Harvesting Millimeter Wave Spectrum for 5G
Ultra High Wireless Capacity
Challenges and Opportunities

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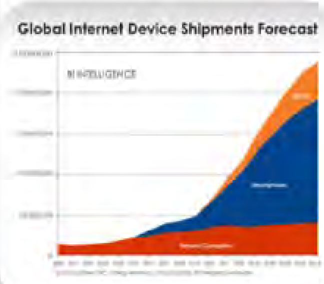
Millimeter for 5G Workshop at CEATEC
Tokyo, Japan, October 8th, 2014

Global Capacity Demand

MiWEBA

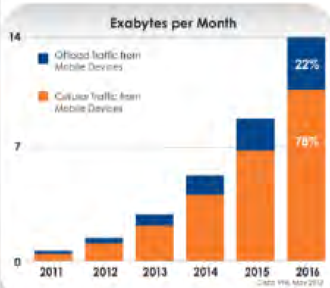
Demand for wireless bandwidth today exceeds network capabilities

Smart Device Proliferation



Video Traffic Growth

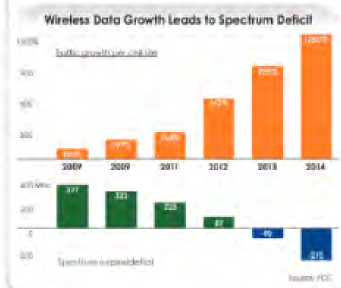
Growth of Mobile Data



OTT Invasion

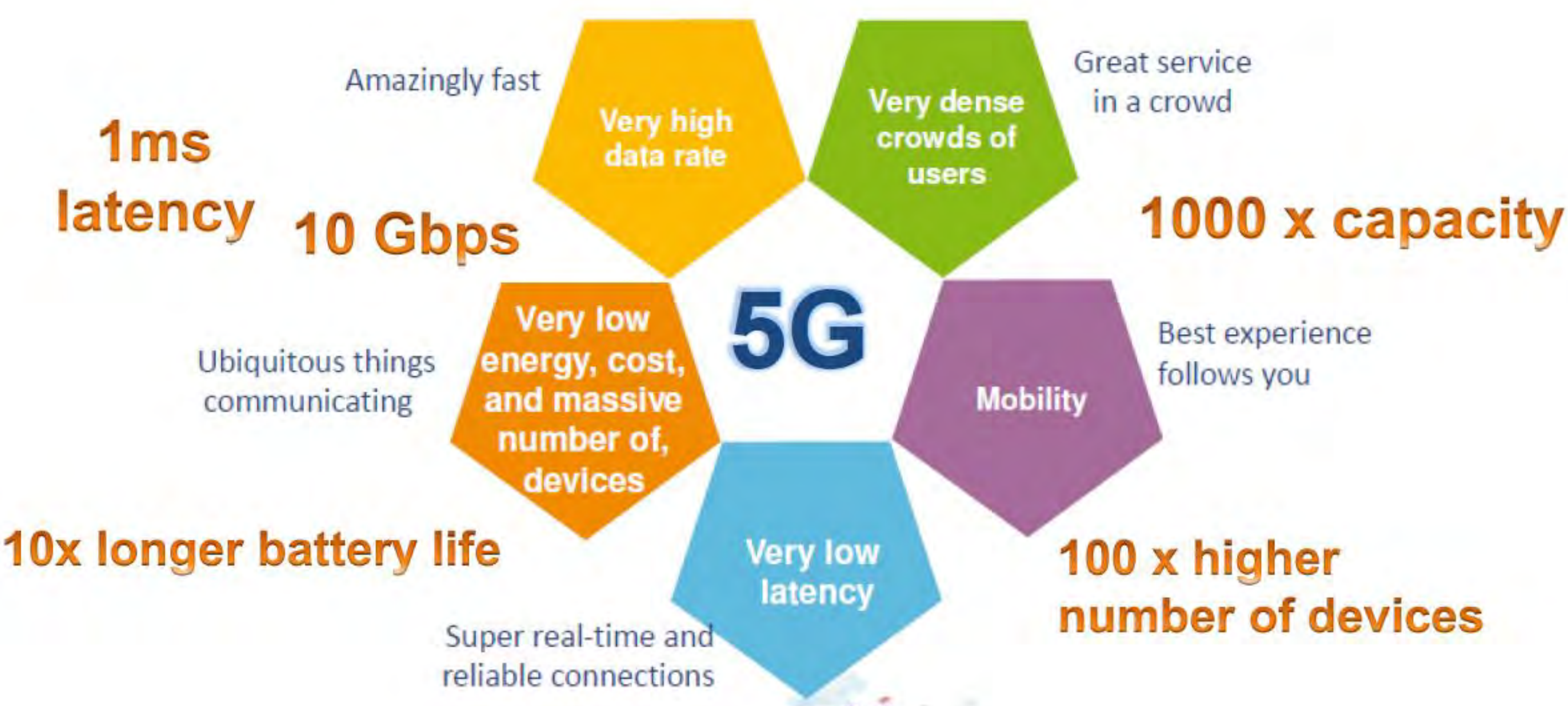
NETFLIX
Dropbox
iCloud
tv
PANDORA
Google
amazon

Spectrum Crunch



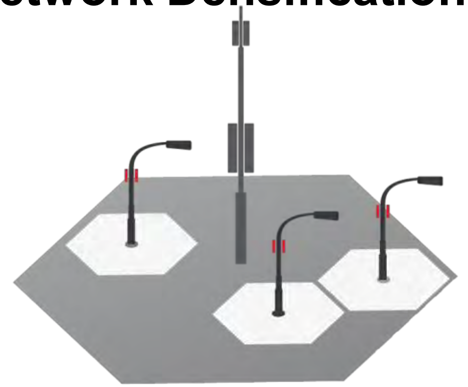
Rich Requirements for 5G

The 5G Vision

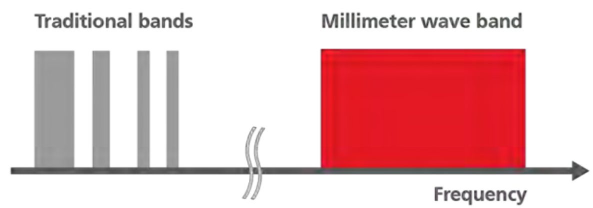


5G Radio Technologies

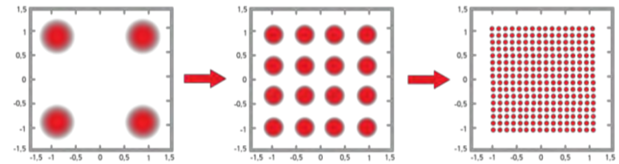
Network Densification



Spectrum Extension

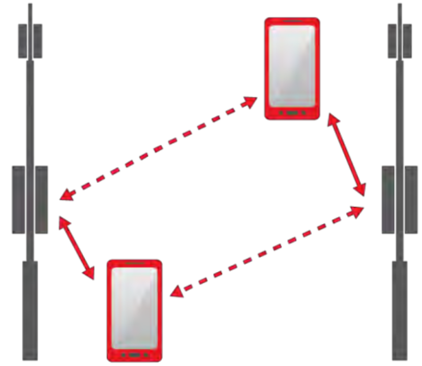


Spectral Efficiency

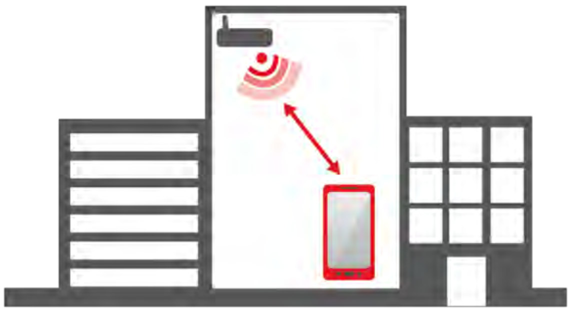


Advanced Antennas

Interference Management



Offload and D2D



5G Public Private Partnership in Europe

MiWEBA

European Commission and industry

Budget (2014-2020)

- 700 million € public funding
- Matched by about 700 million € from private side
- Including leveraging factor 5 of additional private investment value about 3.5 billion €

