4G and 5G Migration and Interworking Strategy

Version No.: 0.2
August 19, 2020
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1 ABSTRACT

5G technology enables mobile operators globally to offer new capabilities not just to traditional mobiles subscriber but different segments such as enterprise services, industry verticals etc. 5G cab be deployed either as greenfield or brownfield by upgrading and interworking with existing 3G/4G etc . By leveraging interworking functions, operators can leverage or transform their existing infrastructures to optimize total cost of ownership. The main goal of this paper is to provide system architecture and methods for interworking and migration between 4G and 5G mobile technologies.

Mobile providers are looking for strategies to introduce 5G seamlessly and enhance their overall service offering with new capabilities. Some key strategic considerations includes, their ability leverage existing packet core and integrate new 5G radio without overloading existing network, leverage network slicing for enterprise, industry verticals, heterogeneous network with indoor WiFi, Smallcell, outdoor macro cellular, enable 5G devices with new applications and enhanced quality of service etc.

This paper start with interworking strategy and goes deepdive into design considerations, and possible solutions. In summary, mobile provider should define their own transformation journey towards 5G because it start with existing 3G/4G network, subscribers, existing services, marketing plans with new business use cases they plan to offer. We have developed this paper based on our experience and industry best practices with practical tips.

2 INTRODUCTION

Majority of mobile operators globally are deploying 5G technology as an overlay on exiting 3G/4G, therefore the migration and interworking strategy is most crucial. Mobile operators should consider optimized total cost of ownership because this will impact their top and bottom-line in long run. 5G technology has brough revolution in the way how services are designed, build and operated using new capabilities such as end-to-end lifecycle automation and self-driving networks.

5G deployment strategies should include re-use or transform existing network to the possible extent, 5G business use cases for consumers and enterprise, 5G user equipment (UE) availability, marketing plans, etc. In [1], authors cover the migration phase and concentrate on the impact on Radio Access Network (RAN) due to transition from 4G to 5G.

In this paper, we discuss different aspects of core network transformation required to upgrade and introduce new elements to support 5G technology. We start with “4G and 5G interworking architecture” at high level where we explain different network functions required between these two technologies. In next section we cover “5G design considerations for two options of deploying 5G using either Non standalone (NSA), Standalone (SA) network. This is followed with deep-dive discussions on different options for migration from 4G to 5G, with considerations for possible migration paths such as 4G to 5G NSA, 4G to 5G SA, and 4G to 5G NSA to 5G SA etc.

For brownfield deployments feasible options is migration from 4G to 5G NSA because this this requires minimum changes in core network and provide ability to connect 5G new radio (5G NR). We also discuss in details about impact on 4G network elements, including network slicing technology implementation using UE Usage Type (UUT) and its mapping to the slice table is discussed in detail.

Automation is most crucial for 5G however it is not an easy to automate everything because of numerous reasons. We describe high level 5G automation architecture however actual implementation depends on "automation maturity" and desired outcome.

3 4G -5G INTERWORKING ARCHITECTURE:

Through our work with several mobile providers, we learned that majority of 5G deployments will be brownfield with upgrade from existing 3G/4G network. For mobile providers deploying 5G as greenfield new network, it has to interwork with 4G for roaming with other providers in same country or international roaming. Figure 1 provides a high-level overview of 4G and 5G network. For clarity all 4G network functions (NF) are on left side (in blue) and 5G network functions are on right side (in red).

