



5G Implementation Guidelines: NSA Option 3

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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 community 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 NSA (non-standalone) Option 3 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 3, reflecting the initial launch strategy being adopted by multiple operators. 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 2, Option 4, Option 5 and Option 7) in addition to Option 3. As a result, this document will be updated to provide guidelines for all 5G deployment options. [Implementation Guideline for Option 2](#) has been completed and available publicly.

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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- Utimaco TS GmbH
- Verizon Wireless
- Vodafone Group
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Abbreviations

Term	Description
2D	2 Dimensions
3D	3 Dimensions
3GPP	3 rd Generation Partnership Project
5GC	5G Core
AMBR	Aggregate Maximum Bit Rate
AMF	Access and Mobility Management Function
AN	Access Network
APN	Access Point Name
AR	Augmented Reality
ARD	Access Restriction Data
AVP	Attribute-Value pairs
BEREC	The Body of European Regulators for Electronic Communications
BPSK	Binary Phase Shift Keying
BW	Bandwidth
CA	Carrier Aggregation
CC	Component Carrier
CDR	Charging Data Record
COTS	Commercial Off The Shelf
CRS	Cell-specific Reference Signal
CU	Centralized Unit
CUPS	Control and User Plane Separation
DC	Dual Connectivity
DCNR	Dual Connectivity with NR
DL	Downlink
DNS	Domain Name System
DSL	Digital Subscriber Line
DU	Distributed Unit
eCPRI	Enhanced Common Public Radio Interface
eLTE	Enhanced LTE
eMBB	Enhanced Mobile Broadband
eNB	eNode B
EN-DC	E-UTRAN New Radio – Dual Connectivity
EPC	Evolved Packet Core
EPS	Evolved Packet System
eSRVCC	enhanced Single Radio Voice Call Continuity

Term	Description
E-UTRAN	Evolved-Universal Terrestrial Radio Access
FQDN	Fully Qualified Domain Name
FTTX	Fiber To The X
FWA	Fixed Wireless Access
GBR	Guaranteed Bit Rate
gNB	gNode B
GW	Gateway
HARQ	Hybrid Automatic Repeat Request
HE	Home Environment
HPLMN	Home Public Land Mobile Network
HSS	Home Subscriber Server
IMS	IP Multimedia Subsystem
IMT-2020	International Mobile Telecommunication system with a target date set for 2020
IP	Internet Protocol
IT	Information Technology
ITU-R	International Telecommunication Union Radiocommunication Sector
LTE	Long Term Evolution
MAC	Medium Access Control
MBR	Maximum Bit Rate
MCG	Master Cell Group
ME	Mobile Equipment
MIMO	Multiple-Input Multiple-Output
MME	Mobility Management Entity
mMTC	Mobile Machine Type Communications
MN	Master Node
MOCN	Multi-Operator Core Network
MORAN	Multi-Operator Radio Access Network
MU-MIMO	Multi-user MIMO
NAS	Non-Access-Stratum
NFV	Network Function Virtualization
NGEN-DC	NG-RAN – E-UTRA Dual Connectivity
NR	New Radio
NR	New Radio
NSA	Non StandAlone
OCS	Online Charging System
PCRF	Policy and Charging Rules Function

Term	Description
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
PGW	PDN Gateway
POP	Point of Presence
PRACH	Packet Random Access Channel
PTP	Point to Point
PUCCH	Physical Uplink Control Channel
QAM	Quadrature Amplitude Modulation
QCI	QoS Class Identifier
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RAT	Radio Access Type
RLC	Radio Link Control
RoHC	Robust Header Compression
RRC	Radio Resource Control
SA	StandAlone
SAE	System Architecture Evolution
SCG	Secondary Cell Group
SC-OFDM	Single Carrier – Orthogonal Frequency Division Multiplexing
SDN	Software Defined Networking
SGW	Serving Gateway
SLA	Service Level Agreement
SMS	Short Message Service
SMSoIP	SMS over IP
SN	Secondary Node
SN	Serving Network
SRVCC	Single Radio Voice Call Continuity
SUL	Supplementary Uplink
SU-MIMO	Single-user MIMO
TCO	Total Cost of Ownership
TDD	Time Division Duplexing
TS	Technical Specification
UE	User Equipment
UL	Uplink
UP	User Plane
uRLLC	Ultra Reliable Low Latency Communications
VI	Virtual Infrastructure

Term	Description
VNF	Virtual Network Function
Vo5G	Voice over 5G
VoCS	Voice over Circuit Switch
VoIMS	Voice over IMS
VoLTE	Voice over LTE
VoNR	Voice over NR
VoWiFi	Voice over WiFi
VPLMN	Visited Public Land Mobile Network
VR	Virtual Reality
WRC	World Radiocommunication Conference
xDSL	x Digital Subscriber Line

References

Ref	Title
[1]	GSMA PRD IR.92, IMS Profile for Voice and SMS
[2]	“BEREC Report on infrastructure sharing”, BEREC 2018.
[3]	GSMA PRD IR.65, IMS Roaming and Interworking Guidelines
[4]	GSMA PRD NG.113, 5GS Roaming Guidelines Note: Document will be available in Q4/2019
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[6]	3GPP TS 23.501, System Architecture for the 5G System
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[8]	3GPP TS 33.401, 3GPP System Architecture Evolution (SAE); Security architecture
[9]	3GPP TS 33.501, Security architecture and procedures for 5G System
[10]	GSMA PRD FS.19, Diameter interconnect security
[11]	GSMA Mobile Policy Handbook
[12]	Migration from Physical to Virtual Network Functions: Best Practices and Lessons Learned

Contents

Overview.....	3	2.11 Migration to virtualized network/Network Transformation [12]	29
Introduction	3	2.12 Roaming.....	30
Scope	3	2.13 Services (IMS – Voice).....	30
Acknowledgements	3	2.13.1 Roaming with VoIMS	30
Abbreviations	4	2.14 Outlook	30
References	5	Annex A Document Management	32
Contents	6	A.1 Document History	32
1. Commercialisation of 5G.....	8	A.2 Other Information.....	32
1.1 Fixed Wireless Access	8		
1.2 Enhanced Mobile Broadband	8		
2. Prerequisite for initial 5G NSA Option 3 launch	11		
2.1 Introduction	11		
2.2 Spectrum	12		
2.2.1 Bands earmarked for 5G and their possible utilisation.....	12		
2.2.2 Amount of spectrum needed	13		
2.3 4G Radio network updates	13		
2.3.1 Number of sites needed	13		
2.3.2 LTE upgrade to support EN-DC (Option 3).....	14		
2.3.3 Considerations in aligning maintenance of LTE sites	14		
2.4 4G Core network updates	15		
2.4.1 Option 3/3a/3x Networking Comparison	15		
2.4.2 Impact Analysis on 4G Core Network Elements	16		
2.4.3 4G Core Network Upgrading Strategy	16		
2.5 5G deployment.....	17		
2.5.1 Massive MIMO Selection	18		
2.5.2 Coverage Enhancement	19		
2.5.3 Synchronisation Configuration.....	21		
2.5.4 NSA and SA Strategy	21		
2.5.5 5G Network Deployment Strategy in initial stage	22		
2.6 Transmission / backhaul.....	23		
2.6.1 Considerations in augmenting existing transmission networks	23		
2.7 Devices	24		
2.8 Network Sharing	25		
2.8.1 Benefits of Sharing	26		
2.8.2 Obligations and challenges	26		
2.9 Testing	27		
2.10 Features.....	27		

An aerial night view of a city, likely Singapore, with a prominent red network overlay consisting of glowing nodes and connecting lines. The city lights are visible in the background, and the network pattern is superimposed over the entire scene.

1

Commercialisation of 5G

1. Commercialisation of 5G

1.1 Fixed Wireless Access

FWA (Fixed wireless access) refers to a wireless link that provides connectivity to objects that are stationary or nomadic (i.e. almost no movement when connectivity is used). This concept has already been frequently used as a substitute to wireline connection in the last mile. Therefore, it is often compared with other last mile connectivity solutions such as FTTx (Fibre-to-the-x) and xDSL (x Digital Subscriber Line). 5G, in all its deployment options, enables the FWA to be competitive substitute to FTTx with its superior radio capabilities and therefore offers business opportunities for the mobile operators

For mobile operators, the FWA provides cost effective network deployment solution. As the wireless links are cheaper to setup and operate, the network cost in the last mile will be significantly reduced with FWA compared to the case of FTTx. This means that the broadband connectivity will be economically feasible with FWA that would otherwise have been infeasible. With FWA, the mobile operators can enjoy the following business opportunities.