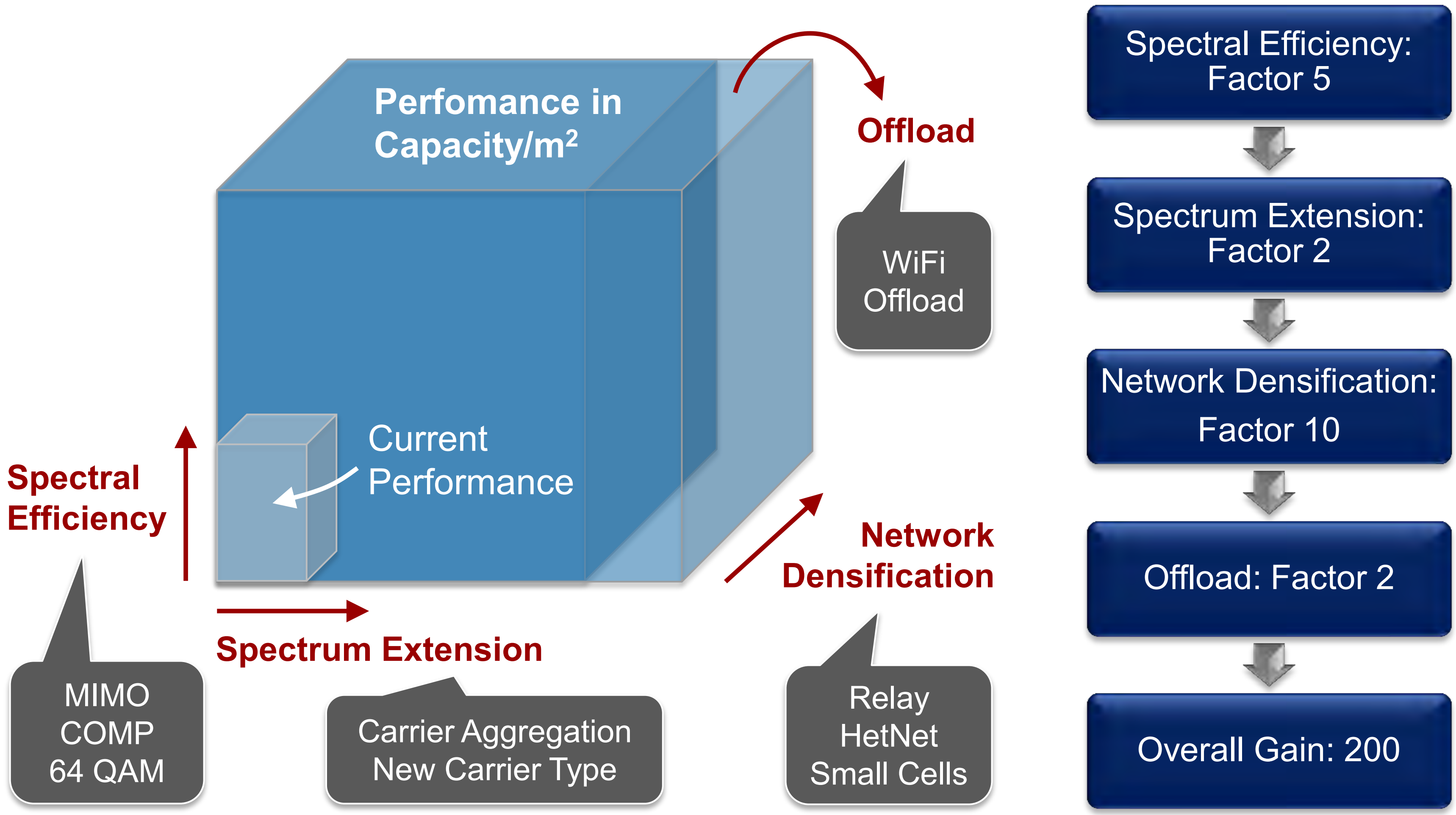
4 Strands with 16 Projects

- Project 4: 5G mm-Wave Air Interface

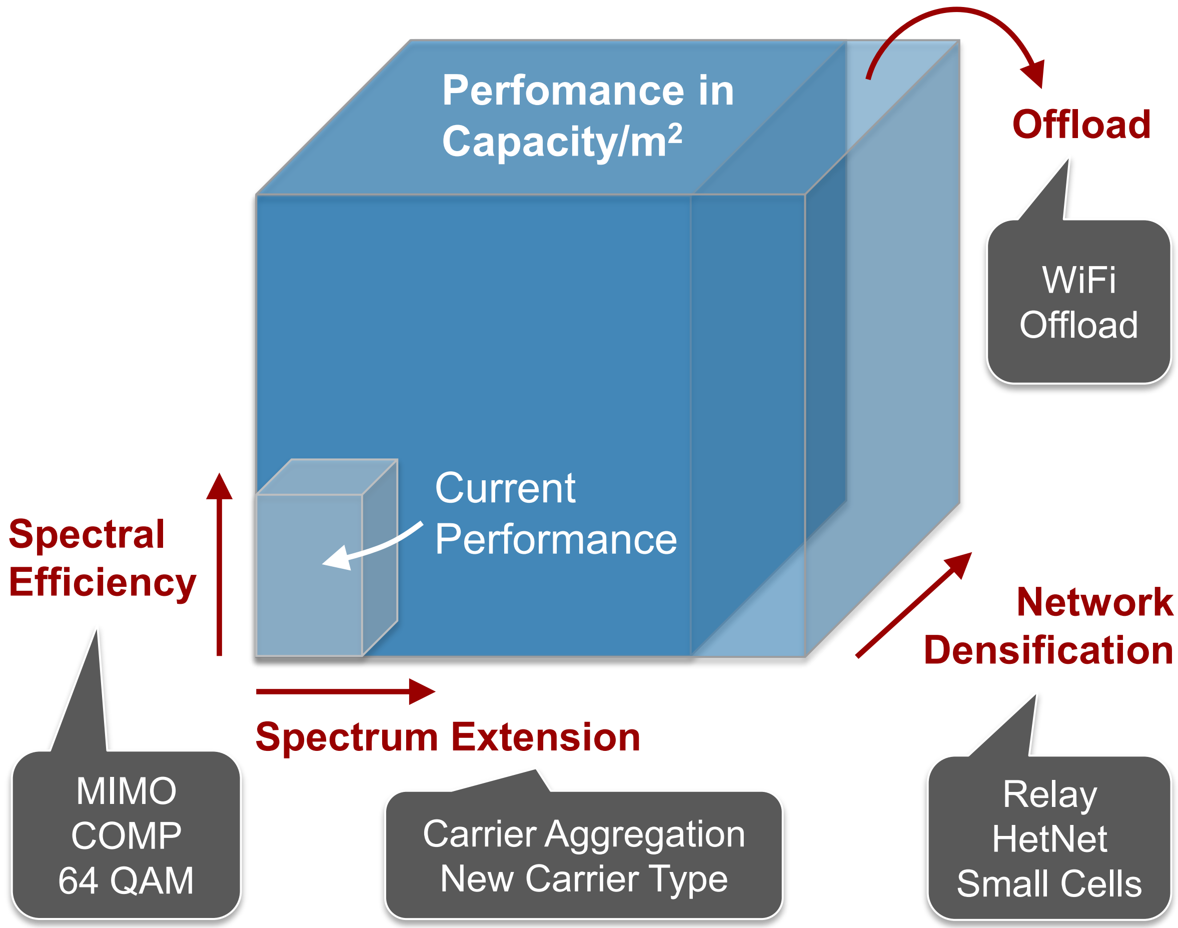
5G PPP

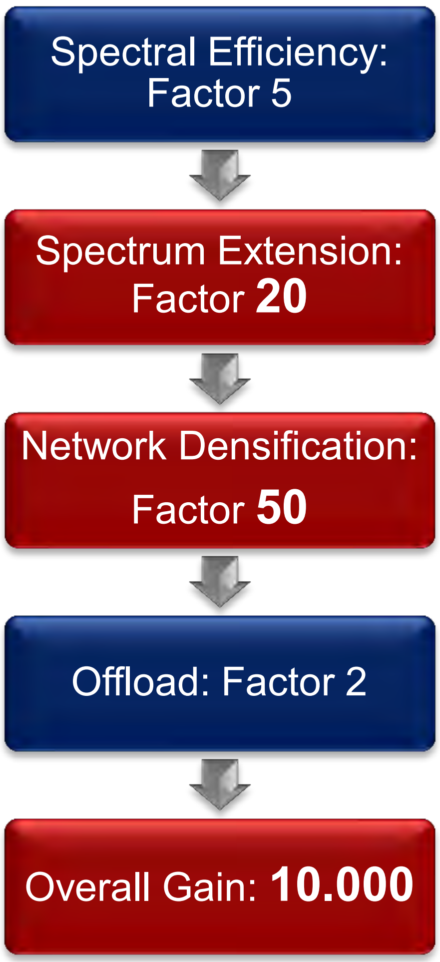
The 5G Infrastructure Public Private Partnership

How to increase Capacity?



Achieving 10.000x above 6 GHz?

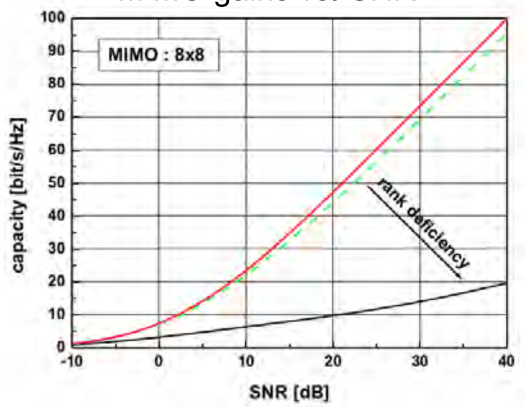




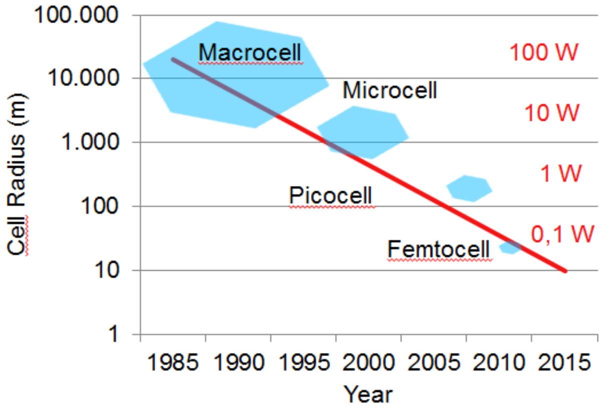
Energy Consumption for more Capacity

- **MIMO:** linear in number of parallel streams (limited at about 8 to 16 streams per sector, depending on spatial degree of freedom of wireless channel)
- **CoMP/Network-MIMO:** linear in number of parallel streams (limits at 8 to 20 streams, depending on spatial degree of freedom of wireless channel across several base station sites)
- **Higher order modulation:** 3dB power increase per 1 bit/s/Hz (limited by SINR achievable on the wireless link, e.g. 2048 QAM for Line of Sight or 256QAM indoors)
- **Carrier Aggregation:** linear in amount of spectrum (limited by amount of spectrum)
- **Network Densification:** required transmit power for same area power density scales inversely proportional vs. cell size therefore remains almost energy- neutral wrt capacity increase (limited often by high trenching costs CAPEX)

MIMO gains vs. SNR



Cell Sizes and Transmit Power



MiWEBA – The Essentials

- **Mi**llimeter-**W**ave **E**volution for **B**ackhaul and **A**ccess
- European-Japanese cooperation

Millimeter-wave introduction

MiWEBA

- **Multiple candidate bands**
  - 28/30 GHz
  - 60 GHz
    - 6-9 GHz freely available spectrum
  - 70/80 GHz (E-Band)
    - light/block licensed

- **Challenging propagation conditions**
  - High pathloss
  - Oxygen attenuation (at 60 GHz)
  - No penetration of buildings, etc.
  - **No comprehensive channel model yet**

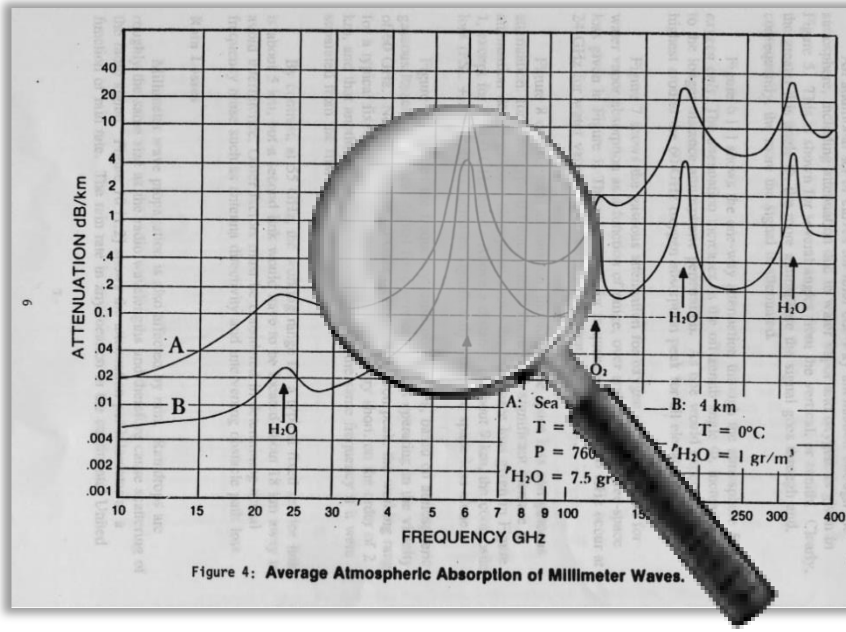
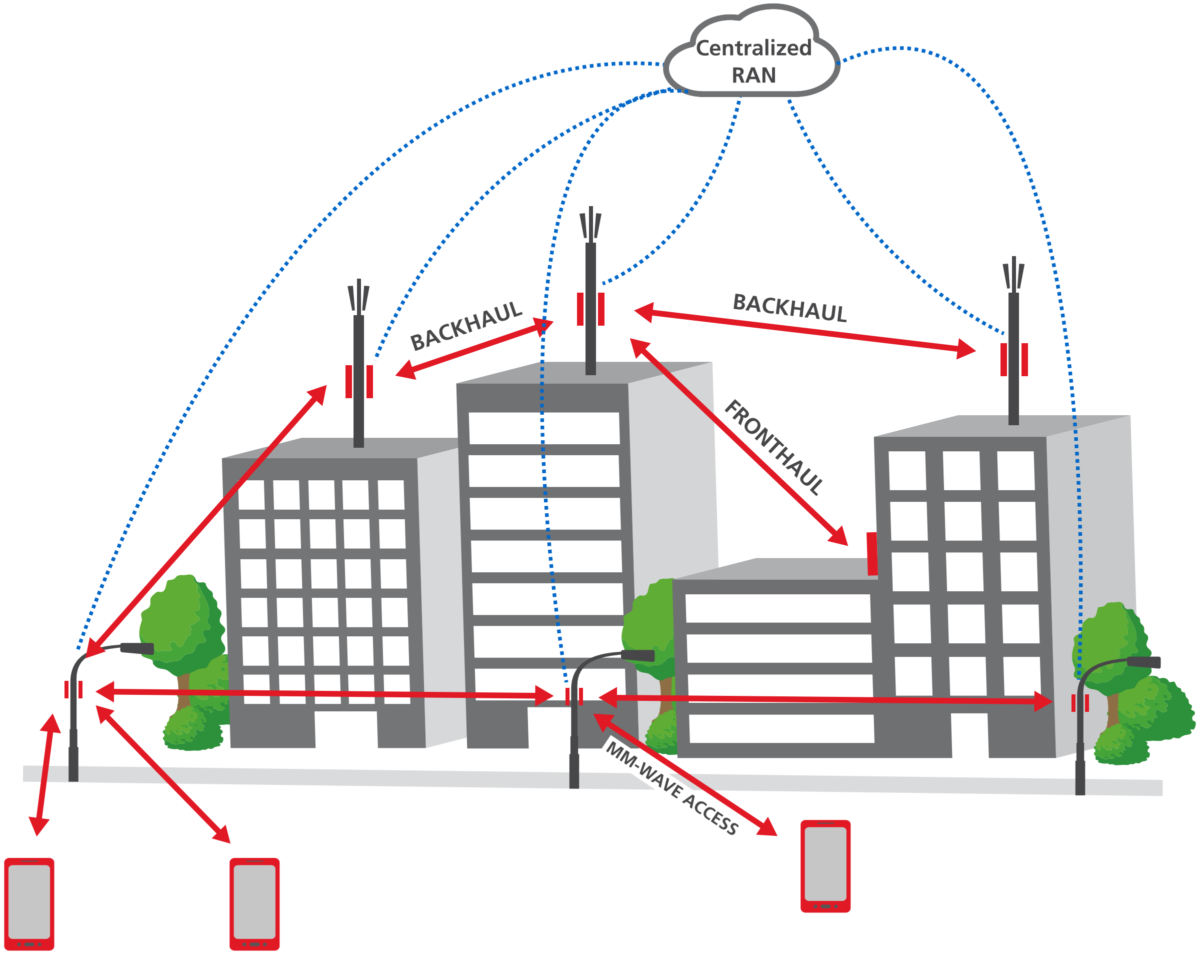