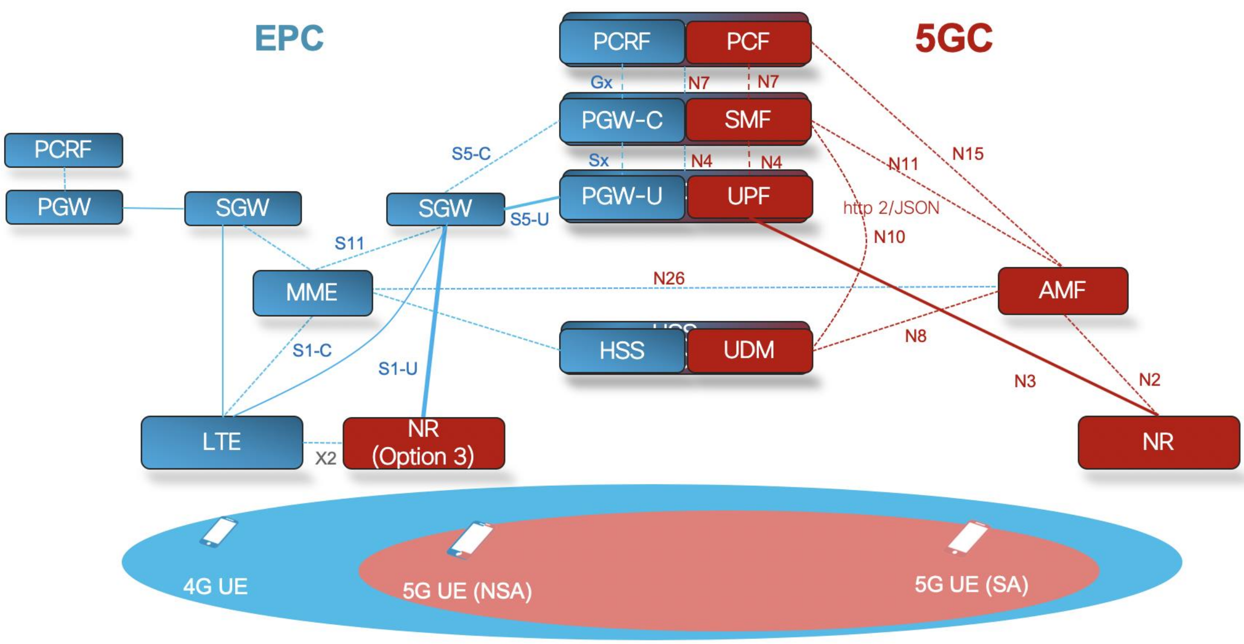

Figure 1: 4G-5G interworking Architecture

5G network description can be overwhelming and confusing therefore we have depicted very simplified version of interworking architecture with explanation from top-down. Technical readers can go through 5G system architecture [2] for more details.

- 5G technology is not about higher bandwidth but capability with differentiated services and quality of experience (QoE). In 5G subscriber services are managed by policy control function (PCF) therefore we need seamless user experience by managing, notifying and ability to charge differently for 5G network usage.
- 5G system network architecture is divided into control and user plane separation because they can scale independently. 5G subscribers are terminated in session management function (SMF). SMF manage

subscribers from the time the attach to network with power on to power-off or detach from network.

- 5G provider much higher bandwidth to subscribers along with low latency services support, therefore user plane function (UPF) are normally deployed at edge. You might hear about Mobile Edge Computing (MEC) or xEdge which normally contains UPF along with low latency applications deployed at edge. Since UPF handles large bandwidth and diverse set of users therefore bulk of traffic of offloaded at edge.
- When subscriber power-on their devices they go thru signaling phase they challenged and authenticated with proper credentials. In 4G entire signaling is handled by mobility management function 9MME) and in 5G this is handled by Access Management Function (AMF). In order to support interworking between 4G and 5G, we use interface which is referred as N26 [3].
- For 4G mobile, subscription information is stored in Home Subscriber System (HSS) whereas for 5G it is stored in universal data system (UDM). We need interworking between both HSS and UDM so that subscription related information is matched between 4G and 5G.
- The biggest change for any technology is at edge and 5G is no exception. New radio (NR) as name suggest provides capability and allow subscribers to use 5G network. We also have existing 3G and 4G radio at edge therefore we must have design considerations to avoid interference and handover mechanism so that user can avail any service available based on their device capabilities and subscription. 5G Non stand Alone (NSA) provide ability where 5G new radio sites can connect to existing 4G Core (4GC). 5G standalone (SA) provides capability where 5G new radio can connect only to 5G Core (5GC) as depicted above.
- When 4G was deployed, virtualization technology was not mature, so it was initially deployed on standalone physical devices and then transitioned into standardized ETSI Management and Orchestration (MANO) based virtualized network function (VNF) architecture on private/public cloud. 5G network functions are deployed as micro-services on cloud native, container-based clusters e.g. Kubernetes. To summarize, there is a difference between 4G and 5G network functions and the underlying cloud technologies. Also, the standards definition for 5G interworking with legacy 2G/3G technologies is in progress.

4 5G DEPLOYMENT CONSIDERATIONS

The transition from 4G to 5G is a significant step for many operators as it impacts and disrupts many areas and each of these areas need to be planned and transitioned carefully to be able to reap the potentials that 5G technology offers. Figure 1 represents a very high-level architecture for a 5G deployment with the 5G network elements.

As shown, the 5G architecture [2] [3] [4] is very different from the existing 4G architecture and requires readiness on multiple aspects listed below:

DATA CENTER AND CLOUD INFRASTRUCTURE: 5G network is typically deployed in cloud native function (CNF) therefore we need major forklift to existing datacenter or interworking between new and old infrastructures. 5G is also deployed with distributed data center approach, wherein there are a few central data centers hosting many core and signaling network functions, multiple regional data centers hosting Multi-access Edge Computing (MEC) nodes having a few hosted applications. Additionally, there can also be many smaller data centers (e.g., far edge centers) hosting the distributed RAN nodes. Datacenter and cloud infrastructure can be either private, hybrid or some form of public hosted cloud provided it meet service assurance, quality and security requirements.