- Broadband demand currently underserved: with cheaper connectivity solution, traditionally unconnected homes that were considered economically infeasible can be connected, creating additional broadband revenue stream.
- Fixed market that can be upgraded to broadband: in places where xDSL or copper lines are hard to be replaced, FWA can offer broadband upgrade and therefore provide upselling opportunities for existing fixed internet customers.
- Time-limited demand: it is economically infeasible to deploy wireline connection to suit demand that are time-limited (e.g., seasonal, holiday, etc.). FWA, on the other hand, can provide a cost effective and easy connectivity solution to such demands.
- Internet of Things: cheaper connectivity solution enables cost effective connectivity for Internet of Things applications, which tend to require cheap connectivity with less stringent requirements than that of the mobile broadband.

In addition to the monetary benefits, the mobile operators will be able to provide social benefits to the nation by bridging the digital divide gap between unconnected and connected. Furthermore, the broadband connectivity will enable advanced services such as e-learning and e-government, contributing to better welfare of the society.

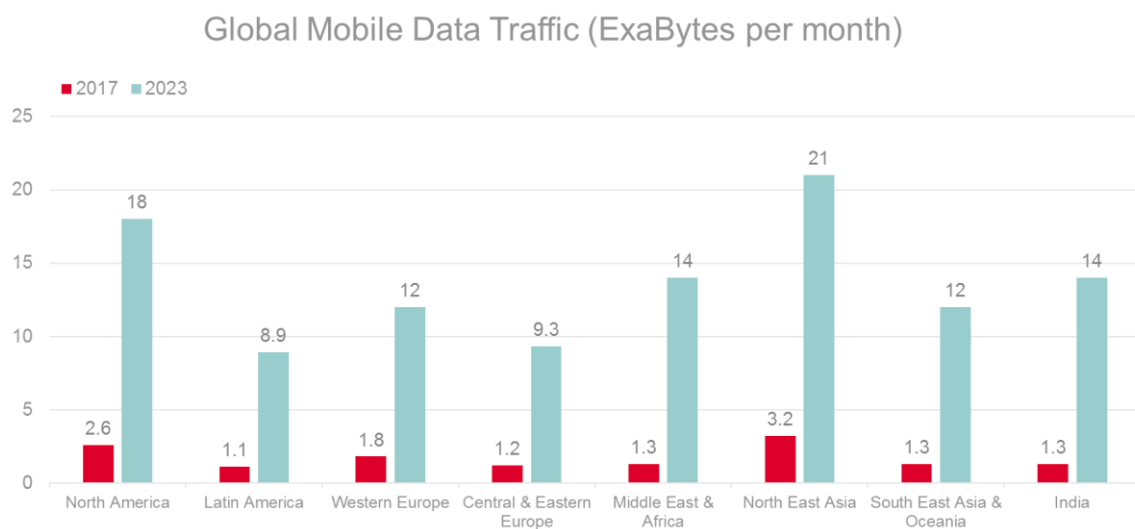
1.2 Enhanced Mobile Broadband

Enhanced mobile broadband refers to the extension of the data demand that was addressed by traditional mobile broadband. 5G will provide enhanced data speeds and experience with its superior radio. Although this is not a new business opportunity, the growth of data demand persists with increasing uptake of multimedia contents (e.g., video) and some markets (e.g., North East Asia and North America that will experience over 20 Exabytes per month mobile data traffic in 2023: see Figure 1) have urgent need to address the demand data growth.

As a proven business case, enhanced mobile broadband is the priority use case in 5G deployment. Over 70% of CEOs surveyed by GSMA in October 2016 have confirmed such.

Although connectivity yields low margin, it offers stable revenue stream that will be able to bankroll the deployment of 5G to suit 5G use cases other than mobile broadband. Furthermore, as mobile broadband is the key value proposition that is offered by the operator, excelling in enhanced mobile broadband will differentiate the early adopter from its competitors. Therefore, although being traditional business case, enhanced mobile broadband will be an integral part of 5G commercialisation.

Figure 1: Global Mobile Data Traffic (Source: Ericsson)





2

Prerequisite for initial
5G NSA Option 3 launch

2. Prerequisite for initial 5G NSA Option 3 launch

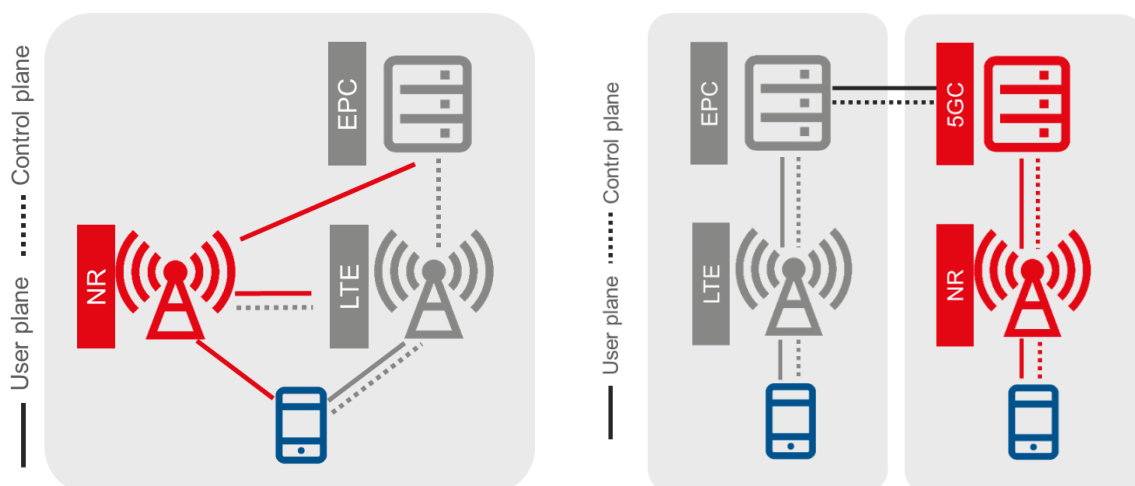
2.1 Introduction

5G can be deployed in five different deployment options, where SA (standalone) options consist of only one generation of radio access technology and NSA options consist of two generations of radio access technologies (4G LTE and 5G). The early deployments will be adopting either non-standalone option 3 or standalone option 2 as the standardisation of these two options have already been completed.

Non-standalone option 3 is where radio access network is composed of eNBs (eNode Bs) as the master node and gNBs (gNode Bs) as the secondary node (see left side of Figure 2). The radio access network is connected to EPC (Evolved Packet Core). The NSA option 3, as it leverages existing 4G deployment, can be brought to market quickly with minor modification to the 4G network. This option also supports legacy 4G devices and the 5G devices only need to support NR (New Radio) protocols so device can also be developed quickly. On the other hand, NSA option 3 does not introduce 5GC and therefore may not be optimised for new 5G use cases beyond mobile broadband. In addition, depending on how 5G devices are developed, the EPC may need to be retained longer than in the case of having EPS (Evolved Packet System) for 4G alone (instead of supporting NSA Option 3).

Standalone option 2 is where radio access network consists of only gNBs (gNode Bs) and connects to 5GC (5G Core), and the 5GC interworks with EPC (see right side of Figure 2). SA option 2 has no impact on LTE radio and can fully support all 5G use cases by enabling network slicing via cloud native service-based architecture. On the other hand, this option requires both NR and 5GC, making time-to-market slower and deployment cost higher than that of NSA option 3. Furthermore, the devices would need to support NR and core network protocols so it would take more time to develop devices. Finally, as the standalone 5G System would need to interwork with EPS to ensure service continuity depending on coverage, the interworking between EPC and 5GC may be necessary.

Figure 2: High-level architecture of NSA Option 3x and SA Option 2



2.2 Spectrum

2.2.1 Bands earmarked for 5G and their possible utilisation

Availability of a suitable amount of spectrum is the most important prerequisite to launch 5G. While globally harmonised bands will be allocated formally at WRC-19, several countries and regions have already identified candidate bands and in some cases already allocated them.

When 5G deployment is driven by providing enhanced mobile broadband, the S and C bands, communications bands extending from 2GHz to 4GHz and 4GHz to 8GHz respectively, accommodate the 3.4GHz to 4.2 GHz frequency range which seems to be the most suitable option. These bands have been identified in many countries as primary bands for 5G and as Figure 3 shows, global harmonisation seems feasible in the lower part of such bands thus unlocking economies of scale in devices.

Another band that has been gaining popularity for use in 5G is the so called millimeter wave band that includes spectrum spanning from 24GHz to 29.5GHz as well as spectrum in the 37GHz to 43.5GHz. The very fast attenuation of the radio signal at these frequencies has cast doubts on the potential of using this spectrum to provide wide area coverage especially in the uplink direction where MIMO and beamforming may not be as effective as in the downlink, however field trials and simulations indicate that there is a key role to be played by mmWave in 5G.

