Taipei, Taiwan
March, 2017

5G Collaboration Meeting

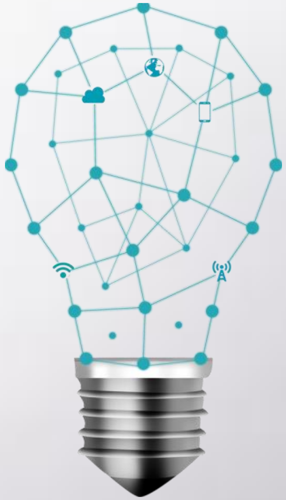
Samsung Electronics Co., Ltd.
DMC R&D Center

Younsun Kim

SAMSUNG

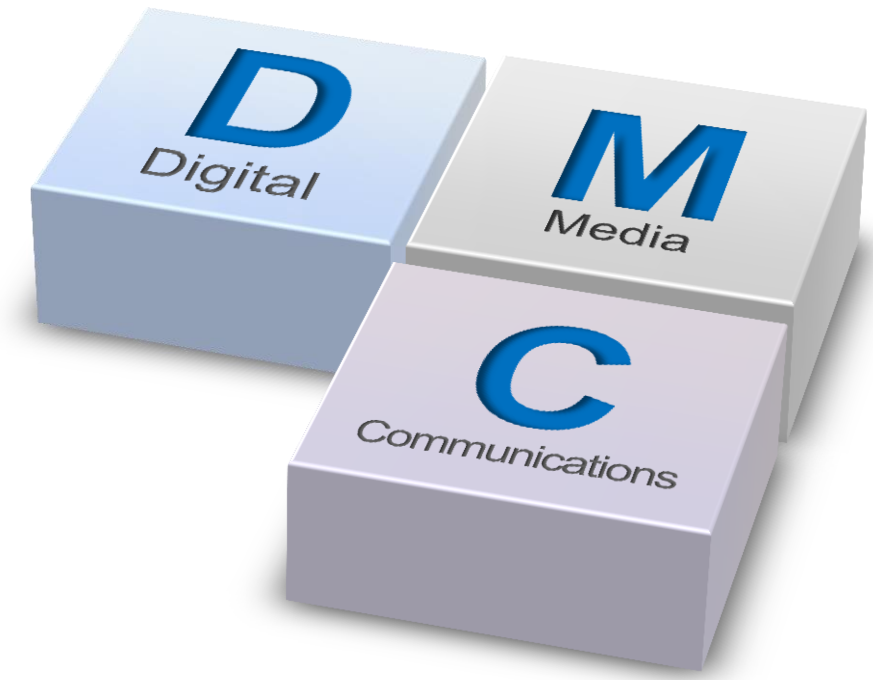
Contents

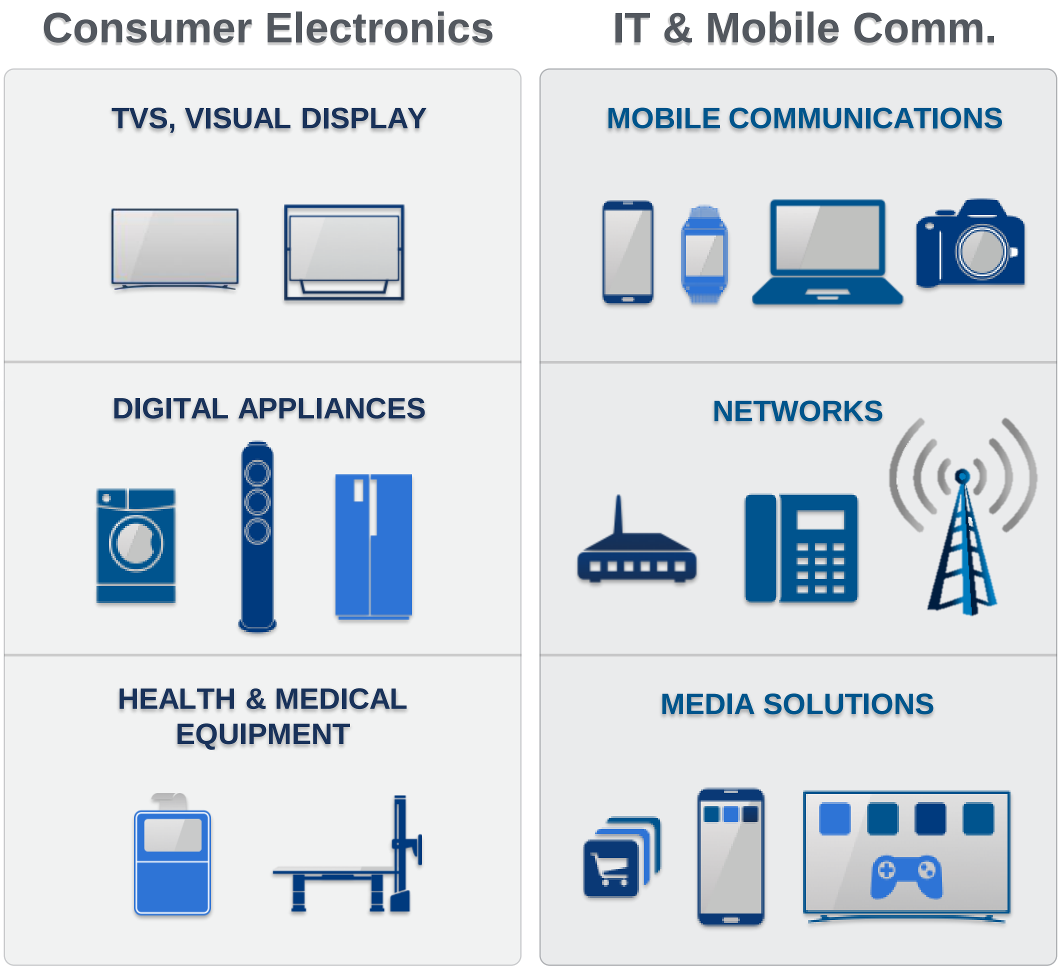
Introduction on DMC R&D Center and Standardization Team



Samsung DMC R&D Center

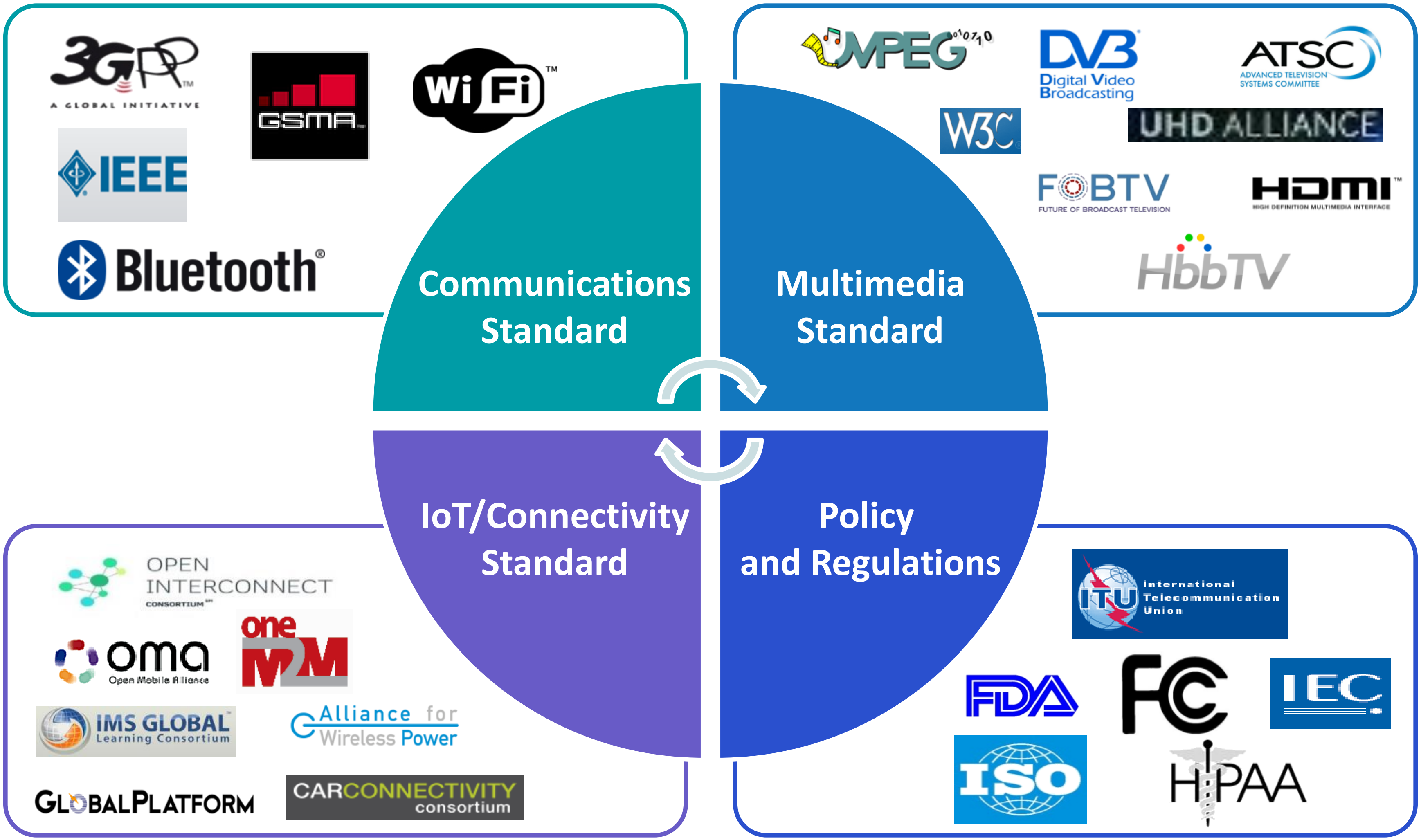
- **DMC R&D Center is responsible for the research of core technologies and laying the technical groundwork for existing and future Samsung set products**





