5G Implementation Guidelines: SA Option 2

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Overview

Introduction

5G is becoming a reality as early adopters have already commercialized data-oriented 5G networks in 2018 and launched consumer mobile 5G in 2019. Whilst early adopters do not necessarily require guidance, there are still majority of the operator communities that are yet to launch commercial 5G services. This document intends to provide a checklist for operators that are planning to launch 5G networks in SA (Standalone) Option 2 configuration

Scope

This document provides technological, spectrum and regulatory considerations in the deployment.

This version of the document currently provides detailed guidelines for implementation of 5G using Option 2, reflecting the initial launch strategy being adopted by multiple operators. There is an implementation guideline for NSA Option 3 already available. However, as described in "GSMA Operator Requirements for 5G Core Connectivity Options" there is a need for the industry ecosystem to support all of the 5G core connectivity options (namely Option 4, Option 5 and Option 7). As a result, further guidelines for all 5G deployment options will be provided in the future.

Note: The topics listed in this document is not exhaustive and is open to suggestion/contribution by any company. Please contact futurenetworks@gsma.com

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Abbreviations

Term	Description
5G	Fifth Generation
5GC	5G Core
5GS	5G System
5G-SRVCC	5G Single Radio Voice Call Continuity
AAU	Active Antenna Unit
AF	Application Function
AI	Artificial Intelligence
AM	Access Management
AMF	Access and Mobility Management Function
APN	Access Point Name
AR	Augmented Reality
AUSF	Authentication Server Function
BBU	Baseband Unit
BPSK	Binary Phase Shift Keying
BSF	Binding Support Function
BWP	Bandwidth Parts
CA	Carrier Aggregation
CAPEX	Capital Expenditure
CBRS	Citizens Broadband Radio Service
CN	Core Network
CP-OFDM	Cyclic-Prefix Orthogonal Frequency Division Modulation
CS	Circuit Switch
CSMF	Communication Service Management Function
cTE	constant Time Error
CU	Central Unit
CUPS	Control and User Plane Separation
DC	Data Centre
DFT-s-OFDM	Discrete Fourier Transform Spread Orthogonal Frequency Division Modulation
DL	Downlink
DN	Data Network
DNN	Data Network Name
DSS	Dynamic Spectrum Sharing
DU	Distributed Unit
E2E	End-to-End

Term	Description
eCPRI	Enhanced Common Public Radio Interface
eMBB	Enhanced Mobile Broadband
eNB	eNodeB
EPC	Evolved Packet Core
EPS	Evolved Packet System
EU	European Union
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FCC	Federal Communications Commission
FDD	Frequency Division Duplexing
FlexE	Flexible Ethernet
gNB	gNodeB
GNSS	Global Navigation Satellite System
GST	Generic network Slice Template
HARQ	Hybrid Automatic Repeat Request
HD	High Definition
HPLMN	Home PLMN
HR	Home Routed
HSS	Home Subscriber Server
IMS	IP Multimedia Subsystems
IoT	Internet of Things
IP	Internet Protocol
IPX	IP Exchange
IRAT	Inter-RAT
ISC	IMS Security Control
IWK	Interworking
LADN	Local Area Data Network
LAN	Local Area Network
LBO	Local Breakout
LDPC	Low Density Parity Check
LTE	Long Term Evolution
MAC	Medium Access Control
Massive MIMO	Massive Multiple Input Multiple Output
MEAO	MEC Application Orchestrator
MEC	Multi-access Edge Computing
MEP	MEC Platform
MEPM	MEC Platform Management
MIMO	Multiple-Input Multiple-Output

Term	Description
ML	Machine Learning
MME	Mobile Mobility Entity
mMTC	Mobile Machine Type Communications
MO SMS	Mobile-Originated Short Message Service
MSISDN	Mobile Station International Subscriber Directory Number
MT	Mobile Terminate
MTC	Machine Type Communication
MU-MIMO	Multi-User Multiple-Input Multiple-Output
NAS	Non-Access-Stratum
NE	Network Element
NEF	Network Exposure Function
NEST	NEwork Slice Types
NF	Network Function
NFV	Network Function Virtualization
NG-RAN	Next Generation Radio Access Network
NR	New Radio
NRF	Network Repository Function
NSA	Non-Standalone
NSI	Network Slice Instance
NSMF	Network Slice Management Function
NSSF	Network Slice Selection Function
NSSMF	Network Slice Subnet Management Function
O&M	Operation and Maintenance
OFDM	Orthogonal Frequency Division Multiplexing
OPEX	Operating Expense
OTA	Over the Air
PCF	Policy Control Function
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
PDU	Protocol Data Unit
PGW	PDN Gateway
PGW-C	Packet Gateway Control function
PGW-U	Packet Getaway User function
PLMN	Public Land Mobile Network

Term	Description
PMN	Public Mobile Network
PRACH	Physical Random Access Channel
PRD	Permanent Reference Document
PS	Packet Switch
PUCCH	Physical Uplink Control Channel
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
R&D	Research & Development
RAN	Radio Access Network
RAT	Radio Access Technology
RB	Resource Block
RCA	Root Cause Analysis
RLC	Radio Link Control
RNA	RAN-based Notification Area
RRC	Radio Resource Control
RRM	Radio Resource Management
RRU	Remote Radio Unit
RSRP	Reference Signal Received Power
SA	StandAlone
SBA	Service-Based Architecture
SC-OFDM	Single Carrier – Orthogonal Frequency Division Multiplexing
SDAP	Service Data Adaptation Protocol
SDN	Software Defined Network
SEPP	Security Edge Protection Proxy
SIB	System Information Block
SGW	Serving Gateway
SLA	Service-Level Agreement
SM	Service Management
SMF	Session Management Function
SMS	Short Message Service
SMSF	Short Message Service Function
SMSoIP	SMS over IP
SMSoNAS	SMS over NAS
S-NSSAI	Single Network Slice Selection Assistance Information
SRS	Sounding Reference Signal
SSB RSRP	SS/PBCH Block Reference Signal Received Power

Term	Description
SSC	Session and Service Continuity
SST	Slice/Service Type
SU-MIMO	Single-user MIMO
SUL	Supplementary UL
TAC	Tacking Area Code
TAS	Telecom Application Server
TCO	Total Cost of Ownership
TDD	Time Division Duplexing
TN	Transmission Network
TRX	Transmission and Reception
UDM	Unified Data Management
UDR	Unified Data Repository
UDSF	Unstructured Data Storage Function
UE	User Entity
UL	Uplink
UPF	User Plane Function
URLLC	Ultra Reliable and Low Latency Communication
V2X	Vehicle to everything
VM	Virtual Machine
Vo5GS	Voice over 5GS
VoLTE	IMS-based voice service provided over EPS as defined in IR.92
VoPS	Voice over PS
VPN	Virtual Private Network
VR	Virtual Reality
WLAN	Wireless LAN
WRC	World Radiocommunication Conference

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Ref	Title
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Contents

1

Commercialisation of 5G

1. Commercialisation of 5G

1.1 Enhanced mobile broadband

Enhanced mobile broadband (eMBB) refers to the extension of the data demand that is addressed by traditional mobile broadband with target performance indicators: 10~20Gbps peak data rate, 50~100Mbps user experienced data rate and 4ms one-way latency in user plane [1].

Compared with Non-Standalone (NSA) Option 3, 5G Standalone (SA) Option 2 network demonstrates advantages in uplink (UL), End-to-End (E2E) latency, edge computing, etc., and therefore provides much user experience:

- 4K live broadcasting services produce and deliver contents in real time, requiring higher uplink data rate. Possibility to provide strong uplink capability with 5G SA Option 2 benefits such services. In January 2019, China Central Television completed 4K live broadcasting and 360° virtual reality live with 250Mbps uplink data rate in 5G SA Option 2 network[2].
- Virtual reality (VR) and augmented reality (AR) applications based on cloud rendering will be a trend, since it helps mobile users enjoy VR/AR services with lower device cost. VR/AR service experience can be greatly optimized by reducing latency through local rendering over edge computing platform in 5G SA Option 2 network.
- Online gaming services, especially real-time interactive games, are quite sensitive to network latency. 5G SA Option 2 network with edge computing can shorten response latency and provide better user experiences.

1.2 Internet of things

5G addresses massive machine type communications (mMTC) use cases, such as smart metering, characterized by low power consumption and vast number of connections. It is expected that 5G is capable of 1 million connections per square kilometer [1].

1.3 Ultra-reliable and low latency

Ultra-reliable low latency communications (URLLC) refers to high reliability, high availability and low latency connection. According to ITU M.2410-0 [1], the minimum requirement for one-way latency in user plane is 1ms, while control plane latency is 20ms and the minimum requirement for the reliability is 99.999%.

Multi-robot coordination, as a typical scenario of URLLC, plays a key role in improving production efficiency. KUKA, a Germany robot company, has verified that two 5G robot arms can drum together in synchronized patterns with 1ms latency and 99.999% reliability [3].

URLLC empowers more applications for enterprise customers with short latency capability, leading to more opportunities for operators. Customers will benefit from these services in terms of improving efficiency and reducing operating cost. Meanwhile, operators will obtain extra revenue by offering services with differentiated latency.

1.4 Verticals

Vertical industries are very diverse and their requirements are determined by the service features of the related vertical market segment. 5G can provide optimal solutions catering to various requirements and business needs of each vertical in an economical way. It also opens new opportunities for operators to extend their businesses and create new revenue streams beyond connectivity. As for operators, there are a number of industries with particular business opportunities around 5G SA Option 2, including media & entertainment, manufacturing and transport &logistics. Each of these industries has potential use cases linked to 5G SA Option 2, some of which are already being explored in pilot projects.

- 5G brings tremendous opportunities for media & entertainment industry. Significant improvements in bandwidth and latency lead to innovations in content and interaction, such as VR live streaming and 360° panoramic view broadcasting delivered in large public venues. Taking a marathon event as an example, combining 5G SA Option 2 networks with 4K/8K, VR/AR and drone allows customers to enjoy High Definition (HD) live streaming with 1Gbps+ downstream, 200-300Mbps upstream and 10ms E2E latency.
- Smart Manufacturing is often referred to as the next Industrial Revolution or Industry 4.0, which enables flexibility, digitalization and automation in production. 5G SA Option 2 can fulfil more stringent and service critical requirements of the manufacturing industry, including latency, reliability, security and real-time capabilities. Manufacturing represents one of the most important industry sectors for new potential revenue to operators.
- The transport & logistics industry, ranging from public buses to logistics harbors, benefits greatly from 5G networks. With 5G SA Option 2, the industry can offer novel time-to-market services, such as high-speed Wi-Fi on bus, HD video surveillance and real-time bus information. Operators have an emerging opportunity to play a key role in transport & logistics industry by providing fast, flexible and secure services.

2

Prerequisite for initial 5G SA Option 2 launch

2. Prerequisite for initial 5G SA Option 2 launch

2.1 Introduction

In 5G SA Option 2 (hereinafter referred to as SA Option 2), New Radio (NR) access network consisting of gNBs connected to 5G Core (5GC). The user-plane and control-plane of SA Option 2 are using NR and are completely independent of Long Term Evolution (LTE). 5G System (5GS), including 5G SA Option 2, is an end-to-end system ranging from devices, radio access network (gNB) and core network (5GC). For the general architecture of 5G SA Option 2, please refer to Figure 1.

5G key technologies including Service-based Architecture (SBA), network slicing and edge computing enable various scenarios and use cases. With SBA and control and user plane separation, network scalability and flexibility are enhanced. Furthermore, Network Function Virtualization (NFV) / Software-Defined Networking (SDN) technology promises SA Option 2 deployment in a virtualized and cloudified way.

5G NR key technologies include new air interface, massive Multi-Input and Multi-Output (MIMO), Uplink enhancement etc., aiming to improve spectrum efficiency, enhance coverage and suppress interference.

5G coupled with Artificial Intelligence (AI) will lead to multiple innovative applications and solutions for customers, especially for vertical industries.

