

4G-5G Interworking

RAN-level and CN-level Interworking
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SAMSUNG

Contents

Introduction	2
4G-5G Interworking	2
RAN-level Interworking	2
CN-level Interworking	3
Performance & Features Comparison	4
Performance Analysis	4
Network Features	11
Deployment Flexibility	12
Migration to a True 5G Network	14
Development at Samsung	15
Conclusion	15
Reference	15
Abbreviations	15

4G-5G Interworking

Introduction

To provide true 5G service to users, 5G cells will be deployed with full coverage and UE (User Equipment) will be able to connect to 5G network everywhere. However, in the early stage of 5G services, the 5G cells will be partially deployed and there will be 5G coverage holes.

The initial 5G commercial service will be launched from early 2019, but the initial investment for 5G service will be limited because of a lack of 5G UE.

So, the 5G network needs to be interworked with the existing LTE network. The interworking solution can provide seamless service to users. This white paper introduces the solutions for 4G-5G interworking and compares the solutions in terms of performance, the features and the migration to a true 5G service network.

4G-5G Interworking

If 5G cells are not deployed with full coverage, a seamless service can be provided to users by interworking with the existing LTE network, which is already deployed with full coverage. When the network evolved from 3G to LTE, LTE cells were deployed by partial coverage when LTE was first commercialized.

In order to overcome coverage shortage, the LTE network also provided seamless service to users by interworking with the 3G network.

Interworking between the 3G network and the LTE network was developed by the Core Network-level interworking solution, in which a 3G Core Network entity, SGSN (Serving GPRS Support Node), directly interfaces with LTE Core Network Entities, MME (Mobility Management Entity) and S-GW (Serving Gateway).

For 4G-5G interworking, two kinds of solutions, RAN-level interworking and CN-level interworking, are under discussion in 3GPP.

RAN-level Interworking

RAN-level interworking provides the interworking service between LTE and 5G using a direct interface between LTE eNB and 5G NB.

The control protocol (RRC) message is transmitted over the LTE radio interface, so the connection and the mobility of UE are controlled by LTE eNB. User traffic is simultaneously transmitted through LTE eNB and 5G NB (PDCP aggregation) or by using 5G NB (CN-split Bearer) only. Although the RRC message can be processed stably by LTE eNBs that provide coverage larger than 5G NBs, LTE radio interface always remains connected, even though user traffic is transmitted over the 5G radio interface (NR).

RAN-level interworking is necessary in NSA (Non-Standalone Architecture), where 5G Radio (NR) cannot be used without LTE Radio.

Two different core networks can be used for RAN-level interworking, as shown in Figure 1.

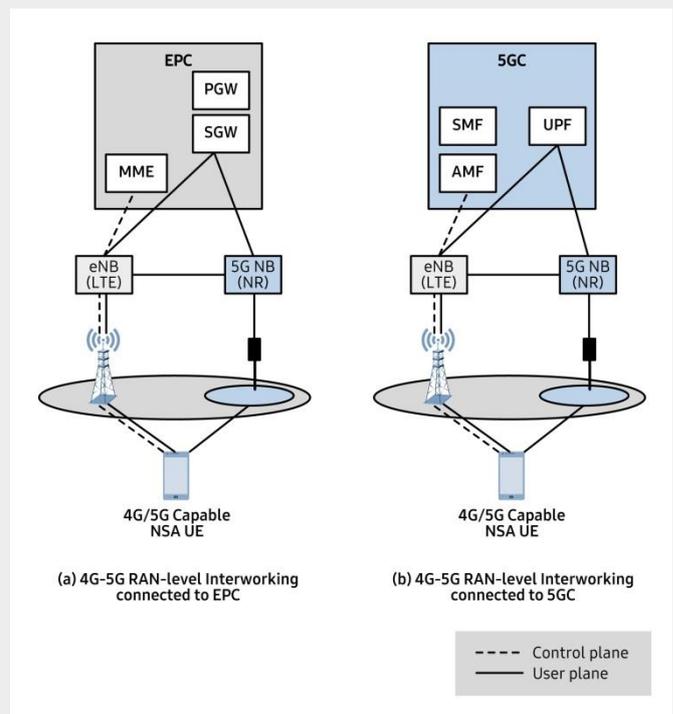


Figure 1. Architecture for RAN-Level Interworking

When using EPC (Evolved Packet Core) for an existing LTE network, basically only EPC-based service can be provided, even though 5G radio technology is used. Only high-speed data service can be provided to users using NR (New Radio) technology.

4G-5G Interworking

LTE and 5G interworking can be achieved by upgrading some LTE eNBs connected to 5G NBs and by increasing the gateway capacity in EPC.

The new 5G Core Network, which is called 5GC (5th Generation Core), can be introduced to support RAN-level interworking.

In this solution, the new 5G core network features, e.g. network slicing, can be supported and the 5G service can be differentiated from the LTE service. However, all LTE eNBs will be upgraded to eLTE eNBs that can be connected to 5GC.

CN-level Interworking

CN-level interworking does not require a direct interface between the LTE eNB and the 5G NB, but the EPC entity is connected to the 5GC entity.

The UE manages LTE and NR radio interface connection independently, and can be connected to a single network, either LTE or 5G. When the UE is located in 5G coverage, it can only connect to the 5G network and receive 5G service. When the UE moves out of 5G coverage, it releases NR radio interface connection and establishes LTE radio interface connection. Even though the network that the UE connects to changes, the IP address assigned to the UE is maintained and seamless service can be provided to the user.

CN-level interworking is necessary in SA (Standalone Architecture), where 5G Radio (NR) can be used without LTE Radio.

For CN-level interworking, the single registration solution and the dual registration solution are possible, as shown in Figure 2.

With the single registration, the UE registers to either one of the LTE or 5G networks at any moment, and the UE context can be delivered through the control interface between MME in EPC and AMF (Access and Mobility Management Function) in 5GC when the connected network for the UE is changed. In order to support the single registration solution, MME will be upgraded to support the MME-AMF interface (Nx) and S-GW needs to be connected to UPF in 5GC. LTE eNB should also be upgraded to support the mobility between LTE and 5G.

The dual registration solution is a way to allow the UE to register individually with EPC and 5GC. Thus, it does not need to forward the UE context between MME and AMF, and the interface between MME and AMF is not required. The movement between LTE and 5G is decided by the UE. The UE performs normal access procedures after moving to the other network.

Therefore, the solution can be supported by LTE eNBs with no or minimal changes. Also, the impact on EPC to support the dual registration solution can be minimized. However, in order to improve the mobility performance between LTE and 5G, it is necessary to temporarily support dual radio transmission when moving to the other network, although the UE can support dual registration solution even with single radio transmission capability.

