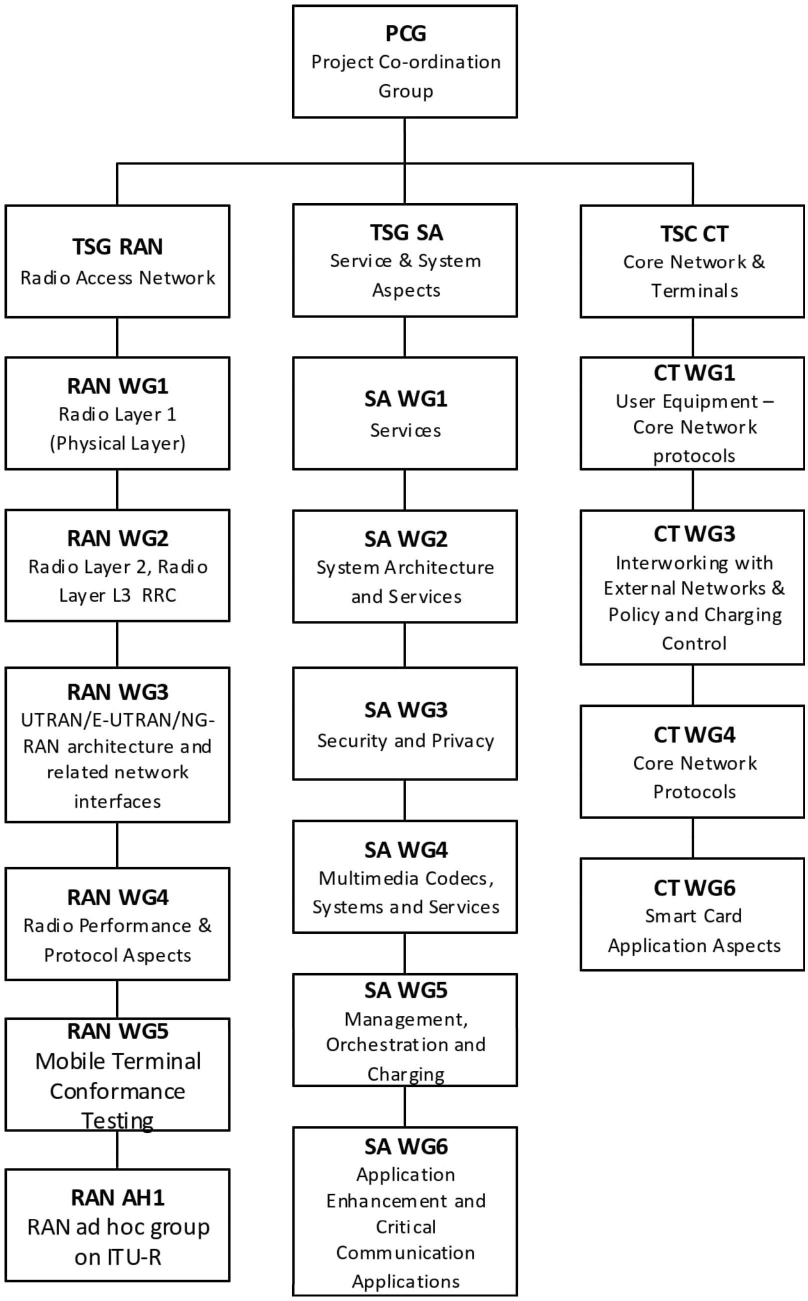

Figure 11. 3GPP standardisation groups.

3.3. Release 15

The 3GPP Release 15 includes specifications for 5G systems and support for non-standalone (NSA) and standalone (SA) architecture options. The Release 15 was divided into three parts. The first part includes NR connectivity option 3 NSA functionality and was released in late 2017. The second part which includes NR connectivity option 2 SA functionality was released in mid 2018 and the third part known as "late drop" was released early 2019. Late drop includes additional migration architectures for NR: NE-DC, NGEN-DC and 5G-5G dual connectivity option known as NR-DC [13].

The timeline for 3GPP NR releases is shown in Figure 12. The Release 15 is also known as "Phase 1" of 5G implementation and Release 16 is considered as "Phase 2" of the 5G implementation [14]. The most notable features in Release 15 are the introduction of 5G System (5GS), network slicing and further improvements to LTE [4].

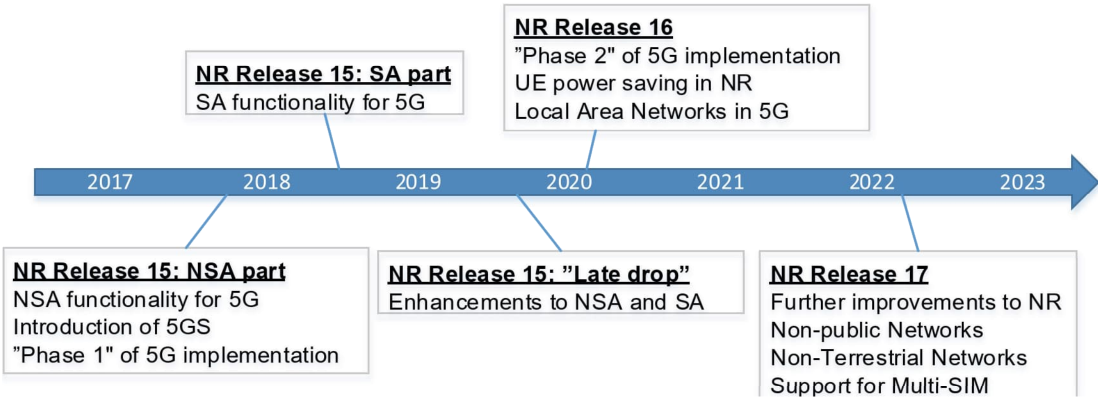

Figure 12. Timeline of 3GPP NR releases.

