COMMUNICATIONS RESEARCH TEAM

SAMSUNG

5G Mobile Communications for 2020 and Beyond

- Vision and Key Enabling Technologies -

IEEE WCNC 2014, Istanbul
April 2014

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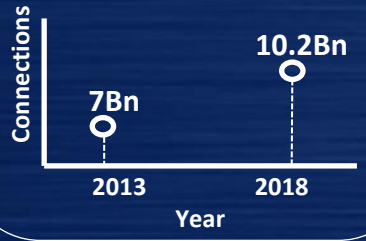
5G Vision

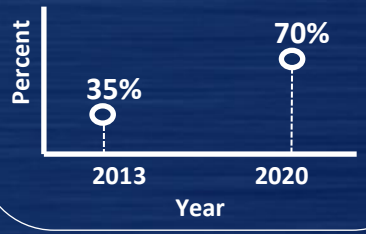
Mobile Trend

Mobile Connections[1]



Mobile Data Traffic[1]

Mobile Cloud Traffic[2]



Things Connected[3]

[1] VNI Global Mobile Data Traffic Forecast 2013-2018, Cisco, 2014
[2] The Mobile Economy, GSMA, 2014
[3] Internet of Things, Cisco, 2013

* EB (Exa Bytes) = 1,000,000 TB (Tera Bytes)

5G Service Vision

Everything on Cloud

Desktop-like experience on the go

Immersive Experience

Lifelike media everywhere

Ubiquitous Connectivity

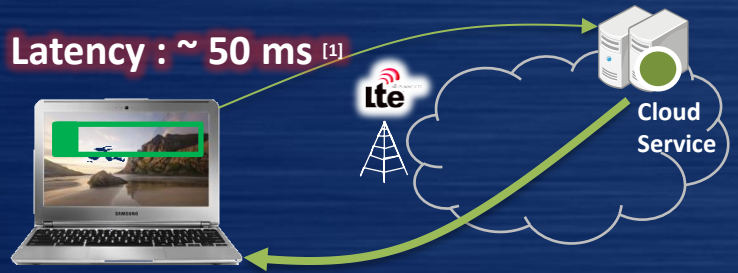
An intelligent web of connected things

Intuitive Remote Access

Real-time remote control of machines

Everything on Cloud

Lagging Cloud Service



~ 20 min
to download HD movie (1.2GB)

Cloud Service Initial Access Time*	
Provider A	82 ms
Provider B	111 ms
Provider C	128 ms

LTE Downlink Performance[2]	
World	7.5 Mbps
Korea	18.6 Mbps
America	6.5 Mbps

* Top 3 Cloud Service Provider measured in Suwon Office (2013)
Including connect time and response time

Instantaneous Cloud Service

~ 9.6 sec
to download HD movie (1.2GB)

Requirements for Mobile Cloud Service

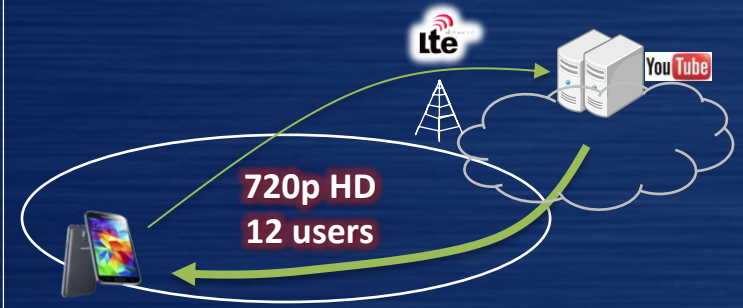
- E2E Latency < 5 ms
- Data Rate > 1.0 Gbps

	Desktop HDD[3]
Access Time	8.5 ms
Transfer Rate	1.2 Gbps

[1] Signals Ahead, AT&T Drive Test Results and Report Preview, 2011
[2] The State of LTE, OpenSignal, 2014
[3] Seagate ST2000DM001 (2TB, 7200rpm), http://www.seagate.com/www-content/product-content/barracuda-fam/desktop-hdd/barracuda-7200-14/ko/docs/desktop-hdd-data-sheet-ds1770-1-1212kr.pdf

Immersive Experience

Selective and Limited



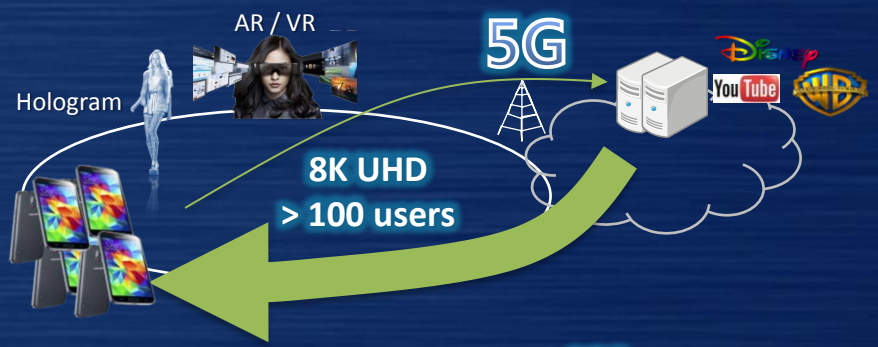
~ 1.6 sec
Loading Delay

User Experience		LTE Cell Capacity	
Loading Delay	1.6 sec*	Cell Throughput	64 Mbps[1]

* Assuming 720p HD, 1 sec buffering, E2E latency 50ms and TCP connection

Required Bandwidth	720p HD[2] : 5 Mbps	8K UHD[3] : 85 Mbps

Lifelike and Commonplace



< 100 ms
Loading Delay

Requirements for Immersive Service

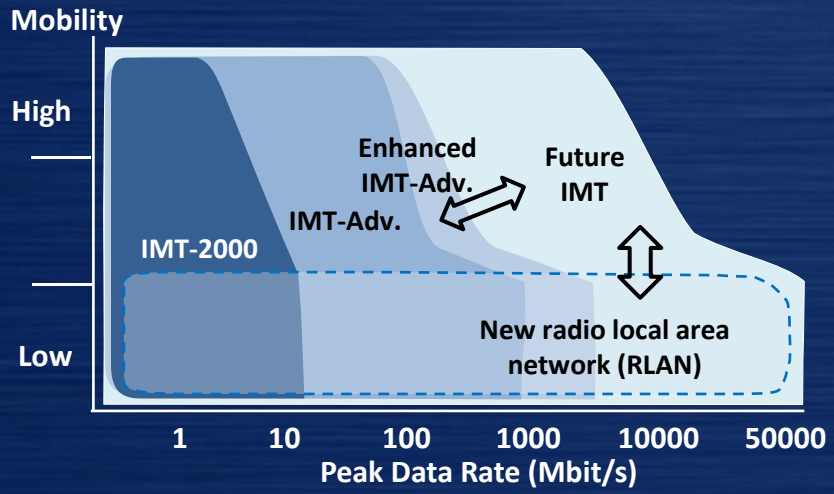
- E2E Latency < 5 ms
- Cell Throughput > 10.0 Gbps

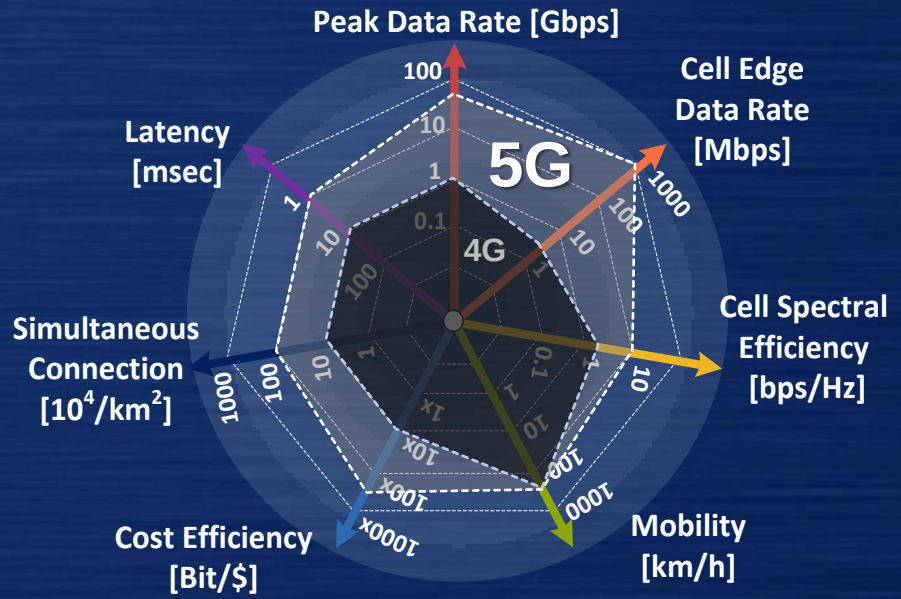
[1] 3GPP Submission Package for IMT-Advanced, 3GPP Contribution RP-090939
[2] https://support.google.com/youtube/answer/1722171?hl=en
[3] http://www.nhk.or.jp/strl/publica/rd/rd140/PDF/P12-21.pdf