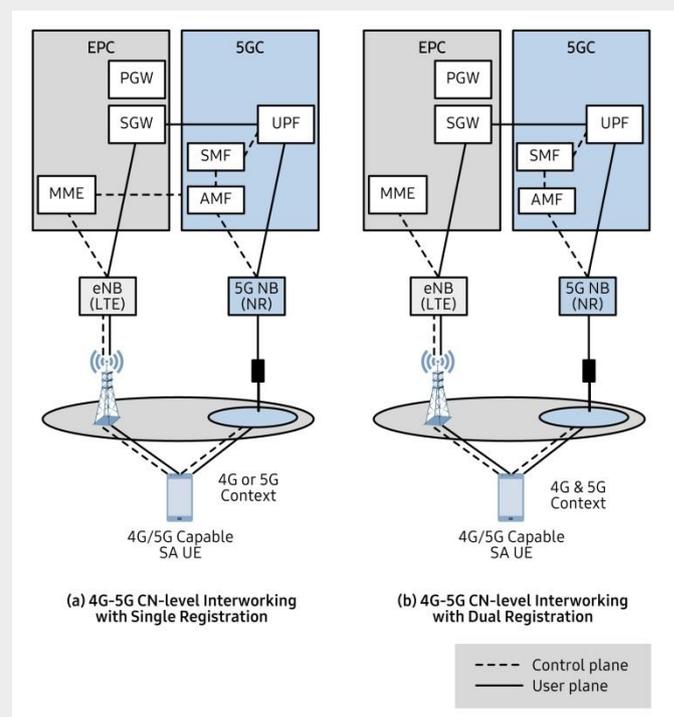


Figure 2. Architecture for CN-Level Interworking

4G-5G Interworking

Performance & Features Comparison

Performance Analysis

4G-5G interworking performance is analyzed in this section for each interworking architecture.

The analytical study is used for peak data rate, control/user/E2E latencies and mobility performance, and simulation is performed for energy efficiency analysis.

Peak Data Rate

Peak data rate is defined as the maximum theoretical data rate that is achievable when all radio resources are assigned to a single UE device. It is also calculated as the product of peak spectral efficiency and available bandwidth. If the available bandwidth for 5G below 6 GHz frequency bands is around 80 MHz and the peak spectral efficiency is 15 bit/s/Hz, the peak data rate would be 1.2 Gbps. On the other hand, if the available bandwidth of bands above 6 GHz is 667 MHz and the peak spectral efficiency in the bands is 30 bit/s/Hz, the peak data rate of 20 Gbps can be achieved.

If a 5G cell is aggregated with a LTE eNB in RAN-level interworking, the peak data rates of LTE link and 5G link can be summed, leading to a maximum peak rate of around 21 Gbps. For CN-level interworking, a single IP flow cannot be served through both LTE and 5G links, which results in the same peak data rate as the standalone case.

Table 1. Throughput Comparison

Item	RAN-level Interworking		5G SA with CN-level Interworking
	RAN-Aggregation	CN-split Bearer	
Max. Peak Rate	21 Gbps	20 Gbps	20 Gbps

Control Plane Latency

The latency performance of a system is analyzed for both control plane and user plane. In 3GPP TR 38.913,

control plane latency is defined as “the time to move from a battery efficient state (e.g. IDLE) to the start of continuous data transfer (e.g. ACTIVE).”

Considering agreements made during the study item phase of NR, the control plane latency can be analyzed as the transition time from an inactive state to the time to send the first uplink packet in the inactive state. Though detailed signaling procedures are not defined yet for connection resumption, the LTE resume call flow in Figure 3 can be used for this analysis, and steps 1 to 5 in the call flow can be considered as components of the control plane latency.

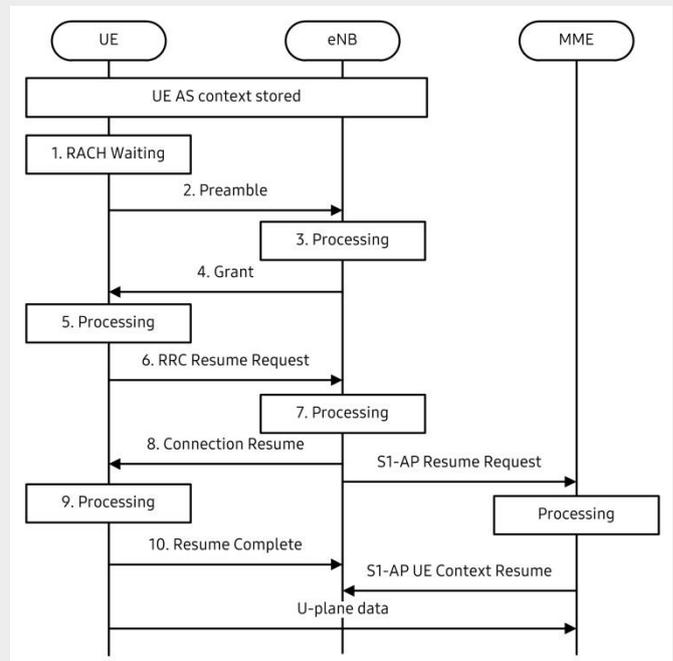


Figure 3. Reference Call Setup Procedure for Control Plane Latency

Table 2 shows the calculated latencies. The LTE Rel.10 column shows the latency with the same TTI length (1 ms) and processing delay as LTE.

The analysis for NR can reuse the same approach as LTE but with different system parameters, such as TTI and processing delay, due to enhanced hardware capability. Considering ongoing discussion and status in 3GPP, a 2-symbol TTI (1/7 ms assuming the same number of symbols as LTE in a 1 ms sub-frame) seems an acceptable assumption for the NR mini-slot.

For processing delay, various options including the same

4G-5G Interworking

delay as LTE, and 50 % less or 33 % less processing delay can be considered for examples.

The remaining columns in Table 2 show the calculated control plane latencies and total latencies for full connection resumption corresponding to the processing delay assumptions.

If a 5G NB is integrated with a LTE eNB, and the control protocol (i.e. RRC) is located in the LTE eNB, the control plane latency will be the same as in the LTE case.

As a result shown in Table 3, the control plane latency in CN-level interworking case is almost 1/3 of that of RAN-level interworking case.

