# Technologies for Unlocking New Spectrum above 6 GHz for 5G

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IEEE ICUWB
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# 5G Global R&D Activities

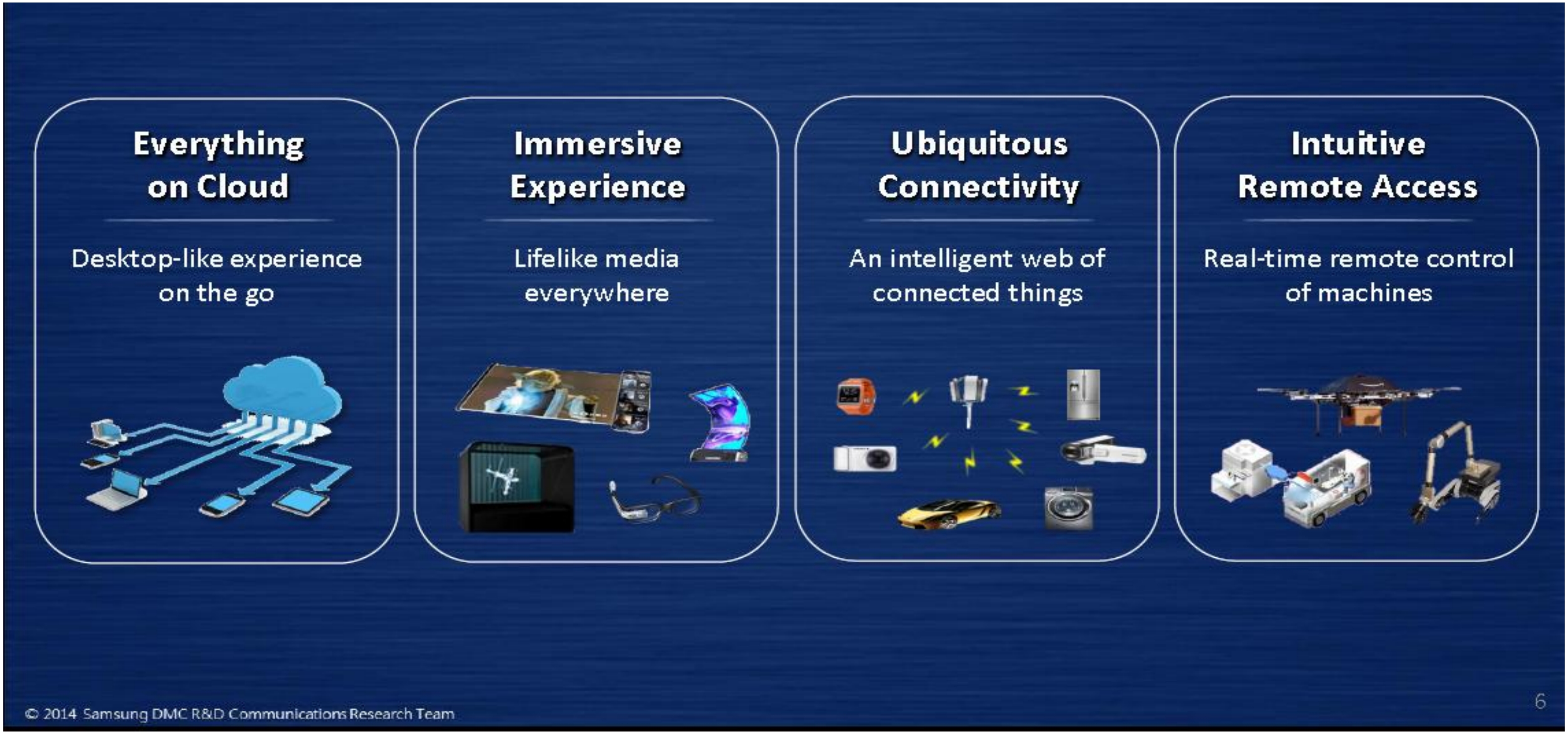
# Samsung's European 5G Activities

- Samsung Electronics R&D UK
  - Established in 1991 in the UK, 200+ R&D staff
  - Branch in Finland (newly established)
- Samsung 5G Activities in Europe
  - Strategic 5G Collaborative Research
  - Part of Samsung's global 5G R&D
  - Key roles in 3G PP, ETSI,DVB, GSMA
  - 5G Spectrum regulations
- Europe is a hub of Samsung's collaborative 5G research
  - Horizon 2020's 5G Advanced Infrastructure Public Private Partnership (5G PPP)
    Samsung is a member of 5G Infrastructure Association
  - UK's 5G Innovation Centre at Surrey University (5GIC)
    Samsung is a founding member
  - COST IC1004
    Samsung is involved in mm-Wave channel modelling for 5G
  - FP7 MiWaveS
    Samsung is a member of the Advisory Boards

Staines Upon Thames, UK

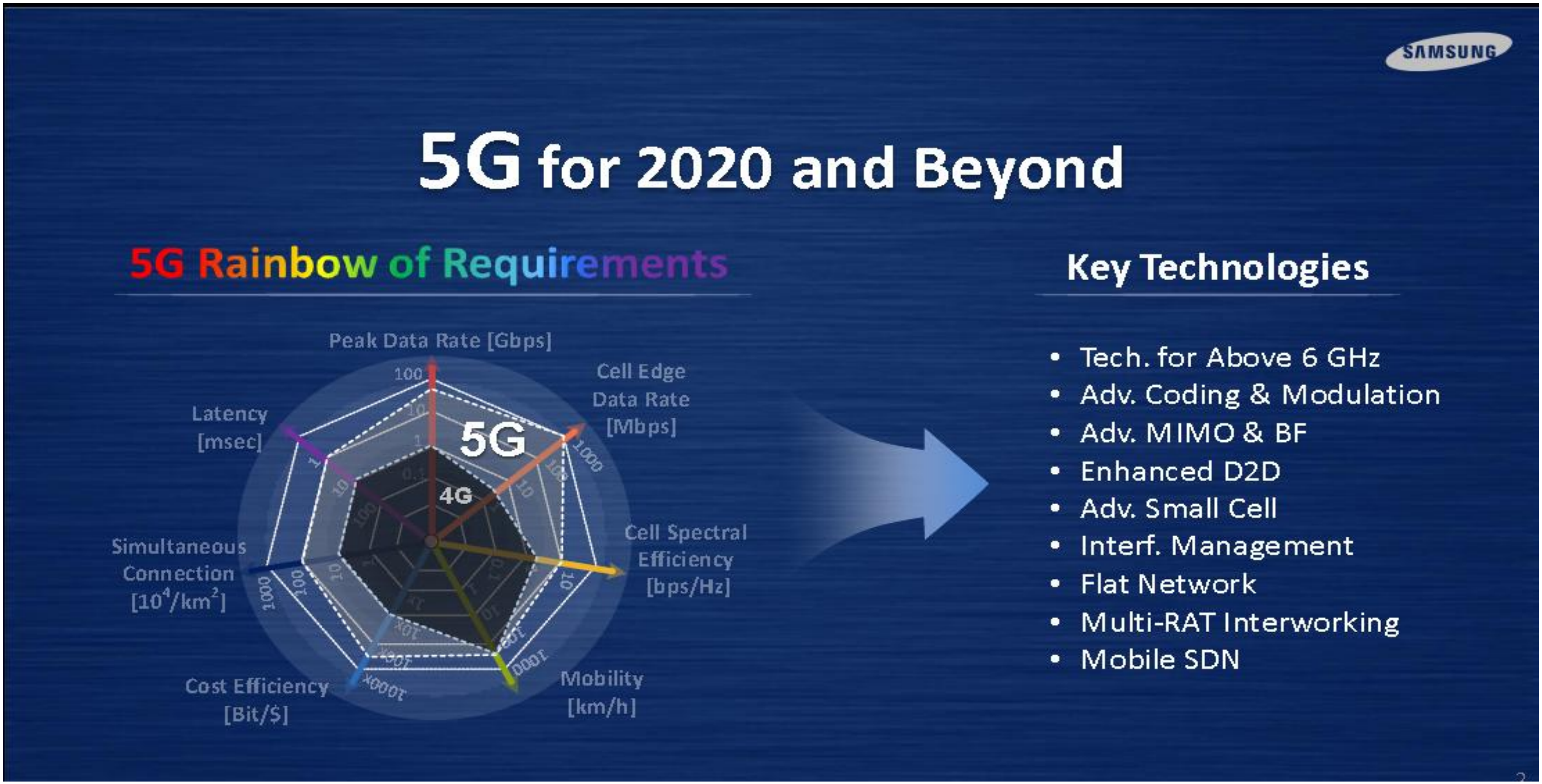
Espoo, Finland

# Samsung 5G vision (1/2)*




*See also WCNC 2014 keynote by Wonil Roh at http://eucnc.eu/files/keynotes/Roh.pdf

# Samsung 5G vision (2/2)*



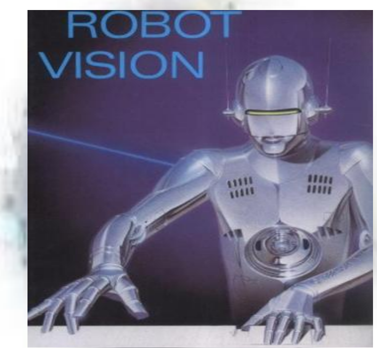
# Enabling the Immersive Service Experiences