3.4. Release 16

The 3GPP Release 16, the second iteration of 3GPP 5G specification, is a major release for the 5G standardisation. This release aims to broaden the 3GPP 5G system by introducing several enhancements to the Release 15 features as well as several new features. Release 16 RAN1 freeze was introduced in late 2019 and ASN.1 freeze was done in mid 2020 [15]. This release brings many new features to 5G standards. Some of the key features introduced in Release 16 are: [16]

- Enhancements to Ultra-Reliable and Low Latency Communications (URLLC) feature released in 3GPP Release 15
- Enhancements to dual connectivity (DC) and carrier aggregation (CA)
- 5GC support for Non-3GPP systems
- Local Area network (LAN) support in 5G
- UE power saving in 5G
- NR positioning services
- Completed the functionality for NR-DC connectivity option
- Dual Active Protocol Stack (DAPS) which allows interruptless data transmission when handover is performed

3.5. Release 17

Release 17 is the third iteration of 5G specification provided by 3GPP [17]. The Release 17 specifications were originally supposed to be feature complete by the end 2021 but because of global situation and work being done remotely, the 3GPP had to reschedule the Release 17 timeline. In the new timeline provided, the functional freeze (Stage 2) was scheduled to be completed in June 2021 and it contains all the functional requirements for the Release 17 specification. Stage 3 Freeze was concluded in March of 2022. This includes all the required protocol features and explains how the new introduced features and enhancements will work. After the Stage 3 Freeze, Release 17 protocol coding freeze for ASN.1 was concluded on June of 2022 which includes all the necessary ASN.1 requirements and changes [18].

The Release 17 expands on 5G NR features introduced in earlier 5G specifications and introduces several key features. These include enhancements to existing features such as non-public networks (NPN) and dynamic spectrum sharing (DSS) and completely new features such as support for non-terrestrial networks (NTN), multicast and broadcast services (MBS), and support for MUSIM devices [17].

3.5.1. Non-Terrestrial Networks

The 3GPP introduced NTN as a work item in Release 17. Study for NTN was started already in 3GPP Release 15 and continued Release 16. NTN as a term covers all networking that involves non-terrestrial objects such as satellites and high altitude platform systems. The motivation for NTN is to bring satellite networks into the 5G ecosystem.

Figure 13 shows an example how satellites can be used for NTN. The UE can leverage the use of satellites for connecting to the 5GC. This can be used for example to guarantee NR coverage for IoT devices and to provide connectivity during disaster situations. [19]

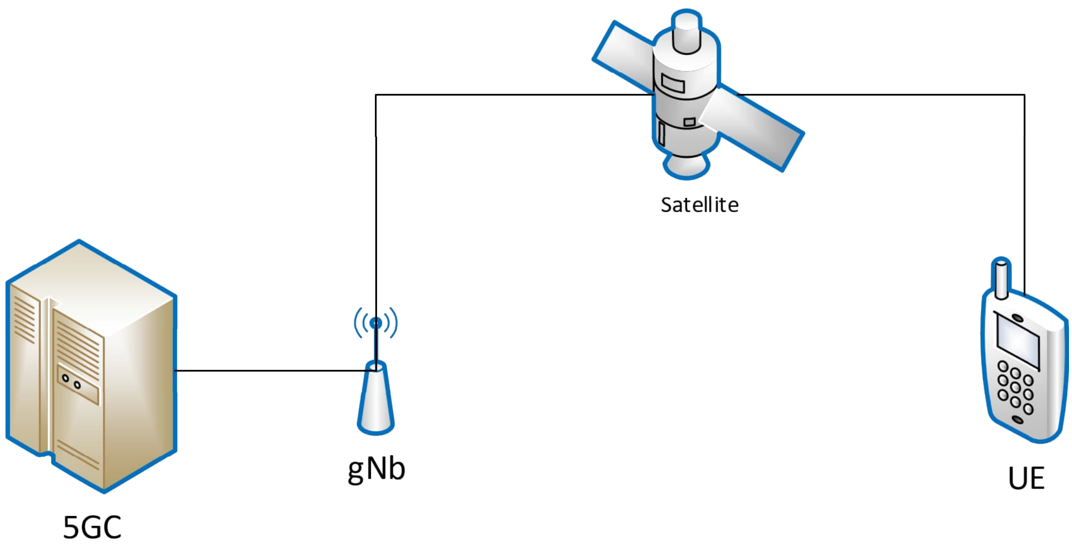

Figure 13. Example of NTN network.

3.5.2. Multi-SIM

Multi-SIM (MUSIM) is introduced in 3GPP specifications for the first time in Release 17. The introduction of MUSIM aims to solve use cases that can not be solved with only proprietary UE implementations. These use cases include support for mobile terminated service, paging, how to UE shall indicate leaving connected state to enable activities on another SIM, and emergency services [20].

4. MULTI-SIM

4.1. Overview of MUSIM

MUSIM enabled devices have existed for a long time. The first MUSIM capable commercial phones were introduced in early 2000s. One of the first dual-SIM phones was the Benefon Twin that was released in 2000 [21].

MUSIM capable device contains two or more Subscriber Identification Modules (SIM)s. These SIMs can be either physical or embedded SIMs (eSIM)s where the latter is the direction the industry is currently heading [22]. For example Apple has released iPhone 14 in 2022 that only supports eSIMs in the US market [23]. Having support for eSIMs is essential for small factor wearables and IoT devices where size can be a limiting factor. The eSIM utilises SIM provisioning which means that one eSIM can contain several different SIMs from different operators and achieves MUSIM functionality this way. The difference between traditional SIMs and eSIMs is illustrated in Figure 14 below.

With MUSIM enabled devices it's possible to have SIMs from two different operators and the SIMs can also be registered to operators from different countries. With setups like these it's possible have a local SIM and a roaming SIM for example during work trips or travelling. There is also possibility to achieve better network coverage using SIMs from different operators as the operators can use different cell towers which the other SIM can't access. There is also the case where one SIM can only provide voice and/or data capability while the other SIM is used only for data. This kind of planning can help to reduce the costs introduced with data usage when roaming for smart phone communications [24].

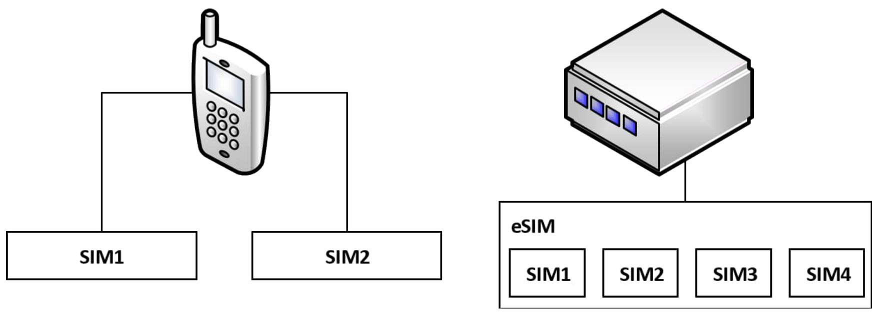

Figure 14. Examples of physical SIM and eSIM

4.2. Existing Implementations

The GSM Association (GSMA) defines two ways of achieving MUSIM operations for the UE. These ways are Dual-SIM Dual Standby (DSDS) and Dual-SIM Dual Active (DSDA) and they are presented in Figure 15 below. For future expansion, GSMA has also defined Multi SIM Multi Standby (MSMS) and Multi SIM Multi Active (MSMA). [25]

DSDS implementation uses one transceiver that is shared between SIMs. Transceiver combines a radio transmitter and a receiver into one component. In DSDS, both SIMs can be registered to the network and be in RRC_IDLE or RRC_INACTIVE states. When either of the SIMs enters active connection, for example due to paging or data transmission, the usage of the other SIM may be limited and e.g. paging can not be received anymore. If the active SIM is used for data transmission, paging can be received in other SIM meaning that call can be received. In DSDA both of the SIMs can be in RRC_CONNECTED state at the same time. Connectivity is achieved by using two transceivers, one for each SIM.

