



Road to 5G: Introduction and Migration

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Executive Summary

Unlike previous generations of mobile networks, the fifth generation (5G) technology is expected to fundamentally transform the role that telecommunications technology plays in the society. 5G is also expected to enable further economic growth and pervasive digitalisation of a hyper-connected society, where not only are all people connected to the network whenever needed, but also many other devices/things virtually creating the society with everything connected (i.e. Internet of Everything). 5G will therefore enable new use cases such as smart cities, smart agriculture, logistics and public safety agencies. Furthermore, there are a variety of spectrum bands available for deployment of 5G, which can be sub-divided in three macro categories: sub-1GHz, 1-6GHz and above 6GHz. In addition, 3GPP (3rd Generation Partnership Project) has specified new 5G radio access technology, 5G enhancements of 4G (fourth generation) network, and new 5G core network.

The variety of requirements and spectrum needs show that there are many options of 5G introduction and different spectrum bands will be needed to support all use cases. Operators must therefore consider the feasibility of different options in meeting their intended initial use cases and interoperability of their choice with other options to ensure their networks deliver the use

cases effectively while supporting global interoperability.

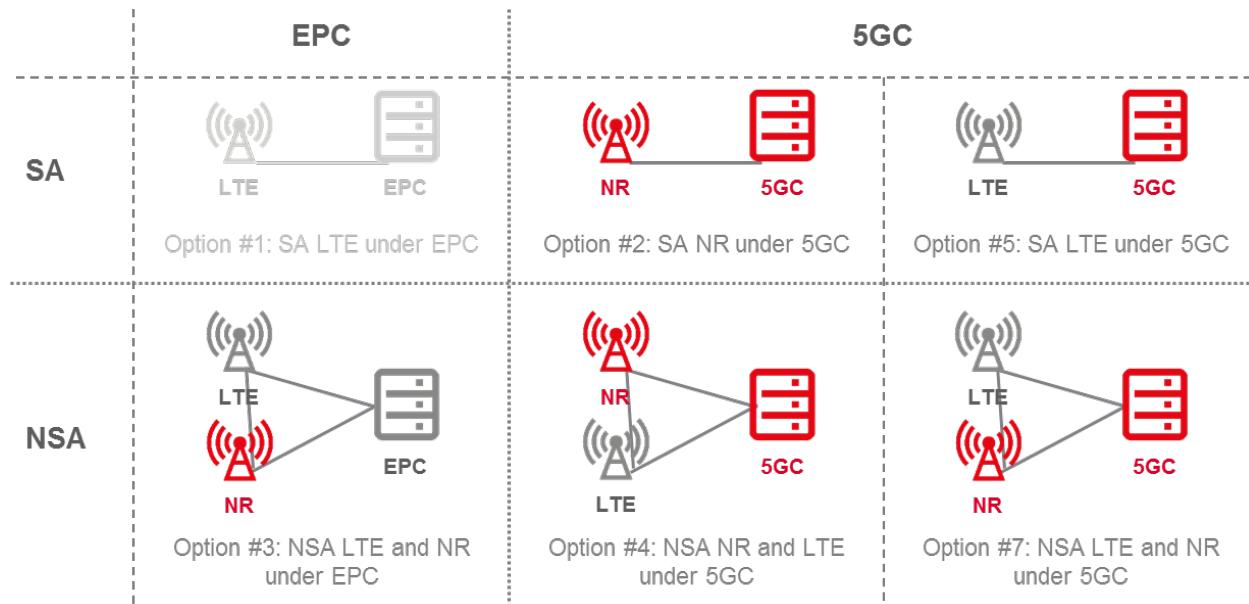
This document therefore analyses the alternatives available for operators intending to introduce a 3GPP compliant 5G system migrating from their 3GPP 4G network. The structure of the document is as follows: Part I provides an high level description of the 5G introduction and subsequent migration along recommendations for collaborative actions while Part II delves into real operator case study and Part III provides advanced technology considerations requiring a reasonably advanced level of understanding of the 3GPP system.

While 3GPP is defining both a new 5G core network (5GC) as well as a new radio access technology called 5G "New Radio" (NR), it is possible to integrate elements of different generations in different configuration with 5G: SA (standalone) and NSA (non-standalone). SA scenario uses only one radio access technology (5G NR or the evolved LTE (Long Term Evolution) radio cells) and the core networks are operated alone. NSA scenario combines NR radio cells and LTE radio cells using dual-connectivity to provide radio access and the core network may be either EPC (Evolved Packet Core) or 5GC (see Table 1 for details).

Table 1: Comparison of 5G radio access and core networks

		Advantages	Disadvantages
Radio access network	SA	<ul style="list-style-type: none"> Simple to manage Inter-generation handover between 4G-5G 	<ul style="list-style-type: none"> Not able to leverage existing LTE deployments if NR is used in SA
	NSA	<ul style="list-style-type: none"> Leverage existing LTE deployments 	<ul style="list-style-type: none"> Tight interworking between LTE and NR required May impact end user experience
Core network	EPC	<ul style="list-style-type: none"> Leverage existing EPC deployment 	<ul style="list-style-type: none"> Cloud support is optional
	5GC	<ul style="list-style-type: none"> Cloud native Easier to support multiple access 	<ul style="list-style-type: none"> New deployment required

Figure 1: 4G and 5G Deployment Options



Consequently, five deployment options are available for 5G as depicted in Figure 1¹. Red colour denotes NR and 5GC.

NOTE: for simplicity, the figure does not depict control and user plane connection

As there can be multiple paths to reach the final target configuration that an operator intends to deploy, it is essential to consider migration steps that would comprise different paths. This document analyses the following migration steps that the 5G Introduction project group members believe to be more likely.

- EPS (Evolved Packet System) to SA Option #2
- EPS to NSA Option #3
- NSA Option #3 to NSA Option #7 and SA Option #5

- NSA Option #3 to NSA Option #3 and SA Option #2
- NSA Option #3 to NSA Option #4 and SA Option #2

The analysis of the paths (see Table 2) take four perspectives. First, feasibility of use case refers to the ability of the path in addressing 5G use cases. Second, deployment considerations consider the support for early 5G devices and core network & radio access network deployment considerations of the migration step (i.e. the core network solution adopted as a result of the path and the extent of leveraging existing LTE deployment). Third, impact on device and network considers the impact of the migration step on device and network. Finally, impact on voice service including service continuity refers to the ease of voice service provisioning and continuity offered by the migration step.

¹ For completeness, the figure also includes "Option 1" representing today's 4G deployments

Table 2: High-level overview of migration step analysis results

Path	Use Case ¹	Deployment	Device/Network	Voice
EPS to SA#2	• Full 5G use cases	• 5G Core benefits • Needs to retain EPC	• Little impact on 4G • 4G/5G system interworking required	• IMS Voice supported • No CS interworking from 5GS
EPS to NSA#3	• Limited support for 5G use case	• Leverage LTE • Quick time-to-market • No 5G Core benefits	• EPC procedures • Impact on 4G	• Leverage existing VoLTE service
NSA#3 to NSA#7 / SA#5	• Full 5G use cases • Initially limited	• 5G Core benefits • Needs to retain EPC	• Impact on NR, LTE • Impact on IMS • 5GC deployment	• IMS Voice supported • No CS interworking from 5GS
NSA#3 to NSA#3 / SA#2	• Full 5G use cases • Initially limited • Core migration	• 5G Core benefits • Needs to retain EPC • Wide area NR	• Impact on NR, LTE • Impact on IMS • 5GC deployment	• IMS Voice supported • No CS interworking from 5GS
NSA#3 to NSA#4 / SA#2	• Full 5G use cases • Initially limited • Core migration	• 5G Core benefits • Needs to retain EPC	• Impact on NR, LTE • Impact on IMS • 5GC deployment	• IMS Voice supported • No CS interworking from 5GS

¹ Limited support for 5G use case denotes focus on enhanced mobile broadband use case

NOTE: CS stands for circuit-switched

The availability of options and migration steps indicate that the mobile industry needs to respect the need of different operators to follow different migration strategies with some degree of divergence. Nevertheless, customers and the wider industry will be able to benefit as a whole if the following collaborative actions are taken by operators in order to guarantee service continuity, services and network interoperability and to unlock economies of scale.

- Global profile for the industry to address
 - Basic connectivity of devices to a 5G network (including interoperability between 5G and LTE networks)
 - IMS (IP Multimedia Subsystem) services delivered over NR
 - Support roaming to/from networks with same/different 5G deployment option
- Global issue registry and resolution group that receives issues encountered during 5G commercialization and collaboratively resolves the issues.

1

1. Introduction



1.1 Scope

This document analyses the alternatives available for operators intending to introduce a 3GPP compliant 5G system migrating from their 3GPP 4G network. For each of the options and consequent migration steps, this paper considers the technical, economic and strategic perspective. The structure of the document is as follows: Part I provides a high level description of the 5G introduction and subsequent migration along recommendations for collaborative actions. Part II delves into real operator case study of deploying 5G while Part III outlines advanced technology considerations requiring a reasonably advanced level of understanding of the 3GPP system.

It is assumed that the mobile network operator deploying a 5G network is already operating a 4G network. This document covers 3GPP mobile accesses (4G and 5G) only. Non-3GPP accesses are not covered in this version of the document.

1.2 Abbreviations

Term	Description
2G	Second Generation (Mobile Network)
3G	Third Generation (Mobile Network)
3GPP	Third Generation Partnership Project
4G	Fourth Generation (Mobile Network)
5G	Fifth Generation (Mobile Network)
5GC	5G Core (network)
5GPPP	Fifth Generation Private Public Partnership
5GS	Fifth Generation System
AMF	Access & Mobility Management Function
AP	Access Point
API	Application Programme Interface
AS	Application Server
ASN.1	Abstract Syntax Notation One
B2B	Business-to-Business
CA	Carrier Aggregation
CAPEX	Capital Expenditure
CN	Core Network
CP	Control Plane
CS	Circuit-Switched

CSCF	Call Session Control Function
CSFB	Circuit Switched Fallback
CUPS	Control Plane – User Plane Separation
E2E	End-to-End
eMBB	enhanced Mobile BroadBand
EMM	EPS Mobility Management
eNB	Evolved Node B
EN-DC	E-UTRA-NR Dual Connectivity
EPC	Evolved Packet Core
ePDG	Evolved Packet Data Gateway
EPS	Evolved Packet System
ESM	EPS Session Management
EU	European Union
E-UTRA	Evolved Universal Terrestrial Radio Access
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
EVS	Enhanced Voice Services
FIFA	Federation Internationale de Football Association
gNB	Fifth Generation NodeB
GSM	Global System for Mobile Communications
GW	Gateway
HEVC	High Efficiency Video Coding
HO	Handover
HSS	Home Subscriber Server
IMS	IP Multimedia Subsystem
IMT	International Mobile Telecommunications
IOC	International Olympic Committee
IoT	Internet of Things
IP	Internet Protocol
IPTV	Internet Protocol Television
ISD	Inter-Site Distance
ITU	International Telecommunication Union
LCS	Location Services
LIPA	Local IP Access
LS	Liaison Statement
LTE	Long Term Evolution

MCG	Master Cell Group
MCPTT	Mission Critical Push-To-Talk
mIoT	Massive IoT
MME	Mobility Management Entity
mMTC	Mobile Machine Type Communications
MN	Master Node
MPS	Multimedia Priority Service
MR-DC	Multi-RAT Dual Connectivity
NAS	Non Access Stratum
NB-IoT	Narrowband-IoT
NE-DC	NR E-UTRA Dual Connectivity
NF	Network Function
NFV	Network Function Virtualization
NGEN-DC	NG-RAN E-UTRA-NR Dual Connectivity
NR	New Radio
NRF	Network Repository Function
NSA	Non-Standalone
NWDA	Network Data Analytics
OEM	Original Equipment Manufacturer
PCF	Policy Control Function
PCRF	Policy and Charging Rules Function
P-CSCF	Proxy Call Session Control Function
PDCP	Packet Data Convergence Protocol
PGW	PDN (Packet Data Network) Gateway
PGW-C	Control plane of the PGW
PGW-U	User plane of the PGW
QCI	QoS Class Identifier
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RRC	Radio Resource Control
RX	Reception
SA	Standalone
SBA	Service Based Architecture
SCG	Secondary Cell Group
SGW	Serving Gateway
SIG	Special Interest Group
SIP	Session Initiation Protocol

SIPTO	Selected IP Traffic Offload
SM	Session Management
SMF	Session Management Function
SMS	Short Message Service
SN	Secondary Node
SRVCC	Single Radio Voice Call Continuity
TB	Terabyte
TCO	Total Cost of Ownership
TV	Television
TWAG	Trusted Wireless Access Gateway
TX	Transmission
U-20	Under 20
UDM	User Data Management
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UPF	User Plane Function
URLLC	Ultra-Reliable Low Latency Communications
USA	United States of America
ViLTE	Video over LTE
VoLTE	Voice over LTE
VoWiFi	Voice over WiFi
WLAN	Wireless Local Area Network

1.3 References

Ref	Title
[1]	"5G New Wave", 5G Forum
[2]	"5G PPP use cases and performance evaluation models", 5GPPP
[3]	"5G Spectrum Public Policy Position", GSMA
[4]	"5G White Paper", NGMN
[5]	"Mobile Broadband Transformation LTE to 5G", 5G Americas
[6]	"The 5G Era", GSMA
[7]	"Understanding 5G", GSMAi
[8]	"White Paper on 5G Vision and Requirements", IMT-2020 PG
[9]	3GPP TS 23.214 Architecture enhancements for control and user plane separation of EPC nodes
[10]	3GPP TS 23.401 General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access
[11]	3GPP TS 23.501 System Architecture for the 5G System; Stage 2
[12]	3GPP TS 23.502 Procedures for the 5G System; Stage 2
[13]	3GPP TS 36.300 Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2
[14]	3GPP TS 37.340 Evolved Universal Terrestrial Radio Access (E-UTRA) and NR Multi-connectivity; Stage 2
[15]	3GPP TS 38.300 NR; Overall description; Stage 2
[16]	ITU-R M.2083 "IMT-2020 Vision", ITU-R
[17]	R2-1713952 LS Reply to SA WG2 on Status Icon related to 5G
[18]	S2-178933 LS Reply to SA WG2 on Status Icon related to 5G

2

2. Why 5G?

Table 3: Key performance requirements of IMT-2020

Requirement	Value	
Data rate	Peak	Downlink: 20Gb/s Uplink: 10Gb/s
	User experienced	Downlink: 100Mb/s Uplink: 50Mb/s
Spectral efficiency	Peak	Downlink: 30 bit/s/Hz Uplink: 15 bit/s/Hz
	5 th percentile user	Downlink: 0.12~0.3 bit/s/Hz Uplink: 0.045~0.21 bit/s/Hz
Average		Downlink: 3.3~9 bit/s/Hz Uplink: 1.6~6.75 bit/s/Hz
Area traffic capacity		10 Mbit/s/m ²
Latency	User plane	1ms~4ms
	Control plane	20ms
		Requirement
		Value
Connection density		1,000,000 devices per km ²
Energy efficiency		Loaded: see average spectral efficiency No data: Sleep ratio ¹
Reliability		1-10 ⁻⁵ success probability of transmitting a layer 2 PDU (protocol data unit) of 32 bytes within 1ms
Mobility		0km/hr~500km/hr
Mobility interruption time		0ms
Bandwidth		100MHz

¹ The fraction of unoccupied time resources (for the network) or sleeping time (for the device) in a period of time corresponding to the cycle of the control signalling (for the network) or the cycle of discontinuous reception (for the device) when no user data transfer takes place.

