EEE4121F Module A
Mobile and Wireless Networks

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In all things, it is better to hope than to despair.

The 5G Network

- ❑ Evolution of Mobile Networks
- ❑ 5G Vision
- ❑ 5G Requirements
- ❑ Important Features of 5G
- ❑ 5G Standards
- ❑ 5G Spectrum
- ❑ 5G Economic Challenge
- ❑ **5G Network Architecture Options**
- ❑ 5G Migration Paths
- ❑ Towards 6G in 2030

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5G Network Architecture Options

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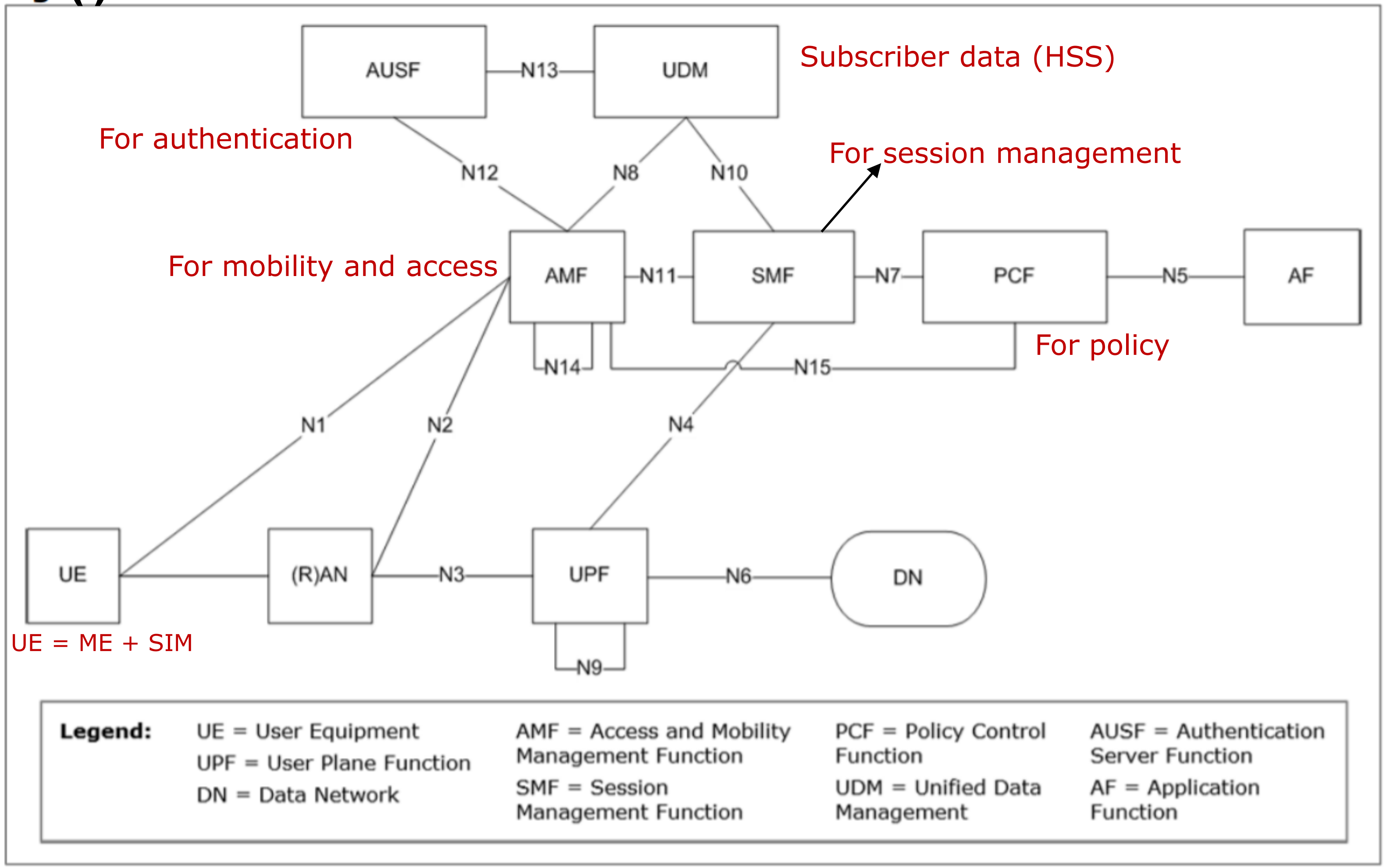
Classification of 5G network architecture as (i) point-to-point architecture and (ii) Service based architecture

AMF, AUSF, UDM, SMF, PCF, and AF together form the control plane of the 5G network

(i) Point-to-Point Next-Generation Reference Architecture



Source: 3GPP TR 23.501, January 2017, Figure 4.2.3-2

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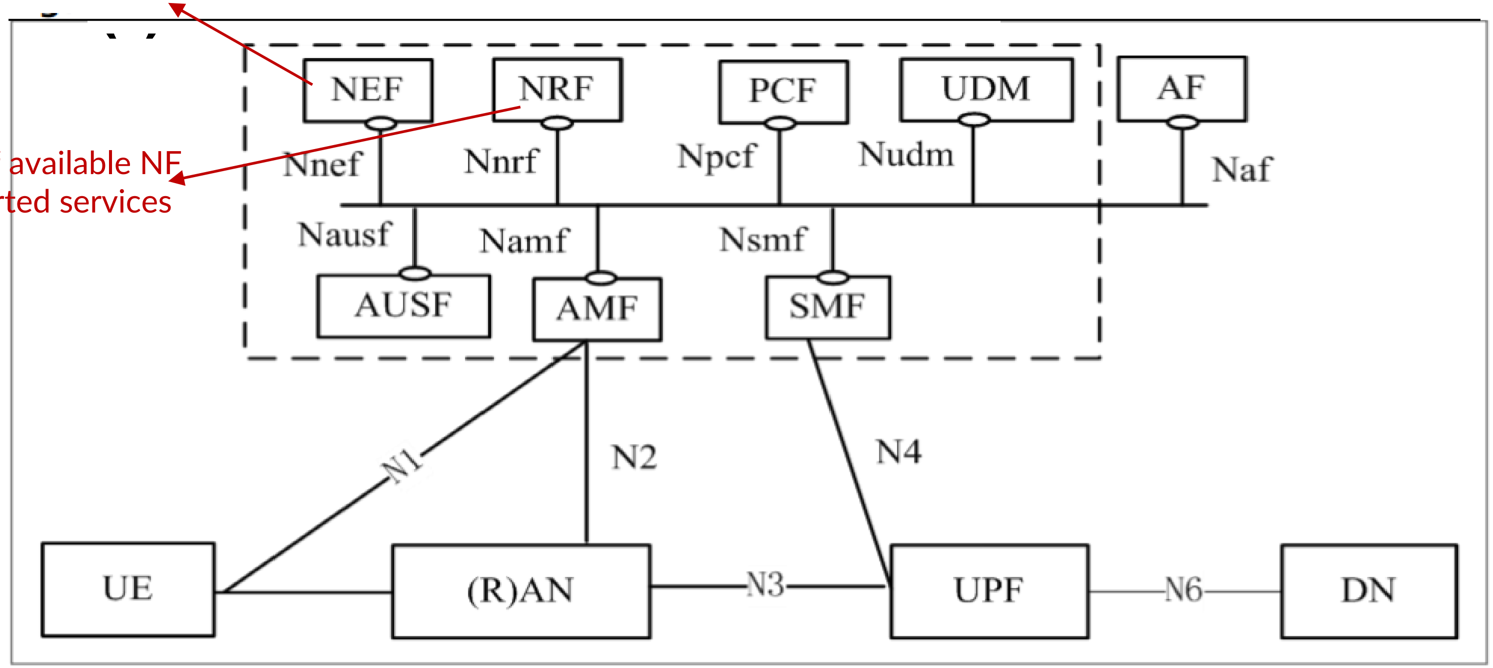
Classification of 5G network architecture as (ii) Service based architecture

- Service-Based Architectures provide a modular framework from which common applications can be deployed using components of varying sources and suppliers.

NEF exposes the network, using APIs to interact with network functions and with partner companies for new business opportunities and development of new services.

(ii) 5G Service- Based Architecture

NRF maintains a record of available NF instances and their supported services



Source: 3GPP TR 23.501, January 2017, Figure 4.2.3-1

Legend:
UE = User Equipment
UPF = User Plane Function
DN = Data Network
AMF = Access and Mobility Management Function
SMF = Session Management Function
PCF = Policy Control Function
UDM = Unified Data Management
AUSF = Authentication Server Function
AF = Application Function