## Wearable/Flexible Mobile Device


Ubiquitous Health Care

Mobile Cloud

Holographic Experience

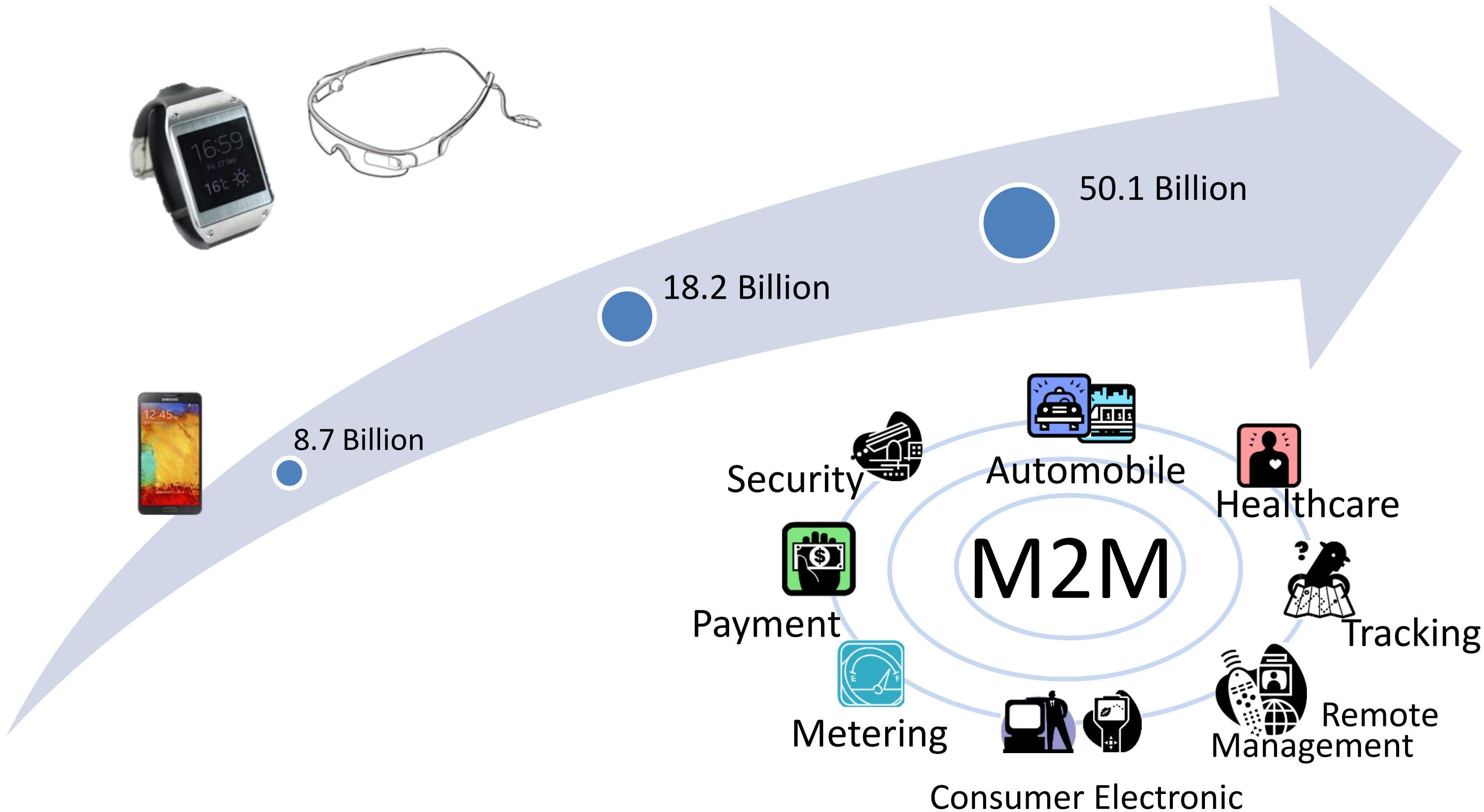



Robotic Vision

Real-Time Interactive Game

# 5G Services (2/2)

## Supporting Massive Connectivity



# 5G Key Enabling Technologies (1/2)

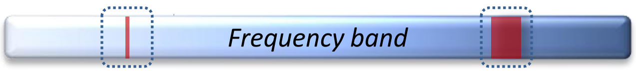
## Disruptive Technologies for Significant Performance Enhancement

### mmWave System Tech.

- Fixed 1 Gbps
- Mobile 100 Mbps

→

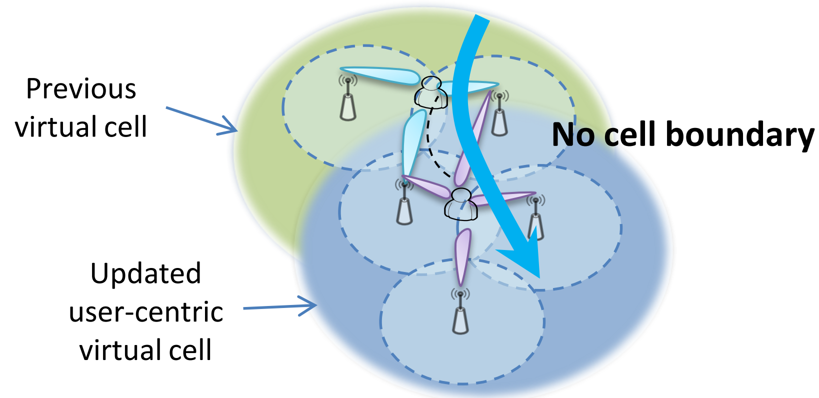
- Fixed >50 Gbps
- Mobile 5 Gbps



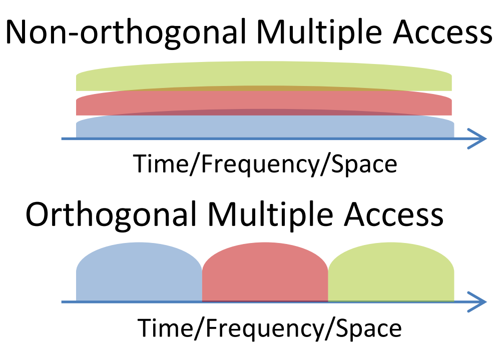

4G frequencies | **New higher frequencies**

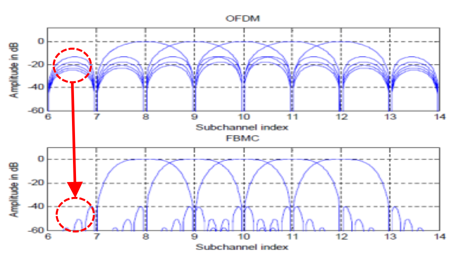
- 20-100 times capacity increase
- 50 Gbps peak data rates

### Adv. Small Cell



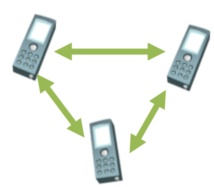

### Adv. Coding & Modulation

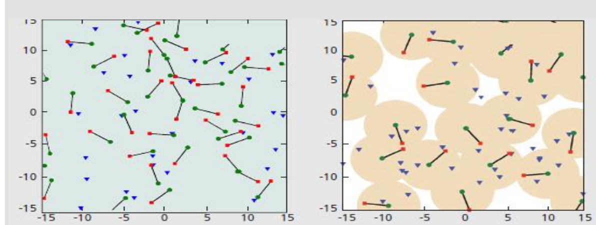



Filter-bank Multi-carrier

### Device-to-Devie (D2D)

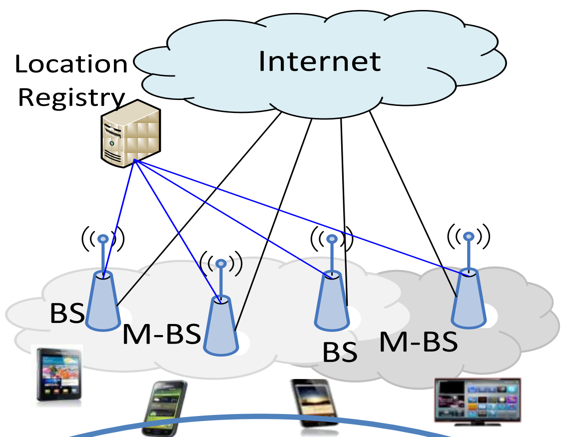




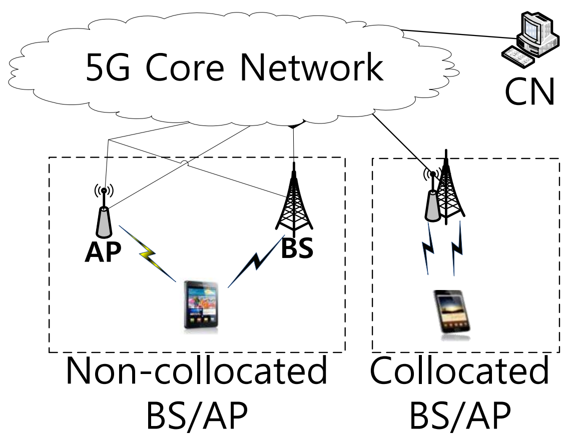
Enhancing areal spectral efficiency

# Disruptive Technologies for Significant Performance Enhancement

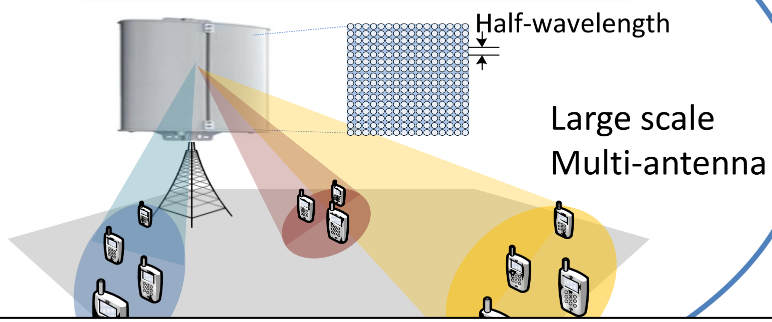
## Enhanced Flat NW




## IWK/Integration w/ Wi-Fi

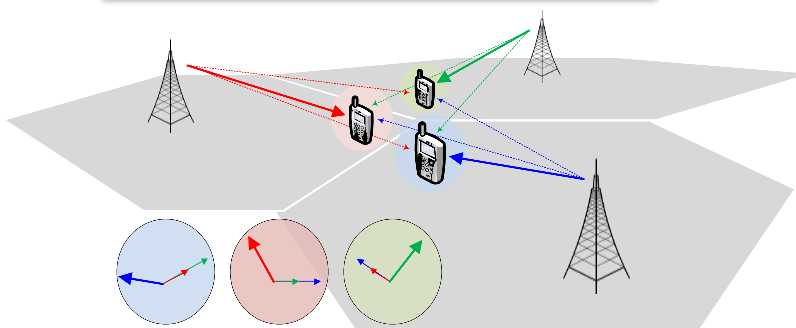



## Adv. MIMO/BF




- Critical component for mm-wave cellular
- Small wavelength enables massive antenna integr ation in  BS and mobile device

## Interference Management



Interference alignment

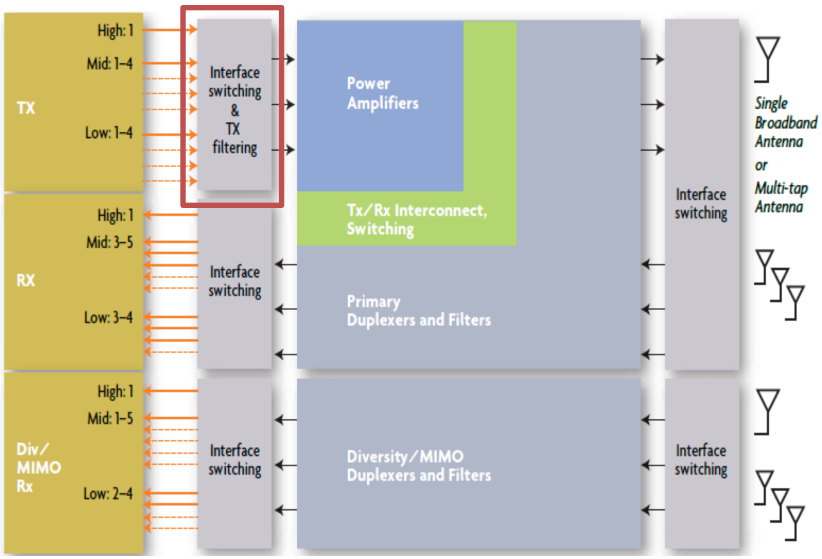
# Spectrum remains a key challenge

## New spectrum below 6 GHz becoming available but is very fragmented

- Limit in expanding bandwidth: Carrier aggregation degrades system performance
- Significant increase in modem cost due to increased RF front-end complexity