2.1 The advent of the 5G era

Unlike previous generations of mobile networks, the fifth generation (5G) technology is expected to fundamentally transform the role that telecommunications technology plays in society. 5G is also expected to enable further economic growth and pervasive digitalisation of an hyper-connected society, where not only are all people are connected to the network whenever needed, but also many other devices/things virtually creating the society with everything connected (i.e. Internet of Everything) [1], [7]. It is not a coincidence that governments around the world (especially in the most advanced economies such as China, EU, Japan, Korea and USA) are demanding acceleration in the introduction of 5G technology in their respective markets.

The variety of business models and services that 5G systems will support, however, leads to numerous strategies a mobile operator has available to introduce 5G services. As global reach and economies of scale for network equipment as well as devices remain a vital component for the success of a mobile telecommunications networks, it is important to ensure that although different operators may follow different 5G introduction and deployment options, those two tenets are preserved.

2.2 Drivers of 5G

While previous generations of mobile networks were purpose built for delivering communications services such as voice and messaging (e.g. 2G) or mobile broadband (e.g. 4G), 5G will have flexibility and configurability at the heart of its design to enable mobile operators to serve IoT (Internet of Things) use cases and to support ultra-reliable, low latency connections as well as enhanced mobile broadband [4], [5], [6], [16]. Particularly, new use cases designed to support smart cities, smart agriculture, logistics and public safety agencies will deeply impact for the better every aspect of our lives.

2.3 Expectations on 5G

Technically, 5G is a system designed to meet the requirements of IMT-2020 set by the ITU-R specification M.2083 [16]. 5G will provide more advanced and enhanced capabilities compared to 4G LTE (IMT-Advanced). The following table summarises some of the key performance parameters.

It can be noted that 5G will aim to provide 20 times the peak data rate (speed), 10 times lower latency (responsiveness) and 3 times more spectral efficiency than 4G LTE.

2.4 Use cases and spectrum bands for 5G

5G has three major use case classes: enhanced Mobile Broadband (eMBB), mMTC and ultra-reliable low latency (URLLC). The requirements for the use case classes and the use cases within each class vary significantly [2], [4], [8]. For example, smart meters will require only periodic transmission of relatively small sized traffic while enhanced mobile broadband will require bursty/continuous transmission of large size traffic.

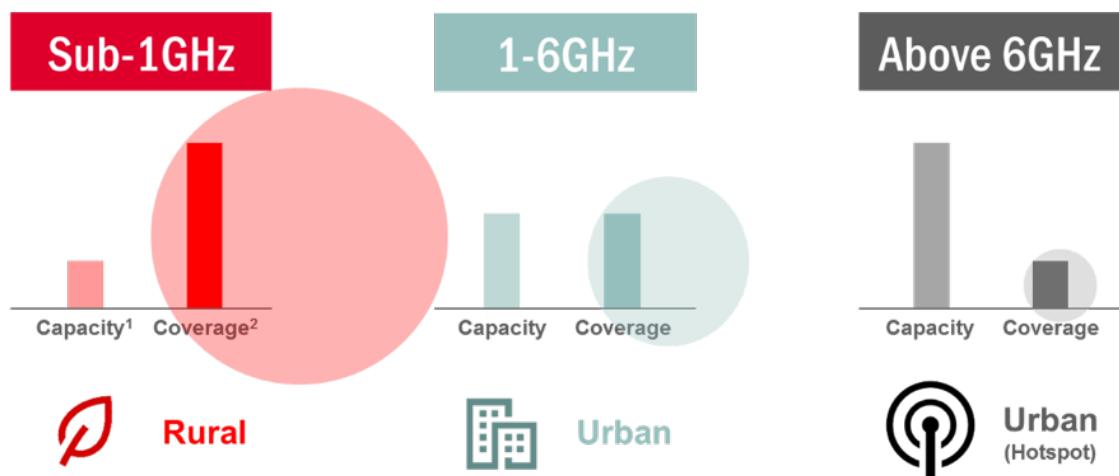
In terms of spectrum bands earmarked for deployment of 5G, they can be sub-divided in three macro categories: sub-1GHz, 1-6GHz and above 6GHz.

Sub-1GHz bands are suitable to support IoT services and extend mobile broadband coverage from urban to suburban and rural areas. This is because the propagation properties of the signal at these frequencies enable 5G to create very large coverage areas and deep in-building penetration. The 1-6GHz bands offer a reasonable

mixture of coverage and capacity for 5G services. There is a reasonable amount of existing mobile broadband spectrum identified with this range which could be used for initial 5G deployments. Spectrum bands above 6GHz provide significant capacity thanks to the very large bandwidth that can be allocated to mobile communications and thus enable enhanced mobile broadband applications [3]. The downside of using high spectrum bands (so called “millimetre wave”²) is the much reduced coverage size of each cell and its susceptibility to blocking.

This variety of requirements and spectrum needs show that there are many options of 5G introduction and different spectrum bands will be needed to support all use cases. Operators must therefore consider the feasibility of different options in meeting their intended initial use cases and interoperability of their choice with other options to ensure their networks deliver the use cases effectively while supporting global interoperability.

Figure 2: Capacity and coverage considerations of spectrum categories



² As the wavelength is defined as the ratio between the speed of light and the frequency of the wave, a 1 mm wavelength is

obtained at 30 GHz, however it is common practice to use this terminology for spectrum bands above 25 GHz.

Part I:

3. 5G Network Deployment Options

3.1 Standalone (SA) and Non-standalone (NSA)

As with the previous generations, 3GPP is defining both a new 5G core network, referred to as 5GC, as well as a new radio access technology called 5G “New Radio” (NR). Unlike previous generations that required that both access and core network of the same generation to be deployed (e.g. Evolved Packet Core (EPC) and LTE together formed a 4G system), with 5G it is possible to integrate elements of different generations in different configurations, namely:

- Standalone using only one radio access technology and
- Non-Standalone combining multiple radio access technologies.

In a standalone scenario, the 5G NR or the evolved LTE radio cells and the core network are operated alone. This means that the NR or evolved LTE radio cells are used for both control plane and user plane. The standalone option is a simple solution for operators to manage and may be deployed as an independent network using normal inter-generation handover between 4G and 5G for service continuity.

Three variations of SA are being defined in 3GPP:

- Option 1 using EPC and LTE eNB access (i.e. as per current 4G LTE networks);
- Option 2 using 5GC and NR gNB access; and
- Option 5 using 5GC and LTE ng-eNB access

In non-standalone (NSA) scenario, the NR radio cells are combined with LTE radio cells using dual-connectivity to provide radio access and the core network may be either EPC or 5GC depending on the choice of operator. This scenario may be chosen by operators that wish to leverage existing 4G deployments, combining LTE and NR radio resources with existing EPC and/or that wish new 5GC to deliver 5G mobile services. This solution will require tight interworking with the LTE RAN. The end user experience will be dependent on the radio access technology(ies) used.

Dual Connectivity: Operation where a given UE consumes radio resources provided by at least two different network points (e.g. NR access from gNB and LTE access from eNB).

Three variations of NSA are defined in 3GPP:

- Option 3 using EPC and an LTE eNB acting as master and NR en-gNB acting as secondary;
- Option 4 using 5GC and an NR gNB acting as master and LTE ng-eNB acting as secondary; and
- Option 7 using 5GC and an LTE ng-eNB acting as master and an NR gNB acting as secondary.

3.2 Evolved Packet Core (EPC) and 5G Core Network (5GC)

5G deployment options are being defined in 3GPP using either the existing EPC (Evolved Packet Core, specified in 3GPP TS 23.401 [10]) or the 5GC (5G Core network, specified in 3GPP TS 23.501 [11]).

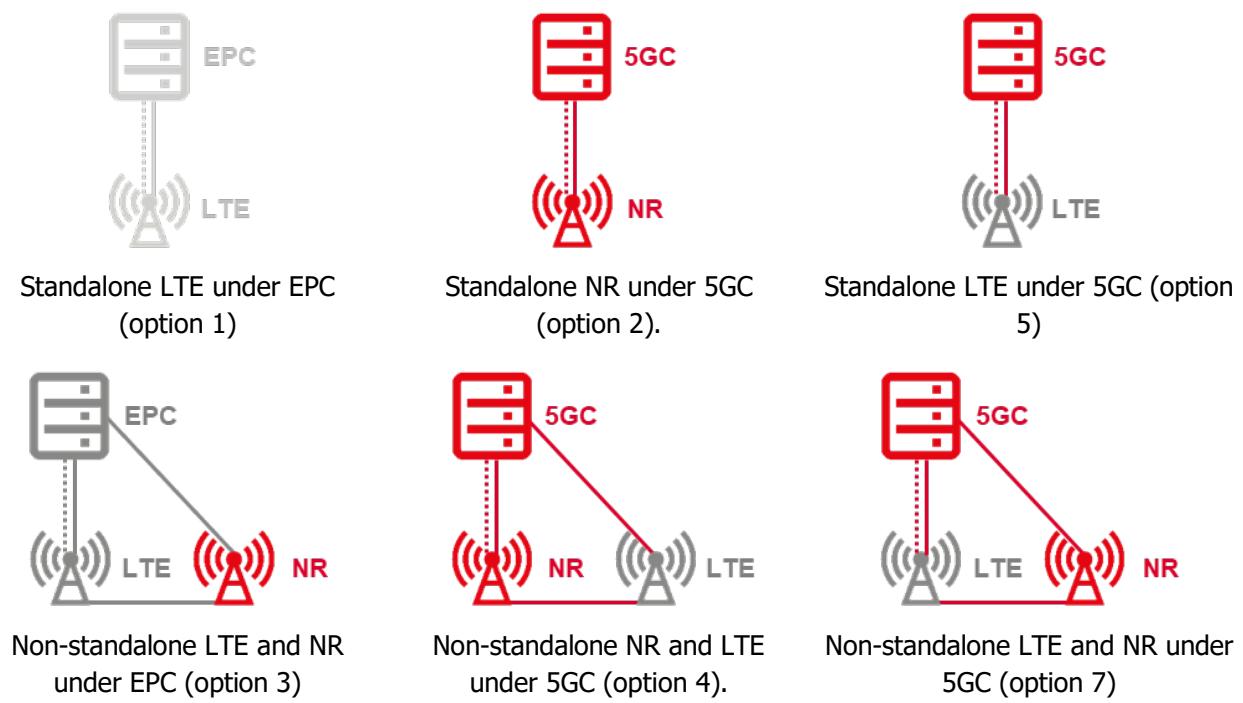
The two architectures follow a very different set of design principles and the main differences are discussed more in detail in section 7.2.

While EPC could be considered an evolution of previous generation packet core networks, the 5GC has been designed from its inception to be “cloud native”, that is inheriting many of the technology solutions used in cloud computing and with virtualisation at its core. 5GC also offers superior network slicing and QoS features.

Another important characteristic is the separation of the control plane and user plane that besides adding flexibility in connecting the users also allows an easier way to support a multitude of access technologies, better support for network slicing and edge computing.