NEF: Network exposure function
NRF: NF (Network Function) Repository Function

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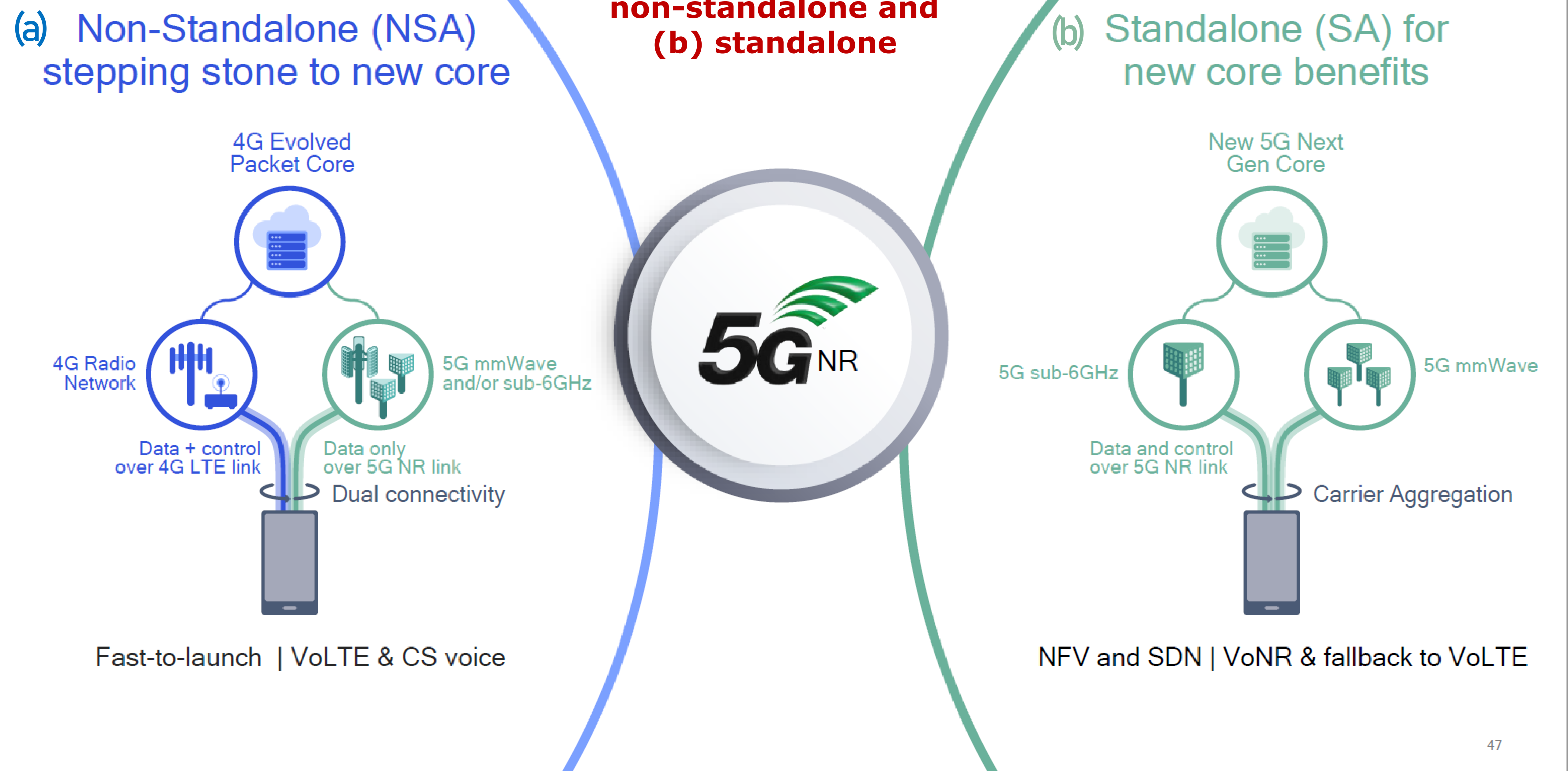
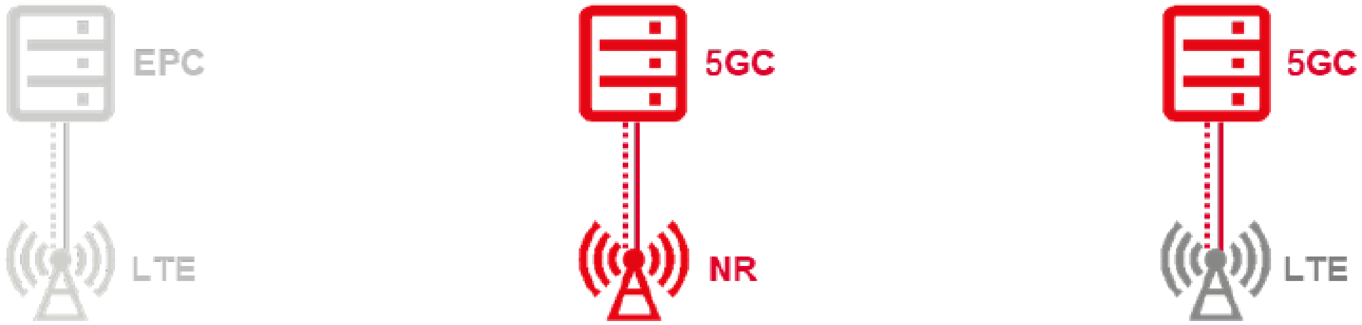
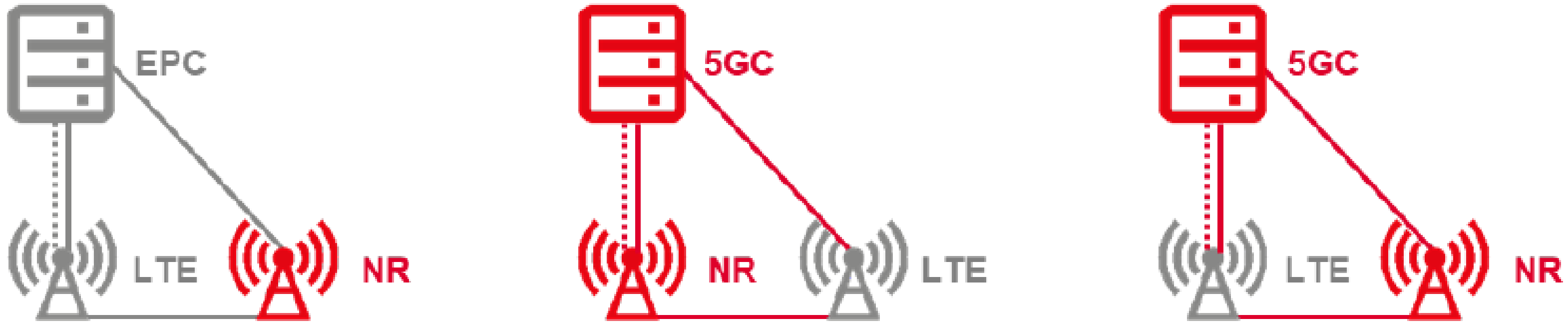
Classification of 5G architecture as (a) non-standalone and (b) standalone



Standalone (SA) and Non-Standalone (NSA) Options for 5G Deployment



Standalone LTE under EPC (option 1) | Standalone NR under 5GC (option 2). | Standalone LTE under 5GC (option 5)



Non-standalone LTE and NR under EPC (option 3) | Non-standalone NR and LTE under 5GC (option 4). | Non-standalone LTE and NR under 5GC (option 7)

- Unlike previous generations that required that both access and core network of the same generation to be deployed (e.g. Evolved Packet Core (EPC) and LTE together formed a 4G system), with 5G it is possible to integrate elements of different generations in different configurations, namely: Standalone (SA) and Non-Standalone (NSA).

- The features that distinguish each Option are:
  (1) Use of Dual Connectivity;
  (2) Radio Access Technology acting as master node
  (3) Core Network used.

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Standalone (SA) and Non-Standalone (NSA) Options for 5G Deployment

