5G Architecture: Deployment scenarios and options

Amine EL RHAYOUR
Networks and Telecommunication Systems Laboratory
National School of Applied Sciences
Kenitra, Morocco
amine.elrhayour@gmail.com

Tomader MAZRI
Networks and Telecommunication Systems Laboratory
National School of Applied Sciences
Kenitra, Morocco
tomader20@gmail.com

***Abstract*—In Morocco, the big decision for the "next generation" is about choosing the best way to combine a 5G New Radio (NR) solution with the existing 4G LTE Network. In fact, the Telecom Service Providers (TSP) faces the issue of finding their path through a wide range of available deployment scenarios defined by 3GPP: "Non-Standalone" (NSA) and "Standalone" (SA) and a list of "options": 2, 3, 4, 5 and 7. This paper discusses the issues underlying the choice of initial 5G service launch and subsequent long-term migration planning based on the influence of business and technical planning.**

***Keywords*—4G, 5G, NSA, SA**

I. Introduction

Increasing Internet data traffic has driven the capacity demands for currently deployed 3G and 4G wireless technologies. Now, intensive research toward 5th generation wireless communication networks is progressing in many fronts. 5G technology is expected to be in use around 2020 and the first issue the TSA face will be the choice of the initial 5G deployment solution. There are two main solutions: "Non-Standalone" (NSA) based solution, combining LTE and 5G NR access with a 4G Enhanced Packet Core (EPC) and "Standalone" (SA) solution, based on 5G New Radio (NR) access and a new 5G Core (5GC) run in parallel with their existing LTE network. The second issue is how their 5G solution should evolve after initial launch to take full advantage of a next generation mobile system designed to support innovative 5G use cases. This paper seeks to address both the initial deployment approach and the subsequent migration paths available. The intention is to highlight the key considerations and some of the most likely migrations [1].

II. Non-Standalone vs Standalone

5G is the next generation of 3GPP technology, after 4G/LTE, defined for wireless mobile data communication. 5G will introduce a major network architectural change from radio access to core.

The two solutions defined by 3GPP for 5G networks in Release 15 are:

- 5G Non Standalone (NSA): The existing LTE radio access and core network (EPC) is used as an anchor for mobility management and coverage to add the 5G carrier. This solution enables operators to provide 5G services with shorter time and lesser cost.
- 5G Standalone (SA): An all new 5G Packet Core will be introduced with several new capabilities built inherently into it. The SA architecture comprises of 5G New Radio (5G NR) and 5G Core Network (5GC). Network Slicing, CUPS, Virtualization, Multi-Gbps support, Ultra low latency, and other such aspects will be natively built into the 5G SA Packet Core architecture.

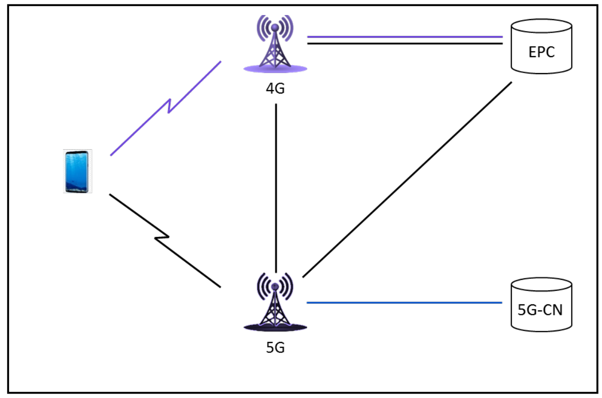

Fig. 1. Non-Standalone vs Standalone

III. 5G Deployment Options

3GPP is standardizing a set of different 5G deployment solutions based on whether or not the 5G NR access is used as an independent radio system in an SA mode or if it is to be combined with a parallel LTE access network using a technology called "Multi-Radio Access Technology - Dual Connectivity" (MR-DC) in an NSA mode. In this mode, one access technology is used as the "Master" system while the other is used as a "Secondary" system. Radio bearers may be either carried over a single radio access system or split and then delivered using a combination of both radio access technologies [2].