28GHz for example, is the band used for many of the Fixed Wireless Access trials and commercial launches and radio cells operating in mmWave are suitable for creating a thick capacity layer where needed (hotspots) as well as for many enterprise scenarios.

The main attractiveness of mmWave, as Figure 4 shows, is the availability of a very large bandwidth and the strong potential for global harmonization.

Figure 3: Spectrum in the S and C bands earmarked for use in 5G in selected countries

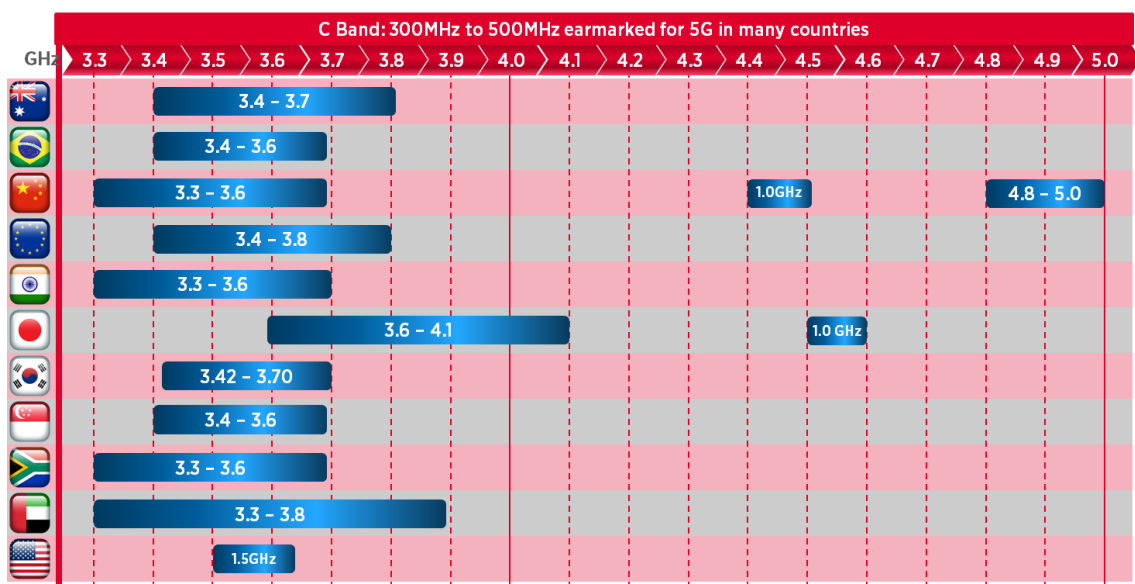
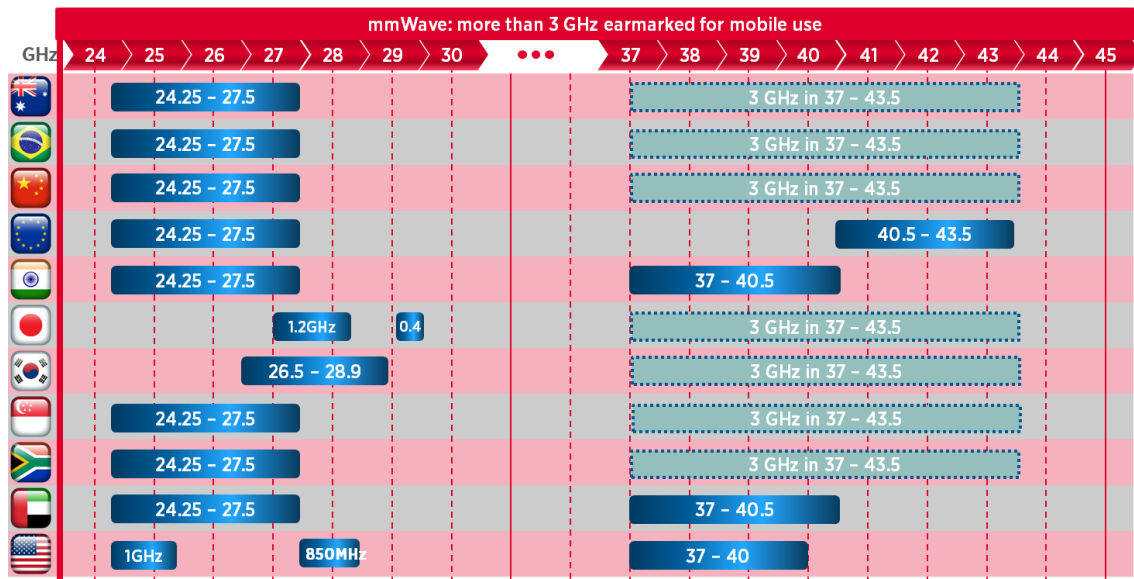


Figure 4: Spectrum allocation in mmWave for selected countries



2.2.2 Amount of spectrum needed

It should be observed that the ITU IMT-2020 requirements, especially with regards to maximum throughput are based on the assumption of using 100MHz channels. From an analysis of the results of recent spectrum auctions in the 3.5 GHz spectrum, it was observed that only in few cases (e.g. Hungary 2016, United Kingdom 2018) operators will have that amount of spectrum available. The consequence is that the actual throughput that can be extracted from the 5G system will be inferior to the IMT-2020 requirement. It is important that operators are in the position to deliver 5G at a lower cost per Gbyte, therefore an allocation of at least 100MHz is vital for such use cases.

2.3 4G Radio network updates

2.3.1 Number of sites needed

Thanks to the possibility of utilising advanced antenna techniques such as MIMO and beamforming, simulations have shown the feasibility of matching the downlink coverage provided by LTE 1800 MHz with 5G radio base stations operating at 3.5 GHz: the same cell grid can therefore be reused for the initial rollout. In the uplink direction MIMO and beamforming are unpractical due to the limited real estate in the device, therefore if the uplink was to use the same frequencies as downlink, the size of the cell would “shrink” to the maximum range in the uplink.

To overcome this problem it has been proposed to utilise lower band spectrum such as the 1800 MHz spectrum for the uplink data. In the first step, this is done using option 3 EN-DC, where the uplink data is transmitted on the FDD-band using LTE. To optimize the coverage further, both NR uplink control and user data channels can be transmitted on the FDD-band. This can be done using either NR-NR Carrier Aggregation (CA) or Supplementary uplink (SUL). Both these techniques allow the uplink transmission to be switched between the FDD-band and the 3.5 GHz band. The key difference is that NR CA also provides NR on the FDD-band downlink, using 3GPP-specified LTE-NR spectrum sharing, if needed. This provides opportunity to aggregate NR bandwidth as well as better operation of the NR uplink. For early device chipset implementations, NR CA seems to be more widely supported than SUL.

Note: In general it is possible to use CA in conjunction with DC. That is CCs can be aggregated (in E-UTRA and/or NR) and then DC is applied.

2.3.2 LTE upgrade to support EN-DC (Option 3)

For a successful deployment of EN-DC the 4G network needs to support dual connectivity between E-UTRAN (LTE) and NR. This enhancement allows a device to consume radio resources provided by both 4G and 5G. Typically the 4G radio will be used to carry control signalling while NR and/or LTE will be used for user data. Three variants of the NSA solution have been defined each producing a different impact on the LTE network.

Option 3 uses the MN (Master Node) terminated MCG (Master Cell Group) bearer for signalling. There are a few variants for data bearer configuration within Option 3. The industry main-stream is to use an SN-terminated split bearer (sometimes referred to as “Option 3x”). This variant has low impact on EPC and enables data to route directly to the NR gNB to avoid excessive user plane load on the existing LTE eNB, which was designed for 4G LTE traffic load and not additional NR traffic load. As service continuity after loss of 5G radio coverage is more graceful in this variant, it also minimizes excessive signalling traffic between RAN and core.

2.3.3 Considerations in aligning maintenance of LTE sites

When existing LTE network is upgraded to EN-DC (dual connectivity between master eNB and secondary gNB), the maintenance of the LTE network may also be affected. While the maintenance window and downtime are left up to operator’s discretion, operators should be mindful of disruption in service for traditional 4G subscribers as well as 5G subscribers when maintaining LTE sites. That is, when a eNB is down due to maintenance, both 4G (standalone LTE) subscribers and 5G (EN-DC) subscribers will not be able to access the particular eNB.

In many commercial deployments, LTE networks will be overlaid on multiple bands and therefore will not significantly impact customer experience during downtime of a particular eNB. However, some degree of consideration must be taken into account to optimize 5G customer experience: aligning the downtime of master eNB and secondary gNB.

This issue may also be dependent on the physical implementation of the eNB and gNB functionalities at the cell site.