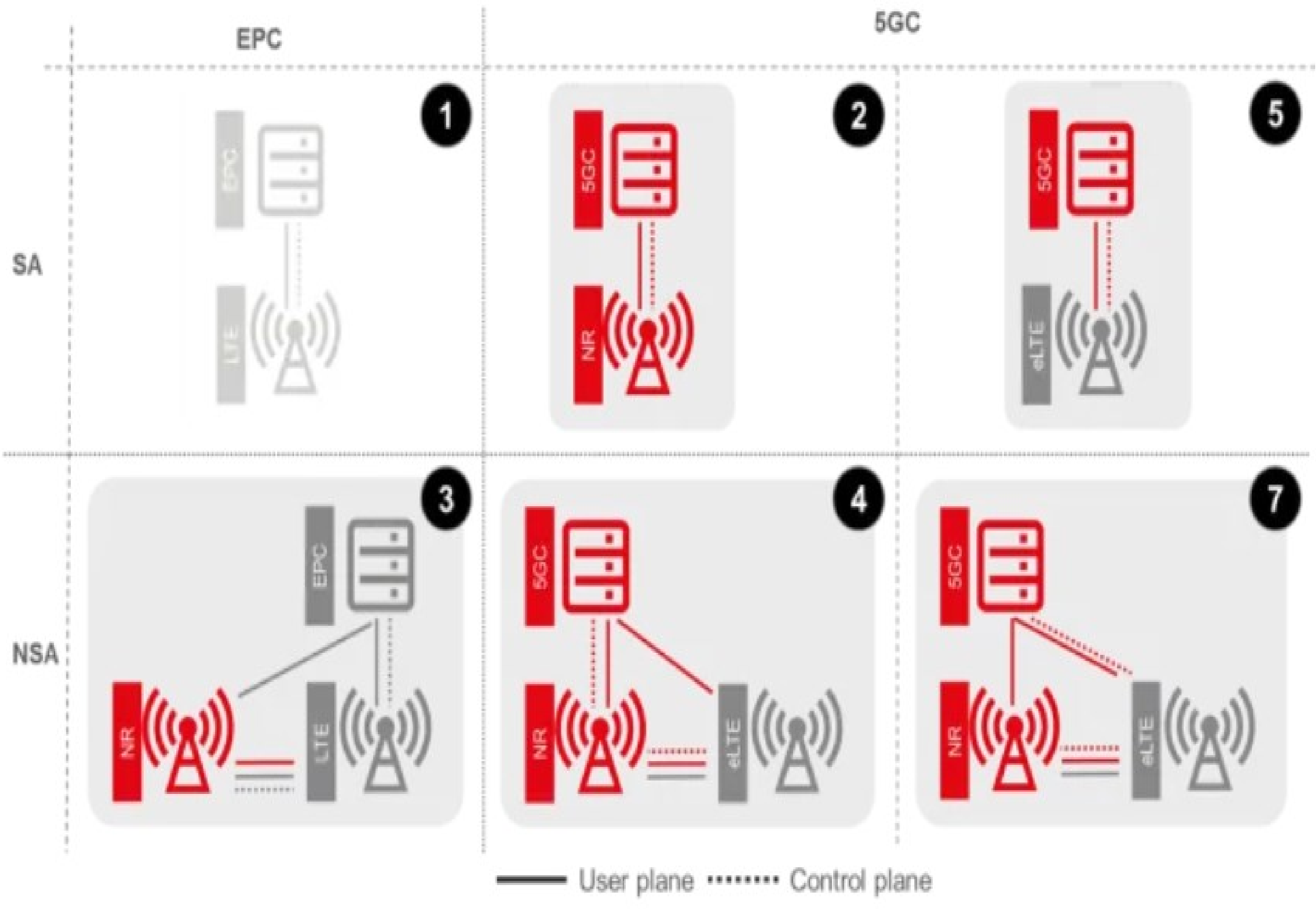


Figure 1: 3GPP defined options for 5G deployment

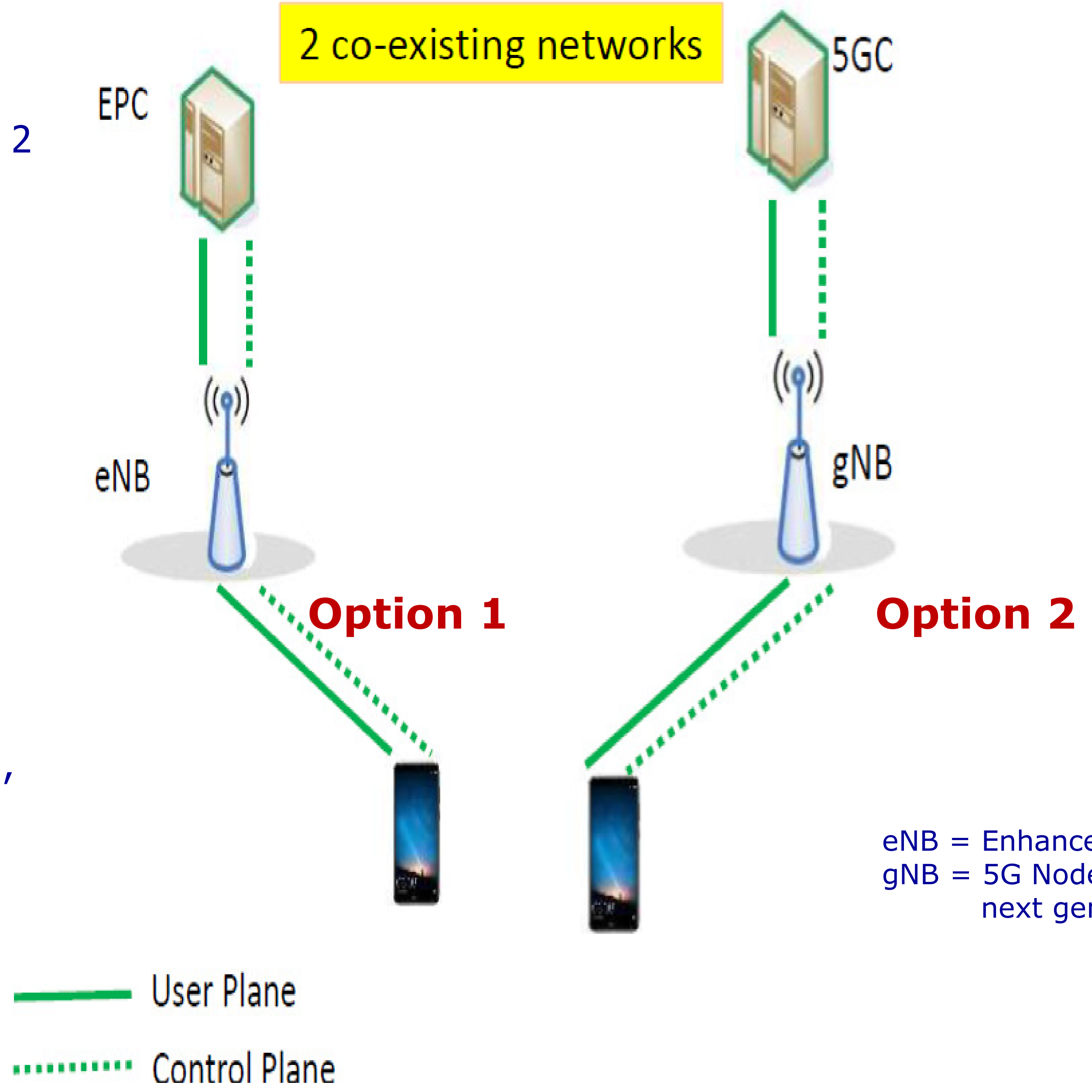
- The Options using Dual Connectivity are grouped together under the term “Non-standalone” (NSA) to indicate that 5G radio access technology (NR) and LTE are used simultaneously to provide radio access. Options where only one radio access technology is in use are referred to as “Standalone” (SA).

- It is widely expected that mobile operators will initially deploy 5G using Option 3 allowing the re-use of existing EPC Core functionality. Option 3 has been fully specified in an early drop of 3GPP Release 15.

- The other deployment Options already fully specified by 3GPP are Option 2 and Option 5, both standalone options differing in the type of radio access technology connected to the new mobile core network 5GC. These options were completed in June 2018.

5G Architecture – Option 1/2

- In this scenario the operator migrates directly from EPS (Option 1) to the standalone Option 2 with inter-RAT mobility mechanisms used to move devices between 4G LTE under EPC coverage and 5G NR under 5GC coverage.
- One of the key benefit of this option is that SA architecture can take full advantage of 5G end-to-end network capabilities supported by NR and 5GC, providing customized service, especially to vertical industry, in an effective and efficient way.
- New features, including service-based architecture, end-to-end network slicing, and MEC, can be enabled according to specific requirement of each service, providing customized superior user experience.



eNB = Enhanced Node B
gNB = 5G Node B or next generation Node B

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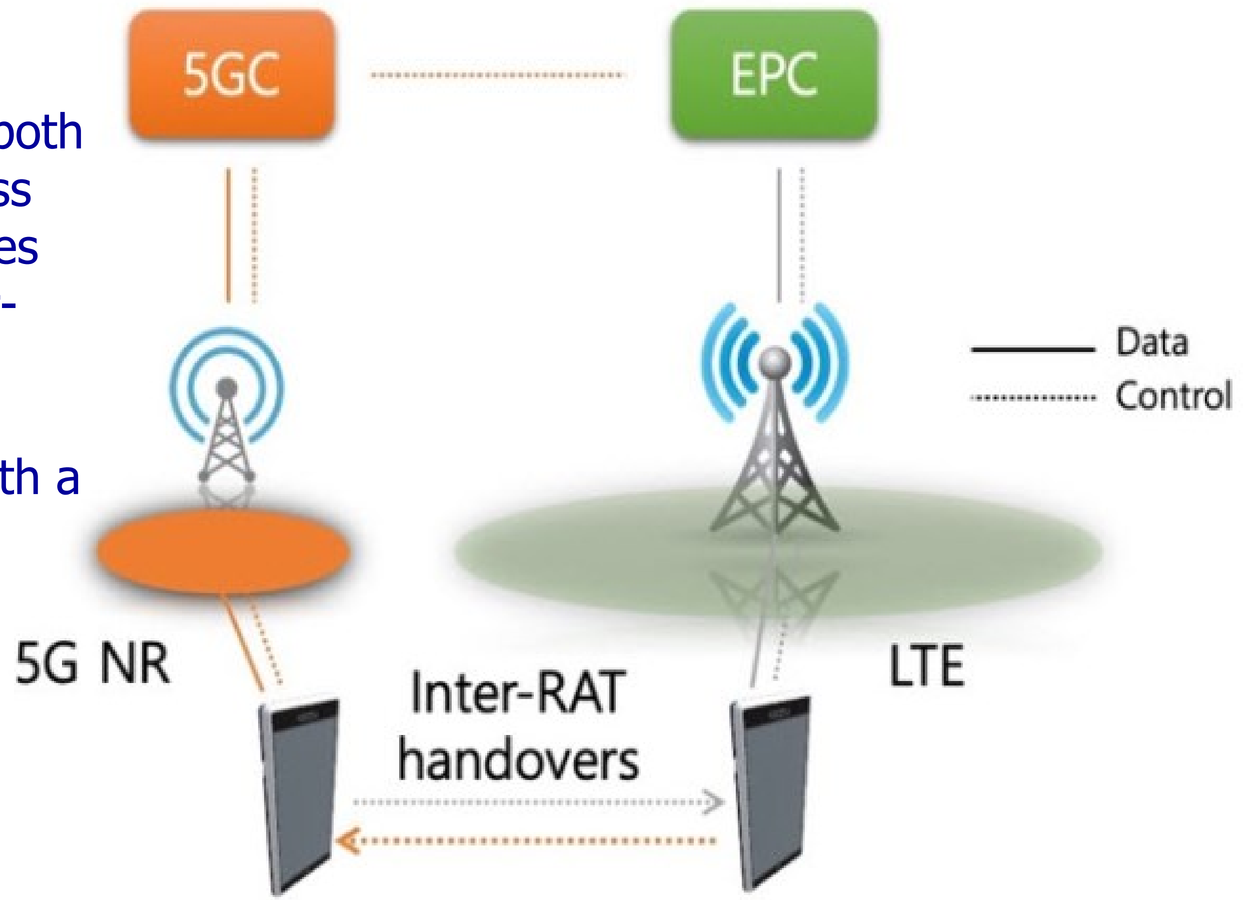
5G Architecture Option 1/2

Impact on Device and Network

- SA Option #2 envisages the deployment of both NR gNB based NG-RAN as a new radio access and 5GC as new core along with new features on LTE eNB based E-UTRAN to support inter-RAT mobility.