Figure 4: Average Atmospheric Absorption of Millimeter Waves.

Concept & Benefits (I)



Millimeter-wave on

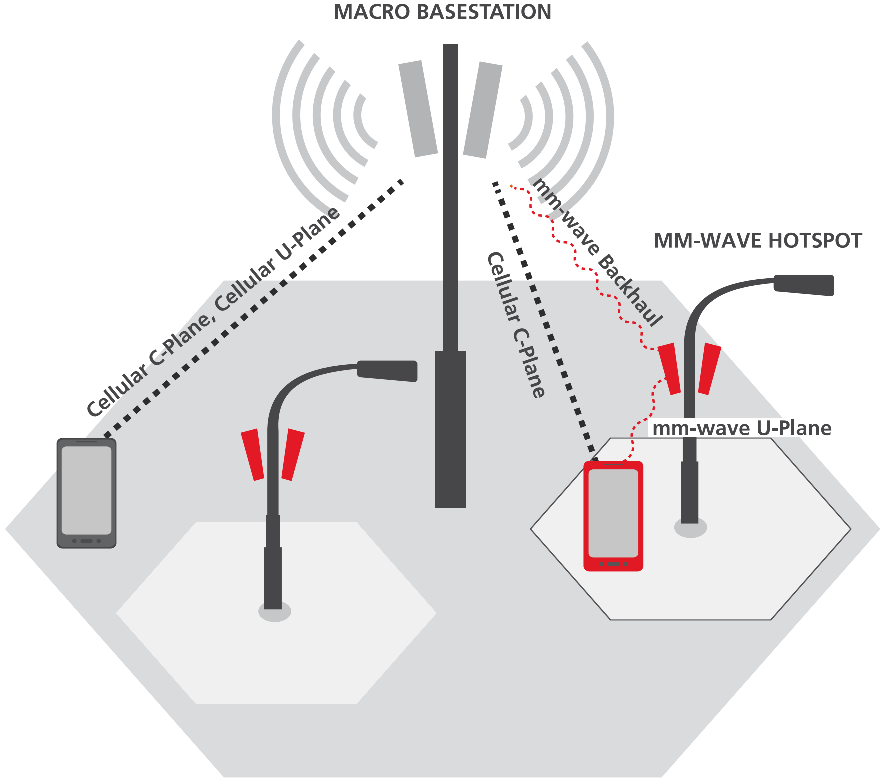
- Access
- Fronthaul
- Backhaul

Enables

- Better user experience
- Dense small cell deployments
- Centralized RAN architecture

Concept & Benefits (II)

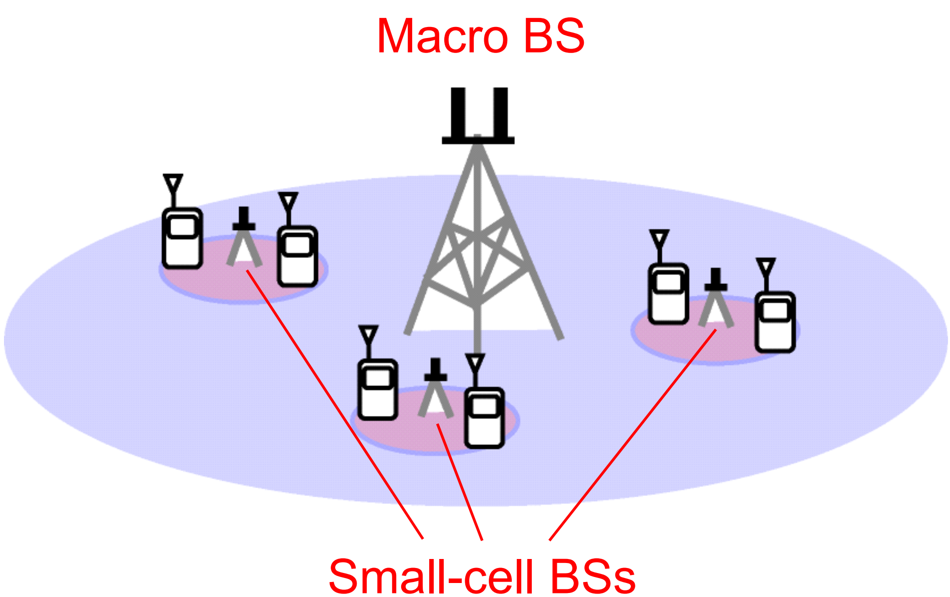
- Millimeter-wave small cell overlay
- Increase rate at hotspots
- Split control and user plane
- Seamless connectivity via legacy control plane
- Centralized coordination of small cells

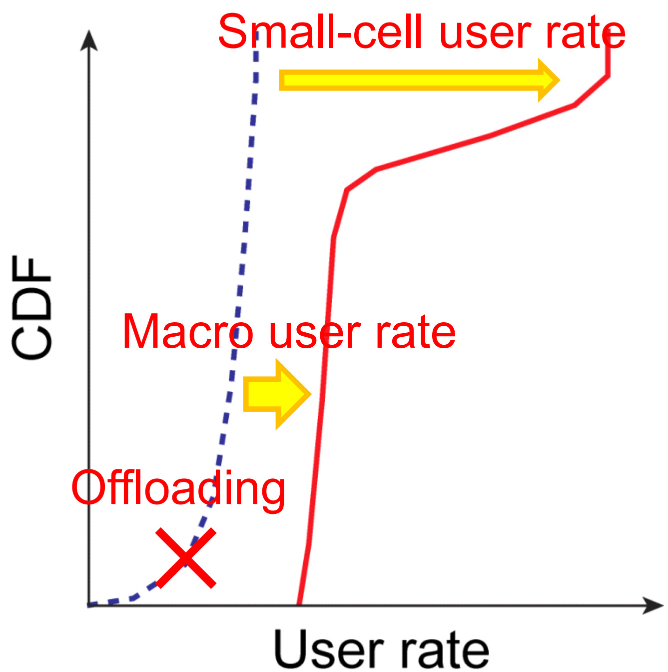


Heterogeneous Networks Multi-RAT, Multi-sized cells and variable spectrum usage

Heterogeneous Network

- Deploy small-cell BSs within macro-cell
- Improve user rate near the small-cell BSs
- Improve system rate by macro user offloading





Multi-Band HetNet

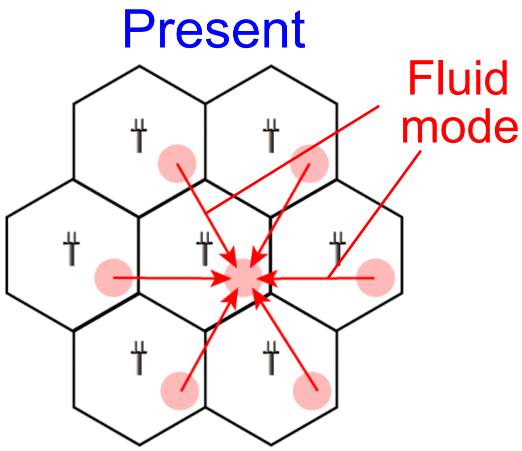
- Inter Macro & small-cell interference management is necessary
- Spectrum splitting loss occurs in single-band HetNet
- Multi-band HetNet achieves BW enhancement without interference

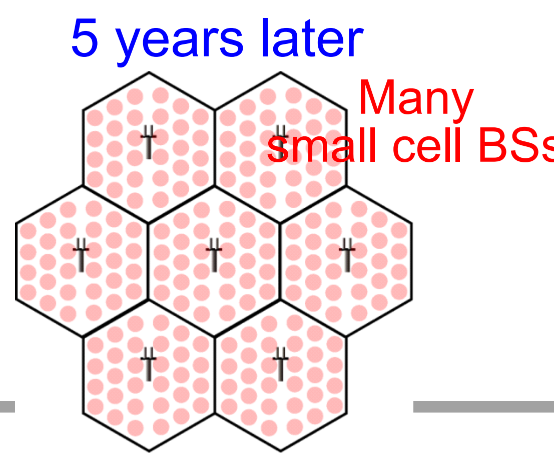
Single-Band	Multi-band	
2GHz band	3GHz band	60GHz band
Macro :	Macro :	Macro :
Center freq: 2GHz	Center freq: 2GHz	Center freq: 2GHz
BW: ρ×10MHz	BW: 10MHz	BW: 10MHz
Tx power: 46dBm	Tx power: 46dBm	Tx power: 46dBm
Small-cell :	Small-cell :	Small-cell :
Center freq: 2GHz	Center freq: 3.5GHz	Center freq: 60GHz
BW: (1-ρ)×10MHz	BW: 100MHz	BW: 2.16GHz
Tx power: 24dBm	Tx power: 30dBm	Tx power: 10dBm

Condition of Analysis

- System rate improvement vs. number of small-cell BSs
- Consider three traffic load cases（present, 5 years later, 10 years later）