On the early stage of 5G SA Option 2 deployment, eMBB service is focus and interworking between 4G and 5G is necessary to ensure service continuity. URLLC and mMTC services will be supported at the later stage.

2.2 5G architecture for SA Option 2

Figure 1 depicts 5G architecture for SA Option 2 as defined in 3GPP TS 23.501 [20].

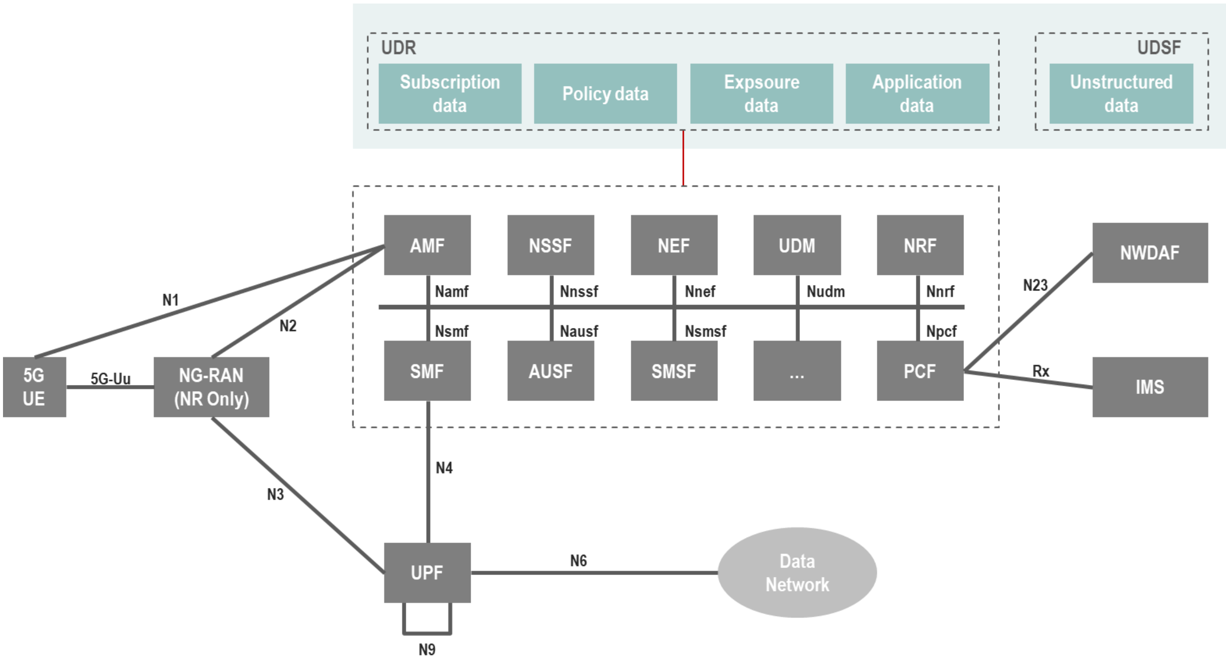

Figure 1 5G architecture for SA Option 2

2.2.1 5G NG-RAN (Next Generation Radio Access Network) with NR only

In the SA Option 2 architecture, gNBs connect to 5GC via N2 and N3 interface. gNBs are interconnected via Xn interface. In SA Option 2, NR network is independent of existing LTE network.

The functionality of the 5G Baseband Unit (BBU) can be partitioned into two entities: Central Unit (CU) and Distributed Unit (DU). In the initial phase, co-located CU/DU is preferred by some operators because of fewer network elements, lower complexity of planning and operation and faster deployment, etc.

2.2.2 5G Core Network

To offer new services, 5GC adopts new paradigm of core network as follows:

- New 5GC is expected to be a cloud-based system that leverages SBA to be more scalable and flexible.
- Separation of control plane and user plane allows better edge deployment for latency sensitive use cases.
- Data layer is categorized into Unified Data Repository (UDR) and Unstructured Data Storage Function (UDSF) to cover both structured data and unstructured data.
- Stateless Network Function (NF) enables common nature for greater robustness.
- 4G/5G interworking via N26 interface between Mobility Management Entity (MME) and Access and Mobility Management Function (AMF) is standardized.
- Possibility for a User Equipment (UE) to be connected to multiple User Plane Functions (UPFs) simultaneously. For example, one remote (e.g., for a Data Network (DN) like Internet) and one close to the edge (e.g., for edge / low latency services).

5GC SBA is based on a set of NFs providing services to other authorized NFs via service-based interfaces (SBI). The Network Repository Function (NRF) allows an NF to register itself and to discover the services offered by other NFs. All these interfaces are standardized and open.

SA Option 2 is expected to also serve vertical use cases. To address these, network exposure capability and network slicing feature are defined to assure openness, Service Level Agreement (SLA), isolation and ease of use.

2.3 Spectrum

To deliver the highly-reliable, ultra-low latency, multi-gigabit connectivity that 5G portends, spectrum for 5G services needs to include low-, mid-, and high-band spectrum. 5G is also able to make use of licensed, unlicensed, and shared spectrum. A global snapshot of allocated or targeted 5G spectrum is shown as Figure 2.

The low-band spectrum will offer several unique advantages as the foundation for 5G networks, including wider coverage and deeper signal penetration inside buildings. US operators have started to deploy 5G in the 600 MHz band while the European Union (EU) has declared 5G a priority in the 700 MHz band and assignments are happening across the region.

5G has been widely deployed worldwide in the 3.3-3.8 GHz IMT range, including China, Europe, the Middle East, Japan, Korea, etc. The U.S. has authorised initial commercial deployments in the CBRS band (3.55 to 3.7 GHz), and this spectrum will be used for 4G and/or 5G. The EU has declared the 3.4-3.8 GHz band as a 'pioneer 5G band' for Europe. In a Notice of Proposed Rule Making issued in 2018 [4], the Federal Communications Commission (FCC) proposed to add a mobile, except aeronautical mobile allocation in 3.7-4.2 GHz band and is in the midst of a proceeding over how much of this band can be transitioned to terrestrial wireless broadband services spectrum and on what terms. Moreover, in July 2019, FCC released an order to transform the entire 2496-2690 MHz band into a regular flexible use band for IMT [5]. Much of this band is already used for 4G and 5G. China has commercially launched 5G in 2.6 GHz band in China.

Millimeter wave bands are critical to provide multi-gigabit connectivity and extremely wide bandwidth capacity. These bands typically consist of a much larger amount of spectrum than is available in lower bands. By using this wider bandwidth and 5G advanced antenna technology, the millimeter wave bands will enable enhanced mobile broadband, massive Internet of Things (IoT), and ultra-reliable, ultra-low latency connectivity for a wide variety of services and devices. In particular, due to the limited range in millimeter wave bands, the spectrum is very well suited to vertical uses. Established service providers as well as new entrants are building next generation networks to support IoT applications and ultra-high-speed connectivity to improve consumer and business productivity using this spectrum. The United States (U.S.) has completed auctions of the 28 GHz and 24 GHz bands [4][6] and also 37 GHz, 39 GHz and 48 GHz bands in December of 2019 [7]—the largest award of millimeter wave spectrum ever. Japan and Korea have assigned the 28 GHz band to operators while Italy became the first country to assign the 26 GHz band for 5G in Europe. The Chinese government has approved 5G technology Research and Development (R&D) trial frequencies usage in 24.75-27.5 GHz & 40 GHz mmWave ranges in July of 2017 [8].

Figure 2 Global snapshot of allocated/targeted 5G spectrum (As of October 2019)

Dynamic Spectrum Sharing (DSS) enables an operator to run 5G in spectrum already in use for 4G. Instead of having to empty a 4G spectrum band before launching 5G—which could take ten years or more—DSS will enable a band to be used simultaneously for both 4G and 5G. The amount of spectrum used for 4G and 5G in a cell changes dynamically depending on the requirements from users at any given time. This flexibility is very spectrum efficient and facilitates a smooth transition from 4G to 5G over time. Besides, China has commercially launched 5G in 2.6 GHz (n41) band since October of 2019. While, 2.6 GHz is still the major LTE Time Division Duplex (TDD) band (B41) for China Mobile in China. DSS will facilitate the operator to smoothly transit the spectrum usage and adapt to the air interface evolution schedule with much flexibility.

5G technology and spectrum allocation is vital for industrial IoT development and wider vertical use. 5G network slicing will address some of the required customisation. Private networks are an important architecture to meet the customised requirements for the throughput, latency and reliability in factories, warehouses, venues, ports, and other similar settings than what is possible today. Bringing 5G to these places can drive tremendous gains in productivity, economic growth, and other benefits. Private networks can use the licensed, unlicensed, dedicated and shared spectrum. Both sub-6GHz and mmWave are required to support many different use cases. Sub-6 GHz presents a good mixture of coverage and capacity while mmWave spectrum opens the very wide bandwidths needed for ultra-high throughput and ultra-low latency requirements. 5G SA Option 2 can be required for mmWave private network deployments where verticals need a fully isolated network. In TDD bands, network performances will be impacted by the selection of the synchronization frame structure.

The way mobile spectrum is being made available by regulators to support verticals currently varies significantly (see global status in Figure 3). One common approach is that mobile operators can deploy private networks for verticals so they can benefit from their significant licensed spectrum assets and deployment experience. Mobile operators can also deploy fully isolated SA Option 2 networks for verticals in dedicated spectrum where this is needed. However, there is also interest in some verticals directly accessing (e.g. owning, leasing or sharing) mobile spectrum so they can deploy their own private networks (rather than work with mobile operators). There are several different approaches being taken, such as sub-lease of the full 3.4-3.8 GHz band in Finland, 3.7-3.8 GHz for industrial IoT and other vertical use in Germany [11], the 3.5 GHz CBRS band in U.S. [13][14].

U.S.	•3.5 GHz CBRS band, exclusive and shared licenses, deployments in 2H 2019 •37-37.6 GHz shared spectrum/local licenses, under evaluation
Germany	•3.7 –3.8 GHz •Local licenses. Assignment complete; available 2H 2019
Japan	•Phase 1: 2,575-2,595 MHz (as NSA anchor) and 28.2-28.3 GHz; Local licenses, legislation planned in December 2019. •Phase 2: 4.6-4.8 GHz & 28.3-29.1 GHz; Local license ,possible regulator database. legislation planned in 2020
U.K.	•3.8-4.2 GHz •Local licenses (50 meters square); regulator database; Decision formalized; applications invited from end 2019
Sweden	•3.7-3.8 GHz •In consultations
Finland	•Sub-licensing of 3.4-3.8 GHz •Local permission via operator lease; Assignment complete
Netherland	•3.5 GHz for local industrial use; 3.7-3.8 GHz (in consultations); 2.3-2.4 GHz (Licensed shared access online booking system) •3.5 GHz for local industrial use; however users may need to move to 3.7-3.8 GHz, if allocated; 2.3 GHz approved for PMSE
France	•2.6 GHz •Regulator database and approval. 20 MHz approved for Professional Mobile Radio
Australia	•24.25-27.5 GHz •Under evaluation
China Hongkong	•24.25-28.35 (400 MHz) •Local licenses; regulator approval. Approved; available 3Q 2019

Figure 3 Global status for local license for vertical use (As of October 2019)

2.4 5G Key technologies and features

5G brings a lot of new technologies and features. This section describes the most important/common ones. The extended list of the features is in Section 2.11.

2.4.1 Overview of New Radio

NR is Orthogonal Frequency Division Multiplexing (OFDM)-based. For downlink, only Cyclic Prefix-based OFDM (CP-OFDM) is used. While for uplink, both CP-OFDM and Discrete Fourier transform spread OFDM (DFT-s-OFDM) can be used. Compared to CP-OFDM, DFT-s-OFDM has merit of lower peak-to-average ratio.

2.4.1.1 Flexible frame structure

The length of a NR radio frame is 10ms and the length of a NR subframe is 1ms. To cover a wide range of frequency, there are 5 types of transmission numerologies defined in NR system with subcarrier spacing 15, 30, 60, 120 and 240 kHz respectively. The length of NR slot is different depending on numerology, as shown in Figure 4.