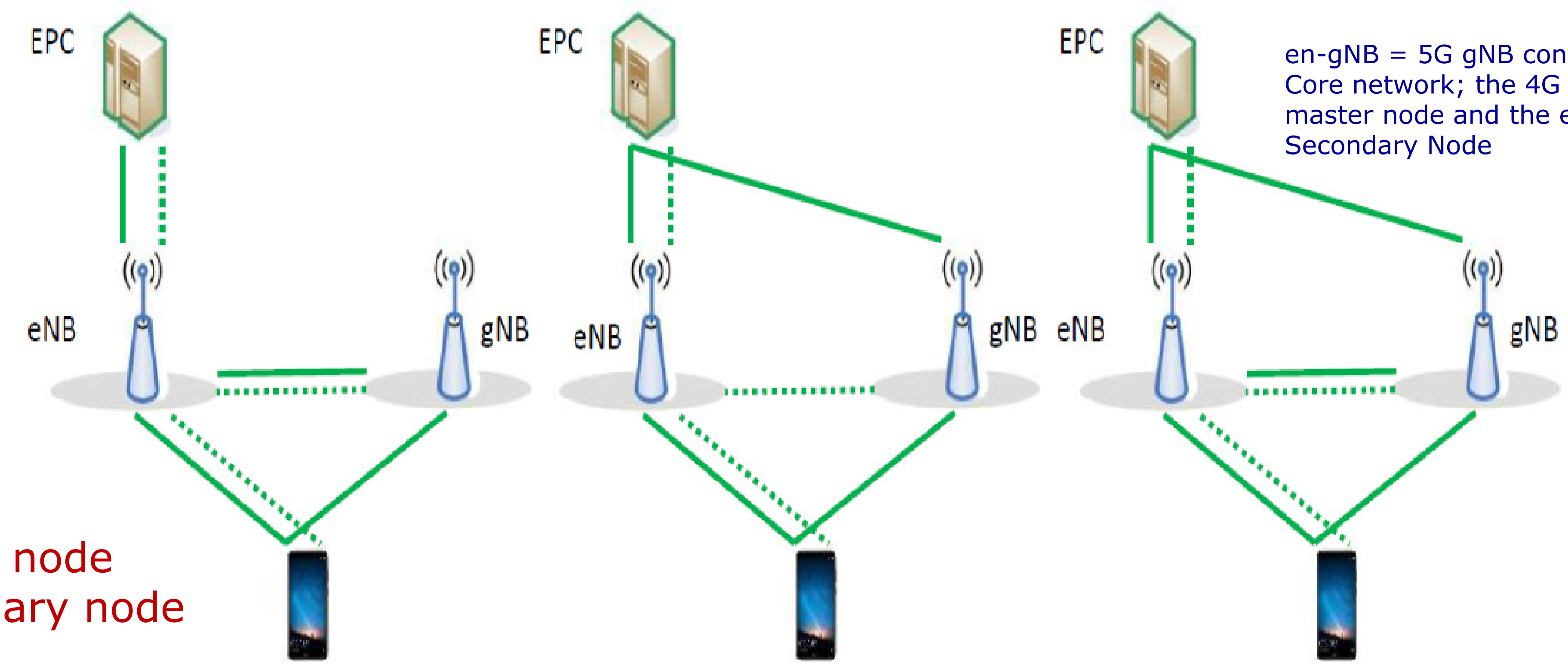
- Option #2 requires the device to support both a radio front end capable of receiving and transmitting data over NR as well as new procedures for the 5GC.



. A new standalone 5G network deploying 5GC and gNodeB (Option 2).

Non-Standalone 5G Network (Option 3/3a/3x)

Core network = 4G | RAN = 4G and 5G with eNB being the **Master Node**



en-gNB = 5G gNB connected to the 4G Core network; the 4G eNB acts as a master node and the en-gNB is used as a Secondary Node

MN = Master node
SN = Secondary node

User Plane
Control Plane

3GPP decided to concentrate initially on NSA option 3 – being the easiest to roll out by operators having existing LTE networks.
The specifications for these were completed in December 2017.

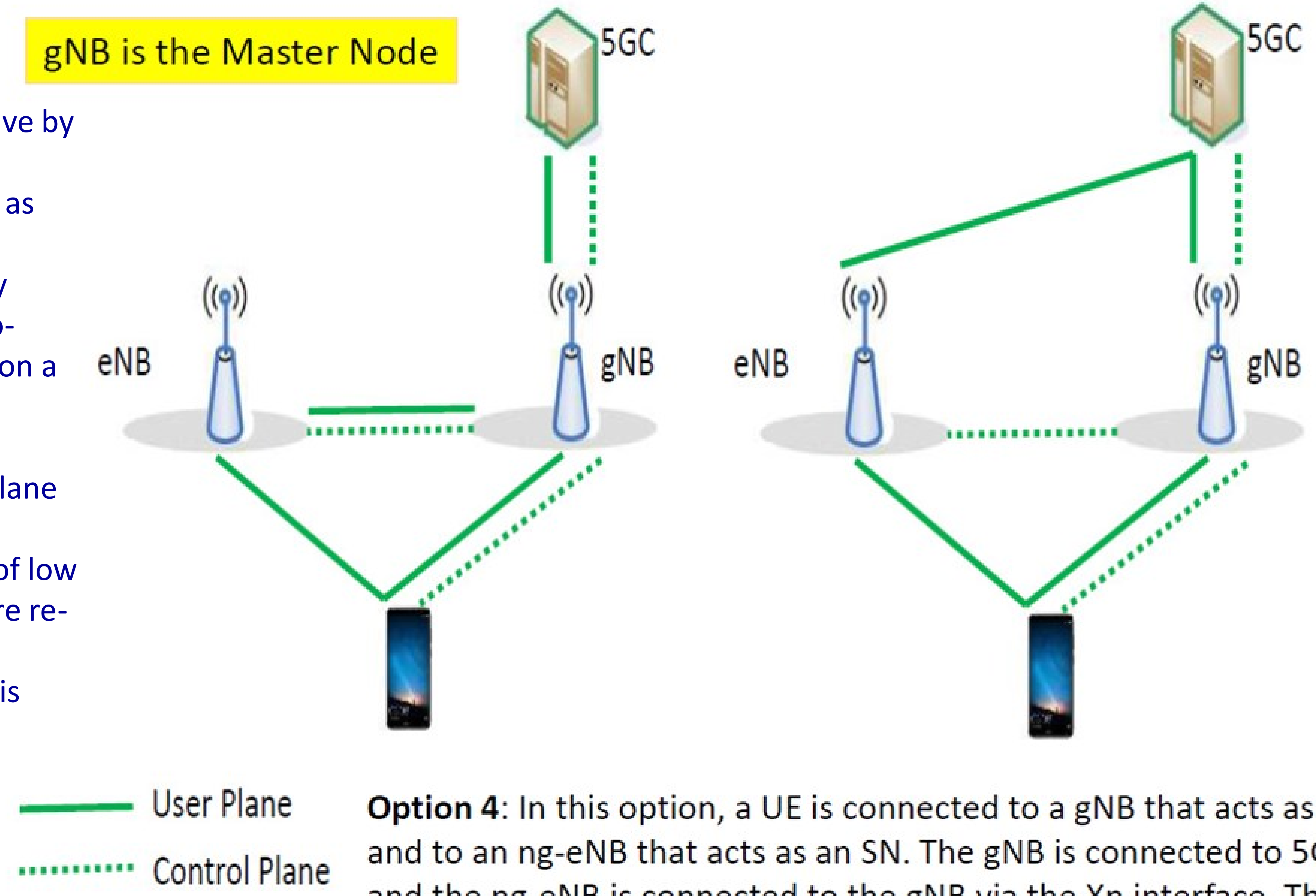
Option 3 or EN-DC (LTE-NR Dual Connectivity): a UE is connected to an eNB that acts as a **MN** and to an en-gNB that acts as a **SN**. The eNB is connected to the EPC via the S1 interface and to the en-gNB via the X2 interface. The en-gNB may also be connected to the EPC via the S1-U interface and to other en-gNBs via the X2-U interface. The en-gNB may send UP to the EPC either directly or via the eNB.

Non-Standalone 5G Network (Option 4)

gNB is the Master Node

- Option 4 is considered attractive by some operators as it allows connectivity to a 5GC with NR as the master cell (control plane anchor), and Dual connectivity (data aggregation) with any co-existing LTE carriers deployed on a site.

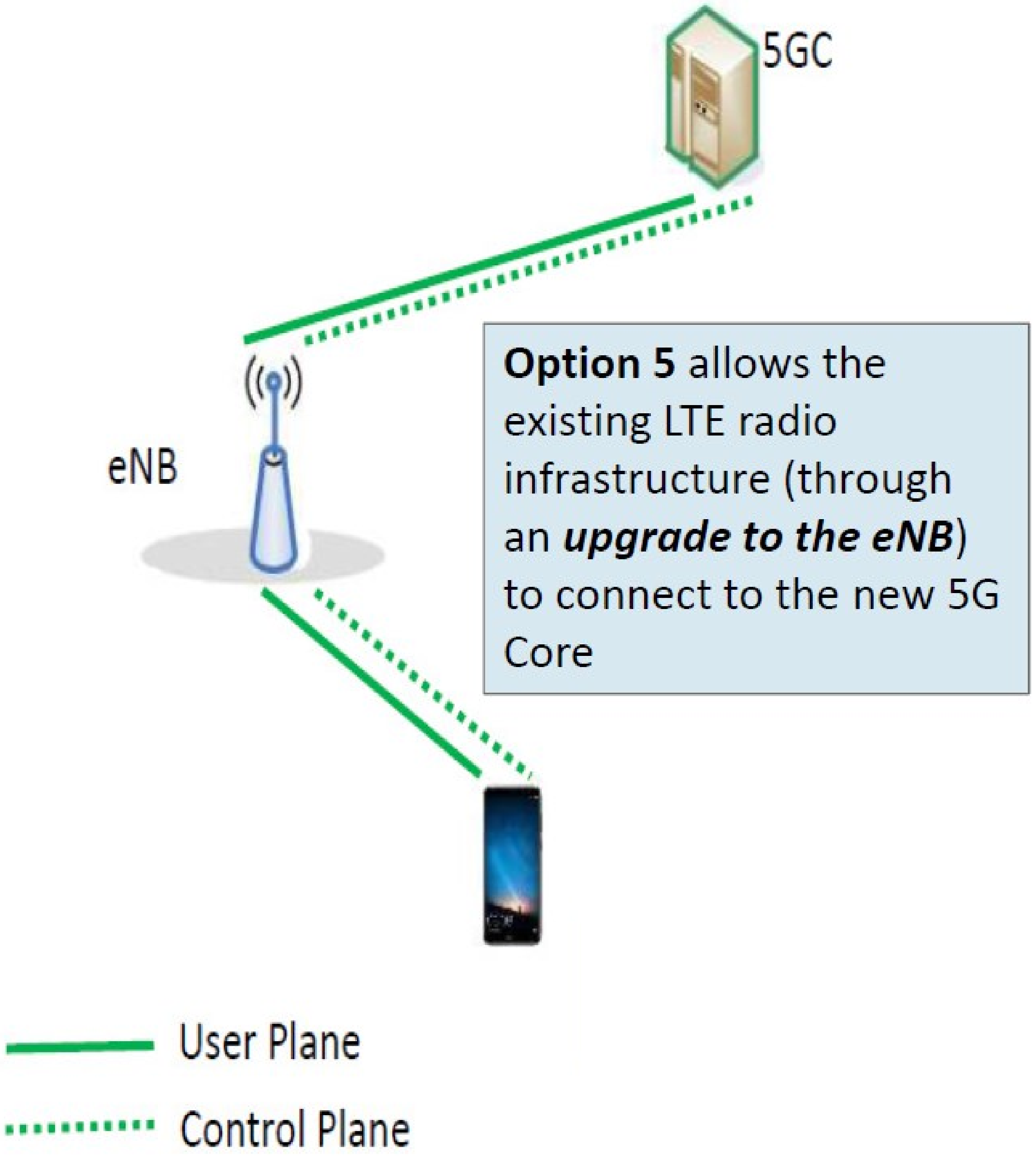
- As the anchor of the control plane is NR, this option is more appropriate for deployments of low band NR, or, in scenarios where re-farming or dynamic spectrum sharing on existing low bands is feasible.



ng-eNB = Next generation (eNB); an enhanced 4G eNodeB that connects to the 5C Core network

Option 4: In this option, a UE is connected to a gNB that acts as a MN and to an ng-eNB that acts as an SN. The gNB is connected to 5GC and the ng-eNB is connected to the gNB via the Xn interface. The eNB may send UP to the 5G Core either directly or via the gNB.

