3GPP RAN Workshop on 5G
Phoenix, AZ, USA, 17-18 Sept., 2015

SAMSUNG

RWS-150039

Vision and Schedule for 5G Radio Technologies

Samsung

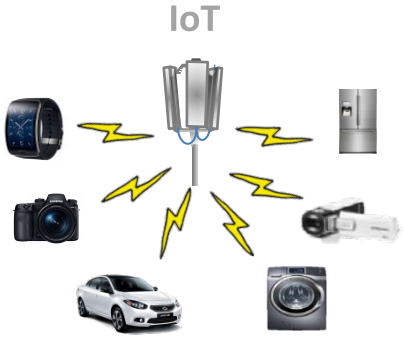
5G Vision

Support a broad range of devices and services

Immersive Experience

Everything on Cloud

Massive Connectivity



Tele-Presence

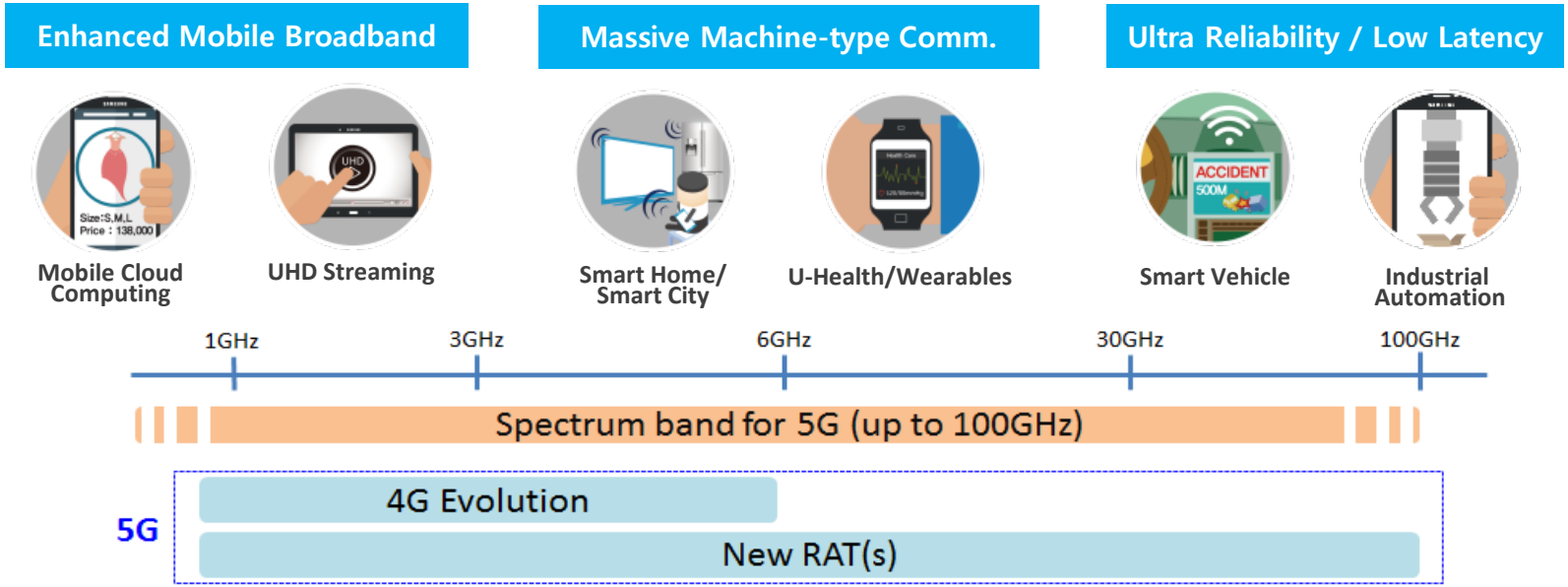
First commercialization of 5G system is expected around 2020

- 5G trial service in Korea (PyeongChang 2018 Winter Olympics)

© 2015 Samsung DMC R&D Center

5G System Overview

- Efficient support for various usage scenarios such as eMBB, mMTC, and UR/LL
- Introduction of new RAT(s) to utilize various spectrum bands up to 100 GHz

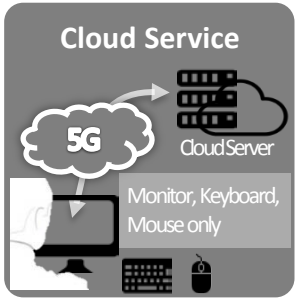


eMBB(Enhanced Mobile Broadband), mMTC(Massive Machine-type Communications), UR(Ultra Reliable), LL(Low Latency)