Table 2. Control plane latency and total latency for full connection resumption

Component	Description	LTE Rel.10	NR-1 (1/7 ms TTI)	NR-2 (1/7 ms TTI, 1/2 processing delay)	NR-2 (1/7 ms TTI, 1/3 processing delay)
1	Average delay due to RACH scheduling period (1 ms RACH cycle)	0.5	1/14	1/14	1/14
2	RACH Preamble	1	1/7	1/7	1/7
3-4	Preamble detection and transmission of RA response (time between the end RACH transmission and the UE's reception of scheduling grant and timing adjustment)	3 (2 + 1)	2 + 1/7	1 + 1/7	2/3 + 1/7
5	UE Processing Delay (decoding of scheduling grant, timing alignment and C-RNTI assignment + L1 encoding of RRC Connection Request)	5	5	2.5	5/3
6	Transmission of RRC Connection Resume Request	1	1/7	1/7	1/7
7	Processing delay in eNB (L2 and RRC)	4	4	2	4/3
8	Transmission of RRC Connection Resume (and UL grant)	1	1/7	1/7	1/7
9	Processing delay in the UE (L2 and RRC)	15	15	7.5	5
10	Transmission of RRC Connection Resume complete	1	1/7	1/7	1/7
Total delay for full resumption	-	31.5 ms	26.8 ms	13.8 ms	9.5 ms
	(TTI Dependent Latency)	5.5 ms	0.8 ms	0.8 ms	0.8 ms
	(Processing Dependent Latency)	26 ms	26 ms	13 ms	8.7 ms

Table 3. Control Plane Latency Comparison

	RAN-level Interworking	5G SA with CN-level Interworking
Control Plane Latency	31.5 ms	9.5 ms

4G-5G Interworking

User Plane Latency

In 3GPP TR 38.913, the user plane latency is defined as “the time to successfully deliver an application layer packet/message from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point via the radio interface in both uplink and downlink directions, where neither device nor Base Station reception is restricted by DRX.”

In other words, the user plane latency is analyzed as the radio interface latency from the time when transmitter PDCP receives an IP packet to the time when receiver PDCP successfully receives the IP packet (and delivers the packet to the upper layer).

Figure 4 shows modeling used for LTE user plane latency analysis in FDD and TDD frame structures. [TR 36.912] The same model can be reused for 5G user plane latency analysis, as the model is suitably generic.

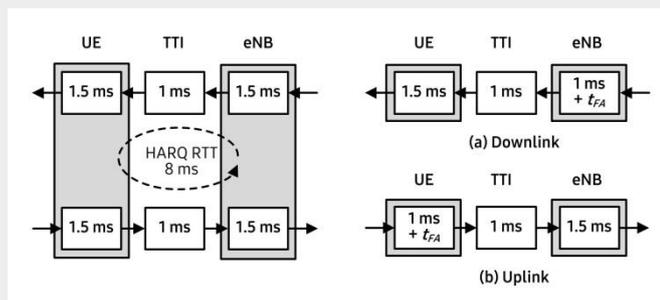


Figure 4. LTE user plane latency for FDD (left) and TDD (right) frame structures

For FDD, the following parameters are assumed to calculate user plane latency. There are already some agreements in 3GPP RAN WG1 regarding subcarrier spacing (15 kHz $\times 2^n$) and the number of symbols for mini-slot (2 symbols). The same approach used for LTE can be re-used in transmitter and receiver processing delay, i.e. same as TTI.

HARQ RTT needs further discussion.

However, examples using HARQ RTT as the same as LTE and as slightly reduced can be considered.

- Subcarrier spacing: 15 kHz, 30 kHz, 60 kHz, etc.
- OFDM symbols per TTI: 2 for mini-slot
- Transmitter processing delay: same as TTI

- TTI: dependent on subcarrier spacing and number of symbols per TTI
- Receiver processing delay: same as TTI
- HARQ RTT: 6 or 8 TTIs (assuming 3 or 4 TTIs for HARQ feedback timing)

Table 4 shows overall user plane latency for LTE and two selected PHY configurations of NR in FDD frame structure. NR-FDD-1 configuration assumes 15 kHz subcarrier spacing and 2-symbol TTI with 8 TTI HARQ RTT, which leads to 0.571 ms user plane latency without HARQ retransmission, and 0.685 ms with 10 % HARQ BLER.

NR-FDD-2 configuration assumes 60 kHz subcarrier spacing, 2-symbol TTI with 6 TTI HARQ RTT that leads to 0.1429 ms and 0.1643 ms user plane latency with and without HARQ retransmission.

For TDD, DL/UL configuration needs to be considered in addition to the parameters used for FDD. A configuration the same as LTE and enhanced configurations to support lower latency, such as repeated S-U sub-frames, can be considered as examples.

The number of OFDM symbols per TTI also needs further consideration, as the same (2-symbol mini-slot) as that used for FDD may not be optimal for TDD, considering additional DL/UL switching overhead.

The agreement for latency reduction in Rel.14-7 symbols per TTI-can be used as the starting point.

- OFDM symbols per TTI: 7 (slot) or less
- DL/UL configuration: same as LTE, repeated S-U, etc.

Table 5 shows the overall user plane latency for LTE and two selected TDD configurations, similar to Table 4.

NR-TDD-1 configuration assumes 15 kHz subcarrier spacing and 7-symbol TTI with a DL/UL configuration the same as LTE TDD configuration #6, which leads to 3.075 ms and 2.775 ms user plane latency for downlink and uplink respectively without HARQ retransmission, and 3.54 ms downlink and 3.2575 ms uplink with 10 % HARQ BLER.

NR-TDD-2 configuration assumes 60 kHz subcarrier spacing, 4-symbol TTI with repeated S/U sub-frames, which leads to 0.3124 ms and 0.355 ms user plane latency with and without HARQ retransmission.

4G-5G Interworking

Table 4. User plane latency w/ and w/o HARQ retransmission for FDD frame structure

	LTE Rel.10	NR-FDD-1	NR-FDD-2
Subcarrier Spacing	15 kHz	15 kHz	60 kHz
OFDM symbols per TTI	14	2	2
(1.1) Transmitter processing delay	1 ms	0.143 ms	0.0357 ms
(1.2) Frame alignment time	0.5 ms	0.071 ms	0.0179 ms
(1.3) Transmission time (= TTI)	1 ms	0.143 ms	0.0357 ms
(1.4) Receiver processing delay	1.5 ms	0.214 ms	0.0536 ms
One way latency = (1.1) + (1.2) + (1.3) + (1.4)	4 ms	0.571 ms	0.1429 ms
HARQ RTT (round-trip time)	8 ms (n + 4 NACK, n + 4 Re-Tx)	1.142 ms (n + 4 NACK, n + 4 Re-Tx)	0.2143ms (n + 3 NACK, n + 3 Re-Tx)
User plane latency with 10 % HARQ BLER 10 % = (one way latency) + 0.1 × (HARQ RTT)	4.8 ms	0.685 ms	0.1643 ms

Table 5. User plane latency w/ and w/o HARQ retransmission for TDD frame structure