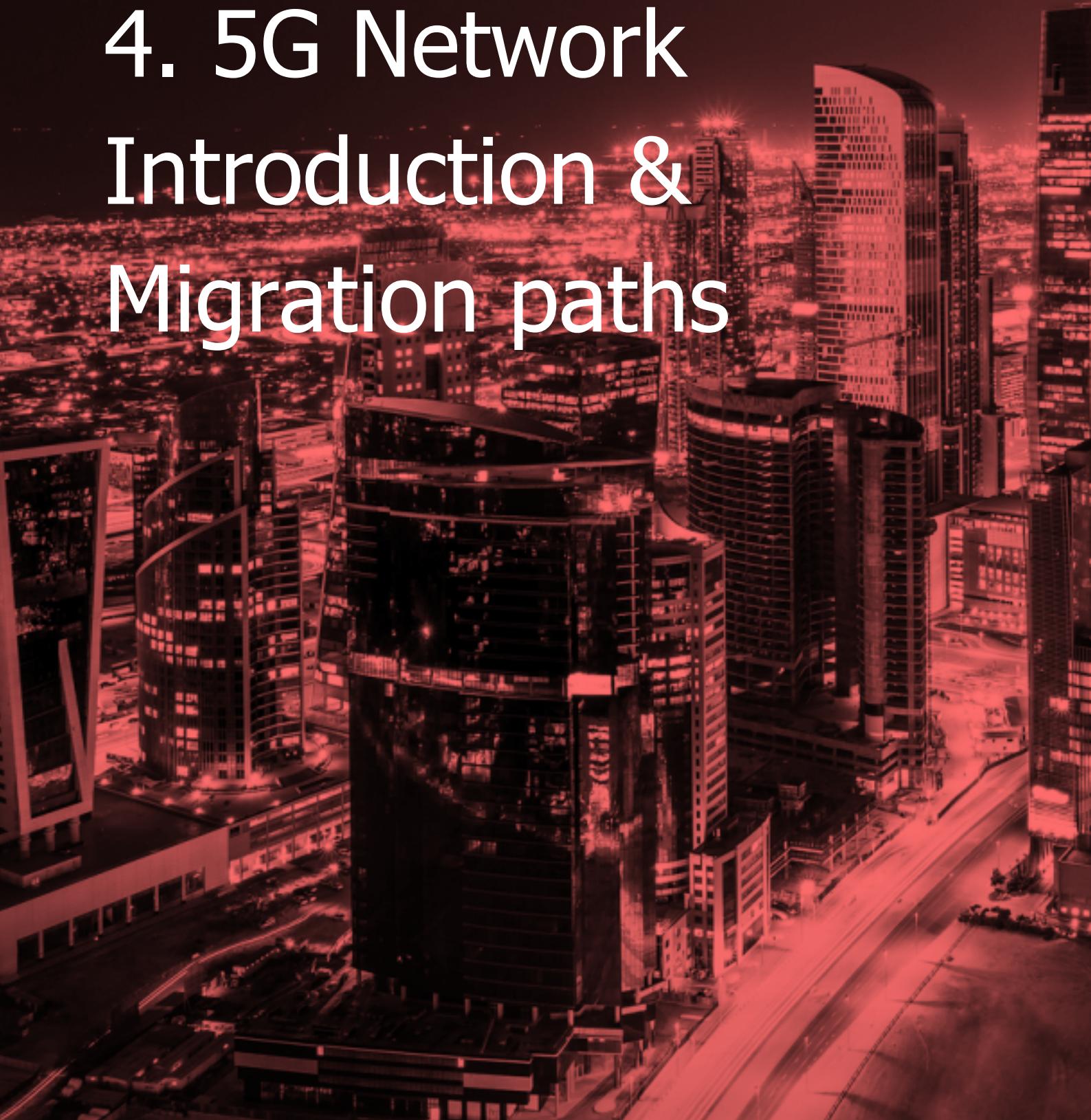
NOTE: from 3GPP Release 14 onwards, the separation of control plane and user plane is also an available option in 4G.

Figure 3: Overview of SA and NSA Options



Part I:

4. 5G Network Introduction & Migration paths



4.1 General observations and assumptions

As discussed in the previous section, 5G can be introduced either in standalone mode (option 2 and option 5) using 5GC or in non-standalone mode, using EPC (option 3) or 5GC (options 4 and 7).

There are therefore several possible “paths” operators can follow to first introduce 5G and then migrate it to the target configuration(s). This section presents a selection of what are thought to be likely introduction and migration scenarios. Readers should be aware that many aspects need to be considered when deciding on the best migration strategy, including spectrum allocation, support for other service and industries, and support of 5G capabilities in terminals.

In this section, it is assumed that the operator:

- has deployed a full 4G system comprising an EPC and LTE access
- plans to migrate in mid- or long-term to 5GS.

4.2 EPS to SA Option #2

4.2.1 Description

In this scenario the operator migrates directly from EPS (Option 1) to the standalone Option 2 with inter-RAT mobility mechanisms used to move devices between 4G LTE under EPC coverage and 5G NR under 5GC coverage.

4.2.2 Feasibility of the path in meeting 5G use cases

One of the key benefit of this option is that SA architecture can take full advantage of 5G end-to-end network capabilities supported by NR and 5GC, providing customized service, especially to vertical industry, in an effective and efficient way. New features, including service-based architecture, end-to-end network slicing, and MEC, can be enabled according to specific requirement of each service, providing customized superior user experience. The 3GPP specifications of Option 2 will be completed by June 2018 with the 5GC stage 2 specification completed in Dec.

2017 (see

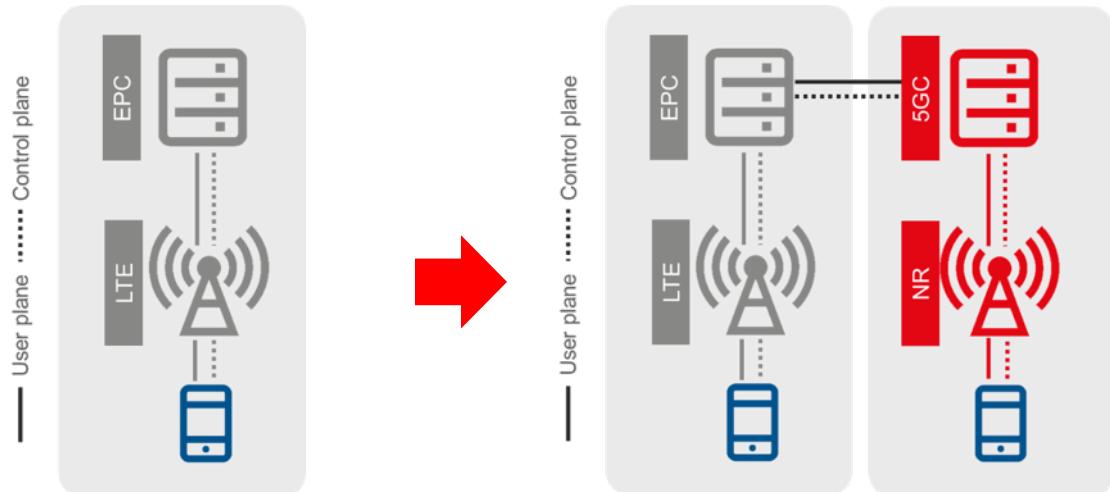
<http://www.3gpp.org/specifications/releases>).

4.2.3 Deployment Considerations

Compared to EPC-based deployment options such as Option 1 and Option 3, this option provides an open, flexible, and service-based network architecture for 5G which can fully exert the ability of 5G. In this context, it may be considered as the deployment choice for operators who need to fulfil the market requirements, especially of vertical industries. It is also a long term network architecture as it already uses both the newly defined radio and core network.

Direct interworking between 5GS and 2G/3G CS domain is not considered at the beginning of deployment for this option.

Figure 4: Description of EPS to SA Option #2



4.2.4 Impact on Device and Network

SA Option #2 envisages the deployment of both NR gNB based NG-RAN as a new radio access and 5GC as new core along with new features on LTE eNB based E-UTRAN to support inter-RAT mobility. Option #2 requires the device to support both a radio front end capable of receiving and transmitting data over NR as well as new procedures for the 5GC.

Since SA operator provides services that are delivered over standalone 5GS, interworking between 5GS and EPS for service continuity for those services may be required. Based on operator strategy, single registration solution with or without AMF-MME interface as defined in 3GPP TS 23.501/502 can be deployed [11], [12]. Converged nodes of SMF+PGW-C, UPF+PGW-U, UDM+HSS and PCRF+PCF are needed accordingly. MME is also impacted to support 5GS and EPS interworking for converged SMF+PGW-C selection or for dual registration without AMF-MME interface.

Since Dual-connectivity is not required for Option #2, workload and cost for 4G existing eNB upgrade and modification is relatively low, with only minor upgrades needed to support interworking with 5G.

The UE supports complete set of functionalities for Control-Plane and User-Plane and for all interfaces to the network.

To avoid the coverage limitations in UL due to different TX/RX configurations and network deployment between downlink and uplink, high power UE can be used to enhance UL coverage.

4.2.5 Impact on voice including service continuity

NOTE: a detailed description of the technical implications for providing service continuity in this scenario is provided in Section 9.

Depending on whether the operator supports voice services over IMS and whether it provides national coverage (i.e. 100% of its coverage) or less, the feasibility of voice service continuity in this migration step will differ.

If the operator provides VoLTE (Voice over LTE) with national coverage, then the operator can either provide IMS voice service over 5G network (5GS) or utilize existing VoLTE service. If IMS voice service over 5G network (5GS) is not provided, the operator may still be in the position to provide voice by adopting non-standardised solutions, hence requiring experimental approach. If the operator only offers VoLTE service over EPS, then interworking of 5GS with EPS is

necessary for subscribers to fall back from 5G to 4G when voice service is required.

If the operator provides VoLTE with partial coverage and CS voice complements VoLTE to support national coverage, then the operator needs to utilize existing VoLTE service and ensure that continuity between LTE and CS access is implemented (i.e., SRVCC: Single Radio Voice Call Continuity). In the case where the VoLTE service does not provide continuity between LTE and CS access, then the voice call continuity would not be guaranteed for regions where VoLTE is not supported.

If the operator does not provide VoLTE and provides CS voice with national coverage only, then this migration step would involve some investment. The operator would need to provide national coverage IMS voice service over 5G network (5GS). Otherwise, the migration step would not guarantee voice service continuity as there is no standardized solution for 5G networks (5GS) equivalent to the SRVCC operation defined for 4G networks (EPS) in initial release of 5G (3GPP Release 15). Note that there is also no Circuit SwitchedFallback (CSFB) operation available for 5GS.

4.3 EPS to NSA Option #3

4.3.1 Description

This section covers the migration from EPS (Option 1) to non-standalone Option 3 with the E-UTRA extended to allow compatible devices to use dual connectivity to combine LTE and NR radio access.

4.3.2 Feasibility of the path in meeting 5G use cases

One of the key advantages of this option is that it only requires the development of specifications of NR as non-standalone access as part of E-UTRAN connected to EPC rather than the specification of the full 5G system as it is the case for standalone NR in section 4.2 and other 5GS cases. In Dec. 2017, 3GPP completed the specifications of Option 3 with the corresponding ASN.1 encoding due in March 2018 as an intermediate milestone before

finishing the specification for other options (see 3GPP news article on [approval of NR spec and industry support for 3GPP NR](#))

Besides the accelerated time to market, as the NR will augment the existing capability of the LTE radio network, this option allows flexible "on demand" deployment where capacity is needed using the same or different vendors for LTE and NR. Furthermore, this option is going to be maintained in future releases of 3GPP (beyond release 15) and therefore can be used in longer-term, even if other options are deployed in parallel.

The capability of deploying NR while anchoring the communication to the EPC network offers the opportunity of making optimal use of the spectrum above 6GHz where operators will have available the large bandwidths necessary to deliver the high throughput in hotspots but that cannot be provided easily over large areas due to the fast signal attenuation. However, NR in option 3 can also be deployed in spectrum bands below 6GHz and the example above should be considered as illustration of one of the possible deployment scenarios.

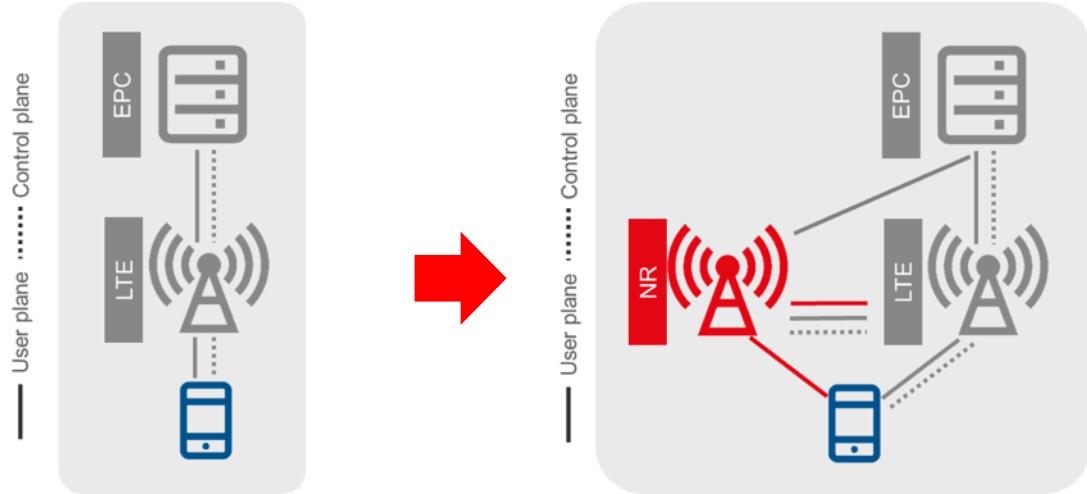
4.3.3 Deployment considerations of option 3

Depending on the EPC features defined by 3GPP in Release 15 and future releases, the EPC capabilities may represent a possible bottleneck (e.g., latency) that limits the performance that could otherwise be extracted from NR.

Data throughput per 5G connected subscriber (e.g. in SGW/PGW) is expected to increase via NR and LTE in dual-connectivity. While the increase of data requires additional consideration in network planning (for example, adding user plane nodes for SGW/PGW), adoption of additional features in the latest releases of 3GPP specification may resolve the challenge.