5G Requirements

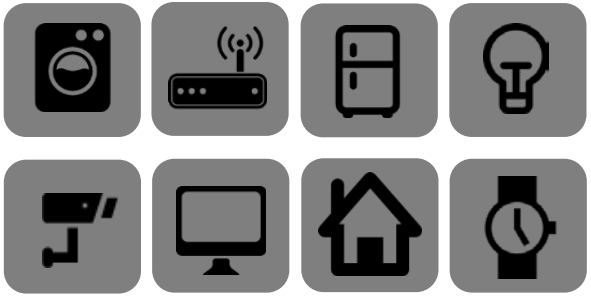
eMBB

- 20 Gbps peak data rate
- 100 Mbps user experienced data rate
- Spectrum efficiency by 3 times over IMT-Advanced
- 500 km/h mobility support
- Network energy saving by 100 times over IMT-Advanced



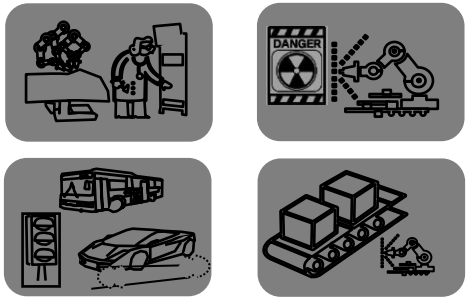
mMTC

- $10^6/km^2$ connection density
- Large coverage to support devices in harsh environments
- Extremely long-life battery for low cost devices (e.g., sensor)



UR/LL

- 1 ms air latency
- 5 ms end-to-end latency
- 500 km/h mobility



5G Design Principle

SAMSUNG

Scalable Modular Design

- Configurable modules
- Easy on-demand integration of modules
- Support broad range of services (eMBB, mMTC, UR/LL)

Forward Compatibility

- Allow easy extension to future services
- Flexible design for future spectrum assignment

Service-Aware Access

- Configurable resource according to service demands
- Flexible use of network/radio resources

© 2015 Samsung DMC R&D Center

Numerology for 5G New RAT

SAMSUNG

Design considerations

- Latency < 1msec
- Support various deployment scenarios using various frequency bands
  - Multiple sets of subcarrier spacing and CP size with reasonable overhead
  - Multiple TTIs with scalability
  - All symbols are better to have the same length within a TTI

Numerology examples

Numerology	Set 0	Set 1		Set 2		
Freq. & Deployment	Low freq., large cell (IoT)	<6 GHz (Including LTE replacement)		Both <6 GHz and >6 GHz		
Potential BW	5 / 1.4 MHz	10 / 20 / 40 / 80 MHz		100 / 200 MHz		
FFT size	2048 / 512	1K / 2K / 4K / 8K		1K / 2K		
Subcarrier Spacing	3.375 kHz	16.875 kHz		135 kHz		
CP Length	30 us (11.1%)	3.2 us (5.1%)	24 us (28.8%)	0.4 us (5.1%)	0.9 us (11.1%)	3 us (28.8%)
# Symbols per 1ms	3	16	12	128	120	96
Subframe Length (TTI)	1 ms	0.25 ms		0.125 ms		

© 2015 Samsung DMC R&D Center

mmWave for Capacity Boost

SAMSUNG

mmWave system to support very high data rate by using very wide BW

Throughput boost of mmWave system is especially helpful for heavy traffic load

Simulation Conditions

- 10 small cells deployed per macro sector (macro ISD 500m)
- FTP traffic model 1, SISO
- Light traffic load : 300 Mbps/km^2
- Heavy traffic load : 150 Gbps/km^2 (10 Gbps per macro cell)

	Macro Cell (2 GHz LTE)	Small Cell (3.5 GHz LTE)	Small Cell (mmWave-band)
Carrier Freq.	2 GHz	3.5 GHz	28 GHz
System Bandwidth	20 MHz	80 MHz	800 MHz
BS Tx Power	49 dBm	39 dBm	39 dBm
BS Antenna Element Gain	17 dBi	5 dBi	5 dBi
Tx Array Gain	0 dB	0 dB	9 dB
Rx Ant. Gain	0 dBi	0 dBi	7 dBi