Standalone 5G Network (Option 5)

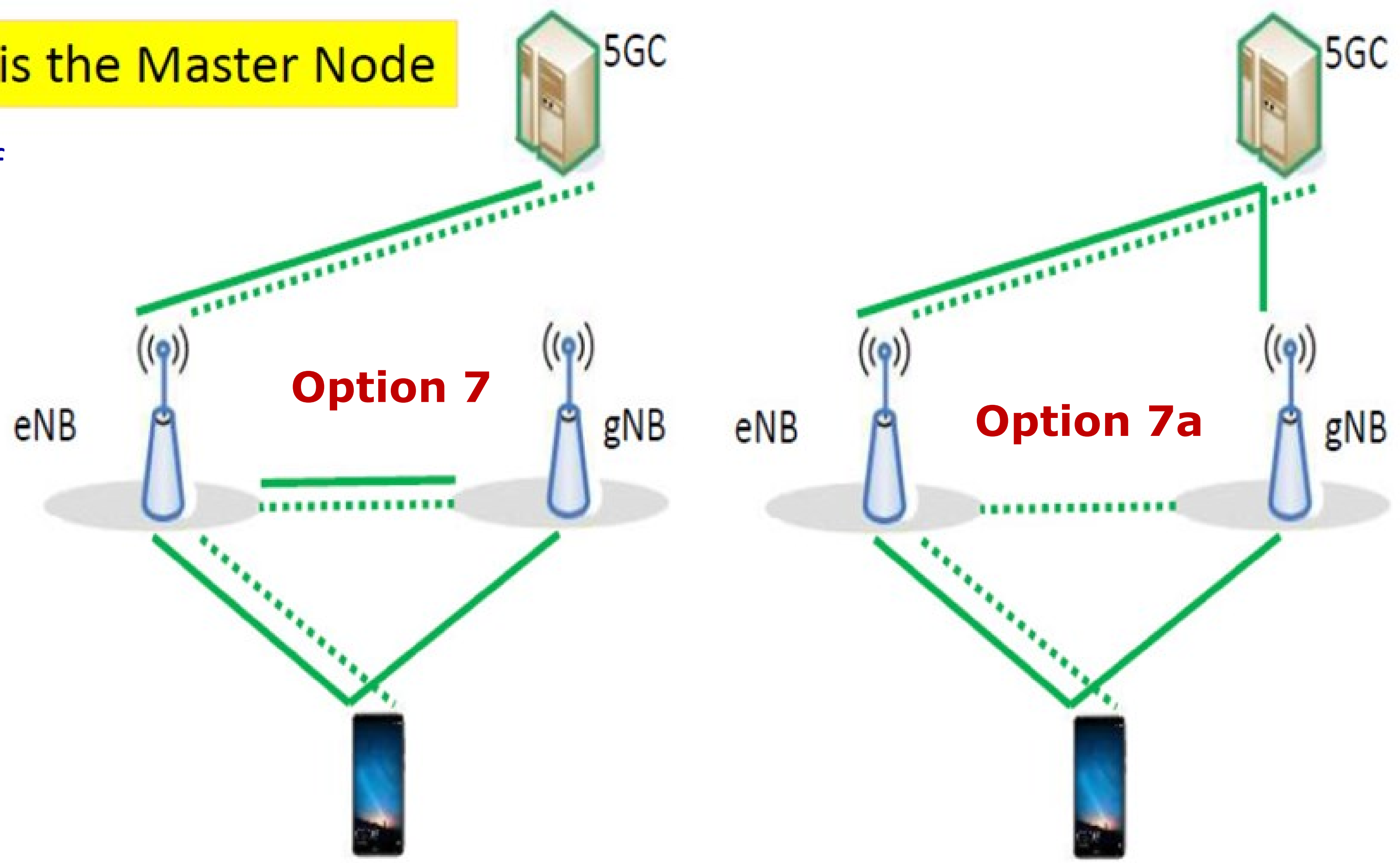


- The key attractiveness of this option lies in the ability for an operator to rapidly roll out wide-area services that require 5GC capabilities (such as Mobile Edge Computing and Network Slicing) by fully leveraging existing LTE coverage and capacity.

- By effectively increasing the utilization of 5GC services for customers over wider LTE coverage areas this will make early 5GC investments more attractive for Operators and minimize any incremental investments in legacy EPC functionality.

Non-Standalone 5G Network (Option 7/7a)

eNB is the Master Node



User Plane

Control Plane

Option 7 combines the advantages of Option 5 with the added benefit of Dual Connectivity allowing data aggregation with any co-existing 5G NR carriers to improve throughput.

Dual Connectivity also improves service continuity when moving between NR and LTE coverage by removing the need for Inter-RAT/Inter Core handovers which may be significant/frequent if 5G NR is deployed on higher bands such 3.5 GHz or millimeter wave bands.

Option 7 effectively forms the natural evolution of Option 3

Option 7: a UE is connected to an ng-eNB that acts as a MN and to a gNB that acts as an SN. The ng-eNB is connected to the 5GC, and the gNB is connected to the ng-eNB via the Xn interface. The gNB may send UP to the 5GC either directly or via the ng-eNB.

In all things, it is better to hope tl

Technical Comparison Between 5G NSA and SA Options

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

- EN-**DC** = LTE-**5G NR** dual connectivity
- NR-DC = NR – E-UTRA Dual Connectivity (Dual Connectivity configuration using the 5GC, whereby both the master and secondary RAN nodes are 5G gNBs)
- NGEN-DC = NG-RAN – E-UTRA Dual Connectivity (Dual Connectivity configuration using the 5GC, whereby the master RAN is a 4G ng-eNB and the secondary RAN node is a 5G gNB).
- MR-DC = Multi-RAT Dual Connectivity (General term given to a range of different Dual Connectivity configuration options)

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Economic Comparison Between 5G NSA and SA Options

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

5G MIGRATION PATHS

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

- There are therefore several possible “paths” operators can follow to first introduce 5G and then migrate it to the target configuration(s).

- This section presents a selection of what are thought to be likely introduction and migration scenarios. However, many aspects need to be considered when deciding on the best migration strategy, including spectrum allocation, support for other service and industries, and support of 5G capabilities in terminals.

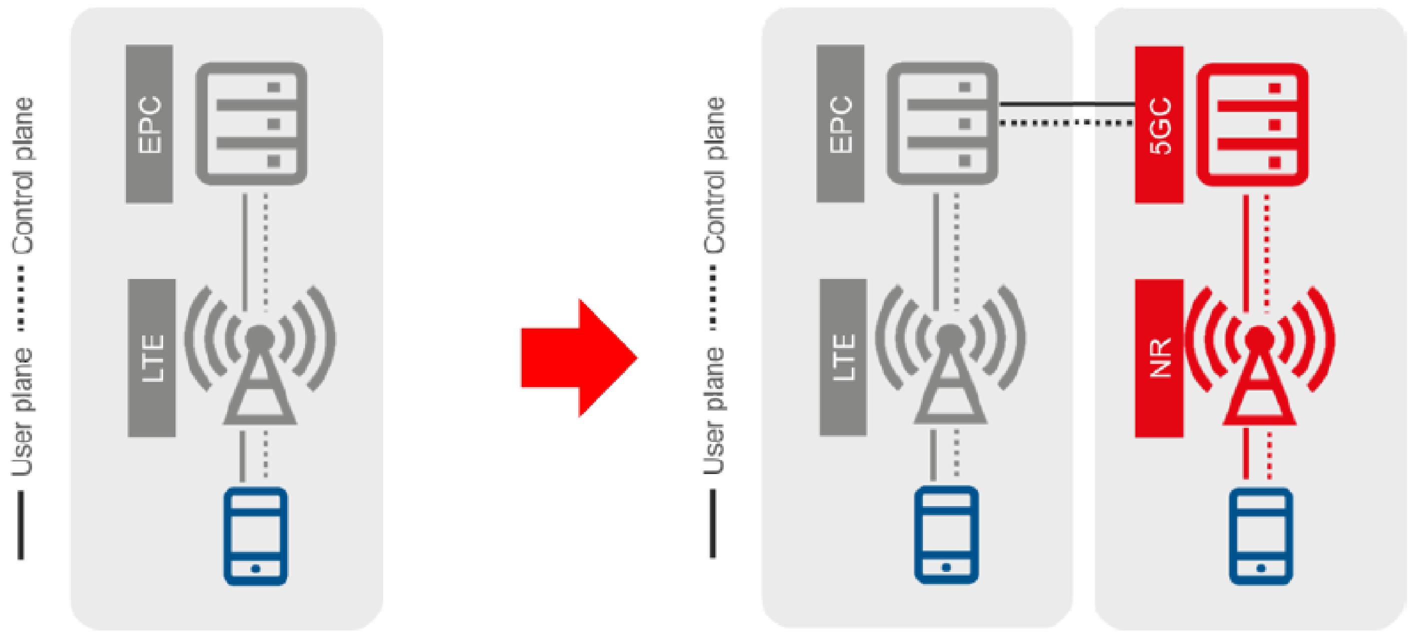
- In this section, it is assumed that the operator:
  - has deployed a full 4G system comprising an EPC and LTE access
  - plans to migrate in mid- or long-term to 5GS.