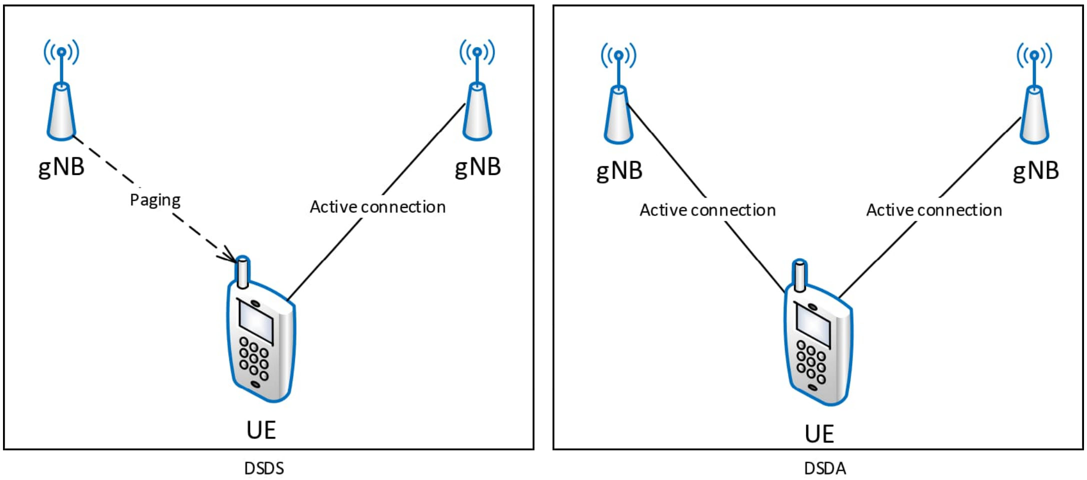

Figure 15. DSDS and DSDA connection types.

To support MUSIM in the UE, the UE needs to have and allocate radio-frequency (RF) resources for the number of modems used. Depending on the UE system on a system on a chip (SoC) implementation, the UE can have one RF resource to share between all modems or have a RF resource for each modem separately. A very simplified illustration of this is shown in Figure 16 below. Each SIM is considered to be separate modem and each modem must have a separate international mobile equipment identifier (IMEI) attached to it [25].

The benefits for having shared RF is the reduced SoC complexity, smaller die size and it is cheaper to produce [26]. The downside is that the available RF resource need to be shared between UE modems in software which means that it is possible that he UE cannot operate in DSDA mode in all cases, depending on the frequencies currently in use for the SIMs. If separate RF resources were to be used for modems, the production costs of such SoC would be more complex and expensive compared to one RF resource implementation as well as have increased power consumption. The benefit for having multiple RF resources available is that the UE will always have enough RF resources available for MUSIM operations. Whichever SoC implementation is used, the UE still needs to consider how much power shall be used for data transmissions, which band combinations are used and that the MUSIM operations between SIMs do not interfere each other.

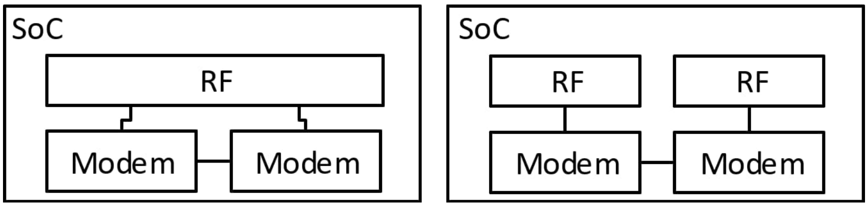

Figure 16. Simplified modem SoC for MUSIM UE.

Depending on the capabilities and implementation of the RF modem, the modem could support different types of MUSIM use cases i.e. 5G+5G, 5G+4G, 4G+4G. In most MUSIM implementations the modem shares one RF across all SIMs meaning that there must be some sort of control software running to be able to handle MUSIM use cases. Example devices and their support for MUSIM is shown in below Table 2.

Table 2. Example devices that support Multi-SIM

Type	**SoC**	**MUSIM Support**
Smartphone SoC	MediaTek Dimensity 8100 [27]	Yes, 5G+5G DSDS
Smartphone SoC	Qualcomm® Snapdragon™ 732G [28]	Yes, 4G+4G DSDS
Smartphone SoC	MediaTek Dimensity 9000 [29]	Yes, 5G+5G DSDA

4.3. Challenges with MUSIM Implementations

There are many MUSIM use cases that would benefit from standardised solutions that allow coordination between UE and NW, for example how reception of paging is handled so that UE does not miss incoming calls and how the current active RRC connection is released so that UE can use the released radio resources for the other SIM. Leaving the current RRC connection for MUSIM operations requires standardisation to provide the option to keep UE and NW in sync. In the UE side there is also the challenge how RF resources are allocated for MUSIM operations and how the introduced MUSIM changes are implemented to ensure correct behaviour with NW. There needs to be a solution for managing the RF resource use between multiple SIMs in the UE.

4.3.1. The Need for Multi SIM Standardisation

As there are many use cases for MUSIM functionality that can not be solved in the UE via proprietary mechanisms, the standardisation to adress some of the problems with MUSIM functionality is necesssary. The standardisation makes sure that every MUSIM device can work as expected in the given scenarios. These changes will also benefit existing MUSIM devices as the UE can avoid unnecessary RF resource usage. The goal for MUSIM standardisation is to provide solutions to issues raised by industry vendors and operators regarding MUSIM operations. Further development and enhancements will be easier as existing designs can be used as a base.

5. RELEASE 17 - MUSIM CHANGES

The 3GPP has studied MUSIM functionality and challenges in technical report (TR) 23.761 where MUSIM coordination between UE and NW is taken into consideration [20]. This TR includes solutions to MUSIM use cases presented in earlier chapters. However, these solutions are not presented as final solutions for Release 17 but rather as guidelines. The key issues are presented in Table 3 below. Only solutions and impacts to 5GC and RRC are taken into consideration in this thesis. The following sections will go into detail about each key issue.