Evaluation Results

- mmWave HetHet shows > 300 Mbps 5%-tile user T'put even in heavy traffic load

Traffic Load	Throughput	LTE HetNet		mmWave BF HetNet	
		LTE BS [Mbps]	LTE SC [Mbps]	LTE BS [Mbps]	mmWave BF SC [Mbps]
Light	**Average UE**	49.94	246.01	60.80	2095.10
	5% Edge UE	19.42	246.72	34.10	2097.20
Heavy	**Average UE**	Outage	Outage	60.89	1560.50
	5% Edge UE	Outage	Outage	34.10	358.21

※ Outage: system capacity is not able to support offered traffic

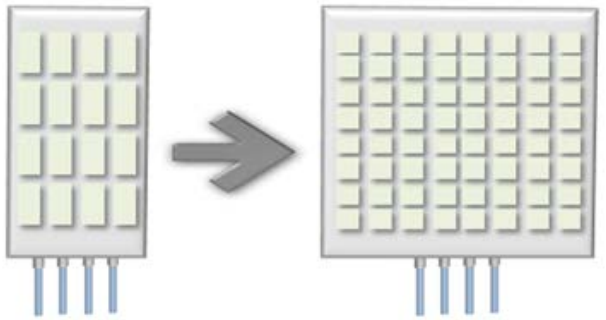
© 2015 Samsung DMC R&D Center

Massive Antenna Technologies

Massive MIMO for below 6 GHz & above 6 GHz

- Evolution of FD-MIMO to use massive number of antennas in a new RAT(s)
- Hybrid beamforming as a key technology with reasonable RF complexity for operation at high frequency bands, e.g., 28 GHz

FD-MIMO Enhancements



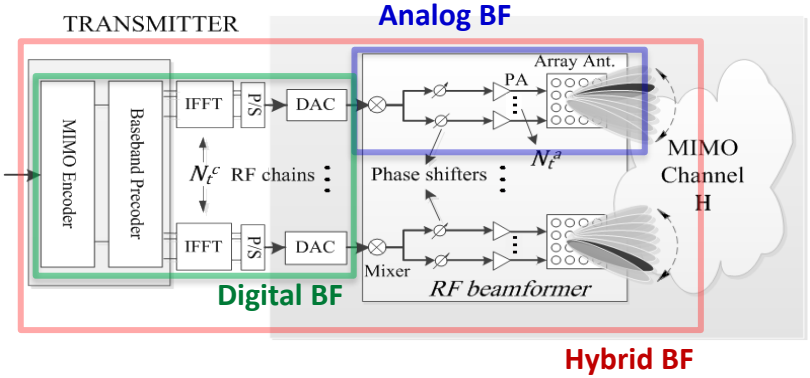
Support 16 ports

Rel-13 FD-MIMO system

Support 32 , 64, 128, ... ports

Rel-14 EFD-MIMO system

mmWave Hybrid BF Architecture

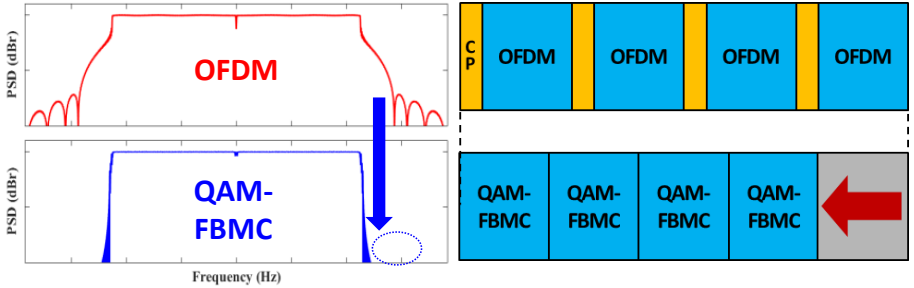


QAM-FBMC for Overhead Reduction

OFDM-based waveform with additional filtering

- Well-localized spectrum by per-subcarrier filtering improves spectral efficiency and enables efficient coexistence with other RATs

Overview



(In frequency) (In time)

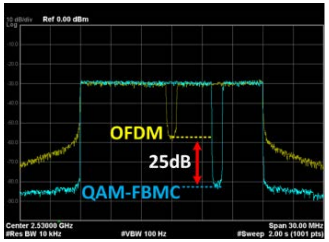
Expected gain examples

- Spectral efficiency enhancement

System		OFDM Overhead		QAM-FBMC* S.E. Gain against OFDM
		Cyclic Prefix	Guard-Band	
4G	LTE	6.7 %	10 %	16.7 %
5G (eMBB)	Micro	10 %	10 %	20.9 %
	Macro	15 %	10 %	28.1 %