FROM EPC to SA Option #2

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

- One of the key benefit of this option is that SA architecture can take full advantage of 5G end-to-end network capabilities supported by NR and 5GC, providing customized service, especially to vertical industry, in an effective and efficient way.

Description of EPS to SA Option #2



- New features, including service-based architecture, end-to-end network slicing, and MEC, can be enabled according to specific requirement of each service, providing customized superior user experience.

- Compared to EPC-based deployment options such as Option 1 and Option 3, this option provides an open, flexible, and service-based network architecture for 5G which can fully exert the ability of 5G.

- In this context, it may be considered as the deployment choice for operators who need to fulfil the market requirements, especially of vertical industries. It is also a long term network architecture as it already uses both the newly defined radio and core network. Direct interworking between 5GS and 2G/3G CS domain is not considered at the beginning of deployment for Option #2 option.

FROM EPC to SA Option #2

Impact on Device and Network

- SA Option #2 envisages the deployment of both NR gNB based NG-RAN as a new radio access and 5GC as new core along with new features on LTE eNB based E-UTRAN to support inter-RAT mobility.

- Option #2 requires the device to support both a radio front end capable of receiving and transmitting data over NR as well as new procedures for the 5GC.

- Since SA operator provides services that are delivered over standalone 5GS, interworking between 5GS and EPS for service continuity for those services may be required.

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

Impact on Voice Including Service Continuity

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

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

FROM EPC to SA Option #2

- If the operator only offers VoLTE service over EPS, then interworking of 5GS with EPS is necessary for subscribers to fall back from 5G to 4G when voice service is required.

- If the operator provides VoLTE with partial coverage and CS voice complements VoLTE to support national coverage, then the operator needs to utilize existing VoLTE service and ensure that continuity between LTE and CS access is implemented (i.e., SRVCC: Single Radio Voice Call Continuity).

- In the case where the VoLTE service does not provide continuity between LTE and CS access, then the voice call continuity would not be guaranteed for regions where VoLTE is not supported.

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

- Otherwise, the migration step would not guarantee voice service continuity as there is no standardized solution for 5G networks (5GS) equivalent to the SRVCC operation defined for 4G networks (EPS) in initial release of 5G (3GPP Release 15).

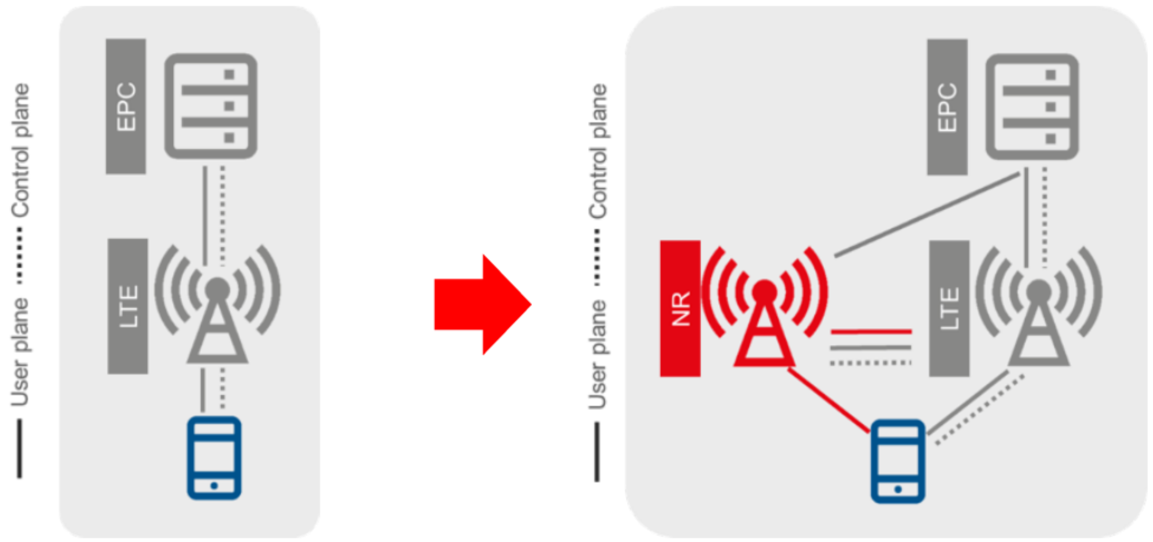
- Note that there is also no Circuit Switched Fallback (CSFB) operation available for 5GS.

FROM EPC to NSA Option #3

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

- One of the key advantages of this option is that it only requires the development of specifications of NR as non-standalone access as part of E-UTRAN connected to EPC rather than the specification of the full 5G system as it is the case for standalone NR and other 5GS cases. In Dec. 2017, 3GPP completed the specifications of Option #3.

Description of EPS to NSA Option #3



- Besides the accelerated time to market, as the NR will augment the existing capability of the LTE radio network, this option allows flexible “on demand” deployment where capacity is needed using the same or different vendors for LTE and NR.

- Furthermore, this option is going to be maintained in future releases of 3GPP (beyond release 15) and therefore can be used in longerterm, even if other options are deployed in parallel.

- The capability of deploying NR while anchoring the communication to the EPC network offers the opportunity of making optimal use of the spectrum above 6GHz where operators will have available the large bandwidths necessary to deliver the high throughput in hotspots but that cannot be provided easily over large areas due to the fast signal attenuation.

In all things, it is better to hope than to despair.

FROM EPC to NSA Option #3

- However, NR in option 3 can also be deployed in spectrum bands below 6GHz and the example above should be considered as illustration of one of the possible deployment scenarios.

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

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

- The 5GC is not going to be used in this option, thus, none of the differentiating capabilities of the new architecture are available to the operator.

Impact on Device and Network:

- NSA Option #3 requires deployment of NSA NR en-gNB in E-UTRAN and new features on LTE eNB to support EN-DC procedures, hence has impacts on E-UTRAN.

- NSA Option #3 has also impact on UE, but limited impact on EPC and HSS depending on operators' choice, and no impact on IMS. From the point of view of the device, the attractiveness of this solution is that it only requires the additional support of specifications of NR as non-standalone access as part of E-UTRAN connected to EPC.

FROM EPC to NSA Option #3

- The device will communicate with the core network using the same EPC procedures used by currently available devices either under only LTE or under both LTE and NR radio coverage.

- It should be noted however that combining of LTE and NR radio interfaces for split bearers may increase memory requirements.

Impact on IMS Voice Including Service Continuity

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

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

- If the operator provides VoLTE with partial coverage and CS voice complements VoLTE to support national coverage, then the operator needs to utilize existing VoLTE service and ensure that continuity between LTE and CS access is implemented (e.g., SRVCC).

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

High-level Overview of Migration Step Analysis Results

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

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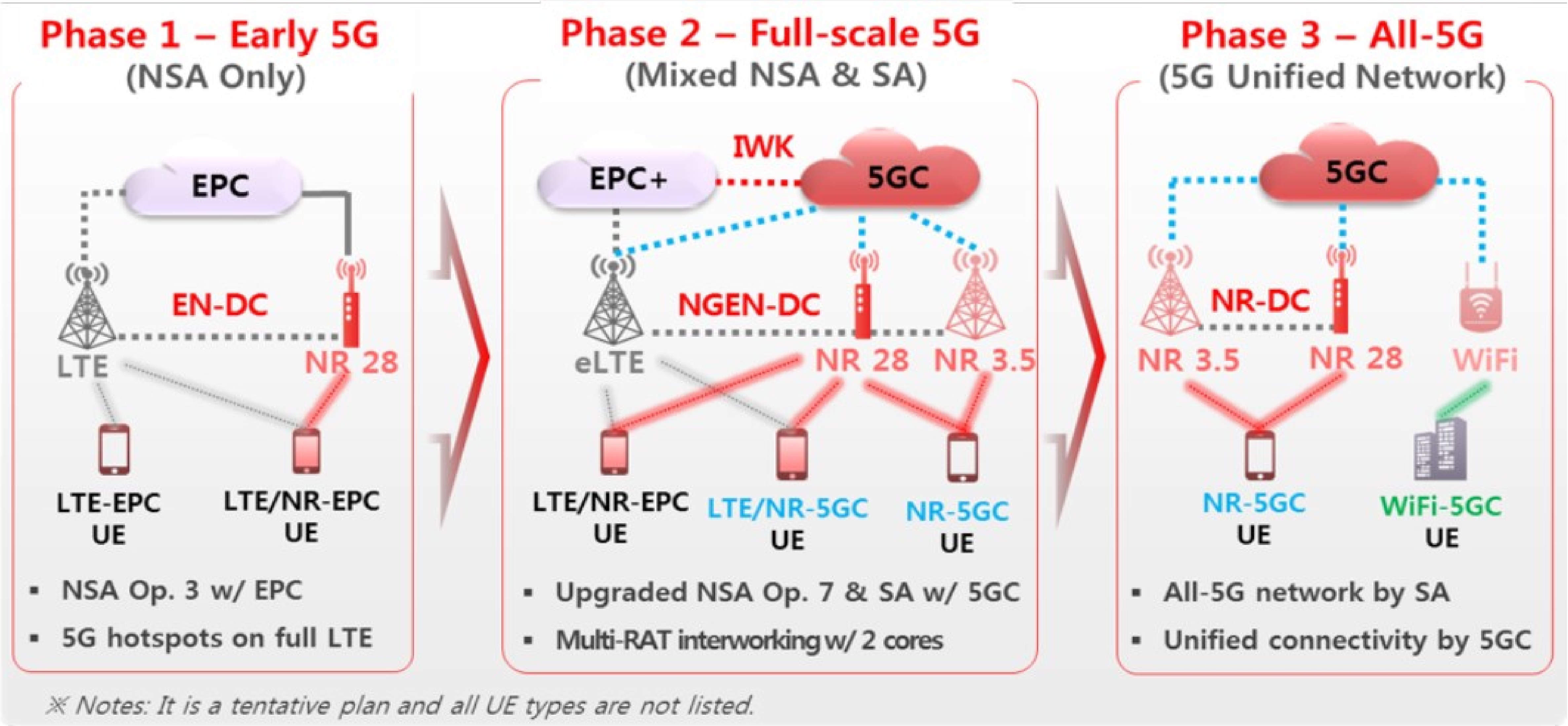
An Example of a Migration Plan of a Network Operator: Korea Telecom (KT)