These solutions are being published in three successive "drops" within the 3GPP release-15 set of specifications:

- Release-15 "Early drop" specifications, completed in December 2017, introduced NSA using Dual-Connectivity between LTE and 5G NR with the control plane on the LTE "master node" and connected to the 4G EPC Core Network (option 3, formally termed "E-UTRA – NR Dual Connectivity" or EN-DC).
- Release-15 "Main drop", completed in June 2018, added the new 5G Core (5GC) network specifications designed to work with SA 5G NR (option 2) and an upgrade to LTE to support 5GC networking (option 5, often referred to as enhanced LTE or eLTE)
- Release-15 "Late drop" is expected to be completed in December 2018 and should add additional NSA modes connected to a 5G Core Network, with either an LTE master system (option 7, formally termed "next generation E-UTRA – NR Dual Connectivity" or ngEN-DC) and an NR master (option 4, formally termed NR – E-UTRA Dual Connectivity" or NE-

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DC). This “drop” will also include support for NR-NR and eLTE-eLTE dual connectivity.

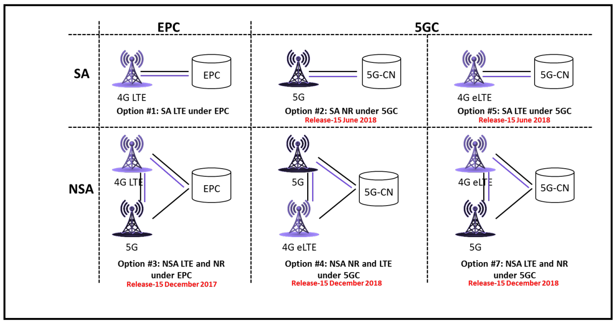

Fig. 2. Deployment options 1, 2, 3, 4, 5 and 7 being defined by 3GPP

Network and device support for these 5G deployment options is expected over the next few years, with first deployments focused on option 3 NSA, with option 2 SA solutions due approximately 6-12 months afterwards. These initial solutions should be followed by support for option 5 “eLTE” and options 4 and 7 NSA when and if mobile devices support these modes and they meet a TSP’s business and service requirements.

Both NSA and SA deployment approaches will support 5G services. The enhanced mobile broadband (eMBB) service may be accommodated on any 5G architecture options with similar total capacity and end-user experience. The theoretical peak throughput will however be initially higher when using the NSA approaches (options 3, 4 and 7). This will apply particularly in networks with many parallel LTE carriers in suburban and rural areas. In this case, mid and high band NR wouldn’t offer significant coverage when used to support SA mode option 2 and there may initially be only one low band NR carrier.

Likewise, low latency services such as Ultra Reliable Low Latency Communications (URLCC) should also be available using any 5G architecture option. However, in this case, the SA option 2 approach is likely to offer lower average latency and superior QoS controls compared to the NSA solution option 3, especially if the LTE access has not been upgraded to support low latency features. Introduction of options 4, 5 and 7 will overcome the EPC QoS limitations but user plane latency may still be affected by the LTE access. This is likely to require substantial changes to the physical layer implementation to support reduced latency on the radio interface [3].

Voice services will remain unchanged compared to 4G LTE solutions, Voice over LTE (VoLTE) and Circuit Switched Fall Back (CSFB), when using option 3. Options 2, 4, 5 and 7, on the other hand, will require an upgrade to the IP Multimedia Subsystem (IMS) solution to support the enhanced solution for QoS management using a 5GC. GSMA is actively working on the corresponding changes to the IR.92 profile to handle these new features [4].

In short, option 3 is considered as a simpler introduction of 5G for eMBB service and maintenance of existing voice services, but any other use case would greatly benefit from the 5G Core Network and optimized 5G NR access, coming with options 2 and 4 (NR anchored) and 5 and 7 (eLTE anchored).