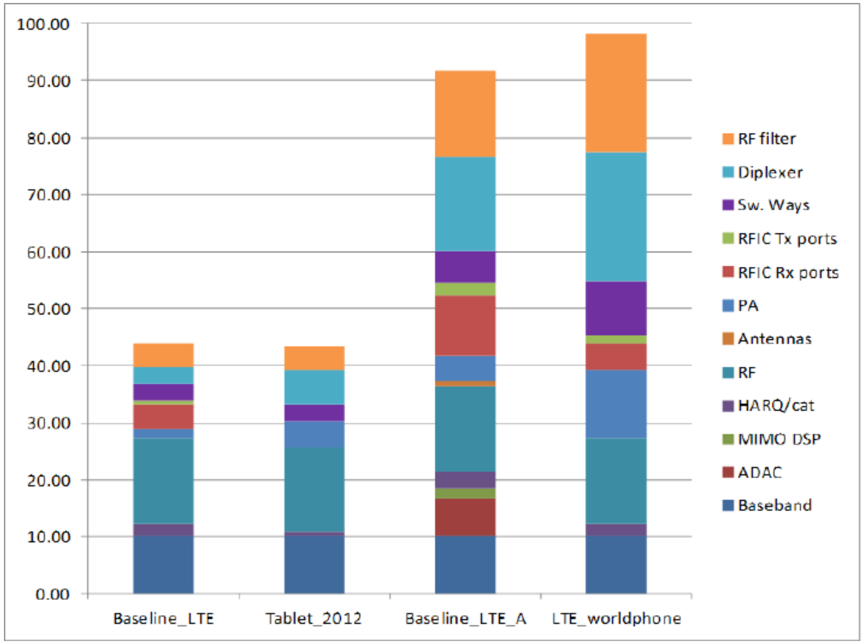
### Performance degradation in carrier aggregation

▷ **Switch loss (1dB per switch)**
▷ **Power amplifier & antenna inefficiency**




※ SiGNALS Ahead, "Improve Your [RF] Front-end in Seven Easy Steps!", May 23, 2012 Vol.8 No.6

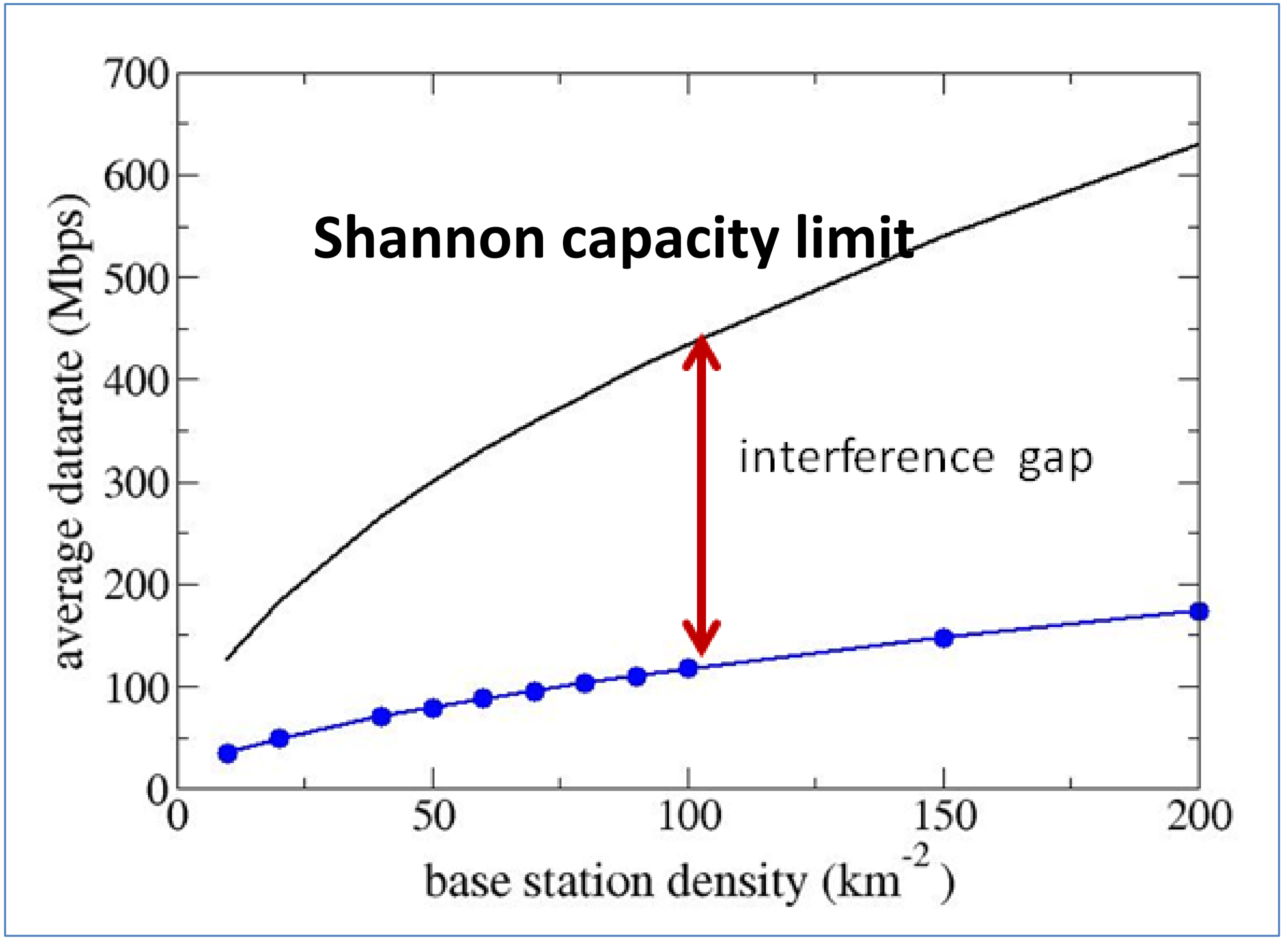
### Impact of the number of bands on the cost of LTE modems




*※RF Front End Technology Challenges ICT KTN-Cambridge Wireless joint Position Paper, December 2013*

# Limits to densification

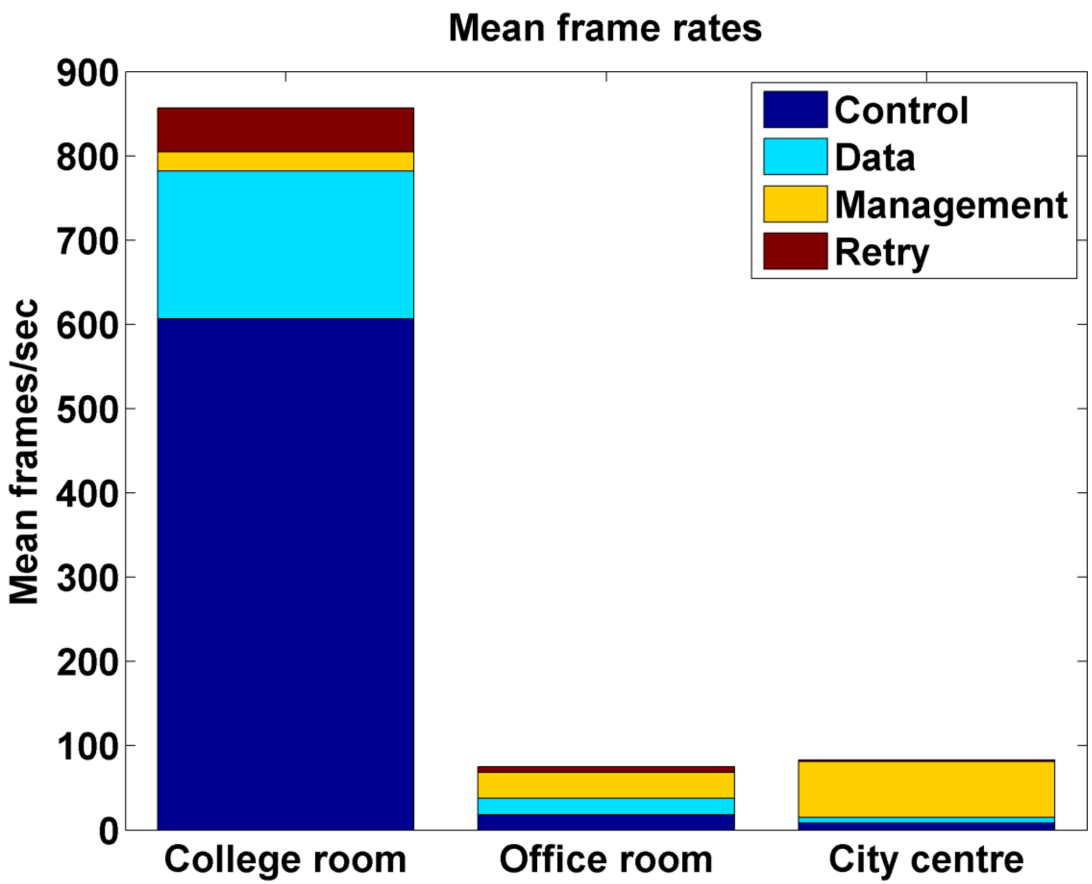
**Network densification helps but is not sufficient**
**Limits to densification due to interference and cost**




※ Spectrum challenges & options for 5G cellular networks
M. Nekovee, in submission

# Limits to Wi-Fi performance

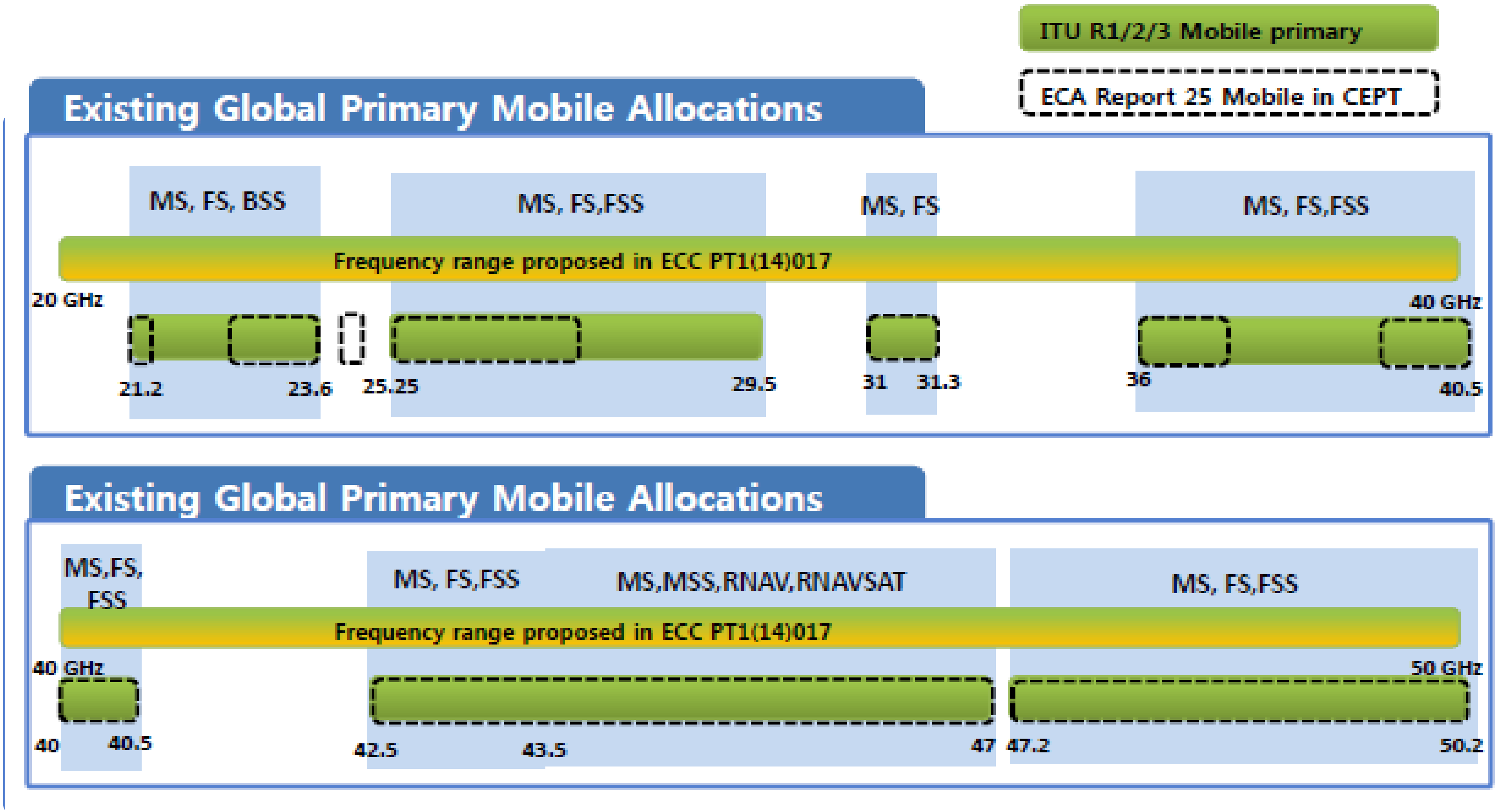
**Wi-Fi medium access very wasteful of bandwidth due to CSMA/CA**
**“Tragedy of commons” due to unlicensed spectrum access**