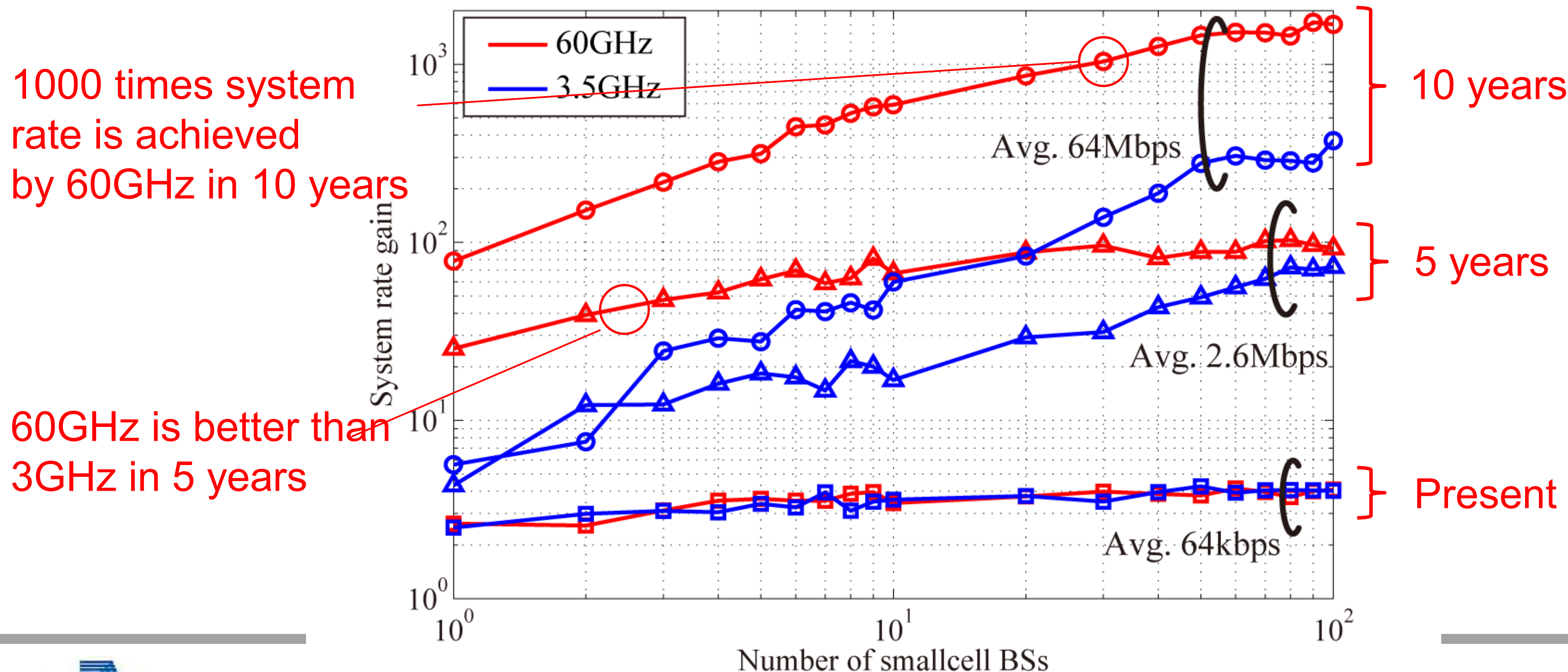
Macro BS	Center freq.	2GHz
	BW	10MHz
	Tx power	46dBm
	ISD	500m
3G small-cell BS	Center freq.	3.5GHz
	BW	100MHz
	Tx power	30dBm
60G small-cell BS	Center freq.	60GHz
	BW	2.16GHz
	Tx power	10dBm
AMC	User rate	≤8bps/Hz × BW/coverage area
Traffic	Present, 5 years later, 10 years later	64kbps, 2.6Mbps, 64Mbps / user
Propagation model	Path loss (PL)	Distance-dependent PL exponent：3, Frequency exponent：2
	Interference model	Fluid model





Numerical Evaluation Results

- System rate increases against # of small-cell BSs in high traffic scenarios
- 1000 times system rate is achieved by 30x 60GHz small-cell BSs in 10 years
- Performance of 60GHz small-cell BSs is better than that with 3GHz small-cell BSs



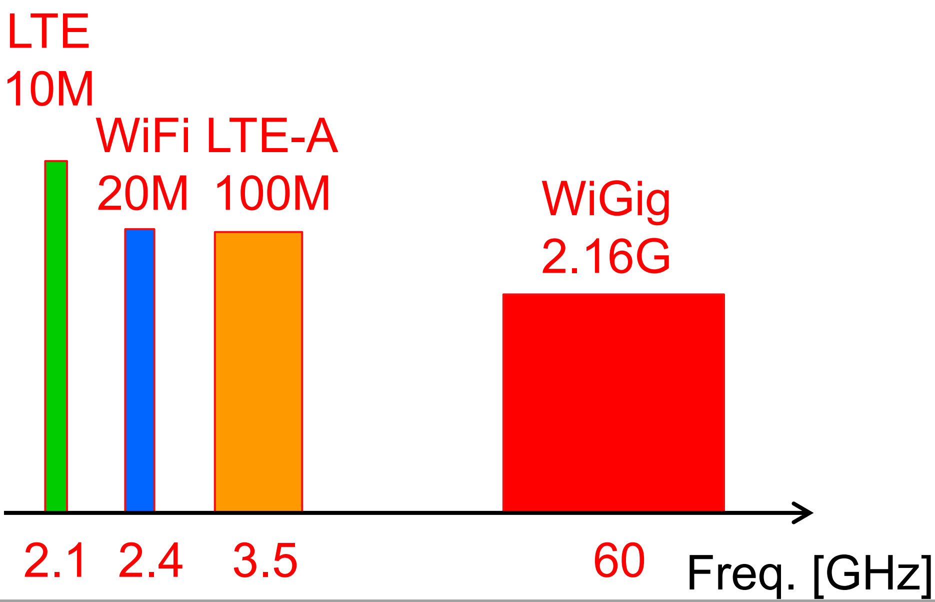
To Realize Multi-band HetNet

- Efficient small-cell discovery
  - UE with dual connectivity is necessary for multi-band HetNet
  - Power efficient small-cell discovery is challenging issue for sparsely deployed small-cell scenario
  - Seamless handover between small-cell & macro and small-cell & small-cell is challenging issue in densely deployed small-cell scenario

- Dynamic operation of small-cell BS
  - To overcome the limited coverage, dynamic operation of small-cells is necessary based on the context (location & traffic) of UEs
  - Dynamic optimization of small-cell BS parameters (tx power, beam angle, UE association) is challenging issue to maximize system rate
  - Dynamic small-cell tracking via beamforming & CoMP for time variant location of hotspot is challenging issue

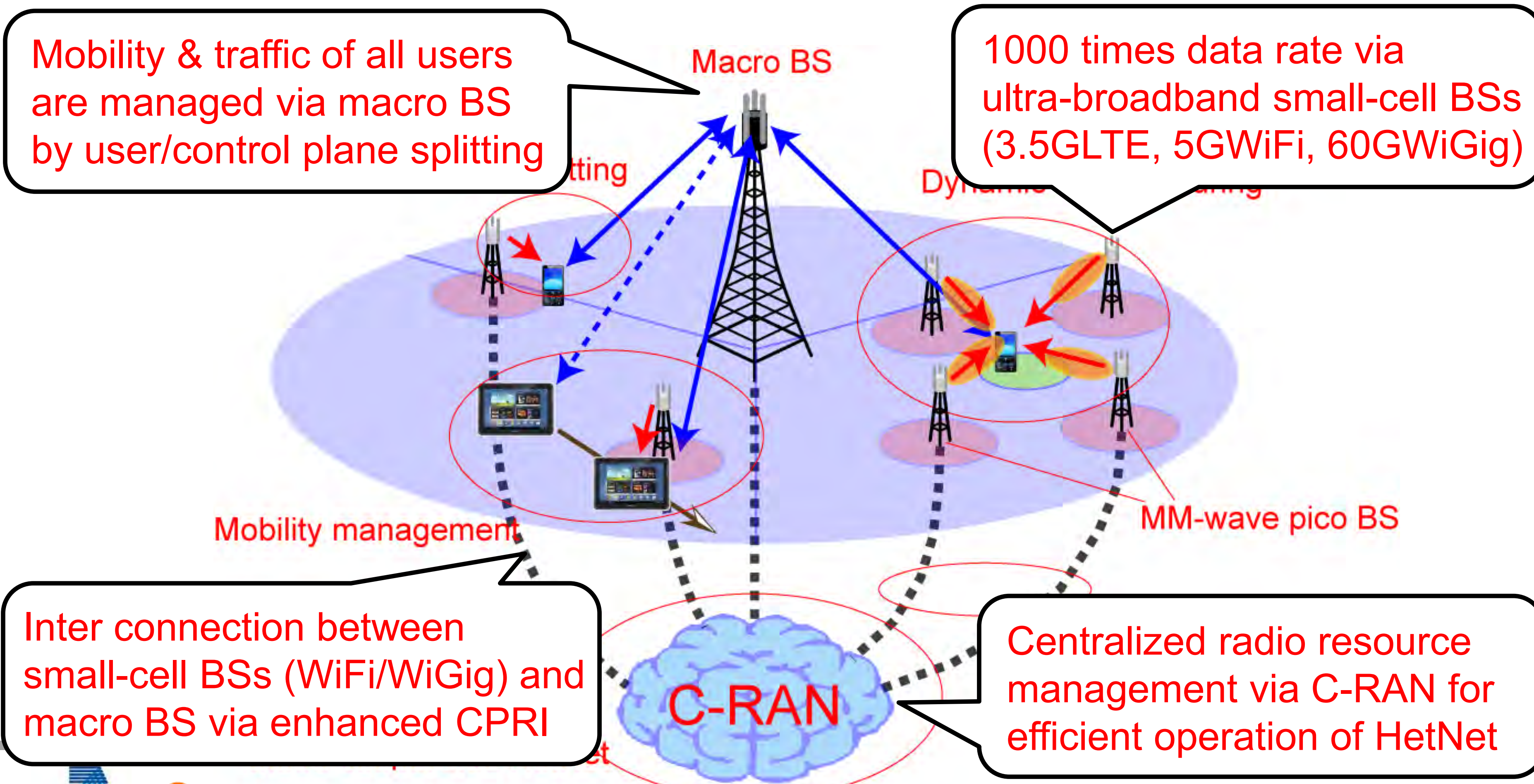
Dual Connectivity & Cell Discovery

- Single connectivity UE cannot perform data commununication & cell discovery at the same time
- UE with dual connectivity is necessary for multi-band HetNet
- Power efficient small-cell discovery & seamless handover are issues to be solved in multi-band HetNet