IV. INITIAL 5G NETWORK ROLLOUT

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A. *Starting 5G services with NSA*

Many early 5G networks will start with option 3 NSA. The primary advantage of this solution is that the well-known 4G EPC network architecture may be used. However, the user plane (Serving Gateway (SGW) and Packet Data Network Gateway (PGW)) will need to be replaced with a higher performance and more distributed solution to support massively higher bitrates and reduced transport latency. One approach would be to deploy new core network elements that are able to flexibly support and deploy both EPC user plane (SGW and PGW) along with next generation 5GC User Plane Function (UPF) and Session Management Function (SMF).

The corresponding Radio Access Network (RAN) solution will use the existing 4G LTE base stations with upgrades to support the NSA features and deployment of new 5G NR cells to provide dual-connectivity, with interconnection using the 3GPP defined extensions of the X2 interface. One particular variant of option 3, known as “3X”, is recommended in this case with the high bandwidth flows first routed directly to the NR gNB to avoid excessive user plane load on the existing LTE eNB equipment. Excessive requirements for signaling traffic between RAN and core is also minimized with this variant, as it offers a more graceful solution to handling service continuity after loss of 5G radio coverage. Furthermore, a 5G cloud RAN architecture is recommended, with the dual connectivity traffic splitting function located at a central point to avoid “trombone” routing of transport flows. This is particularly critical in deployments where the LTE and NR radio cells are not co-located, for example, when using 5G mmWave small cells [5].

With this solution, 5G access would be first deployed in high traffic areas using a Time Division Duplex (TDD) band either above 3 GHz and/or a mmWave to provide capacity relief. Additional lower band NR carriers would be needed if wide area coverage of NSA operation is required. Alternatively, the device could fallback to LTE only coverage when outside the 5G NR coverage areas.

B. *Starting 5G services with SA*

The alternative approach using option 2 SA for initial deployment is being considered by some early launch TSPs and a wider range of TSPs planning to launch 5G services later.

Deployment of option 2 solutions involves the introduction of new 5G Core network functions and 5G NR base stations and will avoid the need to rebuild EPC core networks and minimize changes to LTE eNB. Initial option 2 deployment using TDD bands above 3 GHz is mainly considered for dense-urban areas to provide capacity relief and local low latency services and may also be used as a solution for Fixed Wireless Access (FWA) in suburban or rural areas [6]. To ensure smooth mobility without inter-RAT (Radio Access Technology) handovers, nationwide 5G coverage needs to be considered. However, this would require the deployment of at least one Frequency Division Duplex (FDD) carrier in a lower band (<3 GHz, preferably < 1 GHz) using either new or re-farmed spectrum with the low and high band NR carriers combined using carrier aggregation.

This solution will be able to support native 5G services offered by the new 5G Core network (advanced QoS mechanisms, improved network slicing support, service-based architecture and explicit support for cloud based deployment) with inter-RAT handover used to maintain the connection when moving out of the 5G coverage area.