AR : Augmented Reality
VR : Virtual Reality

Key Requirements

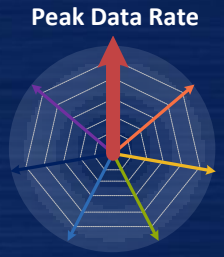
Comprehensive Requirements of “New IMT (5G)” in 7 Categories, Dubbed as “5G Rainbow of Requirements”



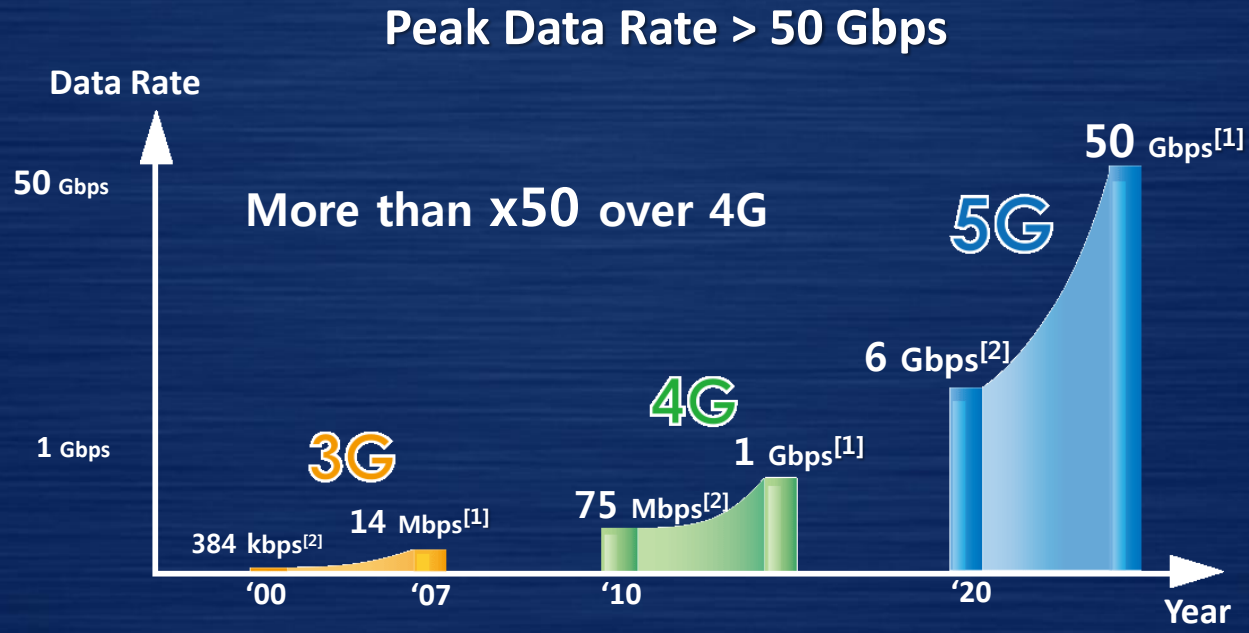


ITU-R WP5D/TEMP/390-E

Ultra Fast Data Transmission

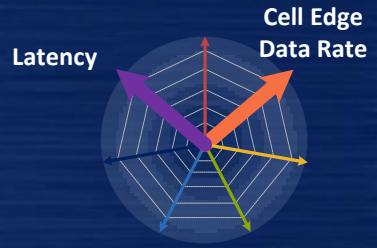


Order of Magnitude Improvement in Peak Data Rate



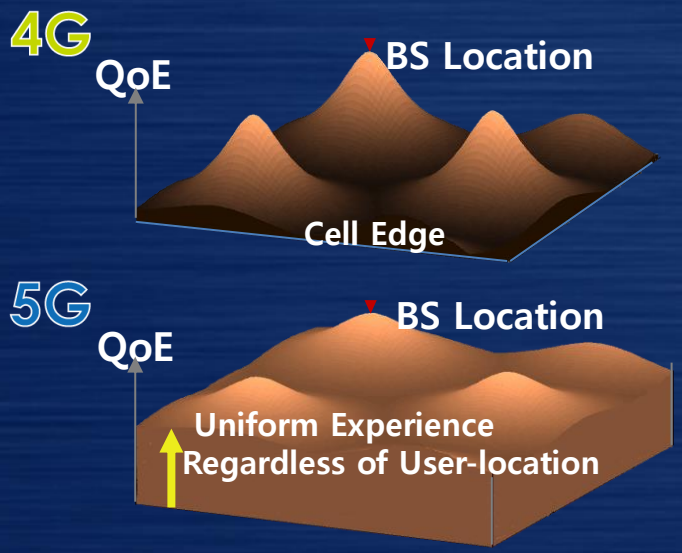
[1] Theoretical Peak Data Rate
[2] Data Rate of First Commercial Products

Superior User Experience

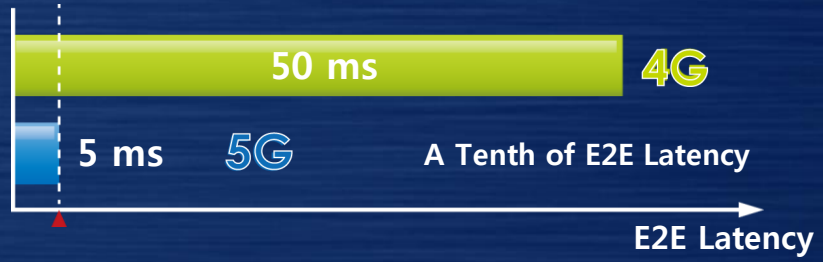


Uniform Experience of Gbps Speed and Instantaneous Response

1 Gbps Anywhere



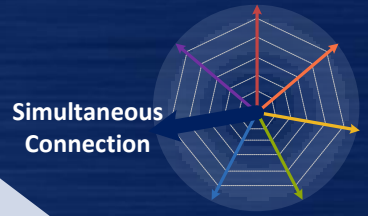
E2E Latency < 5 msec



Air Latency < 1 msec

Massive Connectivity

10 Times More Simultaneous Connections than 4G



2013

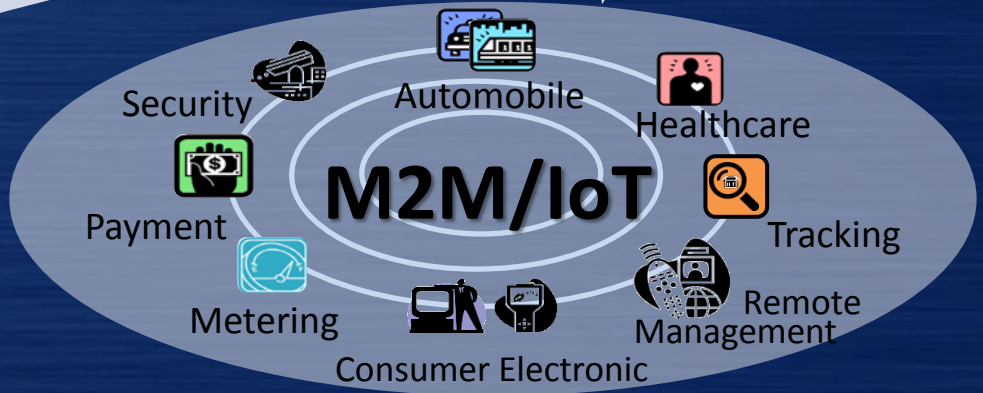
7 Billion[1]