*: No CP overhead, 2% Guard-band

- Efficient coexistence with other RATs
  - RB-unit in-band spectrum nulling
  - Spectrum comparison between OFDM and QAM-FBMC
  - Interference suppression gain (>25dB) against OFDM



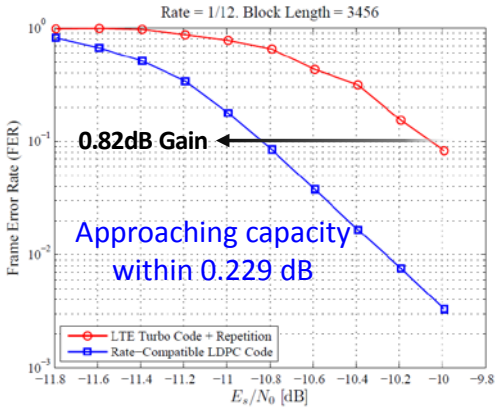
LDPC for Various Usage Scenarios

- **For eMBB: LDPC is preferred over turbo code from decoder complexity perspective**
  - LDPC requires much less chip area than Turbo codes
- **For mMTC: LDPC shows near capacity performance for low code rate**
- **For UR/LL: LDPC guarantees error-floor-free for high reliable services**

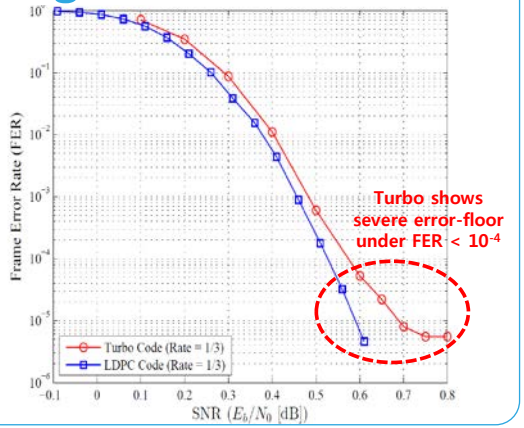
Decoder Complexity [1]

	Turbo code	LDPC
Area Efficiency (Gbps/mm²)	0.3	18.7
Throughput (Gbps)	2.3	130.6
@Clock f (MHz)	500	194
Technology (nm)	65	65 (SVT)
Area (mm²)	7.7	7.0

Low Code Rate



High Reliable Services



[1] Advanced Hardware Design for Error Correcting Codes : Chapter 2 - Challenges and Limitations for Very High Throughput Decoder Architectures for Soft-Decoding, Springer International Publishing Switzerland 2015

© 2015 Samsung DMC R&D Center

SWSC : capacity-achieving scheme (proven in theory, verified by link level simulations)

Sliding-Window Superposition Coding

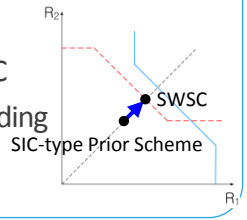
SWSC Concept

- Superposition coding in a staggered manner
  - : Sends a message without split over two consecutive blocks
  - : Recovers it using sliding-window decoding

	block	1	2	3	…	b-2	b-1	b
Sender 1	U	known	$m_1(1)$	$m_1(2)$	…	$m_1(b\text{-}3)$	$m_1(b\text{-}2)$	$m_1(b\text{-}1)$
	V	$m_1(1)$	$m_1(2)$	$m_1(3)$	…	$m_1(b\text{-}2)$	$m_1(b\text{-}1)$	known
Sender 2	W	$m_2(1)$	$m_2(2)$	$m_2(3)$	…	$m_2(b\text{-}2)$	$m_2(b\text{-}1)$	$m_2(b)$

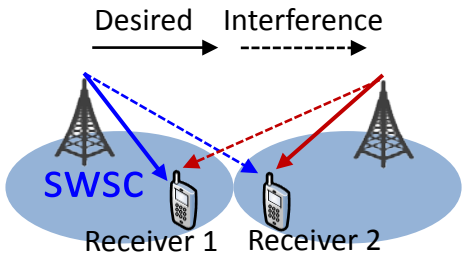
Sliding-window

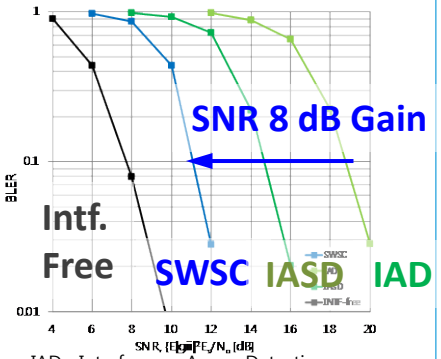
- : Equalizes the effective qualities of the two MAC in IC
- : Achieves the sum rate bound of simultaneous decoding