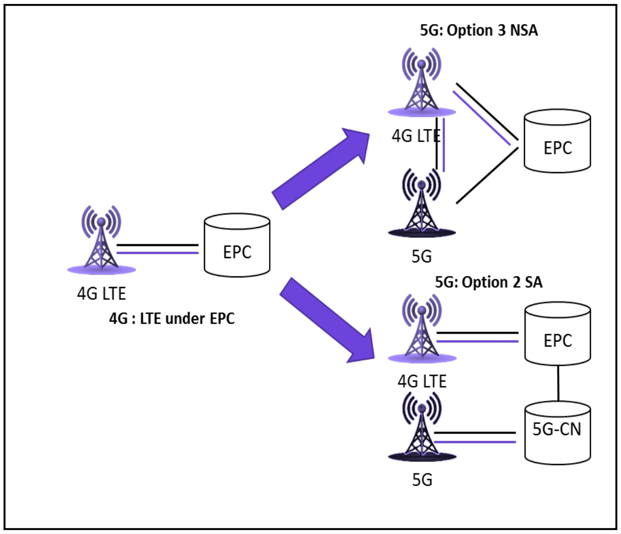

Fig. 3. Short term evolution choice for mobile networks launching 5G services

TABLE I. COMPARISON BETWEEN NSA (OPTION 3) AND SA (OPTION 2) SOLUTIONS

Consideration	Option 3X NSA	Option 2 SA
Solution	Dual connectivity with LTE eNB master node and NR gNB as secondary node with EPC core network	NR gNB as SA RAN with 5GC core network
Standardization	Rel-15 Dec. 2017 with June 2018 corrections	Rel-15 June2018
LTE eNB Core Network interface	S1c control plane S1u user plane	n/a
NR gNB Core Network interface	S1u user plane	N2 control plane N3 user plane
Latency	Average latency affected by packets sent on LTE path when using split bearer	Reduced when using wider sub-carrier spacings
UE Coverage	Identical to existing LTE coverage	Limited by 5G NR band
Service continuity to LTE	UE always attached in LTE. With DC and split bearer, the 5G drop has less effect	Inter-RAT handover or redirection needed when 5G connection drops
Service continuity to 2G/3G	Supported	Not supported. Service continuity from 5G to 3G will be studied for Rel-16
LTE eNB base station impact	Upgrade required to LTE eNB to support NSA mode	Minor upgrade to control plane to support inter-RAT mobility

V. CONSIDERATIONS FOR NEXT MIGRATION STEPS

Once the initial 5G service is in place, TSPs will need to select the longer term migration plan with the potential introduction of options 2, 4, 5 and 7 [7]. The eventual long term option will be running a 5G NR only network when and if all LTE radio resources have been re-farmed.

Options 7, 4 and 5 all require an upgrade to the LTE eNB to support 5GC interfaces (N2/N3 to 5GC and Xn to gNB and ng-eNB). Options 5 and 7 would maintain the LTE ng-eNB as the master node and so terminate the core network control plane interface and the primary RRC signaling interface to the attached mobile devices. Option 4, on the other hand, will act more as an extension of option 2 SA and would result in the LTE eNB taking a secondary node role associated with the NR gNB as master node.

Each of these options has its advantages and effects on network and end-user experience.

- Option 5 provides the "enhanced" LTE (eLTE) extensions to LTE access to support the introduction of native 5GC service across the network's entire LTE coverage zone
- Option 7 extends option 5 to offer NSA dual connectivity under an eLTE master carrier
- Option 4 extends option 2 to offer NSA dual connectivity under an NR master carrier

A more detailed comparison of options 5, 7 and 4 can be seen in TABLE II.

TABLE II. COMPARISON BETWEEN OPTIONS 5, 7 AND 4

Consideration	Option 5	Option 7	Option 4
Solution	Enhanced LTE eNB SA with 5GC core network	Dual connectivity with enhanced LTE eNB master node and NR gNB as secondary node with 5GC core network.	Dual connectivity with NR gNB master node and enhanced LTE eNB as secondary node wi th 5GC core network.
Standardization	Rel-15 June 2018	Rel-15 December 2018	Rel-15 December 2018
LTE eNB Core Netw ork interface	N2 control plane N3 user plane	N2 control plane N3 user plane	None
NR gNB Core Netw ork interface	n/a	N3 user plane	N2 control plane N3 user plane
Primary use case	Network wide access to 5GC services without need to deploy NR carriers at all cell sites. Also acts as the initial mode for option 7 NSA devices prior to establishing dual connectivity	Improved capacity and reduced latency using secondary NR carriers at cell sites with NR capabilities	Improved capacity compared to option 2 SA while offering native NR radio features

VI. EVOLUTION SCENARIOS FOR TSPS LAUNCHING WITH OPTION 3 NSA

For TSPs initially deploying a single carrier (i.e. 3.5 GHz) option 3 NSA solution, the priority will be to introduce 5GC based services. This will add support for network slicing, advanced QoS and session continuity procedures running on a new service-based cloud architecture [8]. Starting from option 3, the TSP could:

1. NSA converts: Add option 2 SA and eventually support option 4 or 7

2. NSA evolves: Evolve NSA to support option 7 and eventually option 2

Either of these approaches would enable the introduction of 5GC based services and offer the combined capacity of both NR and LTE carriers. The main differences are the timing for the upgrade of the LTE eNB and the need to add a low band NR carrier.