KT's 5G Network Migration Plan **(First deployed 5G in April 2019)**



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- Towards 6G in 2030

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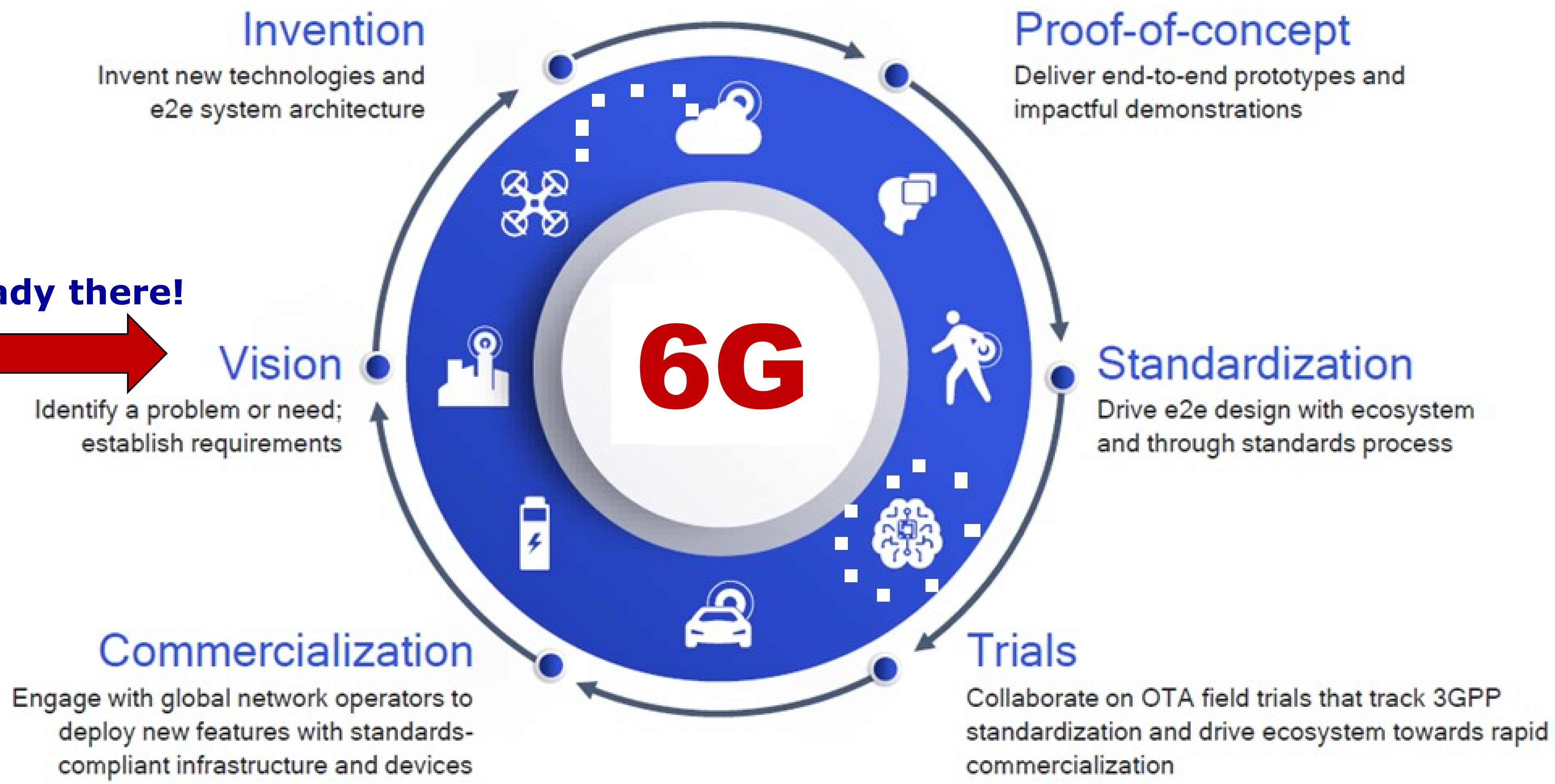
Towards 6G Network in 2030

The vision is already there!