SWSC Feasibility Verification

- Provide virtually edgeless end-user experiences





IAD : Interference Aware Detection

IASD : Interference Aware Successive Detection

- Proven to track ML performance at low complexity[1)]

IC: Interference Channel

SIC : Successive Interference Cancellation

1) L. Wang, E. Sasoglu, and Y.-H. Kim, "Sliding-window superposition coding for interference networks," ISIT 2014

© 2015 Samsung DMC R&D Center

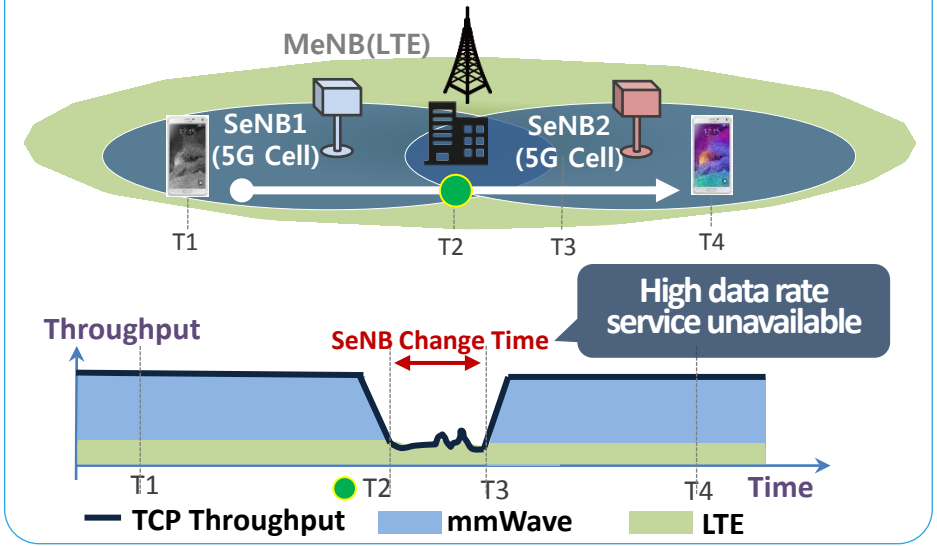
Multi-Connectivity for Service Continuity

5G new RAT enables seamless high data rate experience anywhere

- 4G can be used as a coverage layer

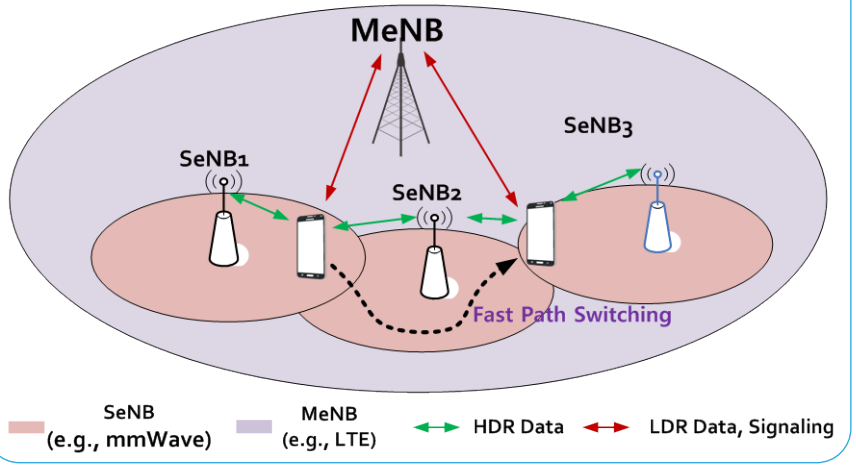
mmWave Mobility Challenge

- **Severe signal drop on the move @ 28 GHz**
  - Even through dual connection, high data rate service is not guaranteed



Multi-Connectivity

- **Multiple eNBs Connection**
  - 1 MeNB (RRC control) + more than 1 SeNB(s) (user plane data)
  - SeNB serves packet transmission/reception which requires ultra high data rate
  - Additional SeNB(s) is ready for a case that serving SeNB is unavailable