A. NSA converts: Add option 2 SA and eventually support option 4 or 7

In this case, the network would be upgraded to add 5GC interfaces to the NR gNB (N2/N3 to 5GC and Xn to gNB) and so offer a parallel option 2 SA solution. In parallel, the TSP would continue to expand 5G NR capacity and coverage via the addition of new NR carriers, using either new and/or re-farmed spectrum and combining using NR-NR carrier aggregation. This approach would allow the TSP to offer advanced 5GC services using native 5G NR features to open new revenue opportunities from other unique 5G use cases. The NR gNB base station would also continue to support existing option 3 NSA mobile devices.

An additional step could then be to convert the solution to support option 4 or option 7 NSA. For option 4, the gNB would act as master, preferably with additional 5G NR carrier(s) to improve coverage and capacity. This would offer native 5G NR features, while also adding additional capacity and peak bitrate using LTE as a secondary node. Alternatively, for option 7 the LTE eNB would act as master as with the option 3 solution but would now be offering 5GC services via an upgrade of the LTE eNB to support "NG" RAN features. Either of these approaches would allow the TSP to offer advanced 5GC services. Option 4 would use native 5G NR radio features, while option 7 would rely more on LTE radio features.

These approaches offer the advantage of rapidly introducing option 2 support for incoming roamers from networks starting with the alternative SA solution and being able to introduce 5GC services without waiting for device support for eLTE features.

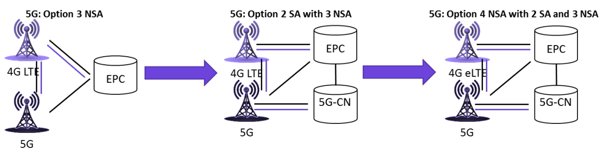

Fig. 4. Long term evolution for 3 solution adding options 2 then 4

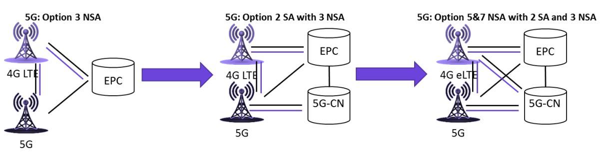

Fig. 5. Long term evolution for 3 solution adding options 2 then 7

B. *NSA evolves: Evolve NSA to support option 7 and eventually option 2*

In this case, the network would maintain the LTE eNB as master but upgrade it to also support the 5GC interfaces (N2/N3 to 5GC and Xn to gNB) and so offer a parallel option 5 SA and option 7 NSA solution. In parallel, the TSP would continue to expand 5G NR capacity and coverage by adding new NR carriers, using either new and/or re-farmed spectrum and combining using NR-NR carrier aggregation. This approach would allow the TSP to offer advanced 5GC services but would not be able to provide native 5G NR features. Once a suitable low band NR carrier is available and sufficient capacity is installed, the TSP would also start to offer parallel option 2 services and eventually option 4, with the aim of eventually re-farming all LTE carriers to offer option 2 only services.

This approach has the advantage of maintaining an NSA architecture and delaying the need for a low band NR carrier. It is, however, dependent upon device support for eLTE features prior to the launch of 5GC based services.