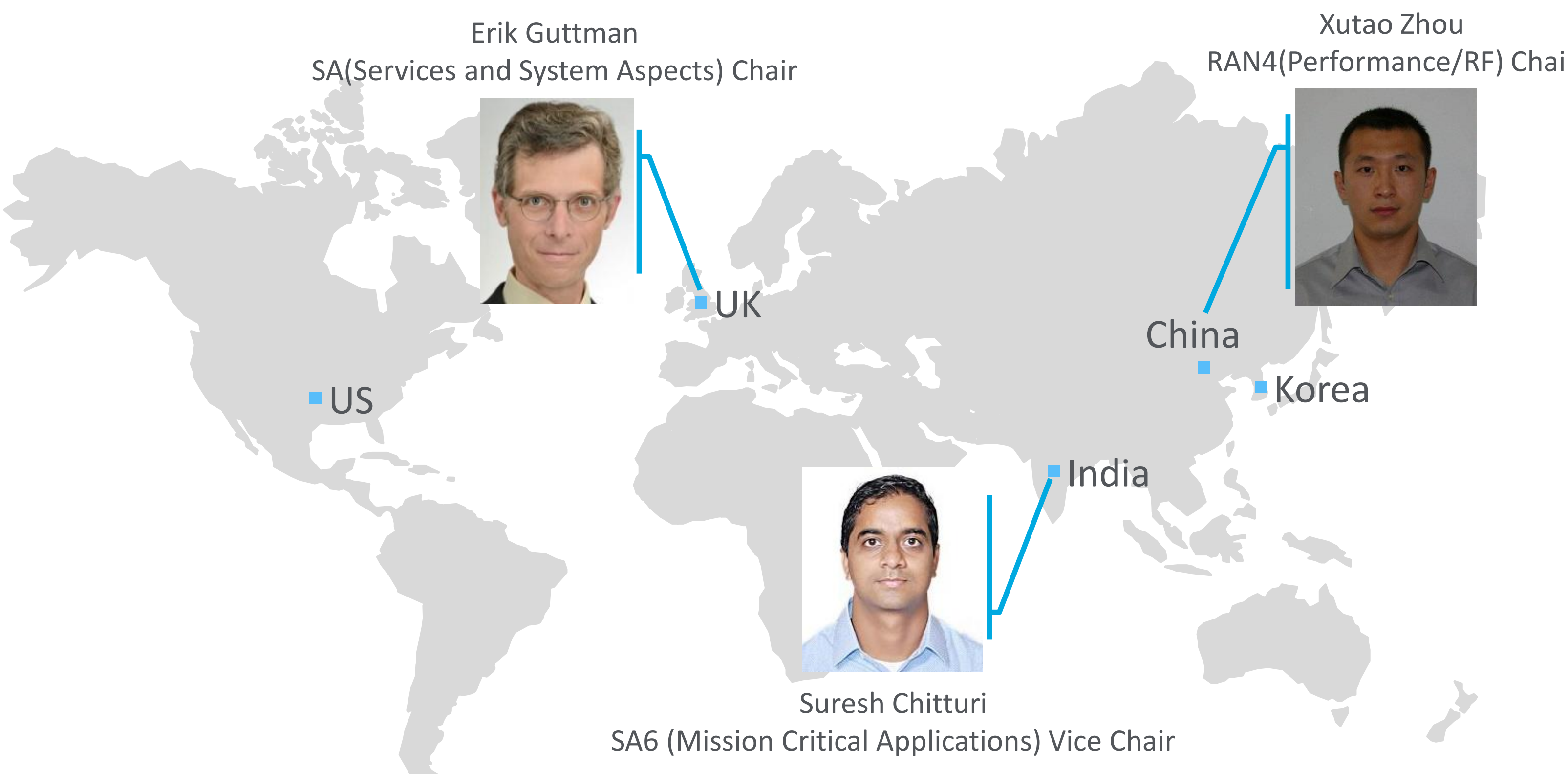
Standardization Team

- We are responsible for the standardization work related to existing and emerging business areas with active participation in ~60 standardization organizations



Samsung 3GPP Standardization

- **Globalized standardization operation with more than 100 technical experts in**
  - Korea: Overall RAN, SA, CT standardization operations
  - China: RAN1(physical layer), RAN3(network signaling), and RAN4(performance/RF)
  - US: RAN1(physical layer) and SA2(architecture)
  - India: RAN2(protocol), SA3(security), SA6(mission critical applications)
  - UK: SA(service and systems aspects), RAN2(protocol), CT1(core network and terminals)



5G Standardization: From Vision to Reality

5G Vision: Service Vision

Everything on Cloud	Immersive Experience	Ubiquitous Connectivity	Tele-Presence

Everything on Cloud

- Giga-bit data rate
- Ultra low latency

Immersive Experience

- Giga-bit data rate
- Ultra low latency

Ubiquitous Connectivity

IoT

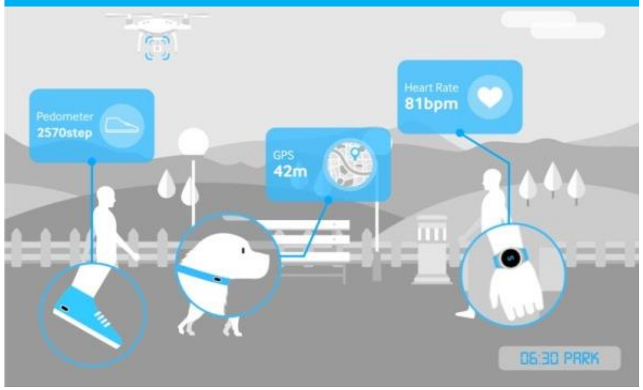
- Massive connectivity
- Ubiquitous coverage

Tele-Presence

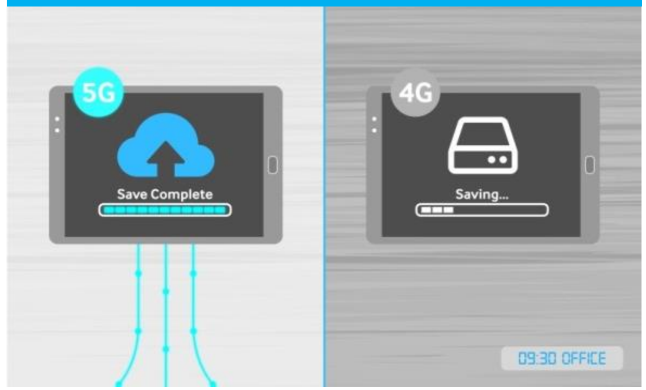
- Giga-bit data rate
- Ultra low latency