	LTE Rel.10	NR-TDD-1	NR-TDD-2
Subcarrier Spacing	15 kHz	15 kHz	60 kHz
OFDM symbols per TTI	14	7	4
DL/UL configuration	LTE conf. #6	LTE conf. #6	S-U repeated
(1.1) Transmitter processing delay	1 ms	0.5 ms	0.0714 ms
(1.2) Frame alignment time	1.4 ms (DL)/ 1.4 ms (UL)	1.325 ms (DL)/ 1.025 ms (UL)	0.0714 ms
(1.3) Transmission time (= TTI)	1 ms	0.5 ms	0.0714 ms
(1.4) Receiver processing delay	1.5 ms	0.75 ms	0.1071 ms
One way latency = (1.1) + (1.2) + (1.3) + (1.4)	4.9 ms (DL)/ 4.9 ms (UL)	3.075 ms (DL)/ 2.775 ms (UL)	0.3124 ms
HARQ RTT (round-trip time)	11.2 ms (DL)/ 11.5 ms (UL)	4.65 ms (DL)/ 4.825 ms (UL)	0.4286 ms
User plane latency (HARQ BLER 10 %)	6.02 ms (DL)/ 6.05 ms (UL)	3.54 ms (DL)/ 3.2575 ms (UL)	0.355 ms

4G-5G Interworking

If a 5G cell is aggregated with an LTE eNB, and an IP flow is transmitted through both the LTE and the 5G NR air interface, the user plane latency is limited to the latency of the LTE link (i.e. 6 ms in Table 6)

Table 6. User Plane Latency Comparison

	RAN-level Interworking	5G SA with CN-level Interworking
User Plane Latency	6 ms	0.35 ms

Mobility

Mobility performance can be evaluated as the interruption time during the handover or while inter-RAT change occurs. For 4G-5G interworking, two scenarios can be considered for performance comparison. The first scenario is the NR-to-NR change scenario, while the second is the NR-to-LTE change scenario.

When RAN-level interworking is used, there are two NR-to-NR change scenarios: NR-to-NR change with or without LTE anchor change. If the LTE anchor is not changed, only the NR-to-NR change signaling procedure is performed, as shown in Figure 5 (a). The change time is similar to the normal macro handover time and is expected to take around 45 ms. But more procedure steps are required for simultaneous LTE anchor and NR cell change.

As shown in Figure 5 (b), the radio resource at source NR cell is released first. Then LTE-to-LTE handover is performed. Finally, the target 5G cell resource is newly assigned. So, NR cell change time with LTE anchor change is longer and may take around 75 ms. Even when a CN-split bearer is used, signaling procedures between the UE and NR/LTE are almost the same. So, the handover time will be the same as when PDCP aggregation is used.

When CN-level interworking is used, NR-to-NR handover is independent of LTE handover.

Furthermore, to improve the handover performance, the handover procedure with multi-connectivity to source and target NR is under development.

When applying multi-connectivity handover procedures, the NR-to-NR handover can be performed with almost zero interruption time as shown in Figure 6.

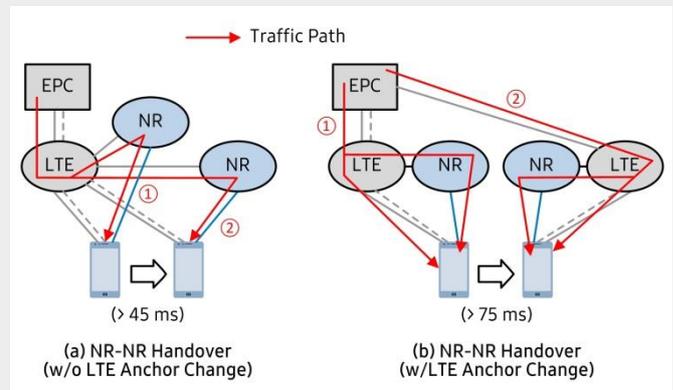


Figure 5. NR-NR Handover/Switching in RAN-level Interworking

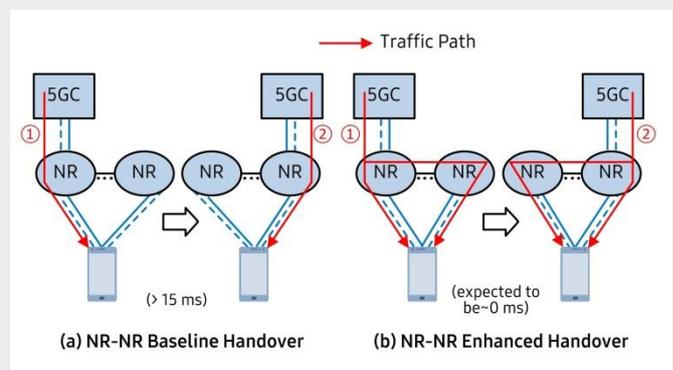


Figure 6. NR-NR Handover in CN-level Interworking

When the 5G radio link is suddenly dropped, user service will be continuously provided with LTE after NR-to-LTE user path switching.

For RAN-level interworking, the LTE radio interface can provide robust connection and decide which radio interface should be used to transmit user traffic.

When user traffic can be simultaneously transmitted over LTE and NR radio interfaces and aggregated at the PDCP layer, the LTE eNB can immediately change the path for user traffic if user traffic cannot be transmitted over the NR radio interface. Low quality 5G link and the NR-to-LTE path switching time will be detected as around 20 ms as shown in Figure 7(a). If a CN-split Bearer is used, the UE needs to resolve the 5G radio link problem and perform additional signaling to switch the bearer path from 5G NB to LTE eNB. The detection and switching will be done in 140 ms as shown in Figure 7(b).

4G-5G Interworking

Table 7. Mobility Performance Comparison

	RAN-level Interworking		5G SA with CN-level Interworking
	PDCP Aggregation	CN-split Bearer	
NR-to-NR Handover/Switching	> 45 ms (w/o LTE HO) > 75 ms (w/ LTE HO)	> 45 ms (w/o LTE HO) > 75 ms (w/ LTE HO)	> 15 ms (Baseline) > 0 ms (Enhanced)
NR-to-LTE Fallback Interruption	> 20 ms	> 140 ms	> 125 ms

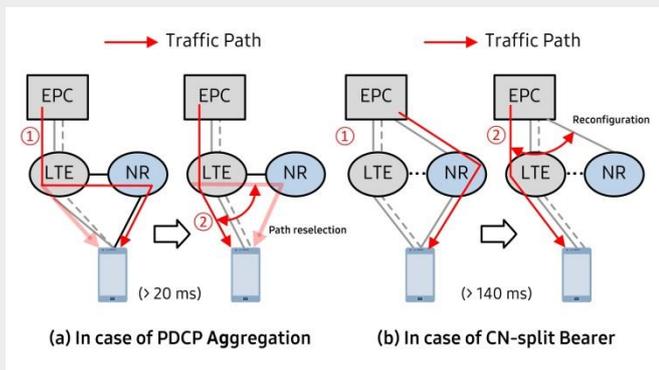


Figure 7. NR-to-LTE Fallback in RAN-level Interworking

For CN-level interworking, the UE should detect the 5G link problem and initiate the data path switch procedure from NR to LTE. The detection and switching time will take around 125 ms as shown in Figure 8.