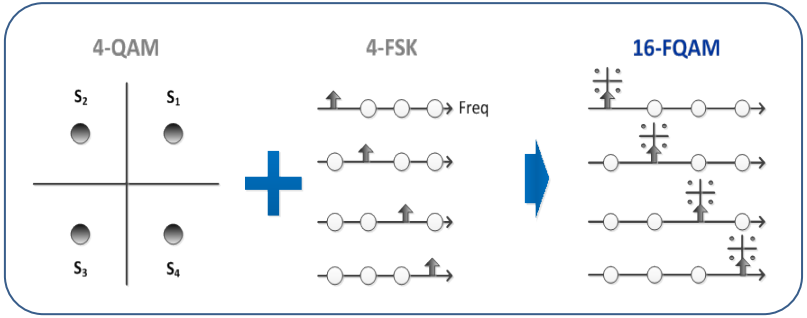
FQAM for Energy Efficient Modulation

FQAM: combines the virtues of QAM and FSK modulation

- Energy efficient & good performance in a low SNR region, useful for coverage extension
- Low PAPR when combined with OFDMA due to small number of active subcarriers

FQAM Transmission

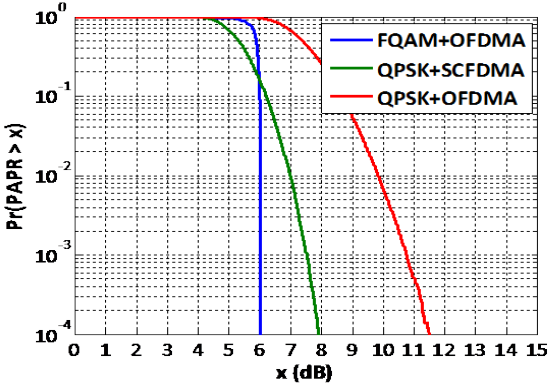
- A QAM symbol is transmitted on a single tone selected among a group of tones



< Example of an FQAM constellations >

Benefits

- Inherits the energy efficient nature of FSK
- Low PAPR when combined with OFDMA



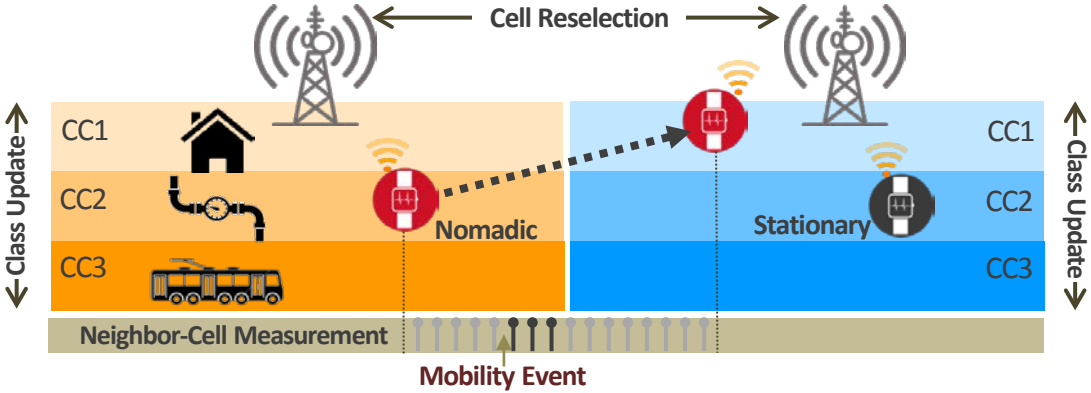
< CCDF of PAPR for various transmission schemes>

© 2015 Samsung DMC R&D Center

Energy Efficient Link Management

Improve battery life for low-end stationary/nomadic devices

1. No handover & no inter-cell measurement during data exchange
2. Idle mobility optimized for stationary/nomadic devices
   - Minimize neighbor cell measurement and avoid unnecessary signaling if stationary
3. Last cell prioritized cell reselection (vs. best cell prioritized cell reselection)
   - Stationary devices – stick to the last camped cell as long as possible
   - Nomadic devices – trigger cell reselection when needed, based on mobility event