Table 3. Multi-SIM key issues

Key Issue	Impacts	Solutions
#1: Mobile Terminated UEs	UE Configuration, Services	1-3, 7-13, 23-26, 28
#2: Paging	UE Configuration, Services	7, 12, 14-21, 24, 26, 27
#3: Coordinated Leaving	UE Configuration, data	4-6, 17, 22, 23, 25, 27
#4: Emergency Handling	The TR 23.761 does not need to address emergency services	No solutions in TR 23.761

5.1. Handling of Mobile Terminated Service

The solutions presented for mobile terminated service can be categorised as presented in Table 4 below similarly as Vikhrova et al. have done in their work [30]. Many of the solutions provided in the TR 23.761 fall into these categories so they are bundled as one entity. The paging solutions are evaluated and present in the Paging section of this thesis.

Table 4. Mobile Terminated Service Solutions

Category	Impacts	TR Solutions
Paging	UE, RAN, AMF, UPF, SMF	1, 9, 10, 11, 24, 26, 28
Short Period Absence	UE, RAN	2
Busy Indication	UE, AMF, SMF, RAN	3
Notifications	UE, AMF, SMF	7, 8, 12, 13, 25

5.1.1. Paging Cause

To help the UE and network decide what to do upon paging, the 3GPP has proposed that the cause of paging is added to paging message. The addition of paging cause would assist in implementation of paging reception logic on the MUSIM UE as it would possible to implement pre-configured logic for the new paging causes.

This solution improves MUSIM UE operation as there could be use cases where, for example, MUSIM UE operates in DSDS mode, SIM1 is in active connection and SIM2 operation is limited, SIM2 receives paging with a new cause which tells the UE that paging received is for voice call. Now that the MUSIM UE knows the reason for paging the UE can trigger RRC connection establishment for paging response in SIM2 and limit SIM1 operations due to DSDS operation. If paging received is not for voice call, the actions done in SIM2 is decided by the UE. Paging cause improves judgement of MUSIM operations in UE MUSIM controller as this information can be used to check if paging requires some specific operations.

The paging cause is sent by the network the UE. This solution needs to be implemented in the network in such a way that network will always indicate the paging cause to the UE. The UE needs to handle the new paging causes added and implement logic for the reception of new paging causes. Currently there is only one paging cause for voice call added in Release 17 but new causes can be added in the next 3GPP releases [31].

5.1.2. Short Period Absence

The short period absence aims to avoid any unaware interruptions, save system resources, and prevent other SIM from performing undesirable operations on the UE. With this feature, the MUSIM UE can negotiate a single short period absence from the current systems RAN. During the negotiated absence period, the UE can determine which network or SIM shall be used after the absence period ends. In the case when UE does not send any data or preferred network, the network can assume that connection shall be resumed on the same RAN where absence period was negotiated.

5.1.3. Busy Indication

With the solution 3, Busy Indication, the UE can judge the importance of paging received to see if there are more important procedures ongoing on the UE. This solution aims to save NW resources as this would allow NW to save on paging resources. When UE receives paging on SIM1, the UE will evaluate and check if the operations performed on SIM2 are more important than the paging received. If the UE evaluates that the operations on SIM2 are more important, SIM1 UE will respond to the paging received with NAS message transfer towards the NW that contains busy indication information. For the transmission of busy indication, SIM1 enters RRC_CONNECTED state and leaves the state after transmission has been done. Figure 17 provides simple illustration on how this feature could work in the MUSIM UE.

This solution impacts the Layer 3 NAS in the UE which means that all signaling is done between NAS and AMF. One point for consideration in this solution is how the UE will perform the evaluation for which SIM operation is more important upon paging reception.

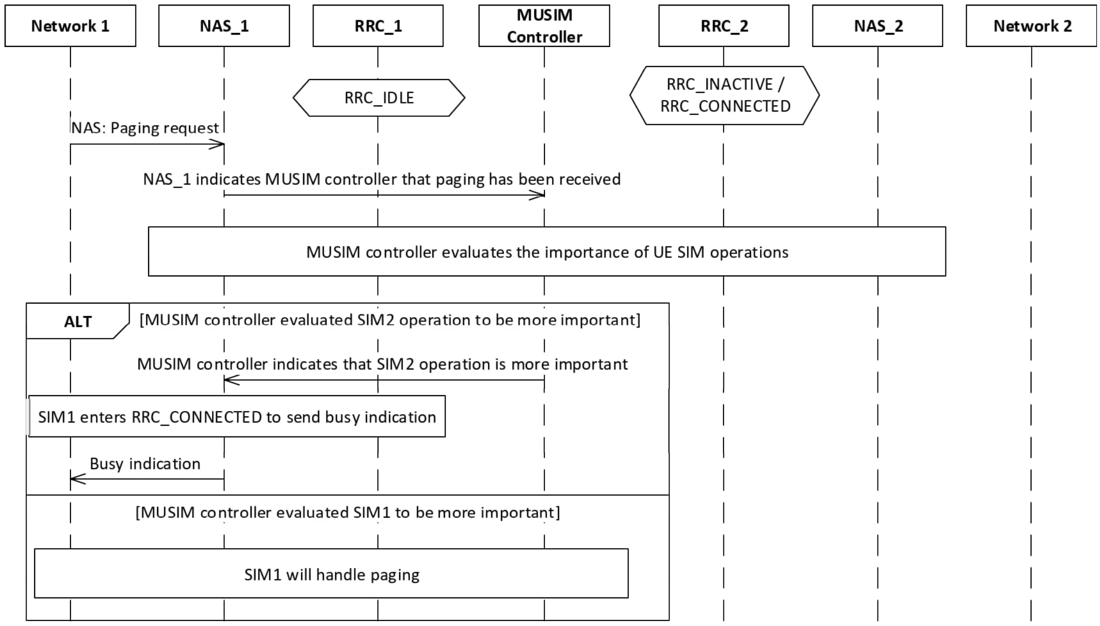

Figure 17. Busy Indication due to MUSIM operation

5.2. Paging

The solutions presented for mobile terminated service can be categorised as presented in Table 5 below. Many of the solutions provided in the TR 23.761 fall into these categories so they are bundled as one entity.