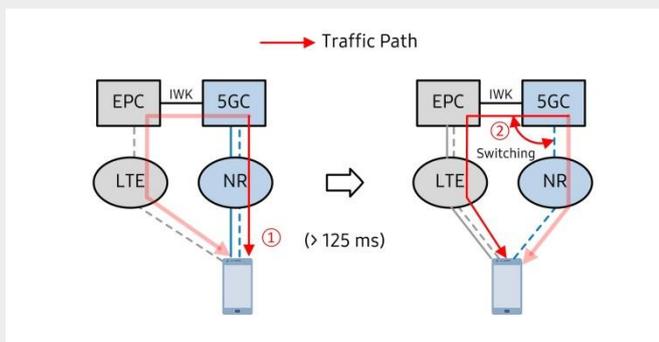


Figure 8. NR-to-LTE Fallback in CN-level Interworking

Based on the analysis of the handover/procedure for RAN-level interworking and CN-level interworking, the mobility performance is compared in Table 7.

The performance in case of normal handover/switching is almost similar, but RAN-level interworking can prove better performance when the 5G radio link is suddenly dropped.

UE Energy Efficiency

LTE has two RRC states: a connected state and an idle state. If there is no data to be transmitted/received, the UE stays in the energy efficient idle state. On the other hand, the connected state is the energy consuming state, as the UE needs to monitor the link quality of the serving and neighbor cells continuously, and provide periodic status information for the radio link.

The proportion of time spent in the connected and idle states depends on a number of key radio parameters, such as the user-inactivity timer and paging DRX cycle.

The user-inactivity timer determines how long the UE stays in the connected state after it receives or transmits the last data packet. When the timer expires, the eNB releases the RRC connection and the UE immediately transitions to the idle state. The shorter the user-inactivity timer, the more UE battery life will be enhanced. However, if a new packet arrives shortly after the UE transitions to the idle state, the core network needs to page the UE with network and radio signaling, causing extra service latency to transit to the connected state. In other words, the length of the user-inactivity timer determines a trade-off point between UE energy consumption and connection latency/CN control signaling overhead.

As shown in Figure 9, UE energy consumption is analyzed in two major usage scenarios: standby with background traffic and video streaming.

Full HD 1080p video streaming from the YouTube server is measured for the analysis of video streaming. Traffic behavior of representative apps such as Google applications and Chinese news apps is captured in the commercial LTE handset for the analysis of background traffic.

As shown in Figure 10, YouTube streaming consists of consecutive progressive download and idle periods.

4G-5G Interworking

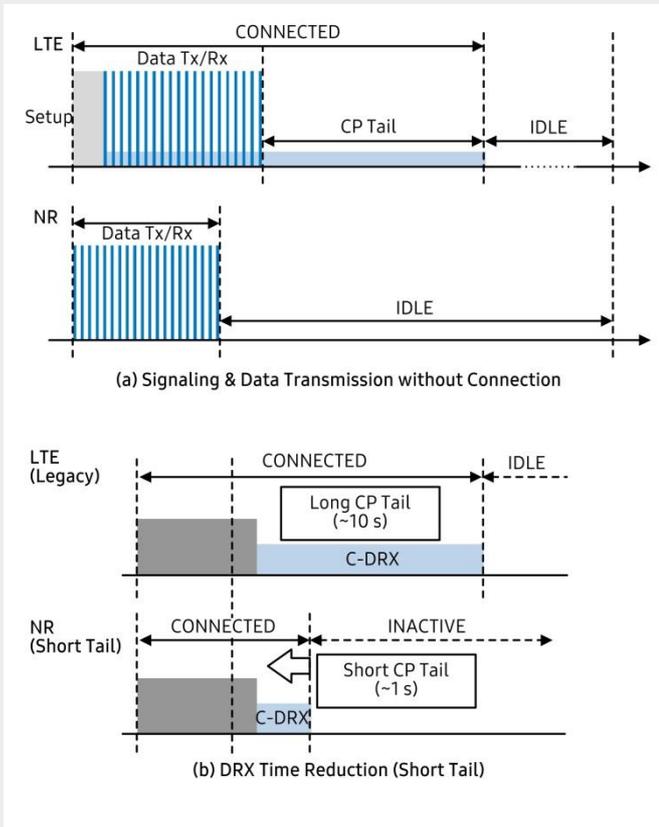


Figure 9. 5G Enhancements for Energy Efficiency

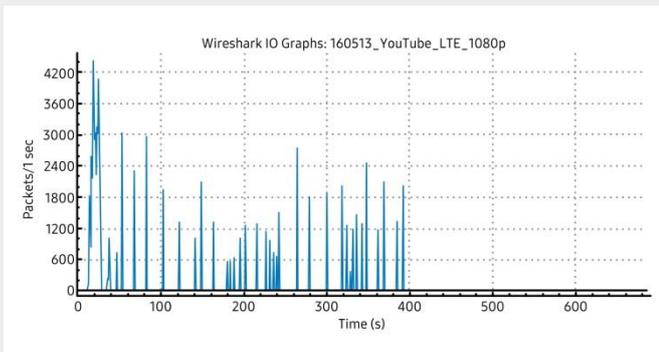


Figure 10. Traffic Pattern of YouTube Streaming

The traffic is further classified into large data (more than 5 kb of data from the server), small data (less than 5 kb of data from the server), C-DRX and Idle from the UE side. The portion of each state is as shown in Table 8.

Table 8. Ratio of UE States When Playing the Reference Video Stream

Large data	Small data	C-DRX	Idle	Total
31.43 sec	9.74 sec	411.65 sec	222.81 sec	675.63 sec
5 %	1 %	61 %	33 %	100 %

UE energy consumption is measured on a mobile device released in 2016 running on Android OS 6.0 and attached to an LTE-A network. The measured current level of the device (including power consumption of the display) is 920 mA for a burst period (of YouTube streaming), 350 mA for a C-DRX period and 230 mA for an idle period. For modem power consumption (without power consumption from other components), the current level is 300 mA for a burst period, 85 mA for a C-DRX period and 6.5 mA for an idle period. The same power consumption is assumed for both LTE and 5G modems.

