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Cellular Telemetry Enhancements in 5G

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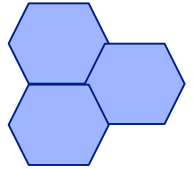
Overview

Key Areas of Improvement with 5G

- Problem Statement and Current Milestones with 4G Cellular in the Testing Range
- 5G Status: Standards and Vendor Ecosystem Directions
- Key 5G Enhancements with direct impact to TRMC
 - mmWave Bands and Beamforming
 - Non-Terrestrial Networks
 - Mobility Enhancements
 - In-Band Backhauling
 - Graceful Migration Path from 4G to 5G

4G LTE Feasibility in the Testing Range

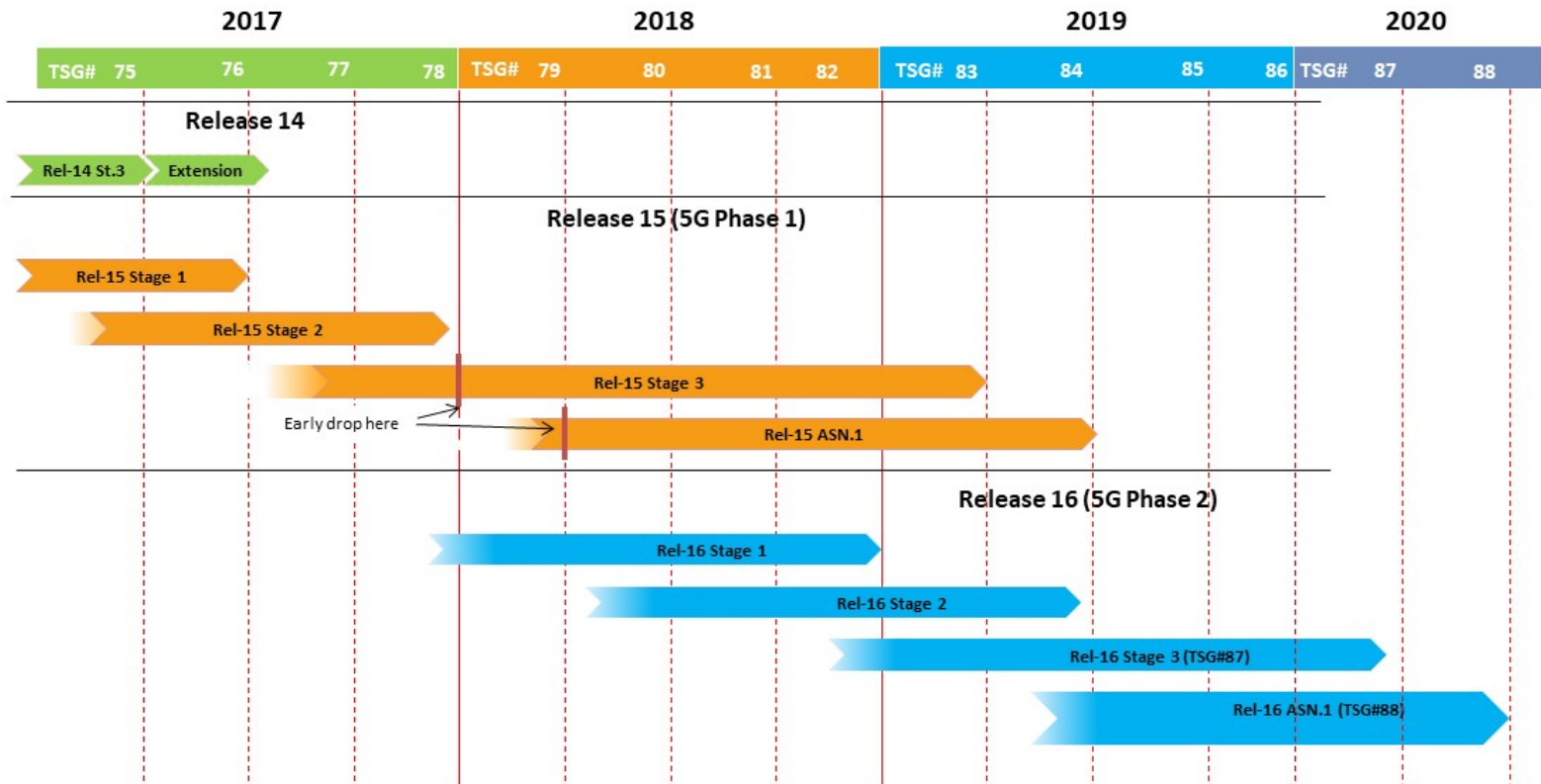
- Cellular approach to serving telemetry links in the test range -> Spectral efficiency and automated multi-test frequency coordination via frequency reuse and LTE's multi-user scheduling
- 4G augmentation of 4G LTE transceiver for aeronautical speeds proven functional with no disruption to 4G signaling or physical layer
- Delivery of high data rates with full duplex links
- Availability of COTS equipment and vendor selection
- Ongoing over-the-air testing in the test range