Table 5. Paging Solutions

Category	**Impacts**	**TR Solutions**
Push Notifications	5GC (Paging Server), AMF, NEF UE	7, 12
Paging Collision	AMF, UE, RAN, NW, UPF	14-20, 24
Scheduling gap for MUSIM UE	UE	21
Paging Reception	UE, AMF	24, 26, 27

5.2.1. Scheduling Gaps for MUSIM

Scheduling gaps functionality presented in TR as solution 21 enables to possibility for UE to indicate gaps to be used in the UE for MUSIM use cases. By giving gap information to the network, the network can avoid wasting resources by only listening or sending data outside of the configured gaps. This features enables the UE to perform MUSIM operations for other SIMs during the configured gaps.

For the MUSIM scheduling gap usage to be possible, both the UE and network must support this feature. If UE has support for MUSIM scheduling gaps, the UE will include this information in UE capabilities towards the network as shown in Figure 18.

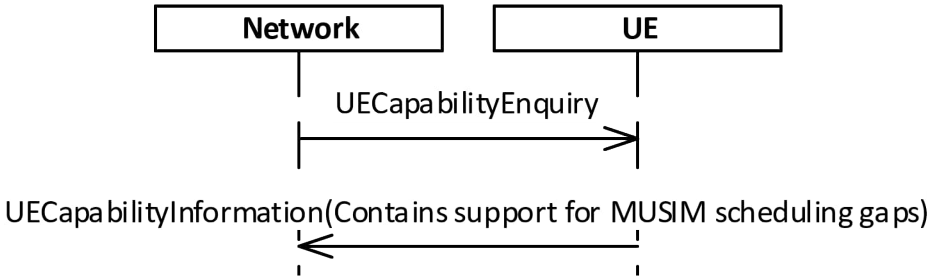

Figure 18. UE Capability for MUSIM Scheduling Gaps

After the UE capabilities have been received by the network, the network can configure musim-GapAssistanceConfig containing prohibit timer T346h duration to the UE contained in RRCReconfiguration PDU. The UE considers musim-GapAssistanceConfig to be configured when the prohibit timer T346h has a valid value. Prohibit timer prohibits the UE from sending UEAssistanceInformation messages to the network for the duration of the prohibit timer.

Implementation proposal for 5G enabled modem is shown in Figure 19 below. In this proposal, after musim-GapAssistanceConfig is configured to RRC_1, RRC_1 requests L1_1 to provide suitable gap information to be used for MUSIM operations. After the RRC_1 request, L1_1 needs to calculate suitable gaps to be used and for this, current configurations from SIM2 are needed. L1_1 uses MUSIM controller to find suitable gap information from L1_2 as can be seen in the figure. Once L1_1 gets suitable gap information from MUSIM controller and judges gap information to be suitable to be used for MUSIM operations, L1_1 provides gap information to RRC_1.

RRC_1 will send UEAssistanceInformation containing the UEs preferred gaps for MUSIM operations and starts prohibit timer T346h once L1_1 provides the suitable gap information. The network knows the UEs preferred MUSIM gaps from the UAI the UE sent and can now configure MUSIM gap configurations to be used by the UE with RRCReconfiguration PDU. The network should respect the UEs preferred MUSIM gap preference because otherwise the UE might not be able to comply with the gap configurations sent by the network. RRC_1 will handle the RRCReconfiguration sent by the network and configure musim-GapConfig from the RRCReconfiguration, configure the received MUSIM gap configurations to lower layers, and sends RRCReconfigurationComplete to the network. After the configuration of MUSIM scheduling gaps to lower layers, L1_1 provides configured gap information to MUSIM controller and MUSIM controller routes this information to L1_2 so that SIM2 can utilise the provided time periods for its radio operations.

The solution provided here impacts RRC for configuring MUSIM gap configuration and L1 for calculating and providing suitable gap information to RRC from the UE side. From the network side, the network needs to support the feature and the network needs to respect the MUSIM gap information provided by the UE.

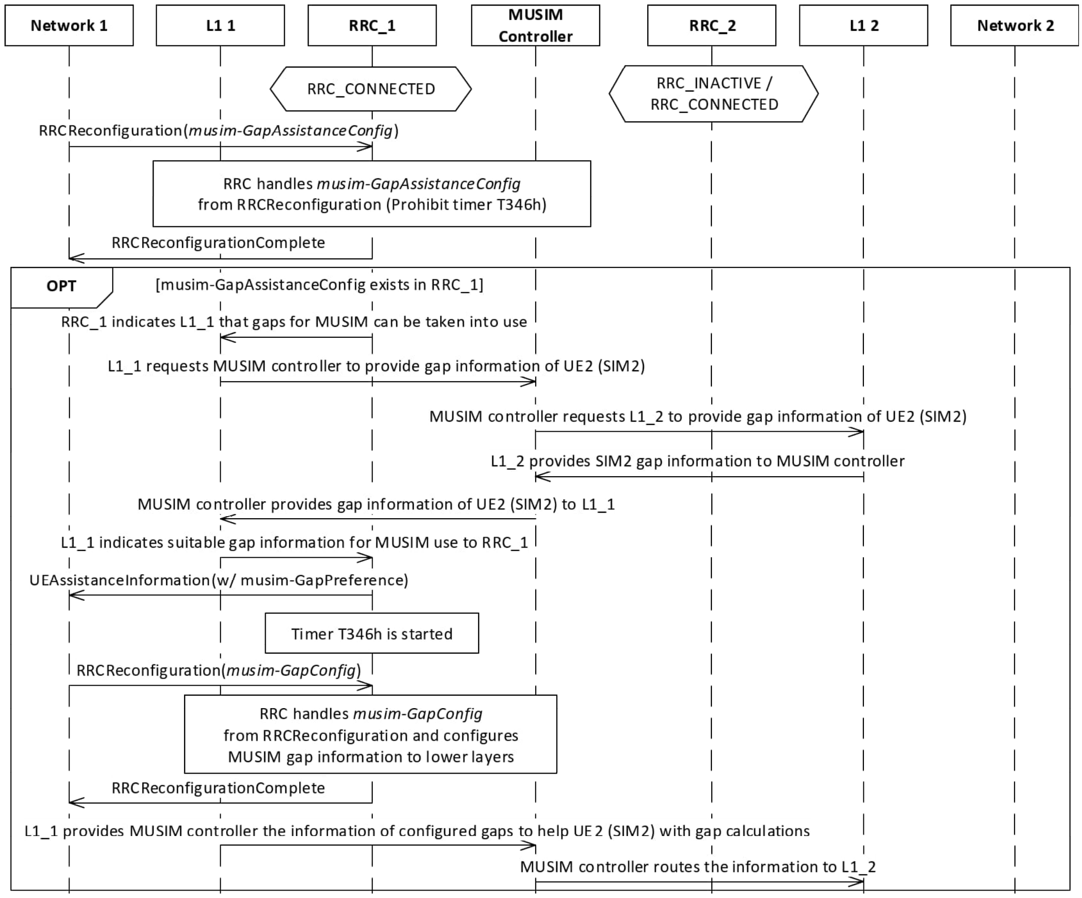

Figure 19. Configuration of MUSIM Scheduling Gaps

5.3. Leaving Active Connection

The solutions presented for leaving can be categorised as presented in Table 6 below. Many of the solutions provided in the TR 23.761 falls into these categories so they are bundled as one entity. Leaving means that the UE will always leave any active connection, i.e., transitions from RRC_CONNECTED state to either RRC_IDLE or RRC_INACTIVE state.