2.3.4 Supporting dynamic spectrum sharing

While there are many spectrum bands that are being allocated for 5G, the existing 4G spectrum bands are still an important asset of the operator. Dynamic Spectrum Sharing (DSS) is a technology that enables operators to use this important asset of 4G spectrum in providing 5G NR. The spectrum resource can be *dynamically* shared among 4G LTE and 5G NR, differentiating this technology from traditional spectrum refarming where 4G spectrum bands have to be completely cleared before it can be used for 5G NR.

With DSS, the spectrum can be dynamically allocated to 4G LTE and 5G NR such that the utilization of spectrum resources can be maximized. This also means that operators can avoid inefficient spectrum utilization for 5G NR during the initial deployment where there is low penetration of devices. As users of 5G NR increase, more spectrum resource can be allocated to 5G, leading to smooth introduction of 5G NR in an existing 4G network.

The costs in deploying DSS, however, may be a hurdle in adopting it. Deploying DSS is easy if the operator has an upgraded LTE infrastructure because it only requires software upgrade. On the other hand, if the operator has legacy LTE infrastructure, the infrastructure must be upgraded before

implementing software upgrade. In the latter case, the operator can decide to do a quick nationwide upgrade and NR deployment in its bands, or it can gradually upgrade its infrastructure and deploy NR with DSS in incremental geographical areas.

2.4 4G Core network updates

4G Core network updating considerations mainly include option 3/3a/3x networking comparison, 4G core network upgrade strategy, network function upgrading.

2.4.1 Option 3/3a/3x Networking Comparison

The standardised NSA EPC networking architecture includes Option 3, Option 3a, and Option 3x.

In the Option 3 networking mode, the X2 interface traffic between eNB and gNB has NSA user plane traffic. This traffic is huge. The core network needs to increase the bandwidth of the S1-U interface to meet the LTE/NSA transmission requirements.

In the Option 3a networking mode, there is only control plane traffic in the X2 interface. So the X2 traffic is very small.

In the Option 3x networking mode, there is a little LTE user plane traffic in the X2 interface.

From the perspective of the impact on the existing network, the Option 3x is relatively small and has become the mainstream choice for NSA networking. By using 4G as the anchor point of the control plane, it can meet good service continuity and support rapid network construction in the initial stage of 5G deployment.

Figure 5: NSA Option 3/3a/3x Networking Mode

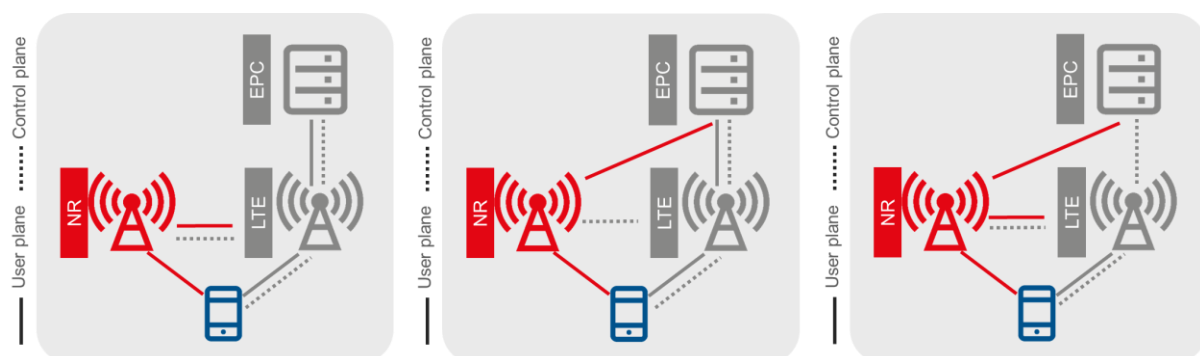


Table 1: Update requirement

NE	Upgrade Requirement
MME	<ul style="list-style-type: none"> • Support high bandwidth with extended QoS • Support 5G subscription access control (DCNR bit, Secondary RAT) • Support reporting Secondary RAT traffic • Support adding the DNS FQDN information with the NC-NR tag and querying the NSA S-GW information
DNS	<ul style="list-style-type: none"> • Match the DNS FQDN with the NC-NR tag and return the NSA S-GW information (no upgrade requirement)
SGW/PGW	<ul style="list-style-type: none"> • Support high bandwidth with extended QoS • • Support reporting Secondary RAT traffic
CG/OCS	<ul style="list-style-type: none"> • CDR supports high bandwidth with extended QoS field portability • CDR supports Secondary RAT field portability • CDR adds 5G traffic report Secondary RAT Usage Reports
HSS	<ul style="list-style-type: none"> • ARD access restriction data adds 5G NR access restriction • AMBR maximum guaranteed bandwidth adds the maximum uplink/downlink bandwidth • Extended-Max-Requested-BW-UL • Extended-Max-Requested-BW-DL
PCRF	<ul style="list-style-type: none"> • A new QoS extended bandwidth AVP is added to the Gx interface: • Extended-Max-Requested-BW-DL and Extended-Max-Requested-BW-UL AVP • Extended-GBR-DL and Extended-GBR-UL AVP • Extended-APN-AMBR-DL and Extended-APN-AMBR-UL AVP

2.4.2 Impact Analysis on 4G Core Network Elements

Dual Connectivity used for Master eNodeB to connect to Secondary eNodeB has been standardized in 4G network. NSA Option 3/3a/3x has adopted the 4G Dual Connectivity process.

The impact on 4G core network elements supports the NSA, which is shown in Table 1.

To support NSA, the 4G core network needs to do a small software upgrade to add or expand several parameters. There is no need to make any modifications to the hardware. The overall process including handover is not different from that of 4G network.

2.4.3 4G Core Network Upgrading Strategy

EPC types include physical EPC based on dedicated hardware and virtualized EPC based on COTS (Commercial Off The Shelf) hardware. There are two typical scenarios for EPC upgrade to support 5G deployment.

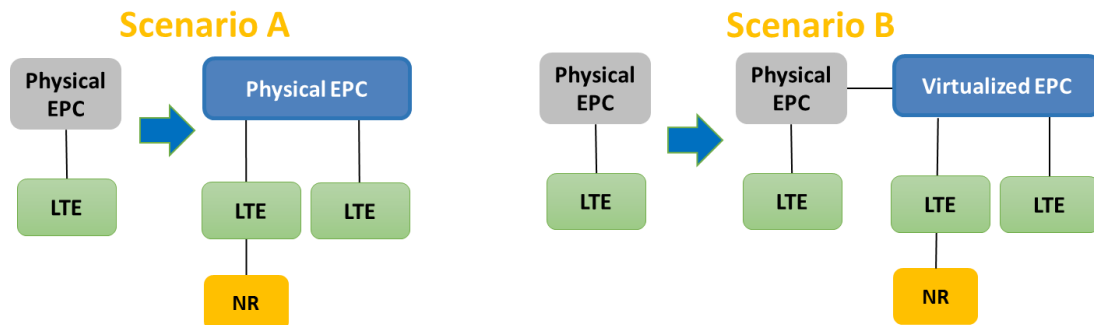
Scenario A:

- Physical EPC is upgraded to support NSA.
- Capacity expansion is based on physical EPC.

Scenario B:

- Build a new virtualized EPC network to support NSA independently.
- Interoperability is made between the new virtualized EPC and the physical EPC.
- Capacity expansion is based on the virtualized EPC

Figure 6: EPC Upgrading for NSA Deployment



Scenario A is the easiest way, but it has also brought a big drawback. When evolving to 5G SA, this physical EPC based on dedicated hardware cannot be used in a virtualized environment. This scenario depends on the capabilities of the existing network equipment vendors. Compared to scenario A, scenario B can be smoothly evolved to the target network through the expansion of virtualized EPC.

2.5 5G deployment

5G network deployment considerations mainly include target network planning, Massive MIMO order selection, coverage optimization especially in uplink, time slot synchronization configuration, NSA and SA strategy and network deployment steps.

ITU-defined 5G applications include three types: eMBB, mMTC and uRLLC. At the current stage, based on the 3GPP R15 standard, 5G network focuses on eMBB service, so 5G target network needs to meet the typical eMBB service experience requirements.

3GPP has defined the performance requirements for high data rates and traffic densities as the following table in 3GPP TS 22.261 [7], and 50Mbps at downlink is the basic requirement of eMBB service experience (see Table 2)

From a business perspective, 4K/8K video and VR are eMBB typical services. As shown in the following table, these services require a downlink throughput of 50 to 100 Mbps and an uplink rate of 3 to 5 Mbps (see Table 3).

For the 5G network deployment in early stage, downlink 100Mbps and uplink 5Mbps are required to meet the service experience requirements.