5G Standards – Current Status & Timeline

Evolution of LTE technology

- Developed within the 3GPP specifications body – as a new Series starting with Rel-15
- Rel-15 introduced with brand new Radio Access and Core Network definitions
 - Advanced Physical Layer compared to LTE (NR)
 - Enhanced Signaling Mechanisms compared to LTE
 - New Core Network architecture – more streamlined than LTE
- Timeline: First Release, Rel-15 ready since early 2019



NR mmWave above 6GHz approved bands

- Current Specifications include:

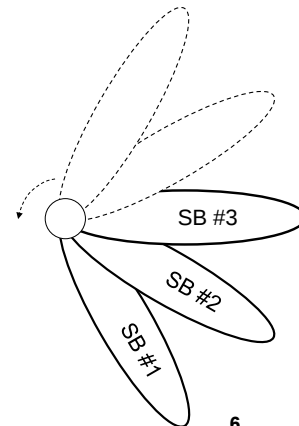
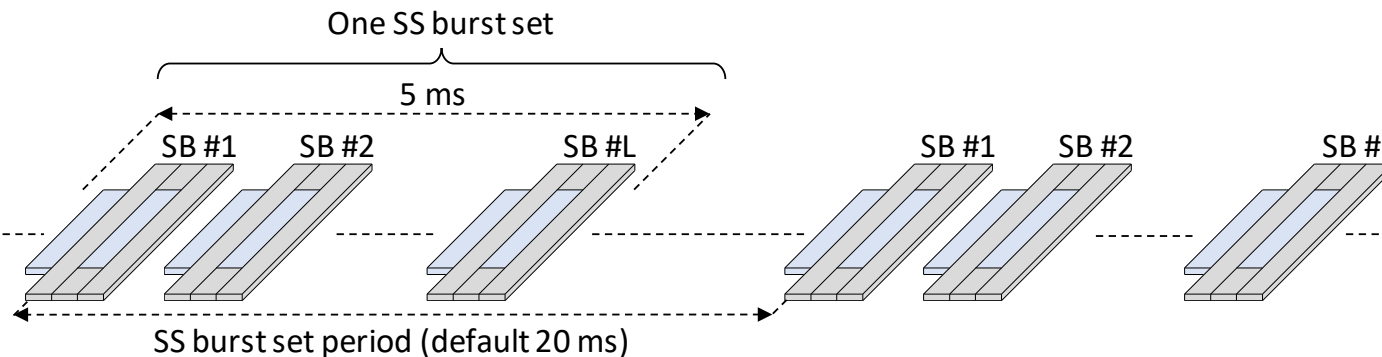
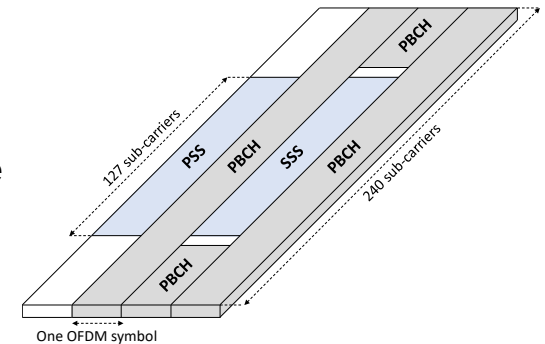
Operating Band	Uplink (UL) operating band BS receive UE transmit	Downlink (DL) operating band BS transmit UE receive	Duplex Mode
	$F_{UL_low} - F_{UL_high}$	$F_{DL_low} - F_{DL_high}$	
n257	26500 MHz – 29500 MHz	26500 MHz – 29500 MHz	TDD
n258	24250 MHz – 27500 MHz	24250 MHz – 27500 MHz	TDD
n260	37000 MHz – 40000 MHz	37000 MHz – 40000 MHz	TDD
n261	27500 MHz – 28350 MHz	27500 MHz – 28350 MHz	TDD