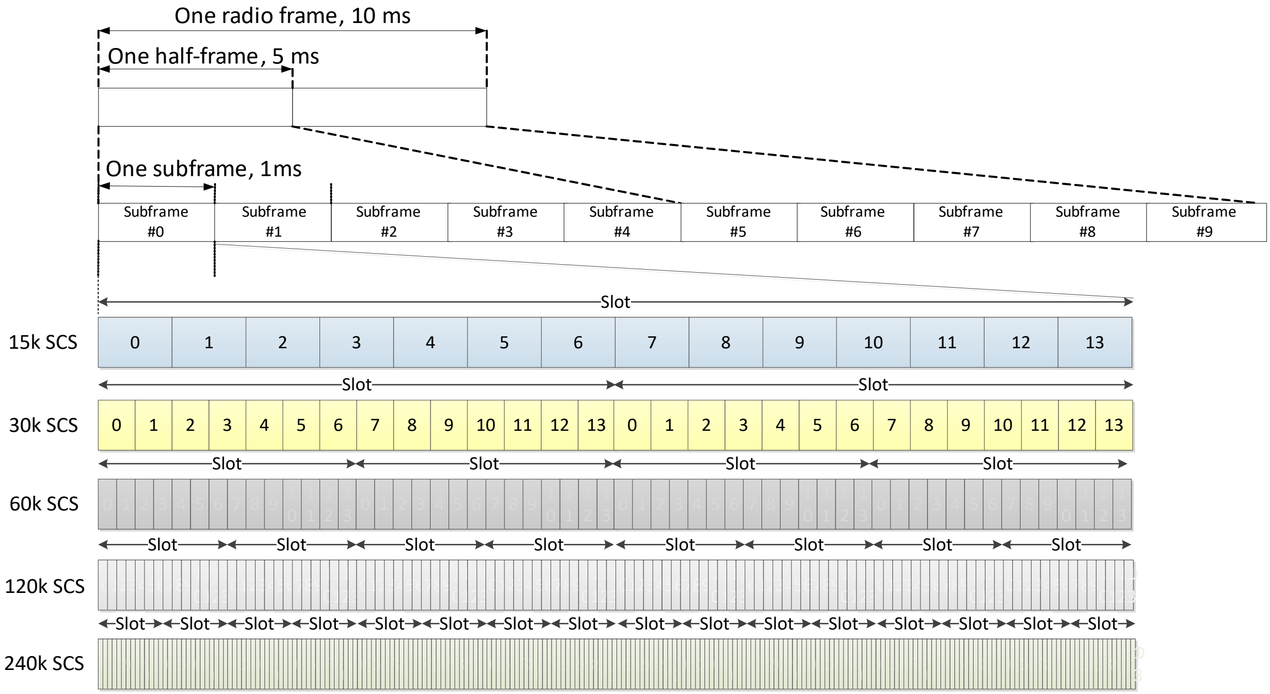

Figure 4 Scalable numerologies in NR

Flexible frame structures in 5G system are presented in Figure 5 and the characteristics of flexible frame structures are listed in Table 1. Operators are suggested to choose suitable frame structure according to their requirements.

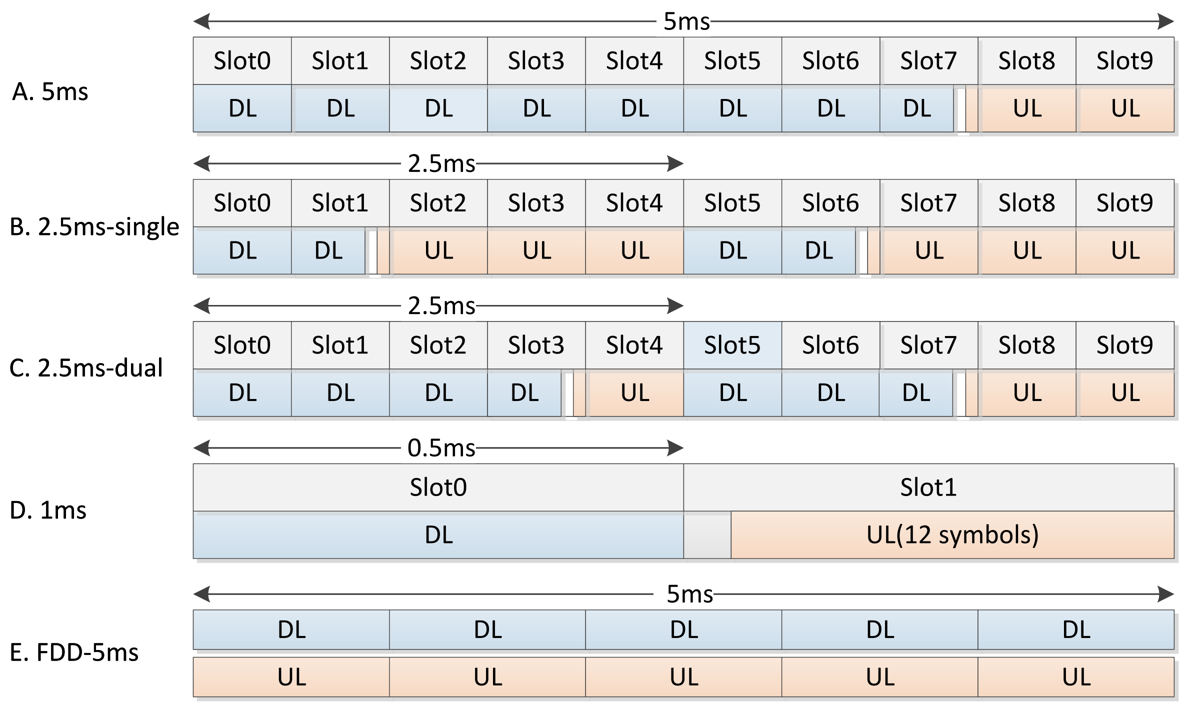

Figure 5 Flexible frame structures defined in NR

	A	B	C	D	E
Duration	5ms	2.5ms	2.5ms	1ms	5ms

DL/UL ratio	8:2	4:6	7:3	1:1	1:1
Switching point/5ms	1	2	2	5	NA

Table 1 Characteristics of flexible frame structures

2.4.1.2 Hierarchical system bandwidth

NR supports hierarchical system bandwidth, which is 5MHz to 100MHz for FR1 (410MHz-7.125GHz) and 50MHz to400MHz for FR2 (24.25GHz-52.6GHz) respectively. Considering power consumption and cost, UE can work on bandwidth parts (BWP).

Frequency range designation	Corresponding frequency range	Recommended System frequency range
FR1	410 MHz – 7125 MHz	50~100 MHz
FR2	24250 MHz – 52600 MHz	50 MHz / 100 MHz / 200 MHz / 400 MHz

Table 2 Definition of frequency ranges

2.4.1.3 New channel coding

Two new types of channel coding are defined in 5G NR: Low-Density Parity-Check (LDPC) for data channel and Polar code for control channel. LDPC provides better performance than Turbo code, including lower error floor and processing latency. Polar code provides better performance than Turbo code and convolutional code at lower bit rate.

2.4.1.4 Mobility and state transition

A new Radio Resource Control (RRC) state named RRC_INACTIVE is introduced in NR. The signalling connection and tunnel between Radio Access Network (RAN) and Core Network (CN) are maintained, rapid transition between RRC_INACTIVE and RRC_CONNECTED reduces latency.

For the purpose of RAN reachability management of UE in RRC_INACTIVE state, the concept of RAN-based notification area (RNA) is introduced. The gNBs transmit paging to the UE in the cells belonging to the RNA. The UE needs to notify gNB by RNA update signalling once it moves out of the configured RNA.

2.4.2 Massive MIMO

Massive MIMO is one of the critical physical layer technologies in NR. It plays a key role in improving capacity and coverage and spectrum efficiency, and then improves user experience. It's also necessary to suppress inter-cell interference.

More Transceivers (TRX) will meet requirements on higher capacity scenarios, for example, 64T64R in urbans.

The Active Antenna Unit (AAU) configuration should be chosen to suit the deployment scenario, both with respect to performance, deployment requirements (e.g., weight, volume and wind load) and total network deployment cost.

64T64R/32T32R provide additional beamforming capability in vertical dimension. Furthermore, 64T64R can provide more beamforming patterns and higher beamforming gain to suit various scenarios. Therefore, 64T64R can significantly improve the performance better than fewer TRX channels.

2.4.2.1 Outdoor Deployment Scenario

For mid-band, 64T64R is a preferred option in macro deployment scenario from the performance point of view, meanwhile engineering constraint is also an important aspect to consider, as there are restrictions to the weight and volume of the 5G AAU in some scenarios. Therefore, AAU with fewer TRX channels, is also an option for deploying 5G AAU.

For high-band, AAU has smaller volume and is lighter. Due to the large bandwidth available, 2T2R or 4T4R channels with large-scale antenna array AAU may be an appropriate choice.

For low-band, Remote Radio Unit (RRU) with traditional antennas is an option instead of AAU to exploit existing infrastructure as much as possible and to facilitate evolution to 5G.

2.4.2.2 Indoor Scenario

In high-traffic and/or high-value indoor scenarios, 4T4R can provide higher capacity and higher peak data rate and therefore is the appropriate option regardless of cost.

In low-traffic indoor scenarios, 2T2R would be used to meet 5G requirements in a cost-effective way.

2.4.3 Uplink Enhancement for NR

Uplink performance of NR needs to be enhanced in some aspects:

- Uplink Coverage: When 5G NR is deployed on mid-band, the uplink coverage is expected to suffer from high path loss and penetration loss, which leads to poor user experience, particularly for TDD frame structure with less uplink slots. Although some 5G technologies like multi-antenna transmission could mitigate the issue to some extent, the coverage performance gap between LTE and NR still exists. It means more NR base stations are needed which results in higher Capital Expenditure (CAPEX)
- Uplink Capacity: another scenario that demands coverage with high uplink throughput is live HD video for the diverse uplink-heavy applications such as smart city, factory supervising. As these applications become popular, they pose a big challenge on 5G network.

Given the fact that uplink resource utilization of low-band Frequency Division Duplex (FDD) spectrum in some areas is low, the uplink enhancement solutions can achieve the goal of improving the uplink coverage and capacity for 5G network. This is done by time-frequency coordination and combination of TDD mid-band and FDD low-band in the uplink, in particular to use Downlink (DL) slot of TDD frame structure for lower FDD frequency uplink transmissions. The uplink enhancement solutions have additional capability requirements for both network and devices. In order to further improve uplink performance and reduce CAPEX for 5G network, the uplink enhancement solutions are recommended in the nascent stage.

2.4.4 Network Slicing

A network slice is a logical network serving a defined business purpose or customer, consisting of all required network resources configured together. It is created, changed and removed by management functions. Hence network slicing divides an operator's physical network into multiple logical networks. These logical networks would permit the implementation of tailor-made functionality and network operation specific to the needs of each slice customer, rather than a one-size-fits-all approach as witnessed in the current and previous mobile generations which would not be economically viable [22].