Table 2: Performance requirements for high data rates and traffic densities

Scenario	Experienced data rate (DL)	Experienced data rate (UL)	Area traffic capacity (DL)	Area traffic capacity (UL)	Overall user density
Urban	50 Mbps	25 Mbps	100 Gbps/km ²	50 Gbps/km ²	10 000/km ²
Rural	50 Mbps	25 Mbps	1 Gbps/km ²	500 Mbps/km ²	100/km ²
Indoor hotspot	1 Gbps	500 Mbps	15 Tbps/km ²	2 Tbps/km ²	250 000/km ²
Dense urban	300 Mbps	50 Mbps	750 Gbps/km ²	125 Gbps/km ²	25 000/km ²
High-speed vehicle	50 Mbps	25 Mbps	[100] Gbps/km ²	[50] Gbps/km ²	4 000/km ²

Table 3: Service requirements

Service	Resolution	2D	3D
Smart phone/ Surveillance	720P	~1.5Mbps	
	1080P	~4Mbps	
	2K	~10Mbps	
4K/ Basic VR/AR	4K	~25Mbps	~50Mbps
8K/Immersive VR/AR	8K	~50Mbps	~100Mbps

Source: Huawei

2.5.1 Massive MIMO Selection

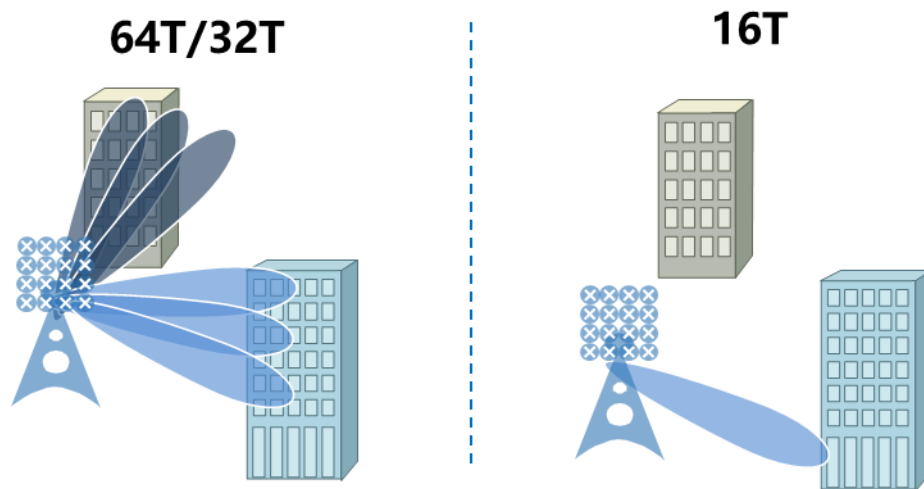
Massive MIMO can improve both coverage and capacity and is a key technical solution for 5G network. But the deployment of Massive MIMO requires three considerations including performance requirements, installation requirements, and TCO saving.

In the initial stage of 5G, from the perspective of coverage and capacity maximization, it is recommended that 5G and 4G co-site deployment to ensure continuous coverage and reduce infrastructure, planning and optimization costs.

Engineering constraint is also an important aspect to consider. In some scenarios, there are limits to the weight and volume of the Massive MIMO unit. For example, in South Korea, the engineering department requires AAU weight not to exceed 25kg, and the installation of equipment over 40kg requires the use of Crane in the Netherlands, which costs 1K Euro per 6 hours. In this scenario, 32T/16T are an options for deploying 5G networks.

In high-rise scenarios, 2D beamforming will provide benefits compared to 1D beamforming, see Figure 9, and therefore 64T or 32T may have performance advantages compared to 16T. In urban and suburban areas, the user spread in the vertical dimension is normally so small that vertical beamforming will not provide any substantial advantages. Therefore 16T will have similar performance as 64T or 32T in many such scenarios.

Figure 7: Comparison between 64T/32T and 16T



5G network deployment needs to fully consider performance, cost, space and weight limitation, etc. The most cost effective configuration, 64T, 32T or 16T may be different for different deployment scenarios due to the different performance benefits in the scenarios, respectively. 64T/32T tends to perform better in dense-urban high-rise scenarios and hence may be more cost efficient, whereas 32T or 16T tend to be more cost efficient in urban and suburban scenarios.

2T2R/4T4R/8T8R solution should be considered as a basic configuration for 5G deployment, deploying 16T16R/32T32R/64T64R to meet capacity requirements in those sites that need capacity upgrades and are heavy loaded.

2.5.2 Coverage Enhancement

C-band is the primary band for 5G network and it has the large bandwidth making it perfect for 5G eMBB services. Downlink coverage is better than uplink coverage on C-band spectrum due to the large downlink transmit power of the gNodeB and to disproportion in uplink and downlink timeslot allocations of NR. The application of technologies such as beamforming and cell-specific reference signal (CRS)-free reduces downlink interference and further increases the difference between C-band uplink and downlink coverage. As shown in Figure 8, taking the downlink 50Mbps and the uplink 5Mbps as an example, the C-band uplink and downlink coverage differs by 16.2dB.

The C-Band downlink can achieve the similar coverage as the LTE 1800MHz, but there is limitation in the uplink coverage and becomes 5G deployment bottleneck which will affect the user experience. As shown in Figure 9, the difference between C-Band and LTE 1800MHz uplink coverage is 7.6 dB for 2R and 10.4dB for 4R.

3GPP Release 15 introduces two mechanisms to handle the limited uplink coverage on the higher bands, namely NR Carrier Aggregation (CA) and supplementary uplink (SUL). The use of these mechanisms effectively utilize idle sub-3 GHz band resources, improve the uplink coverage of C-band, and enable the provisioning of 5G services in a wider area. Both solutions, NR CA and SUL, offer transport of UL user data using sub-3GHz band NR radio resources. NR CA provides the added benefit of also providing sub-3GHz DL user data support. Based on the SUL, the feature Uplink and Downlink Decoupling defines new paired spectrums, where C-band is used for the

downlink and a sub-3 GHz band (for example, 1.8 GHz) for the uplink, thereby improving uplink coverage. Figure 10 shows how UL and DL Decoupling works.

Field tests show that combining DL on C-band with UL on sub-3 GHz can improve both uplink and downlink experience by 6 times (see Figure 11).

Figure 8: Uplink and Downlink Coverage difference of C-Band

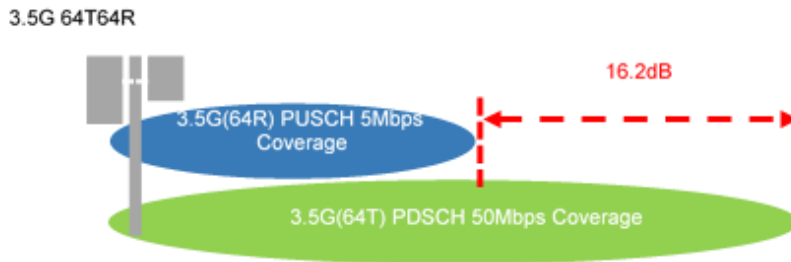


Figure 9: Uplink Coverage difference between C-Band and LTE 1800

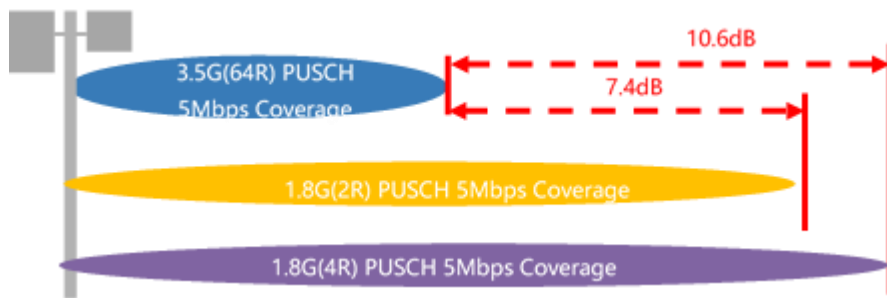


Figure 10/11: Combining DL on C-band with UL on sub-3 GHz band, Field Test Result