- In the US, new spectrum to be allocated at 37, 39, and 47GHz

5G NR mmWave & Beamforming

- To close the link in NR mmWave, beamforming is required at both the base station and the mobile device.
- Macro-cell coverage with mobility is already commercially trialed at 24GHz, in the US
- 5G Signaling mechanisms enhanced to operate with beamforming
 - Cell search and initial random access include beam search with up to L=64 beams
 - Beam tracking is continuous

PSS: Primary Synchronization Sequence
SSS: Secondary Synchronization Sequence
PBCH: Physical Broadcast Channel
SS Block: System Synchronization Block



5G NR – mmWave and BF

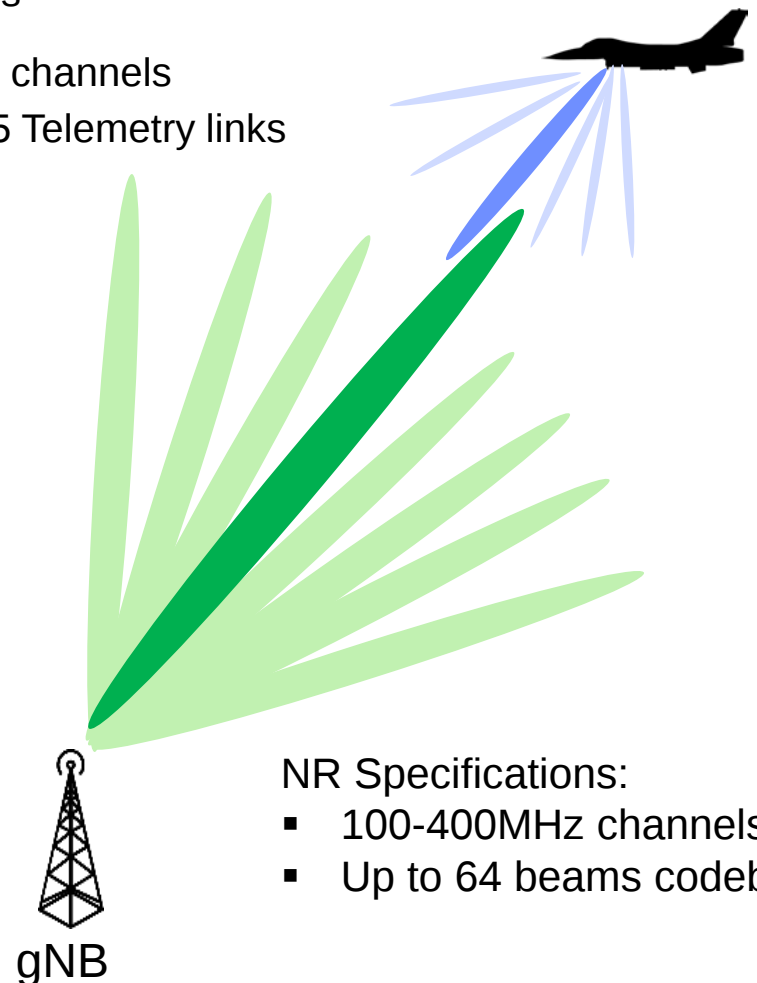
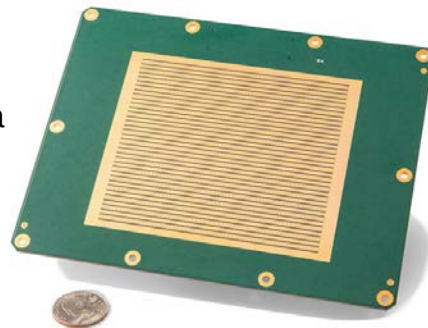
High Frequency Operation in NR