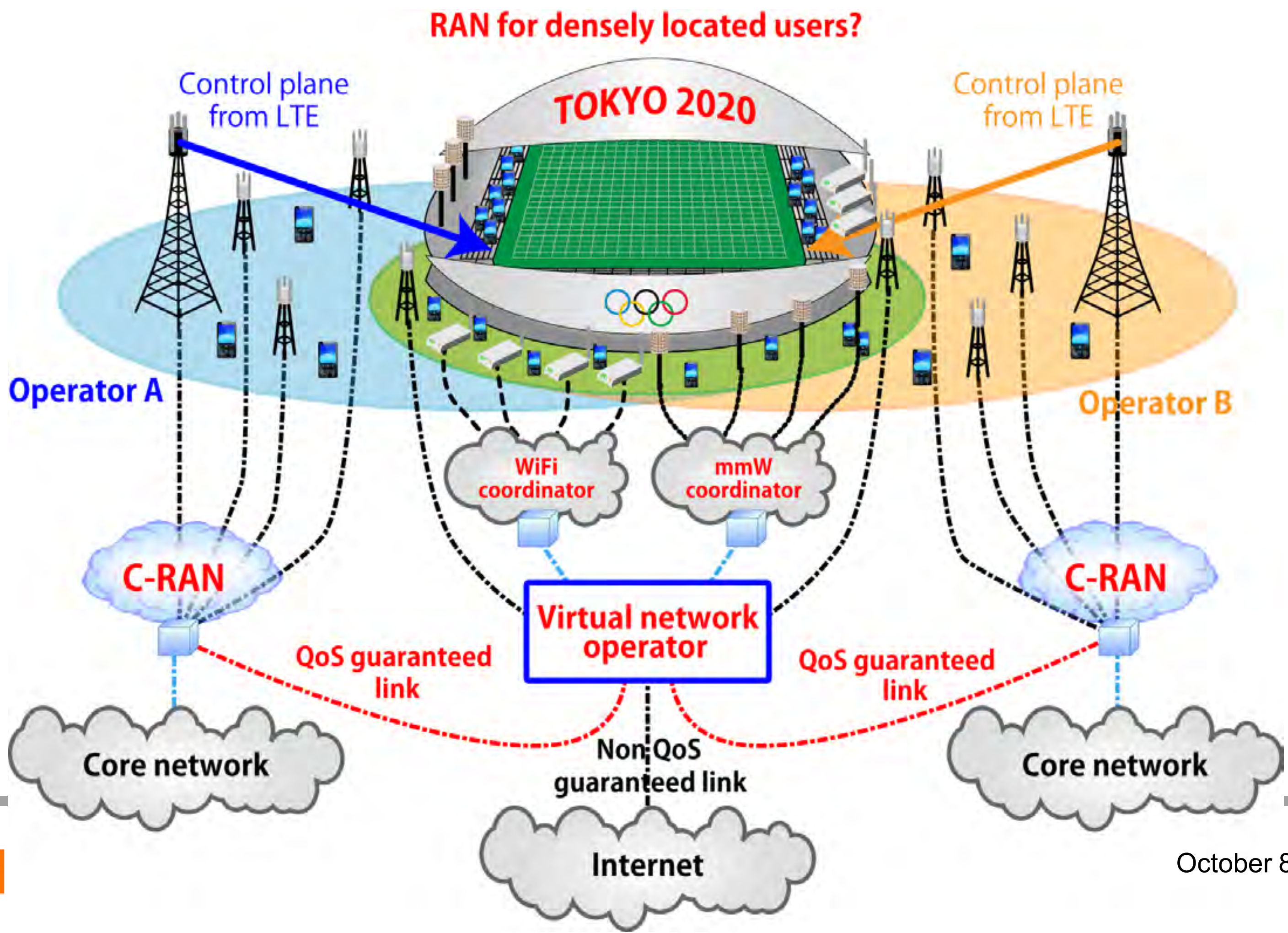
Cloud Cooperated HetNet

- HetNet consists of small-cell BSs for data plane & macro BS for control plane
- Efficient operation of HetNet by C-RAN (seamless handover, dynamic cell, ...



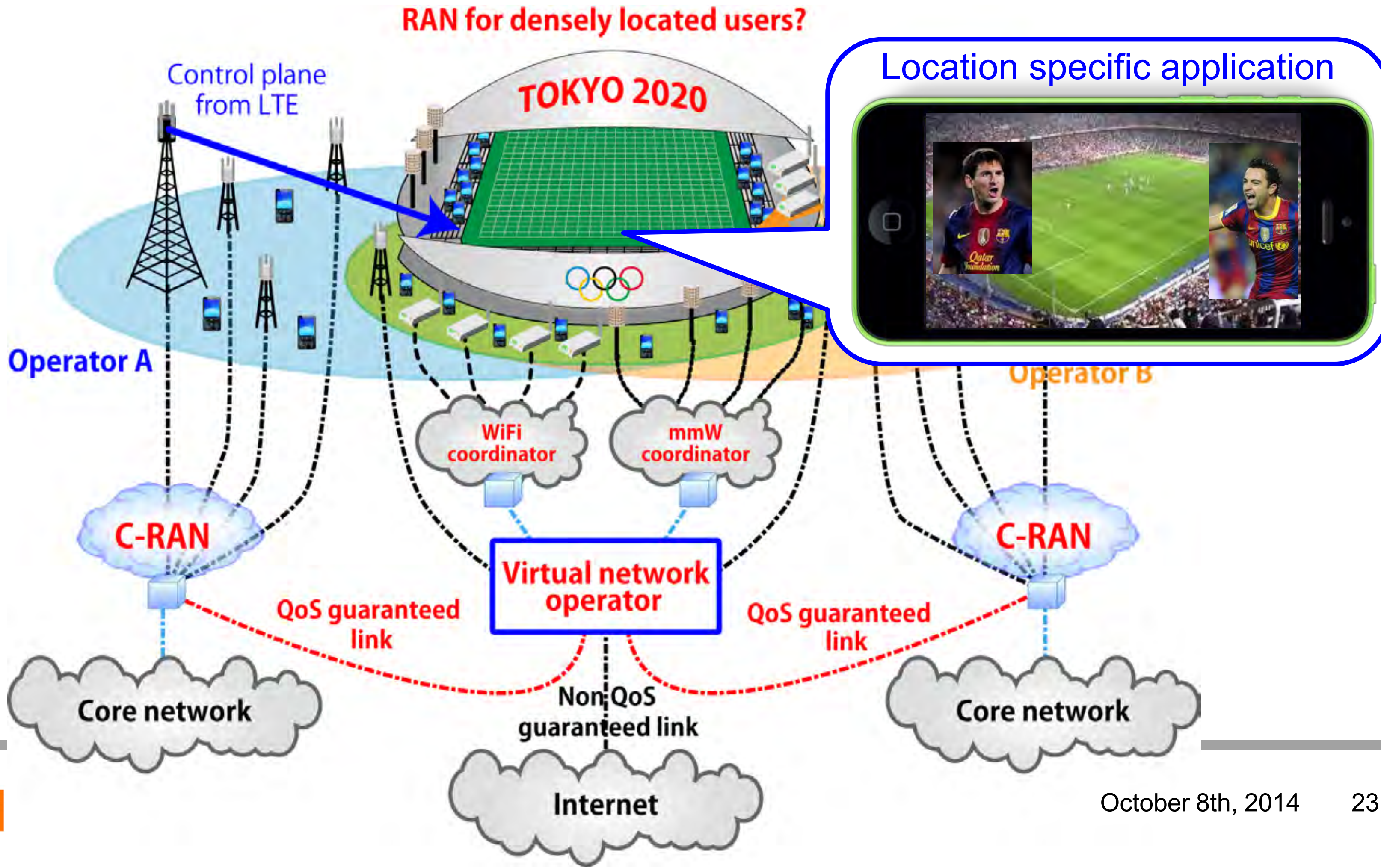
Proposal of 5G

- Virtual operator deploys 3GLTE, 5GWiFi, 60GWiGig for hotspots (unlicensed)
- Legacy operators share RAN for hotspot via virtual operator (CAPEX/OPEX)



Proposal of 5G

- Virtual operator deploys 3GLTE, 5GWiFi, 60GWiGig for hotspots (unlicensed)
- Legacy operators share RAN for hotspot via virtual operator (CAPEX/OPEX)
- Measured rate charging for location specific applications (profit from bits)

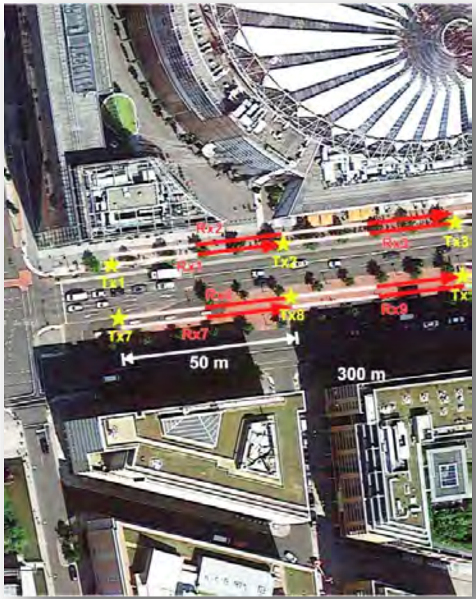


Propagation Measurements and Channel Modelling

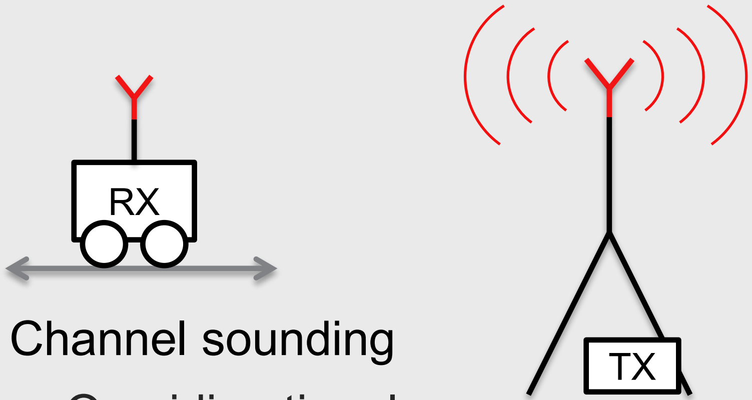
Gathering Measurement Data

- Prerequisite for model elaboration/extension
- Detailed information on spatial and temporal characteristics, time evolution
- Statistically reliable measurement data for typical scenarios

- Measurement campaign in Berlin, Germany
- Small cell urban access channel
- Potsdamer Straße (street canyon) & Leipziger Platz (city square)
- TX: “small cell base station”, RX: “mobile”
- TX-RX distance: 0–50 m
- 12 TX locations for street canyon
- 3.75 million snapshots with mobile RX (0.5 m/s)
- 3.25 million snapshots with static RX

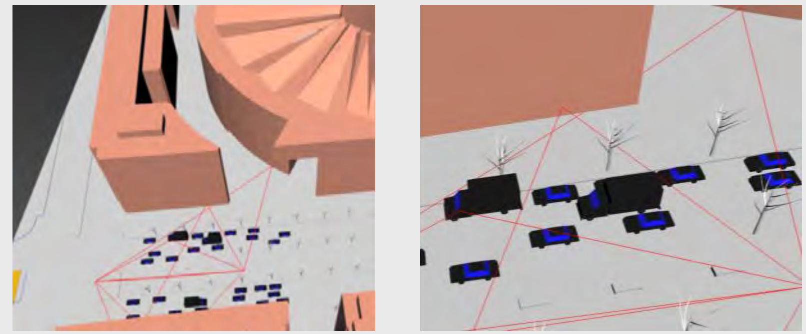


Measurement Approach



Channel sounding

- Omnidirectional
- Time resolution



Ray-tracing simulation

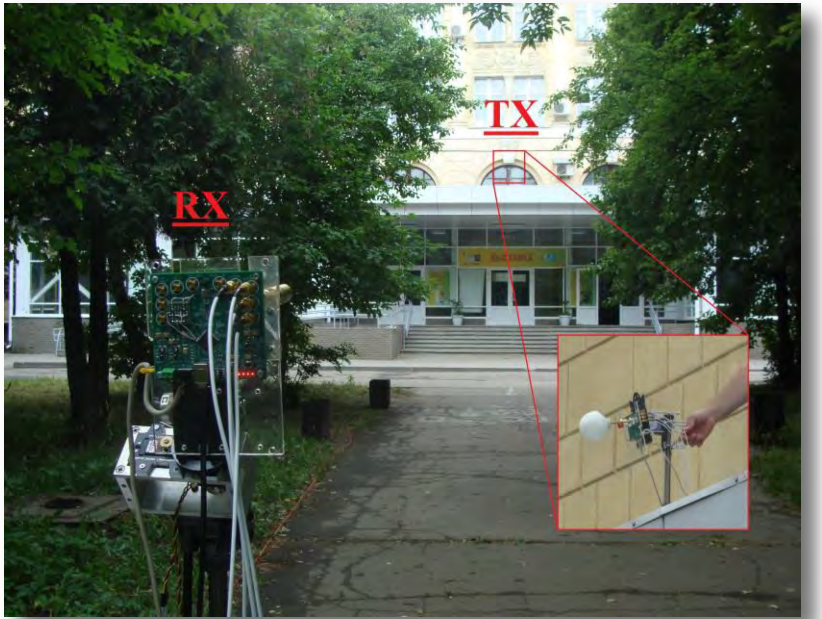
- Matched to measurement
- Full angular information