VIRTUALIZED RADIO NETWORK: 5G radio is also virtualized and dis-aggregated at edge with typical cellsite is only antenna, Radio Unit (RU) and an interface function with ethernet capability. Low level radio processing is done by virtualized digital unit (vDU) and this can be deployed either at cellsite or at edge datacenter. There is industry trend to deploy vDU with layer-3 routing function at cellsite to facilitate heavy processing signaling. Clocking requirements between RU and DU is very stringent therefore it vDU is deployed at cellsite this will help in faster processing and also reduced capacity for fronthaul. Also when vDU is deployed at cellsite, we can leverage IP network to connect edge-datacenter where virtual control unit (vCU) can be deployed.

5G XHAUL TRANSPORT: 5G xHaul is divided into three parts front-haul (segment between cellsite and edge datacenter), Midhaul (segment between edge datacenter and regional datacenter) and IP core (providing connectivity between datacenters, internet edge and partner connectivities). Unlike previous mobile technologies clocking and synchronization is very stringent and crucial for fronthaul and Midhaul design. 5G xHaul should designed to support resilient routing. Number of cellsite and network function are huge therefore xHaul should be design with preferably either IPv6 or dual stack (IPv4v6) with long term goals of migrating to native IPv6.

5G CORE (5GC): 5G core is micro-services based architecture deployed on cloud-native infrastructures. It is very different how micro-services are deployed and managed. 5G microservices connect with each other using new interface called Service-based Interfaces (SBI) using REST API. We also need service communication proxy (SCP) and load balancers to manage resiliency to failovers.

Optimal slice selection during UE mobility towards 4G and NSA**:** 4G and 5G technologies will coexist for foreseeable future with 5G radio coverage in host-spots and densely populated area. This might require frequent handover between 4G and 5G at edge, however we can leverage network slicing technology and terminate subscriber in such as way that session continuity is maintained without frequent relocation of subscriber session. Network slicing can optimize cost and provide a preferred Quality of Service (QoS) for different class of subscribers. We can leverage an appropriate slice and node selection to ensure seamless connectivity for users in the overlapping coverage regions for NSA, SA, and 4G networks.

Roaming partner N26 interface**:** For green field 5G deployment, mobile operators shall deploy new network however they have to inter-work with 4G networks. Sometime roaming partner networks (domestic roaming partners) may support N26 interface and sometimes there might be no N26 support on the roaming network / support for N26 interface but with compatibility issues that can impact the seamless mobility between 5G home network and a roamer network. It is important for the home network to plan roaming for different services offered accordingly. In the first wave of 5G SA deployment most of the operators might not have the voice over new radio (VoNR) deployed in the home network and will rely on the EPS fallback procedure to provide support for Voice services. In such cases, if the roaming partner does not support N26 interface especially in the case of domestic roaming, the EPS fallback procedure may not be possible. Radio planning in such cases should ensure that for such scenario's the 5GSA coverage for their home network does not overlap directly with the 4G coverage of a roaming partner network and instead have a EPS fallback possibility within the home network 4G coverage.

UE APN/DNN M**APPING**: Most of the operators transitioning from 4G to 5G plan their device transitioning also incrementally wherein the firmware upgrades to their consumer handsets are incrementally upgraded from 4G→5GNSA→5GSA. This leads to a complex scenario wherein the network needs to handle not only different types of handsets but also with different Access Point Names (APN) being used by these handsets. The node selection algorithms in the 4G as well as 5GNSA network will need enhancements to accommodate the different combinations of UE subscriptions, APN's used and the UE capabilities to ensure optimized mapping. Table1 describes the various combinations of these parameters and the required enhancement to the node selection logic.

5 MIGRATION STRATEGIES FROM 4G TO 5G

5.1 TRANSITIONING FROM 4G TO 5G

The transition from 4G (Option1) [2] to 5G (Option 2) [2] can be a multi-step process with various intermediate steps. Some of the most popular transitions adapted by most of the service providers are:

- $Option1LTE \rightarrow Option7xNSA \rightarrow Option2SA$
- $Option1LTE \rightarrow Option3xNSA \rightarrow Option2SA$
- $Option1LTE \rightarrow Option4NSA \rightarrow Option2SA$