- Beam switching over a set of 64 beams at mmWave in a commercial 1-2Km cell is now in field. A larger cell in the test range is within reason
 - Extend range with much larger antenna arrays
 - Simultaneous beams pointing to multiple test articles
- mmWave offers capability for 100MHz – 400MHz wide channels
 - can support the needs for concurrent 100Mbps F-35 Telemetry links
- BF at both ends provides interference protection:
 - Against other co-channel links (spectrum re-use)
 - Coexistence with legacy Telemetry

Qualcomm 27-40GHz
Transceiver and
phased array



ANSYS 28GHz
Phased 8x8 Antenna
Array



NR Specifications:

- 100-400MHz channels
- Up to 64 beams codebook

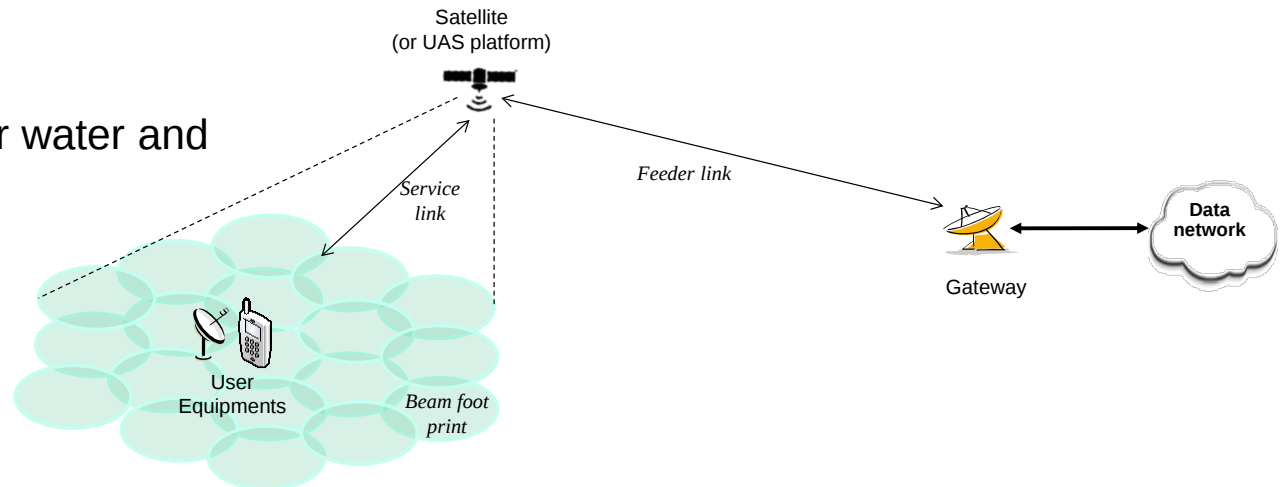
5G Non-Terrestrial Networks (NTN)

Satellite and High-Altitude Links

- Strong industry interest has driven the study (and upcoming standardization for Rel-17) of NR to accommodate links between terrestrial (train and airplane inclusive) and LEO/MEO/GEO satellites or High Altitude aircraft.
- Development of pre-specification enhancements needed currently being drafted, TR 38.821:
 - Timing and Frequency Acquisition (augmented by ephemeris)
 - Timing Advance extension
 - Random access and response window
 - Physical layer link quality control loops and HARQ modifications
 - Window size changes for Layer 2/3 protocols, user plane timer extensions
 - Handover robustness to latency