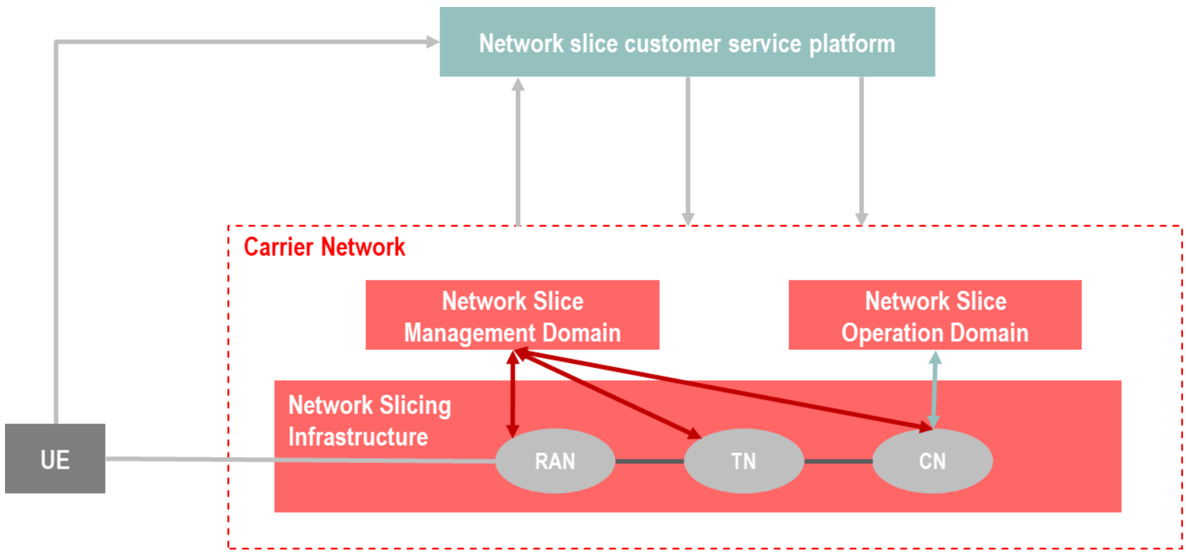

Figure 6 5GS Slicing System Architecture

As shown in Figure 6, the network slicing system architecture consists of three parts: UE, network slice customer service platform and carrier network. The latter includes network slicing infrastructure providing the necessary support for network slices in RAN, Transport Network (TN) and CN and implements assurance. Network slice instance management provides lifecycle management of network slice instances as defined in 3GPP TS 28.530 [27]. Main functions of network slicing service operation include network slice offering release, network slice offering subscription, network slice charging, and network slice member management

GSMA has furthermore introduced the concept of Generic Slice Template (GST) in Permanent Reference Document (PRD) NG.116 "Generic Network Slice Template" [22] that helps operators to define Network Slice Types (NESTs) by providing values to the GST attributes. The NEST can be defined for 3GPP standardised service slice types (SST) and for operator specific SST for a particular customer or operator to satisfy their specific operational needs.

According to 3GPP TS 28.533 [28], there are three network slice related management functions: CSMF (Communication Service Management Function), NSMF (Network Slice Management Function), NSSMF (Network Slice Subnet Management Function).

CSMF is responsible for translating the customer services related requirement to network slice related requirements. NSMF is responsible for management and orchestration of NSI (Network Slicing Instance), and derives network slice subnet related requirements from network slice related requirements. NSSMF is responsible for management and orchestration of NSSI (Network Slice Subnet Instance). A network slice could span across multiple parts of the network – subnets (e.g. RAN, CN and TN). Depending on the business requirements, network slices can be isolated. Isolation provides additional level of security. Each network subnets can have different levels of isolation and there are different aspects related to isolation:

- RAN must be network slice aware, support interconnection with core network slicing and transmission network slicing, and support network slicing level KPI statistics. Spectrum sharing is mainly used. When network congestion occurs, UEs in high-priority network slices can pre-empt resources of UEs in low-priority slices. The RAN can also reserve Resource Block (RB) resources for network slices based on service requirements. The RAN can also support different types of network slices in different cells based on cell capabilities.

- Transport network slice or a slice in TN has not been defined yet. However, transport network provides multiple methods to separate the traffic on multiple layers (e.g FlexE, Segmented routing, Virtual Private Network (VPN), etc.)
- For CN, NFs can be flexibly orchestrated based on service requirements to different network slices, exclusively used or shared by different network slices. Some NFs (such as Authentication Server Function (AUSF), User Data Management (UDM) and Policy Control Function (PCF)) can be shared by multiple network slices. Other NFs (such as Session Management Function (SMF) and UPF) can be dedicated for each network slice. An unique AMF must be used for a given UE regardless of the number of network slices used.

2.4.5 Support for Edge Computing in 5GS

Edge computing in 5GS enables operator and 3rd party services to be hosted close to the UE's access point of attachment, so as to achieve an efficient service delivery through the reduced end-to-end latency and load on the transport network. The 5G Core Network selects a UPF close to the UE and executes the traffic steering from the UPF to the local Data Network via a N6 interface. This may be based on the UE's subscription data, UE location, the information from Application Function (AF), policy or other related traffic rules.

The 5GS specifications in 3GPP contain a set of functionalities that serve as enablers for edge computing, e.g.:

- Network capability exposure: 5G Core Network and Application Function to provide information to each other via Network Exposure Function (NEF) as described 3GPP TS 23.502 [26];
- Quality of Service (QoS) and Charging: PCF provides rules for QoS Control and Charging for the traffic routed to the local Data Network.
- The ability of an Application Function to influence UPF (re)selection and traffic routing directly via the PCF
- User plane (re)selection: the 5G Core Network (re)selects UPF to route the user traffic to the local Data Network. The UPFs that terminate these interfaces are said to support Packet Data Unit (PDU) Session Anchor functionality. Traffic steering by the UPF is supported by Uplink Classifiers that operate on a set of traffic filters matching the steered traffic.
- The Session and Service Continuity (SSC) modes for different UE and application mobility scenarios.
- Support of Local Area Data Network (LADN): the 5GC supports to connect to the LADN in a certain area where the applications are deployed. The access to a LADN is only available in a specific LADN service area, defined as a set of Tracking Areas in the serving PLMN of the UE.

2.4.6 Multi-Access Edge Computing

Edge Computing in 5G network may have more than one deployment options. In many cases of verticals requiring ultra-low latency, ultra-high bandwidth, and Highly automated node management, the Edge Computing platform deployment will be collocated with UPF. While in some other cases, the Edge Computing and UPF may be loose-coupling.

ETSI MEC (Multi-access Edge Computing) framework provides an architecture reference to create a standardized, open environment which allows the efficient and seamless integration of applications from vendors, service providers, and third-parties across multi-vendor MEC platforms. Due to diverse requirements, an Edge Computing solution vendor may have its customized implementation, adopting the emerging technologies in this field.

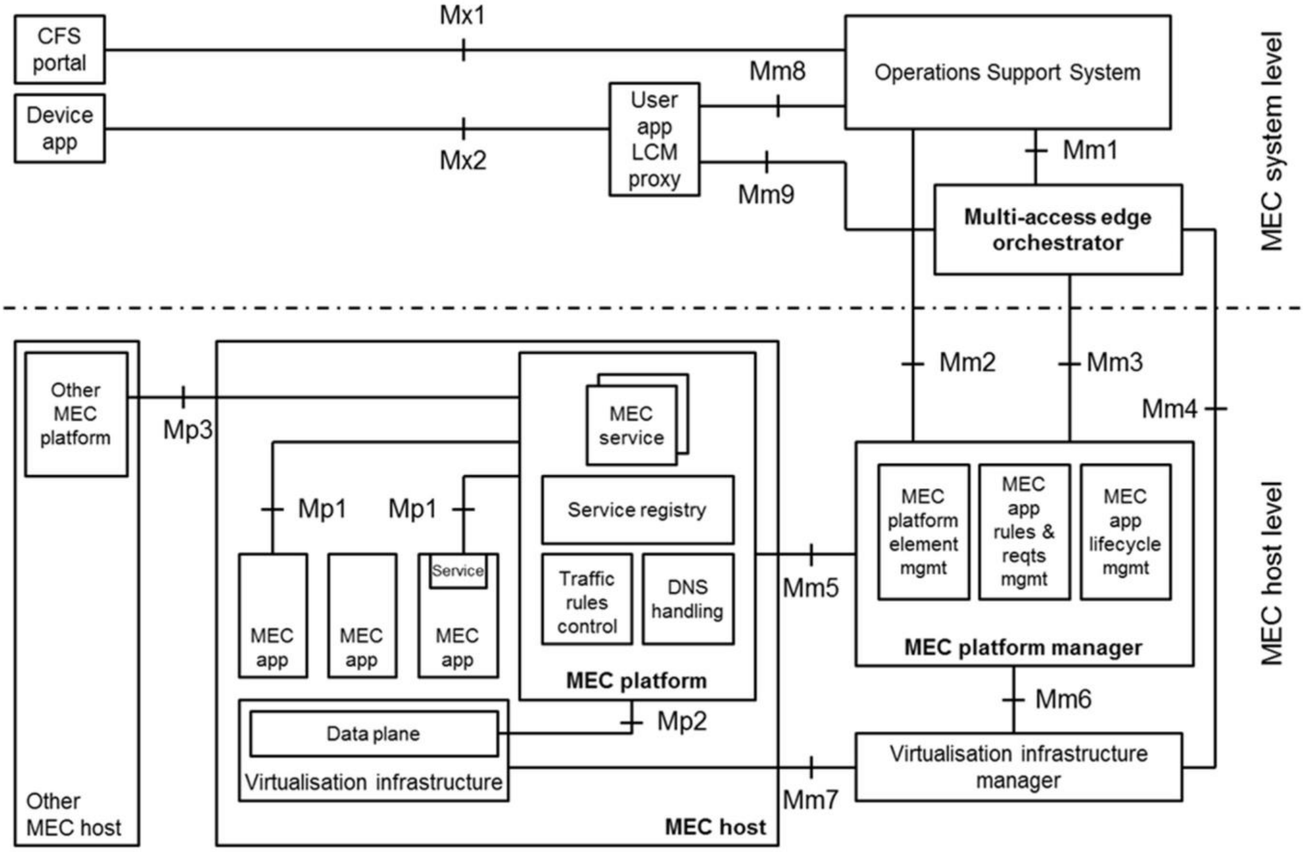

Figure 7 ETSI-defined MEC Network Framework

The MEC architecture reference defined by ETSI is as defined in ETSI GS MEC 003 [29] (see Figure 7). For ETSI has defined Multi-access Edge Computing reference architecture and network framework, which is already used by the CT industry. the detailed functional blocks and interfaces definition, please check corresponding ETSI specification (ETSI GS MEC 003 [29]). In the ETSI-defined framework, MEC entities are grouped into host-level and system-level entities.

MEC host-level entities include the MEC platform (MEP), applications, UPF data plane, MEC platform manager (MEPM), and virtualization infrastructure. The functionality of data plane maps to any functional element(s) of a real network architecture, e.g. UPF in 5GS. MEP loads, starts, stops and delivers configurations of MEC applications. MEPM is responsible for managing MEP.

MEC system-level management entities mainly include multi-access edge application orchestrator (MEAO), which controls the resources and capacity of the MEC network.

2.5 Deployment Guideline

2.5.1 SA Option 2 Network Deployment Strategy in initial stage

5GS, including support for SA Option 2, has been defined by 3GPP R15. It is an E2E system, including 5GC, gNB and terminals.

If an operator starts with SA Option 2, then the newly deployed gNBs shall support (or are configured to use) Option 2. If an operator starts with NSA Option 3, then it is preferred to reconfigure or upgrade already deployed gNBs to support both Option 3x and Option 2. Another possible option is to deploy new gNBs supporting Option 2 directly. Mobility between Evolved Universal Terrestrial RAN (E-UTRAN) and NG-RAN is supported in both deployment scenarios. Considering there're some NSA Option 3 only UEs at 5G early stage which may be in operation for many years, NSA Option 3 & SA Option 2 dual-mode network may exist for long-term to make sure these UEs are able to continue operation.

The SA Option 2 network topology is determined by the network scale. The following show examples of two typical types of SA Option 2 network topology:

- Type 1 is mainly used for large-scale network segmented into regions, in which 5GC NFs are deployed in either regional Data Centres (DCs) or central DC. Figure 8 shows an example of NRF in central DC used for NFs discovery between different regions. Other NFs can be in central DC as well.
- Type 2 is mainly used for medium or small scale network, in which most 5GC NFs are deployed in the central DC and UPF may be in both central and edge DC, as shown in Figure 9.