Figure 11 shows UE current consumptions with different user-inactive timer configurations. When shorter user-inactivity timer 2 sec [or 1 sec] is configured, the current consumption of the UE modem is improved by 43 % [or 54 %] as compared to that of the UE with longer user-inactivity timer 10 sec.

In addition, total UE current consumption including display is reduced by about 14 % [or 17 %] when a shorter user-inactivity timer 2 sec [or 1 sec] is configured, as compared to that of the UE with longer user-inactivity timer 10 sec.

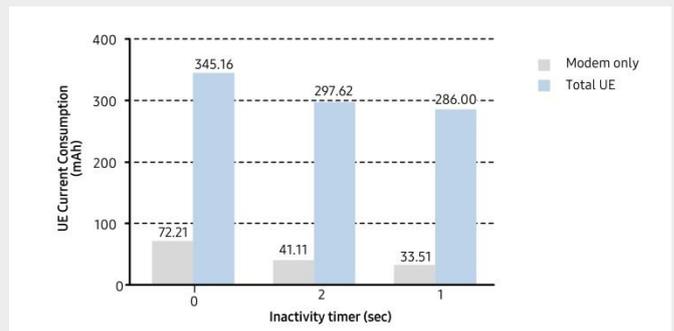


Figure 11. UE Current Consumption with different User-Inactive Timer Configurations

In the idle state, the UE periodically transmits and receives small amounts of data—a “keep-alive message”—to maintain a TCP connection with the network or to check/report the presence of the UE.

4G-5G Interworking

The traffic pattern of keep-alive data is highly dependent on the server and client applications.

Figure 12 shows an example of keep-alive traffic from a Google application. The average inter-burst arrival time is approximately 11 minutes and one traffic burst consists of 20 consecutive uplink and downlink packets. The overall average packet size is 240 bytes: 120 bytes for uplink and 400 bytes for downlink respectively.

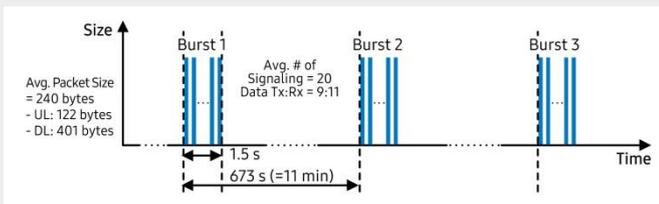


Figure 12. An Example of UE Current Consumption Pattern by Keep-Alive Packets

If the keep-alive data is transmitted in the connected state, it requires RRC state transition from an inactive to a connected state, which causes long C-DRX duration. This is not needed for small data transmission such as keep-alive messages. If the keep-alive packets are transmitted in the inactive state as part of the RRC resume procedure (step 6 and step 8 of Table 2 for downlink and uplink packets), unnecessary RRC state transition and long C-DRX duration can be avoided, preventing UE energy wastage.

If the small packets are transmitted without connection establishment, the UE power consumption is reduced by almost 50 % for news apps, and by approximately 20 % for Google apps as shown in Figure 13. It should be noted that the overall gain in UE battery life will be the aggregation of all the gains expected for all the apps installed on the UE.

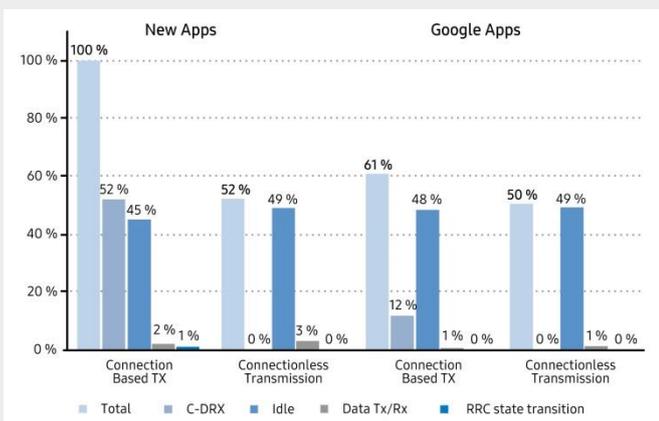


Figure 13. UE Power Consumption Improvements with Connectionless Data Transmission

If a 5G cell is aggregated with a LTE eNB, and both the LTE and 5G NR air interfaces need to be activated at the same time to exchange UE data, the UE power consumption of non-standalone 5G is more than doubled compared with standalone 5G for video streaming as shown in Table 9.

Table 9. UE Energy Efficiency Comparison

	RAN-level Interworking	5G SA with CN-level Interworking
No traffic (Standby)	Same as LTE Idle State	Same as NR Idle State
BG traffic (Keep-alive)	7.43 mAh	6.17 mAh (No CDRX tail, 17 % less)
VoD (YouTube)	89.3 mAh	33.5 mAh (Single Link with Short CDRX tail, 61 % less)

Network Features

In order to support various 5G services, such as MBB (Mobile Broadband), MTC (Machine Type Communication), and UR/LL (Ultra Reliable/Low Latency) in 5G, the network slice is introduced as shown in Figure 14.

This is a complete logical network comprising a set of network functions and corresponding resources necessary to provide certain network characteristics.

LTE has the DCN (Dedicated Core Networks), which also provide specific characteristics/functions for UE or subscribers (e.g. M2M subscribers, subscribers belonging to a specific enterprise, etc.).

The difference between the two technologies is that the network slice supports service-based networks, but the DCN supports device-based networks. Therefore, the UE simultaneously obtains multiple services from multiple network slices in 5GC.

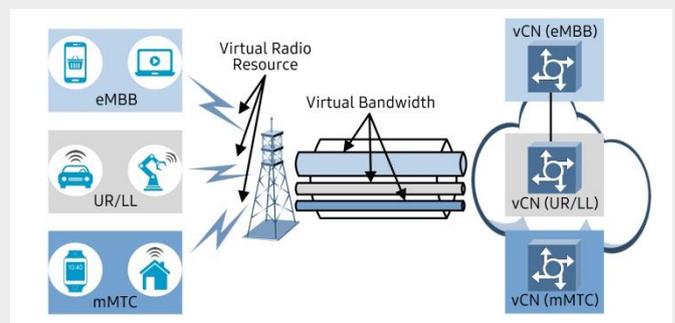


Figure 14. Network Slicing

4G-5G Interworking

5G Session Management supports a PDU connectivity service that provides PDU exchange between a UE and a Data Network, including the IP PDU session type.

In 5GC, an SMF is responsible for handling Session Management procedures. There is a notable difference in session management between EPC and 5GC.

In EPC, the whole session is maintained by a single NE (i.e. MME) in a centralized way, so that the UP path is established via a centralized PGW. This results in the concentration of backhaul traffic at the PGW.