Finally, as the 5GC is not going to be used in this option, none of the differentiating capabilities of the new architecture described in Section 7.1.2 are available to the operator.

Figure 5: Description of EPS to NSA Option #3



4.3.4 Impact on Device and Network

NSA Option #3 requires deployment of NSA NR en-gNB in E-UTRAN and new features on LTE eNB to support EN-DC procedures, hence has impacts on E-UTRAN. NSA Option #3 has also impact on UE, but limited impact on EPC and HSS depending on operators' choice, and no impact on IMS.

From the point of view of the device, the attractiveness of this solution is that it only requires the additional support of specifications of NR as non-standalone access as part of E-UTRAN connected to EPC. The device will communicate with the core network using the same EPC procedures used by currently available devices either under only LTE or under both LTE and NR radio coverage. It should be noted however that combining of LTE and NR radio interfaces for split bearers may increase memory requirements.

4.3.5 Impact on IMS voice including service continuity

NOTE: a detailed description of the technical implications for providing service continuity in this scenario is provided in Section 9.

Depending on whether the operator supports voice services over IMS and whether it provides national coverage (i.e. 100% of its coverage) or

not, the feasibility of voice service continuity in this migration step will differ.

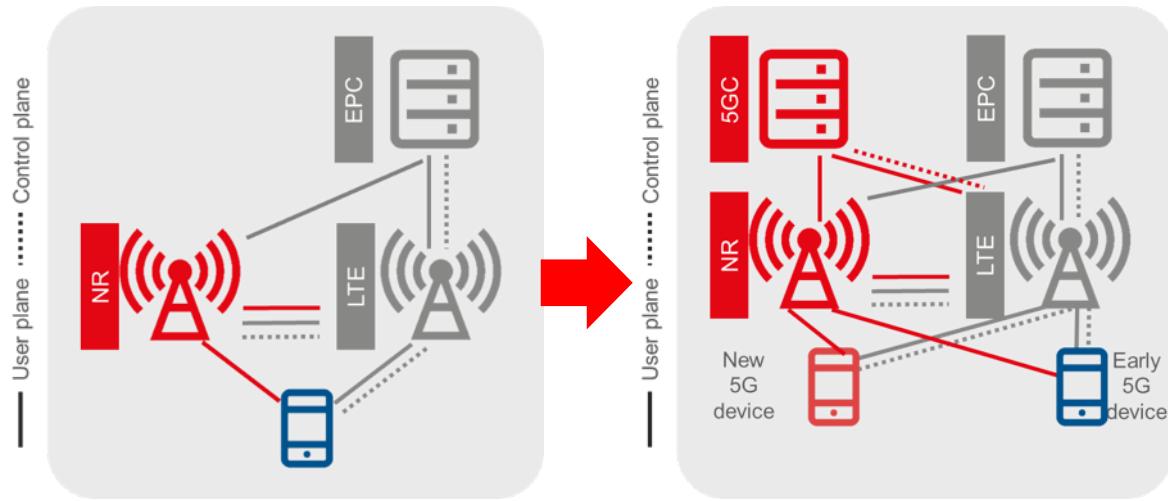
If the operator provides VoLTE with national coverage, then there is no negative impact associated with migrating from EPS to NSA Option #3. The operator can utilize existing VoLTE service.

NOTE: The operator can also choose to upgrade VoLTE to utilize NR

If the operator provides VoLTE with partial coverage and CS voice complements VoLTE to support national coverage, then the operator needs to utilize existing VoLTE service and ensure that continuity between LTE and CS access is implemented (e.g., SRVCC). However, this is something an operator would consider independently from the deployment of 5G to ensure voice service continuity.

If the operator does not provide VoLTE and provides CS voice with national coverage only, then the operator needs to utilize existing CS voice service and ensure CSFB is implemented. As is the case of VoLTE with complementary CS voice, the decision to adopt this technical solution is independent from the introduction of 5G.

Figure 6: Description of NSA Option #3 to NSA Option #7 and SA Option #5



NOTE 1: Early 5G device refers to devices that support only NSA Option #3 5G deployment option

NOTE 2: New 5G device refers to devices that support NSA Option #3 and also other 5G deployment option(s)

4.4 NSA Option #3 to NSA Option #7 and SA Option #5

4.4.1 Description

This section covers the migration from non-standalone Option 3 to non-standalone Option 7 and standalone Option 5 with RAN connectivity to 5GC in parallel to EPC connection for early 5G devices.

4.4.2 Feasibility of the path in meeting 5G use cases

Whereas the network was not able to leverage the advantages of 5GC in NSA Option #3, in this path 5GC is deployed so that the full advantage of 5G end-to-end network capabilities can be delivered to the users. This path enables operators to provide initial 5G use cases (e.g., mobile broadband) leveraging LTE and EPC installed base, while new use cases can be addressed on clean slate 5GS architecture.

4.4.3 Deployment considerations

Since the 5GC is now used, this path requires that devices support the new protocol stack to access this core network. This is problematic not only for legacy 4G-only devices, but also for early 5G devices supporting only NSA Option #3 that only

have an EPC protocol stack. Mobile network operators are likely to maintain Option #3 support after the introduction of Options #7/5. LTE RAN also needs upgrade to connect to 5GC and more LTE base stations (eNode B) may need to be upgraded to interwork with NR. This path also requires tight interworking between LTE and NR.

This path allows operators to continue to selectively deploy NR only where needed. As LTE is already offered in wide-area coverage in initial condition (NSA Option #3), the network can still leverage the wide-area coverage LTE network and deploy NR only when intended use case requires it.

4.4.4 Impact on Device and Network

Option #7/5 upgrade from Option 3 requires deployment of 5GC and upgrade of LTE eNB to support 5GS session, mobility, QoS management and MR-DC procedures and 5GC N2/3 RAN-core interfaces along with upgrade of NR gNB to support 5GC N3 RAN-Core user plane interface. In addition to the need to deploy the new 5GC and (for Option 7) DC, devices will need to support 5GC NAS messages, devices and E-UTRA need to support extensions to the LTE RRC layer, E-UTRA

will need upgrades to terminate the 5GC N2/3 RAN-Core interfaces and both E-UTRA and IMS will require upgrades to support changes to QoS model. N2 interface is the interface between the 5G RAN and AMF, while N3 interface is the interface between the 5G RAN and UPF.

4.4.5 Impact on IMS voice including service continuity

NOTE: a detailed description of the technical implications for providing service continuity in this scenario is provided in Section 9.

Depending on whether the operator supports voice services over IMS and whether it provides national coverage (i.e. 100% of its coverage) or not, the feasibility of voice service continuity in this migration step will differ.

If the operator provides VoLTE with national coverage, then there is no significant impact to service continuity as a result of migrating from NSA Option #3 to NSA Option #7 and SA Option #5. The operator can either provide IMS voice service over 5G network (5GS) or utilize existing VoLTE service. If IMS voice service over 5G network (5GS) is provided, the operator will need to ensure that adequate tests are performed. If VoLTE service is utilized, then EPC is necessary for subscribers when voice service is used.

If the operator provides VoLTE with partial coverage and CS voice complements VoLTE to support national coverage, then the operator needs to utilize existing VoLTE service and ensure that continuity between LTE and CS access is implemented (e.g., SRVCC and CSFB). In the case where the VoLTE service does not provide continuity between LTE and CS access, then the voice call continuity would not be guaranteed for regions where VoLTE is not supported.

If the operator does not provide VoLTE and provides CS voice with national coverage only, then this migration step would involve some investment. The operator would need to provide national coverage IMS voice service over 5G network (5GS). Otherwise, the migration step would not guarantee voice service continuity as

there is no standardized solution for 5G networks (5GS) equivalent to the SRVCC operation defined for 4G networks (EPS) in initial release of 5G (3GPP Release 15).

4.5 NSA Option #3 to NSA Option #3 and SA Option #2

4.5.1 Description

This section covers the migration from having only non-standalone Option 3 to adding standalone Option 2 with inter-RAT mobility mechanisms used to move devices between 5G NSA LTE plus NR under EPC coverage and 5G NR under 5GC coverage.

4.5.2 Feasibility of the path in meeting 5G use cases

Whereas the network was not able to leverage the advantages of 5GC in NSA Option #3, in this path 5GC is deployed so that the full advantage of 5G end-to-end network capabilities can be delivered to the users. This path enables operators to address all use cases on clean slate 5GS architecture. However, the operator may need to consider migration of initial use cases served by EPC to 5GC if all use cases are to be supported by 5GC.

4.5.3 Deployment considerations

Since there is no tight interworking at radio level between 4G and 5G, this path works best when NR has been deployed to support wide-area coverage: while operators can offer seamlessly handover traffic from 5GC to EPC, this transition requires also a change of core network architecture and QoS model and therefore should not be used too frequently.

Early 5G devices supporting only NSA Option #3, and capable of communicating only with EPC, will be able to use their 5G radio capabilities in the target scenario provided the gNB is able to support both option #2 and #3 devices simultaneously.

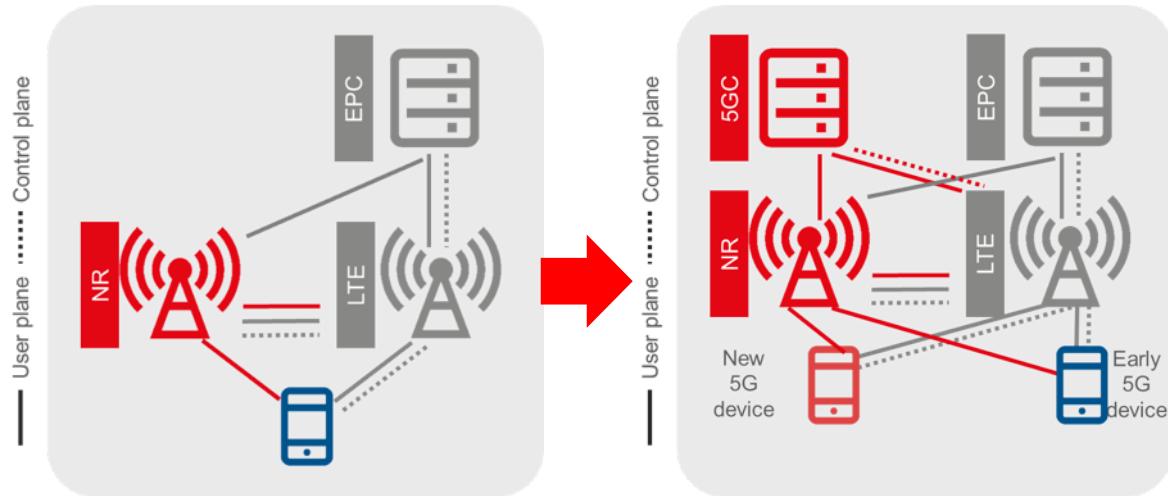
4.5.4 Impact on Device and Network

Option #2 requires deployment of 5GC and update of NR gNB to support both NSA (option

#3) and SA (option #2) in parallel. Option #2 has impacts on E-UTRAN connected to EPC to support

inter-RAT mobility, IMS to support 5GS QoS management and also on UE.

Figure 7: Description of NSA Option #3 to NSA Option #3 and SA Option #2



NOTE 1: Early 5G device refers to devices that support only NSA Option #3 5G deployment option

NOTE 2: New 5G device refers to devices that support NSA Option #3 and also other 5G deployment option(s)

4.5.5 Impact on IMS voice including service continuity

NOTE: a detailed description of the technical implications for providing service continuity in this scenario is provided in Section 9.

Depending on whether the operator supports voice services over IMS and whether it provides national coverage (i.e. 100% of its coverage) or not, the feasibility of voice service continuity in this migration step will differ.

If the operator provides VoLTE with national coverage, then there is no significant impact associated with migration from NSA Option #3 to SA Option #2. The operator can either provide IMS voice service over 5G network (5GS) or utilize existing VoLTE service. Prior to the adoption of IMS voice service over 5G network (5GS), the operator may need to perform extensive testing. If VoLTE service is utilized, then it is necessary to continue to support EPC for subscribers using voice services.

If the operator provides VoLTE with partial coverage and CS voice complements VoLTE to support national coverage, then the operator needs to utilize existing VoLTE service and ensure that continuity between LTE and CS access is implemented (e.g., SRVCC). In the case where the VoLTE service does not provide continuity between LTE and CS access, then the voice call continuity would not be guaranteed for regions where VoLTE is not supported.