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6G RAN KPIs

HUAWEI

Peak Data Rate:
1Tbps

Guaranteed Rate:
10-100Gbps

Network Capacity:
1000X w.r.t. 5G

Energy Efficiency
100X w.r.t. 5G
Energy Consumption<= 5G

Position Accuracy:
<50cm outdoor, 1cm indoor
Sensing Accuracy and Resolution
xx

Sensing Battery Life:
20 Years

Air Interface Latency:
0.1ms

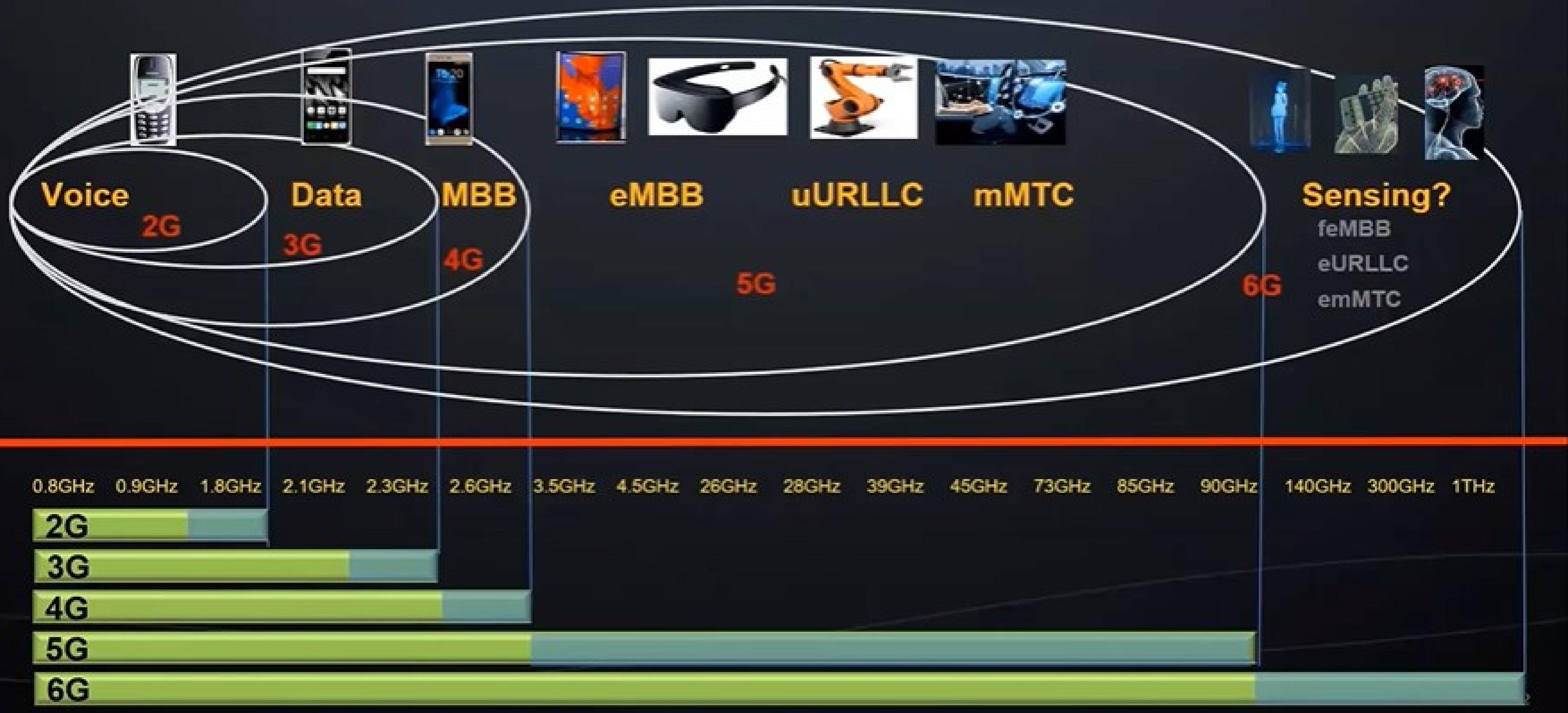
Device Density:
10millions/km^2

Reliability:
99.99999%

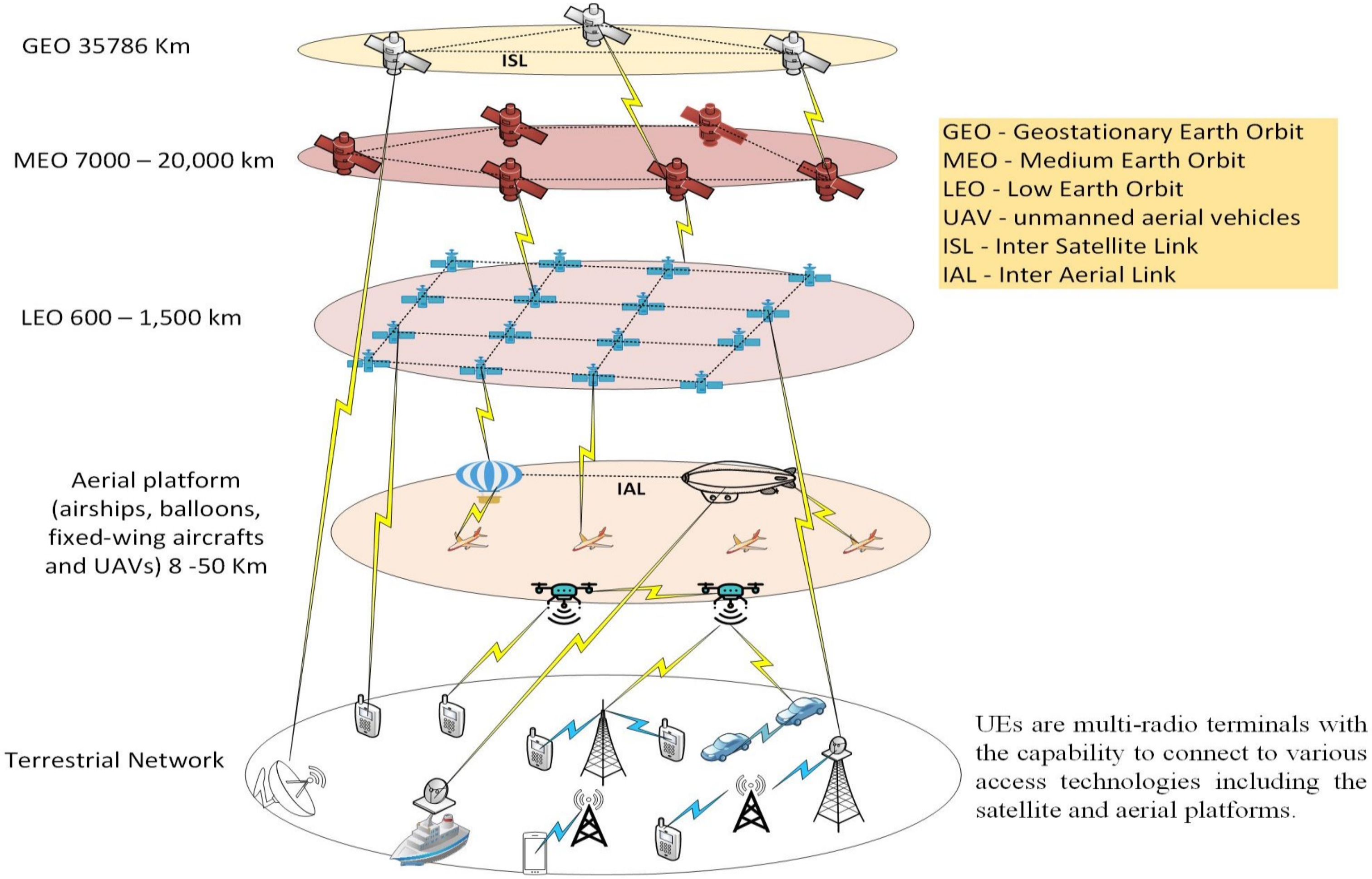
Network Coverage:
167dB

Air Interface Jitter:
+/-0.1ns

What are the New 6G Services?



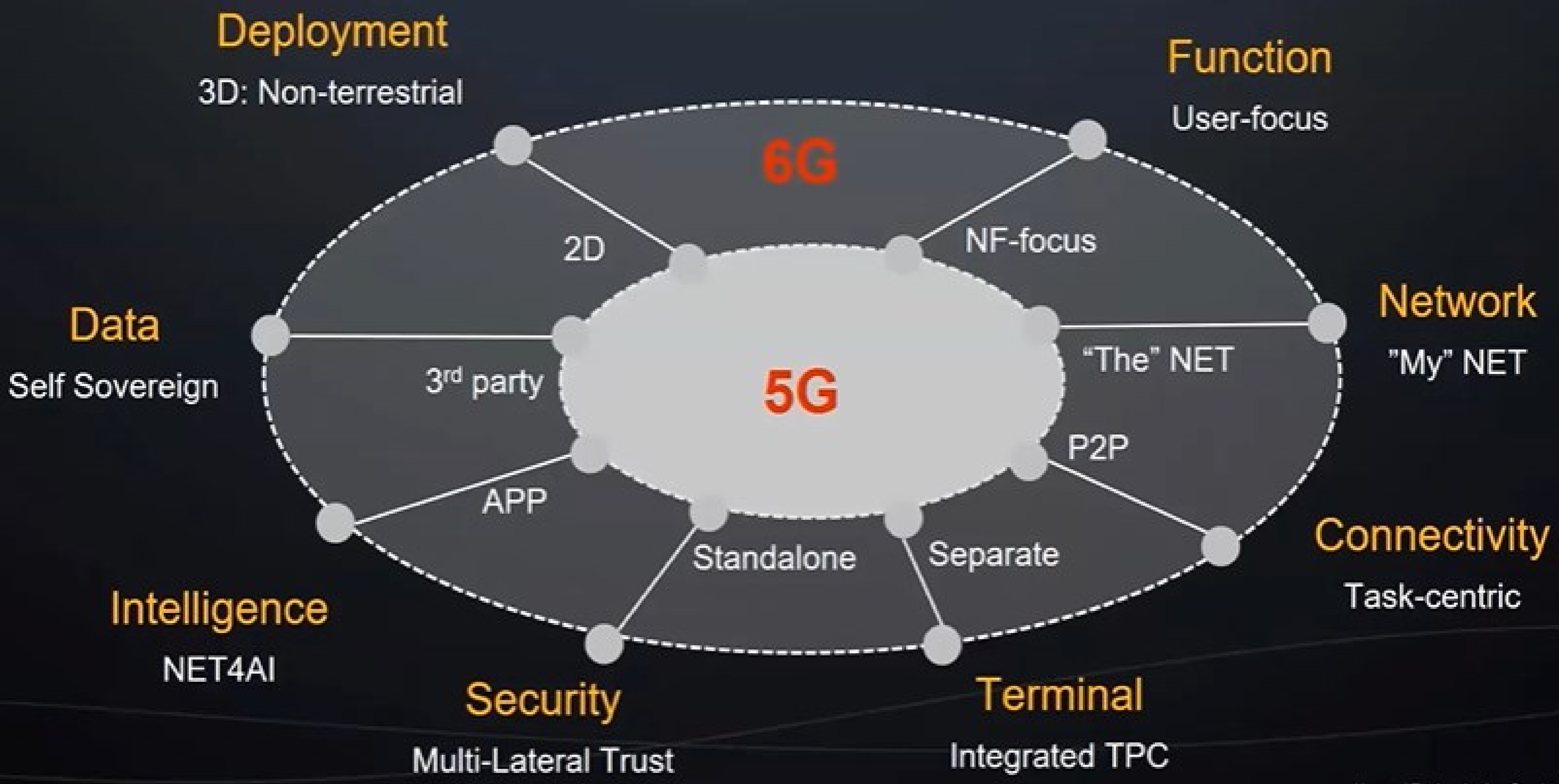
Towards 6G Network in 2030



Layered architecture of the terrestrial and non-terrestrial integrated network

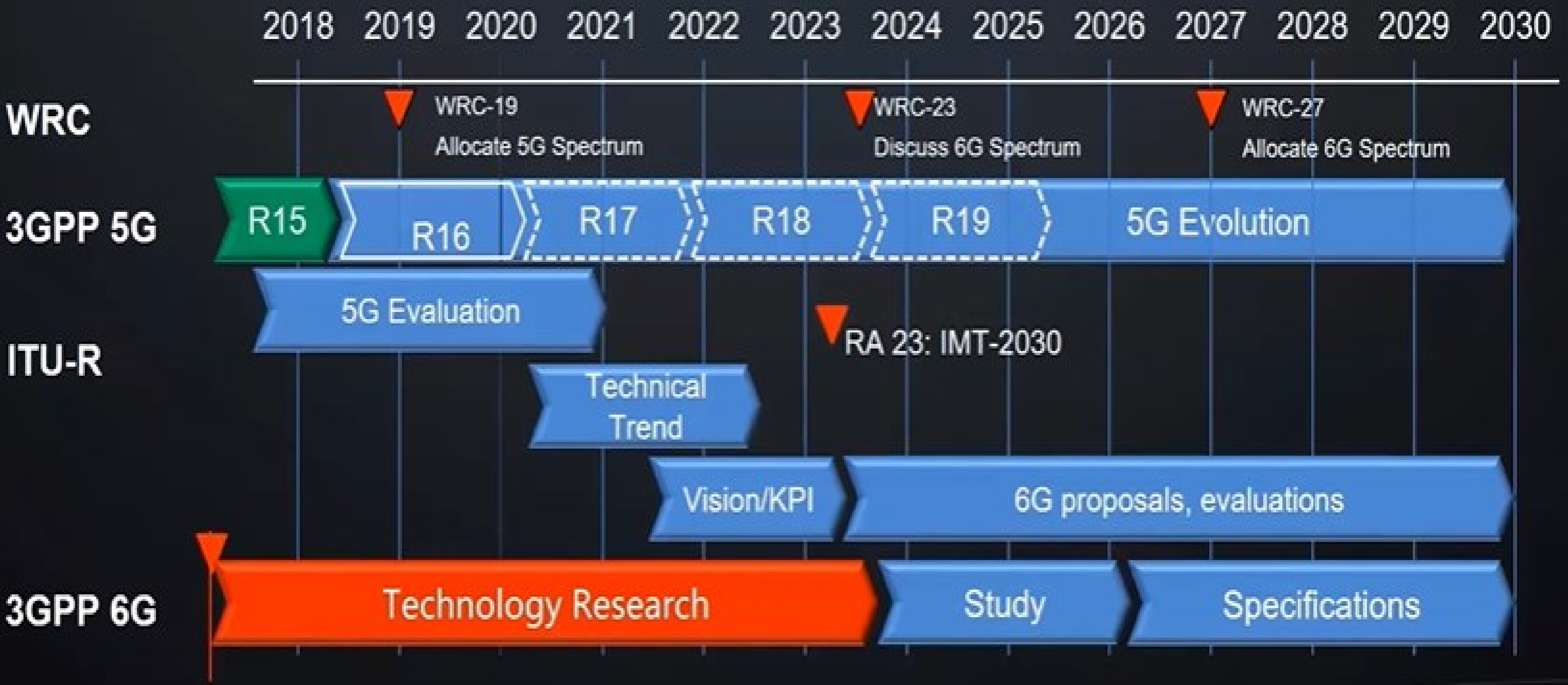
- It is envisioned that one of the enabling features of 6G is large dimensional coverage through space, air, ground, and sea network integration.
- To increase 5G's capabilities in providing ubiquitous broadband connectivity, 3GPP and ITU have proposed to integrate 5G with non-terrestrial networks (NTNs) such as:
  - satellite communications (SatComs)
  - high altitude platforms (HAPs)
  - low altitude platforms (LAPs) e.g. unmanned aerial vehicles (UAVs)

Paradigm Shifts of Future Network Architecture



Standardization Roadmap

The success of 6G remains a single global standard



EEE4121F Module A

"S/he who will attain the incredible must attempt the impossible."

"Never admit failure until you have made your last attempt. Never make your last attempt until you have succeeded."

"Every problem has a shelf life and an expiry date."

Never give up!

In all things, it is better to hope than to despair.