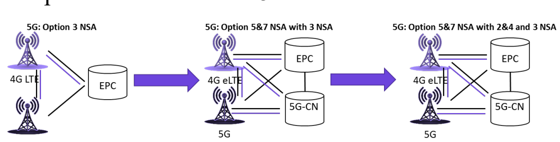

Fig. 6. Long term evolution for 3 solution adding options 5 & 7 then 2 & 4

VII. Choices Facing TSPs Launching with Option 2 SA

On the other hand, a TSP initially deploying a single carrier (i.e. 3.5 GHz) option 2 solution with NR gNB connected to the 5GC and operating in SA mode could choose to:

1. SA build out: Maintain the option 2 architecture and gradually expand NR coverage and capacity

2. SA evolves: Maintain the NR gNB as master but add capacity from LTE

3. SA converts: Expand solution to also support LTE eNB as master

All of these approaches would maintain support of 5GC based services and offer wide area coverage and capacity. The main differences are the timing for the upgrade of the LTE eNB, the need to add a low band NR carrier and the timing for LTE spectrum re-farming.

A. *SA build out: Maintain the option 2 architecture*

In this case, the network would need to expand 5G NR capacity and coverage by adding new NR carriers, using either new and/or re-farmed spectrum and combining using NR-NR carrier aggregation. This would allow the TSP to expand coverage and capacity of their advanced 5GC services such as Network Slicing and rich QoS and use native 5G NR radio features such as Radio Resource Control Inactive mode (RRC - Inactive) and 5G Cellular Internet of Things (CIoT) connectionless mechanisms (expected to be included in 3GPP release 16). However, the method would not allow the TSP to use their installed LTE radio resources to offer higher peak bitrates and capacity. A parallel LTE network would be maintained for some period of time to serve legacy 4G devices and roaming 5G option 3 only devices, but eventually the TSP would refarm all LTE carriers to offer only option 2 services.

This approach has the advantage of providing 5GC based services from initial service launch, based on a clean separation between 5G and 4G networking and is very similar to the previous 3G to 4G migration.

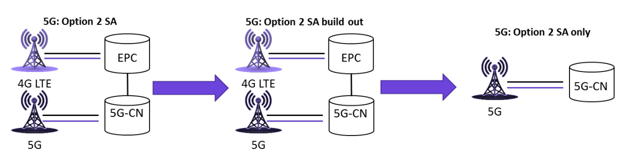

Fig. 7. Long term evolution for option 2 solution adding additional NR carriers for coverage and capacity

B. *SA evolves: Maintain the NR gNB as master but add LTE capacity*

In parallel to adding additional 5G NR carrier(s) to improve coverage and capacity and hence offer native 5G NR features, the network solution could be converted to also support option 4 NSA and so expand capacity via the addition of LTE carriers using NR-LTE dual connectivity. This approach would allow the TSP to expand coverage and capacity of their advanced 5GC services and make use of native 5G NR radio features. Furthermore, the combination of LTE and NR carriers would allow the TSP to use both radio technologies to provide peak bitrates and capacity. A parallel LTE network would be maintained for a time to serve legacy 4G devices and roaming 5G option 3 only devices. However, eventually the TSP would refarm all LTE carriers to offer only option 2 services.

This approach has the advantage of providing high peak bitrate eMBB services during the transition period while avoiding a premature re-farming of LTE spectrum.

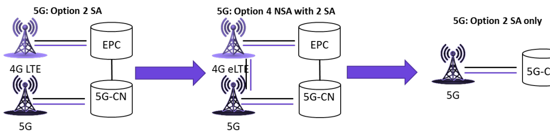

Fig. 8. Long term evolution for option 2 solution adding NSA 4

C. SA converts: Maintain the 5GC solution but convert to LTE eNB as master

This method involves maintaining the 5GC network in place and converting the solution to offer parallel option 3 and then option 5 SA and option 7 NSA solution after the upgrade of the LTE eNB to support 5GC interfaces (N2/N3 to 5GC and Xn to gNB). This would use LTE-NR dual connectivity to combine LTE and NR radio resources. This solution could be converted back to option 2 once a substantial proportion of LTE carriers have been re-farmed to support NR.