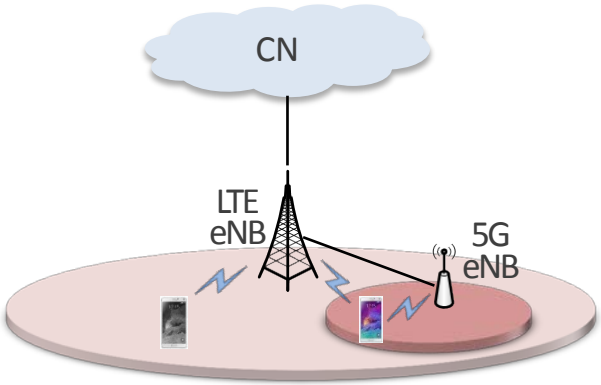
5G Radio Access Network Architecture

Providing 5G deployment flexibility

Support both non-standalone and stand-alone 5G access

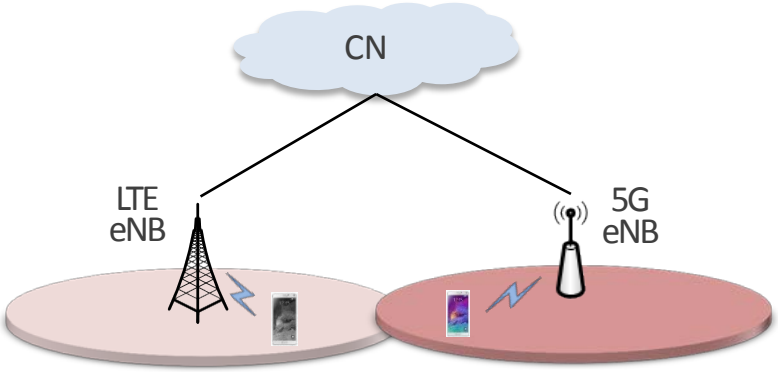
Non-Standalone

- Tight integration with LTE eNB, e.g., dual connectivity
  - Access & mobility are controlled only by LTE eNB
  - Higher data rate experience: aggregation/fast switching



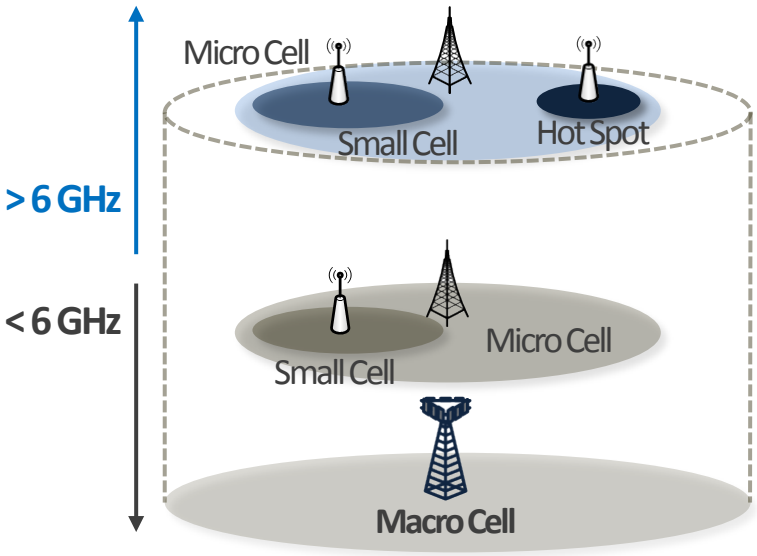
Standalone

- Interworking with LTE eNB
  - Access & mobility can be controlled by LTE eNB and 5G eNB
  - Less impact on legacy LTE eNB & easier deployment