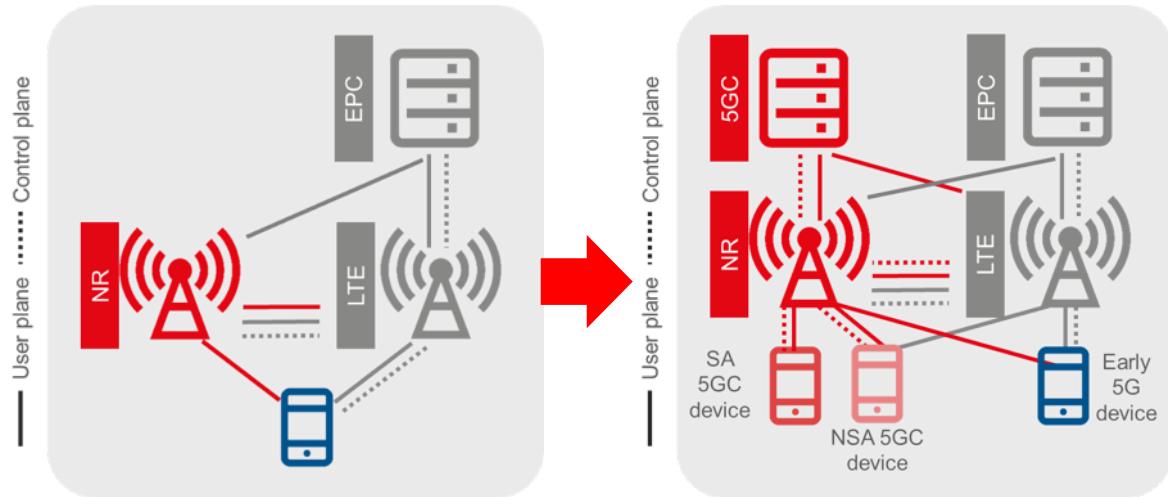
If the operator does not provide VoLTE and provides CS voice with national coverage only, then this migration step would involve some investment. The operator would need to provide national coverage IMS voice service over 5G network (5GS). Otherwise, the migration step would not guarantee voice service continuity as there is no standardized solution for 5G networks (5GS) equivalent to the SRVCC operation defined for 4G networks (EPS) in initial release of 5G (3GPP Release 15).

4.6 NSA Option #3 to NSA Option #4 and SA Option #2

4.6.1 Description

This section covers the migration from non-standalone Option 3 to non-standalone Option 4 and standalone Option 2 with RAN connectivity to 5GC in parallel to EPC connection for early 5G devices.

Figure 8: Description of NSA Option #3 to NSA Option #4 and SA Option #2



NOTE 1: Early 5G device refers to devices that support only NSA Option #3 5G deployment option

NOTE 2: NSA 5GC device refers to devices that support NSA Option #4

NOTE 3: SA 5GC device refers to devices that support SA Option #2

4.6.2 Feasibility of the path in meeting 5G use cases

In this path, unlike in NSA Option #3, the 5GC core network is used to replace the EPC in serving 5G use cases (if 5GC replaces EPC completely then legacy 4G UEs or UEs with 4G only subscription will no longer be served). This means that users can take full advantage of 5G end-to-end network capabilities. This path enables operators to address all use cases on clean slate 5GS architecture. However, the operator may need to consider migration of initial use cases served by EPC to 5GC if all use cases are to be supported by 5GC.

4.6.3 Deployment considerations

Early 5G devices supporting only NSA Option #3 and only able to connect to EPC will imply that

operators will keep maintaining the EPC for long-term. In addition, LTE RAN needs upgrade to connect to 5GC and more LTE base stations (eNodeB) may need to be upgraded to interwork with NR. This path also requires tight interworking between LTE and NR.

This path allows operators to continue to selectively deploy NR only where needed. However, compared with the migration described in section 4.4., this path may require the deployment of a larger number of more NR gNB since NR acts as the master node with LTE secondary node in the area where option #4 is to be used. As the starting point of this migration is scenario #3 where NR and eLTE are already tightly interworking, it is possible to continue to leverage the wide area coverage of LTE and

supplement it with selective NR deployment based on demand.

4.6.4 Impact on Device and Network

Option #4/2 upgrade from Option 3 requires deployment of 5GC and upgrade of NR gNB to support 5GS session, mobility, QoS management and MR-DC procedures and 5GC N2/3 RAN-core interfaces along with upgrade of LTE eNB to support 5GC N3 RAN-Core user plane interface (only required if option 4A is adopted). N2 interface is the interface between the 5G RAN and AMF, while N3 interface is the interface between the 5G RAN and UPF. This step also has impacts on IMS to support 5GS QoS management and also on UE (refer to Section 7 for more details).

4.6.5 Impact on IMS voice including service continuity

NOTE: a detailed description of the technical implications for providing service continuity in this scenario is provided in Section 9.

Depending on whether the operator supports voice services over IMS and whether it provides national coverage (i.e. 100% of its coverage) or not, the feasibility of voice service continuity in this migration step will differ.

If the operator provides VoLTE with national coverage, then there is no significant impact associated with migrating from NSA Option #3 to NSA Option #4. The operator can either provide IMS voice service over 5G network (5GS) or utilize existing VoLTE service. Prior to the adoption of IMS voice service over 5G network (5GS), the operator may need to perform extensive testing. If VoLTE service is utilized, then EPC is necessary for subscribers when voice service is used.

If the operator provides VoLTE with partial coverage and CS voice complements VoLTE to support national coverage, then the operator needs to utilize existing VoLTE service and ensure that continuity between LTE and CS access is implemented (e.g., SRVCC). In the case where the VoLTE service does not provide continuity between LTE and CS access, then the voice call continuity would not be guaranteed for regions where VoLTE is not supported.

If the operator does not provide VoLTE and provides CS voice with national coverage only, then this migration step would involve some investment. The operator would need to provide IMS voice service over 5G network (5GS). Otherwise, the migration step would not guarantee voice service continuity as there is no standardized solution for 5G networks (5GS) equivalent to the SRVCC operation defined for 4G networks (EPS) in initial release of 5G (3GPP Release 15).

4.7 Other migration steps

This section lists the migration steps that are not covered in this version of the document for reader's information:

- NSA Option #7 to NSA Option #4
- SA Option #5 to NSA Option #4
- EPS to NSA Option #4
- EPS to NSA Option #7

NOTE: The list above is not exhaustive and includes only the migration steps that are considered as more likely by the project group

Part I:

5. Recommendations for collaborative actions

The variety of options and migration steps available for deploying 5G allow operators to adopt different strategies that suit the specific market situations, business models and competition needs. Also, customers and the wider industry will benefit as a whole from operators taking certain collaborative actions that are aimed to guarantee service continuity, service and network interoperability and to unlock economies of scale. Similar to the work carried out earlier for IMS services (e.g. VoLTE, VoWiFi, ViLTE), a profile should define the minimum requirements that need to be fulfilled in order to ensure interoperability, roaming and portability across the various 5G deployment options. These profiles should aim to address:

- Basic connectivity of devices to a 5G network including interoperability between 5G and LTE networks
- IMS services delivered over NR
- Support roaming to/from networks with same/different 5G deployment option

The creation of a database of issues to be encountered during the 5G commercialisation, as it was done for IMS services, will allow the industry to efficiently address them and find solutions that every stakeholder will benefit from.

Part II:

6. Study of 5G network introduction case

This section contains 5G case studies contributed by KT to share their 5G network introduction cases to provide insights and foresight for challenges in 5G commercialisation in the near future. This case study addresses KT's 5G trial activities, tentative 5G commercialization plan and roadmap, issues in 5G deployment/migration and KT's challenges from technology and business perspectives.

6.1 Why 5G?

6.1.1 5G technology and service trial activities

To develop early technical specifications for 5G trial system and services for the PyeongChang Winter Olympics that will be held in February 2018, KT launched '5G SIG (Special Interest Group)' along with global mobile manufacturers (Ericsson, Intel, Nokia, Qualcomm, and Samsung) in September 2015 and then completed the 5G SIG specifications in November 2016.

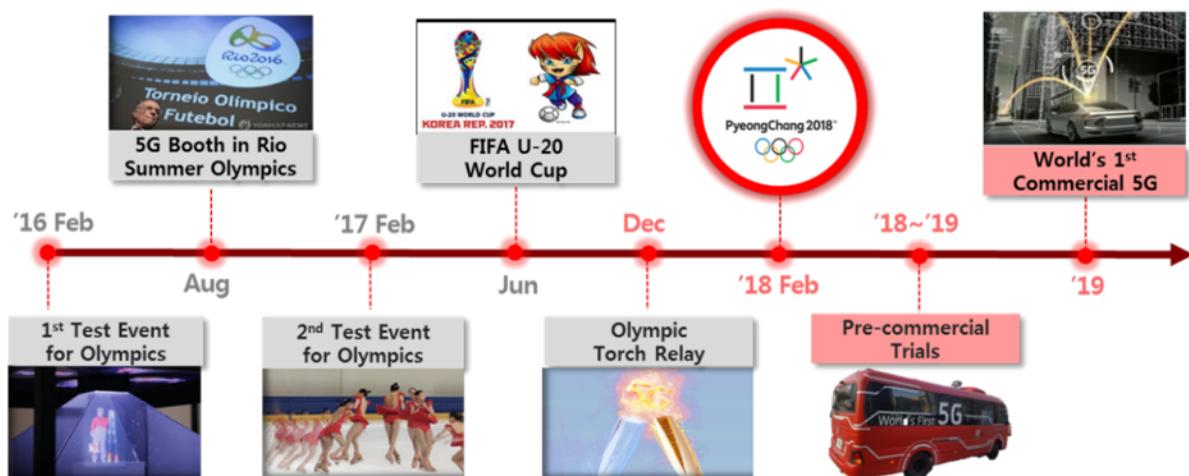
Furthermore, KT successfully completed the IOC Olympic Test Events in 2016 and 2017 based on 5G trial base stations and terminals. KT is currently carrying out lab and field tests for debugging and verifying the functionalities and performance of 5G as well as service demos

during major events, as shown in Figure 9. During the FIFA U-20 World cup held in South Korea, interactive broadcasting of soccer games using 360-degree VR and Time Slice technology was offered through 5G connections.

The 5G trial system including core and radio access network, along with the 5G trial devices, will be deployed by the end of 2017 in Seoul and Olympic venue areas. 5G trial services will be offered during the Olympic Games in PyeongChang, GangReung, JeongSeon, and BoGwang areas as well as in Seoul.

In PyeongChang Olympics, various 5G trial services will be offered by KT such as fixed wireless access service, mobile services, and autonomous vehicle services.

Figure 9: KT's 5G Trials and Commercialization Activities



In PyeongChang Olympics, various 5G trial services will be offered by KT such as fixed wireless access service, mobile services, and autonomous vehicle services. Some key examples of the 5G services are shown in Figure 10 and Figure 11.

- Sync View enables viewers to enjoy the game with high-resolution player-view cameras on players.
- 360-degree Live VR offers capability for viewers to watch interactive UHD-class media in 360-degrees.
- Hologram Live enables mobile users to transfer next-generation 3D hologram media contents.
- Time Slice Broadcasting offers capability for viewers to watch realistic and close slow-motions of Olympic events by using multiple connected cameras.

- Smart Surveillance offers perfect safety and security for visitors and on-site operators by using connected, intelligent surveillance fixed cameras and drones.
- 5G-connected Autonomous Vehicles offer autonomous driving experience and immersive in-vehicle next-generation media.

6.1.2 Other business/social drivers in the nation

South Korea is fully covered with nation-wide LTE network and the LTE traffic already comprises more than 99% of the mobile traffic. Total number of mobile subscribers is around 60 million and smartphone adoption rate is 85% in South Korea.

Figure 10: KT's 5G Trial Services for Olympics

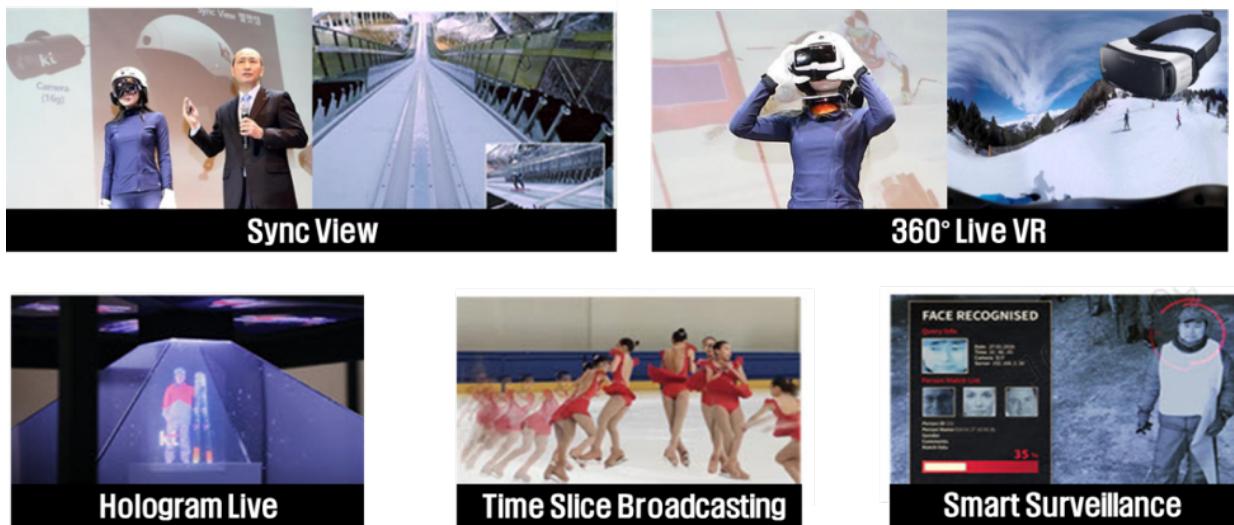


Figure 11: KT's 5G-connected Autonomous vehicle



Besides, the annual growth rate of mobile-connected IoT devices in South Korea is around 20%. It is also expected that subscribed IoT devices will grow in number as commercial IoT network based on 3GPP NB-IoT specifications was deployed for KT LTE network in July 2017. Furthermore, KT is also concentrating on enterprise and B2B IoT segments like home/office IoT, smart factory, smart city and smart energy.

In South Korea, video traffic occupies the biggest portion of the traffic (i.e. 56% as of June 2017), where mobile IPTV and video streaming services over LTE connection are widely spread. That is, smartphones/tablets are starting to substitute traditional TV.