5G Vision: Service Scenarios

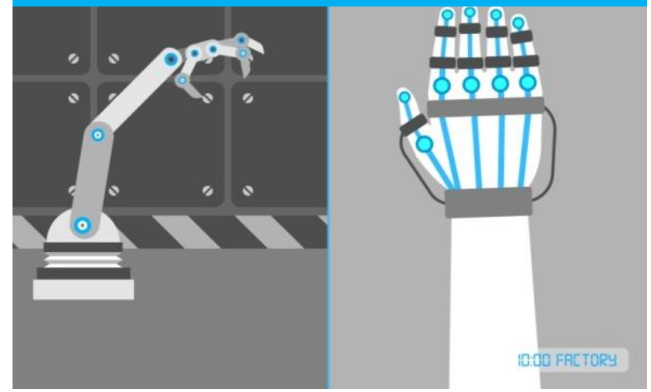
Internet of Things



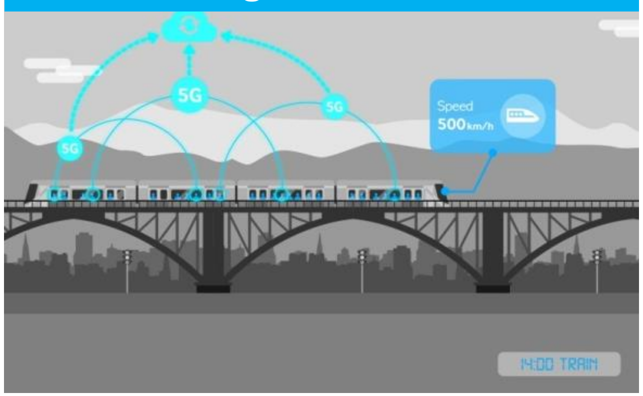
Mobile Cloud Service



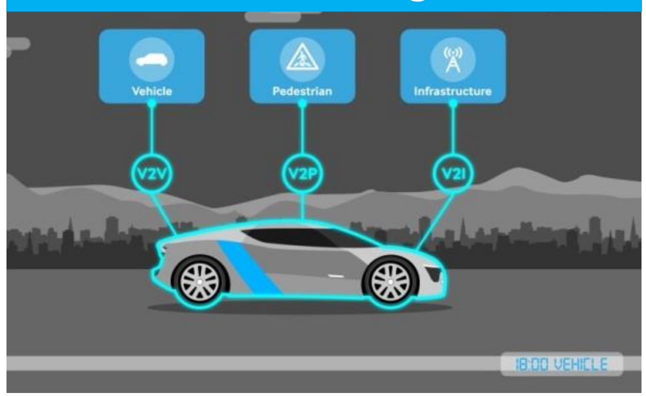
VR Remote Machine Control



Mobile Giga Internet Service

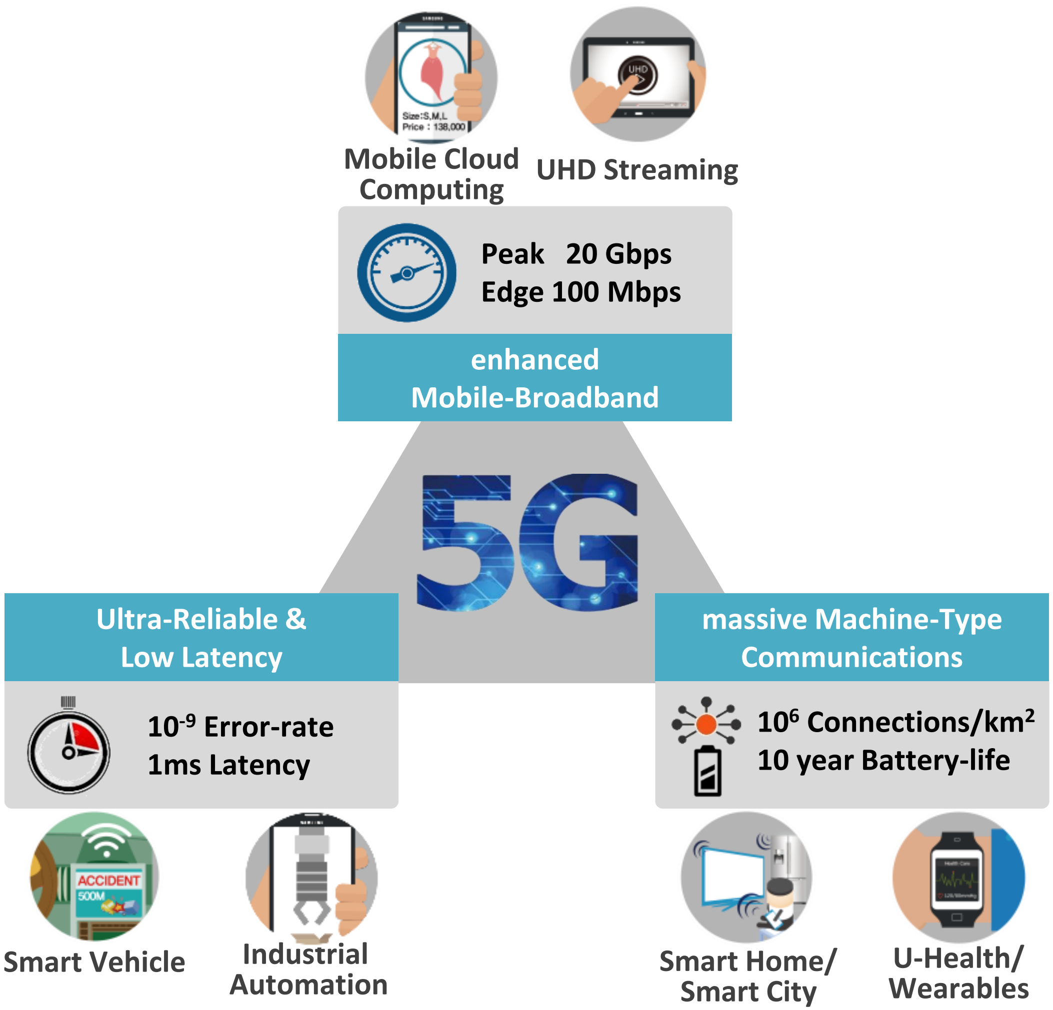


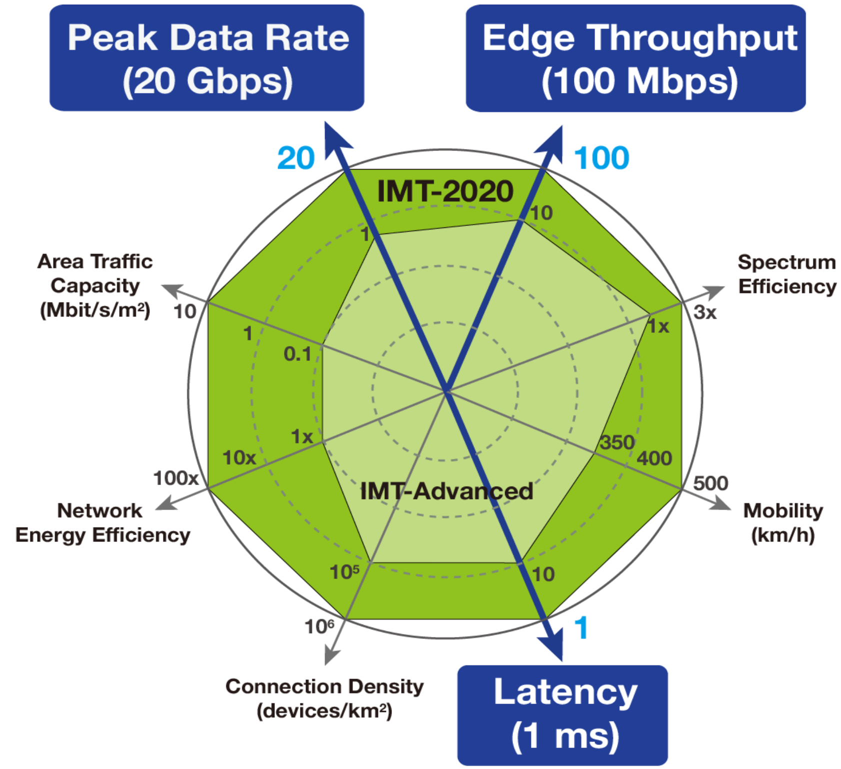
Autonomous Driving and V2X



Wireless Backhaul Service

5G Vision: Use Cases and Requirements





※ ITU-R document 5D/TEMP/625

5G Pre-Standards Research: FD-MIMO

Global leader in MIMO technology for LTE and NR

- First to propose FD-MIMO for LTE (2012) and demonstrate potential performance gains (2013)
- Proponent of NR-MIMO Adv-CSI for efficient multi-user transmission (ongoing in 3GPP)

< World's First FD-MIMO system: 2013 >

- *128 elements*
- *32 TX/RX*
- *TDD, 2.582GHz*
- *Automatic self calibration*
- *Size: 50x100cm*

FD-MIMO Baseband unit

- *Compliant with LTE air interface*
- *32 channel precoding with sounding*
- *4-UE MU-MIMO*

FD-MIMO RF unit with antenna panel

Front view

Back view

< First Demo of FD-MIMO In Real Time: 2015 >

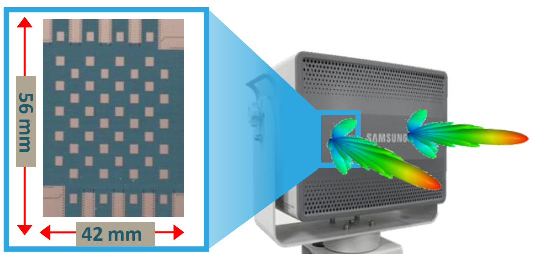
5G Pre-Standards Research: mmWave

Pioneer of mmWave testbed and antenna/RFIC for mobile devices

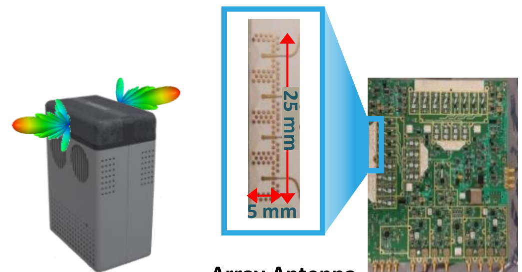
- World's first 28GHz based 5G data transmission of 1Gbps at pedestrian speed (2013)
- Record-breaking 1.2Gbps data transmission at over 100km/h (2014)
- Demonstrated 5G-era data rate of 7.5Gbps in stationary conditions (2014)