At the Testing Range

- Serve remote areas over water and inter-range transitions



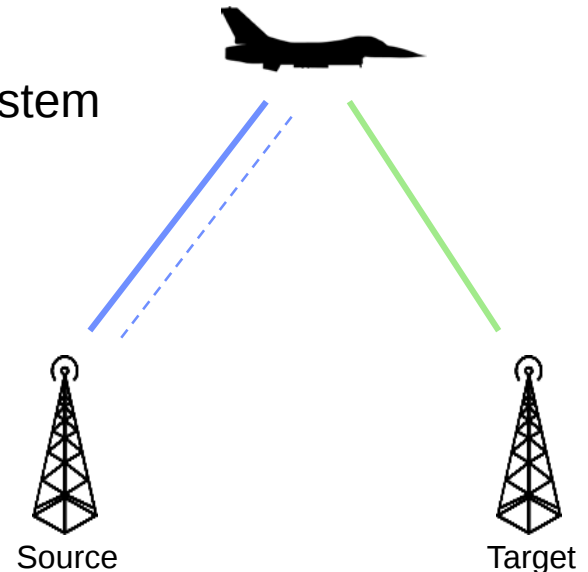
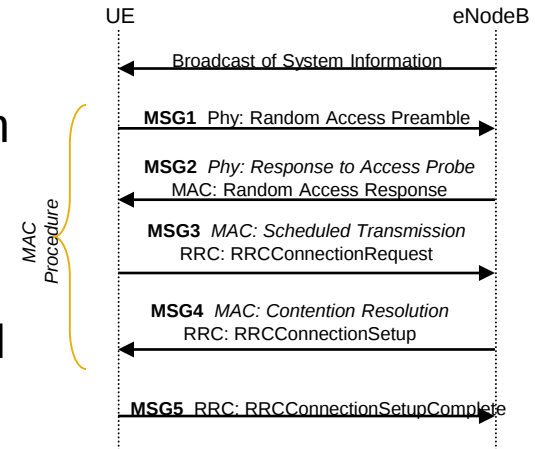
Field of view of the satellite (or UAS platform)

5G NR – Mobility Enhancements

Increase robustness & speed (reduce interruption time)

- Feature is currently in development
- Reduce Interruption Time (0msec interruption): Adoption of Make-Before-Break (MBB) mechanism
 - RACH-less handover
 - Prepares all parameters of target cell in advance
 - Simultaneously connect to source & target using Dual Connectivity principles
- Increase Robustness
 - Conditional Handover: Prepare multiple cells as candidates to be the target
 - Fast handover failure recovery: Do not wait for system information broadcast measurements (SIB/MIB)