Mobile data usage in South Korea is steadily increasing. As of June 2017, total data volume per month exceeds 290,000 TB and monthly data volume per subscriber exceeds 5 GB. This is around 5 times the average volume of mobile traffic of the past 5 years. Besides, the growth rate of mobile traffic from the previous year is around 40%. It can be estimated that mobile traffic of around 700,000 TB and 1,000,000 TB will be reached in the end of 2019 and 2020,

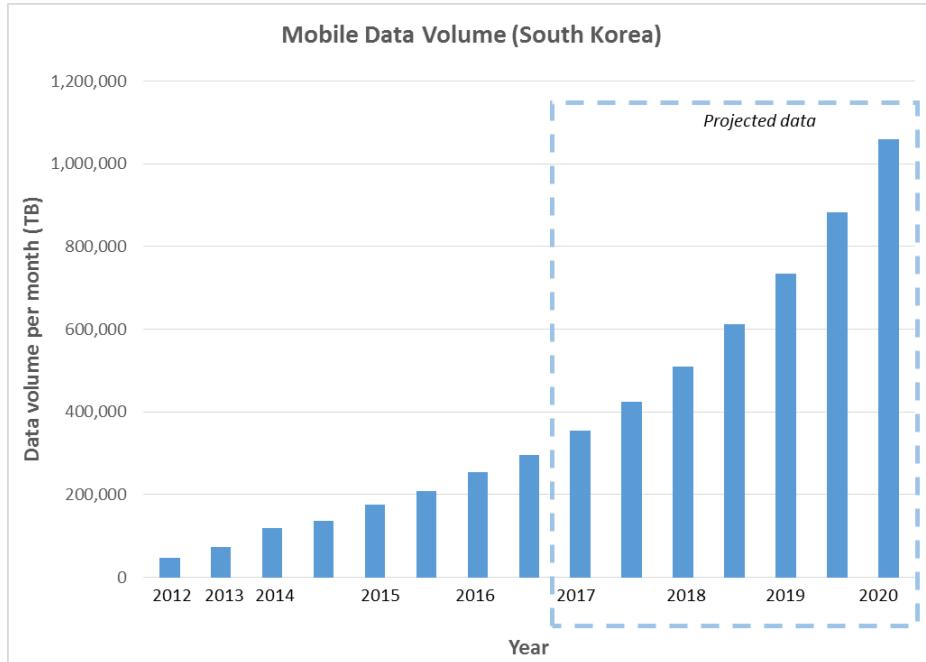
respectively. Of course, connected vehicles may accelerate the growth of mobile traffic in the future. Figure 12 shows the trend and forecast of mobile data traffic in South Korea from 2012 to 2019. Note that projected data during December, 2017 to December, 2020 are estimated based on the recent mobile status reports of KCC (Korea Communications Commission), South Korea.

Since mobile capacity in 2020's must be expanded to accommodate the growth of mobile traffic as well as the adoption of mobile broadband services and IoT devices (especially in urban and hot-spot areas), the early introduction and deployment of 5G mobile broadband network is inevitable.

6.1.3 Deployment purpose and spectrum at disposal

In South Korea, social needs and market competition for reducing retail cost per mobile data used (bit) is growing, as mobile technology is widespread and is commoditized in everyday life. Therefore, timely response from mobile operators becomes urgent. It is expected that epoch-making cost reduction for mobile data can be achieved by introducing relatively low-cost, ultra-broadband millimetre-wave bands to mobile network.

Figure 12: Exploding Mobile Traffic in South Korea



South Korean government released 'K-ICT' national spectrum plan in January 2017 to serve the world's first commercial 5G mobile network in South Korea, so that new broadband spectrum up to 300 MHz bandwidth in 3.5 GHz and 1,000 MHz bandwidth in 28 GHz is planned to be allocated in 2018~2019 timeframe. Therefore, KT is positively considering using these new bands including LTE bands for 5G network deployment.

KT's 5G network will be deployed to serve primarily eMBB services by offering ultra-high speed and sufficient capacity in the initial stage, and then will be extended to accommodate URLLC and mMTC services. Especially, the large-scale deployment of small cells in Seoul urban areas is required due to the accommodation of large traffic and smaller millimetre-wave band cells (i.e., cell ISD of 100~200 meters). Therefore, the acquisition, deployment, and operation of ultra-dense cells become more important. This means that the development of small-sized and low-weight base stations, multi-vendor interoperability of end-to-end system, and next-generation SON technology are urgently required for commercial 5G network.

6.2 Analysis of 5G migration options

Several 5G network options for non-standalone and standalone architectures are specified in 3GPP, as described in the Section 3. The technical comparison between 5G NSA and SA options for mobile network can be summarized as Table 4. For simplicity, we consider only the NSA Option 3/7 and the SA Option 2 here, so that we can further discuss and analyse major technical issues of NSA and SA options.

- Spectrum: Due to the coverage limitation and cost burden of mmWave band cells, it is best used only for sub-6GHz SA or NSA mobile networks.
- Core network: Since Option 7 and Option 2 require new 5GC system, the development and verification of 5GC is needed. Besides, enhancement of EPC like CUPS of EPC for Option 3 is desirable to accommodate large NR capacity. To support inter-system mobility in SA network, interconnection interface between 5GC and EPC may be required which is not necessary for NSA network. When it comes to 5G-specific services, 5GC can naturally support them through new QoS framework and network slicing features.

In terms of devices, since Option 3 requires

single EPC-NAS protocol, UE complexity is lower than that of Option 7 or SA Option 2.

- RAN: Because the NSA networks can fully leverage existing LTE infrastructure as coverage layer, it is ideal in quickly deploying full-coverage 5G network with

relatively small investment. However, this deployment requires upgrade of LTE eNB and EPC based on EN-DC for Option 3. Furthermore, significant upgrade of LTE ng-eNB based on NGEN-DC and introduction of 5GC are required for Option 7.

Table 4: Technical comparison between 5G NSA and SA options

	NSA		SA (Op. 2)
	Op. 3	Op. 7	
3GPP 5G specification	Rel-15 ('17.12) – 1 st prioritised,	Rel-15 ('18.6)	Rel-15 ('18.6)
5G spectrum	Sub-6GHz and mmWave bands are feasible	Sub-6GHz and mmWave bands are feasible	Sub-6GHz band is desirable
CN	EPC,	5GC	5GC
CN interworking	Not required	Not required	Required (with or without N26 interface between 5GC and EPC)
Network slicing and 5G QoS	Not supported	Supported	Supported
UE impact (for 5G/LTE dual-mode)	EPC-NAS	5GC/EPC-NAS	5GC/EPC-NAS
Leverage of LTE	Full	Full	Partial (Reattach)
LTE upgrade	Required (eNB and EPC)	Required (ng-eNB and 5GC)	None or minor
RAN interworking	EN-DC	NGEN-DC	NR-DC (Intra-RAT)
Inter-RAT data session continuity	MR-DC and intra-system handover	MR-DC and intra-system handover	Inter-system handover (N26)
Forward compatibility with SA or Release-16 onwards	Low	Mid	High

6.3 Rationale behind migration option

In this section, we also discuss and analyse major economic and business issues of NSA and SA options. The key comparison between 5G NSA and SA options for mobile network in terms of cost, time, and service aspects can be summarized as follows. Note that the estimation of cost and time can be different depending on various technical and business variables.

- System/Device availability: From its experience in LTE commercialisation, KT spent 18 months to develop LTE systems and devices and then deployed commercial LTE network in major cities and provinces in South Korea after 3GPP LTE specifications were ready. Therefore, it is expected that KT will be able to commercialise 5G network during 2019 as 3GPP 5G specifications will be completed during 4Q of 2017 as Phase 1 (NSA Option 3) and 2Q of 2018 as Phase 2 (SA) of Release-15. Of course, the exact 5G commercialisation plan may change depending on different factors.

- Deployment: Since NR cells can be deployed in urban hotspot areas as capacity and speed boosting cells in NSA network, deployment time will be shortened and NR CAPEX will be lower than that of SA network. However, more investment will be required to upgrade existing LTE RAN for Option 7. In addition, acquisition cost for 5G spectrum for SA is higher than that for NSA since sub-6GHz band is required for nation-wide coverage.
- Migration: KT has a plan to migrate to SA network from initial NSA network in short to mid-run. Therefore, initial deployment of NSA network requires additional cost and time for migration to mature SA network. When it comes to the upgrade aspects of LTE system, Option 7 requires more costs because of the major upgrade of legacy LTE base stations as well as the introduction of 5GC than other options.
- Services: Option 3 has a big disadvantage as it is limited in supporting 5G-specific services due to the use of legacy EPC. On the other hand, nation-wide SA network will give best NR coverage quality although the coverage of initial SA network is limited. In

addition, since Option 7 has evolved, 5G-grade LTE access and core network capabilities, overall service quality is higher than that of Option 3.

6.4 Challenges in actual migration

We observe that there are significant trade-offs among deployment time, customer experience, TCO, and system/UE availability for 5G introduction. The technical and business aspects

dealt in the previous sections indicate that smooth, phased migration of 5G network based on NSA and SA architectures is desirable for quick and stable introduction of 5G networks within 2019 timeframe. First of all, MR-DC plays key role in 5G-LTE interworking and migration. Of course, standalone EPC/LTE network has to be supported for a considerable time, especially to support in-bound roaming users.

Table 5: Economic comparison between 5G NSA and SA options

	NSA		SA (Op. 2)
	Op. 3	Op. 7	
System availability (estimated from Spec.+18 months)	'19.2Q	'19.4Q	'19.4Q
Required time for deployment	Short	Medium	Long
Deployment cost (NR)	Low	Mid	High
Cost for LTE system upgrade	Low	High	Low
Acquisition cost for 5G spectrum	Medium (mmWave bands can be used for SN cells)	Medium (mmWave bands can be used for SN cells)	High (Sub-6GHz band is required for coverage cell)
Migration cost to SA	High	Medium	None
Support of new 5G services	Not supported	Supported	Supported
Overall service quality (initial deployment)	Medium	High	Low
NR coverage quality	Low	Low	High (Sub-6GHz + mmWave), Medium (Sub-6GHz or mmWave)
Voice service for 5G UE	CSFB and VoLTE	CSFB and VoLTE	VoLTE and VoNR

KT is currently considering both 5G NSA Option 3 and/or SA Option 2 networks as the prioritized options for our nationwide 5G network. The adoption of Option 7 evolving from Option 3 is to be decided. The SA Option 5 is not considered and the NSA Option 4 requires further analysis. Figure 13 shows KT's 5G mobile network migration plan that consists of three deployment phases:

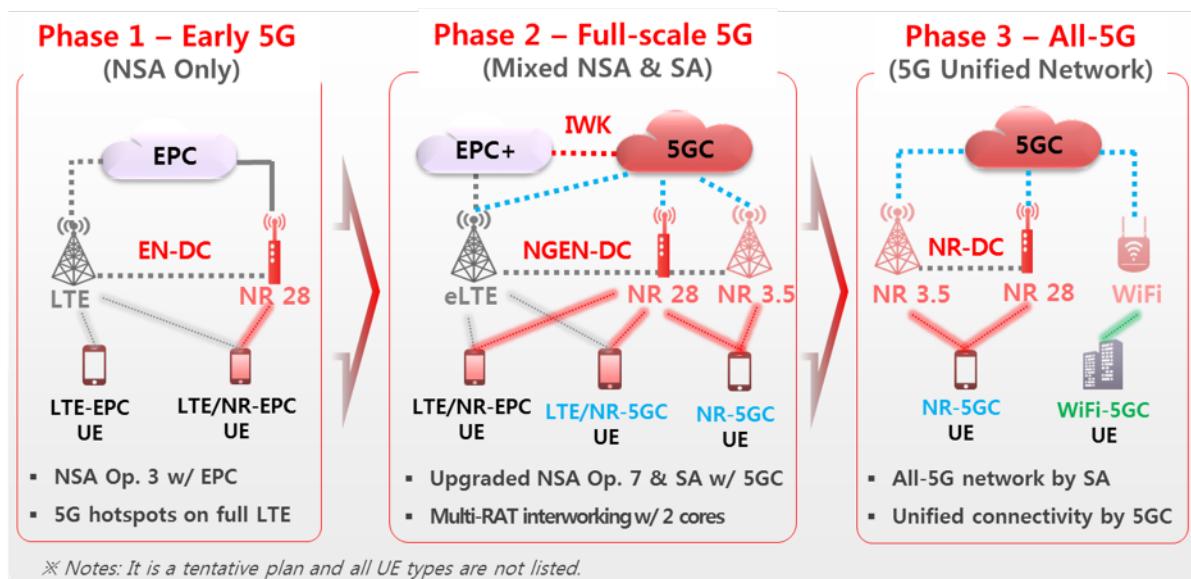
- Phase 1 (Early 5G): The NSA Option 3 network is deployed where NR and LTE cells interwork through EN-DC. NR cells act as data boosting cells in hot-spot areas under nationwide LTE cells.
- Phase 2 (Full-scale 5G): The NSA Option 3 network can migrate to NSA Option 7 network based on NGEN-DC. LTE eNB will be upgraded to support the LTE evolution (eLTE) of Release-15 onwards. It is also possible that the SA Option 2 network coexists with the NSA network or replaces the NSA network.
- Phase 3 (All-5G): As a long-term migration path of 5G, 5G unified network based on the SA Option 2 along with standalone LTE network will be operated. Refarming of LTE bands can be performed at this stage. Further, 5GC may control mobile network as well as WiFi Ap through 5G's access-agnostic core feature.