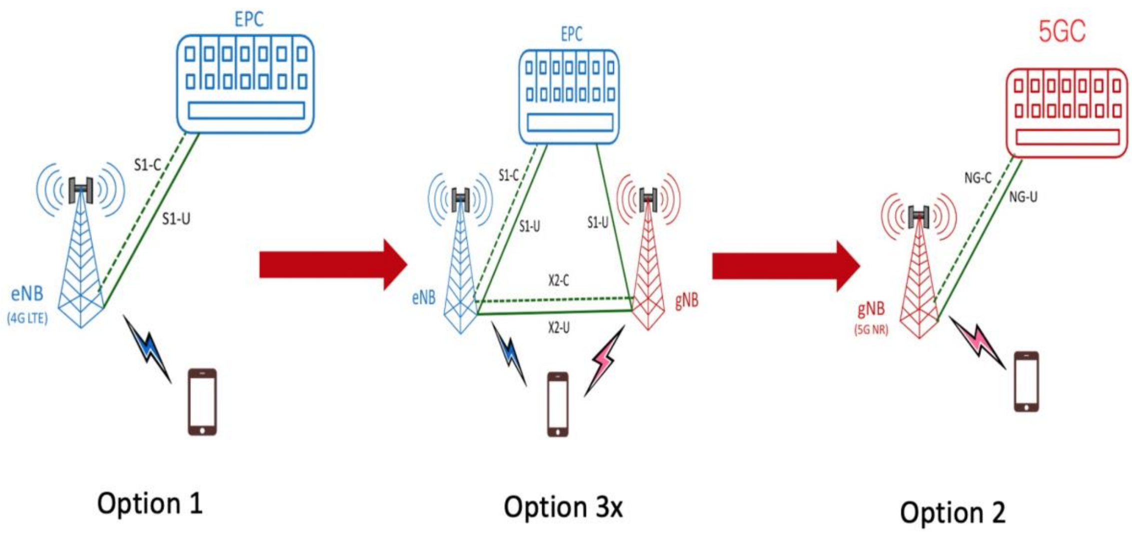

Figure 2: 4G to 5G Migration Path

Figure 2 shows the transition (for $Option1LTE \rightarrow Option3xNSA \rightarrow Option2SA$) where the radio network is first upgraded, wherein NR (new radio) gNB is connected to the existing 4G core to provide higher speeds for 5G capable UEs. The core network is then upgraded to connect the gNB to the 5G core and the 4G coverage is slowly phased out.

5.2 5G READINESS OPTIONS

Operators have many approaches prepare 4G, 5G interworking

NON-DISRUPTIVE APPROACH: In this approach (adapted by a major operator in the North American region), the transition from 4G to 5G is planned in a manner where the existing 4G infrastructure is not disrupted immediately but 5G radio and core network nodes are added alongside 4G as standalone units to provide 5G coverage and service in specific regions. By doing so, the operator can provide 5G service very quickly to the end users (i.e., limited to enhanced Mobile Broadband (eMBB) use case). In such a network, to provide complex use cases, such as support for multiple slices and implementation of MEC use cases, there is a need to plan and realize the distributed data center, IP core enhancements, automation readiness, and virtualized and distributed radio network readiness.

GREENFIELD APPROACH: Another radical deployment approach (as adopted by a major greenfield operator in the Asia Pacific region) considers the data centers readiness, IP backbone readiness, and automation readiness for 5G as a part of the initial 4G deployment plan. All the network components including the radio network elements are virtualized using automated deployment and distributed across different data centers during the 4G deployment phase. The transition to 5G for such operators is easier and more efficient as the infrastructure is readily available to handle multiple slices, MEC use cases, and other 5G use cases. Also, monitoring, troubleshooting, and Life Cycle Management (LCM) systems in such cases can be built faster.

5.3 UE Mobility Network Selection from 4G to 5G

5G core with slice-based design and architecture provides a flexible, user's slice subscription-based choice of the core network elements and the application mapping to the user requested slice during PDU establishment phase.

This mechanism ensures that the desired Quality of Experience (QoE) for the Packet Data Unit (PDU) session is met and the network elements are planned and utilized efficiently based on the type of application used by the user. In the 4G network, when UE executes an initial attach to the Evolved Packet Core (EPC), UE and MME are not aware of the slicing concept and cannot select a proper Network (e.g., EPC or 5GC) and the network slice. This can prevent a 5G capable UE to seamlessly handover from 4G to 5G network as shown in figure 3.

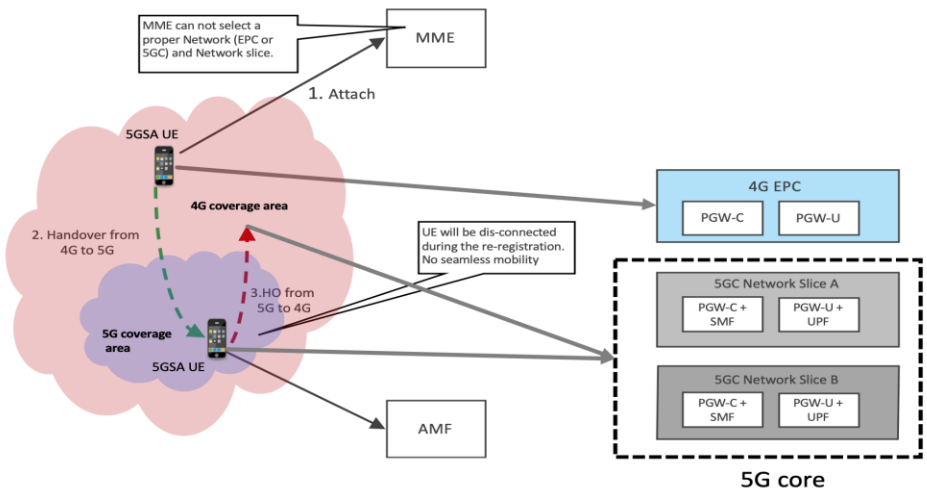

Figure 3: Standard Design for Network Slice Selection

A specific mechanism to select the proper network (e.g., EPC or 5GC) and the correct network slice based on the UE's slice subscription and application mapping is required. MME need to select a proper network slice when the 5G UE is in a 4G network coverage area, as shown in figure 4.