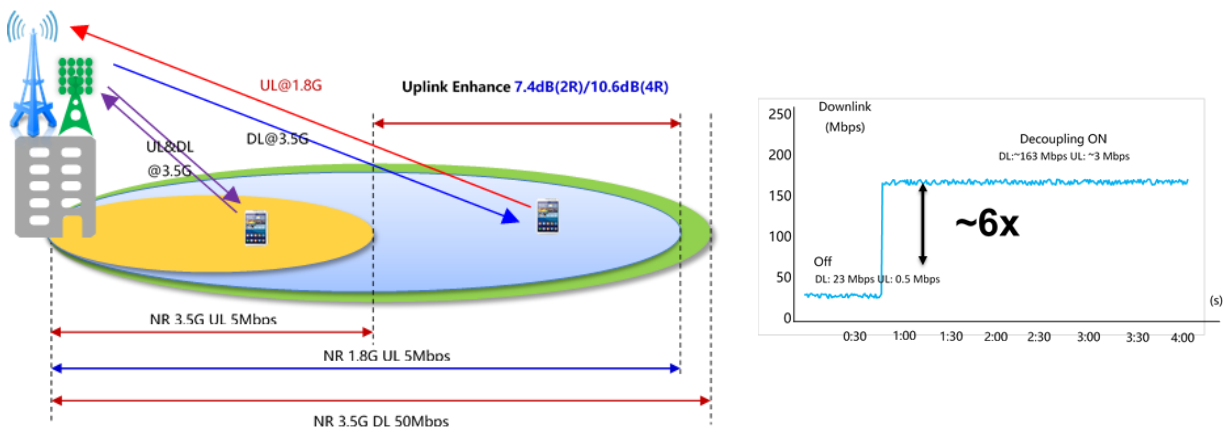


Figure 12: Interference and Guardband with non-synchronization time slot

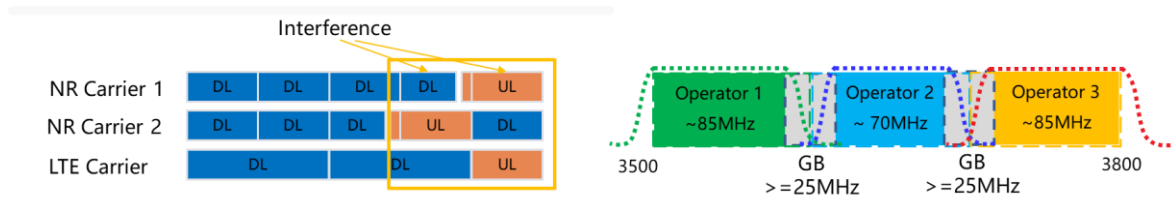
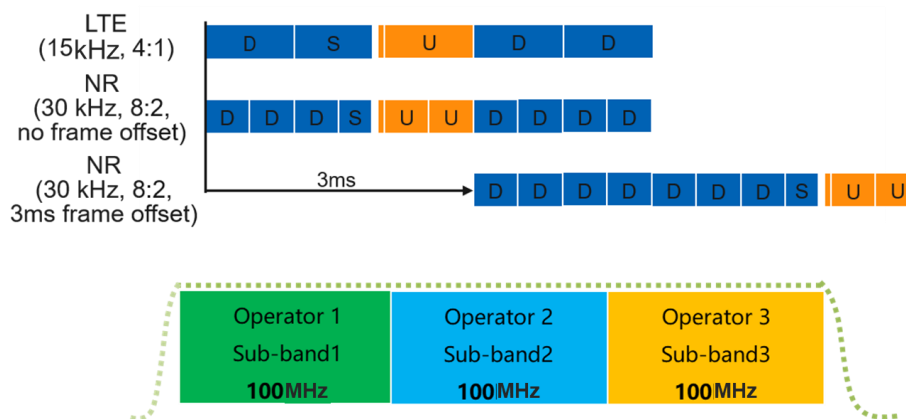


Figure 13: 4:1 and 8:2 time slot configuration



2.5.3 Synchronisation Configuration

The TDD system has the same TX/RX frequency bands, the TX signal of the asynchronous system directly interferes with RX frequency band. If 5G macro-cell networks are not synchronized, more than 25 MHz additional guard band together with additional transceiver filters would be required. Thus, synchronization of 5G network becomes the best way to avoid interference. In this way, efficient spectrum usage is ensured – no additional guard band is required – and network equipment cost can be reduced (see Figure 12).

For operators in the same country and region, it is recommended to use the unique synchronisation configuration in the adjacent frequency bands to avoid interference.

In the scenario without C-Band TDD LTE, a 3:1 or 4:1 configuration can be used. In the scenario with C-Band TDD LTE, two NR 8:2 configurations are possible to match existing TD-LTE network making spectrum fully utilized, one with the same frame start as LTE and the other with a frame start offset compared to LTE (see Figure 13).

2.5.4 NSA and SA Strategy

3GPP defines NSA and SA architectures and the two architectures have been concluded. Option 3x for NSA and Option 2 for SA has become an industry consensus.

SA is the target architecture, but the NSA ecosystem leads the SA for 6 months. The NSA can quickly deploy 5G network to support eMBB services and can be software upgraded to SA in the future. Key factors of NSA / SA architecture selection listed in Table 5.

A network that migrates from NSA to SA will typically support multiple Options simultaneously, by selecting the most suitable configuration for each device.

Figure 14: Option 3x for NSA and Option 2 for SA

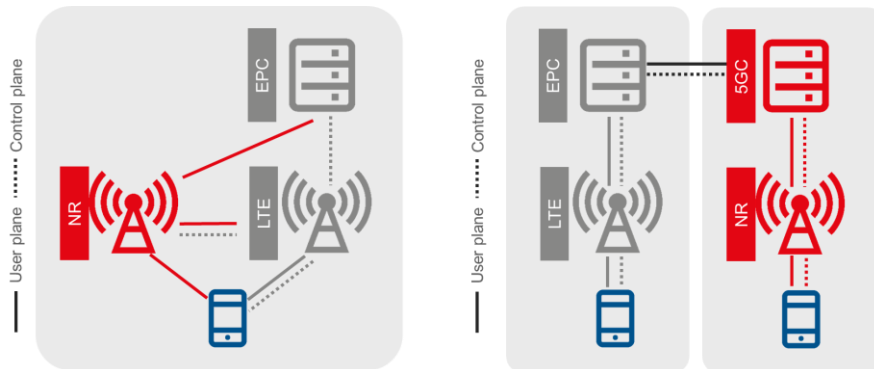


Table 5: Comparison between NSA Option 3 and SA Option 2

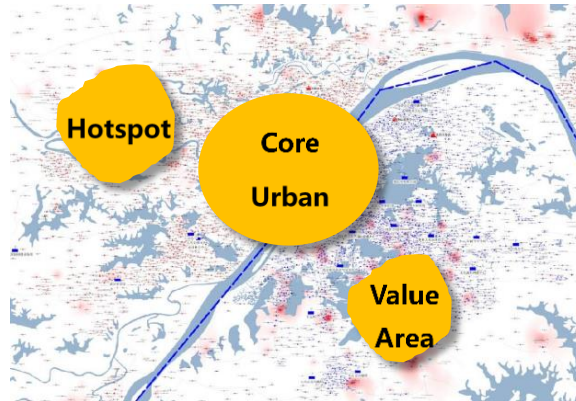
	Option 3x	Option 2
Standard	17Q4	18Q2
	Option3x support 5G initial fast deployment, Option 2 0.5~1year late	
Data Experience	Option 3x: Smooth mobility without a need for frequent inter RAT handover or inter RAT reselection (unless wide 5G coverage), better peak rate (unless LTE-NR spectrum sharing/reframing)	
Coverage	DC / NR-CA or DC / SUL	NR-CA (or SUL)
	EN-DC provides coverage and service continuity for NSA, NR-CA (and possibly SUL) optimizes coverage for both NSA & SA, and provides service continuity for SA	
Voice	VoLTE	EPS fallback (initially) or VoNR (target)
	Suitable solution with the experience at same level	
Service Readiness	eMBB	eMBB/uRLLC
Deployment complexity	DC	NR CA / LTE-NR spectrum sharing (SUL)
	NSA with mandatory DC needs LTE upgrade; SUL which extends SA Coverage need LTE upgrade, complexity at same level	
Relevance with existing LTE	DC	LTE-NR spectrum sharing, SUL / Refarming
	DC, SUL are both relevant to LTE; Coordination after Refarming Legacy LTE is important, NSA/SA are both closely relevant to legacy LTE.	

2.5.5 5G Network Deployment Strategy in initial stage

Compared with 4G, the capacity of 5G network is larger, which can greatly enhance the user experience. In addition, operators need to consider 5G network deployment from high value scenarios, users, and services to enhance brand and user experience. That means that operators will focus on core urban areas, hotspots, and high value areas to rapidly deploy 5G networks and provide services with traffic and brand demand.

- High-value scenarios and areas include CBD, universities, governments, hospitals, airports, subways, venues etc.
- High-value users include three type users: high package, high traffic volume and high value terminal.
- Besides eMBB services such as video and VR, operators focus on industry incubation, evaluate the earliest mature areas including connected drones, industrial internet, telemedicine and so on and work with innovative partners.

Figure 15: 3 Areas for Initial 5G Deployment



2.6 Transmission / backhaul

Fronthaul implementation is considered as a key element in order to manage mobile data growth, reduced latency required by 5G use cases and provide scalability in terms of RAN densification, micro cells deployment and future evolutions towards Cloud RAN.