Table 6. Leaving Solutions

Category	Impacts	TR Solutions
Local Leaving	UE, RAN, AMF	4
Graceful leaving and resumption	UE, RAN, SMF, UPF	5
UE leave and return	UE, AMF, RAN	6
Coordinated Leaving	UE, RAN, AMF, SMF, UPF	22, 25, 27

5.3.1. Local Leaving

The TR solution 4 introduces two different ways for the UE to perform local release: NAS initiated local release and RRC initiated local release. The purpose for for local release indications is to keep UE and NW in sync and avoid wasting network and UE resources. This will always lead to UE transition out of RRC_CONNECTED state.

In NAS initiated local leaving, NAS sends UL NAS TRANSPORT with release request to the network and will then trigger UE to locally release RRC connections. The NAS initiated local leaving does not need a response from the NW when leaving for MUSIM purposes but rather just notifies the NW that UE will leave current RRC connection.

A solution for RRC initiated local release is presented in Figure 20 for MUSIM operation below. This procedure has three phases similarly as the scheduling gaps for MUSIM. These phases are UE capability signaling where UE indicates that the UE is capable of supporting MUSIM local release, the configuration phase where NW configures MUSIM RRC local release configurations to the UE. The last phase is that the UE (RRC) signals the NW that UE will leave current RRC connection.

As shown in the below figure, UE supports MUSIM RRC connection release after NW has configured musim-LeaveAssistanceConfig that contains the duration of prohibit timer T346g. When UE determines that the RRC_1 in currently active connection needs to be released, for example when paging on RRC_2 is received, the MUSIM controlled will indicate RRC_1 to leave the connection.

If the RRC_1 has musim-LeaveAssistanceConfig configurations, the RRC_1 will send UEAssistanceInformation (UAI) to the NW which contains the preferred RRC state where RRC_1 wants to transition. The reception of this UAI in the NW allows the NW to send RRCRelease PDU to RRC_1 to perform NW initiated NW release. If NW does not respond after UAI has been send, the UE will trigger local release after the timer T346g expires and transitions to RRC_IDLE. The UE will then indicate the MUSIM controller, that RRC_1 is now in RRC_IDLE and SIM2 can enter RRC_CONNECTED.

This solution would not have a big implementation impact for the UE. However, this solutions also needs NW to implement support for the UAI so that NW could respond with RRCRelease towards the UE. This solution is beneficial for devices that operate in DSDS mode as no two active RRC connections can exist at the same time.

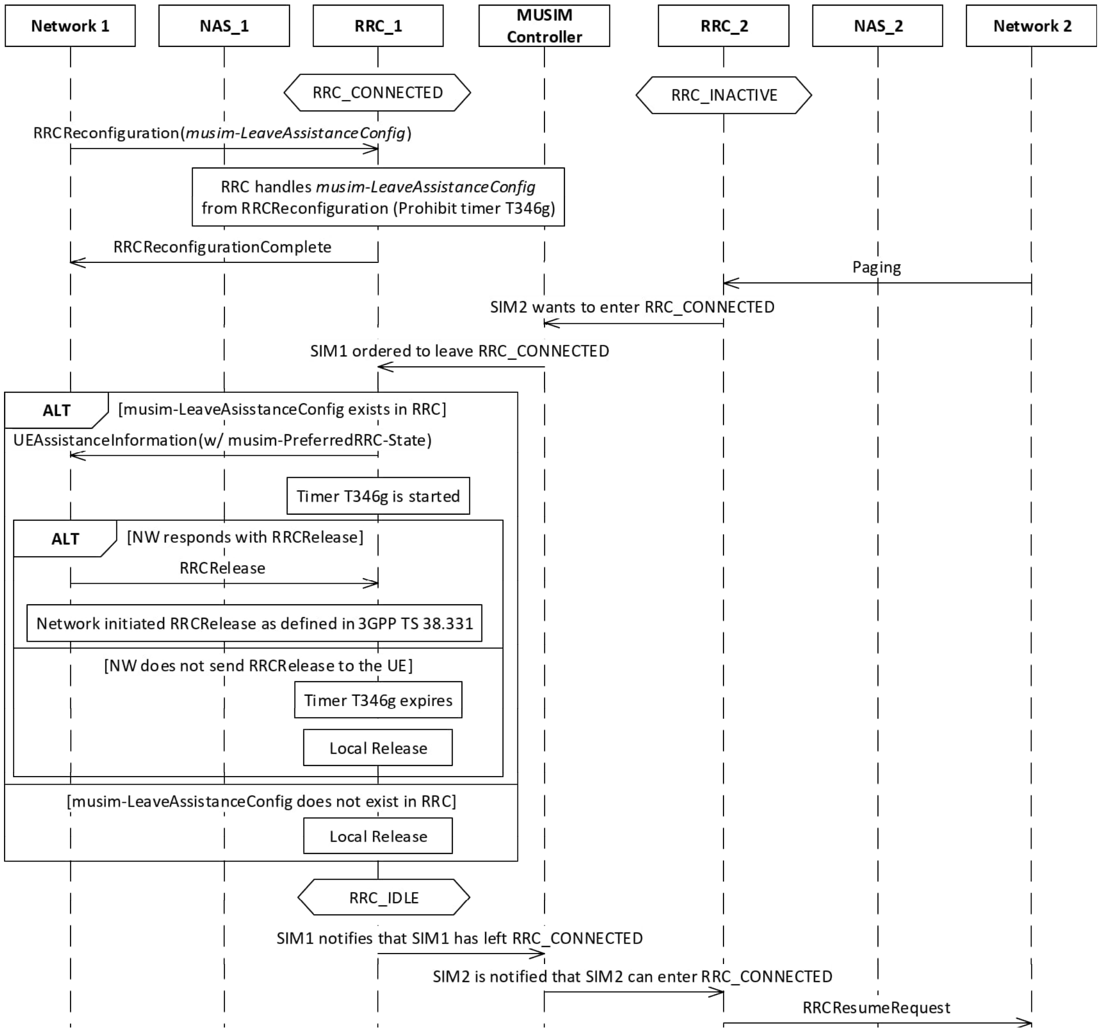

Figure 20. RRC Initiated Local Release

5.4. Emergency Handling

While the 3GPP TR 23.761 mentions emergency handling as a key issue for MUSIM operations there are no solutions for it. The TR mentions that 3GPP technical specification (TS) 22.101 contains the necessary requirements for emergency handling for a MUSIM UE. MUSIM UE needs to be able to select any SIM on the device according to priorities. These priorities are if SIM is in normal service or limited service, the SIM will be used. Another requirement is that the UE needs to avoid any interruptions from another SIM while MUSIM UE is in a emergency call procedure. This means that the emergency handling will be handled within the UE and contains proprietary solutions. [32]