Base Station

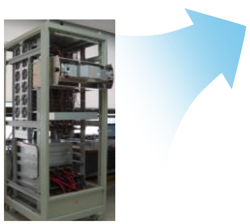
Mobile Station



Array Antenna
8x6 (=48) Antenna Elements



Array Antenna
4x1 (=4) Antenna Elements



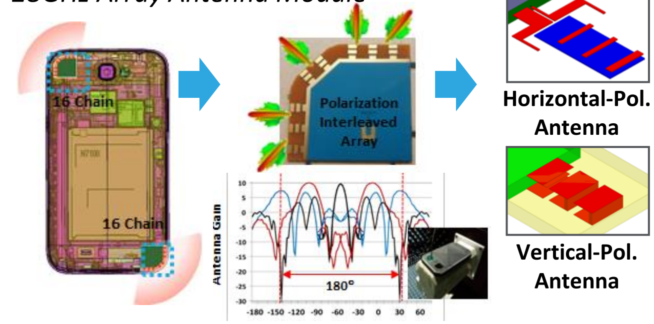
RF + Array Antenna

	BS	MS
Carrier Frequency	27.925 GHz	
Bandwidth	800 MHz	
FFT Size	4096-FFT	
Power (EIRP)	59dBm	30dBm
Beam Width	10°	20°(AZ) /60°(EL)

Baseband Modem

28 GHz Antenna/RFIC

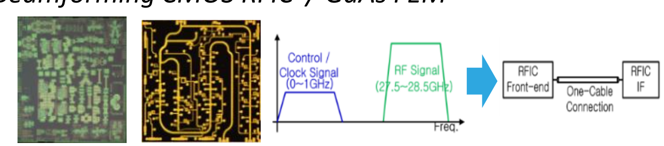
28GHz Array Antenna Module



Horizontal-Pol. Antenna

Vertical-Pol. Antenna

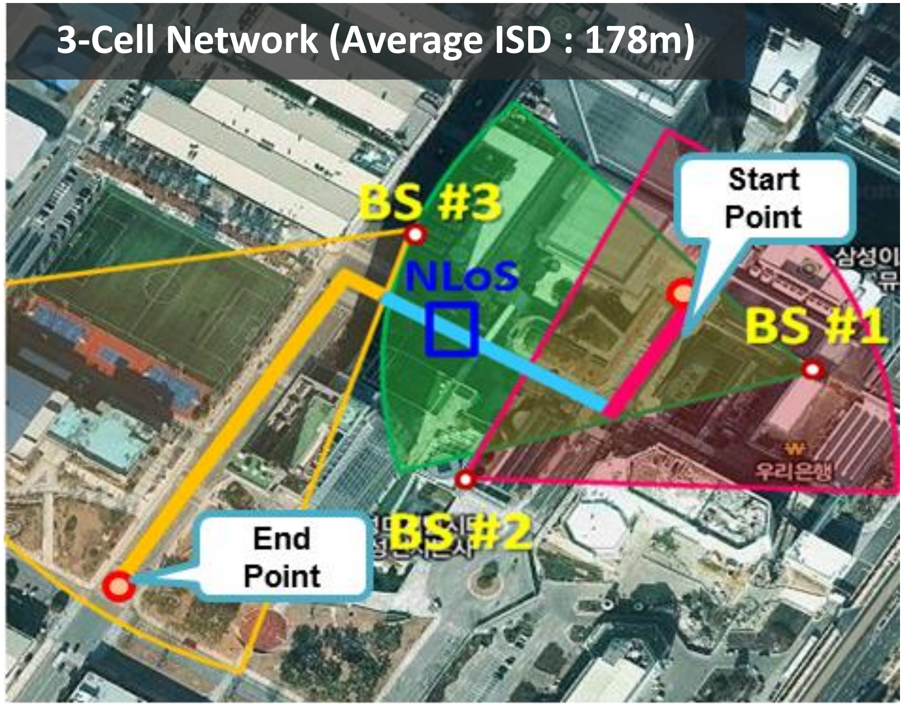
Beamforming CMOS RFIC / GaAs FEM



CMOS RFIC **GaAs FEM** **One-Cable Connection**

mmWave Handover Tests

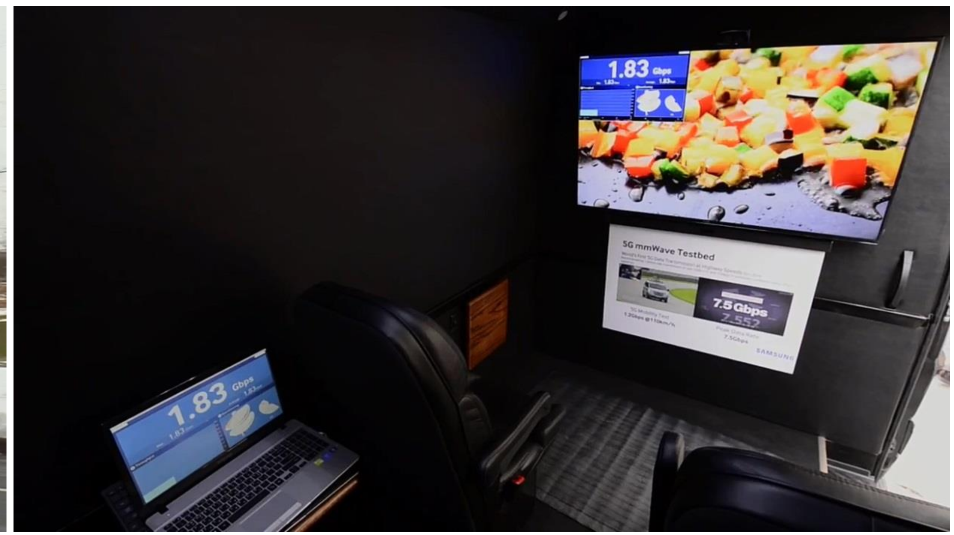
- **World's 1st mmWave multi-cell handover (September 2015, Suwon, Korea)**
  - Handover latency of 21ms with fast adaptive hybrid beamforming
  - Average throughput of 1.67Gbps at driving speed of 25km/h

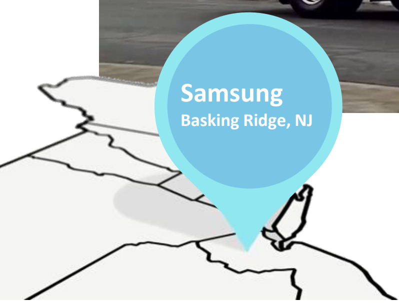


mmWave Field Tests in US

5G mobile and fixed wireless tests at Verizon HQ (Feb. 2016, Basking Ridge, NJ)

- Mobile, fixed wireless and in-building penetration 5G wireless tests delivering max 3.77Gbps
- Live streaming of 360-degree virtual reality content in 4K UHD using Samsung Gear VR



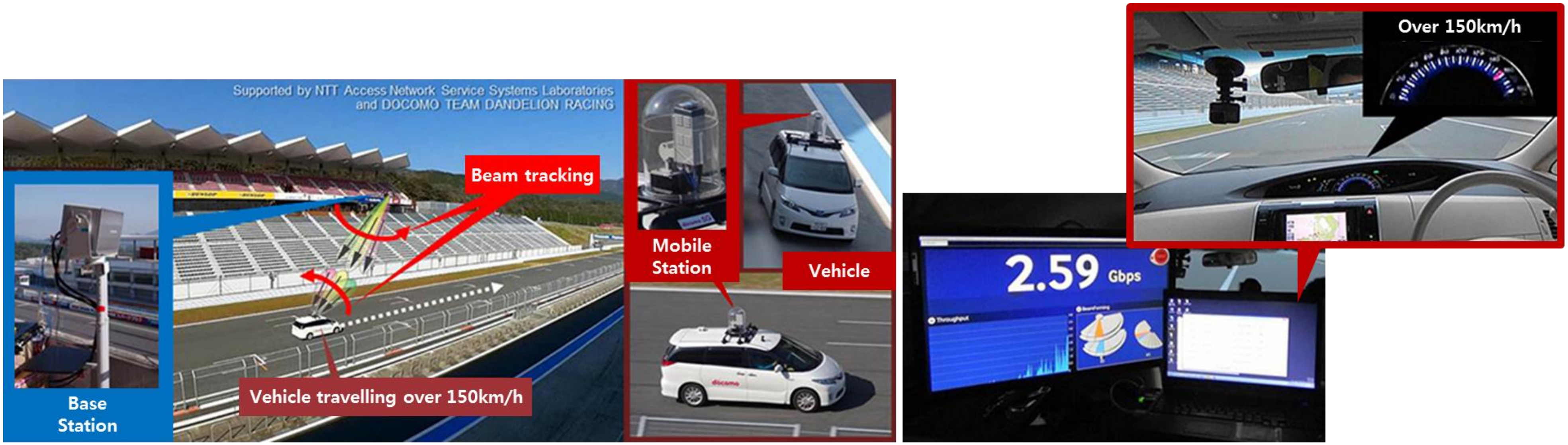


※ Source : Verizon, “Verizon Trials Driving 5G Ecosystem” (https://youtu.be/XFjmrzw-9EM)