When it comes to spectrum considerations for 5G, the combinations of low (sub-3 GHz), mid (3~6 GHz), and high (above-6 GHz) spectrum bands will be used. Each spectrum band are to provide wide-coverage, capacity-enhanced coverage, and full-capacity booster cells, respectively. Therefore, the promising band combinations of 3.5 GHz and 28 GHz for NSA and SA networks under consideration are as follows:

- NSA (MR-DC): LTE 1.8 GHz (master) + NR 28 GHz (secondary)
- SA (NR-DC): NR 3.5 GHz (master) + NR 3.5/28 GHz (secondary)

Note that NR 3.5 GHz band, if available, can also be used as secondary cells in the NSA network.

Figure 13: KT's 5G Network Migration Plan



When it comes to 5G mobile network deployment scenarios, we are considering two possible scenarios for nationwide deployment, as illustrated in Figure 14. Of course, the scenarios can be adjusted according to future business and investment plan, frequency auction, allocation, regulation, etc.

- Scenario #1 (NSA-First Deployment): NSA → SA (or SA and NSA): Quick 5G deployment with low CAPEX and simple operation
- Scenario #2 (Mixed-First Deployment): SA in Seoul metropolitan and major cities + NSA in other areas → nationwide SA: Traffic-driven deployment with geographically different options

We have identified and discussed key 5G deployment and migration issues; however, there can still be many issues remaining. They are briefly listed below for further study:

- Migration timeframe from NSA to SA: Different specification versions can be applied to NSA and SA networks separately. For example, NSA in 2019 with Release-15 and then SA in 2020 with Release-16 can be used.
- Whether to upgrade to Option 7 after the initial deployment of Option 3 or not: Option 7 offers better performance than SA Option 2 with MR-DC and ng-eNB capabilities. Besides, Option 7 can offer 5G-grade services even for upgraded LTE users. Upgrade to Option 7 will be smooth

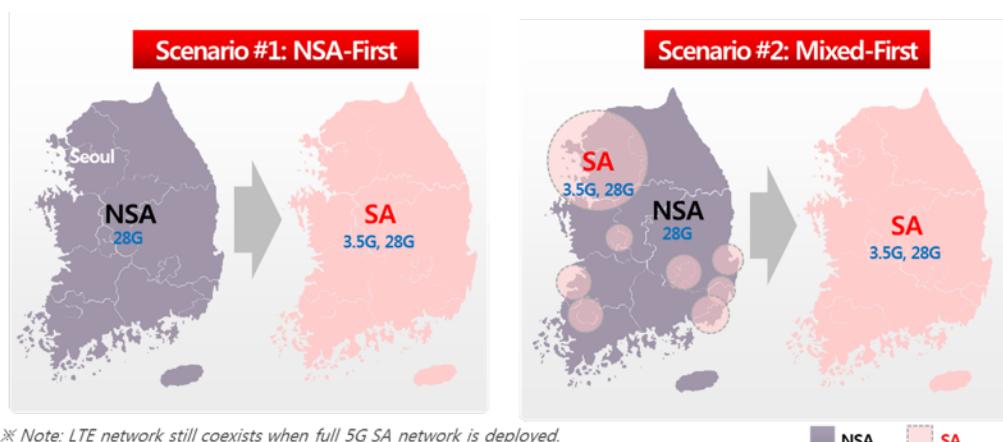
when 5GC is deployed and full spec is available. However, migration to Option 7 from Option 3 may not be necessary as SA Option 2 network will be quickly deployed nationwide.

- Partial refarming of LTE to NR band can be considered at the mature 5G stage: Bandwidth expansion (up to 150 MHz) can be achieved through 1.8 GHz + 3.5 GHz NR CA. Co-existence between 5G and LTE needs to be studied further.
- Support of legacy 5G devices: For example, NSA Option 3 devices should be supported even for Option 7 and the SA networks
- Early adoption of SA network for NR-based FWA (Fixed Wireless Access) service before 2019 timeframe
- Unified control of WiFi Aps through 5G network: Access-agnostic 5GC in Option 7 and SA networks can provide unified mobile and WiFi access and control capability (expected in 3GPP Release-16 onwards). Therefore, the role of WiFi AP in 5G needs to be clarified and positioned.

6.5 Lessons learned from migration case study

KT is actively designing and developing commercial 5G systems and devices by collaborating with major operators and manufacturers. This is for KT to pre-emptively establish next-generation mobile infrastructure to enable a wide-spectrum of convergence services in 2020's through ubiquitous ultra-fast Giga-bit mobile broadband connectivity in South Korea.

Figure 14: KT's 5G Network Deployment Scenarios



Part III:

7. Core network considerations

7.1 Core network solutions

7.1.1 EPC (Evolved Packet Core) [10]

EPC is the core network element of 4G network, which consists of MME (Mobility Management Entity), HSS (Home Subscriber Server), S-GW (Serving Gateway), P-GW (PDN Gateway) and PCRF (Policy and Charging Rules Function). While MME handles the control plane, S-GW and P-GW handle both control and user plane. PCRF is also an integral component of EPC that provides rules for policy (e.g., QoS) and charging.

NOTE: There may be more network nodes depending on the features implemented.

EPC handles EMM (EPS Mobility Management) procedures and ESM (EPS Session Management) procedures. See Figure 15 for the architecture of EPC.

NOTE: For simplicity, the figure does not include interworking with GSM/UMTS networks

Control and User Plane Separation (CUPS) is a new feature introduced in Release 14 of 3GPP. CUPS allows operators to flexibly place the separated control and user plane functions to support diverse deployment scenarios without affecting the overall functionality provided by EPC entities. In addition, EPC will be able to address latency limits if Control and User Plane Separation is deployed but not otherwise. CUPS supports flexible/scalable user plane deployment without expanding or upgrading the control plane. Especially in cloud native case, the simpler configuration and maintenance work of user plane nodes can be achieved. It is also important to note that CUPS in EPS can be deployed before or together with Release 15 Option 3 when needed. See Figure 16 for the EPC architecture with CUPS implemented. (Reference: 3GPP TS 23.401 [10] and 3GPP TS 23.214 [9])

NOTE: For simplicity, the figure does not include interworking with GSM/UMTS networks

Figure 15: EPC architecture – non-roaming

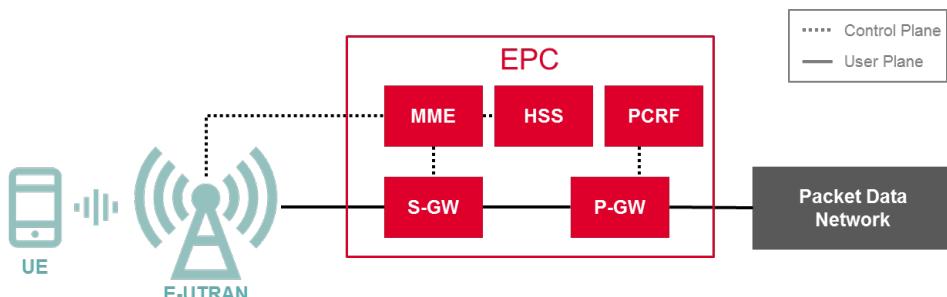
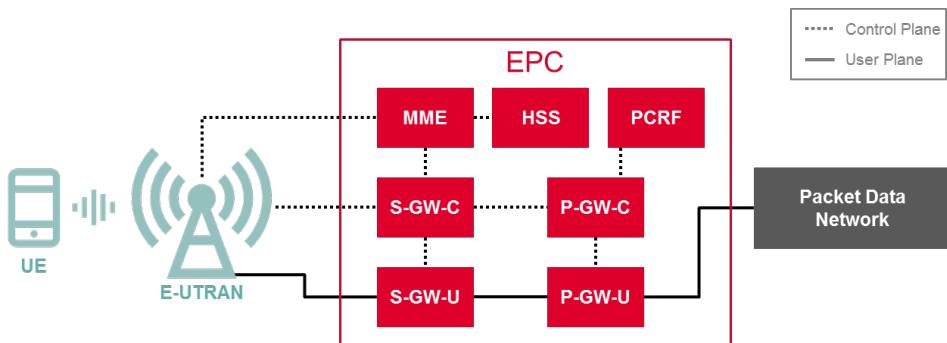


Figure 16: EPC Architecture with CUPS – non-roaming



7.1.2 5GC (5G Core) [11]

With the NFV technologies, the mobile network functions can be virtualized and hosted in a cloud environment. The physical boundary between traditional EPC network elements such as MME, SGW, and PGW will be blurred with virtualization and software. This promotes the 5GC to be redesigned and become open and flexible enough to meet the diversity of service and business requirement in 5G era.

- AF: Application Function
- AMF: Access and Mobility Management Function
- AUSF: Authentication Server Function
- NEF: Network Exposure Function
- NRF: Network Repository Function
- NSSF: Network Slice Selection Function
- PCF: Policy Control Function
- SMF: Session Management Function
- SMSF: SMS (Short Message Service) Function
- UDM: User Data Management
- UPF: User Plane Function

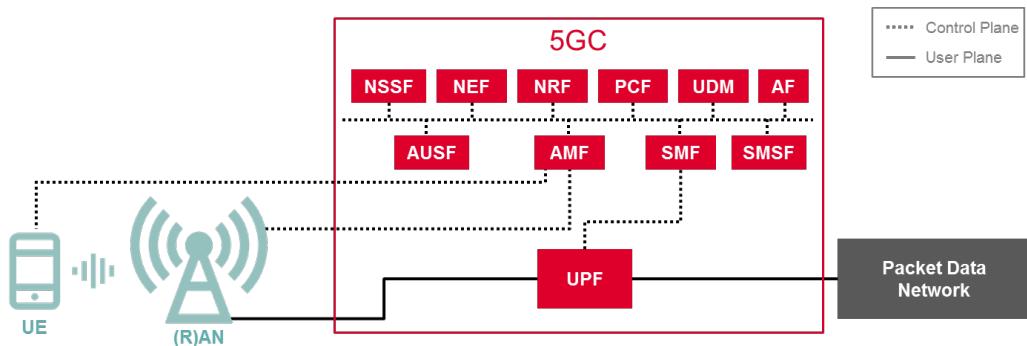
5GC proposes the SBA architecture, which provide unprecedented efficiency and flexibility for the network. SBA is an architectural for building system based on fine-grained, interaction of loosely coupled and autonomous components

called services. This architecture model is chosen to take full advantage of the latest virtualization and software technologies.

Compared to the previous generation reference point architecture as EPC, the elements of service-based architecture are defined to be the NF(network functions), which interconnect with the rest network functions across a single API calling interface and provide the authorized services to them. Network repository functions (NRF) allows every network function to discover the services offered by other network functions.

A service is an atomized capability in a 5G network, with the characteristics of high-cohesion, loose-coupling, and independent management from other services. This allows individual services to be updated independently with minimal impact to other services and deployed on demand. A service is managed based on the service framework including service registration, service authorization, and service discovery. It provides a comprehensive and highly automated management mechanism implemented by NRF, which greatly reduces the complexity of network maintenance. A service will interact with other services in a light-weight manner, e.g. API invocation.

Figure 17: Service Based Architecture of 5G Core – non-roaming



To provide the smooth migration to 5GS, the 5GC is required to support the interworking with legacy EPC and IMS system, including N26, Cx, Sh, Rx interfaces, as illustrated in Figure 18, Figure 19 and Figure 20. In principle there are two possibilities to implement the interworking functionality. The first one is that the NF of SBA where the services operate provides the legacy-reference-point interface to support the interworking with the EPC/IMS network elements. An alternative way is that the EPC/IMS network elements provides the service-based interface that interworks with the NF of 5GC. Either should be designed and developed with little impact on the individual function of the 5GC NF or the EPC network element. According to the present 3GPP specifications in Rel-15, the AMF, UDM/HSS and PCF(5GC network function) supports the legacy reference-point interface that respectively interworks with MME(EPC network element) via N26 interface and AS/CSCF/P-CSCF (IMS network elements) via Sh/Cx/Rx interface.

Figure 18: 5GC exposes N26 legacy- reference-point interface to EPC domain

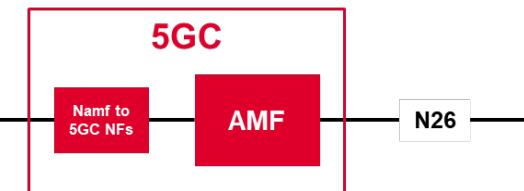
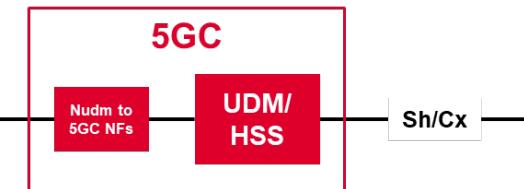


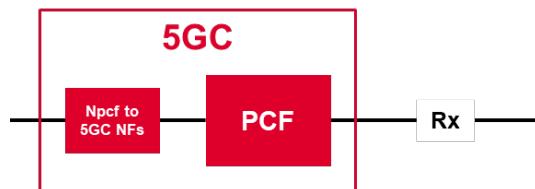
Figure 19: 5GC exposes Sh/Cx legacy- reference-point interface to IMS domain



SBA is the natural step that enables 5G network functionality to become more granular and decoupled, which shall bring the following benefits to 5G:

- The network is highly efficient on rolling out new network features, allowing network operators to quickly deploy new business and services. Services that operate with finer granularity than in legacy networks and that are loosely-coupled with each other allow individual services to be upgraded with minimal impact to other services. This reduces the time to market for installing bug fixes, and rolling out new network features.
- The network is extensible. Each service can interact directly with other services with a single light-weighted service based interface. In such manner, the service based interface can be easily extended without introducing new reference points and corresponding message flows.
- The network will be modular and support reusability. The network is composed of modularized services, which reflects the network capabilities. A service can be easily invoked by other services (with appropriate authorization), enabling each service to be reused as much as possible.
- The network is easily open. The information about a 5G network can be easily exposed to external users such as 3rd-parties (e.g. enterprise) through a specific service without complicated protocol conversion.