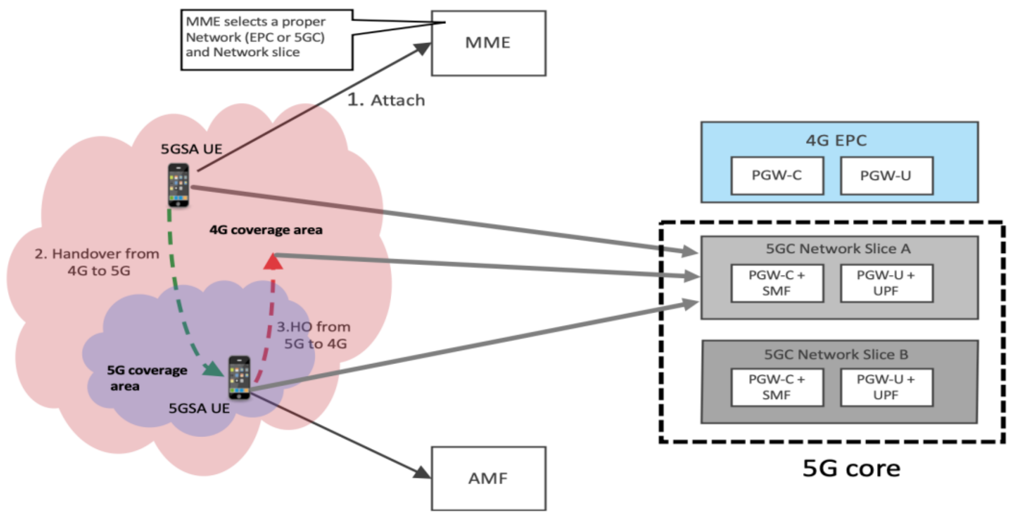

Figure 4: Reference Design for Network Slice Selection

5.4 5G NSA UE Traffic Offloading

Before the deployment of 5GC, the EPC would serve 4G UE and 5G (NSA) UE. However, considering the 5GC will have 5GC SMF/ UPF as well as EPC PGW features (i.e., PGW-c and PGW-u), it is important to design the 5GC in a manner that it provides operators with the flexibility to plan the traffic offloading of NSA UEs based on the capacity and load status on the EPC node. In the standard NSA deployment, 5G NSA traffic is typically routed to the 4G EPC core as shown in figure 5.

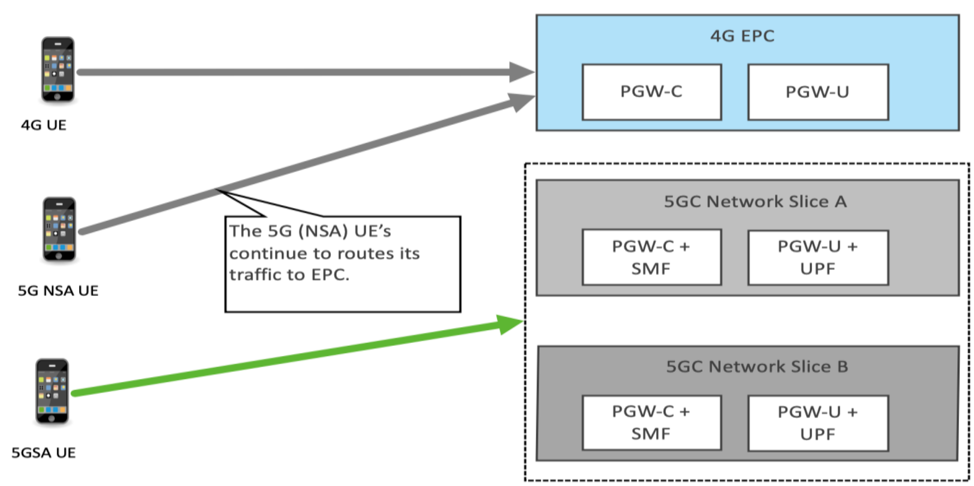

Figure 5: Standard Design for NSA Traffic Offload

Figure 6 shows an ideal 5GC design which considers 5G NSA UE traffic offloading capability.