6. DISCUSSION

The goal of thesis was to analyse the 3GPP Release 17 and the introduced MUSIM features in particular. Another goal was to present novel solutions for the 5G enabled MUSIM UE for several of the 3GPP features introduced which impacts RRC. Impacts to UE and networks were also described. The solutions done in this thesis were based on the 3GPP MUSIM study where possible MUSIM features in Release 17 were discussed. While writing this thesis 3GPP completed Release 17 specification that contains several features for MUSIM operation.

The 5G modem solutions for MUSIM features presented in thesis could be implemented in advance to the UE so that verification can start immediately once support from networks is available. The features introduced in 3GPP Release 17 specifications allow for UE and the network to perform connection release and scheduling radio resources for other SIM activities in a coordinated fashion, avoiding radio resource wastage and potential unsynchronisation between the UE and the network.

If these solutions are expanded to support MSMS or MSMA devices that contains more than two SIMs new solutions could be based on the dual-SIM solutions presented in this thesis. MSMS and MSMA solutions add additional complexity to the UEs MUSIM controller due to need to keep the status of every SIM up to date. This will also add complexity to the UEs RF resource management and new solutions for dividing limited resources are needed.

The solutions were not verified in this thesis. Validation for these features can not be completed until support exists in 5G network side as well. For reference there are way more 5G network vendors and operators than there are 5G modem vendors. It will most likely take a while before we see the 3GPP-specified MUSIM features in consumer 5G devices.

The upcoming 3GPP Release 18 is currently being planned and it will include new MUSIM features and enhacements. One planned feature that is currently under study is adding support for dual transmission/reception for MUSIM [33]. New MUSIM features will most likely use Release 17 MUSIM speficiations as a base for development but it remains to be seen until Release 18 specification is completed.

7. SUMMARY

In this thesis, 3GPP New Radio Release 17 specification was analysed and MUSIM features introduced were studied. Background information about New Radio networks were also described and challenges for MUSIM standardisation was discussed. The goal of this thesis was to study the 3GPP Release 17 MUSIM features and provide solutions to certain aspects of MUSIM functionality.

The solutions presented for 5G modem in this thesis were able to provide solutions to certain functionaly issues for MUSIM issues detected in 3GPP. The solutions provided are applicable to dual-SIM UEs but they can be further developed to support UEs with more SIMs. However, the solutions provided were not able to solve to all 3GPP issues regarding MUSIM functionality because not every 3GPP MUSIM solution proposal was analysed. Additionally, validation for the presented solutions was not done as there is no support from networks at this stage.

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9. APPENDICES

Appendix 1 MUSIM related fields introduced in 3GPP Release 17

```
-- ASN1START
-- TAG-PAGING-START

Paging ::=                          SEQUENCE {
    pagingRecordList                    PagingRecordList    OPTIONAL, -- Need N
    lateNonCriticalExtension            OCTET STRING        OPTIONAL,
    nonCriticalExtension                Paging-v1700-IEs    OPTIONAL
}

Paging-v1700-IEs ::=                SEQUENCE {
    pagingRecordList-v1700              PagingRecordList-v1700    OPTIONAL, -- Need N
    pagingGroupList-r17                 PagingGroupList-r17       OPTIONAL, -- Need N
    nonCriticalExtension                SEQUENCE {}               OPTIONAL
}

PagingRecordList ::=                SEQUENCE (SIZE(1..maxNrofPageRec)) OF PagingRecord

PagingRecordList-v1700 ::=          SEQUENCE (SIZE(1..maxNrofPageRec)) OF PagingRecord-v1700

PagingGroupList-r17 ::=             SEQUENCE (SIZE(1..maxNrofPageGroup-r17)) OF TMGI-r17

PagingRecord ::=                    SEQUENCE {
    ue-Identity                         PagingUE-Identity,
    accessType                          ENUMERATED {non3GPP}    OPTIONAL,    -- Need N
    ...
}

PagingRecord-v1700 ::=              SEQUENCE {
    pagingCause-r17                     ENUMERATED {voice}      OPTIONAL     -- Need N
}

PagingUE-Identity ::=               CHOICE {
    ng-5G-S-TMSI                        NG-5G-S-TMSI,
    fullI-RNTI                          I-RNTI-Value,
    ...
}

-- TAG-PAGING-STOP
-- ASN1STOP
```

Figure 21. Changes to Paging

```
UEAssistanceInformation-v1700-IEs ::= SEQUENCE {
    ul-GapFR2-Preference-r17                UL-GapFR2-Preference-r17                OPTIONAL,
    musim-Assistance-r17                    MUSIM-Assistance-r17                    OPTIONAL,
    overheatingAssistance-r17               OverheatingAssistance-r17               OPTIONAL,
    maxBW-PreferenceFR2-2-r17               MaxBW-PreferenceFR2-2-r17               OPTIONAL,
    maxMIMO-LayerPreferenceFR2-2-r17        MaxMIMO-LayerPreferenceFR2-2-r17        OPTIONAL,
    minSchedulingOffsetPreferenceExt-r17    MinSchedulingOffsetPreferenceExt-r17    OPTIONAL,
    rlm-MeasRelaxationState-r17             BOOLEAN                                 OPTIONAL,
    bfd-MeasRelaxationState-r17             BIT STRING (SIZE (1..maxNrofServingCells)) OPTIONAL,
    nonSDT-DataIndication-r17               SEQUENCE {
        resumeCause-r17                         ResumeCause                         OPTIONAL
    }                                                                               OPTIONAL,
    scg-DeactivationPreference-r17          ENUMERATED { scgDeactivationPreferred, noPreference }    OPTIONAL,
    uplinkData-r17                          ENUMERATED { true }                     OPTIONAL,
    rrm-MeasRelaxationFulfilment-r17        BOOLEAN                                 OPTIONAL,
    propagationDelayDifference-r17          PropagationDelayDifference-r17          OPTIONAL,
    nonCriticalExtension                    SEQUENCE {}                             OPTIONAL
}
```