mmWave Field Tests in Japan

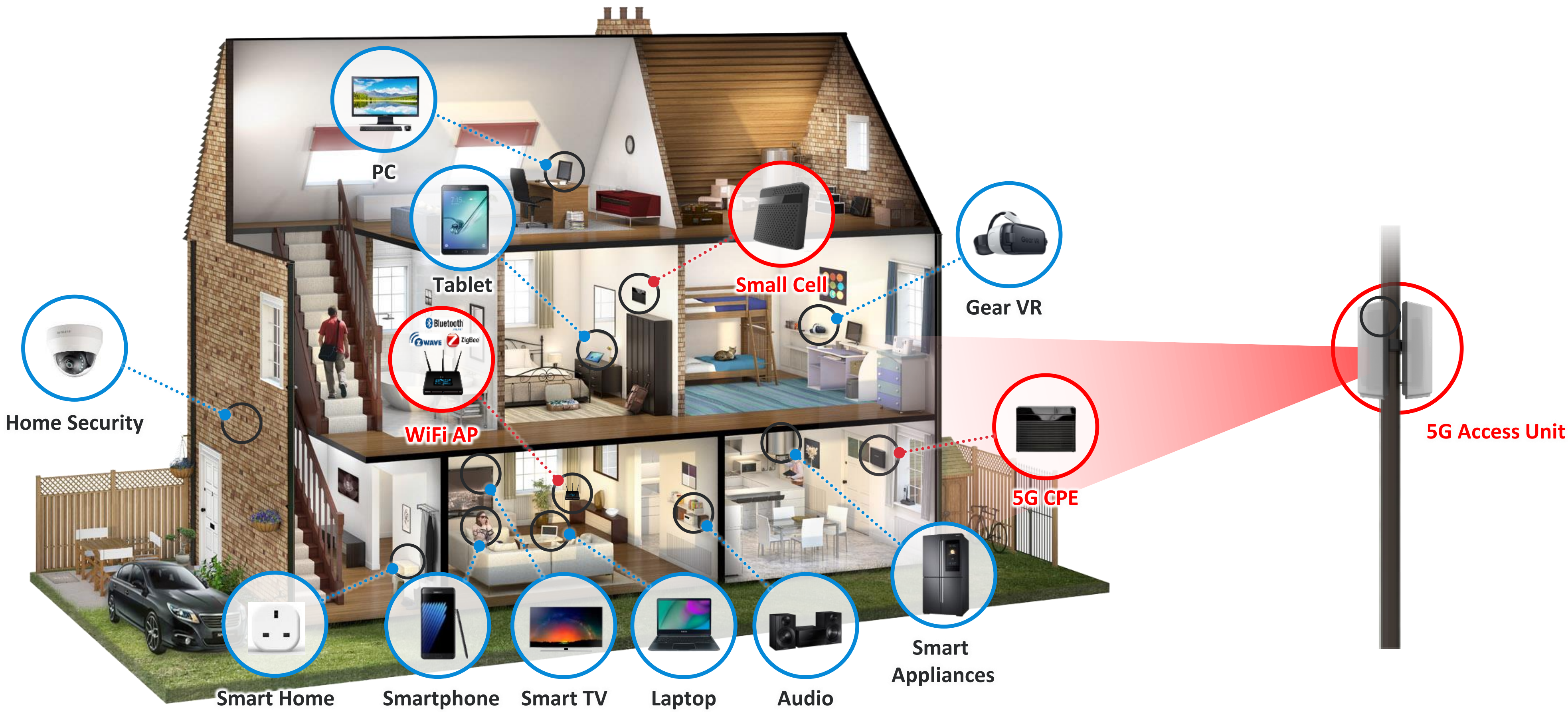
5G high speed mobility tests at Fuji Speedway (Nov. 2016, Fuji Speedway, Shizuoka)

- Data speed of more than 2.5Gbps with a mobile device in a vehicle travelling 150km/h
- Verifying the feasibility of stable connectivity for 5G mobile devices in fast-moving trains



※ Source : DOCOMO, "Succeeded at 2.5 Gbps 5 G wireless data transmission experiment at high speed movement of 150 km / h"
(https://www.nttdocomo.co.jp/info/news_release/notice/2016/11/16_00.html)

mmWave based Fixed Wireless Access (FWA)



5G Pre-Standards Research: Alliances

- **Active engagement of global 5G initiatives by Samsung**

5G PPP Association (Full Member)
Leading and Participating the EU Flagship 5G Projects

5GIC Founding Member

5G Forum Executive Board Member

Member of Giga KOREA Project

NYU Wireless Center
(Board Member)

Proposed NPRM
(28/37/39/64-71 GHz)

IMT-2020 Promotion Group

Member of Future Forum

Contributor to 863 Project

5GMF
(5G Mobile Promotion Forum)

NR Requirements

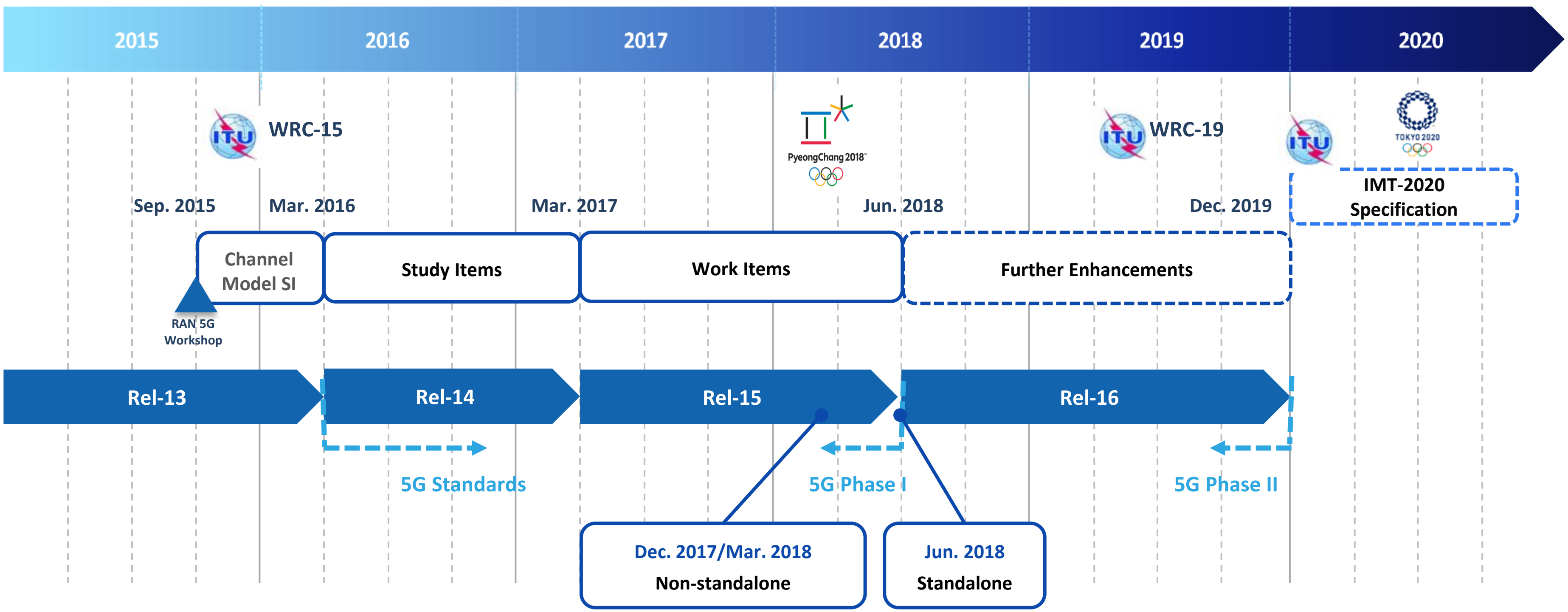
* Note: ITU-R requirements are under discussion and will be finalized by June 2017