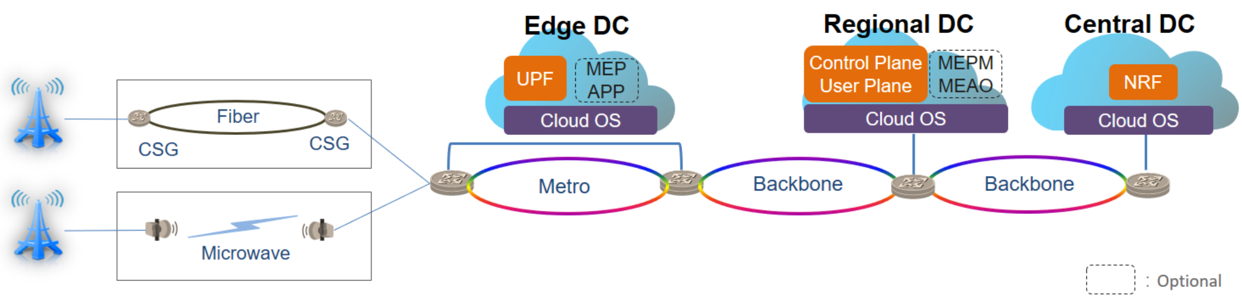

Figure 8 SA Option 2 Deployment Type 1

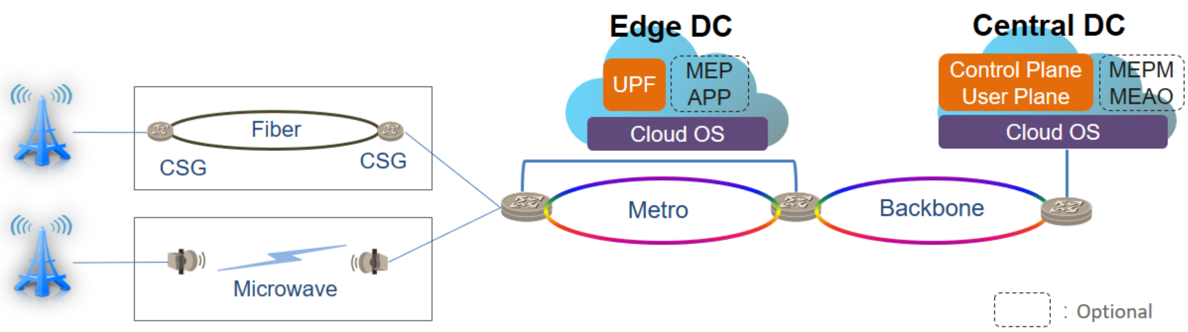

Figure 9 SA Option 2 Deployment Type 2

For type 1, NRF is deployed in central DC for NFs discovery between different regions. The control plane and user plane, such as the AMF, SMF, NRF, UDM, PCF, NSSF, AUSF, Binding Support Function (BSF), and UPF are deployed in regional DC. The UPF is deployed in edge DCs on demand. For type 2, control plane NFs, and UPF are deployed in central DC. The UPF is deployed in edge DCs on demand.

In MEC solution, MEPM and MEAO are deployed in central DC or regional DC. The UPF, MEP and applications are deployed in edge DCs.

2.5.1.1 Considerations for Edge Computing Deployment

A 5G network supporting edge computing deployment requires network capability exposure, which is implemented by NEF. Then the third party's applications invoke Application Programming Interfaces (APIs) exposed by NEF on demand for the purpose of improving performance, monitoring status of application instances and users, etc.

Edge computing deployment inside 5G network usually has limited hardware resources and site conditions and therefore requires lightweight virtualization infrastructure. Traditional NFV architecture pays more overhead cost on the virtualization mechanism and lacks efficiency and flexibility for limited resource usage. Container-based technology is being introduced in this area to optimize resource efficiency and decoupling at application layer. In some deployment scenarios, dedicated hardware of edge may be considered to meet the environment condition at edge site, for example, the limitation of power supply, room space, cooling, transport connection, etc.

Multiple Access Support (e.g., 5G NR, WIFI and fixed broadband network) may be considered for Edge Computing deployment according to specific service requirements and scenarios.

With the expanding of Edge Computing being used in diverse verticals, the requirements of building open eco-system and interaction protocol refinement across multiple parties, including vendors and operators, will increase.

2.5.2 SA Option 2 Network Evolution

Even though 3GPP Rel-15 has provided solid foundation for SA Option 2 deployment, there are more scenarios and use cases to be covered in the later standardization releases. SA Option 2 network evolves continuously with newer 3GPP releases.

In the areas of IoT, architecture, automation and additional non-3GPP access, there are multiple improvements in 3GPP Release 16.

In terms of architecture, SBA is introduced into the IP Multimedia Subsystem (IMS) domain, e.g., using SBA interface when accessing PCF.

To address the flexible deployment requirements in cross-region user plane connectivity, the topology of SMF and UPF in 5GC is optimized, an I-SMF is added between the SMF and the AMF.

For URLLC use cases, dual connectivity to support end to end redundant user plane would bring better URLLC assurance for vertical applications. Due to complexity, it is up to operators' deployment choice.

Service continuity is also important to consider. Per 3GPP TS 23.216 Release 16, 5G Single Radio Voice Call Continuity (5G-SRVCC) enables voice service continuity to 3G CS.

In terms of radio, MIMO enhancements will benefit massive MIMO deployment and performance. Full URLLC/Industrial IoT functionality are introduced to enable URLLC services in vertical industries. Location-based services will be deployed to enrich service offering over SA Option 2 networks. Furthermore, sidelink communication (e.g. 5G Vehicle to everything (V2X)) is also promising to enable autonomous driving. Power saving features, such as UE power saving, are also used for extending the battery life further.

The network deployment in the later stages should not be limited to the items above.

2.5.3 SA Option 2 Communication Model Selection

3GPP Release 15 has introduced the direct communication with and without NRF interaction. The Indirect Communication using the Service Communication Proxy (SCP) have been added into 5GC

SBA in 3GPP Release 16, and hence with Release 16 there are four communication models specified by 3GPP:

- Model A, Direct Communication without NRF interaction.
- Model B, Direct Communication with NRF interaction.
- Model C, Indirect Communication without delegated discovery.
- Model D, Indirect Communication with delegated discovery.

In Model A, NF consumers are configured with the service providers and perform selection of service provider, i.e. there is no interaction with NRF and no service discovery. In Model B every NF consumer interacts with NRF for service discovery and has to support discovery result caching, and selection. Model C adds the SCP on communication path. The SCP aggregates Hypertext Transfer Protocol (HTTP) links, and provides centralized signalling monitoring. Model D shares these characteristics of Model C. Besides, the SCP in Model D takes over service discovery and selection for NF consumers hence NF consumers need not to perform discovery and selection of service providers any more.

The different communication models have different characteristics and implications.

To choose the appropriate communication model(s), the following functionalities and aspects (non-exhaustive list) may be considered:

- Flexibility
- Network topology
- network evolution
- Signalling monitoring
- Load balancing and overload control
- Multi-vendor integration and interoperability
- Failure isolation and troubleshooting
- Risk of failure
- Performance impact

Operators can choose hybrid deployments with Direct Communication and Indirect Communication models at different interfaces. And obviously a single communication model for all the interfaces can be chosen.

2.6 4G/5G interworking

2.6.1 Impact Analysis on 4G RAN

To support the 4G/5G SA Option 2 interworking, the impacts on 4G RAN are shown in Table 3.

System broadcast and measurement	LTE system broadcast can send NR neighbouring cell information and cell reselection parameters in System Information Block 24 (SIB24).
	Support NR-CellReselectionPriority configuration
	Support different system measurement configurations, capable of configuring NR SS/PBCH Block (SSB) Reference Signal Received Power (RSRP) measurements
	Support Event B1 measurement configuration in RRC_CONNECTED state
	Support Event B2 measurement configuration in RRC_CONNECTED state

Idle mode interoperation	Support LTE to NR reselection based on coverage in UE RRC_IDLE state
	Support reselection threshold and other important parameters settings
Connectedmode interoperation	Support Packet-Switched (PS) handover from LTE to NR based on NR coverage in RRC_CONNECTED state
	Support PS handover from LTE to NR based on UE capability in RRC_CONNECTED state
	Support PS handover from NR to LTE based on LTE coverage in RRC_CONNECTED state
	Support handover threshold and other important parameters
	Support blind redirection from LTE to NR (transfer from LTE RRC_CONNECTED state to NR RRC_IDLE state through RRC Connection Release without system message)
	Support return to NR after Evolved Packet System (EPS) fallback with redirection procedure.

Table 3 LTE and NR interoperability requirements

2.6.2 Impact Analysis on Evolved Packet Core (EPC)

The single-registration mode by interworking with 5GS over N26 has been standardized in 4G networks. To support 4G/5G SA Option 2 interworking, the impacts on EPC are shown in Table 4.

NE (Network Element)	Upgrade requirements
MME (Mobility Management Entity)	N26: Handover parameters related to 5GS
	S11/S5: Determine 5GC interworking indication to Serving Gateway / PDN Gateway (PGW) based on N1 mode support, subscription data, network configuration
	S6a: Handle new subscription data “CN Type restriction”, updated Radio Access Technology (RAT) type restriction for NR, per Access Point Name (APN) level 5GC interworking support
	Discover AMF using 3-octet Tracking Area Code (TAC) at EPS to 5GS handover
	Support EPS Fallback and Emergency calls for voice services and the establishment of IMS and Emergency bearers
DNS (Domain Name System)	Configure the <network-capability> as “smf” to support the selection of a PGW Control Plane (PGW-C)/SMF for 5G UEs (no upgrade required)
SGW (Serving Gateway)	Support to handle MME's 5GS Interworking Indication from the S11 interface if the Indication is set to indicate that the UE supports 5G and the Packet Data Network (PDN) connection supports interoperation with the 5GS. SGW carries this identification to the PGW through the S5/S8 interface

Table 4 EPC Upgrade Requirements

2.6.3 Requirement Analysis on NR

To support 4G/5G SA Option 2 interworking, the function requirements on NR are shown in Table 5.

System broadcast and measurement	NR system broadcast can send LTE neighboring cell information and cell reselection parameters
	Support NR-CellReselectionPriority configuration
	Support different system measurement configurations, capable of configuring LTE RSRP measurements
	Support Event B1 measurement configuration in RRC_CONNECTED state
	Support Event B2 measurement configuration in RRC_CONNECTED state
Idle mode interoperation	Support NR to LTE reselection based on coverage in UE RRC_IDLE state
	Support reselection threshold and other important parameters settings
Connected mode interoperation	Support PS handover from LTE to NR based on NR coverage in RRC_CONNECTED state
	Support PS handover from LTE to NR based on UE capability in RRC_CONNECTEDstate
	Support PS handover from NR to LTE based on LTE coverage in RRC_CONNECTED state
	Support handover threshold and other important parameters
	Support blind redirection from NR to LTE (transfer from NR RRC_CONNECTED state to LTE RRC_IDLE state through RRC Connection Release without system message)
	Support return to NR after EPS fallback with redirection procedure.

Table 5 4G/5G SA Option 2 interworking function requirements for NR

2.6.4 Requirement Analysis on 5GC

To support 4G/5G SA Option 2 interworking, the function requirements on 5GC are shown in Table 6.