※ Spectrum utilization and congestion of IEEE 802.11 networks in the 2.4 GHz ISM band.
J. W van Bloem, Journal of Green Engineering, 2013

# mmWave bands : New spectrum for 5G

- **Candidates for Ultra Wide Bands of Contiguous Licensed Spectrum**

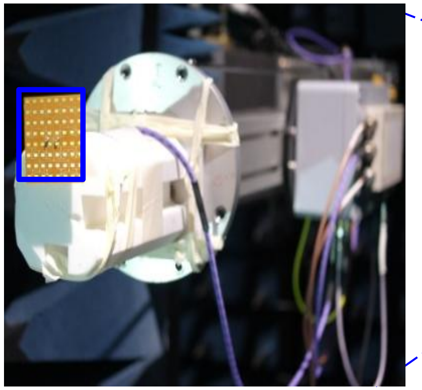


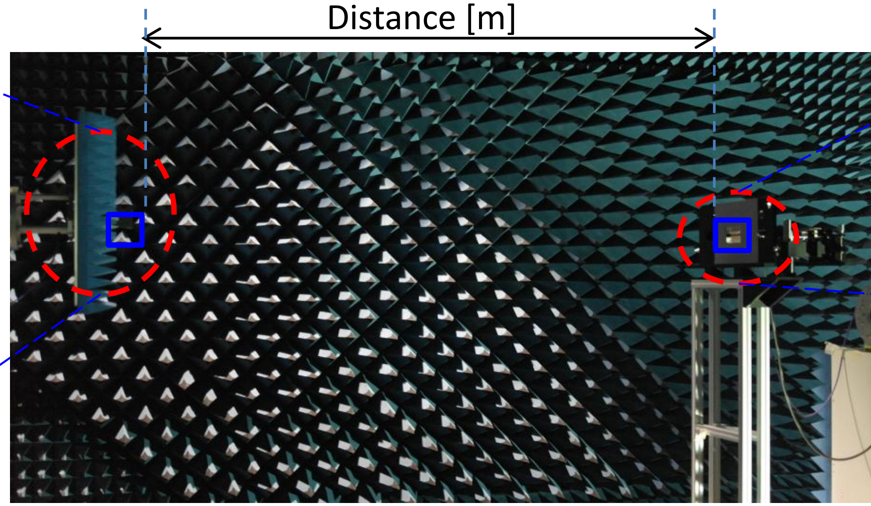

EESS (Earth Exploration-Satellite Service) FSS (Fixed Satellite Service)
MS (Mobile Service) FS (Fixed Service)

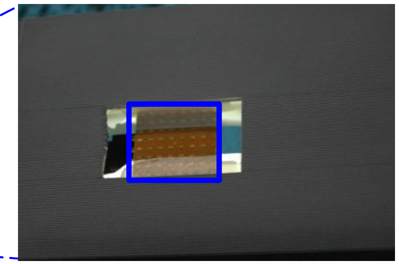
# mmWave channel measurements

## Measurement of Path-loss

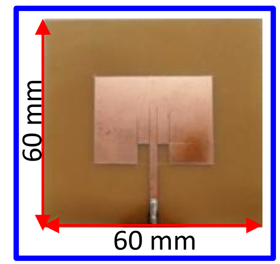
### ☐ Same Size of Rx Aperture Captures Same Rx Power Regardless of Frequency

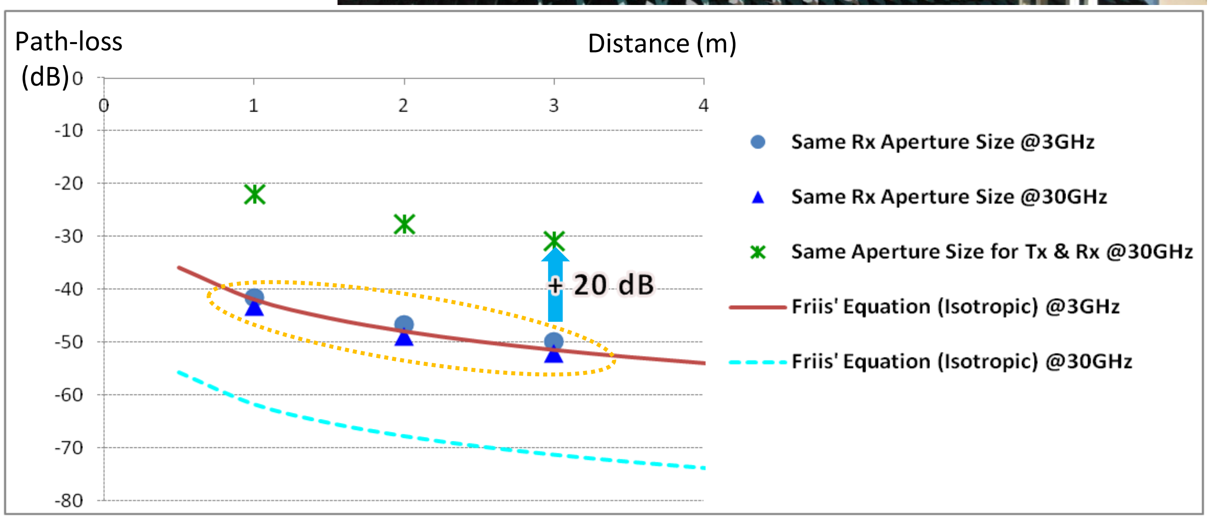




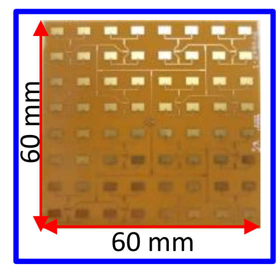



Patch Antenna @ 3 GHz




Array Antenna @ 30 GHz

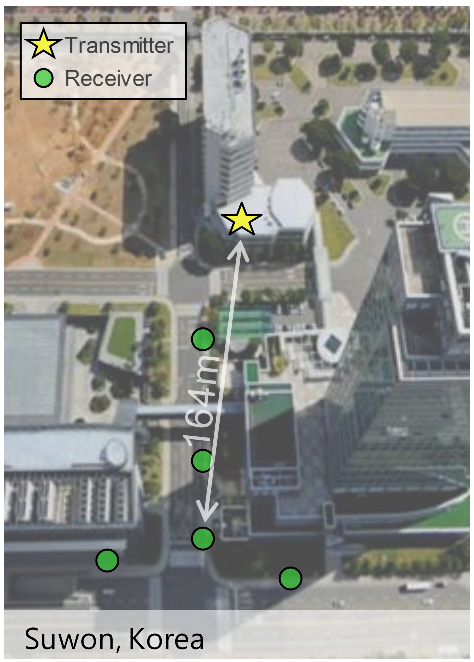


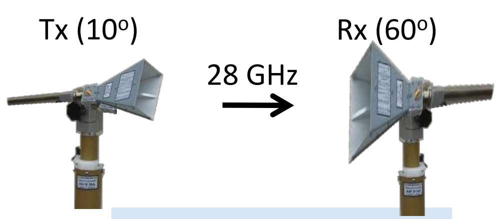
# Channel Measurement – Sub-Urban

- **Similar Path-loss Exponent & Smaller Delay Spread Measured** (w.r.t current cellular bands)
  - Measurements were made by using horn-type antennas at 28 GHz and 38 GHz in 2011

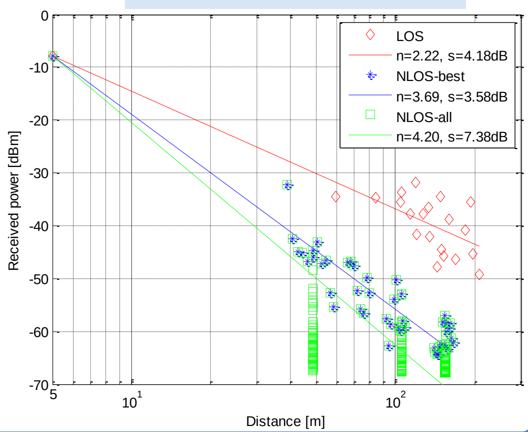
## Samsung Campus, Korea

| | | LOS | NLOS |
|---|---|---|---|
| Path Loss Exponent | | 2.22 | 3.69 |
| RMS Delay Spread [ns] | Median | 4.0 | 34.2 |
| | 99% | 11.4 | 168.7 |



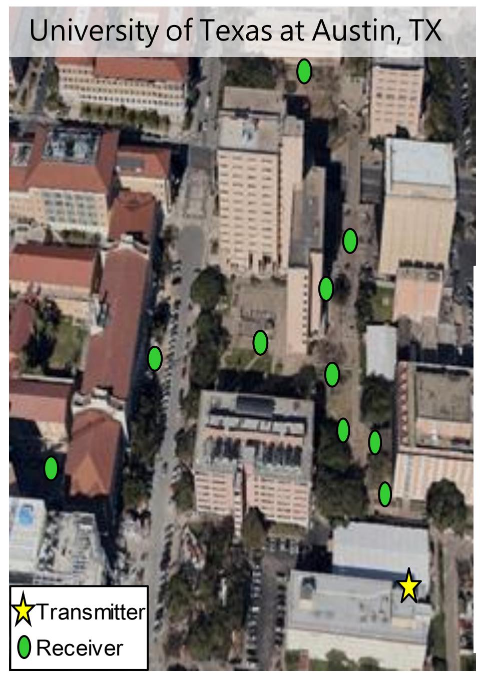



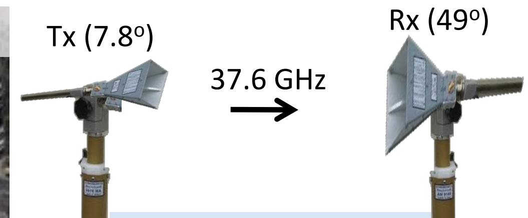

[Received Power]