<table>
<tr><th>Parameters</th><th>3GPP (TR38.913)</th><th>IMT-2020 (5G, ITU-R*)</th><th>IMT-A (4G, ITU-R M.2134)</th><th>Critical spec support</th></tr>
<tr><td>Peak data rate</td><td>· DL: 20 Gbps
· UL: 10 Gbps</td><td>· DL: 20 Gbps
· UL: 10 Gbps</td><td>DL: 1 Gbps</td><td>Channel coding</td></tr>
<tr><td>Average spectral Efficiency</td><td>3x IMT-A</td><td>3x IMT-A</td><td><table><tr><th>Environ-ment</th><th>DL (bps/Hz/cell)</th><th>UL (bps/Hz/cell)</th></tr><tr><td>InH</td><td>3</td><td>2.25</td></tr><tr><td>UMi</td><td>2.6</td><td>1.80</td></tr><tr><td>UMa</td><td>2.2</td><td>1.4</td></tr><tr><td>RMa</td><td>1.1</td><td>0.7</td></tr></table></td><td>MIMO, frame structure design</td></tr>
<tr><td>5% spectral efficiency</td><td>3x IMT-A</td><td>3x IMT-A</td><td><table><tr><th>Environ-ment</th><th>DL (bps/Hz/cell)</th><th>UL (bps/Hz/cell)</th></tr><tr><td>InH</td><td>0.1</td><td>0.07</td></tr><tr><td>UMi</td><td>0.075</td><td>0.05</td></tr><tr><td>UMa</td><td>0.06</td><td>0.03</td></tr><tr><td>RMa</td><td>0.04</td><td>0.015</td></tr></table></td><td>MIMO, frame structure design</td></tr>
<tr><td>Mobility Interruption</td><td>0 msec</td><td>0 msec</td><td>27.5 msec</td><td>L1/L2 mobility support</td></tr>
<tr><td>User Plane Latency</td><td>URLLC: 0.5 msec
eMBB: 4 msec</td><td>1 msec</td><td>10 msec</td><td>Frame structure design, protocol design</td></tr>
<tr><td>Reliability</td><td>10^{-5}</td><td>10^{-5}</td><td>Not defined</td><td>Channel coding, frame structure design</td></tr>
<tr><td>Connection Density</td><td>10^6 devices/km^2</td><td>10^6 devices/km^2</td><td>Not defined</td><td>Frame structure design</td></tr>
</table>

NR Standardization Timeline

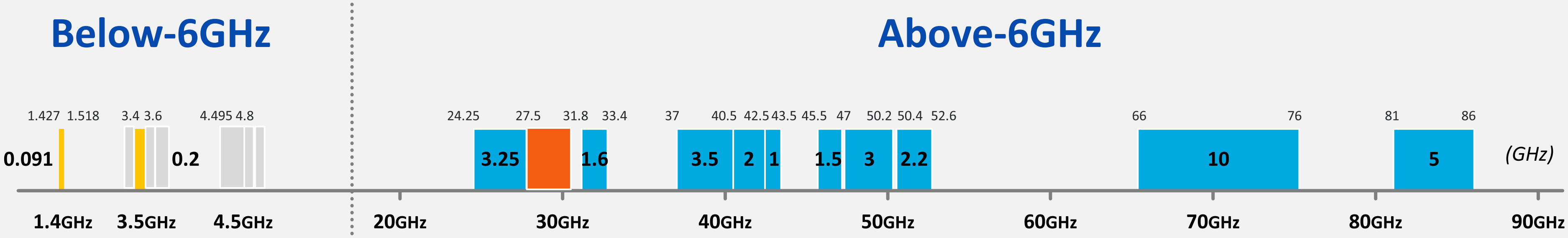
Samsung pursues a two track strategy with 5G standardization/commercialization

- Both above-6GHz and below-6GHz
- Both 5G standalone (SA) and non-standalone (NSA)



NR Spectrum for Above/Below-6GHz

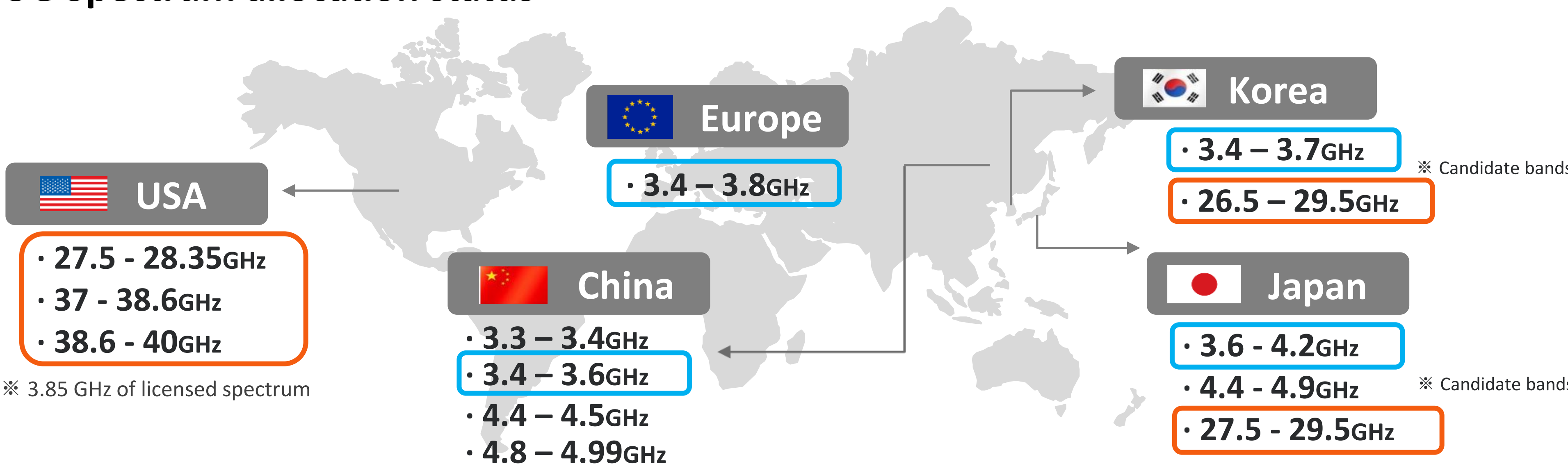
5G Candidate frequency bands at ITU WRC-15 (Nov. 2015)



[IMT Spectrum] (1.427-1.518), (3.4-3.6)

[WRC-19 Candidates] (24.25-27.5), (31.8-33.4), (37-40.5), (40.5-42.5), (42.5-43.5), (45.5-47), (47-47.2), (47.2-50.2), (50.4-52.6), (66-76), (81-86)GHz

5G Spectrum allocation status



NR Band Discussion

Discussion on defining "NR Band" in 3GPP RAN4

- Inputs from operators draw attention to 3.5GHz band (<6GHz) and 28GHz band (>6GHz)
- Strategic & technical discussions on the range of the bands are needed

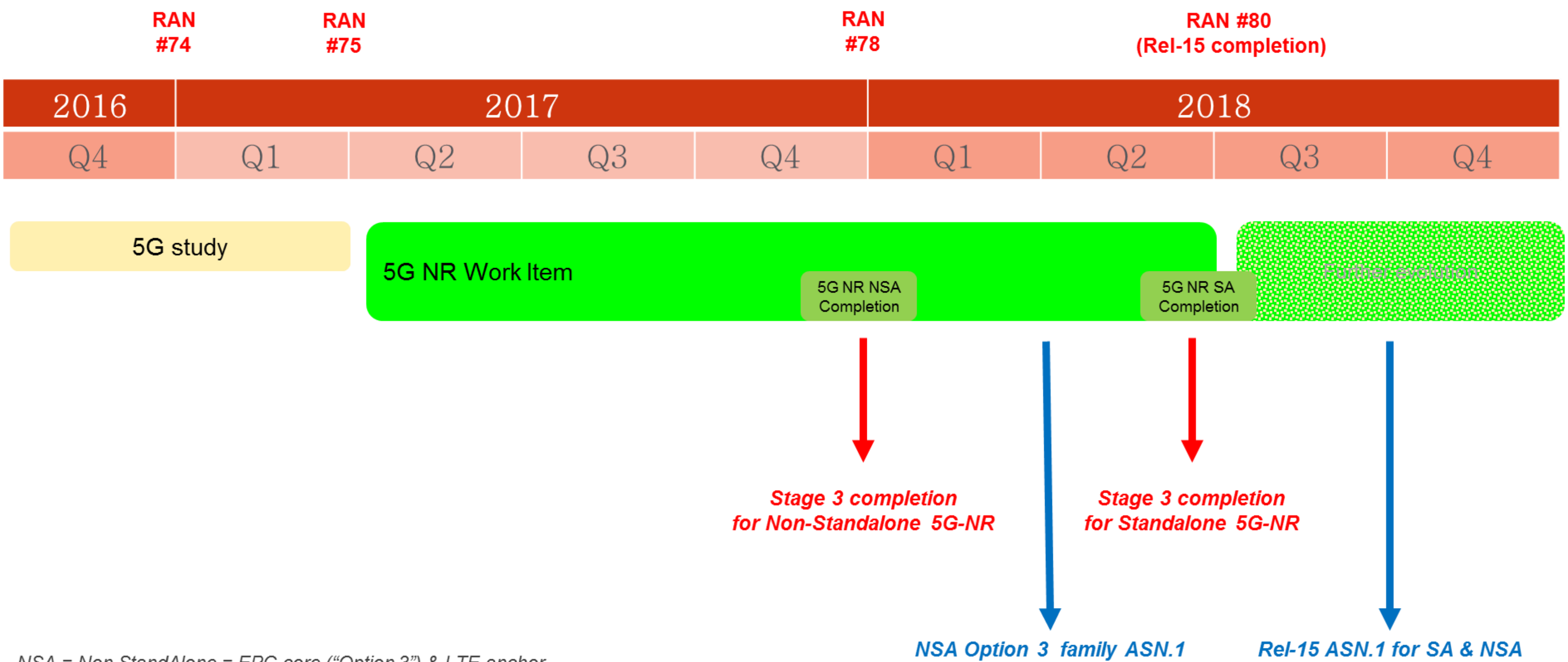
		< 6GHz						> 6GHz			
		< 1GHz	1GHz	2GHz	3GHz	4GHz		6-24GHz	24-30GHz	30GHz	40GHz
SPRINT				B41(2.6G)							
CTC				B41(2.6G)	B42(3.5G) 3.3-3.4	4.4-4.5 4.8-4.99					
AT&T										37.6-40 37-37.6	
DOCOMO					3.3-4.2	4.4-4.99			26.5-29.5 (24.25-29.5)		
KT		B8(900M)	B3(1.8G)	B1(2.1G) B40(2.3G)	3.4-3.7				26.5-29.5 24.25-27.5 (24.25-29.5)	31.8-33.4 37-40.5	
CMCC ERICSSON					B42(3.5G) SI on 3.3-4.99						
ORANGE		B20(800M), B28(700M)	B3(1.8G)	B1(2.1G) B7(2.6G)	B42(3.5G) B43(3.7G)			5.925-8.5	24.25-27.5	31.8-33.4	
DISH								12.2-12.7			
HUAWEI					3.3-[3.8-4.2]	4.4-4.99			24.25-27.5 26.5-29.5	37-40	40.5-43.5
ZTE					3.4-3.6		•••		24.25-27.5 27.5-29.5		
SAMSUNG (No Input)					**3.4-3.7**				**26.5-29.5 24.25-27.5**	**37.6-40 37-37.6**	