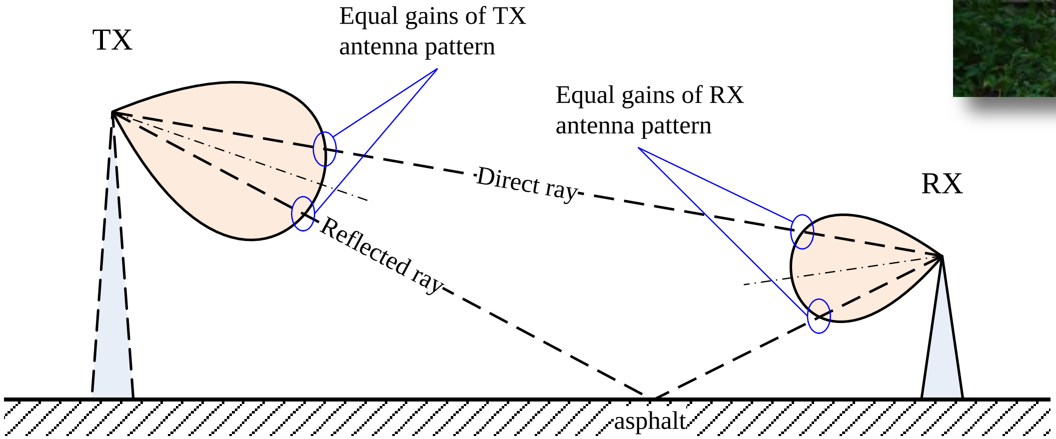
3D Time Variant Channel Model

Scenario: Open Area (Campus)

Investigation of reflection properties

- Ground reflection
- Antenna heights
- High gain antennas

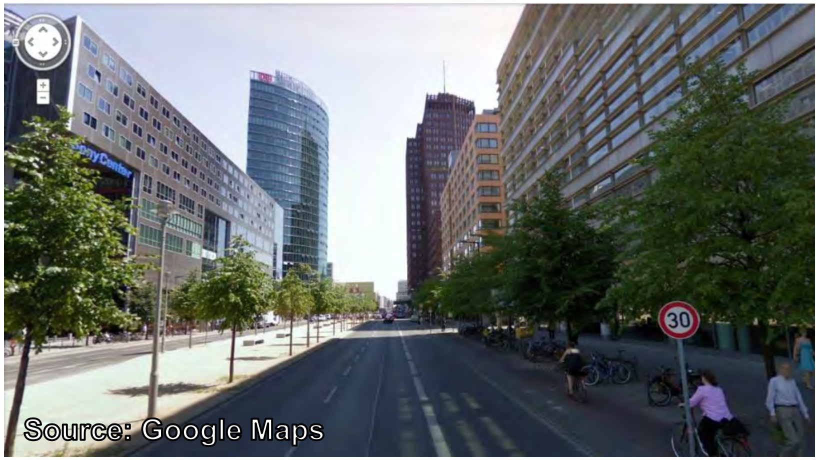


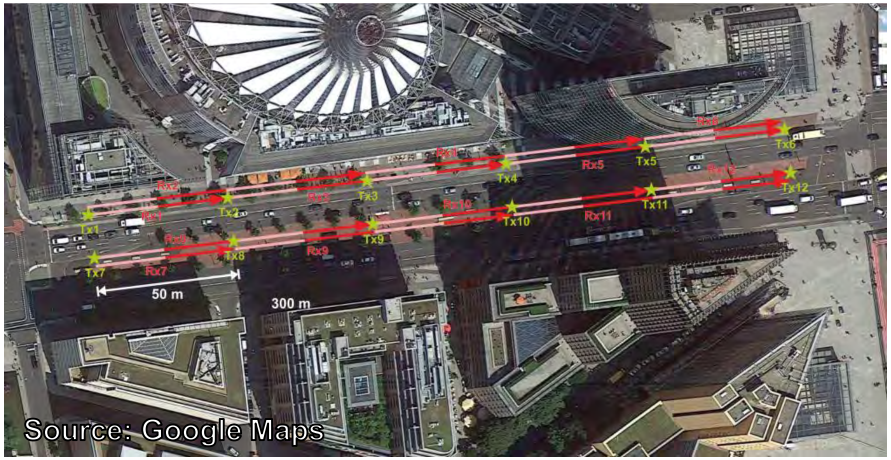


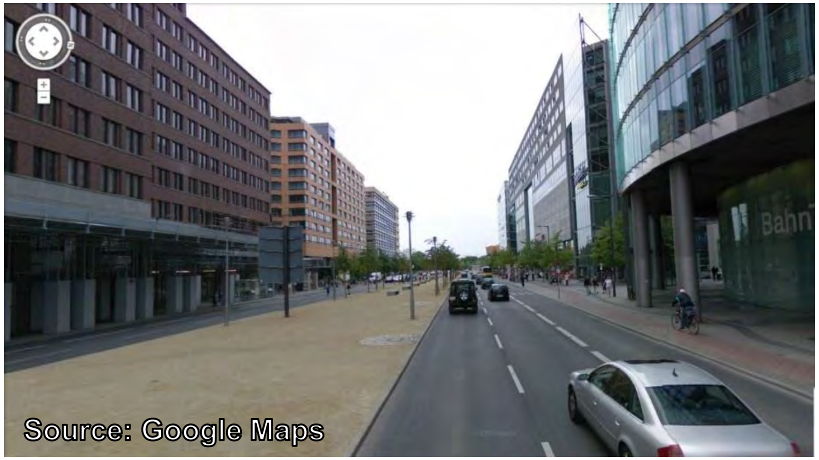
Scenario: Street Canyon

Potsdamer Str / Sony Center Berlin

- Modern office buildings
- Significant reflections to be expected from flat surfaces
- Street width: 52 m

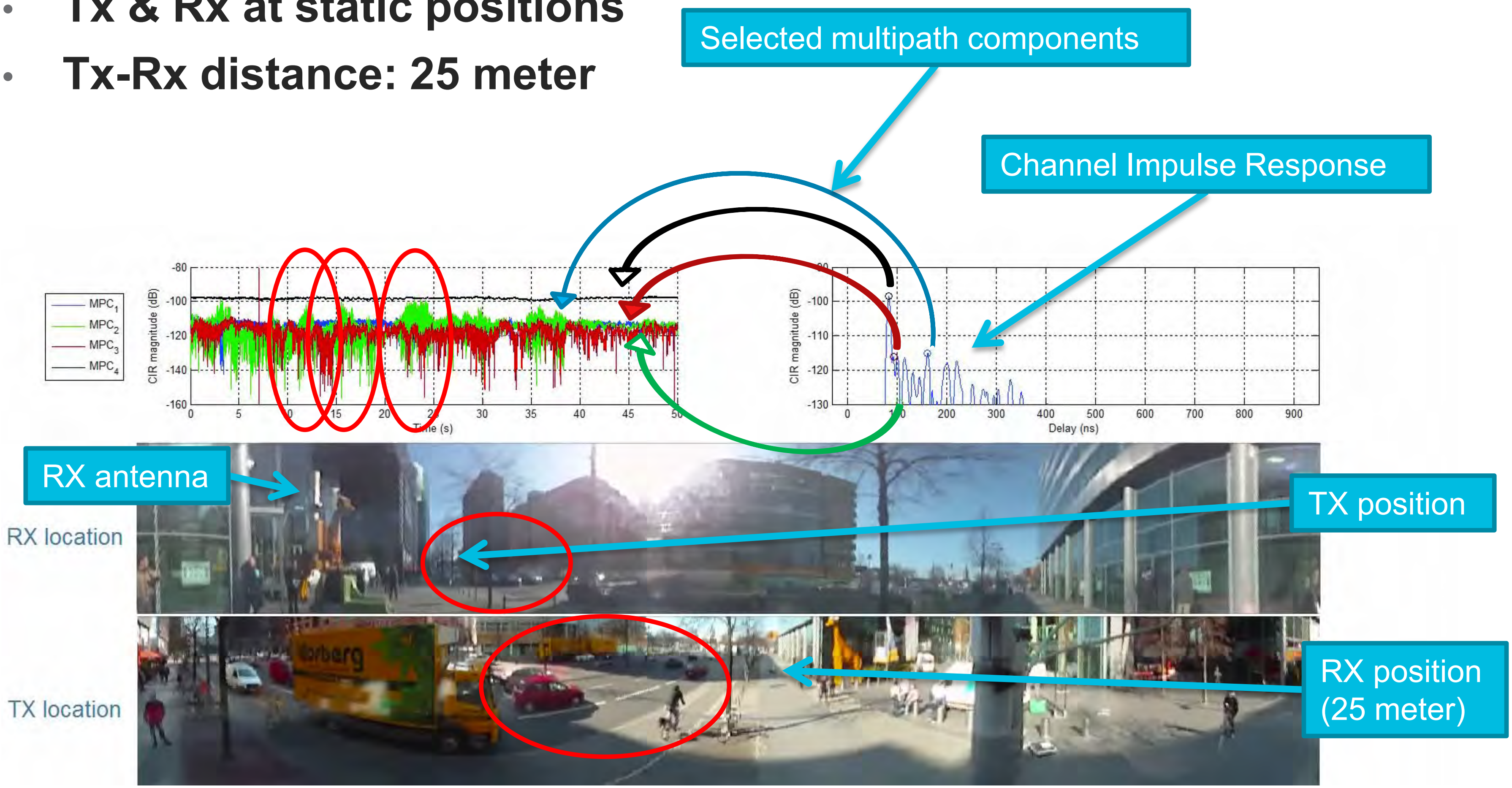






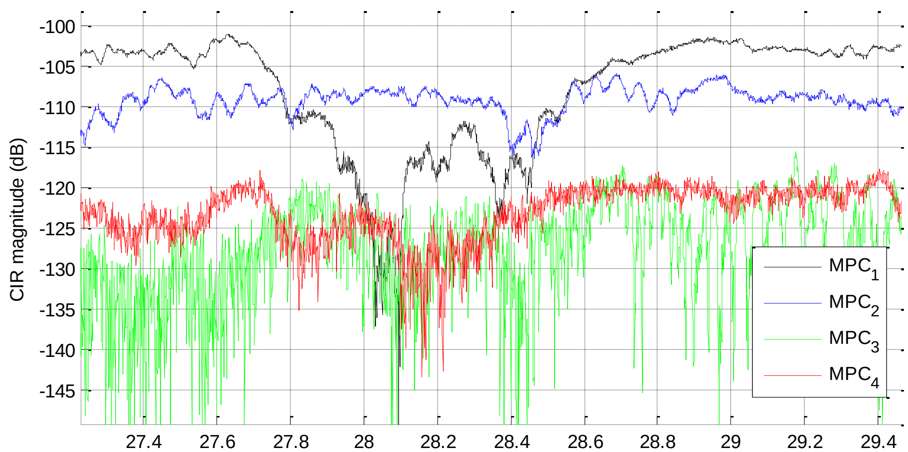
Outdoor Measurements – Results (I)