2018

10.2 Billion[1]

2020

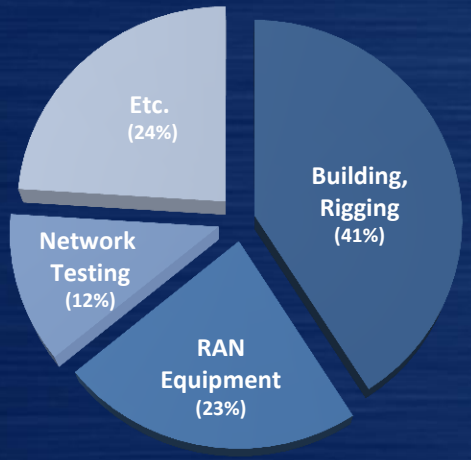
12 Billion



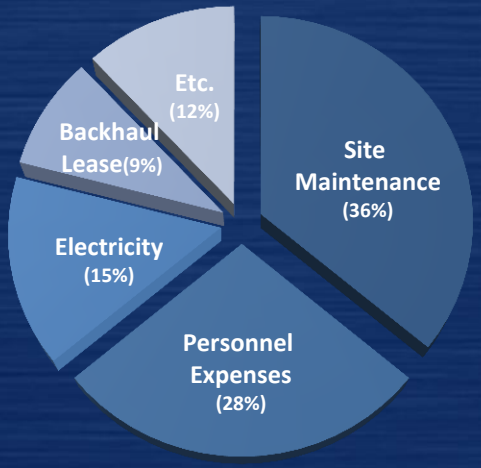
[1] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013-2018

Cost Effectiveness

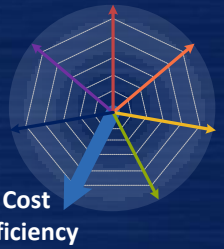
50 Times More Cost Effective than 4G

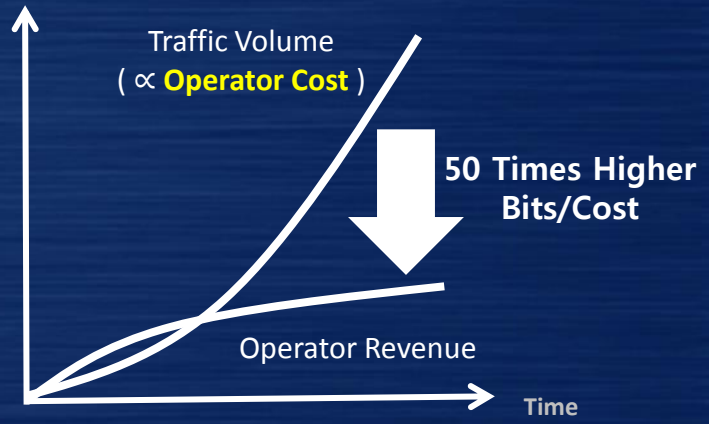


CAPEX[1]



OPEX[2]





[1]Radio Network Sharing – new paradigm for LTE, http://www.telecom-cloud.net/radio-network-sharing-the-new-paradigm
[2]Quest for margins: operational cost strategies for mobile operators in Europe, Capgemini Telecom & Media Insights, Issue 42