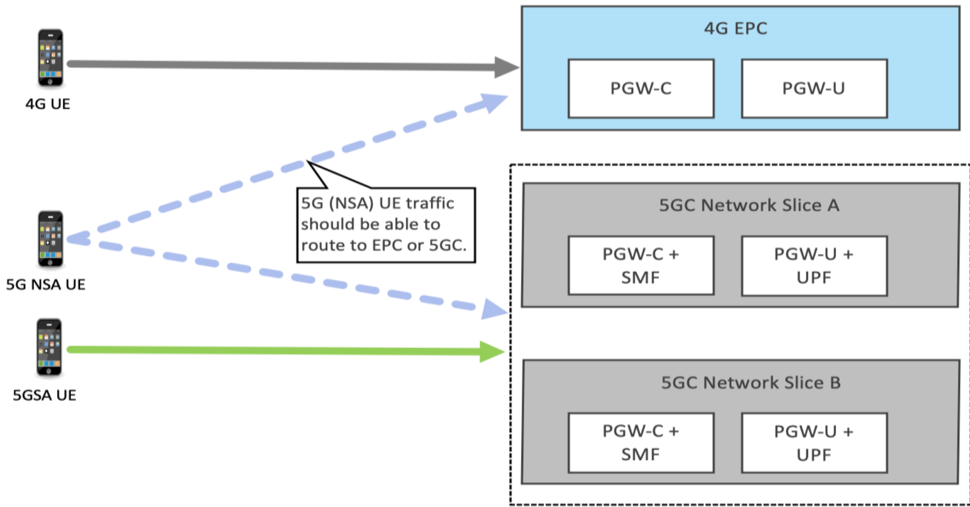

Figure 6: Reference Design for NSA Traffic Offload

5.5 Overlapping NSA and SA Coverage

The gNB used for a 5G NSA and a 5GSA can be the same for many deployments. This leads to a situation where there is overlapping coverage area for the 5G NSA and the 5G SA users.
In many cases, the same gNB can be connected to the 4G core as well as 5G core to cater to the secondary RAT addition for NSA users and handover to the 5G SA users.
Considering many of the 5G UEs and subscriptions can have NSA and 5GSA subscriptions in place, there is a need to plan and prioritize one over the other in these overlapping instances. Fallback upon failure and the type of services that are used by the user should also be considered for planning in such cases for efficiency.

5.6 UE capability subscription and APN Mapping

UE capability subscription and APN mapping can act as one of the solutions to the scenarios mentioned in section IV-A, IV-B, and IV-C. As a part of this solution, new APNs are introduced for the 5G users for data usage, which are different from the normal 4G users APNs for the same service.

Introducing the 5G SA nodes brings in additional changes to the 4G network in terms of logic that will be required on MME / DNS to select the right node from 4G (i.e., SGW & PGW (SAEGW)) or 5G (i.e., PGW+SMF combo node) for a 5G SA capable UE trying to establish a connection in 4G with an appropriate APN.

The new network/node selection algorithm should consider the following parameters to ensure seamless interworking in case the UE moves from 4G to 5G coverage area and vice versa.

- UE capability (4G / 5G NSA / 5G SA).
- UE subscription.
- APN selected by the UE (all possible APNs including default).

The options in this scenario are:

- If the requested APN by the UE is 5G-DATA-APN and the MME receives ULA (Update Location Accept) from HSS with allowed APN for the UE as 5G-DATA- APN, UE is 5G capable and NRSRNA (New Radio as Secondary Rat Not Allowed) flag is set to (Allowed), the MME along with DNS selects the 5G PGW-SMF (combo) node instead of the 4G SAEGW nodes.
- If the requested APN by the UE is 4G-DATA-APN and even if the ULA received from the HSS suggests that the

UE can use 5G-DATA-APN, the MME along with the DNS will select the 4G SAEGW / PGW nodes instead of the new 5G PGW-SMF (combo) node.
- If the requested APN by the UE is 5G-DATA-APN and if the ULA received from the HSS suggests that the UE is not allowed to use 5G-DATA-APN, the MME will reject the Attach / TAU request from the UE.
- If the requested APN by the UE is 4G-DATA-APN and if the ULA received from the HSS suggests that the UE can use 4G-DATA-APN, the MME will select the 4G SAEGW / PGW nodes.

Table below shows the APN-based enhancement to the 4G network logic of selection of gateway nodes either 4G (i.e., SGW & PGW (SAEGW)) or 5G (i.e., PGW+SMF combo node) for the UE based on the UE capability, UE subscription, APN used by the UE (assuming there is an N26 interface between the MME of the 4G network), and the AMF of the 5G Network.

UE capability	UE subscription	APN selected by the UE	SAEGW selection logic on MME
5G SA capable	5G Subscription	4G Data APN	SAEGW in EPC
		5G Data APN	S-GW in EPC P-GW in 5GC (new combo node)
5G SA capable	4G subscription	4G Data APN	SAEGW in EPC
		5G Data APN	Attach / TAU Rejected
4G Capable	5G Subscription	4G Data APN	SAEGW in EPC
		5G Data APN	S-GW in EPC P-GW in 5GC (new combo node)
4G Capable	4G Subscription	4G Data APN	SAEGW in EPC
		5G Data APN	Attach / TAU Rejected

Table1: Selection Logic of Gateway Nodes

Figure 7 illustrate the logic for a UE in 4G and 5G network coverage area when it initiates a registration with different APN/ Data Network Name (DNN).