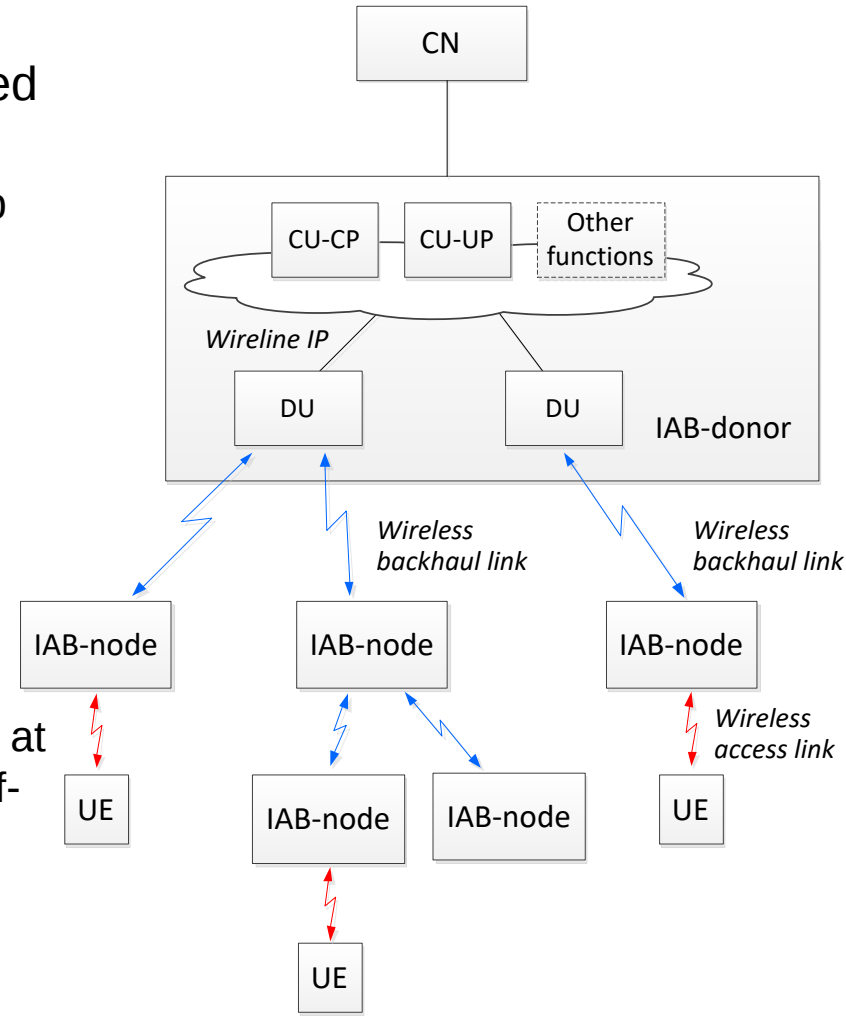
Initial Attach



In-Band Backhauling in 5G

Integrated Access and Backhaul (IAB) feature in NR

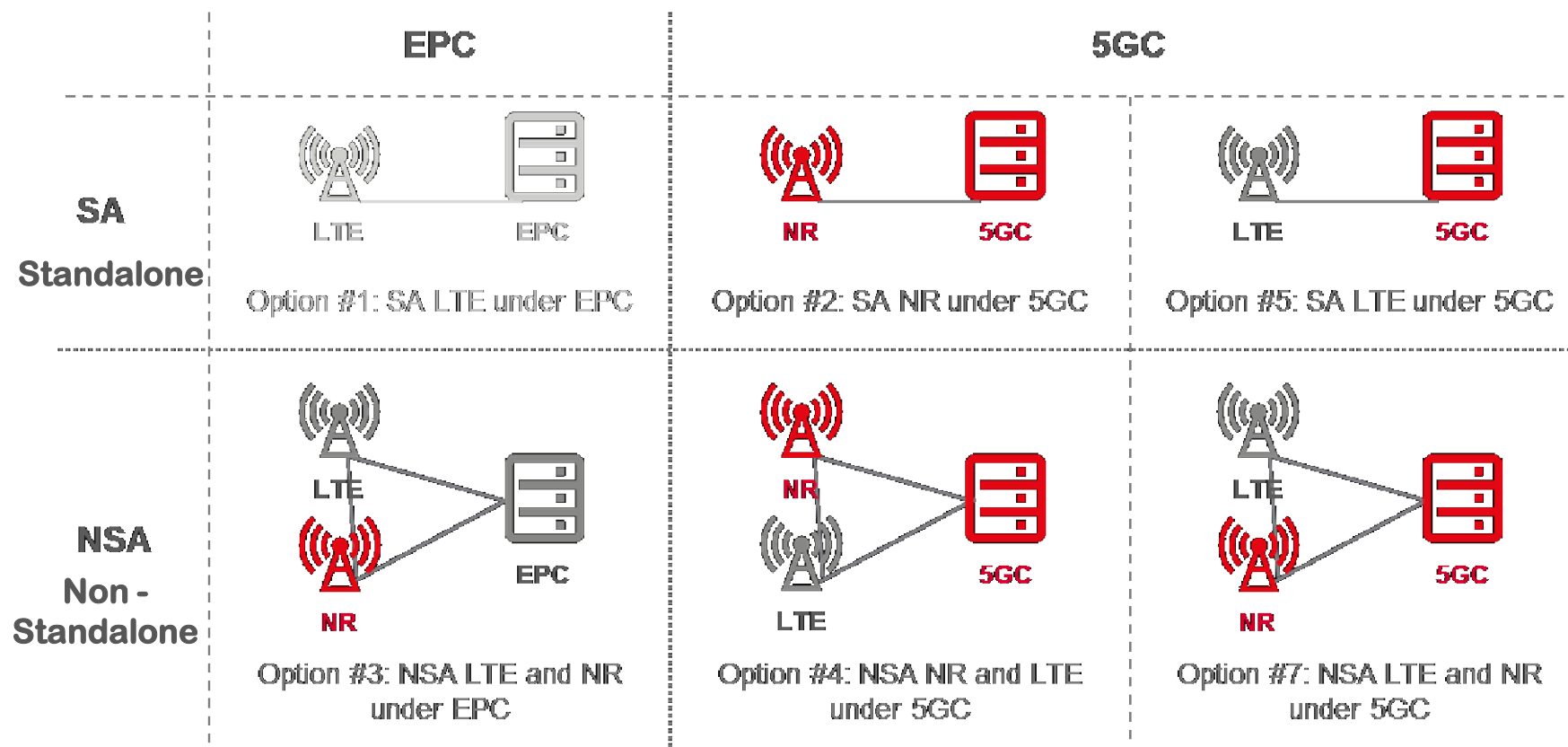
- IAB enables flexible extension to an existing 5G network without need to deploy new wired transport network
 - Topology management for single-hop/multi-hop and redundant connectivity
 - Route selection and optimization
 - Dynamic resource allocation between the backhaul and access links
 - High spectral efficiency while also supporting reliable transmission
- Use Cases:
 - IAB with physically fixed relays
 - In-band backhauling: access and backhaul link at least partially overlap in frequency creating half-duplexing or interference constraints
 - Out-of-band backhauling
 - Backhauling of NR-access traffic over NR backhaul links