However, in 5GC different PDU sessions can be maintained by possibly different SMFs, and their UP paths are established via multiple UPFs, as shown in Figure 15.

This can distribute the cellular operator's backhaul traffic within the 5GC and reduce user-perceived latency.

Compared to LTE's QoS framework, which is bearer-based and uses only C-plane signaling, the 5G system adopts the QoS Flow-based framework, and uses both C-plane and U-plane (i.e. Reflective QoS) signaling in order to satisfy various OTT QoS requirements.

The QoS Flow-based framework enables flexible mapping of QoS Flow to DRB by decoupling QoS Flow and the Radio Bearer, allowing more flexible QoS characteristic configuration.

When Reflective QoS is used, the 5G UE can create a QoS rule for the uplink traffic based on the received downlink traffic without generating C-plane signaling overhead, as shown in Figure 16.

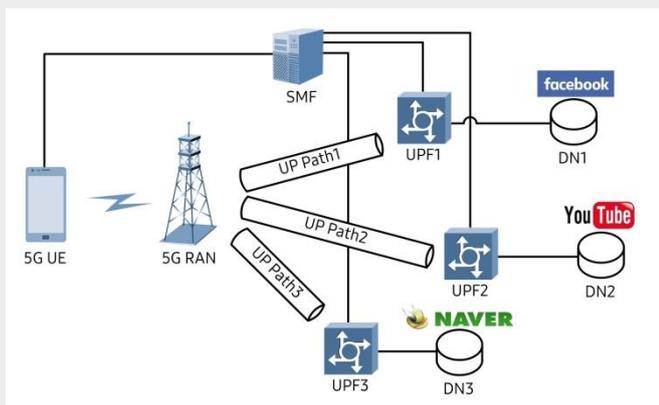


Figure 15. Illustration of 5G Session Management

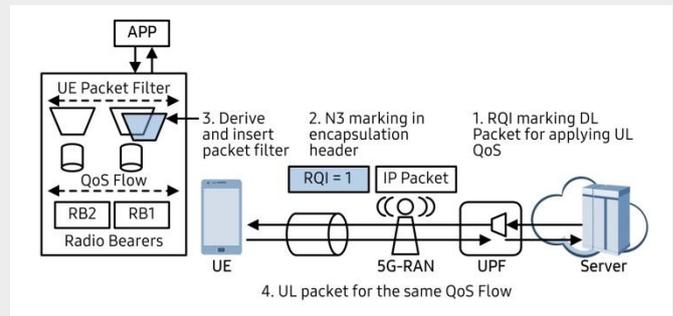


Figure 16. Reflective QoS in 5G

Table 10 summarizes the network features that can be supported in RAN-level interworking and CN-level interworking.

The supported features are differentiated depending on the Core Network type, not the interworking solution.

Deployment Flexibility

When new 5G base stations are deployed, 5G cell planning affects overall 5G performances and installation cost. Therefore, deployment flexibility is important for 5G commercialization.

RAN-level interworking solution operates LTE as master and 5G as secondary.

Therefore, when a handover occurs between LTE eNBs, 5G NB change is also required. The 5G cell boundaries should be aligned with the LTE cell boundaries to maintain performance during LTE handover.

If the boundaries are not aligned, 5G coverage holes may occur at LTE boundaries, depending on 5G cell deployment, or 5G cells should be overlapped at the LTE cell boundaries.

CN-level interworking does not require the interface between LTE eNB and 5G NB. The handover for LTE and 5G can be performed independently, so even if the handover occurs between LTE cells, 5G cells do not need to be changed and the user can continuously experience 5G service. Therefore, optimized cell planning is possible only by considering 5G coverage.

4G-5G Interworking

Table 10. Network Feature Comparison

	RAN-level Interworking		5G SA with CN-level Interworking
	w/ EPC	w/ 5GC	
Network Slicing	Per Device (Dedicated Core)	Per Service (Enabling 3rd Party Service)	Per Service (Enabling 3rd Party Service)
Session Management	Limited & Centralized	Flexible & Distributed (Lower-cost, Lower-latency)	Flexible & Distributed (Lower-cost, Lower-latency)
QoS	<ul style="list-style-type: none"> Per-Bearer NW-Initiated 	<ul style="list-style-type: none"> Per-Flow UE/NW-Initiated (Dynamic QoS) 	<ul style="list-style-type: none"> Per-Flow UE/NW-Initiated (Dynamic QoS)

Figure 17 shows the LTE/5G coverage alignment comparison between RAN-level and CN-level interworking cases.

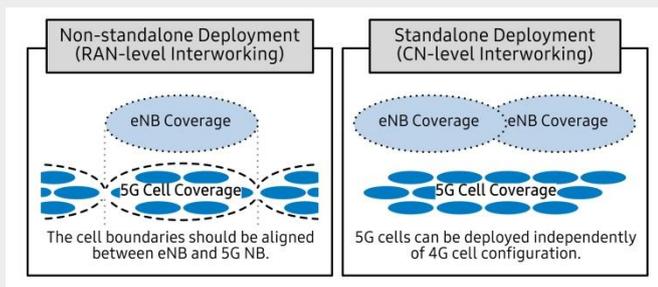


Figure 17. Deployment Flexibility

Table 11 compares what to consider when deploying 5G cells to support RAN-level interworking and CN-level interworking. For RAN-level interworking, LTE and 5G coverage should be aligned.

5G cell planning should be done per LTE/5G integrated NB unit, and interoperability between LTE eNB and 5G NB should be guaranteed.

On the other hand, for CN-level interworking, 5G cell planning is possible per unit of 5G Access, and interoperability between LTE eNB and 5G NB is not required.

So, CN-level interworking is a relatively easy way to implement multi-vendor RAN and reduces cell planning costs due to fewer deployment considerations.

Table 11. Comparison of Deployment Flexibility

	RAN-level Interworking	5G SA with CN-level Interworking
LTE/5G Coverage Alignment	Required	Not Required
Scalability	Per 4G/5G integrated NB	Per 5G Access Unit
LTE eNB-5G NB Inter-Operability Test	Required	Not required

4G-5G Interworking

Migration to a True 5G Network

In order to provide 5G service, 5G cells should be deployed with full coverage. However, as described above, 5G coverage is expected to be partially secured in the early stages of 5G service commercialization and interworking with LTE is inevitable, to compensate for insufficient 5G coverage. When initially deploying 5G, the operator can choose RAN-level interworking or CN-level interworking.