This approach has the advantage of maintaining Machine-Type Communications (MTC) devices in LTE based access while adding support for 5GC services [9].

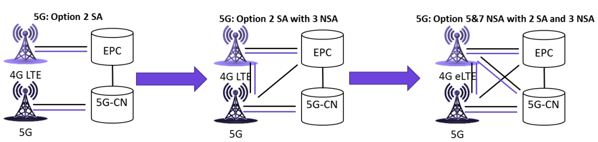

Fig. 9. Long term evolution for option 2 solution adding NSA 3 then 7

VIII. COMPARING LONG-TERM MIGRATION STRATEGIES

All these migration approaches are feasible, with the best path dependent on a range of TSP specific considerations:

- Availability of suitable spectrum to support a 5G NR FDD carrier to ensure wide area coverage and allow NR gNB to support network wide SA (option 2) solutions and act as master node (option 4)
- Business and technical planning for the deployment of the 5G core network and introduction of native 5G services, network slicing and flexible QoS management (options 2, 4, 5 and 7)
- Investment plan for LTE eNB upgrades to support "e"LTE features (options 5 and 7) and secondary node operation (option 4)
- Long term 2/3G and LTE spectrum re-farming strategy
- Approach to encouraging end-customer adoption of 5G devices
- Ability to upgrade early 5G devices to support 5GC deployment scenarios (options 2, 4, 5 and 7)
- National regulation affecting 4G LTE and/or 5G NR sharing between TSPs

Table III summarizes the key steps and observations for each migration path.

TABLE III. COMPARISON BETWEEN DIFFERENT LONG-TERM MIGRATION APPROACHES

Approach	Key steps	Observations
NSA converts	• 3X then 2 then 4	• Uses option 2 device support • Delays need for eLTE
NSA converts	• 3X then 2 then 7X	• Delays need for low band NR carrier • Relies on LTE for wide area coverage
NSA evolves	• 3X then 5&7X then 2&4	• Delays introduction of NR master carrier • Requires early device support for eLTE
SA build out	• 2 then more NR carriers	• Focuses future investment on NR capacity • Reduced peak bitrate compared to NSA solutions
SA evolves	• 2 then 4	• Maintains SA based solution but adds capacity from LTE carriers
SA converts	• 2 then 3X then 7X	• Avoids need for low band NR carrier

Interestingly, most of these migration scenarios have very similar effects on the network and TSPs may decide to support more than one migration path on the same network. In this sense, the migration path and hence the supported options could be part of an overall end-to-end approach to network slicing, with different slices using different deployment options while making use of a common architecture [10].

Key components of a flexible solution would include:

- New cloud-native core network nodes supporting both EPC and 5GC network functions deployed using both virtual and physical implementations. This would have a highly distributed user plane to support massive bandwidths and provide low latency.
- LTE eNB and NR gNB nodes based on cloud RAN technologies linked together using open X2 and Xn interfaces and able to support multiple deployment options on the same platforms.
- Orchestration tools in place to manage the overlay of different deployment options on a slice-by-slice basis.

IX. CONCLUSIONS

A number of potential long term 5G migration approaches may be identified and determining which unique approach is best for a given TSP requires a careful balance of many factors. These include spectrum holdings, acquisition and re-farming strategy, business and technical planning, national regulations and mobile device availability.

This paper has presented the most likely migration paths starting for both NSA and SA scenarios and has concluded that potentially the best solution would be to plan to support multiple deployment options in parallel using a flexible cloud-based core and RAN. The recommended approach based on staged deployment of multiple options gives the TSP the ability to offer new 5G use cases (e.g. low latency and end-to-end slicing) for new market segments while also supporting initial deployments focused on eMBB services. Mobile devices would be assigned to a given set of options using network slicing technologies, with a specific solution selected at any time based on available radio resources, location, service requirements, network load and mobility.

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