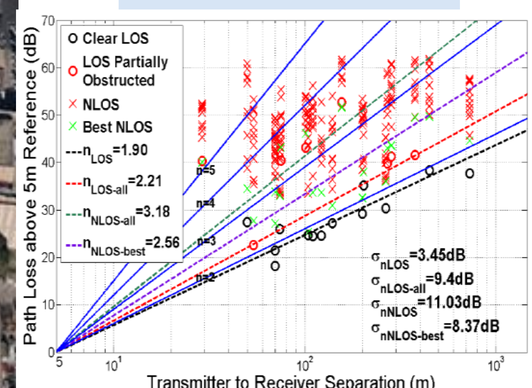

## UT Austin Campus, US

| | | LOS | NLOS |
|---|---|---|---|
| Path Loss Exponent | | 2.21 | 3.18 |
| RMS Delay Spread [ns] | Median | 1.9 | 15.5 |
| | 99% | 13.7 | 166 |




[Received Power]






* Reference : Prof. Ted Rappaport, UT Austin, 2011

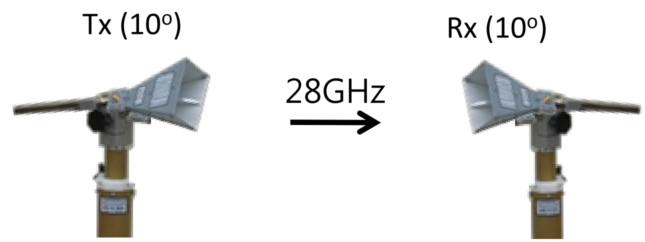
# Channel Measurement – Dense Urban

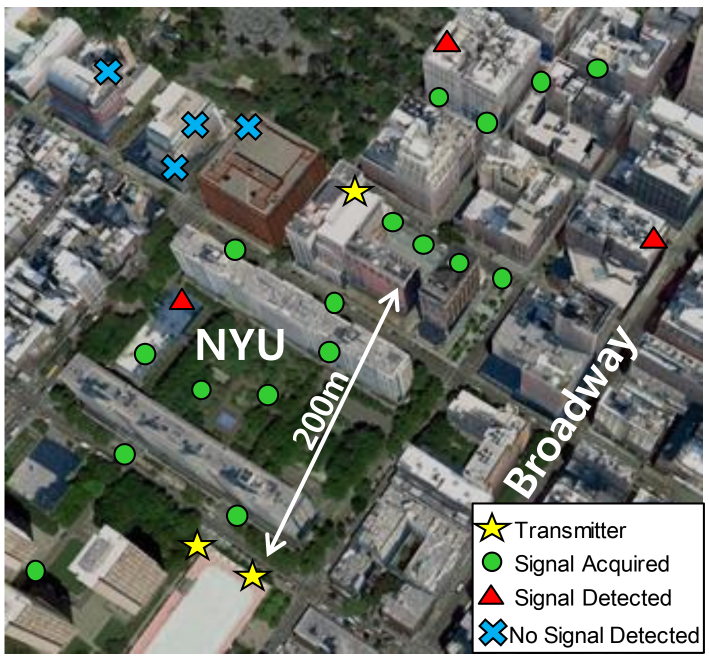
- **Slightly Higher But Comparable Path Loss Measured in New York City in 2012**

## New York, Manhattan, US

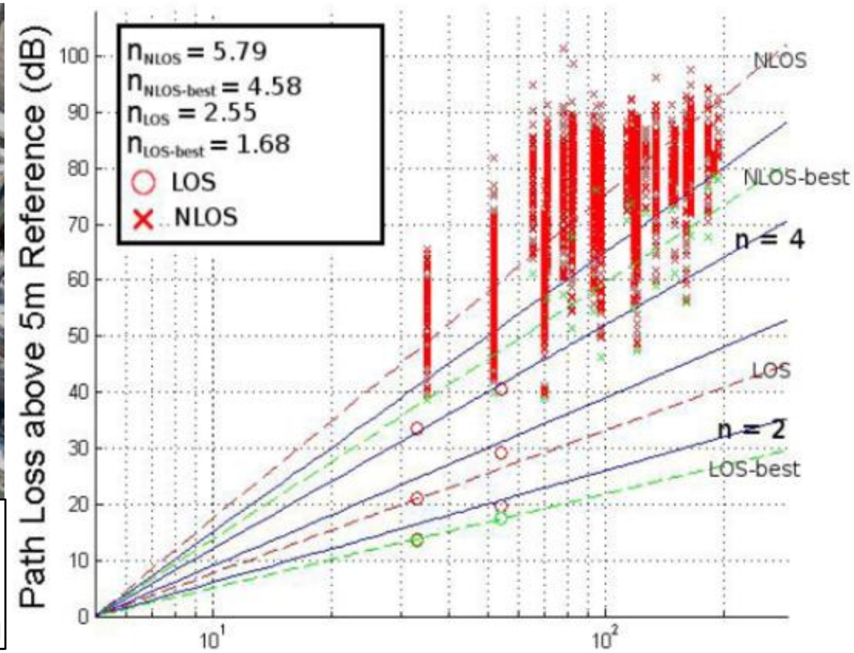
- Reference : Prof. Ted Rappaport, NYU, 2012
  - T. S. Rappaport et.al. "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!", IEEE Access Journal, May 2013

| | LOS | NLOS |
|---|---|---|
| Path Loss Exponent | 1.68 | 4.58 |
| Delay Spread [ns] | Expected to be larger than the previous,<br>But to be still smaller than current bands | |




[New York, Manhattan – NY University]

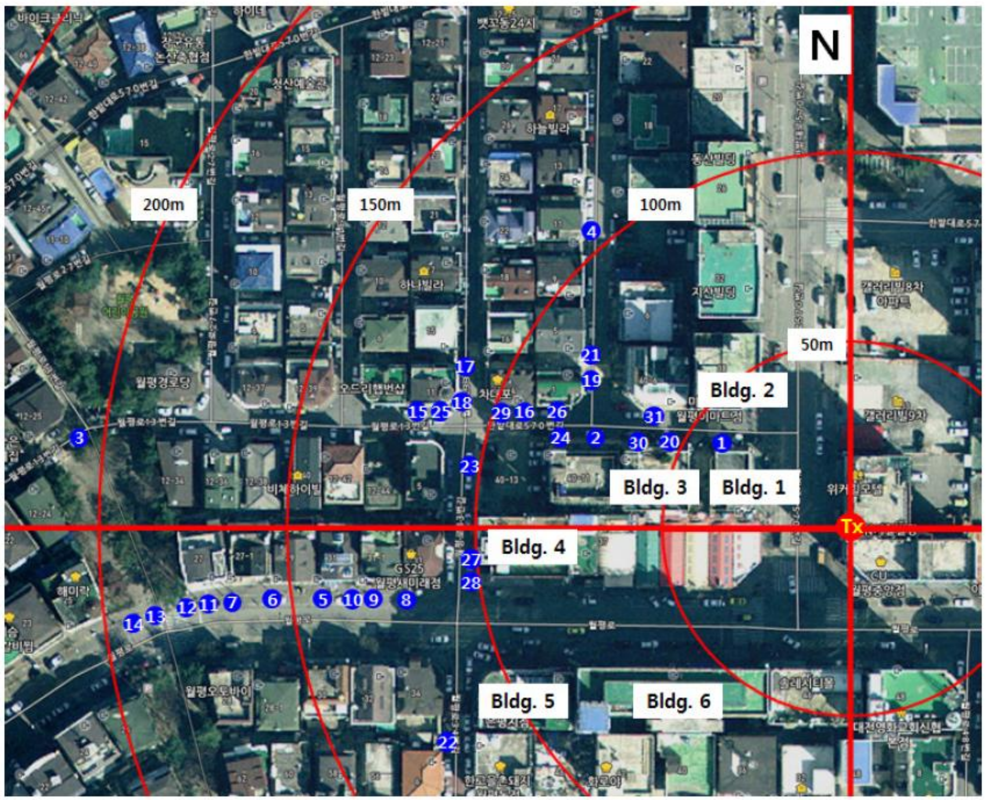



[Path Loss]

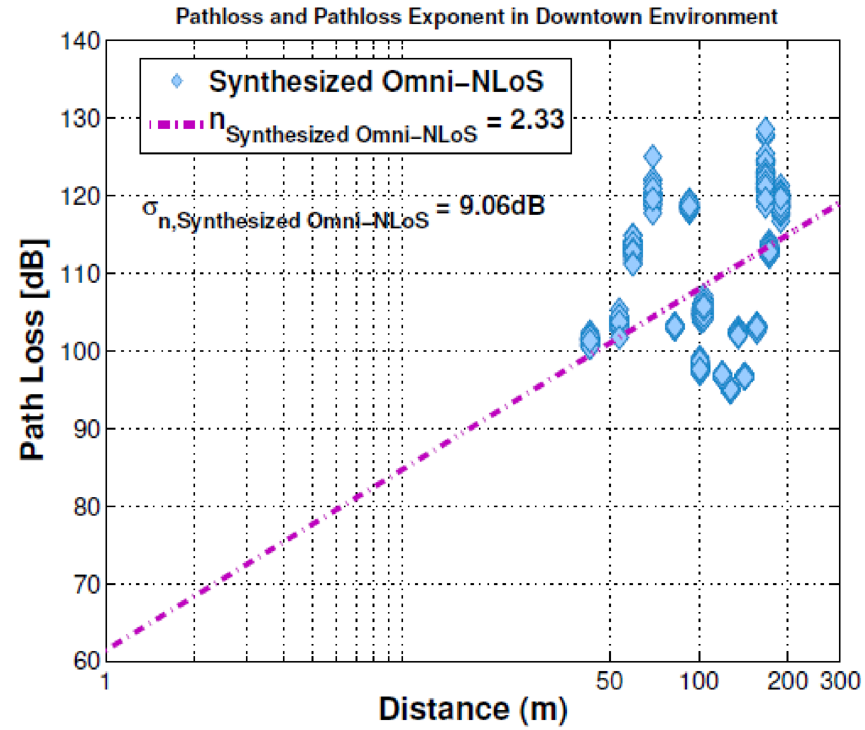
# Channel Measurement – Dense Urban (Samsung, August 2014)

## In-building, Campus, Downtown

| | $d$ [m] | $d_0$ [m] | $n$ | $\sigma$ [dB] |
|---|---|---|---|---|
| In-building LoS | $10 < d < 60$ | 1 | 1.56 | 8.78 |
| In-building NLoS | $10 < d < 60$ | 1 | 2.79 | 3.23 |
| Campus NLoS | $100 < d < 300$ | 1 | 2.50 | 7.55 |
| Downtown NLoS | $40 < d < 300$ | 1 | 2.33 | 9.06 |