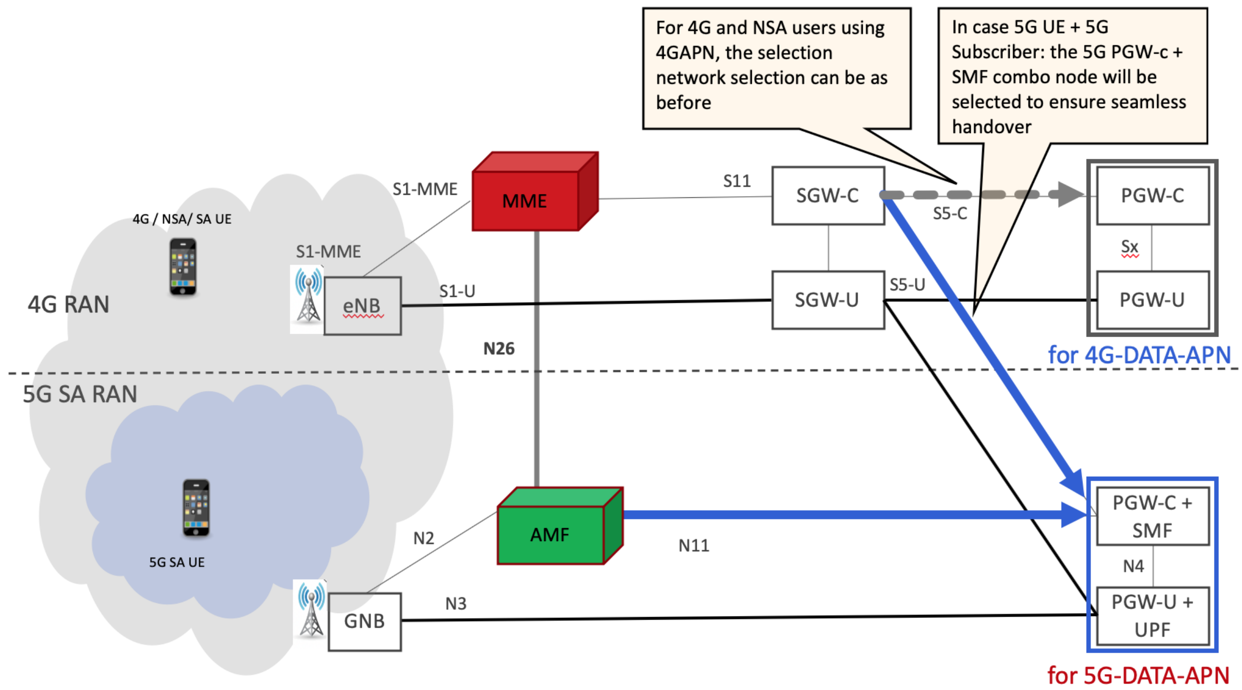

Figure 7: Selection Logic for 4G/5G Gateway Node

With this solution, there is a good chance of selecting the right 5G PGW/SMF node in the 4G network to ensure a seamless transition when the UE makes mobility from the 4G network to the 5G network.

In a more complex deployment scenario, there are multiple slices in 5G network and the single network slice selection assistance information (S-NSSAI) mapping on the 5G network can lead to multiple, different slices selection. Under such scenarios, the UE capability subscription and APN mapping solution might not result in a very accurate selection of 5G PGW/SMF node in the 4G network.

In such a case, default slice node selection on the 4G network might be required to reduce the complexity. The session continuity will also need to be maintained for users when they move from 4G to 5G coverage area and vice versa.

6 MIGRATION FROM 4G TO NSA

6.1 DEPLOYMENT SCENARIOS OF 5G OPTION 3

5G option 3 will be an intermediate stage for operators who wants to offer high-speed 5G data rate and connectivity to use with 5G enabled devices. NSA also provide an opportunity for the operators to leverage their existing 4G infrastructure and be the leading adopter of 5G technology in the market. NSA uses both LTE and New Radio (NR) using only the EPC core for routing signaling and data traffic. The 4G eNB acts as the anchor point for directing all signaling traffic to the EPC core. As shown in figure 8, there are different deployment scenarios of Option 3 based on the connectivity of the gNB and eNB to the EPC core and how the data traffic is routed between them [5] [6] [7].

1) *Option 3:* eNB acts as the anchor point for all communication between the EPC core and gNB. There is no connectivity between the gNB and the EPC core. Xx interface exists between the gNB and eNB.
2) *Option 3a:* S1-U connectivity exists between eNB and gNB and the data traffic can flow directly between the EPC and 4G eNB, and between EPC and 5G gNB, but no communication exists between gNB and eNB (no X-U

interface).