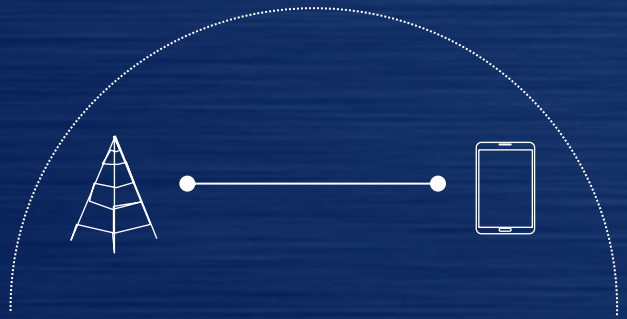
Enabling Technologies : RAN

Capacity

System Capacity : Determined by Bandwidth, Spectral Efficiency and Areal Reuse

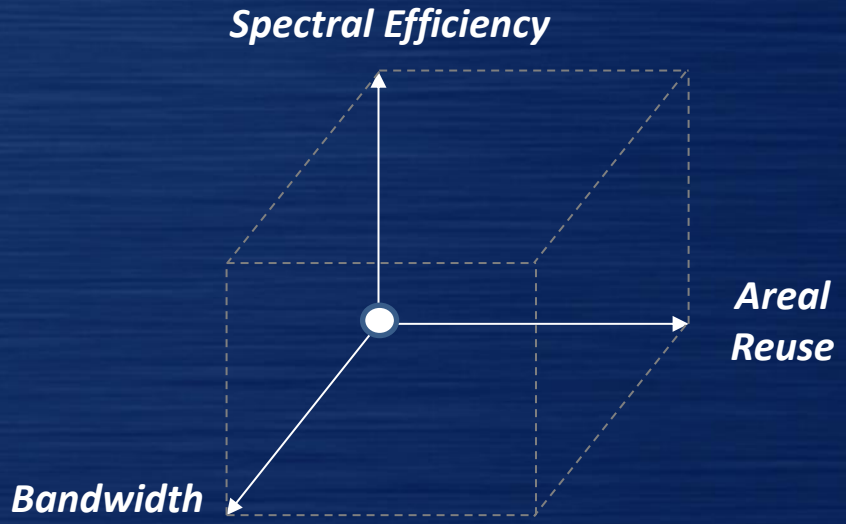
Link Capacity

Point to Point Link with Single Antenna



$$C = Wlog_2(1 + SNR)$$

System Capacity

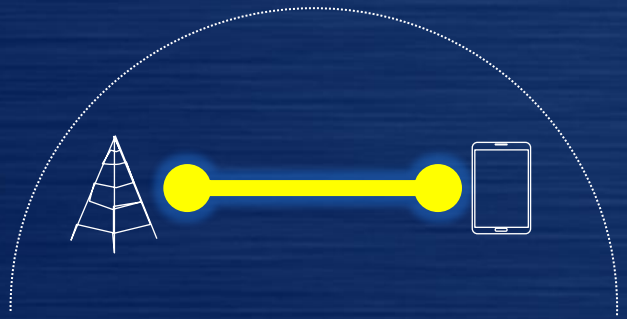


Capacity – Bandwidth

Most Straightforward for Capacity Increase

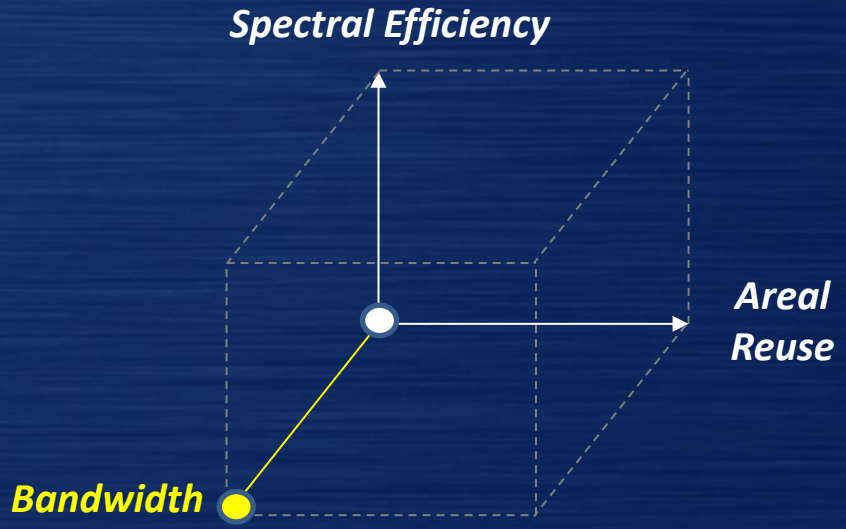
Bandwidth Increase

Carrier Aggregation, Higher Frequencies



$$C = W log_2(1 + SINR)$$

System Capacity

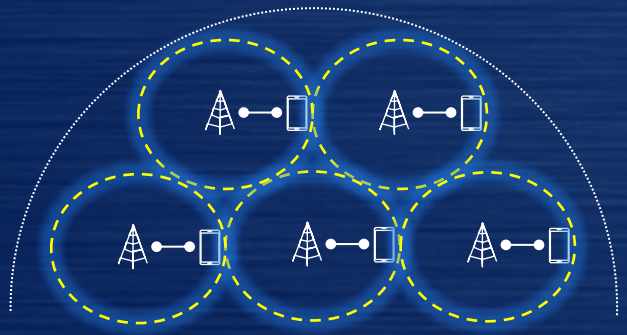


Capacity – Areal Reuse

Utilization of Various Small Cells for Increase of Areal Reuse

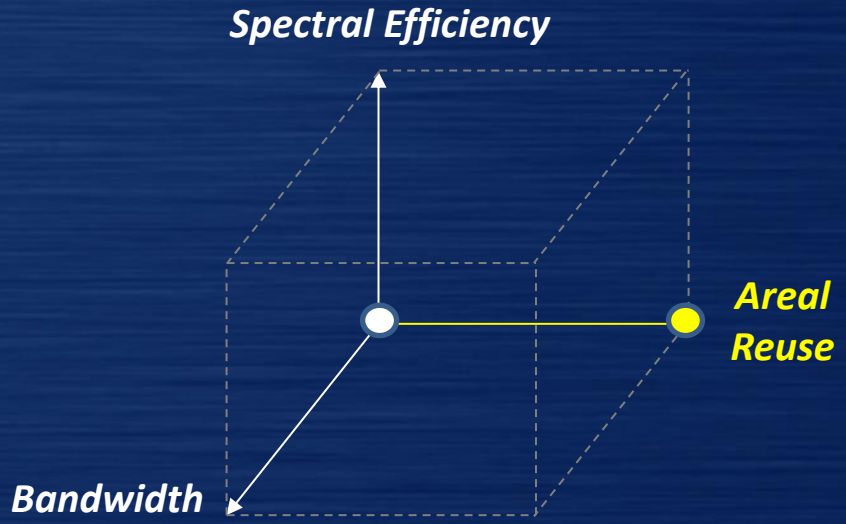
Areal Reuse Increase

Sectorization, HetNet, Small Cells



$$C = W \sum log_2(1 + SINR)$$

System Capacity

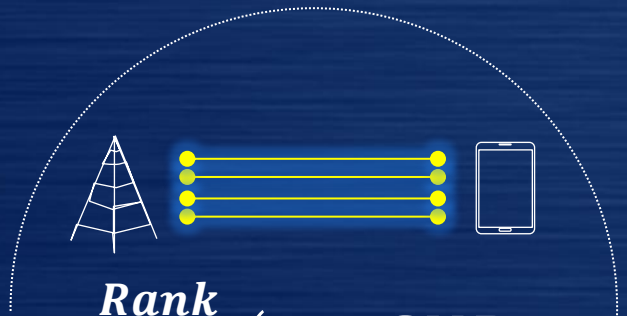


Capacity – Spectral Efficiency (1/2)

Use of MIMO and Advanced Coding & Modulation for Higher Efficiency

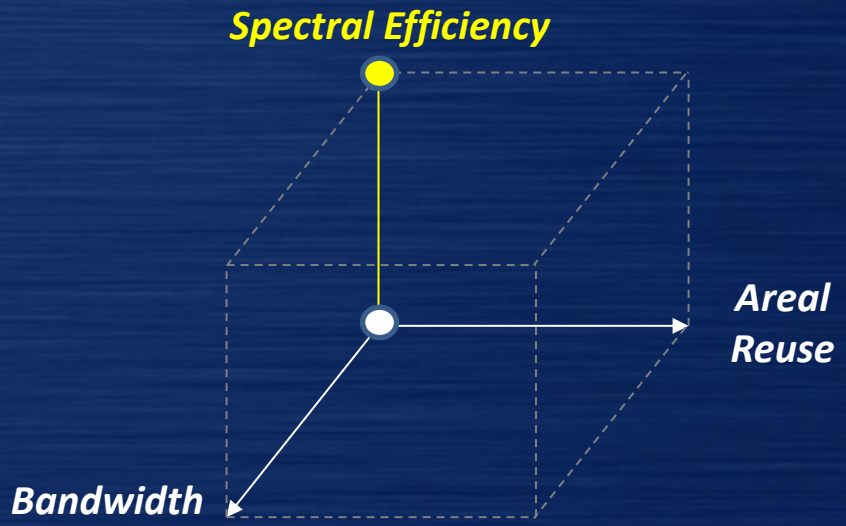
Higher Spectral Efficiency

MIMO, Adv. Coding and Modulation



$$C = W \sum_{r}^{Rank} \left(1 + \frac{SNR_{avg}}{N_{TX}} \lambda_r\right)$$

System Capacity



Capacity – Spectral Efficiency (2/2)

New Waveform Design for Exploiting Non-Gaussianity of Channel

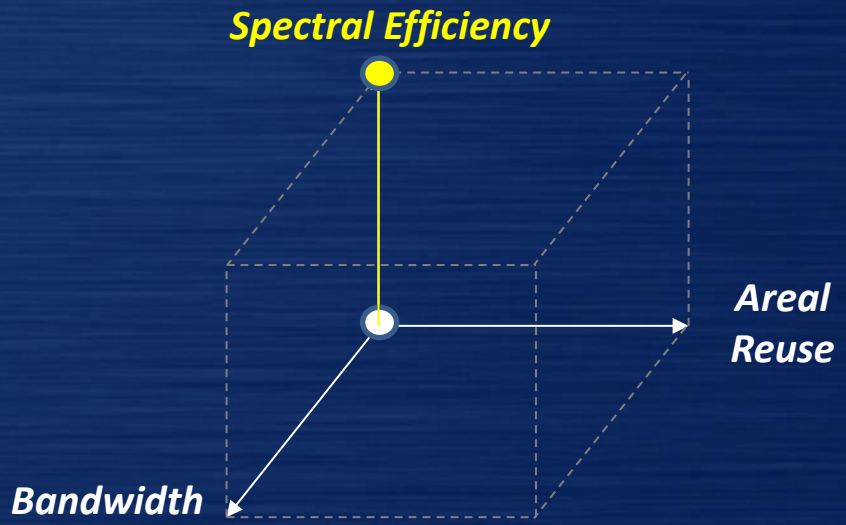
Higher Spectral Efficiency

FQAM (Hybrid Modulation of FSK and QAM)

$$C_{Non-Gaussian} > C \quad [1]$$

$$where \quad C = Wlog_2(1 + SNR)$$

System Capacity



[1] I. Shomorony, et al., "Worst-Case Additive Noise in Wireless Networks," IEEE Trans. Inf. Theory, vol. 59, no. 6, June 2013.

Overview of Enabling Technologies – RAN (1/2)

SAMSUNG

Disruptive RAN Technologies for Significant Performance Enhancements

- Peak Data Rate
- Cell Edge Data Rate
- Cell Spectral Efficiency
- Mobility
- Cost Efficiency
- Simultaneous Connection
- Latency

Technology for Above 6 GHz

Increase of Peak Data Rate

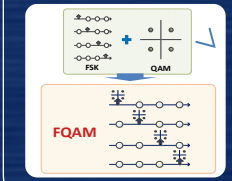
Peak Rate 1 Gbps → Peak Rate 50 Gbps

4G frequencies

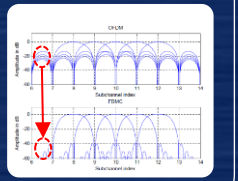
New higher frequencies

Advanced Coding & Modulation

Enhancement of Cell Edge Data Rate

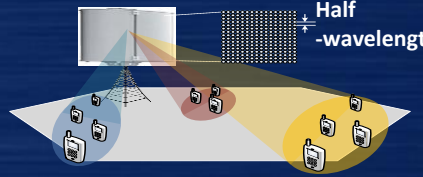


Filter-Bank Multi-Carrier



Advanced MIMO & BF

Enhancement of Cell Capacity



BF : Beamforming

Overview of Enabling Technologies – RAN (2/2)

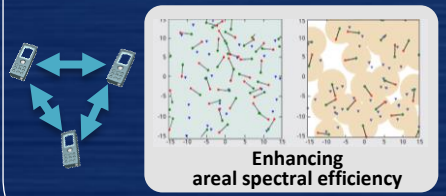
SAMSUNG

Disruptive RAN Technologies for Significant Performance Enhancements

- Peak Data Rate
- Cell Edge Data Rate
- Cell Spectral Efficiency
- Mobility
- Cost Efficiency
- Simultaneous Connection
- Latency