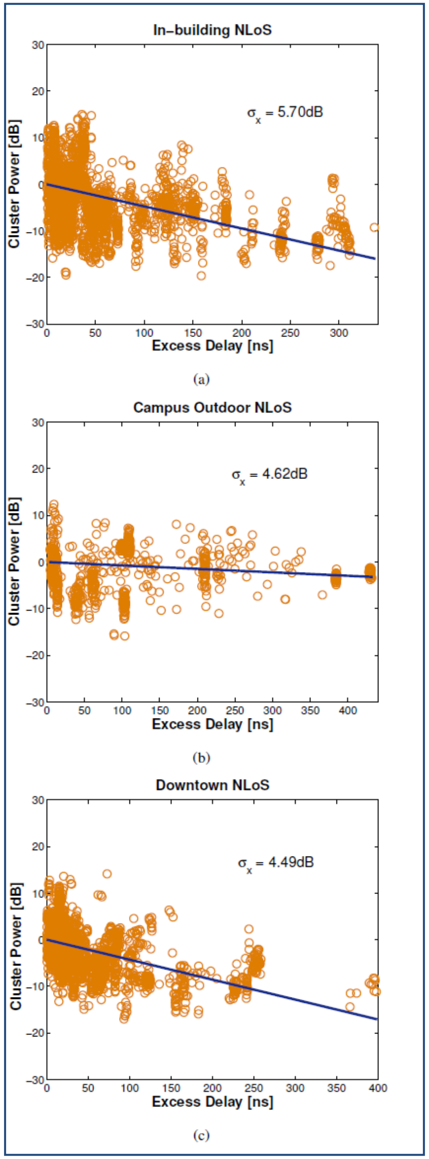



- **Reference : S. Hur et. al**
  **- To be presented at COST IC1004 Meeting, Krakow, September 2014**



# Excess delay and clusters

- **Reference : S. Hur et. al**
  **- To be presented at COST IC1004 Meeting, Krakow, September 2014**



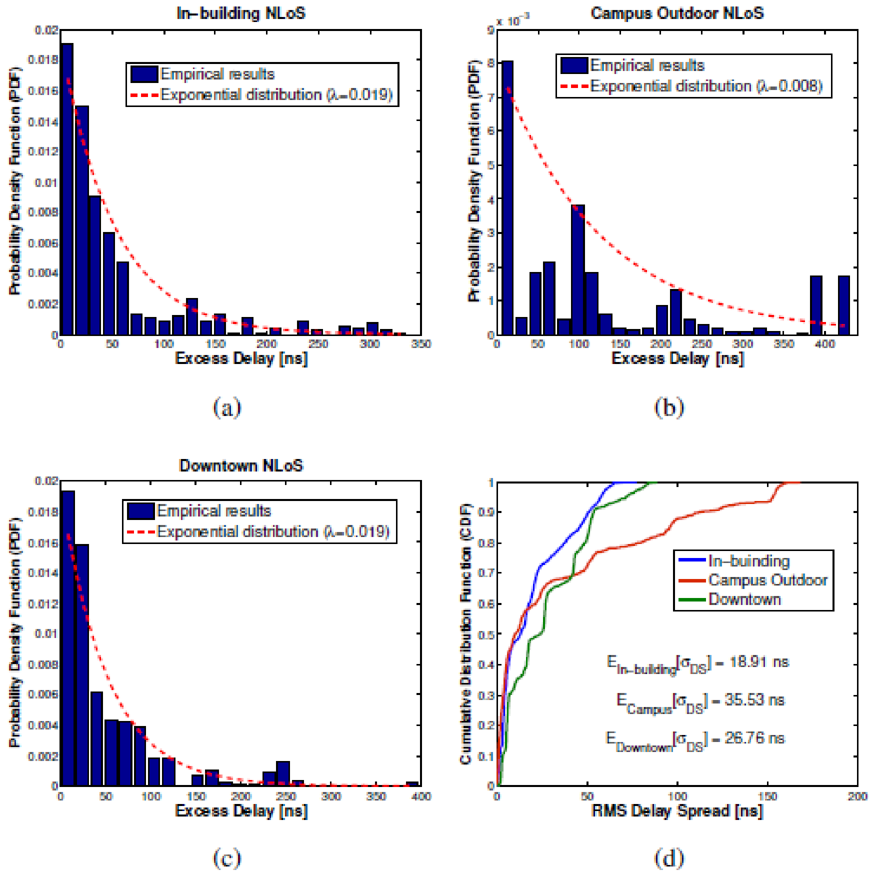
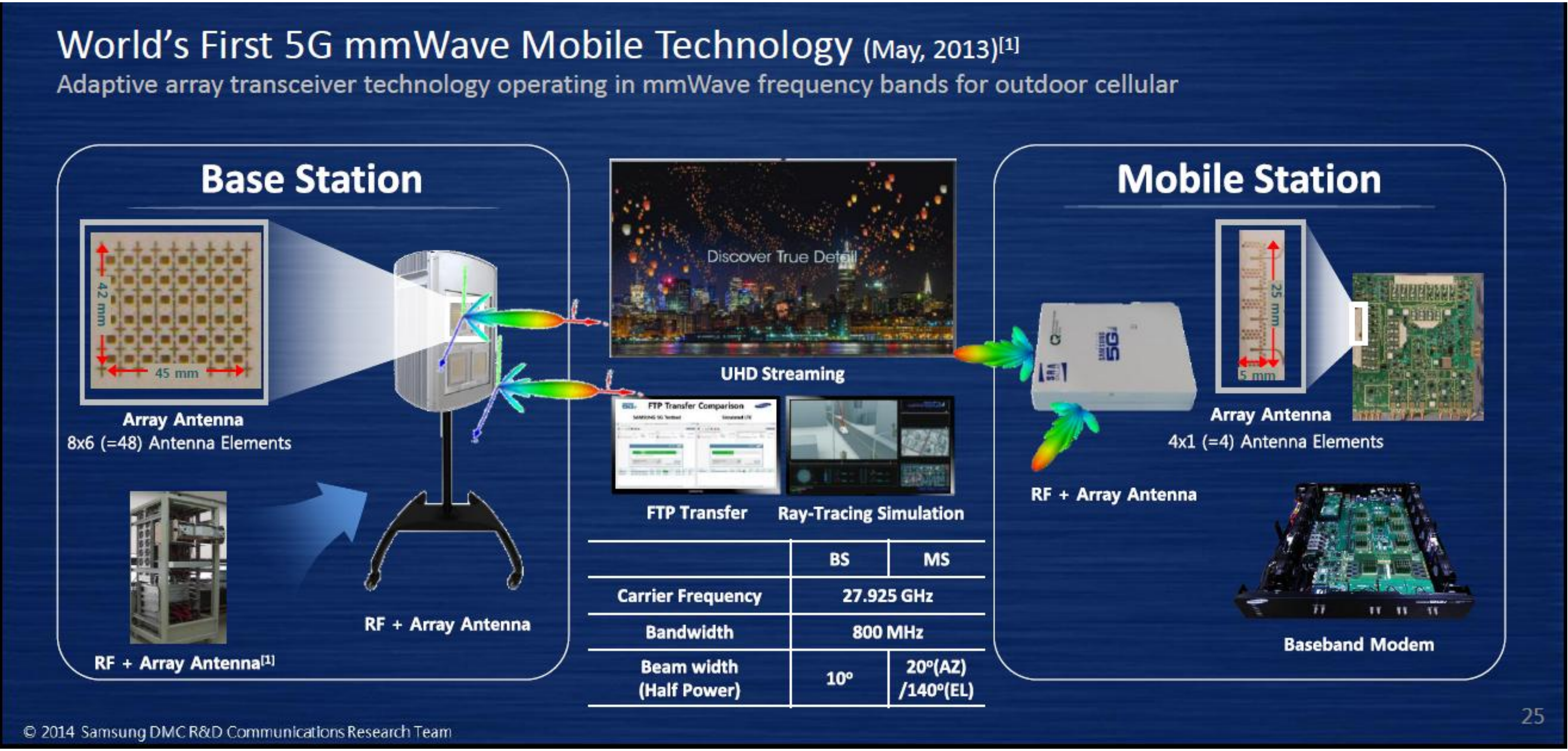




Fig. 10. Probability density functions of excess delays for (a) In-building NLoS environment, (b) Campus outdoor NLoS environment and (c) Downtown NLoS environment. (d) Cumulative distribution functions of RMS delay spreads for the in-building, campus and downtown NLoS environments.

# mmWave BF Prototype & Test Results

# Prototype System overview



# Test Results – Range

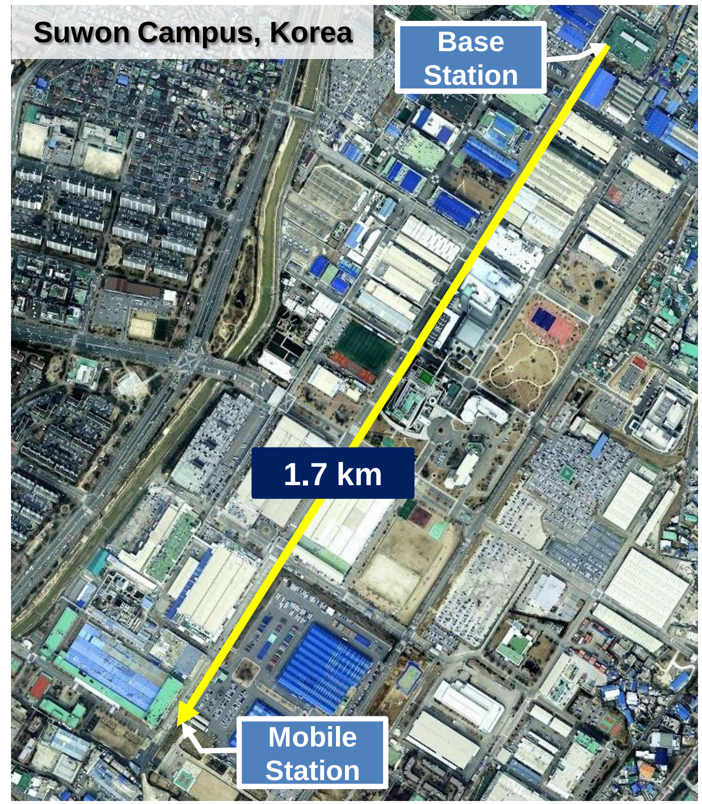
## Outdoor Line-of-Sight (LoS) Range Test

- Error free communications possible at 1.7 km LoS with > 10dB Tx power headroom
- Pencil BF both at transmitter and receiver supporting long range communications

### LoS Range

☐ **Support wide-range LoS coverage**

- ✓ 16-QAM (528Mbps) : BLER $10^{-6}$
- ✓ QPSK (264Mbps) : Error Free


BLER : Block Error Rate  QPSK : Quadrature Phase Shift Keying  QAM : Quadrature Amplitude Modulation

# Test Results – Mobility

## Outdoor Non-Line-of-Sight (NLoS) Mobility Tests

- Adaptive Joint Beamforming & Tracking Supports 8 km/h Mobility even in NLOS

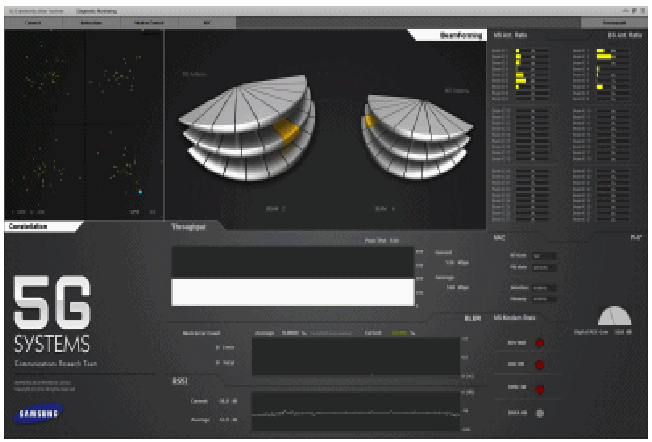
•Beam tracking period for Tx-Rx best beam pairs is 45 ms.
•Best beam pairs are selected by Mobile Station