NR Standardization in 3GPP

NR Standardization Schedule

NR Phase-1 work item approved

- Non-standalone mode to be completed by Dec, 2017
- Standalone mode to be completed by June, 2018
- All Layer 1 and Layer 2 user plane specifications to be completed by Dec, 2017

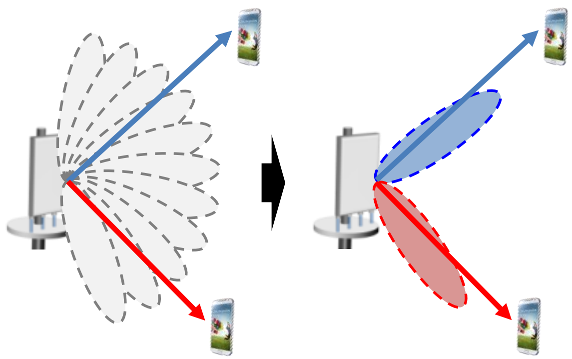


NSA = Non StandAlone = EPC core ("Option 3") & LTE anchor
SA = StandAlone

3GPP Key Technologies: NR-MIMO

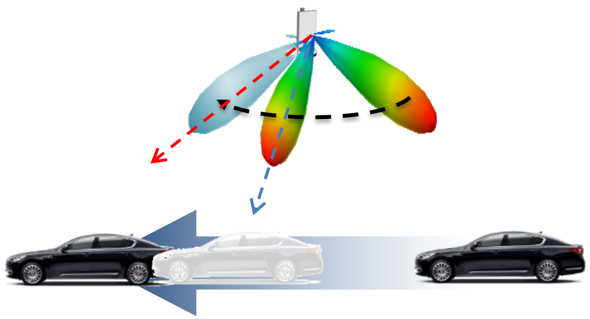
NR needs to achieve 3 times the spectral efficiency of LTE and NR-MIMO will be the main technology to achieve this target

Advanced CSI



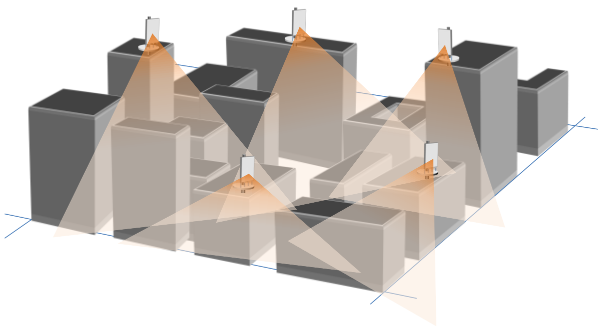
- LTE's CSI is not accurate enough to suppress MU interference
  - Without accurate CSI, performance from MU transmission will be suboptimal
- NR's advanced CSI will focus on improving CSI for MU transmissions

New Transmission Schemes



- Closed loop beamforming will not provide sufficient gains at high UE velocity
- NR's transmission schemes will be optimized not only for low mobility but also for high mobility

3D Network Coordination



- Cell edge performance remains critical to maintaining constant user experience
  - Without sufficiently high cell edge performance, introducing new verticals that are data hungry remains problematic

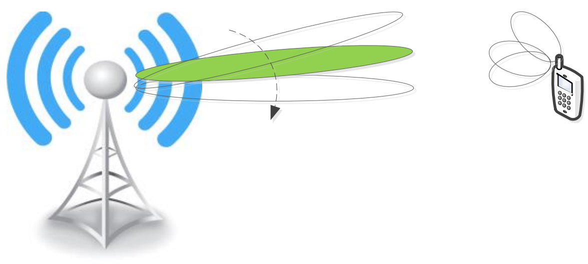
3GPP Key Technologies: Beam Management

- **NR mmWave system is multi-beam-based operation**
  - Multiple beams need to provide coverage to entire cell area
  - Beam management procedure to acquire and maintain best beam for each TRP/UE pair
- **NR supports L1/L2 beam management procedures: P-1, P-2, P-3**

P-1: Initial beam acquisition

- UE measures different TRP Tx beams to select best TRP/UE beam

P-2: TX beam refinement



- UE refines the TRP Tx beam

P-3: RX beam refinement

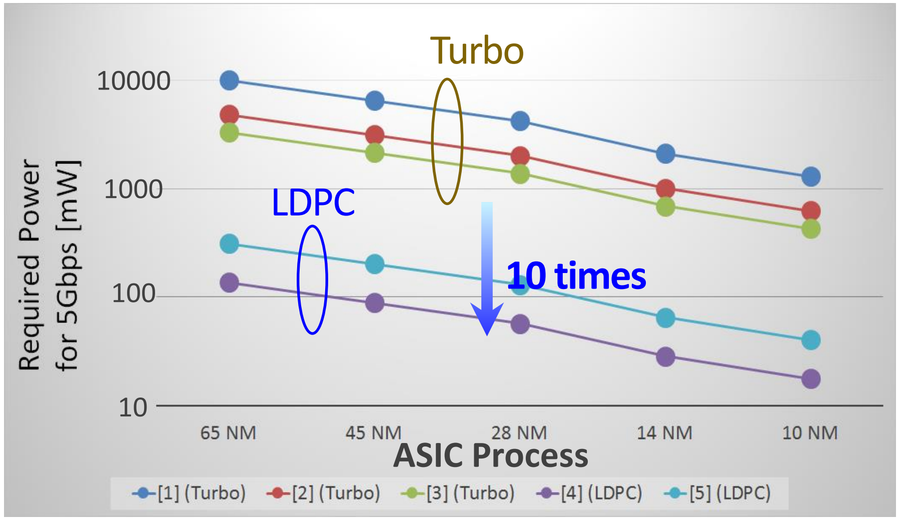
- UE sweeps the Rx beams with respect to one TRP Tx beam

3GPP Key Technologies: Channel coding

- **3GPP has relied on turbo code since its first specification in 1999 (less than 1Mbps)**
  - Turbo code is part of W-CDMA, HSPA, and LTE specifications
- **For 5G, turbo code cannot meet all the requirements to support 20 Gbps**
  - LDPC is a better solution considering performance, complexity, and power consumption