© 2015 Samsung DMC R&D Center

5G Spectrum and RAT Features

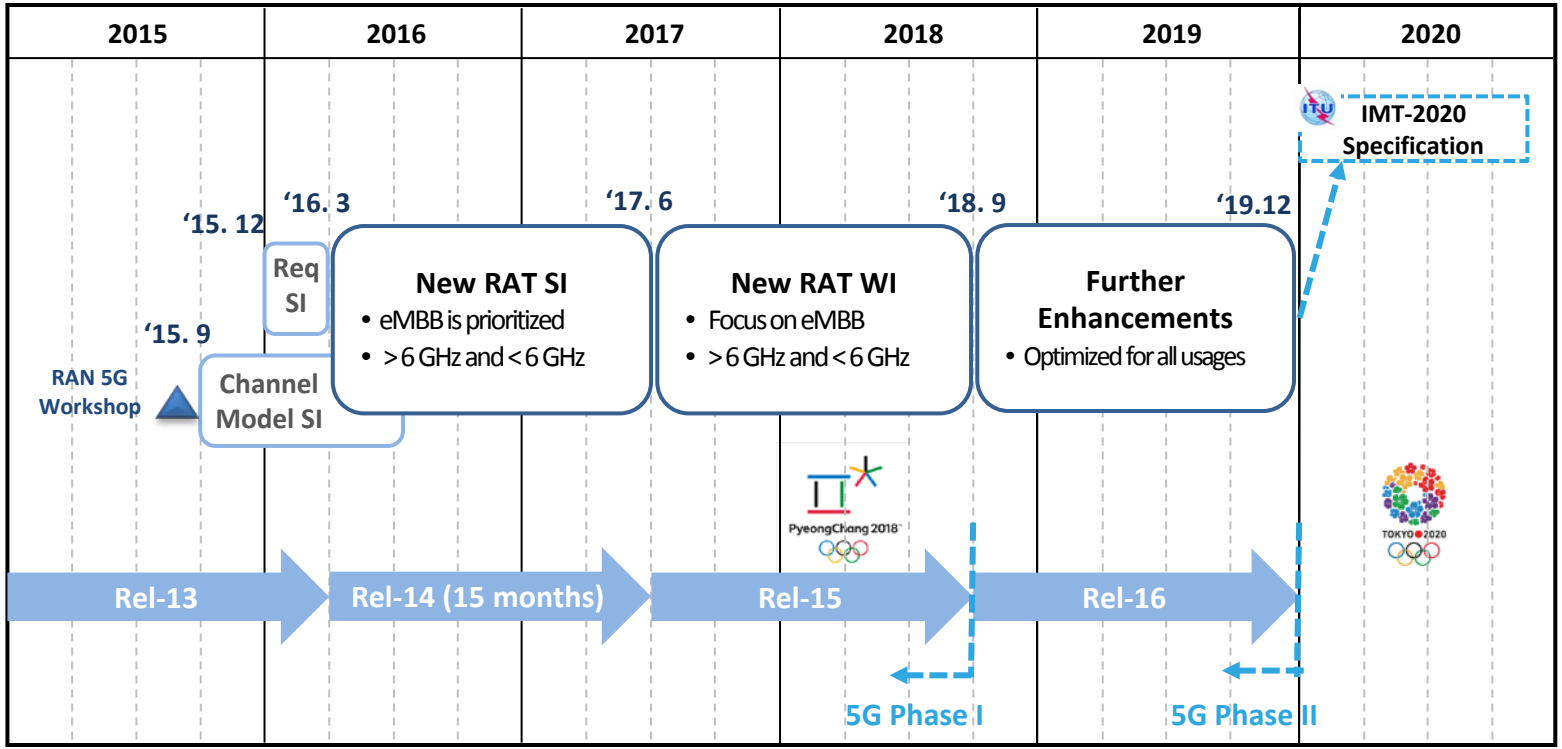


Features	LTE Evo.	5G New RAT	
	< 6GHz		> 6GHz
Duplexing	TDD/FDD	TDD/FDD	TDD(/FDD)
Bandwidth	1.4/3/5/10/15/20 MHz	Up to 100MHz	At least 100MHz
Waveform	OFDM	OFDM based (potentially with additional filtering)	OFDM based (potentially with additional filtering)
Multiple Access (DL/UL)	OFDMA (DL) SC-FDMA(UL)	OFDMA (DL/UL)	OFDMA (DL/UL)
MIMO Type	FD-MIMO	FD-MIMO	FD-MIMO or Hybrid-BF
MIMO Order (DL)	~8 layers for SU Total 4-8 layers for MU	~8 layers for SU Total 4-8 layers for MU	~8 layers for SU Total 8 layers for MU
Channel Coding	Turbo Code	LDPC	LDPC
LTE Integration	-	Dual Connectivity	Dual Connectivity

© 2015 Samsung DMC R&D Center

5G Standard Timeline

Phased approach to meet early commercial request around 2020



Phases for Specification Work

SAMSUNG

Phase I until Sep 2018

- **Focus on eMBB usage scenario**
  - Target spectrum : up to 40 GHz
  - Main deployment scenarios : HetNet / UMi for eMBB (UMa also considered)
  - Forward compatible design
  - Optimized for low mobility UE
  - TDD
  - Mobility can be supported by LTE/Macro
    - Non-standalone operation may be prioritized for timely commercialization

Phase II until Dec 2019

- **Optimized for all 5G usage scenarios**
  - Optimized for all deployment scenarios
  - Both TDD and FDD
  - Additional features can be considered, e.g., D2D, unlicensed bands operation

© 2015 Samsung DMC R&D Center

Thank You