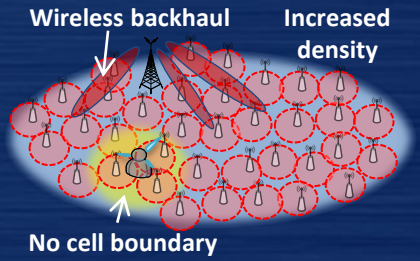
Enhanced D2D

Increase of Areal Spectral Efficiency



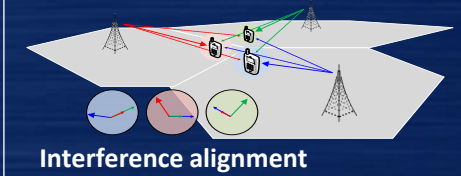
Advanced Small Cell

Enhancement of Capacity & Cell Edge



Interference Management

Enhancement of Cell Edge Data Rate



D2D : Device-to-Device

Enabling Technologies : RAN

- Recent R&D Results for Above 6 GHz Bands

Wider Bandwidth for 5G

Availability of More than 500 MHz Contiguous Spectrum Above 6 GHz

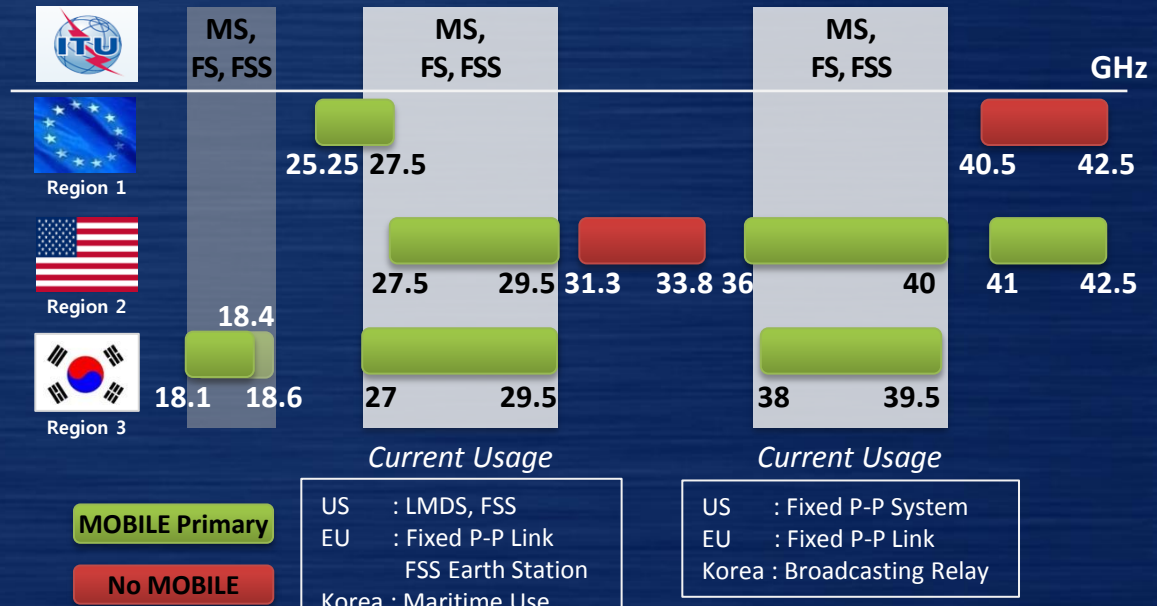
Below 6 GHz

300 MHz — 6 GHz

< 1 GHz [MHz]	410-430, 470-694/698, ***694/698-790****
1-2 GHz [MHz]	1300-1400, ***1427-1525/1527***, 1695-1700/1710
2-3 GHz [MHz]	2025-2100, 2200-2290, 2700-3100
3-5 GHz [MHz]	3300-3400, ***3400-4200***, 4400-5000
5-6 GHz [MHz]	5150-5925, 5850-6245

Globally Hot Interest for WRC-15

Above 6 GHz



* WRC-15 AI 1.2

MS : Mobile Service
FS : Fixed Service
FSS : Fixed Satellite Service
P-P : Point to Point
LMDS : Local Multipoint Distribution Service

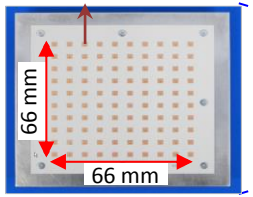
Test Results – Prototype System Overview

World's First 5G mmWave Mobile Technology (May, 2013)

Adaptive array transceiver technology operating in mmWave frequency bands for outdoor cellular

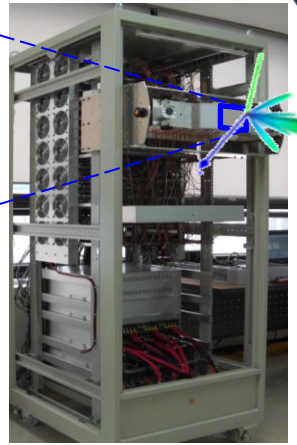
Base Station

Antenna Elements



Array Antenna

Baseband Modem



RF + Array Antenna

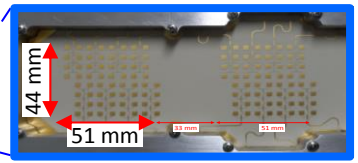
Downlink Tx

Uplink Tx

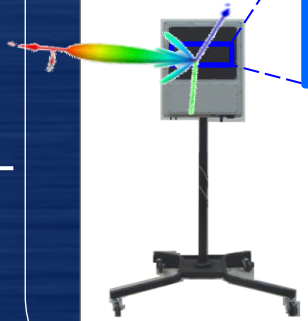
DM (Diagnostic Monitor)

Carrier Frequency	27.925 GHz
Bandwidth / Duplexing	500 MHz / TDD
Array Antenna	8 x 8, 8 x 4
Beam-width (Half Power)	10°
Channel Coding	LDPC
Modulation	QPSK / 16QAM

Mobile Station



Array Antenna



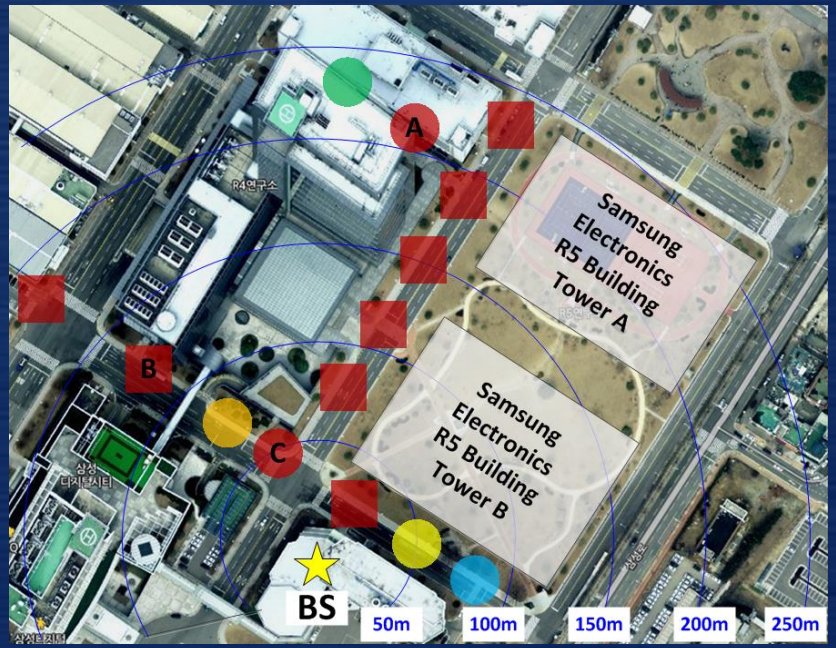
RF + Array Antenna

Baseband Modem

Test Results – Outdoor Coverage

Outdoor Non Line-of-Sight (NLoS) Coverage Tests Performed [1]

Satisfied connection with BLER < 0.01% even in NLoS 200m distance



BLER result

- Below 0.01%
- Below 0.1%
- Below 1%
- Below 10 %
- Below 25%
- Below 50%
- Below 75%
- Below 100%