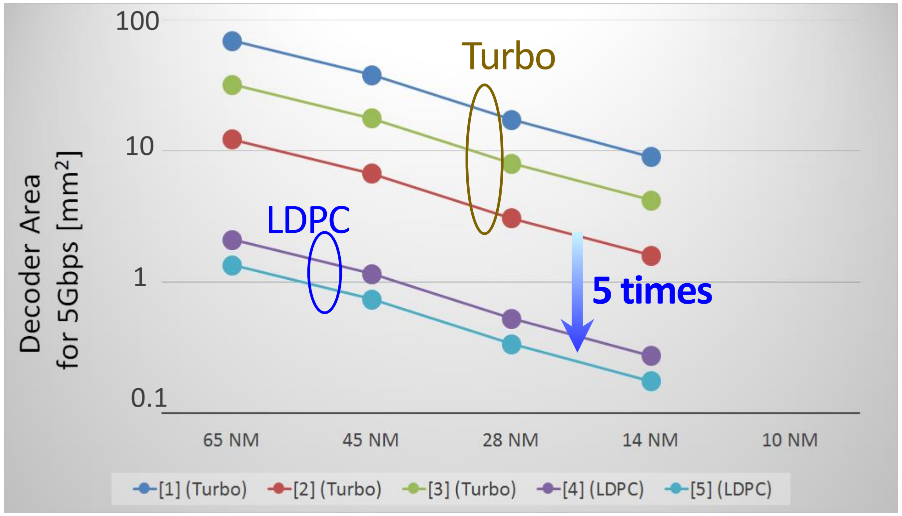
Lower power consumption

- LDPC consumes 10 times less power than turbo code



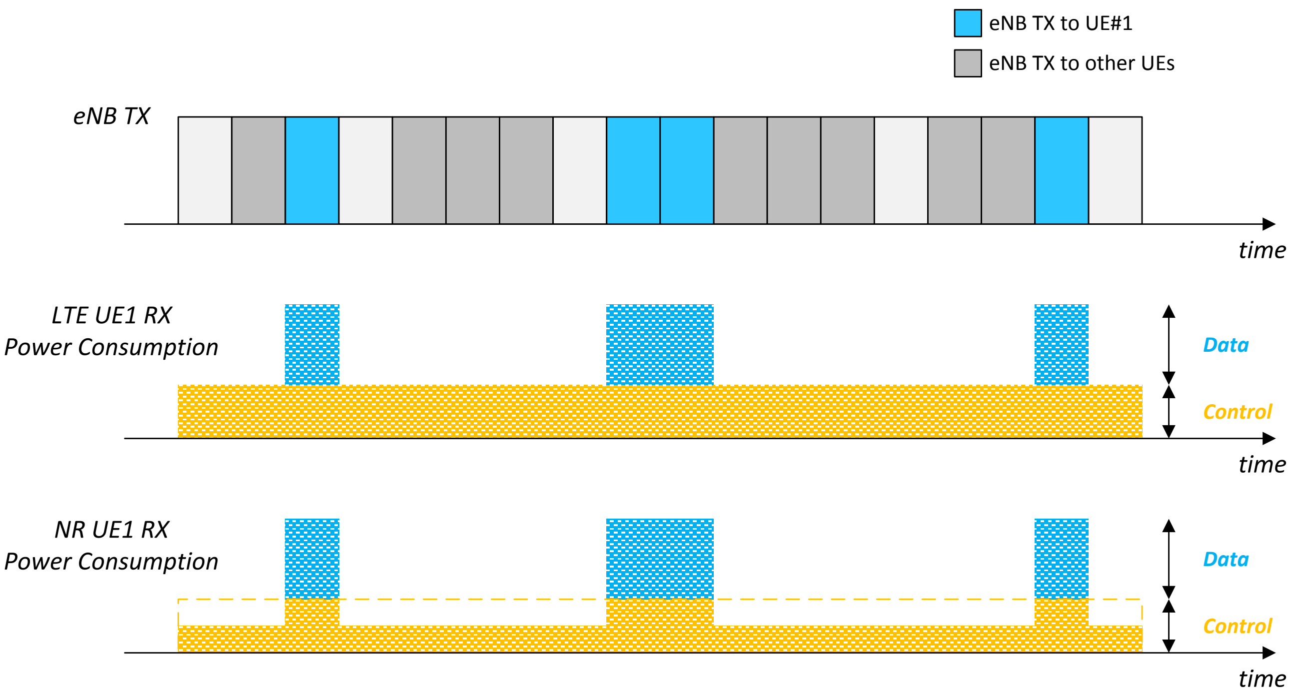
Smaller area

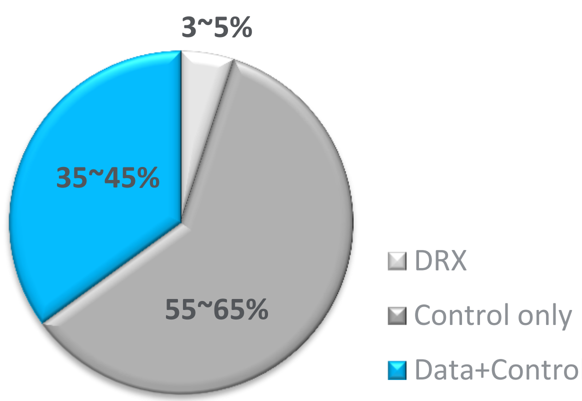
- LDPC requires 5 times smaller chip area than turbo code



3GPP Key Technologies: UE Power Savings

- **In LTE, UE receiver consumes more power on control channel than on data channel**
- **For NR, our goal is to reduce receiver power consumption on control channel by 50%**
  (+50% longer active mode)
- **We are evaluating different approaches to achieve this goal**
  - Adaptation of control channel blind decoding, reducing control channel monitoring BWs, etc





<Measured from Samsung modem>

NR Phase-2

- **NR Phase-2 study items approved (work to start in June ~)**
  - Study on unlicensed spectrum
  - Study on non-orthogonal multiple access
  - Study on Integrated Access Backhaul (aka Relay SI)
  - Study on eV2V evaluation methodology
  - Study on non-terrestrial networks
  - Study on 5G self-evaluation

- **Given there are only 9 months to complete NR Phase-1 L1/L2 specs, it is important that this work has highest priority in RAN**
  - If necessary, NR Phase-2 study items should be postponed to a later date (decision can be made in RAN#76)

NR Phase-2 Proposals from Samsung

Shared Spectrum Access (SSA)	✔ **Intelligent spectrum access and management for unlicensed spectrum (5GHz, 60GHz), lightly licensed spectrum (US 3.5GHz, CBRS), and licensed spectrum** • With different coexistence mechanism for different regional regulation and requirements
Integrated Access Backhaul (IAB)	✔ **Efficient in-band wireless relay for NR** • For frequency ranges up to 100 GHz with mechanisms for joint operation of backhaul link and access link
NR MBMS	✔ **NR MBMS numerology to fulfill NR MBMS requirements** ✔ **Advanced technologies to improve NR MBMS capacity** ✔ **Dedicated MBMS network and network sharing between multiple MNOs**
NR V2X	✔ **Support for NR-based V2V, V2I/N and V2P services covering use cases defined in [SA1 TR: TR 22.885] and advanced use cases defined in [SA1 TR: TR 22.886]** • NR V2X should be able to operate as a standalone system without relying on LTE
NR-MIMO (TBD)	✔ **Enhancements for type-2 CSI** ✔ **Extension of NR-MIMO for new verticals** ✔ **3D network coordination to manage highly directional multi-cell interference**

Defining the Role of LTE and NR

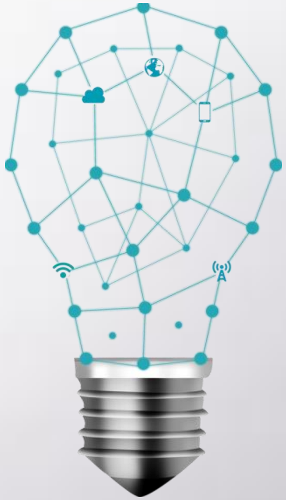
- **NR is designed not only for high throughput data (eMBB) but also to accommodate existing and future vertical services**
- **Evolution on the LTE track also continues to expand it's capability to new service areas**
  - For example, V2X, latency reduction, MTC/NB-IoT, MBMS, public safety, aerial vehicles, ….

- **We need to consider the relationship between NR and LTE**

Option 1: Standalone NR design	Option 2: Minimize overlap
	
• NR is designed to support both LTE functionalities and advanced NR-only functionalities	• NR is designed to avoid overlap with LTE as much as possible

- **In order to make sure that NR doesn't end up being a sub-system to LTE and increase market opportunities, we prefer option 1 over option 2**

RAN1 Elections



Upcoming Elections in RAN1

- **RAN1 election schedule**
  - Chairman: August, 2017 (could change subject to RAN chair election results)
  - 1st vice-chairman: August, 2017
  - 2nd vice-chairman: October, 2017
- **Following candidates are running for RAN1 chairman and vice-chairman positions**
  - Chairman: Brian Classon(Huawei) and Wanshi Chen(Qualcomm)
  - Vice-chairman: **Younsun Kim(Samsung)**, Tong Hui(CMCC), Kazuki Takeda(DOCOMO), Havish Koorapaty(Ericsson), Hanbyul Seo(LGE)
- **Samsung's candidate for the vice-chairman position is Younsun Kim**
  - 15 years of standardization experience in 3GPP and 3GPP2
  - Samsung RAN1 prime since 2013 and lead developer of CoMP/FD-MIMO technologies
  - Maintains tight coordination with Samsung terminal/NW businesses as well as other WGs
  - Consensus builder who has worked with companies to reach consensus in tough situations