4G Migration to 5G

Gradual transition of a 4G network to 5G

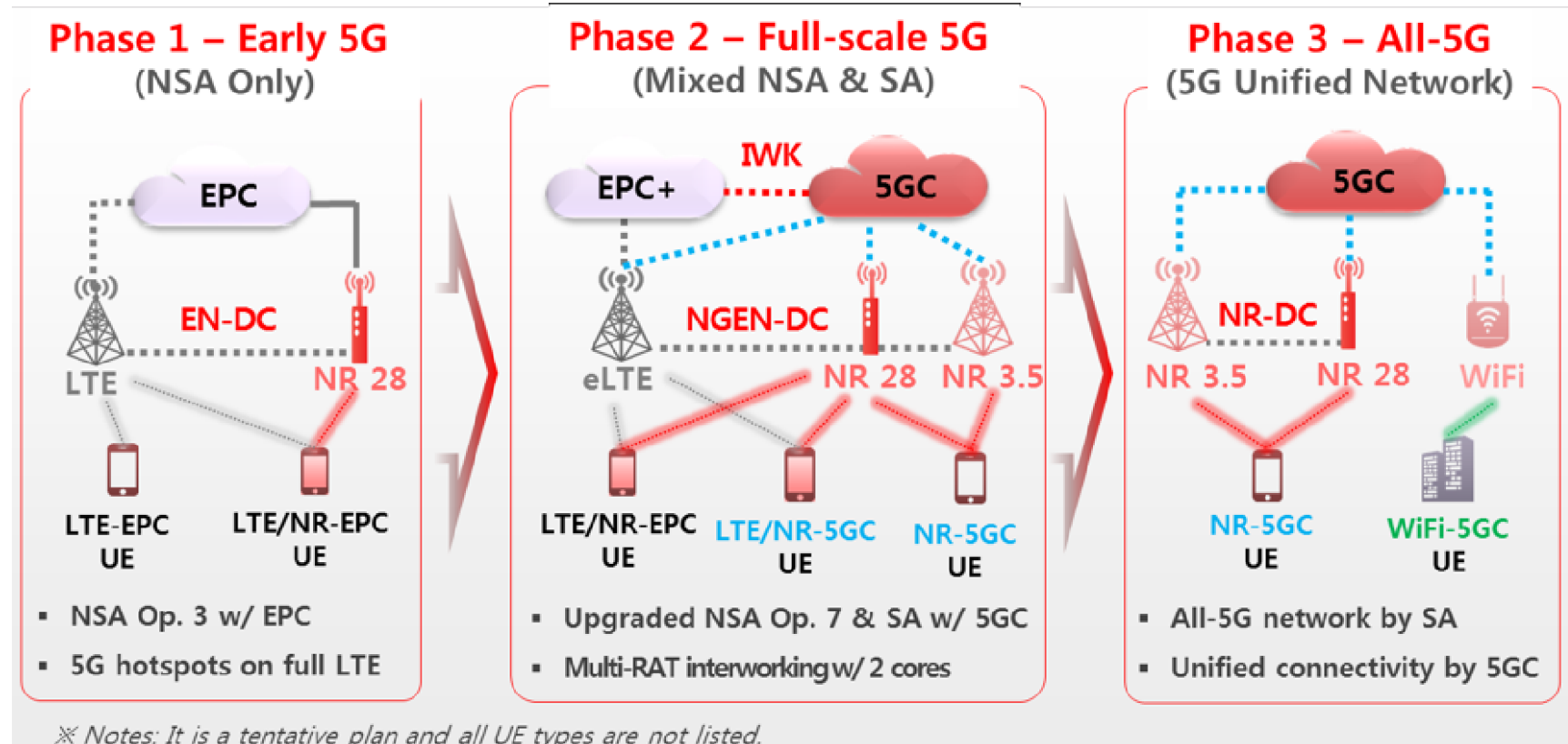
- 3GPP specifications have been developed for gradual introduction of 5G into an existing 4G network (Migration)
- An existing capital investment to deploy a 4G network now is also in use with 5G
- Architecture options and various migration plans are supported starting with Rel-15 LTE