RAN-level interworking is expected to be built primarily as a way to provide high-speed data rates in hotspots. It is expected that service will start using EPC, and that LTE eNB will be upgraded to eLTE eNB by introducing 5GC. After 5G cell coverage is extended and full 5G coverage is established, 5G NB is upgraded to support standalone 5G access. In RAN-level interworking, the control message is transmitted using the LTE radio interface. On the other hand, in standalone 5G systems, the control message (RRC) is transmitted using the NR radio interface. So, as RAN-level interworking UE is initially deployed, 5GC support and 5G-only connection support may be difficult or an upgrade may be required.

When CN-level interworking is deployed in the initial stage of 5G service, it is expected to provide 5G service by deploying 5G cells in some 5G service areas locally. In this case, a new 5GC is introduced from the outset.

This can provide the service with the 5G NBs and the 5GC while minimizing the impact of existing LTE eNBs. If full 5G coverage is established, 5G service will be provided without interworking between EPC and 5GC. UE supporting CN-level interworking can operate as 4G-only or 5G-only. Even in a standalone 5G system, the UE can be used without upgrades.

Figure 18 shows migration scenario examples for RAN-level interworking and CN-level interworking cases. Table 12 summarizes the cost per migration stage of each migration scenario.

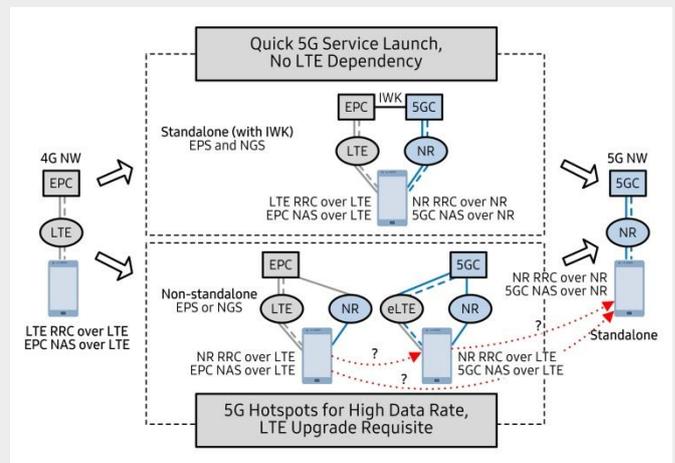


Figure 18. Migration Scenario Example & Forward Compatibility

Table 12. Migration Cost Comparison

	RAN-level Interworking	5G SA with CN-level Interworking
Initial	Support RAN-level IWK with EPC <ul style="list-style-type: none"> • NR Deployment • EPC Capacity Increase • LTE Upgrade (LTE-NR DC) 	Support CN-level IWK <ul style="list-style-type: none"> • NR • 5GC • EPC Upgrade (only for single registration) • LTE Upgrade (only for single registration)
Intermediate	Support RAN-level IWK with 5GC <ul style="list-style-type: none"> • 5GC Deployment • LTE Upgrade (to support eLTE) • NR Upgrade (to support eLTE) 	-
Final	Support True 5G <ul style="list-style-type: none"> • NR Deployment • 5GC Deployment • EPC Capacity Increase • LTE Upgrade (to support eLTE) • NR Upgrade (to support eLTE) • NR Upgrade (to support Standalone) 	Support True 5G <ul style="list-style-type: none"> • NR • 5GC • EPC Upgrade (only for single registration) • LTE Upgrade (only for single registration)

4G-5G Interworking

Development at Samsung

Samsung is actively working on 5G standardization. In 3GPP, specifications for 5G systems are under development and due to be completed in June 2018.

The RAN-level interworking standard linked to EPC is expected to be made in December 2017, and the specifications to support 5G Standalone with CN-level interworking and eLTE will be completed in June 2018. In order to improve the completeness of the 5G standard, Samsung is contributing to the core technologies for 5G radio access network and 5G core network.

Prior to the completion of the 5G standard in 3GPP, Samsung is developing commercial systems for Fixed Wireless Access (FWA) services using core 5G technologies. FWA service will be launched in early December 2017. Samsung is also developing the terminals and the systems for the 5G mobile trial service in February 2018. Samsung expects the first 5G commercial service based on 3GPP Rel-15 will be launched in early 2019. The terminals and the systems to support standard-based commercial service will be ready by then and RAN-level interworking and CN-level interworking will be supported.

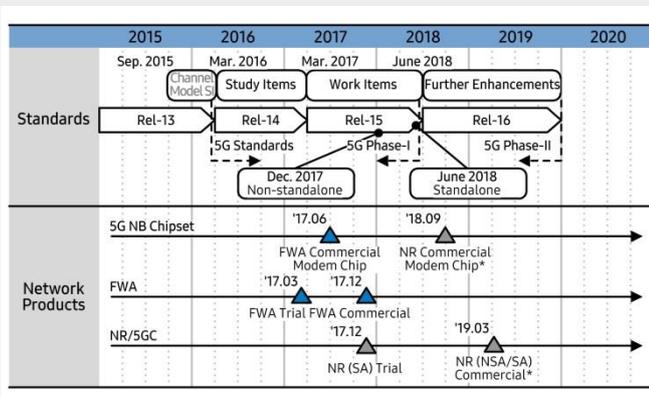


Figure 19. 3GPP Standard and Samsung's Product Plan (Schedule subject to change)

Conclusion

5G is a revolutionary generation of mobile communication service that can provide multi-Gbps and high quality user experience. The 5G system will also enable brand new services that lead to revenue growth for mobile operators based on new devices. True 5G service is achieved when devices can access the 5G system anytime and anywhere.

In practice, 5G coverage may be limited in the initial deployment and interworking with the legacy LTE network is unavoidable as it is studied on LTE migration from 3G. To support 4G-5G interworking, 3GPP has been developing RAN-level and CN-level interworking solutions.

The former is characterized by non-standalone (NSA) architecture, while the latter features standalone (SA) architecture.

NSA has an earlier standard schedule and less initial CAPEX. However, SA/NSA commercial products will be available at the same time slot, because the bottleneck is a common chipset. Migrating to SA via NSA leads to a higher TCO because of a 4G Core/eNB upgrade for interworking with 5G NB. It may also cause future compatibility issues.

5G standalone (SA) provides new network features and significant improvements over NSA. The new network features includes network slicing, flexible session and dynamic QoS. The performance improvements are in mobility (HO), latency and UE power consumption. SA also enables flexible deployments without dependency on legacy networks

Reference

1. 3GPP TR 23.799 Study on Architecture for Next Generation System
2. 3GPP TR 38.801 Study on New Radio Access Technology; Radio Access Architecture and Interfaces
3. 3GPP TR 38.804 Study on New Radio Access Technology; Radio Interface Protocol Aspects
4. 3GPP TR 38.913 Study on Scenarios and Requirements for Next Generation Access Technologies

Abbreviations

NR	New Radio
CN	Core Network
RAN	Radio Access Network
SA	Standalone
NSA	Non-standalone

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