LoS / NLoS

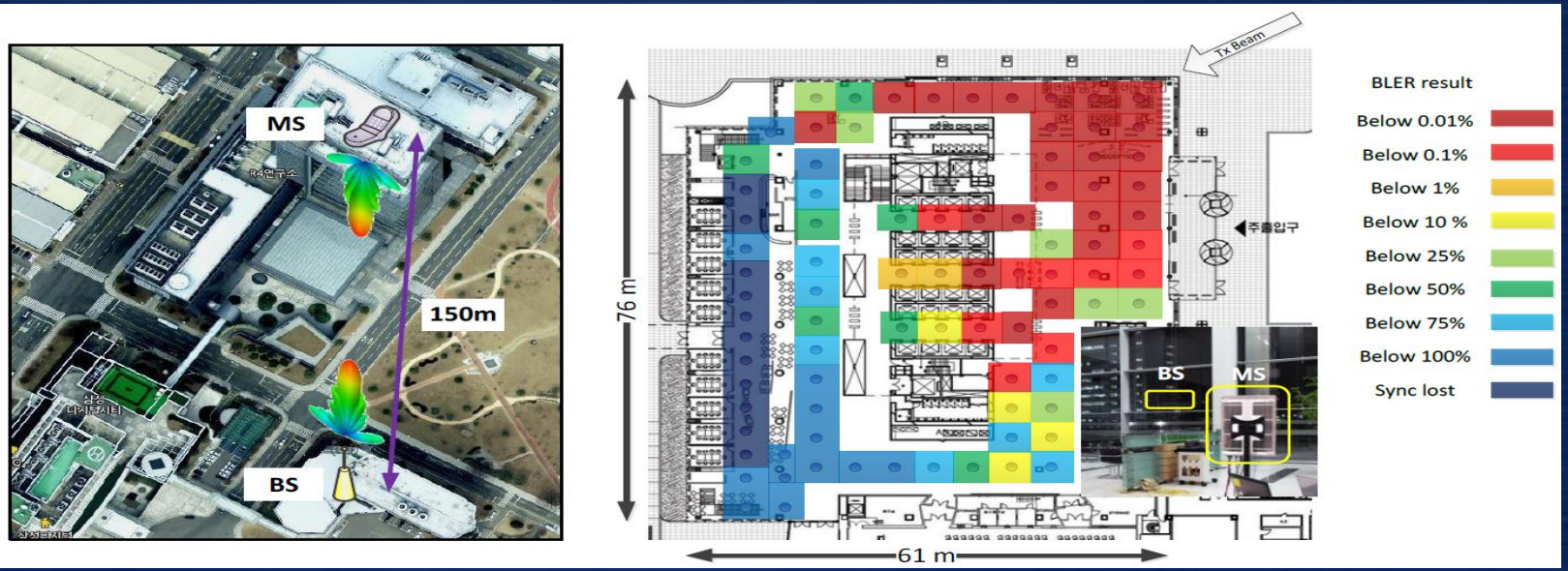
- LoS
- NLoS

[1] Wonil Roh, et al., "Millimeter-Wave Beamforming as an Enabling Technology for 5G Cellular Communications: Theoretical Feasibility and Prototype Results," IEEE Communications Magazine, Feb. 2014.

Test Results – Outdoor to Indoor Penetration

Outdoor-to-Indoor Penetration Tests Performed [1]

Most signals successfully received at indoor MS from outdoor BS

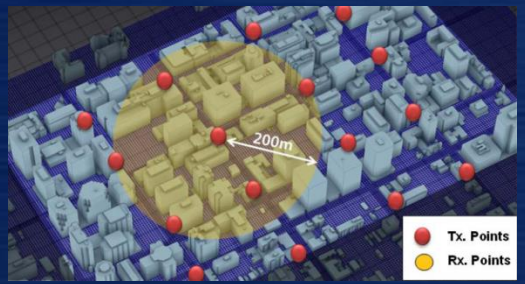


[1] Wonil Roh, et al., "Millimeter-Wave Beamforming as an Enabling Technology for 5G Cellular Communications: Theoretical Feasibility and Prototype Results," IEEE Communications Magazine, Feb. 2014.

Multi-Cell Analysis (1/2)

Ray-Tracing Simulation in Real City Modeling with Different BS Antenna Heights

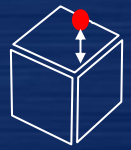
Real City (Ottawa)



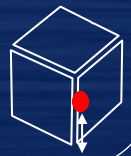
BS Antenna Heights

Scenario 1
30m above Rooftop

Scenario 2
5m above Rooftop



Scenario 3
10m above Ground



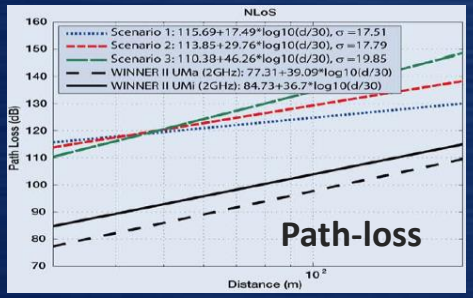
Ray-Tracing

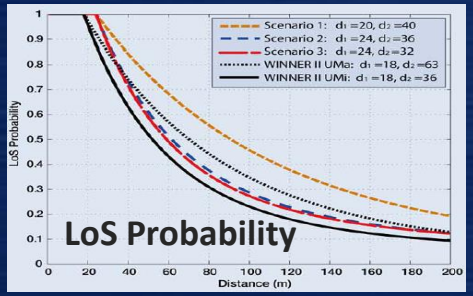
Multi-Cell Analysis (2/2)

Ray-Tracing Based Channel Modeling and System Level Simulations

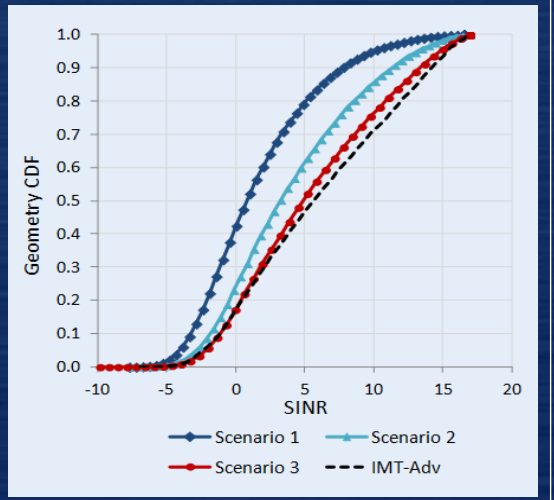
Scenario 3 (Higher Path-loss Exponent) produces better system performances in multi-cell deployment

Channel Models

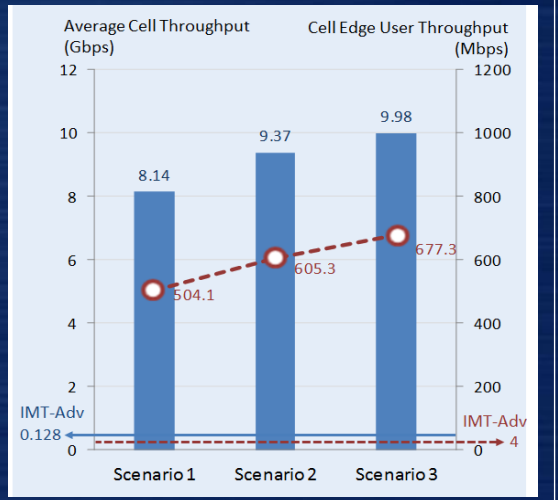




System Geometry



Avg. & Edge T'puts



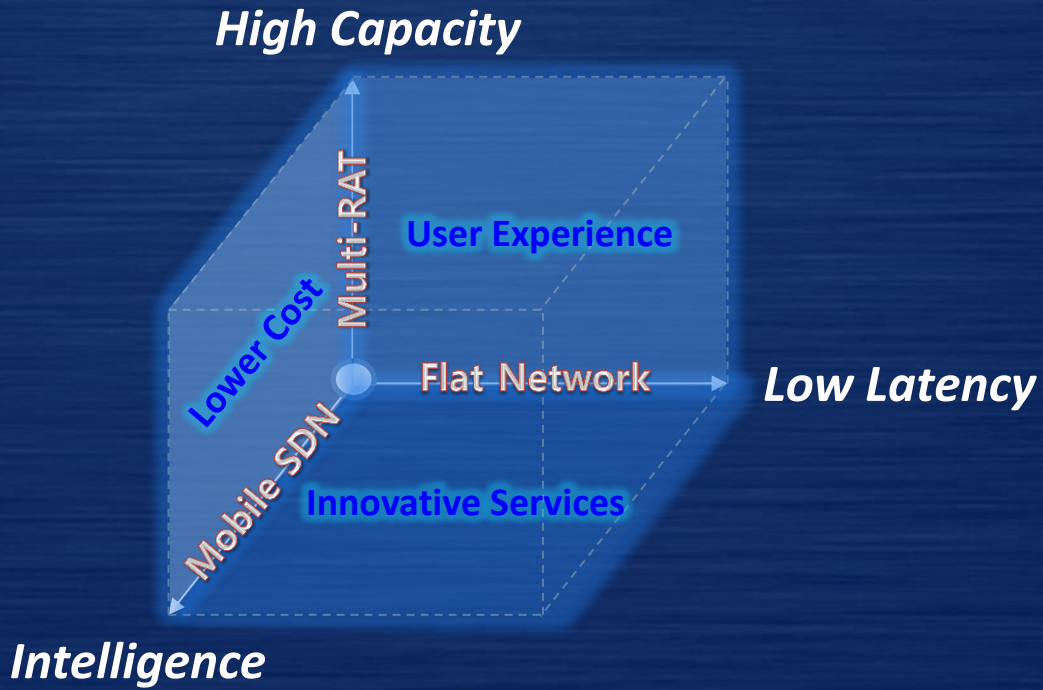
Simulated User Experience

Simulations are Based on Ray-Tracing in 28 GHz for Multi-Cell Deployment Scenario
Total 10 Small Cell BSs to Provide Coverage of 928 m x 586 m of Dense Urban City
At least 4 Gbps User Throughput Expected Using 1 GHz Bandwidth