NE	Function requirements
AMF	N1: Handle S1 mode supported
	N8: Handle new subscription data: 1). CN type restriction “EPC”, and RAT restriction in EPS， 2). Single-Network Slice Selection Assistance Information (S-NSSAI) level EPC Interworking (IWK) support, per Data Network Name (DNN)
	N11: Determine EPC IWK indication at PDU Session setup
	N26: Handle N26 interface for idle and active mode mobility
SMF + PGW-C	Provide mapped EPS bearer context to the UE
UPF + PGW-U	Provide mapped EPS user plane to the UE
UDM + Home Subscriber Server (HSS)	Handle new and updated subscription data

Table 6 4G/5G SA Option 2 interworking function requirements for 5GC

2.6.5 4G/5G Interworking Strategy

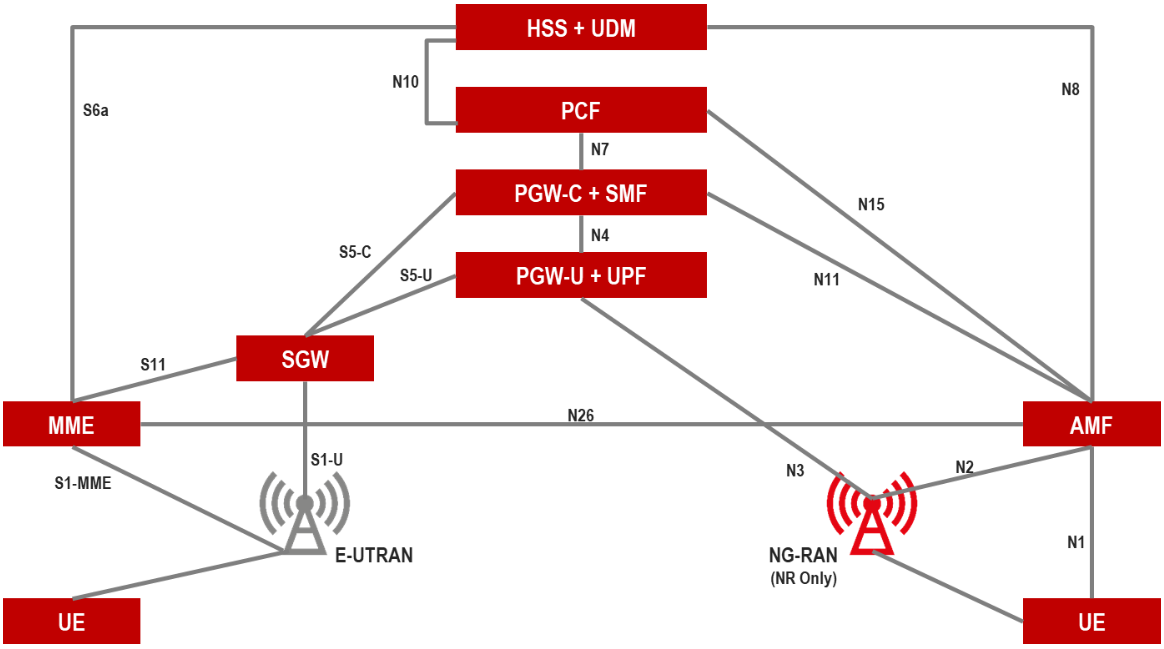

Figure 10 4G/5G Interworking

In order to allow Inter-RAT (IRAT) handover between 4G and 5G network, 4G/5G interworking is supported by a common subscription data access function (HSS/UDM), combined functions such as PGW-C/SMF, PDN Gateway User Plane (PGW-U) / UPF and the N26 interface between MME and AMF as illustrated in Figure 10. This enables service continuity and mobility outside of the 5G coverage, and also enables a smooth migration.

Compared with NSA Option 3, tight coupling between eNB and gNB is not needed for SA Option 2 deployment. SA Option 2 devices access 5GC with control signalling independent of 4G network and achieve interoperability between 4G and 5G networks through their core networks. 4G/5G interworking mainly includes cell (re)selection in RRC_IDLE state, redirection and handover in RRC_CONNECTED state.

In RRC_IDLE state, it is suggested to configure 5G frequency with higher priority than 4G in 4G/5G overlapping area. Devices can camp on the 5G cell and initiate services to improve user experience.

In RRC_CONNECTED state, redirection, which configures frequency list, is simple to implement, while inter-RAT handover has less latency. It is recommended to apply handover and/or redirection depending on different use cases. In the nascent stage, EPS fallback is required to guarantee voice service (by moving the UE from 5GS to EPS) before IMS-based voice service can be used on NR connected to 5GC (see 2.13.1 for details).

2.7 Transmission / backhaul

In SA Option 2, high-band (mmWave) can be used to address 5G bandwidth requirements. In this case, the gNBs are deployed ultra-densely and carry heavy traffic, which means that hundreds of gigabits traffic may have to be supported from the core network through backhaul. Current 4G transport network may not meet these stringent requirements in terms of capacity, availability, latency and cost efficiency. Fibre and microwave are both viable solutions to feed 5G backhaul networks. While fibre is favourable solution, microwave is a vital option especially suitable or regions that have relatively lower fibre penetration and laying fibre could be prohibitively expensive or difficult.

2.7.1 High capacity

High capacity such as 10GE, 25GE, 50GE, 100GE in the access layer and N*100GE FlexE bonding and 200GE/400GE ports in the aggregation and core layer will meet the future requirements. The hardware platform needs to meet the long-term development requirements of 5G and consume low power to save the Operating Expense (OPEX).

2.7.2 High reliability and low latency

The URLLC scenarios are highly sensitive to latency and reliability. Per 3GPP[15][16], for the most demanding scenario, one-way E2E latency needs to be less than 1ms, and 99.9999% reliability needs to be guaranteed.

The low processing latency of core network and transport network brings a huge challenge for 5G network structure and equipment capability. The 5G low latency solution has to adopt several rules in order to achieve the URLLC latency requirements:

- It is necessary to adopt low latency transport technologies to reduce the transport device latency. New technology should provide a deterministic and low latency for dedicated services.
- It is beneficial to use SDN technology for the latency-based best path selection to avoid network link congestion and latency growth.

To improve network reliability：

- Introduce SDN controllers to improve network reliability in case of multi-point failures to achieve 50ms protection for any node/links failure [17];
- Support key unit redundancy of transport devices to ensure that services are not affected by hardware failures.

2.7.3 Intelligent Operation and Maintenance

In SA Option 2, the centralized core network evolves to a distributed network with ubiquitous and flexible connections. This architecture allows to move the UPF closer to the users that create complex network flow and network O&M (Operation and Maintenance).

The backhaul network needs to meet the requirements of dynamic selection of service anchor points, network re-architecture and inter-cloud traffic. It is necessary to introduce the semi-automated workflows and transform expert experience into internal rules in order to facilitate automated OAM. The system can use new technologies such as SDN or AI to visualize network state, accurately monitor quality of service, and provide self-optimization of bandwidth capacity, fast fault location, self-healing and self-learning to adjust the O&M rules intelligently and automatically, so as to achieve network intelligence and automation.

2.7.4 High Precision Time Synchronization

According to 3GPP TS 38.401, the gNB shall support a logical synchronization port for phase and/or frequency synchronization. Logical synchronization port for phase- and time-synchronization shall provide two things. One is accuracy that allows to meet the gNB requirements on maximum relative phase difference for all gNBs in synchronized TDD-unicast area. Second one is continuous time without leap seconds traceable to common time reference for all gNBs in synchronized TDD-unicast area. A logical synchronization port for phase- and time-synchronization may also be provided for e.g., all gNBs in FDD time domain inter-cell interference coordination synchronization area. When the LTE network is not time-aligned with NR-TDD network, UE may not detect NR TDD SSB signal within measurement gap during LTE to NR inter-RAT handover which inter-RAT handover failure may occur. Therefore, LTE network is recommended to synchronize with NR-TDD network.

To meet 5G requirements for high-precision time synchronization, and eliminate time errors, two rules can be adopted. Firstly, the transport network has to use highly precise ground time source as to supplement and enhance of the original Global Navigation Satellite System (GNSS) solution. Moreover, the highly precise time source can be moved to the aggregation layer, to reduce forwarding hops and to eliminate time error. Secondly, the transport device has to reduce time errors, which include ingress time-stamp errors, system phase-locked loop and system time allocation errors, and improve the equipment side ultra-high precision time accuracy. The constant Time Error(cTE) should meet the Class B/C level of ITU-T G.8273.2 [17].

2.8 Cloud-based SA Option 2 Network

SA Option 2 network can be virtualized and cloudified end to end. Based on cloud computing, it has become a consensus in the industry to reconstruct telecom networks through NFV technologies and distributed data centres. With the benefits of "cloud-like properties" of scalability, pooling, load balancing and resiliency, operators can provide 5G services in a much more cost-efficient way.

With SBA and cloud native technologies, 5GC is expected to be more elastic, scalable and flexible. Meanwhile, it also introduces more deployment modes. Three typical modes are shown in Figure 11.

- Virtual Machine (VM) Deployment: VNFs can be deployed directly in the VM operating system. It has been widely applied in virtualized networks.
- Container Deployment: Containers are deployed on bare metal servers. Compared to VM deployment mode, it is more resource-efficient with higher performance. Grey upgrade and seconds-level scale in/out can be achieved. Due to shared kernels, it also introduces isolation constraints.
- Container in VM Deployment: Containers are deployed in VMs. Compared to container deployment mode, it inherits most of the benefits while reduces isolation concerns with VM level isolation. However, it consumes more resources and has lower performance.

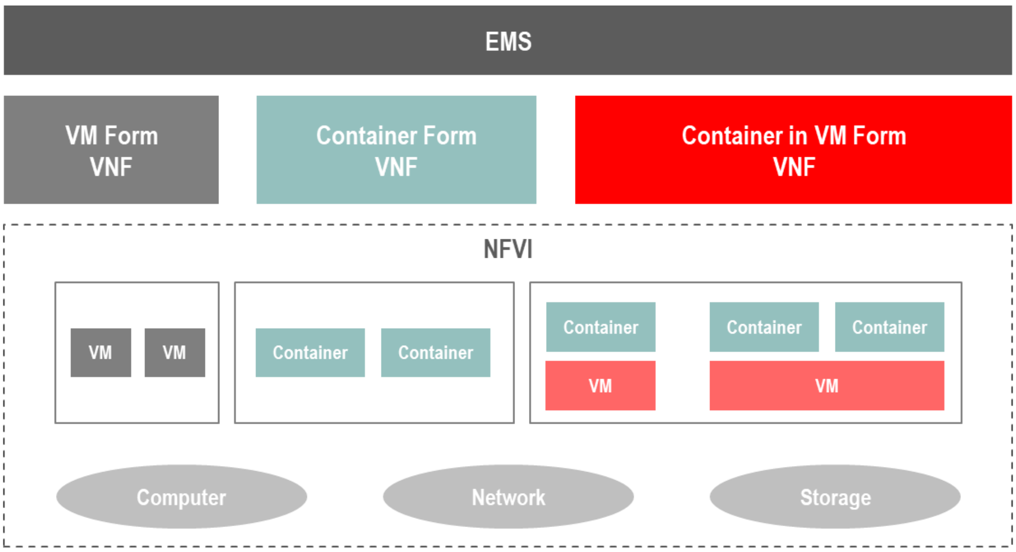

Figure 11 Typical VNF Deployment Modes

Given the challenges of complexity in cloud 5G network, some key areas in O&M to be improved are listed as below:

- Application of big data and AI to understand the network status and identify optimization actions.
- Zero-touch deployment and automatic verification to reduce deployment cycle time and improve success rate.
- Enhanced Root Cause Analysis (RCA) tools to assist problem solving.

Cloud-based RAN is driven by Total Cost of Ownership (TCO) reduction and functionality enhancement. Stepwise approach to cloud RAN includes multi-cells coordination based on centralized RAN architecture; CU/DU split; deployment of CU, UPF and Edge Cloud, etc. At initial stage, CU/DU co-located deployment is more suitable, which can reduce E2E latency, CAPEX, time to market, complexity on network planning and operation. CU/DU split deployment is possible another option to support small pack service of mMTC.

2.9 Devices

The device deployment needs to follow the related Network deployment option.

For network deployment supporting SA Option 2, 5GC supports new Non-Access Stratum (NAS) protocol and procedure. Therefore, devices need to support the 5G NAS protocol, 5G authentication and 5G security procedure.

SA Option 2 network deployment can provide some specific features, i.e., network slicing, edge computing and different session continuity mode. In order to support these new features, network can provide UE policy information to the devices, devices can establish PDU session based on the received UE policy information.

In SA Option 2 network deployment, devices receive the allowed S-NSSAI information from 5GC for different Public Land Mobile Network (PLMN)s and request PDU sessions with specific S-NSSAI for different network slicing. Devices can select the appropriated S-NSSAI based on the received UE policy information or local configuration.