### Mobility Support in NLoS

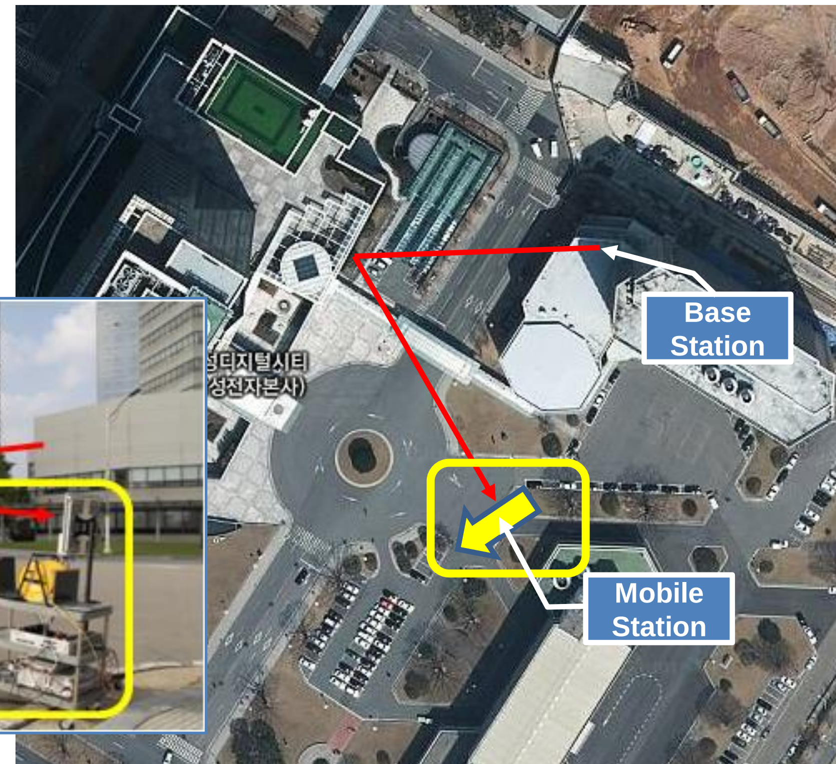
☐ **Mobility support up to 8 km/h at outdoor NLoS environments**

✓ 16-QAM (528Mbps) : BLER 0~0.5%

✓ QPSK (264Mbps) : Error Free




[ DM Screen during Mobility Test]

# Test Results – Building Penetration

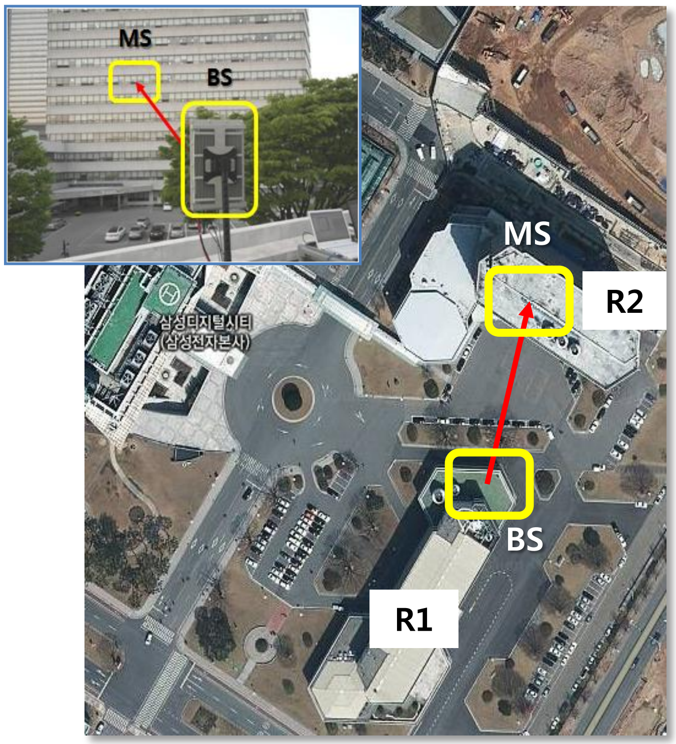
## Outdoor-to-Indoor Penetration Tests

- Most Signals Successfully Received at Indoor MS from Outdoor BS
- Outdoor-to-indoor penetration made through tinted glasses and doors

### Outdoor to Indoor #1

☐ **Signal measured inside office on 7th FL of R2**

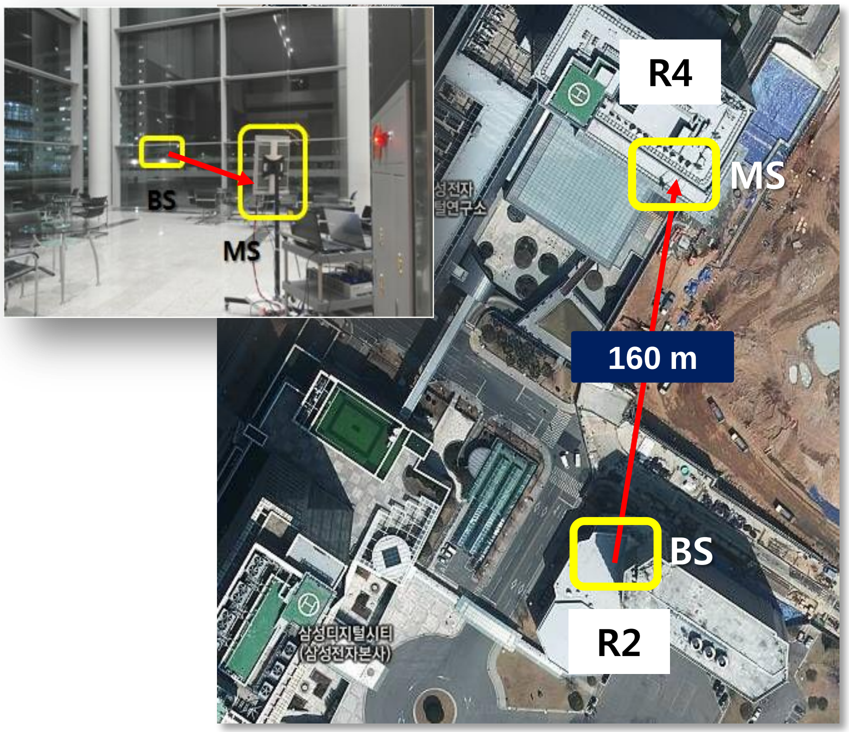
- QPSK : BLER 0.0005~0.6% (Target : < BLER 10%)




### Outdoor to Indoor #2

☐ **Signal measured inside the lobby at R4**

- QPSK : BLER 0.0005~0.3% (Target : < BLER 10%)

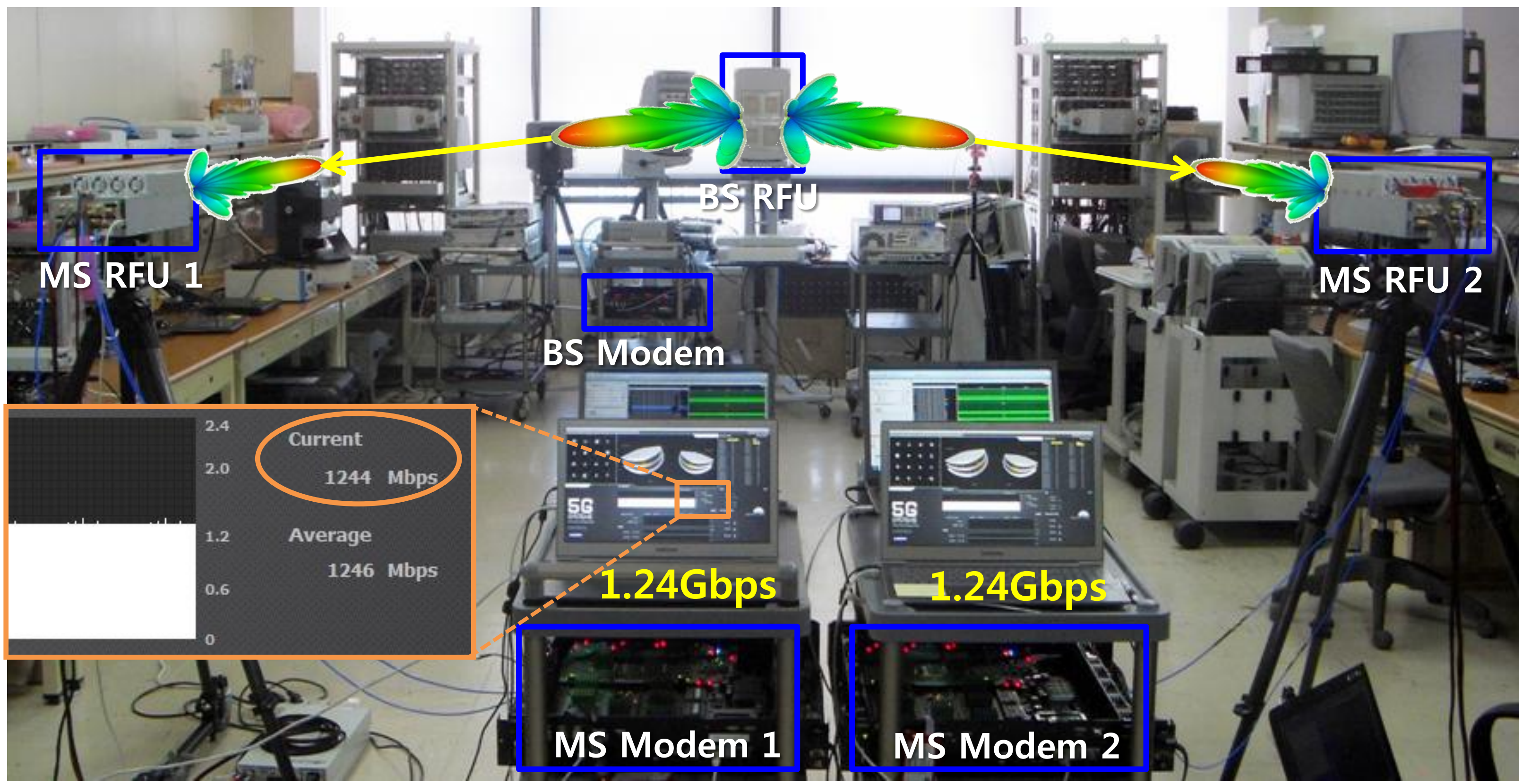


# Test Results – Multi-User Support

- **Multi-User Communication Tests**
  - 2.48 Gbps aggregate throughput in MU-MIMO mode

| PARAMETER | VALUE |
|---|---|
| Carrier Frequency | 27.925 GHz |
| Bandwidth | 800 MHz |
| Max. Tx Power | 37 dBm |
| Beam-width (Half Power) | 10º |
| Multiple Antenna | 2x2 MIMO |