Enabling Technologies : Network

Network Evolution

Network Evolution for Innovative Services, Lower Cost and Better User Experience



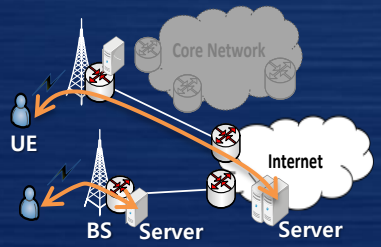
Overview of Enabling Technologies - Network

Innovative Network Technologies for Enhanced User Experience and Cost Reduction

- Peak Data Rate
- Cell Edge Data Rate
- Cell Spectral Efficiency
- Mobility
- Cost Efficiency
- Simultaneous Connection
- Latency

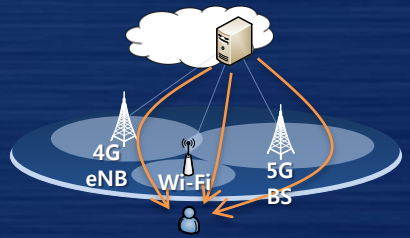
Flat Network

Reduction of E2E Latency



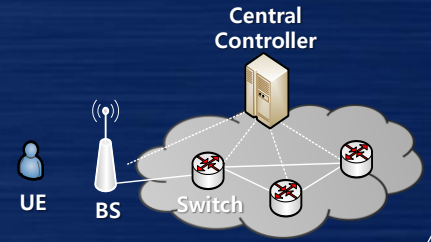
Multi-RAT Interworking

Enhancement of Radio Capacity



Mobile SDN

Increase of Energy & Cost Efficiency

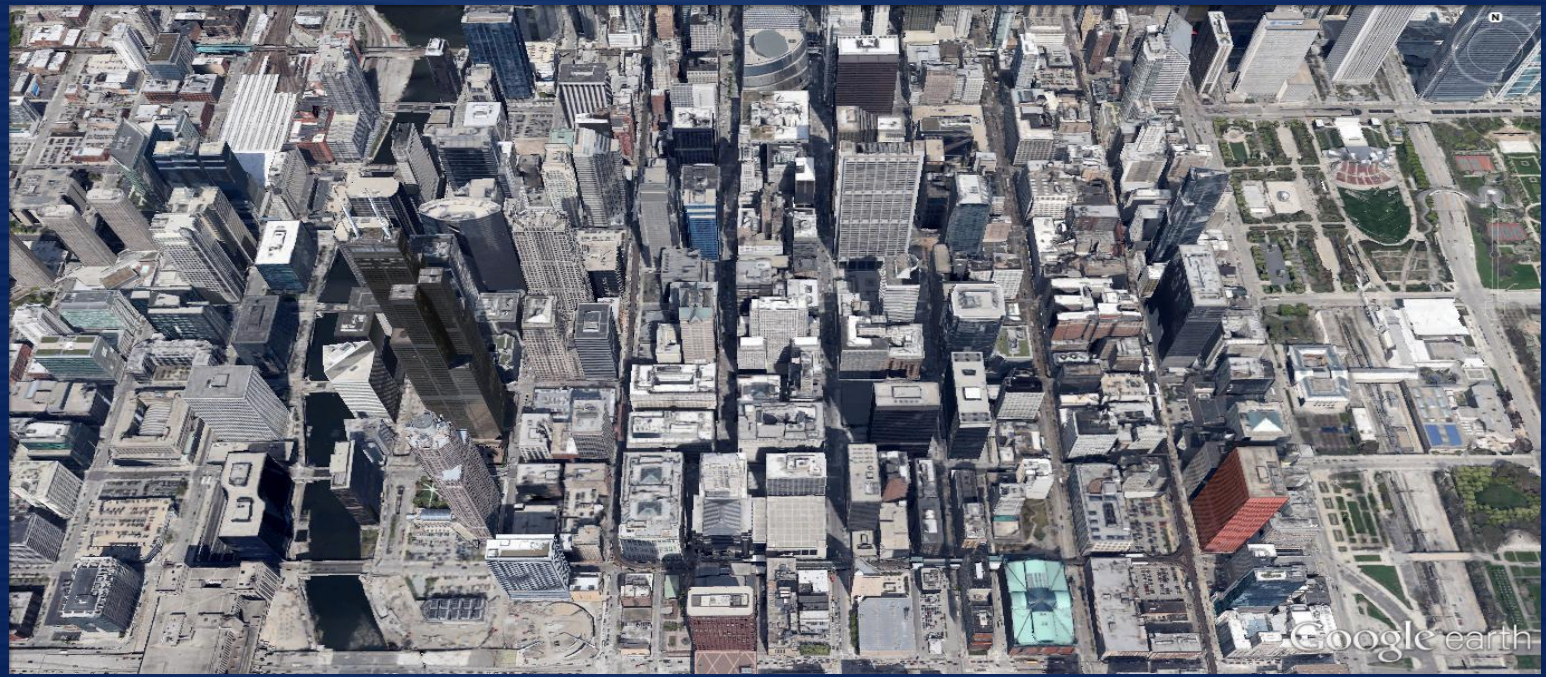


SDN : Software Defined Network

Deployment Scenarios

5G Deployment Scenarios

Bird’s Eye View of Chicago



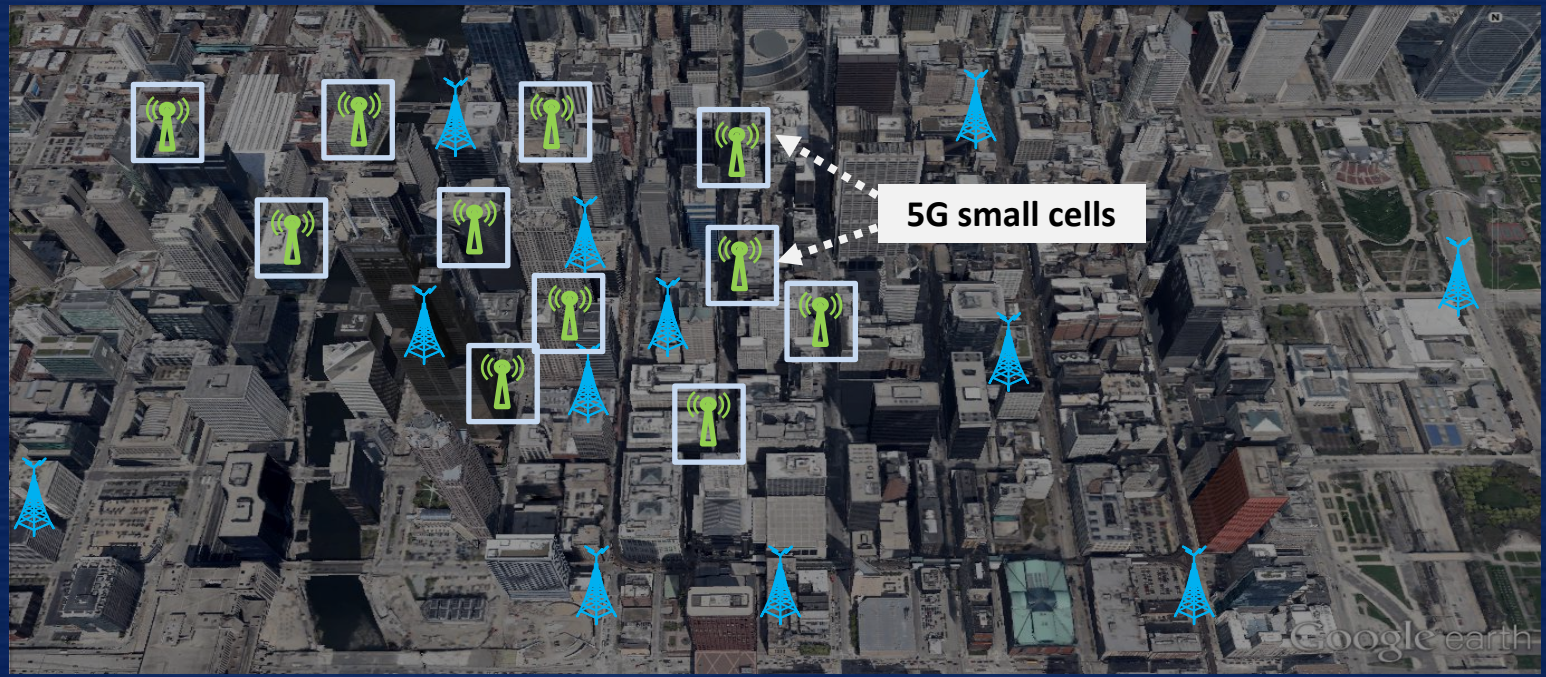
5G Deployment Scenarios

Existing 4G Deployments

5G Deployment Scenarios

5G Small Cells Overlayed in 4G Networks

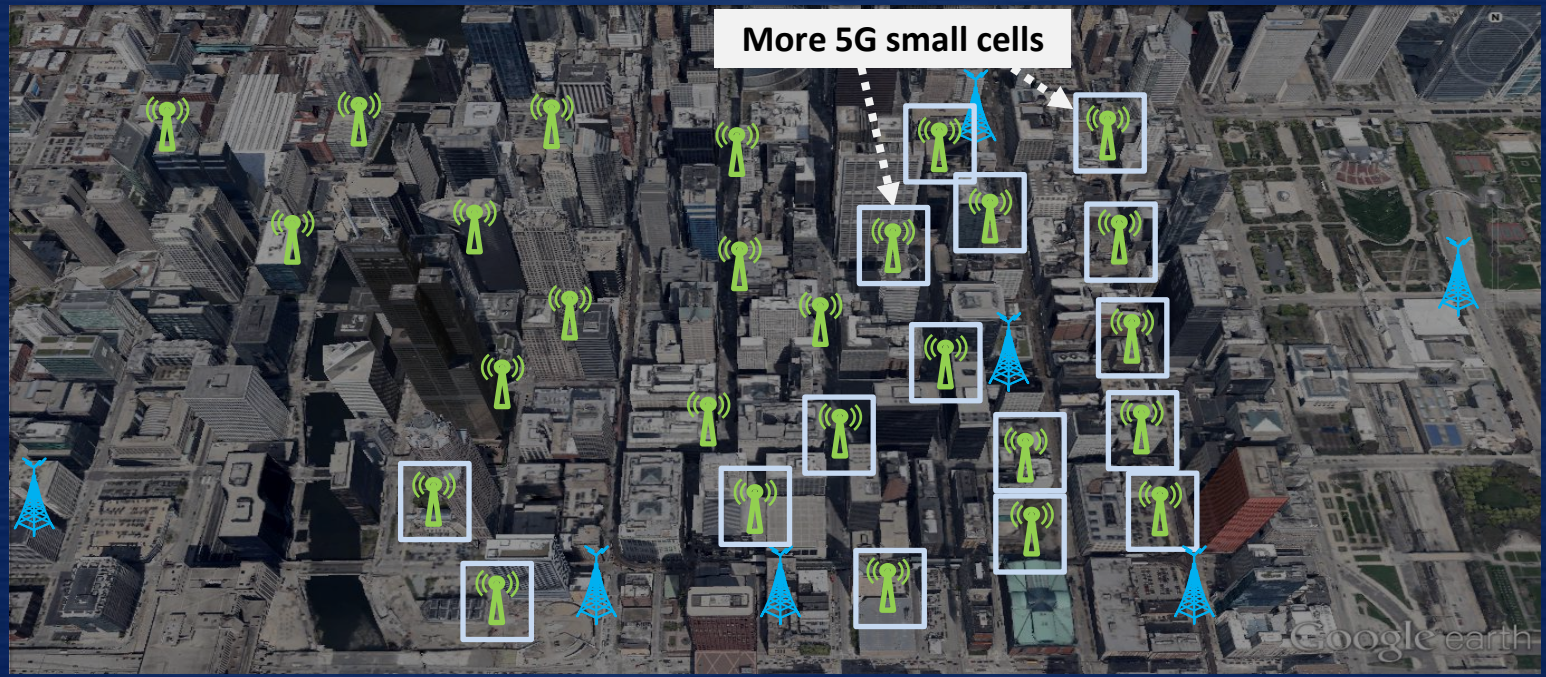
Reduced CAPEX/OPEX for initial deployment



5G Deployment Scenarios

Gradual Expansion of 5G Coverage

Full capability standalone 5G systems appear



5G Deployment Scenarios

Gradual Coverage Expansion

Full capability standalone 5G systems covering most areas

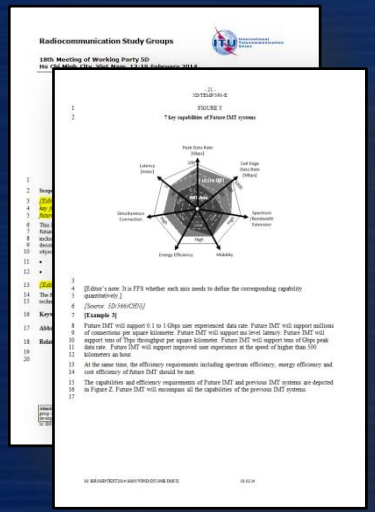
Global R&D Activities & Timelines

Global R&D Activities

Current Global 5G Research Initiatives and Samsung's Active Engagements

Expected Timelines

Expected Standardization in 3GPP Rel-14, Spectrum Allocation in WRC-18/19