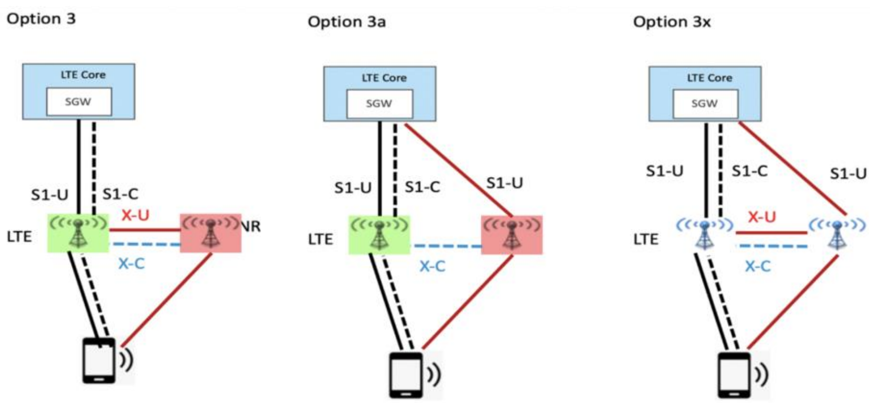

Figure 8: NSA Option 3 Variants

3) *Option 3x:* This is a combination of option 3 and option 3a. In option 3x the user plane traffic is primarily terminated on the gNB and very little traffic is split over the X-U interface towards the LTE eNB. This provides two significant advantages:
   - The excessive user plane traffic on eNB is eliminated.
   - The eNB acts as the master node and controls the traffic split between gNB and eNB allowing a seamless mobility and service continuity between 4G and 5G.

   In summary, option 3x has very little impact on the existing 4G network and would be the preferred choice for operators to introduce 5G services to their customers.

6.2 EPC CORE IMPACT TO SUPPORT NSA

The implementation of 4G NSA requires EPC core to support dual connectivity, extended bit rate, NR capable gate- way selection, and access restriction capabilities. The table II provide a high-level overview of EPC core impact to support NSA.

Features	RAN	MME	SGSN	HSS	S/PGW-C	S/PGW-U	PCRF	CHG	DNS	Support
Subscription Control	√	√	√	√						Restrict subscriber from NR access based on subscription
5G Icon Display	√	√		√						Display of 5G icon
Dual Connectivity Mobility Support	√	√								Allow / reject the NR addition
Max Bitrate Value	√	√		√	√	√	√			Encoding and processing of extended MBR/GBR values
Voice Support	√									Prevent voice to move to NR
Security Impact	√	√								5G security capabilities
SPGW selection		√	√		√	√			√	S/PGW which can support NR high data rate
NR usage reporting	√	√			√			√		UE usage of NR reporting
Low latency support	√				√		√			NEW QCI value of NR support

Table2: EPC core impact to support NSA

6.3 NSA INTERACTION WITH 5G CORE

As explained in Section V-A, migration to 5G core will need NSA + SA to co-exist with the EPC core until they can migrate to a fully independent option 5.

There are a few challenges for operators to manage 4G- PGW/5G-UPF selection based on the UE capability, UE sub- scription, APN requested by the UE, and the dual connectivity capability of the UE. Operators with 5G core having multiple slices co-existing with the NSA core must select the right network slice when a 5G NSA subscriber attaches to the 4G network requesting a 5G APN. This is the preferred design for a class of subscribers who have preferential QoS treatment and perform mobility between 4G NSA and 5G SA radio coverage. The following logic provides a few design options for operators to decide in selecting the right 4G-PGW or 5G UPF.

7 SUMMARY

The journey from 4G to 5G services is evolutionary and must consider a seamless interoperability of 5G CN with the 4G packet core. The interworking between 4G, NSA, and 5G SA will continue to evolve for a foreseeable future. Service providers must continue to leverage the full capabilities of their 4G network, launch 5G services in a short time frame, and consider all current and future 5G consumer experience use cases.

The automation and virtualization is a must for 5G network infrastructures including application use case deployments. Automation use case examples include auto-deployment, con- figuration, assurance, healing, and life-cycle management, etc. Further study can focus on how automation can provide seamless mobility and interworking between 4G and 5G.

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9 GLOSSARY OF TERMS

AMF	Access and Mobility Management Function
CN	Cloud-Native
CU	Centralized Unit
CUPS	Control and User Plane Separation
DCI	Datacenter Interconnect
DU	Distributed Unit
eNB	e NodeB
EPC	Evolved Packet Core
EVPN	Ethernet Virtual Private Network
gNB	g NodeB
IMS	IP Multimedia Subsystem
MEC	Multi-access Edge Compute
NFVI	Network Function Virtualization Infrastructure
NSA	Non-Standalone
SA	Standalone
SDN	Software Defined Networking
SMF	Session Management Function
SP	Service Provider
SR	Segment Routing
URLLC	Ultra Reliable Low Latency Communications
UPF	User Plane Function
(V)NF	(Virtualized) Network Function