Figure 20: 5GC exposes Rx legacy- reference-point interface to IMS domain



7.2 Comparison of EPC and 5GC

The following table provides a comparison of main differences between EPC and 5GC that will impact feasibility of 5G use cases.

Table 6: EPC vs. 5GC (Main differences)

Feature	EPC (4G Core)	5GC (5G Core)
Access Network interface	S1 with per UE assigned MME & SGW (in case of CUPS: single SGW-C and multiple SGW-U) & multiple PDN GWs ePDG and TWAG for non-3GPP access	N2/3 common to all access with per UE assigned AMF & multiple N3 to UPFs
Procedures	Access dependent procedures.	Unified registration, authentication, session management for 3GPP, non-3GPP access (including untrusted, trusted WLAN and in Rel 16 also fixed access), Common N1/N2/N3 for 3GPP and non-3GPP access, enabling seamless mobility
Network slicing	Single slice per UE with multiple PGW	E2E multiple slices per UE with shared AMF, slicing aware RAN and per slice SMF/UPF (potentially slice specific PCF, NRF, etc.)
QoS model	QCI based bearers	QoS flow based framework, including reflective QoS support
Cloud native	Possible but node based (box driven)	Native support for cloud based deployment with service based architecture and service-based interfaces within 5GC CP; Definition of NF services
Local applications	Support LIPA/SIPTO based deployment	Support for edge computing. Application influence on traffic routing.
Session/service continuity	Supports full IP address preservation for centralized GW or break before make solution for local GW (LIPA/SIPTO); service continuity with 2G/3G PS and SRVCC	Improved Session model including different Session and Service Continuity modes. Support for concurrent (e.g. local and central) access to a data network. No service continuity with 2G/3G PS and no support of SRVCC.
Policy framework	Support SM/QoS based policies	Unified Policy framework for Access and mobility control, QoS and charging enforcement, policy provisioning in the UE; introducing NWDA (Network Data Analytics) for data analytics support.
Services supported	SMS over NAS over 3GPP access, IMS services over 3GPP access and non-3GPP access, LCS, MPS, MCPTT, mobile broadband	SMS over NAS (including over Non- 3GPP), support of IMS services over 3GPP access and non-3GPP access, LCS, MPS, MCPTT, mobile broadband
Support for RRC INACTIVE state	Support not specified	Support for RRC inactive (RRC state machine includes 3 states: RRC IDLE, INACTIVE, CONNECTED)

Part III:

8. Detailed considerations on 5G deployment options

8.1 Standalone considerations

In standalone deployment, MR-DC (Multi-RAT Dual Connectivity) is not employed and only single RAT is used to connect UE to the relevant core network. In other words, different generations of radio access network elements are not interconnected with each other but only with those of the same generation (e.g., gNB and gNB are interconnected but gNB and ng-eNB are not interconnected in standalone scenario).

Depending on the deployment option considered, the following radio access network elements are relevant:

- eNB: Option #1 (Standalone E-UTRA in EPS) (3GPP TS 36.300) [13]
- gNB: Option #2 (Standalone NR in 5GC) (3GPP TS 38.300) [15]
- ng-eNB: Option #5 (Standalone evolved E-UTRA in 5GC) (3GPP TS 38.300) [15]

In deployment option #1, eNB is connected to EPC via S1 interface (3GPP TS 23.401) [10].

In deployment option #2, gNB is connected to 5GC via N2 and N3 interface (3GPP TS 23.501) [11].

In deployment option #5, ng-eNB is connected to 5GC via N2 and N3 interface (3GPP TS 23.501) [11].

The general principle in MR-DC is that there is one control plane connection between the MN and a corresponding core network entity for each MR-DC UE. The SN for the MR-DC UE establishes control plane connection via MN. (3GPP TS 37.340) [14]

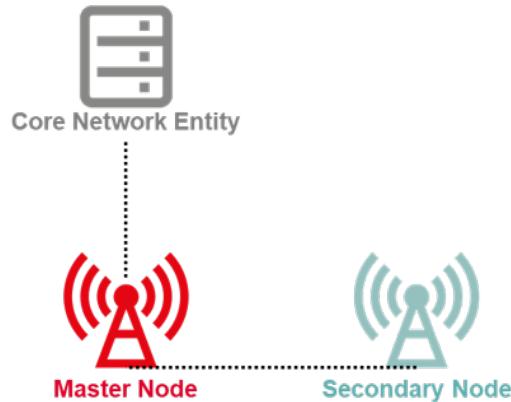
For user plane, there are different connectivity options and hence the user plane bearers are defined per the entity it connects with and the type of resource it uses. For the transport of user plane connection between the core network entity and master/secondary node, the following types of bearers are defined, each of which can be either an MN terminated or SN terminated bearer:

- MCG (Master Cell Group) bearer
- SCG (Secondary Cell Group) bearer
- Split bearer

8.2 Non-standalone considerations

In non-standalone deployment, MR-DC is employed. MR-DC enables the UE to utilise radio resources provided by two distinct schedulers in two different nodes connected via non-ideal or ideal backhaul, as described in 3GPP TS 37.340 [14]. One scheduler is located in the MN (Master Node) and the other in the SN (Secondary Node), and one node provides E-UTRA access and the other node provides NR access. The MN and SN are interconnected and at least MN is connected to the core network. (3GPP TS 37.340) [14]

Figure 21: Control-plane connectivity for MR-DC



MN/SN terminated bearer corresponds to the user plane connection to the CN entity that terminates in the MN/SN respectively. MCG (Master Cell Group) bearers use only MN radio resources while SCG (Secondary Cell Group) bearers use only SN radio resources. Split bearers, however, can use both MN and SN radio resources. The split bearers transfer PDCP data between the SN and the MN via the MN-SN user plane interface (X2/Xn).

While MR-DC is a general concept, the specific terminology to denote MR-DC depends on the deployment option considered, see also 3GPP TS 37.340 [14].

- EN-DC (E-UTRA-NR Dual Connectivity): Option #3 (Non-standalone NR in EPS)
- NGEN-DC (NG-RAN E-UTRA-NR Dual Connectivity): Option #7 (Non-standalone NR in 5GS)
- NE-DC (NR-E-UTRA Dual Connectivity): Option #4 (Non-standalone E-UTRA in 5GS)

For deployment option #3 (EN-DC with the EPC), the master node is eNB and the secondary node is en-gNB (i.e. gNB that is connected to EPC), where eNB is connected to the EPC via S1 interface and to the en-gNB via the X2 interface. In this configuration, en-gNB may also be connected to the EPC via the S1 interface (user plane) and to other en-gNBs via X2 interface (user plane). Hence in EN-DC:

- MCG-bearer uses only E-UTRA radio resources
- SCG-bearer: uses only NR radio resources
- Split bearer can use both E-UTRA and NR radio resources

For deployment option #7 (NGEN-DC with the 5GC), the master node is ng-eNB and the secondary node is gNB, where ng-eNB is connected to the 5GC via N3 interface and gNB is connected to the ng-eNB via the Xn interface. Hence in NGEN-DC

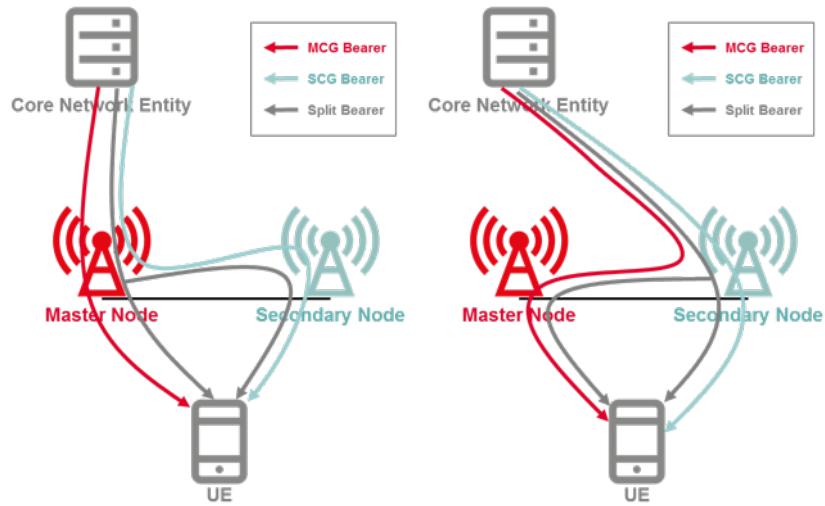
- MCG-bearer: uses only E-UTRA radio resources
- SCG-bearer: uses only NR radio resources
- Split bearer: can use both E-UTRA and NR radio resources

For deployment option #4 (NE-DC with the 5GC), the master node is gNB and the secondary node is ng-eNB, where gNB is connected to 5GC via N3 interface and ng-eNB is connected to the gNB via the Xn interface. Hence in NE-DC

- MCG-bearer: uses only NR radio resources
- SCG-bearer uses only E-UTRA radio resources
- Split bearer: can use both NR and E-UTRA radio resources

Figure 22: User-plane connectivity for MR-DC

(Left: MN terminated; Right: SN terminated)



Part III:

9. Impact on voice
including service
continuity

9.1 Options for operator voice/video communications service in 5G

This section provides overview of Voice/Video options in different deployment options.

Note: Emergency call is not considered but must be supported as required by national regulation.

IMS voice and video call will be supported in all 5G deployment options described in this document, however, there are differences regarding which core network and which radio access technology (RAT) is being used for media and SIP signalling in each of the deployment options. For Option 3 (E-UTRAN NR Dual Connectivity), 4 (NR-E-UTRA Dual Connectivity) and 7 (NG-RAN E-UTRA-NR Dual Connectivity) where both NR and LTE can be used as RAT, the decision on which RAT is used for SIP signalling and media is made in the Radio Access Network (RAN). In more detail, this means the following two solutions are possible for IMS voice and video call:

Solution 1: IMS voice or video call via 5GC, media and SIP signalling using

- In Option 2: NR via 5GC
- In Option 4: NR and/or LTE via 5GC using MCG, SCG and/or split bearer (controlled by NG-RAN)
- In Option 5: LTE via 5GC
- In Option 7: LTE and/or NR via 5GC using MCG, SCG and/or split bearer (controlled by NG-RAN)

In addition, one or both of the following functionalities may be supported in solution 1 during the call establishment

- RAT fallback from NR connected to 5GC in Option 2/4 to E-UTRA connected to 5GC in Option 5/7. Any ongoing data transfers would be maintained using the procedures defined by 3GPP Release 15 for intra 5GC PS HO.
- EPS fallback from 5GS in Option 2/4/5/7 to Option 1 or 3. Any ongoing data transfers would be maintained e.g. if using a PS HO with change from 5GC to EPC core attachment using the procedures defined by 3GPP Release 15.

Solution 2: IMS voice or video call via EPC, media and SIP signalling

- In Option 3: LTE and/or NR via EPC using MCG, SCG and/or split bearer (controlled by E-UTRAN)

For networks that have not deployed IMS Voice and video and have continued to use the Circuit Switched Fallback (CSFB) solution defined in 3GPP Release 8 and subsequent releases, the following solution can apply.

Solution 3: CS voice via MSC

- In Option 3: CSFB to 2G/3G CS – Devices currently attached to EPC may use this solution to initiate or terminate a voice or video call (the call is established on CS).

Note: CSFB from NR or LTE cell under 5GC is not specified in 3GPP Release 15.

For an IMS voice and video call, the session continuity during mobility can be ensured as follows

- If the UE is using IMS voice or video call via 5GC, then
 - PS HO from 5GC to EPC
 - if two RANs are connected to 5GC (one supporting option 2 or 4 and the other Option 5 or 7): Intra 5GC PS HO between NR and E-UTRA connected to 5GC
- If the UE is using IMS voice or video call via EPC, then
 - PS HO from EPC to 5GC
 - Existing SRVCC to 2/3G (if required), e.g., after loss of LTE radio coverage

After call completion, the terminal can either stay on the currently used access / core or one of the following procedures is possible

- If the UE is on 2G/3G after SRVCC, fast return to EPS
- If the UE is on EPC, EPC>5GC PS HO
- If the UE is on 5GC, Intra 5GC PS HO between NR and E-UTRA connected to 5GC

9.2 Recommendations for voice/video communications service in 5G

When evolving to 5G based on 5GC and if NR coverage is continuous, then IMS voice and video call on NR via 5GC (solution 1 with Option 2) is most applicable, as cost of NR is much lower than LTE and cell capacity of NR is much more than LTE.

EVS codec is recommended as default voice codec and HEVC is recommended as default video codec for IMS voice and video call on NR capable terminal for better QoS/QoE.

When evolving to 5G based on EPC, IMS voice and video call on EPC (solution 2 with option 3) is most applicable.

Annex A

Other considerations for operators



A.1 Status Icon related to 5G

As 5G network may consist of elements from evolved 4G networks (e.g., Evolved E-UTRA and Evolved EPC), the decision on when 5G should be displayed on the user interface of the terminal is not as clear as previous generations. Operators agree that it would be beneficial to have consistency across device OEMs of the RAT indicated to the user. Survey and discussion among operator members of the 5G Introduction project indicates that different requirements need to be satisfied for deciding when to present a 5G status icon depending on the operators. The 5G Introduction project group sent the results of the survey and discussion to 3GPP as a reply to the LS from 3GPP SA2 for information. The liaison statement can be accessed in the public in 3GPP document repository (SA2: S2-178933 [17]; RAN2: R2-1713952 [18]).



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