Regarding interfaces to be adopted, eCPRI and O-RAN seem to be the main candidate for RRU and CU/DU connection for the 5G scenario, with a bandwidth granularity of 25 Gbit/s. Even though CPRI is currently proposed for 4G Fronthaul deployment, the aim should be to adopt a single interface, eCPRI, for both 4G and 5G networks with defined requirements in term of Jitter/latency.

It is still to be investigated the opportunity to deploy also Midhaul segment, e.g. by mean of aggregation rings between Distributed Unit (DU) and Centralized Unit (CU).

Given the fact that 5G networks are mainly based on TDD multiplexing, accurate Phase synchronization is mandatory. The implementation of a GPS receiver on each radio system represents a potential solution, even though this approach comes with high deployment cost and reliability or security issues. Another solution is based on PTP ITU profiles implementation in Partial Timing Support or Full Timing Support.

IPSec deployment in 5G transport network will have to consider potential Edge Computing implementation. In fact, the shift of Virtualized Functions at the edge of the network will imply to not use IPSec or terminate IPSec tunnels at Edge POP level.

2.6.1 Considerations in augmenting existing transmission networks

NSA Option 3 is where existing LTE network is upgraded to EN-DC connected to EPC. This means that there is likely to be additional data load and requirement (e.g., latency and synchronisation), because the gNBs will need to accommodate some traffic and the requirement will become more stringent depending on the amount of traffic handled by gNB. This needs to be addressed by the existing transport network that have been dimensioned for 4G use cases and requirements, requiring augmentation of the transport network.

In this case, the operator may choose to adopt new and/or expand transport network. An alternative in expanding transport network is described in Table 6 for information (Source: Mobile Backhaul Options, GSMA).

Table 6: Comparison of backhaul technology alternatives

Segment	Microwave (7-40GHz)	V-Band (60GHz)	E-Band (70/80GHz)	Fiber-Optic	Satellite
Bandwidth availability	Medium	High	High	High	Low
Deployment cost	Low	Low	Low	Medium	High
Support for Mesh/Ring Topology	Yes	Yes	Yes	Yes where available	Yes
Interference immunity	Medium	High	High	Very high	Medium
Range (km)	5-30	>1	<3	<80	Unlimited
Time to deploy	Weeks	Days	Days	Months	Months
License requirement	Yes	Light license /unlicensed	Light license /unlicensed	No	No

2.7 Devices

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

A device that needs to work within a Network implementing NSA option, it shall support all protocols requested by NSA implementation and could support all protocols requested by SA implementation.

A device that needs to work within a Network implementing SA option, it shall support all protocols requested by SA implementation and could support all protocols requested by NSA implementation.

As true for Network deployment also for device deployment the support to the NSA option, with the eNBs (eNode Bs) as the master node, could be faster than the whole SA deployment.

The above NSA option permits to the devices to avoid supporting also 5G core network protocols at first stage.

While for Network deployment supporting SA options the device needs to support whole 5G core network protocols with higher deployment cost and time.

Based on the experience for 3G and 4G technologies also for 5G technologies we expect progressive deployment and support of whole 5G functionalities in order to find a way to average the time-to-market with the new services support.

Same approach is valid for devices also when we consider the support to the different frequency bands.

On one side the support to the sub-6GHz band can create affordable challenge to the device manufacturers permitting a faster time-to-market; on the other side this band is not optimised for new 5G use cases except the mobile broadband.

Instead the so called mmWave bands are the optimised bands to support the whole 5G services and use cases; but due to the very fast attenuation of the radio signal and the difficulties to manage so high frequencies their support can create big challenges to device manufacturers requesting more time and higher cost compared with only Sub6GHz support.

Based on above aspects the test-set related to the 5G devices should be customized based on device functionalities support, considering different sub-set related to NSA, SA, Sub6GHz, mmWave, VoNR.

2.8 Network Sharing

Mobile networks operate on a network infrastructure, which is not only limited to electronic components, but also includes passive elements such as physical sites and towers that are required to operate network. As network have been densified from previous generations to 4G, sharing of network infrastructure is becoming more popular. This is expected to continue in the 5G era where networks will be densified even more. Network sharing comes in many forms, but it is mostly classified according to the technological components that are being shared (see Figure 16).

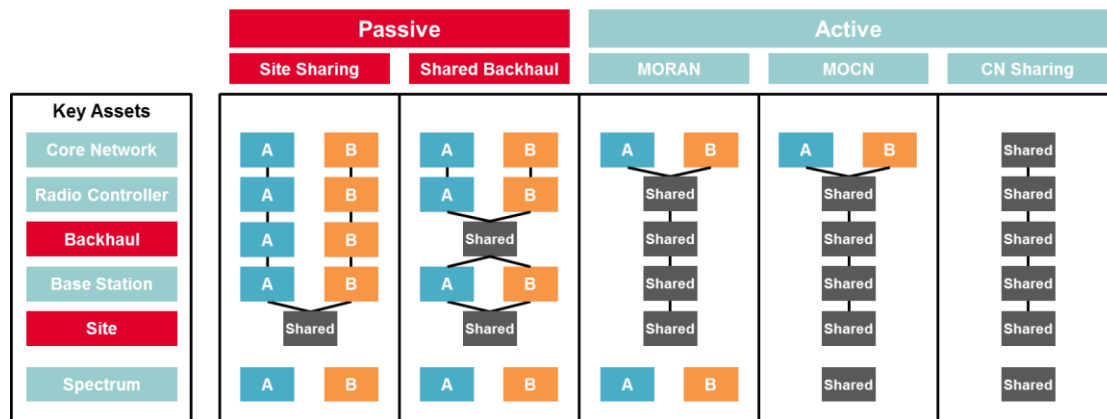
Passive infrastructure sharing is where non-electronic infrastructure at a cell site, such as power supply and management system, and physical elements such backhaul transport networks are shared. This form can be further classified into site sharing, where physical sites of base stations are shared, and shared backhaul, where transport networks from radio controller to base stations are shared.

Active infrastructure sharing is sharing of electronic infrastructure of the network including radio access network (consists of antennas/transceivers, base station, backhaul networks and controllers) and core network (servers and core network functionalities). This form can be further classified into MORAN (Multi-Operator Radio Access Network), where radio access networks is shared and dedicated spectrum is used by each sharing operator, MOCN (Multi-Operator Core Network), where radio access networks and spectrum are shared, and core network sharing, where servers and core network functionalities are shared.

Note that passive infrastructure sharing is the simplest and can be implemented per sites, which enables operators to easily share sites and maintain their strategic competitiveness depending on the sites shared. Operation is also easier with this form of sharing because network equipment remains separated. However, the cost saving potential of sharing is limited relative to other forms of sharing.

MORAN and MOCN enables greater cost sharing potential than passive sharing, and they can be implemented per sites and enables strategic differentiation. However, operation of network equipment needs to be shared (or at least issues must be shared with participants) and therefore increases the complexity of sharing relative to site sharing. Core network is complicated to operate and to maintain strategic differentiation. It is important to note that core network sharing has not been popular and only few cases have been suspected to be so.

Figure 16: Classification of network infrastructure sharing



2.8.1 Benefits of Sharing

BEREC [2] published a document where the following benefits are listed:

- Cost Savings benefits:
 - passive sharing cost savings: [16%-35%] CAPEX, [16%-35%] OPEX;
 - active sharing (excl. spectrum) cost savings: [33%-35%] CAPEX, [25%-33%] OPEX;
 - active sharing (incl. spectrum) cost savings: [33%-45%] CAPEX, [30%-33%] OPEX;
 - core network sharing: core network sharing cost savings are limited.
- Environmental benefits – reduces energy consumption, mitigate citizens' concern over radiation
- Customer experience – sharing can lead to better quality of the services, better coverage, higher data speed.
- Coverage obligation can be met

The reduced cost can be diverted to other services and innovation, maximizing the potential of the capital resources of the mobile operator. Furthermore, network infrastructure sharing resolves difficulties in acquiring sites for the access network, where sharing operators can jointly cooperate to acquire sites. Consequently, the cost of 5G deployment can be reduced with sharing of costs/difficulties associated with sites. The technical enablers in the 5G era such as SDN (Software Defined Networking) and NFV (Network Function Virtualization) also makes the network more accommodating to the network infrastructure sharing.

2.8.2 Obligations and challenges

Network infrastructure sharing may lead to hindrance in competition among mobile network operators. When the network infrastructure is shared, it is inherently difficult to differentiate or corroborate own network infrastructure to compete against the sharing partners. Whilst it is possible to compete on the basis of services, the regulatory obligation of mobile networks tends to focus on the network connectivity and consequently the infrastructure. This concern can be minimized if the sharing is limited to the scope of passive infrastructure. As active components can be differentiated while optimising the cost of passive infrastructure, competition among sharing operators can still be active.