4G Migration to 5G - Example

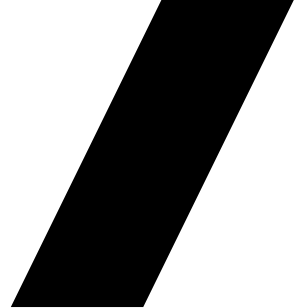
Gradual transition of a 4G network to 5G

- Assumes a Rel-15 User Equipment (UE)
- Initially introduce NR gNBs on 4G EPC (Option 3).
- Then introduce 5GC and transition to Option 7
- Final stage is use of NR and 5GC in Standalone (SA)

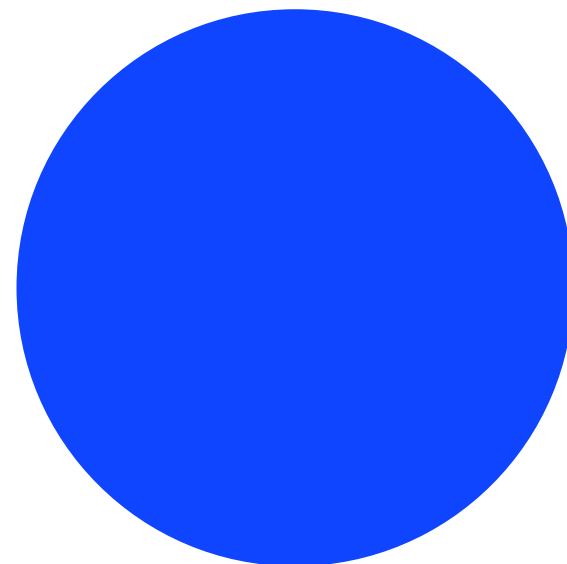


Summary

- The first 5G standards release is complete.
- 5G Rel-15 components are available within 2019
- Additional important features to be introduced in Rel-16 and Rel-17
- Migration Path from 4G to 5G is key to not postponing deployment
- Leverage the global ecosystem of vendors to address the Test Ranges use cases



Thank you



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