In SA Option 2 network deployment, devices can also provide different session continuity mode for different PDU sessions, i.e. SSC mode 1, SSC mode 2 and SSC mode3. If SA Option 2 network supports mobility interaction to 4G system, devices need to support the related inter-RAT mobility mechanism.

In order to support voice service, devices need to support Voice over 5GS (Vo5GS) and EPS fallback according to NG.114 [24]. Devices launched prior to publication of NG.114 may not follow NG.114 requirements strictly.

SA Option 2 network supports RRC_INACTIVE state, devices need to support the RNA update procedure during the RRC_INACTIVE state, devices can initiate the resume procedure to transit from RRC_INACTIVE state to RRC_CONNECTED state.

In addition, it’s recommended for a device to support Sounding Reference Signal (SRS) antenna switching for its better performance.

Different from NSA Option 3 devices, which can maintain simultaneous connectivity to the eNB and the en-gNB, the SA Option 2 device only connects with gNB.

For interworking with LTE, SA Option 2 device needs to support both NR and LTE measurement, and handover and redirection between NR and LTE according to NG.114 [24]. Devices launched prior to publication of NG.114 may not follow NG.114 requirements strictly.

In terms of uplink performance, 1 Transmitter (Tx) for LTE and 1 Tx for NR are used for NSA Option 3 device to transmit data. While for SA Option 2 device, 2 Tx can connect with 5G gNB for data transmission.

2.10 Testing

For deploying a SA Option 2 network, items in Table 7 need to be tested to ensure reliable and functional 5G network.

Content	Item	Function
Mobility Management	NR Intra-frequency Cell Reselection/Handover	To test NR Intra-frequency Cell Reselection/Handover
	NR Inter-frequency Redirection/Cell Reselection/Handover	To test NR Redirection/Inter-frequency Cell Reselection/Handover
	NR->LTE PS Redirection/Cell Reselection/Handover	To test NR->LTE PS Redirection/Cell Reselection/Handover
	LTE->NR PS Redirection/Cell Reselection/Handover	To test LTE->NR PS Redirection/Cell Reselection/Handover
	EPS Fallback (Redirection/Handover to LTE network)	To test EPS Fallback (Redirection/Handover to LTE network)
Performance	Single UE DL Throughput	To test single UE DL throughput
	Single UE UL Throughput	To test single UE UL throughput
	Cell DL Peak Throughput	To test cell DL throughput
	Cell UL Peak Throughput	To test cell UL throughput
Latency	Control Plane Latency	To test control plane latency
	User Plane Latency	To test user plane latency
Massive MIMO	Single-user MIMO (SU-MIMO) DL	To test SU-MIMO DL functionality
	Multi-user MIMIO (MU-MIMO) DL	To test MU-MIMO DL functionality
	MU-MIMO UL	To test MU-MIMO UL functionality
5GC	Service discovery and selection	To test service based architecture highlights.
	Connection, registration and mobility management	To test UE related mobility scenarios including registration/de-registration, service request, reachability and UE configuration update.
	Session Management	To test UE related scenarios including PDU session establishment, modification & release and session continuity.

	Policy Framework	To test scenarios including Access Mobility (AM), Session Management (SM) & UE policy association management.
	Handover & interworking with EPC	To test scenarios including handover between 5G Access Network, interworking with EPC based on N26.
	Voice & Message	To test scenarios including EPS fallback, Vo5GS, Short Messaging Service (SMS) over Internet Protocol (IP) (SMSoIP) and SMS over NAS.
	Charging	To test scenarios including offline charging, online charging.
	Redundancy & Restoration	To test restoration scenarios including pooling scheme, active-standby scheme, scaling, overload control and failure process.
	Performance	To test 5GC system performance based on given traffic model.

Table 7 Test items for SA Option 2 Deployment

2.11 Features

A SA Option 2 network provides the features as described in Table 8.

NOTE: The features listed in this section are based on 3GPP Release 15. This is NOT intended to be an exhaustive list of features but to provide shortlist as a starting point

Content	Item
Network Architectures	Option 2
Connection Management	System Information Broadcasting
	Synchronization
	Random Access Procedure
	RRC Connection Management
	Interface Management (NG-C/NG-U/Xn/F1)
Mobility Management	NR Intra-frequency Cell Reselection/Handover
	NR Inter-frequency Redirection/Cell Reselection/Handover
	NR->LTE PS Redirection/Cell Reselection/Handover
	LTE->NR PS Redirection/Cell Reselection/Handover
	EPS Fallback (Redirection/Handover to LTE network)
Radio Resource Management	Radio Admission Control
	Load Control
QoS Management	QoS Flow Mapping
	5G QoS Guarantee

User Plane Process	Medium Access Control (MAC) PDU and Functions
	Radio Link Control (RLC) PDU and Functions
	Packet Data Convergence Protocol (PDCP) PDU and Functions
	Service Data Adaptation Protocol (SDAP) PDU and Functions
CU-DU Split	Enhanced Common Public Radio Interface (eCPRI)
	Higher Layer Split (between PDCP/RLC)
Radio	Basic Physical Layer Support
	Single Carrier OFDM (SC-OFDM)
	Basic Modulation Schemes (Binary Phase-Shift Keying (BPSK)/Quadrature Phase-Shift Keying (QPSK)/16 Quadrature Amplitude Modulation (QAM)/64QAM/256QAM)
	Subcarrier Spacing (15/30/60/120KHz)
	Physical Random Access Channel (PRACH) with Long/Short Sequence
	Long Physical Uplink Control Channel (PUCCH)/Short PUCCH
	Slot Format Configuration
	Dynamic Scheduling
	UL/DL Hybrid Automatic Repeat Request (HARQ)
IMS based Services	Voice, Conversational video & Messaging
5GC	Registration Management
	Connection Management
	Mobility Management
	Session Management
	User plane Management
	Interworking with EPC
	SMS over NAS
	IMS support
	Location Services
	Application Triggering Services
	5G Local Area Network (LAN)-type Services
	Mobile Station International Subscriber Directory Number (MSISDN)-less MO SMS Service
	Security Aspects
	Charging
	Support for Edge Computing
	Support of Emergency Services
	Control Plane Load Control, Congestion and Overload Control
	External Exposure of Network Capability

Table 8 Features supported by SA Option 2 Deployment

2.12 Roaming

In the roaming case, Home LPMN (HPLMN) can have 5GC with EPC interworking support or two separate cores (5GC and EPC), as depicts in Figure 10 in Section 2.6.5 and described in Section 2.6. If both HPLMN and Visited PLMN (VPLMN) support 5GC/EPC interworking, then also idle and active mode mobility between EPC and 5GC can be supported between the roaming partners, assuming a suitable roaming agreement.

Table 9 below lists the possible roaming scenarios when the HPMN supports 5GC with EPC interworking or two separate cores.

	HPLMN 5GC with EPC Interworking	**HPLMN has separate 5GC and EPC**
VPLMN has 5GC only	5GS roaming [21]	5GS roaming [21]
VPLMN has EPC only	EPS roaming [25]	EPS roaming [26]
VPLMN has separate 5GC and EPC	5GS roaming [21] and/or EPS roaming [25]	5GS roaming [21] and/or EPS roaming [26]
VPLMN 5GC with EPC Interworking	5GS roaming [21] and/or EPS roaming [25], with idle and active mode mobility between EPC and 5GC	5GS roaming [21] and/or EPS roaming [26]

Table 9 Roaming Scenarios

The following architectural solutions for roaming are available:

- Local Breakout (LBO) - In the LBO roaming case the AMF selects a SMF in the VPLMN
- Home Routed (HR) – In the HR roaming case the AMF selects a SMF in the VPLMN and a SMF in the HPLMN and provides the identifier of the selected SMF in the HPLMN to the selected SMF in the VPLMN.

The use of a particular roaming solution depends on the roaming agreement between operators as well as the APN/DNN involved.

2.12.1 Security

As the inner PLMN is exposed to the other network, a comprehensive security approach is needed.

There is the need for all PLMN operators and IP Exchange (IPX) Providers to:

- Have a secure network design that isolates all parts of the network that need not to be reached from the outside;
- Secure all entry points into their networks at the edge;
- Deploy secure communication between PLMNs;
- Introduce, apply and maintain security procedures.

A secure network design guarantees that the impact of a failure or an attack is limited, as it cannot spread to other parts of the network. As a concrete measure, PLMN operators should only expose the network functions to the IPX Network that are to be reachable by partners. All entry points should be configured securely and security should be applied on all layers.

Security support (User Plane and Control Plane) is part of the solution as described in NG.113 [21]. The Security Edge Protection Proxy (SEPP), in particular, forms an integral part of this solution on each Public Mobile Network (PMN) side to protect inter-PMN signalling.

2.13 Services

One of the important aspects for SA Option 2 is to support voice and related services (e.g. SMS, conversational video). The focus is Voice service over IMS via 3GPP based 5G access network, which can also be applied for SMSoIP and video service over IMS. Here, the IMS based voice solution includes support of IMS based Emergency Service. Non-IMS based voice services, voice service over IMS via Wireless Local Area Network (WLAN) and its interworking with IMS based voice services over 5G access is out of scope.

2.13.1 Voice and Video services over IMS

5G voice/video service will still be provided based on IMS (5G as one of the access modes for IMS voice/video), and the introduction of 5G voice/video will not change the IMS network architecture. Support of IMS based services is based on GSMA NG.114 “IMS Profile for Voice, Video & Messaging over 5GS”. In the early stage of SA Option 2, VoLTE will still be the important basic voice solution and will work with the 5G network to ensure voice service continuity. In this early stage, the data service will be provided over 5GS and it is only the voice services that will be dependent on VoLTE.

Therefore, there are two major voice solutions:

- EPS Fallback: When a voice call is setup via NR and 5GC, NR instructs the UE to access LTE by triggering a handover or redirection procedure. This solution is applicable to the early phase of 5G deployment where NR coverage is not sufficient. It can avoid voice interruption caused by frequent handovers, thus guaranteeing user experience of the voice service. Meanwhile data service is handed over to 4G with voice service in single registration mode, which may have a negative effect on user experience of the data service.
- Voice over 5GS[1]: When 5G UE camps on NR, both voice and data services are transferred via NR and 5GC. When UE moves to the edge of NR coverage, the voice service is handed-over to LTE. This solution is applied after large-scale deployment of SA Option 2. As a target voice solution, it provides fast call setup as well as high-speed data transmission.

The system architecture of IMS-based voice and video services is shown in Figure 12.