Radiocommunication Study Groups

18th Meeting of Working Party 5D

FIGURE 1

7 key capabilities of Future IMT systems

[Editor's note: It is FFS whether each axis needs to define the corresponding capability quantitatively.]

[Source: 5D/568(CH)]

[Example 3]

Future IMT will support 0.1 to 1 Gbps user experienced data rate. Future IMT will support millions of connections per square kilometer. Future IMT will support sub-ms level latency. Future IMT will support tens of Tbps throughput per square kilometer. Future IMT will support tens of Gbps peak data rate. Future IMT will support improved user experience at the speed of higher than 500 kilometers an hour.

At the same time, the efficiency requirements including spectrum efficiency, energy efficiency and cost efficiency of future IMT should be met.

The capabilities and efficiency requirements of Future IMT and previous IMT systems are depicted in Figure 2. Future IMT will encompass all the capabilities of the previous IMT systems.

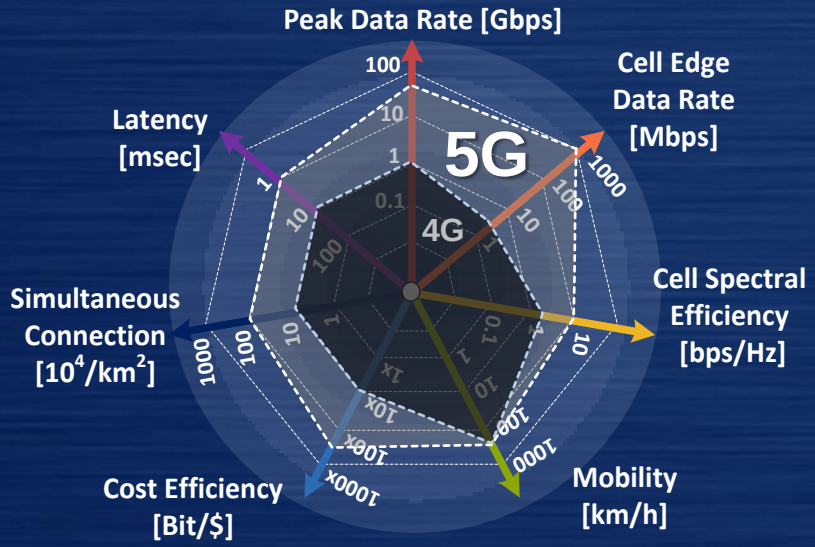
ITU Document 5D/TEMP/390-E

IMT Vision – "Framework and overall objectives of the future development of IMT for 2020 and beyond"

Summary

5G for 2020 and Beyond

5G Rainbow of Requirements



Key Technologies

- Tech. for Above 6 GHz
- Adv. Coding & Modulation
- Adv. MIMO & BF
- Enhanced D2D
- Adv. Small Cell
- Interf. Management
- Flat Network
- Multi-RAT Interworking
- Mobile SDN

COMMUNICATIONS RESEARCH TEAM

Thank You

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