## MU-MIMO Configuration

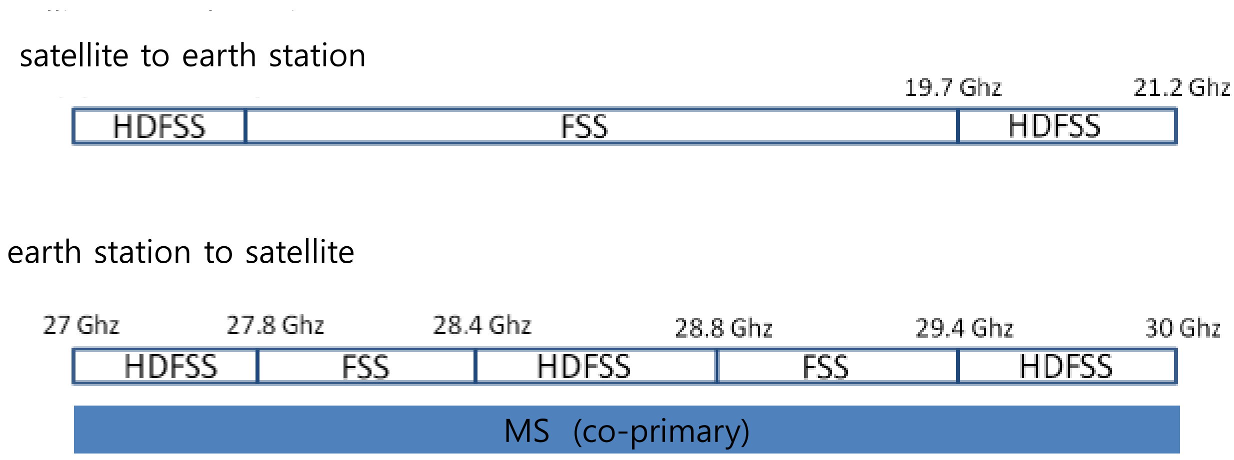


# Simulated user experience

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

Samsung DMC R&D Center, "*5G mmWave communications*," YouTube, 21 April 2014.
(http://www.youtube.com/watch?v=U6dABJBJ4XQ)

# Coexistence in mmWave spectrum



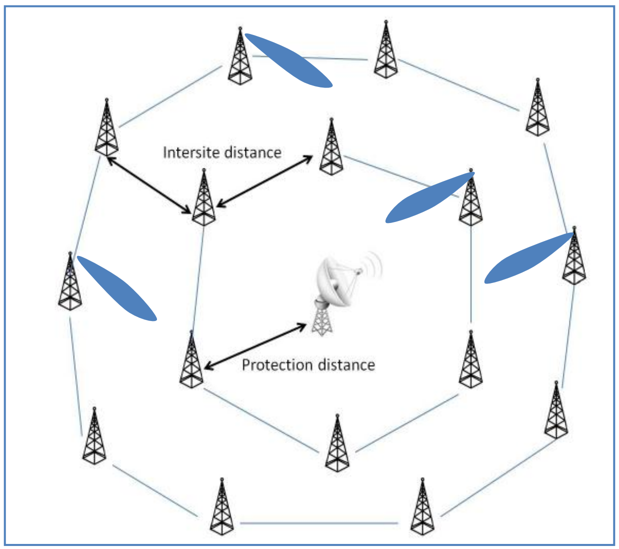

FSS : Fixed Satellite System HDFSS : High Density Fixed Satellite Systems MS: Mobile Services

# Coexistence results – Interference from FSS

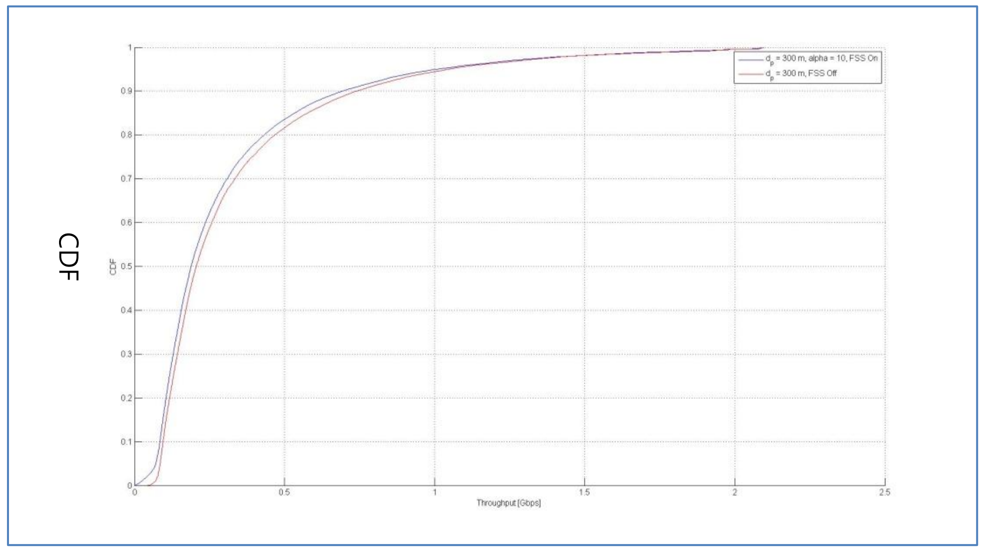
- **Dense deployment of mmWave cellular base stations**
  - Interference from FSS and aggregate interference for other BS considered
  - Analogue beam-forming at BS; random distribution of UE's (omni)
  - Service provisioning requires a relatively small protection distance (~2000 m) around FSS

## Parameters

| | |
|---|---|
| Carrier Frequency | 28GHz |
| Bandwidth | 500 MHz |
| Max. Tx Power | 30dBm |
| Number of antenna elements | Up to 64 |




CDF

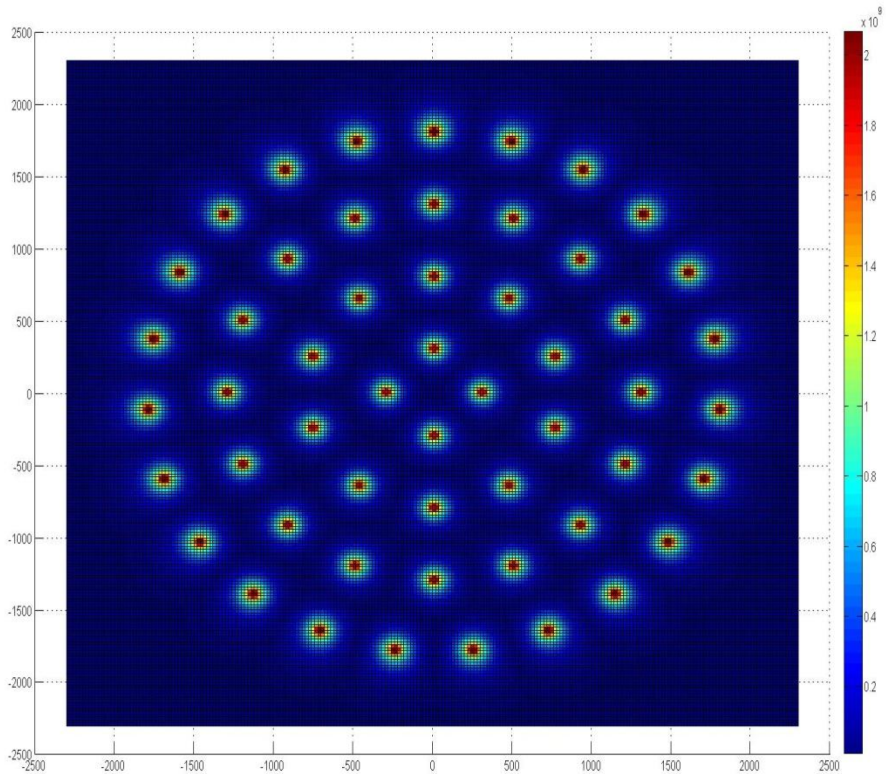


User Throughput (Gbps)

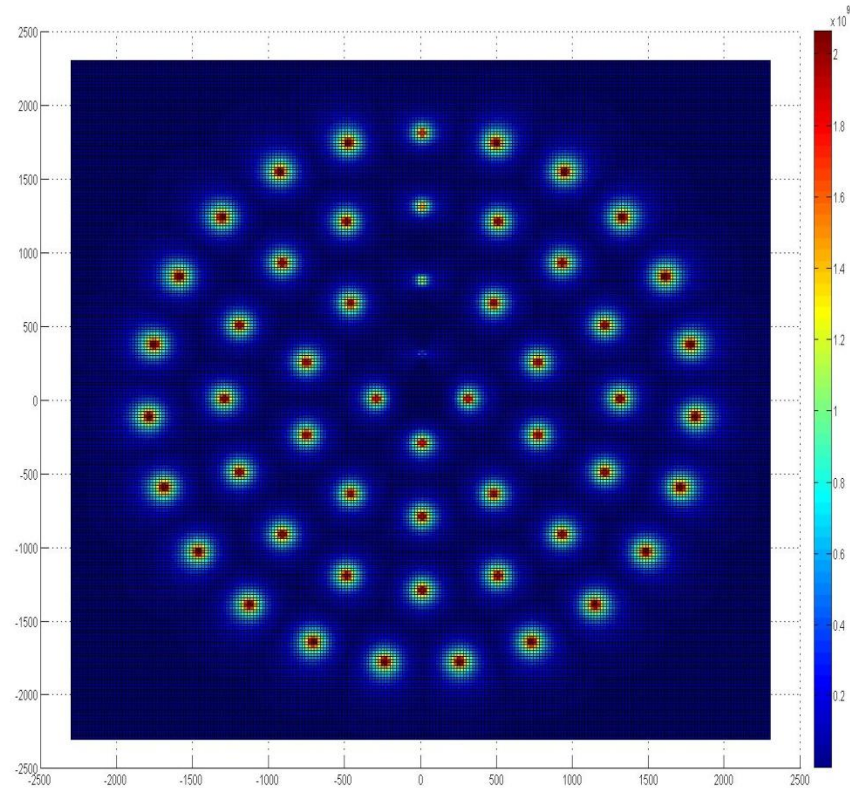
BS : Base Station FSS : Fixed Satellite System UE : User Equipment

# Coexistence results – Interference from FSS

- **Dense deployment of mmWave cellular base stations**
  - Impact of FSS on user throughput (downlink) of mmWave cellular




No FSS interference




FSS interference

BS : Base Station FSS : Fixed Satellite System UE : User Equipment

# Summary and outlook

- **mmWave BF Technology as a Viable Solution to Provide Gbps Experience**
  - ✓ Extensive mmWave channel measurement and modeling has been performed; much more will be provided (e.g. COST IC1004)
  - ✓ Real-time adaptive beamforming and tracking implemented and demonstrated,
  - ✓ Achieving cellular range (200m), supporting mobility and multi-user access
- **Great progress has been made but much more is needed towards 5G**
  - **Research:** Channel, PHY, MAC,RF, Antennas, Architectures
  - **Regulations:** Frequency bands, coexistence, licensing models
  - **Standards:** 3GPP, ETSI, …

A GLOBAL INITIATIVE

THANK YOU FOR LISTENING!

HAPPY TO TAKE YOUR QUESTIONS