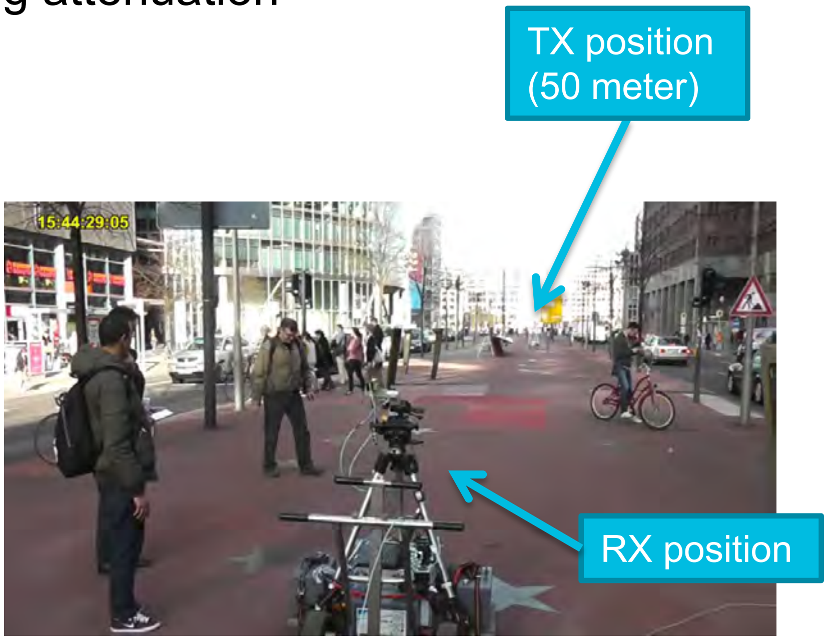
- **Tx & Rx at static positions**
- **Tx-Rx distance: 25 meter**



Human Body Shadowing – Results (II)

Shadowing of line of sight path (MPC1) as expected [3]
Other multi path components (MPC) exist that are **not blocked**
Antenna **beam switching** would avoid strong attenuation

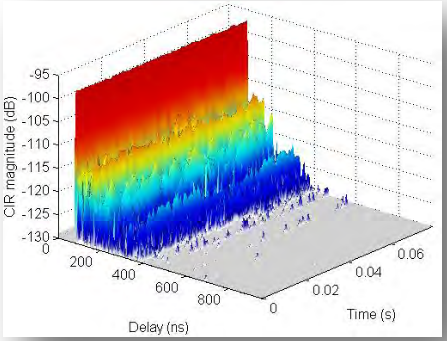


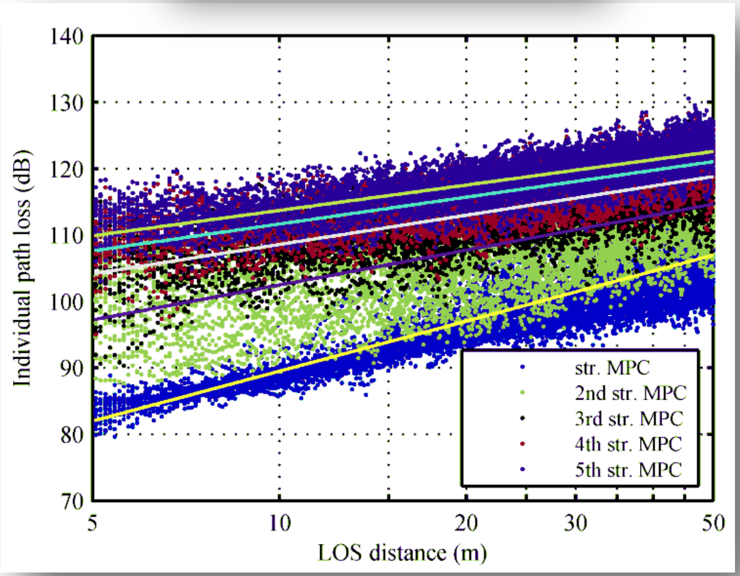


[3] *Analyzing Human Body Shadowing at 60 GHz: Systematic Wideband MIMO Measurements and Modeling Approaches*, M.Peter, M.Wisotzki, M.Raceala-Motoc, W.Keusgen, R.Felbecker, M.Jacob, S.Priebe, T. Kürner, EUCAP 2012, Prague

Street Canyon Measurements – Results (III)

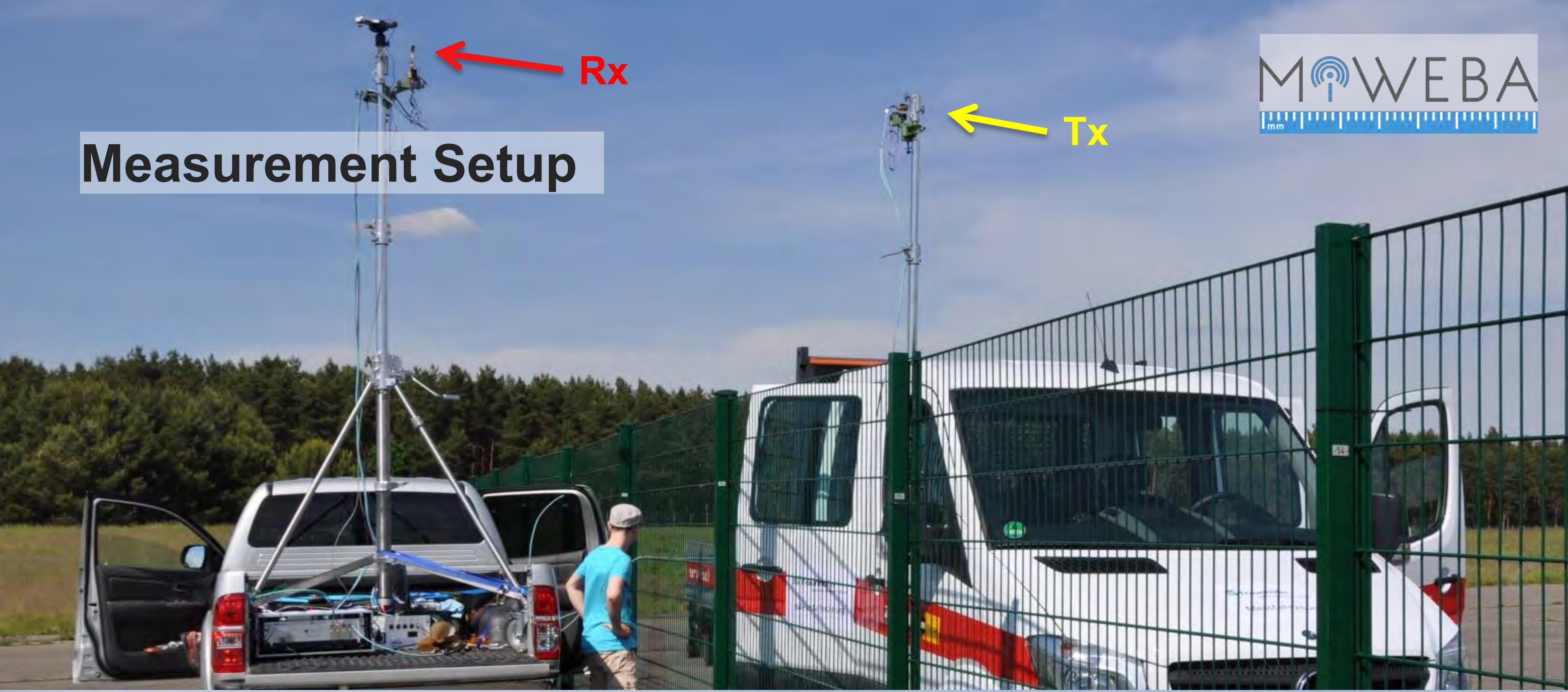
- **Highly time variant (except LOS path)**
- **Distinctive number of Multi Path Components (MPC)**
  - MPC are resolved in time domain
  - No spatial resolution of MPC (fading may occur)
- **Long multipath delays can be observed (300 ns or even longer)**