Figure 22. Changes to UEAssistanceInformation

```
MUSIM-Assistance-r17 ::=                SEQUENCE {
    musim-PreferredRRC-State-r17            ENUMERATED {idle, inactive, outOfConnected}      OPTIONAL,
    musim-GapPreferenceList-r17             MUSIM-GapPreferenceList-r17                      OPTIONAL
}

MUSIM-GapPreferenceList-r17 ::= SEQUENCE (SIZE (1..4)) OF MUSIM-GapInfo-r17
```

Figure 23. New MUSIM fields added in UEAssistanceInformation

```
OtherConfig-v1700 ::=                      SEQUENCE {
    ul-GapFR2-PreferenceConfig-r17             ENUMERATED {true}                                      OPTIONAL, -- Need R
    musim-GapAssistanceConfig-r17              SetupRelease {MUSIM-GapAssistanceConfig-r17}           OPTIONAL, -- Need M
    musim-LeaveAssistanceConfig-r17            SetupRelease {MUSIM-LeaveAssistanceConfig-r17}         OPTIONAL, -- Need M
    successHO-Config-r17                       SetupRelease {SuccessHO-Config-r17}                    OPTIONAL, -- Need M
    maxBW-PreferenceConfigFR2-2-r17            ENUMERATED {true}                                      OPTIONAL, -- Cond maxBW
    maxMIMO-LayerPreferenceConfigFR2-2-r17     ENUMERATED {true}                                      OPTIONAL, -- Cond maxMIMO
    minSchedulingOffsetPreferenceConfigExt-r17  ENUMERATED {true}                                     OPTIONAL, -- Cond minOffset
    rlm-RelaxationReportingConfig-r17          SetupRelease {RLM-RelaxationReportingConfig-r17}       OPTIONAL, -- Need M
    bfd-RelaxationReportingConfig-r17          SetupRelease {BFD-RelaxationReportingConfig-r17}       OPTIONAL, -- Need M
    scg-DeactivationPreferenceConfig-r17       SetupRelease {SCG-DeactivationPreferenceConfig-r17}    OPTIONAL, -- Cond SCG
    rrm-MeasRelaxationReportingConfig-r17      SetupRelease {RRM-MeasRelaxationReportingConfig-r17}   OPTIONAL, -- Need M
    propDelayDiffReportConfig-r17              SetupRelease {PropDelayDiffReportConfig-r17}           OPTIONAL  -- Need M
}

MUSIM-GapAssistanceConfig-r17 ::= SEQUENCE {
    musim-GapProhibitTimer-r17        ENUMERATED {s0, s0dot1, s0dot2, s0dot3, s0dot4, s0dot5, s1, s2, s3, s4, s5, s6, s7, s8, s9, s10}
}

MUSIM-LeaveAssistanceConfig-r17 ::=      SEQUENCE {
    musim-LeaveWithoutResponseTimer-r17      ENUMERATED {ms10, ms20, ms40, ms60, ms80, ms100, spare2, spare1}
}
```

Figure 24. New MUSIM fields in OtherConfig

```
RRCReconfiguration-v1700-IEs ::=        SEQUENCE {
    otherConfig-v1700                   OtherConfig-v1700                        OPTIONAL, -- Need M
    ul-GapFR2-Config-r17                SetupRelease { UL-GapFR2-Config-r17 }    OPTIONAL, -- Need M
    sl-L2RelayUEConfig-r17              SetupRelease { SL-L2RelayUEConfig-r17 }  OPTIONAL, -- Cond L2RelayUE
    sl-L2RemoteUEConfig-r17             SetupRelease { SL-L2RemoteUEConfig-r17 } OPTIONAL, -- Cond L2RemoteUE
    dedicatedPagingDelivery-r17         OCTET STRING (CONTAINING Paging)         OPTIONAL, -- L2U2NRelay
    needForNCSG-ConfigNR-r17            SetupRelease {NeedForNCSG-ConfigNR-r17}  OPTIONAL, -- Need M
    needForNCSG-ConfigEUTRA-r17         SetupRelease {NeedForNCSG-ConfigEUTRA-r17} OPTIONAL, -- Need M
    musim-GapConfig-r17                 SetupRelease {MUSIM-GapConfig-r17}       OPTIONAL, -- Need M
    scg-State-r17                       ENUMERATED { deactivated }               OPTIONAL, -- Need S
    appLayerMeasConfig-r17              AppLayerMeasConfig-r17                   OPTIONAL, -- Need M
    nonCriticalExtension                SEQUENCE {}                              OPTIONAL
}
```

Figure 25. New MUSIM fields in RRCReconfiguration

```
MUSIM-GapConfig-r17 ::=                  SEQUENCE {
    musim-GapToReleaseList-r17  SEQUENCE (SIZE (1..2)) OF MUSIM-GapID-r17     OPTIONAL,
    musim-GapToAddModList-r17   SEQUENCE (SIZE (1..2)) OF MUSIM-GapInfo-r17   OPTIONAL,
    musim-AperiodicGap-r17      MUSIM-GapInfo-r17                OPTIONAL, -- Need N
   ...
}
MUSIM-GapInfo-r17 ::=          SEQUENCE {
    musim-GapID-r17                           MUSIM-GapID-r17            OPTIONAL, -- Cond periodic
    musim-Starting-SFN-AndSubframe-r17        MUSIM-Starting-SFN-AndSubframe-r17  OPTIONAL, -- Cond aperiodic
    musim-GapLength-r17                       ENUMERATED {ms3, ms4, ms6, ms10, ms20}  OPTIONAL,
musim-GapRepetitionAndOffset-r17        CHOICE {
        ms20-r17                              INTEGER (0..19),
        ms40-r17                              INTEGER (0..39),
        ms80-r17                              INTEGER (0..79),
        ms160-r17                             INTEGER (0..159),
        ms320-r17                             INTEGER (0..319),
        ms640-r17                             INTEGER (0..639),
        ms1280-r17                            INTEGER (0..1279),
        ms2560-r17                            INTEGER (0..2559),
        ms5120-r17                            INTEGER (0..5119),
        ...
}          OPTIONAL -- Cond periodic
}
MUSIM-Starting-SFN-AndSubframe-r17 ::=           SEQUENCE {
    starting-SFN-r17            INTEGER (0..1023),
    startingSubframe-r17        INTEGER (0..9)
}
```

Figure 26. MUSIM gap configurations in RRCReconfiguration