Furthermore, it is very challenging to consolidate existing network infrastructure to share. An existing network is a result of planning and operations phases based on specific operator requirements, and consolidating existing networks is likely to be difficult if any of the requirements conflict. As NSA option 3 leverages existing LTE network infrastructure, it may also be challenging to implement network infrastructure sharing, unless it is limited to new NR base stations. The sharing of network infrastructure may be more feasible with SA option 2, where both radio access and core networks will be newly deployed, given that the operators will collaborate from the planning phase.

2.9 Testing

In deploying NSA 5G network, the items in Table 7 need to be tested to ensure reliable and functional 5G network.

2.10 Features

NSA Option 3 5G networks provide the features as described in Table 8.

Table 7: Test items for NSA Deployments (Option 3)

Content	Item	Function
LTE/NR DC	LTE/NR Interface	To test X2 interface
	MN terminated MCG Bearer	To test MN terminated MCG bearer functionality
	SN terminated SCG Bearer	To test SN terminated SCG bearer functionality
	MN terminated split Bearer	To test MN terminated split bearer functionality
	SN terminated split Bearer	To test SN terminated split bearer functionality
LTE/NR DC mobility management	SN Addition	To test SgNB addition functionality
	SN Re-configuration	To test SgNB re-configuration functionality
	LTE/NR DC Handover	To test LTE/NR DC handover functionality
Data split algorithm	DL Data Split Algorithm	To test DL data split algorithm
	UL Data Split Algorithm	To test UL data split algorithm
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	SU-MIMO DL	To test SU-MIMO DL functionality (2 steams)
	MU-MIMO DL	To test MU-MIMO DL functionality (16/24 steams)
	MU-MIMO UL	To test MU-MIMO UL functionality (8/16 steams)

Table 8: Features supported by NSA Deployments (Option 3)

Content	Item
NSA Network Architectures	Option 3/3a/3x
Connection Management	System Information Broadcasting
	Synchronization
	Random Access Procedure
	Radio Access Bearer Management
	Interface Management (S1-U/X2/Xn/F1)
Mobility Management	SN Change Procedure in NSA
	Intra-MN Hand Over without SN Change in NSA
	Intra-MN Hand Over with SN Add/Release/Change in NSA
	Inter-MN Hand Over without SN Change in NSA
Radio Resource Management	Radio Admission Control
	Congestion Control
	Load Control
QoS Management	MBR/AMBR
	MBR for non-GBR services
	Legacy Standard QCI
User Plane Process	MAC PDU and Functions
	RLC PDU and Functions
	PDCP PDU and Functions
	Robust Header Compression (RoHC)
RAN Split and Cloud RAN	eCPRI
	Integrated Management and Control
	Network Function Virtualization
Radio Part	Basic Physical Layer Support
	SC-OFDM
	Basic Modulation Schemes (BPSK/QPSK/16QAM/64QAM/256QAM)
	Subcarrier Spacing(15/30/60/120KHz)
	PRACH with Long/Short Sequence
	Long PUCCH/Short PUCCH
	Slot Format Configuration
	Dynamic Scheduling
UL/DL HARQ	

2.11 Migration to virtualized network/Network Transformation [12]

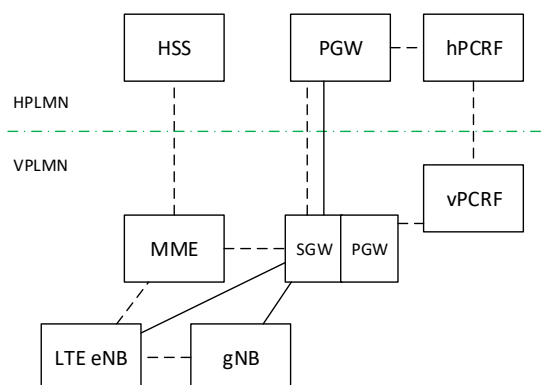
5G core networks will be designed with the assumption that the network will be fully virtualized and cloud native. In addition, 3GPP has standardized CUPS technology that decouples control and user plane of the 4G core network. This means that the operators would need to consider stable migration from their legacy 4G network consisting of proprietary equipment to a virtualized network.

In addition to transitioning to the new paradigm of core networks in 5G, virtualized networks possess promising advantages in terms of costs, time to market and fostering service innovation. Before adopting fully virtualized network of 5G core network, operators can familiarize themselves with the new paradigm by migrating their legacy 4G networks to a virtual one. However, the migration to virtual network is not free from hurdles and needs careful considerations.

GSMA Future Networks Programme conducted [case studies of leading operators that have virtualized their 4G core networks and IMS \(IP Multimedia Subsystem\)](#). These leading operators all point out that there are many challenges and risks in migrating a legacy network to a fully virtualized network. First, ensuring carrier grade SLA (Service Level Agreement) on IT platform is a great challenge, for example five 9s availability. This also leads to potential lock-in to specific IT vendors as only few vendors would be able to provide telco-grade solutions. There is also challenge in enlarged base of stakeholders and resulting integration of products. Finally, the cost can increase if VNF (Virtual Network Function) and VI (Virtualized Infrastructure) managers are proprietary.

Fortunately, the experience of the operators can help other mobile operators in the migration journey to fully virtualized network. In initial stages of virtualisation, single vendor approach may have advantages as it avoids complicated troubleshooting and cross layer fault detection. Such integration savings can also be realised lowering the Total Cost of Ownership. Second, an end-to-end design of the network can help achieve the telco-grade quality as industry standards for virtualised components are generally below telco-grade and hence end-to-end approach helps to overcome it. Third, the operator organisation needs to reflect the shift in operations and management paradigm associated with virtualized network, as the current organization fit for legacy operations and management would not be appropriate. In relation to this point, operators may benefit from becoming integrators of the equipment used in their networks and train staff accordingly, as virtualized network is analogous to an integrated system for specific purposes.

Figure 17: Roaming architecture



2.12 Roaming

5G NSA Option 3 will not introduce any changes to the existing roaming architecture and procedures. It is up to the VPLMN operator to allow inbound roamers to use 5GS NSA Option 3 or to only allow SA/LTE (Option 1).

2.13 Services (IMS – Voice)

One of the important aspects of migration to 5G is the support of voice and related services (e.g. SMS, conversational video). In what follows, however, the focus will be on IMS based services for voice via 3GPP based 5G access network. Non-IMS based voice is out of scope here. Note that the reasoning for IMS based voice (“VoIMS”) can apply for IMS based SMS (“SMSoIP”) and IMS based conversational video (“VoIMS”). VoIMS refers here to the generic IMS based voice solution; it includes the support of IMS based Emergency Services. VoIMS support over WLAN (“VoWiFi”) and its interworking with VoIMS over 5G access is also out of scope.

The initial configuration corresponds to the use of VoIMS over LTE / EPC (“VoLTE” per IR.92 [1]). It refers to the usage over legacy LTE system (EPS) - so called 3GPP architectural SA/LTE (“Option 1”) - which can also be used by NSA/EN-DC (“Option 3”) (see Figure 18).

2.13.1 Roaming with VoIMS

Roaming support for VoIMS is an important feature and is essentially based on IMS Roaming in a 4G or 5G environment. The principle of IMS and in particular VoIMS roaming in a 4G environment has been defined in IR.65 [3].

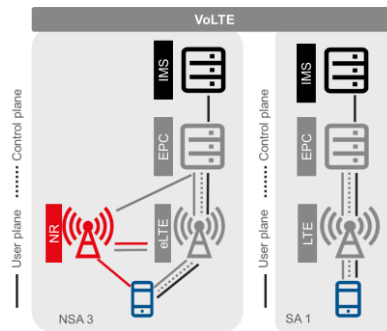
The Home Routed solution is usually the path for data / Internet roaming (e.g. for 3G and 4G) but has been used in 4G for (Vo)IMS roaming because it offers a quicker and easier deployment solution independent of the VPMN despite some constraints and additional standardisation effort that was required (e.g. for Lawful Interception).

2.14 Outlook

The document will be open for contributions/suggestions and will keep evolving to provide support for more deployment options and considerations. Currently, the following topics are planned for further development.

Please contact futurenetworks@gsma.com if you would like to contribute or suggest topic to be covered by this document.

Figure 18: VoIMS variants in options 1 and 3



NOTE: The use of terminologies such as "VoLTE" is an informative suggestion only and does not preclude other or more appropriate naming proposed / agreed by GSMA

Annex A Document Management

A.1 Document History

Version	Date	Brief Description of Change	Approval Authority	Editor / Company
0.1	16-Oct-2018	CR001 incorporated	5GNSA	Sandra Ondrusova / CK Hutchison
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Reviewed & Approved by	5GPCG
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Your comments or suggestions & questions are always welcome.