[1] Voice over 5GS here refers to the use of IMS-based voice solution over standalone NR gNB connected to 5GC

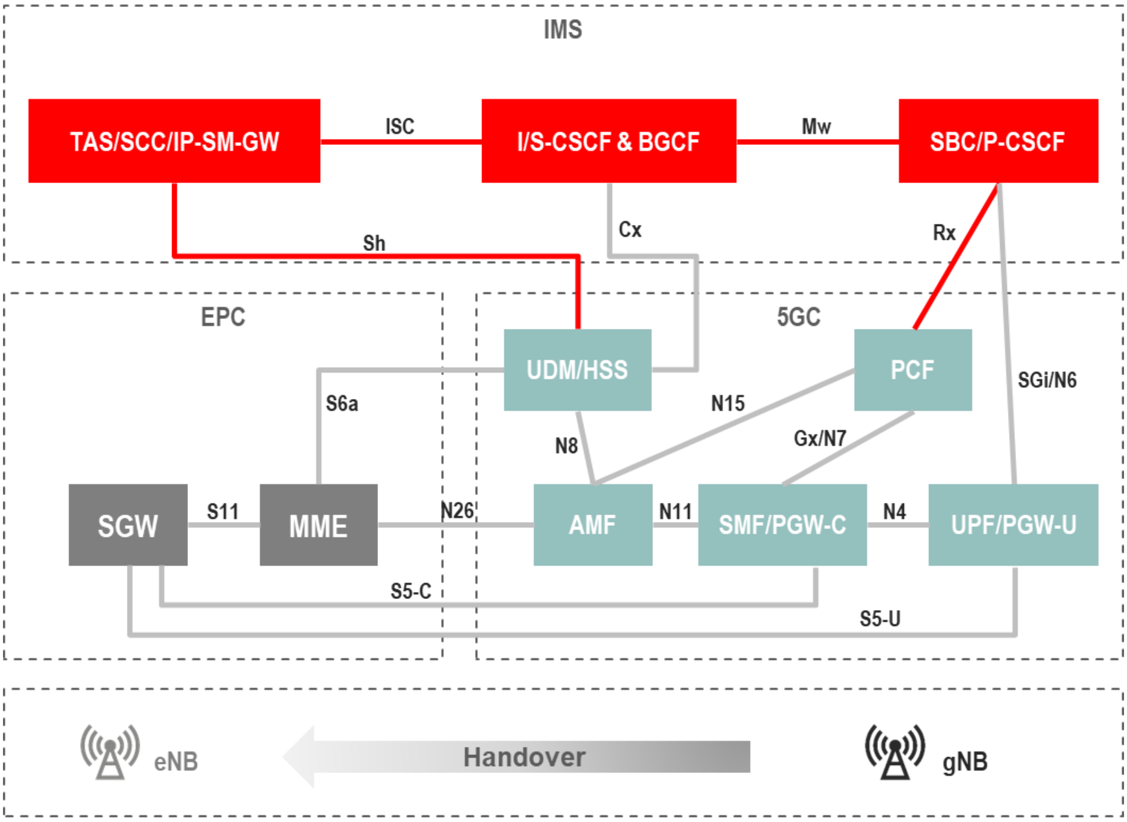

Figure 12 System architecture of IMS-based voice and video services

NOTE 1: ISC interface is between P-CSCF/I-CSCF/S-CSCF

NOTE 2: Mw interface is between AS and S-CSCF

2.13.1.1 Impact on the existing IMS

The entire system architecture for voice service over IMS follows three basic principles, as described below:

- Voice service is still provided based on IMS.
- IMS architecture remains unchanged.
- Some IMS interfaces need to be upgraded for interworking with 5GC.

The change made to IMS is to add access type and location information parameters to related interfaces, including Rx, Sh, Rf, Ro, Gm, Mw, ISC, etc.

2.13.1.2 Domain Selection

When a UE registers to 5G, AMF notifies the UE of the network's Voice over Packet-Switched (VoPS) support capability. If the network does not support VoPS, the voice centric UE will re-select LTE access. In EPS Fallback scenario, AMF also notifies the UE of the network's VoPS support capability.

During a Mobile Terminated (MT) call procedure, Telephony Application Server (TAS) queries the network capability and determines whether to initiate the MT call procedure from PS or Circuit-Switched (CS) accordingly. In addition, TAS shall support flexible configuration of second MT call policy after first MT call failure.

2.13.1.3 Emergency Call

Operators can choose to directly support emergency call in 5G or notify UE to fall back to 4G/3G to perform emergency service. When a UE registers to 5G, AMF notifies the UE of the network's emergency service support capability, emergency call list, and the required emergency call fallback indication.

2.13.2 SMSoIP and SMSoNAS

Within 5GC, SMS Function (SMSF) supports SMS over NAS (SMSoNAS) defined in 3GPP TS 23.501. Besides, SMSoIP can also be considered as IMS based SMS solution under 5G network. SMSoIP can be deployed simultaneously with voice service over IMS to provide both voice and short message service. It is recommended to use SMSoNAS solution if voice services over IMS is not supported or for a 5G data card/Machine Type Communications (MTC)/Non-IMS device without voice service. The network architecture of SMSoIP and SMSoNAS is shown in Figure 13.

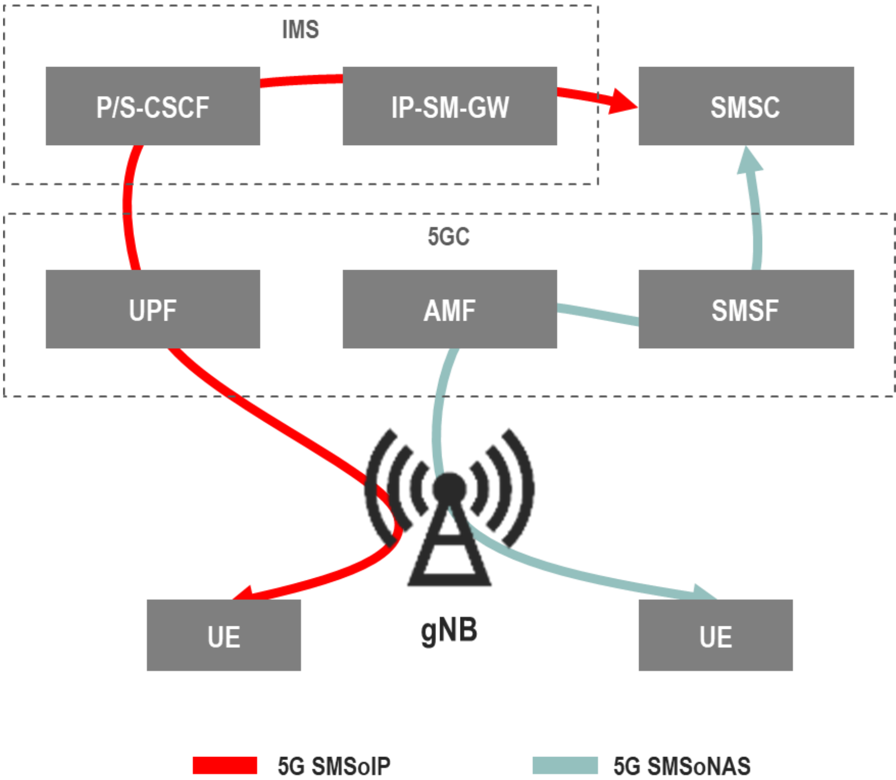

Figure 13 System Architecture of SMSoIP and SMSoNAS

2.13.3 Roaming with IMS services in 5GS

As mentioned in section 2.12, two types of standard roaming architectures are possible, and these apply to IMS (e.g. voice) services in a 5GS environment as well.

2.14 Migration from NSA Option 3 to SA Option 2

SA Option 2 architecture can provide full 5G potential, possess the unique capability that supports vertical industry and enables innovative applications for exploring new revenue source. Generally, SA Option 2 would be an important evolution direction. Figure 14 shows one of the possible migration paths in how to migrate from NSA Option 3 to SA Option 2.

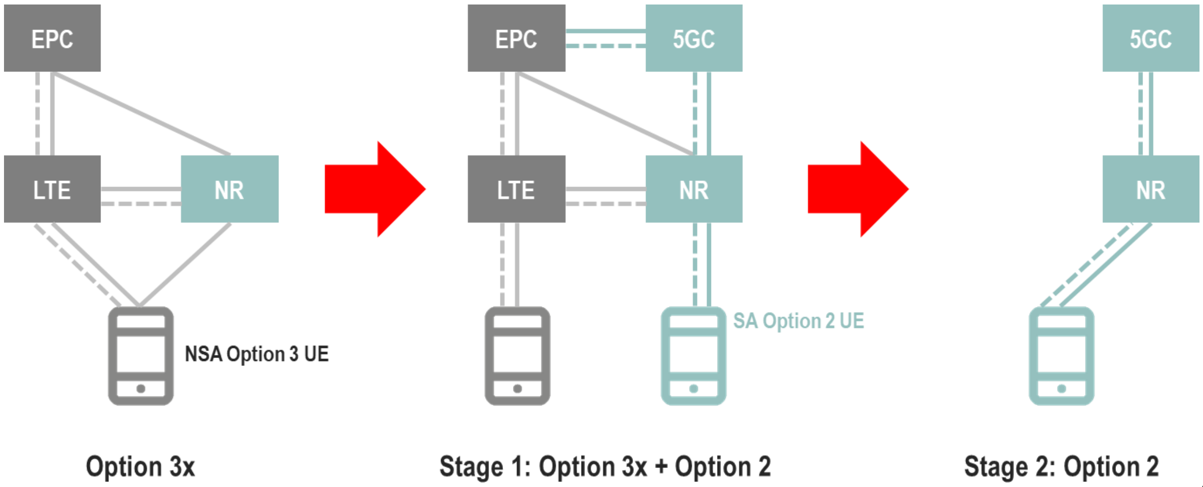

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Figure 14 Possible Evolution Path from NSA option 3 to SA option 2

Two stages for migration are introduced, as the majority of early NSA Option 3 UEs only support Option 3x and cannot upgrade to Option 2 via Over-the-air (OTA). To minimize this issue, it is recommended that terminals support OTA upgrade. In stage 1, NSA Option 3 / SA Option 2 cells serve both SA Option 2 and NSA Option 3 UEs simultaneously. In cell selection procedures, NSA Option 3 UEs camp on the LTE cell and SA Option 2 UEs camp on the NR cell. Already during the stage 1, operators are encouraged to introduce SA Option 2 UEs to accelerate the migration to stage 2.

2.15 AI powered SA Option 2

Due to new technologies, features and services introduced in 5G, there are some emerging issues including low O&M efficiency, high power consumption and low resource utilization, which seems intractable with traditional methods. AI is generally considered as a powerful tool to address these challenges [18][19].

Regarding some new features and high performance, such as edge computing, high data rates, low latency etc, online deployment of AI is practical, which can empower more innovative applications and solutions for customers, especially for vertical industries.

Based on points above, deploying an intelligent 5G network seems to be an essential strategy and goal for 5G operators.

2.15.1 AI for 5G Operation and Maintenance efficiency

For 5G network planning and operation, AI could be helpful in intelligent site planning, capacity dimensioning, and coverage assessment to save manpower and time. Based on this, operators could more effectively utilize traffic information, such as recommendations on building cell sites and prediction of customer gathering points.

AI can also be used to process complex network information, optimize network around the clock, and change the operation from ‘passive’ to ‘active’ and improve network O&M efficiency. Through machine learning (ML), data model can be derived from the massive operation and maintenance data from the network, and the root causes of reported O&M events can be analysed to accurately locate the fault. At the same time, the future event can be predicted by extracting common characteristics.

2.15.2 AI for Energy Efficiency

Due to massive MIMO and wide bandwidth utilized in NR, NR consumes more power consumption than LTE. While 5GC is cloud-based and virtualized, data centres also lead to high power consumption regardless of traffic variations.

In this case, AI will be helpful on scenario awareness, traffic prediction and policy decision. All these usages could be intelligent triggers for traditional energy saving functionalities (e.g., sleep/wake up and load balancing) to realize smart power saving in 5G networks.

2.15.3 AI for Resource Utilization

As computing power is increasing in SA Option 2 network, AI function, real-time or non-real-time AI, can be deployed to improve Radio Resource Management (RRM) accordingly, e.g. ML optimized scheduler, ML based beam management for massive MIMO, ML optimized RRM and load balancing etc. It can be also applied to transport network and virtualized resource optimization in 5GC.

AI may support automatic E2E network slice deployment and service launch by predicting user behaviours, traffic model and network status. Business requirements can also be translated to network resources with AI assistance.

2.15.4 AI for 5G innovative services and solutions

With new features and high performance introduced in SA Option 2, online deployment of AI is feasible. Traditional AI, such as video analysis, image recognition, trend prediction, could be much more effective in many scenarios, including security, industrial operation, indoor positioning, autonomous driving etc., which could empower more innovative applications and solutions for customers, especially for vertical industries.

5G business leveraging AI power will offer magnificent potential to operators. However, it is still at a nascent stage.

Annex A Document Management

A.1 Document History

Version	Date	Brief Description of Change	Approval Authority	Editor / Company
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A.2 Other Information

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Reviewed & Approved by	5GSA

It is our intention to provide a quality product for your use. If you find any errors or omissions, please contact us with your comments. You may notify us at 5GNetworks@gsma.com

Your comments or suggestions & questions are always welcome.