Outdoor Measurements @ former Airport

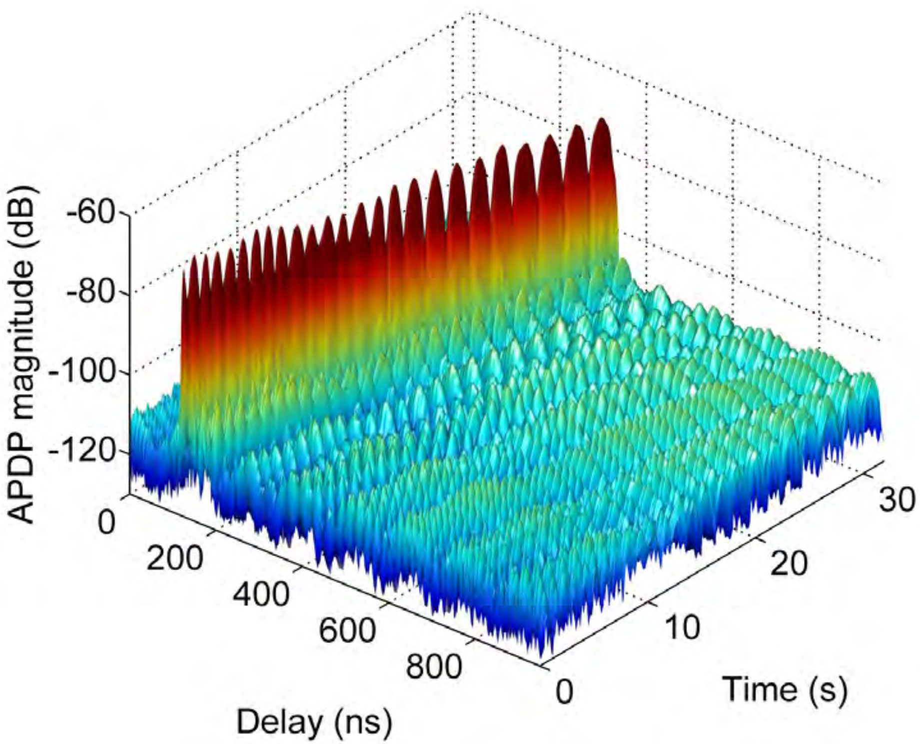
Measurement Setup



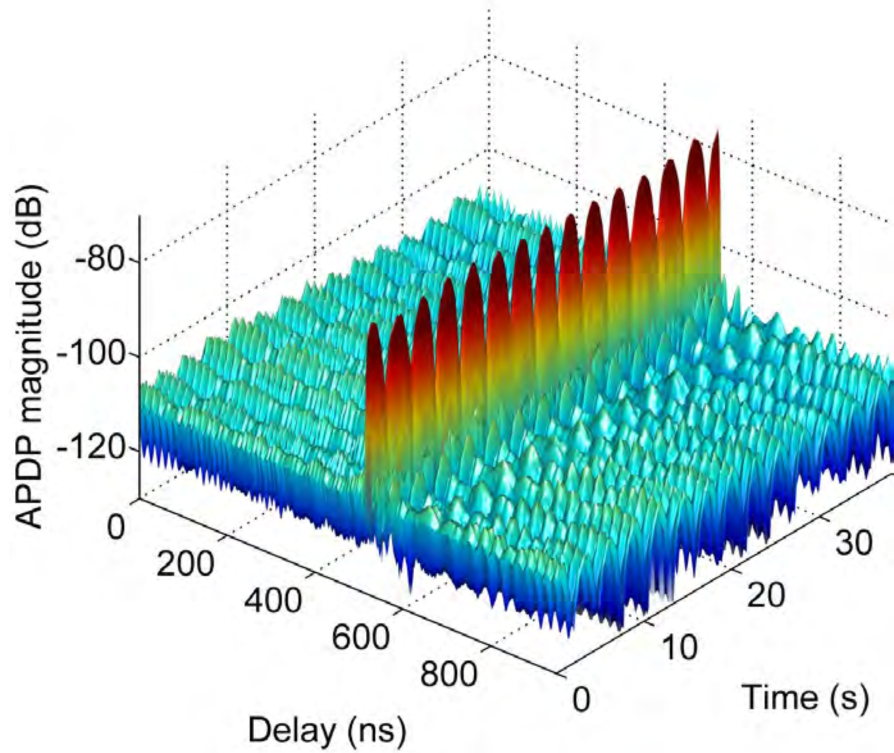
Measurement on runway

Measurement on grasland

Airfield Measurement Results



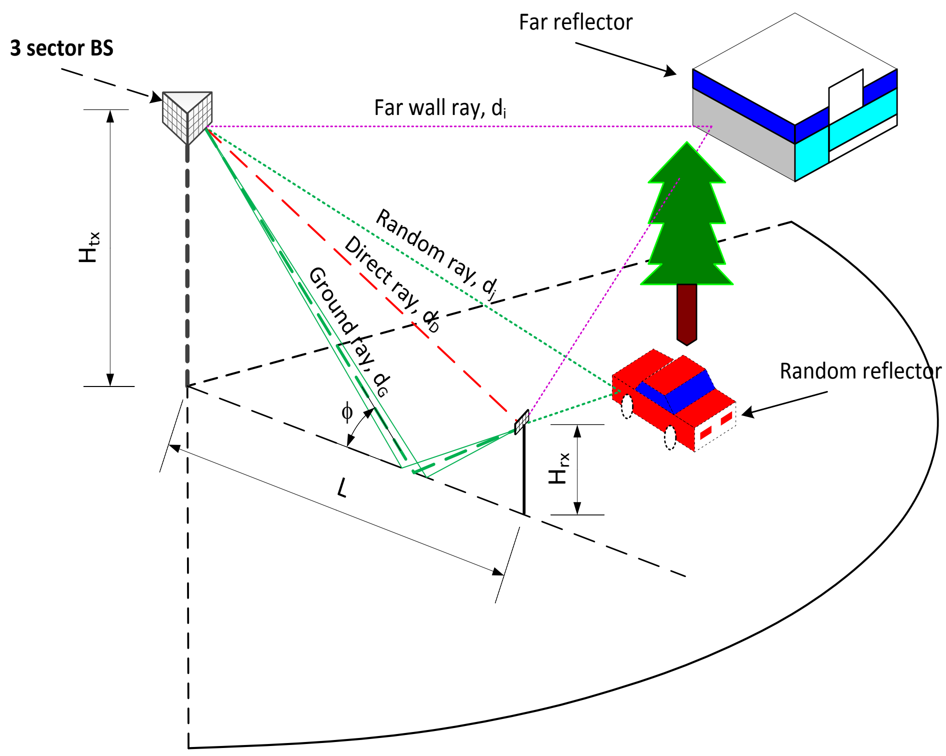
Moving Rx (100–160 m) on runway



Height Variation Rx (220 m) on runway

Quasi-Deterministic (Q-D) Channel Model

Methodology for D-Rays and R-Rays



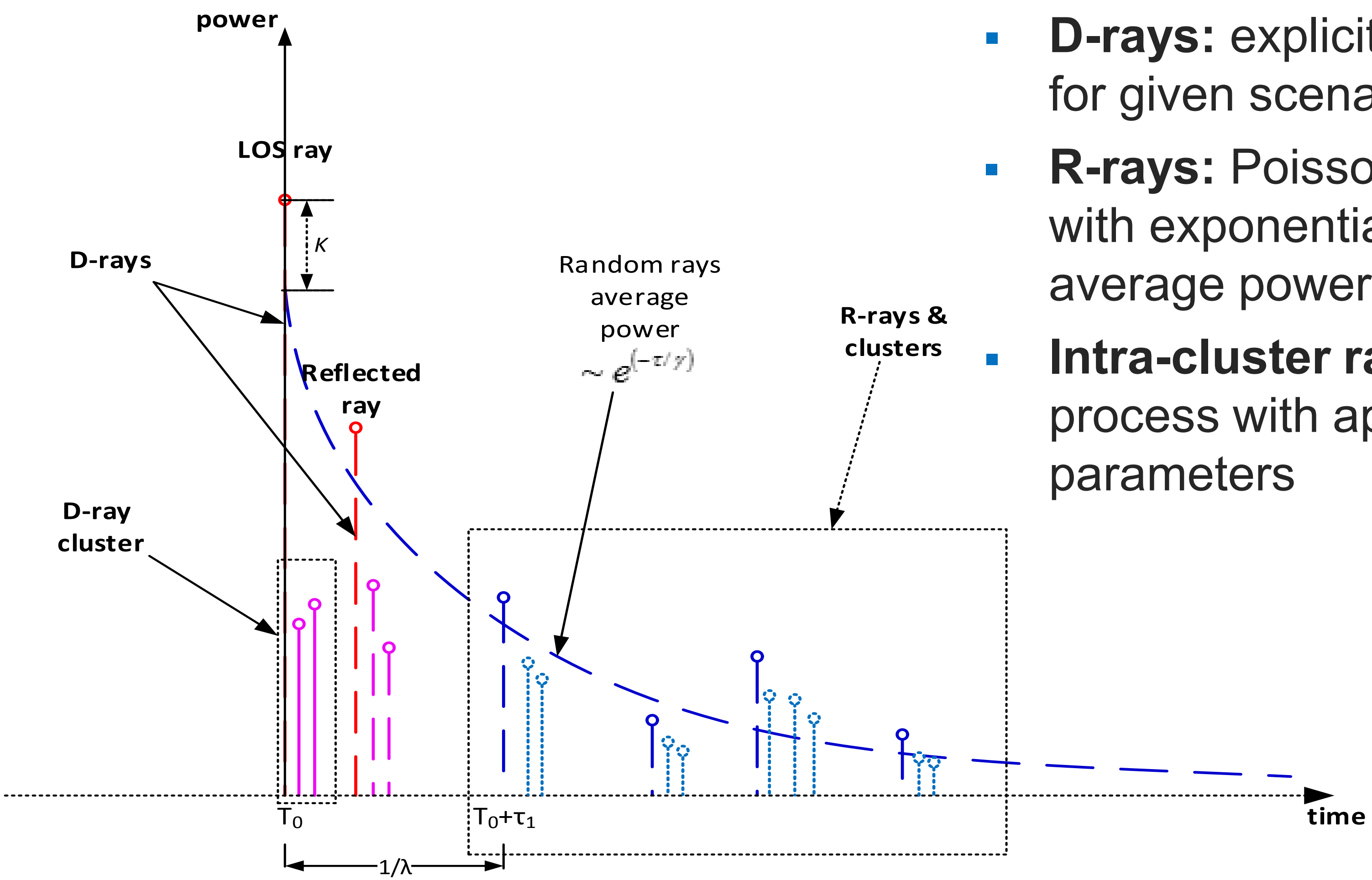
D-rays:

- Direct ray and strong reflections (e.g. ground reflection)
- Given by free space loss, reflection coefficient, polarization, and mobility effects (Doppler shift and user displacement)

R-rays

- Far-away reflections
- Defined by PDP, angular and polarization characteristics according to scenario-specific probability distributions

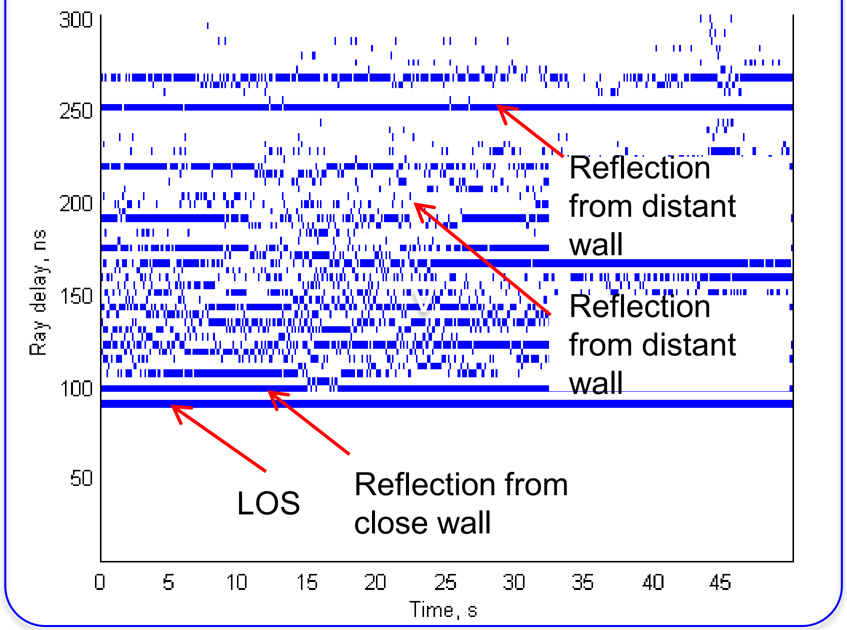
Channel Impulse Response Structure

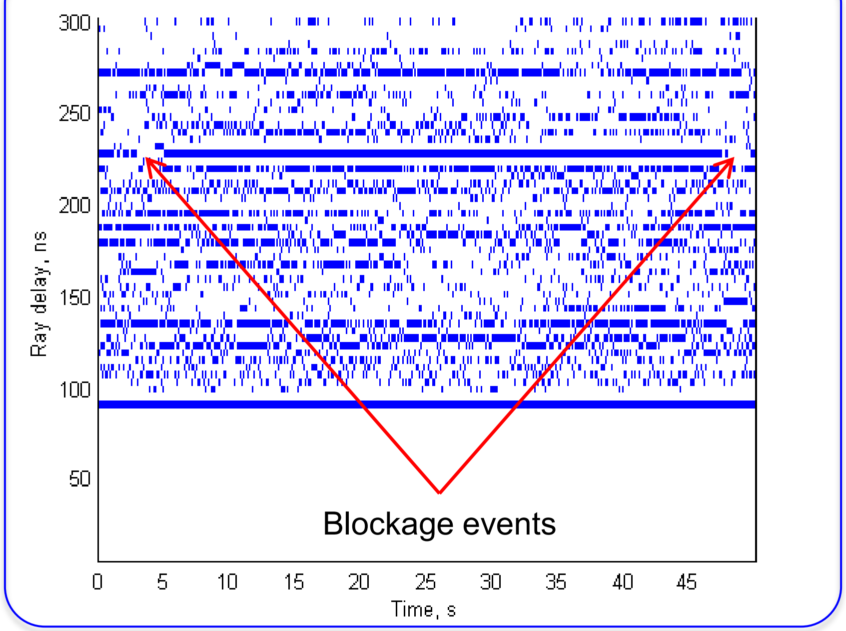


- **D-rays:** explicitly calculated for given scenario
- **R-rays:** Poisson process with exponentially decaying average power
- **Intra-cluster rays:** Poisson process with appropriate parameters

Blockage and Time Variance

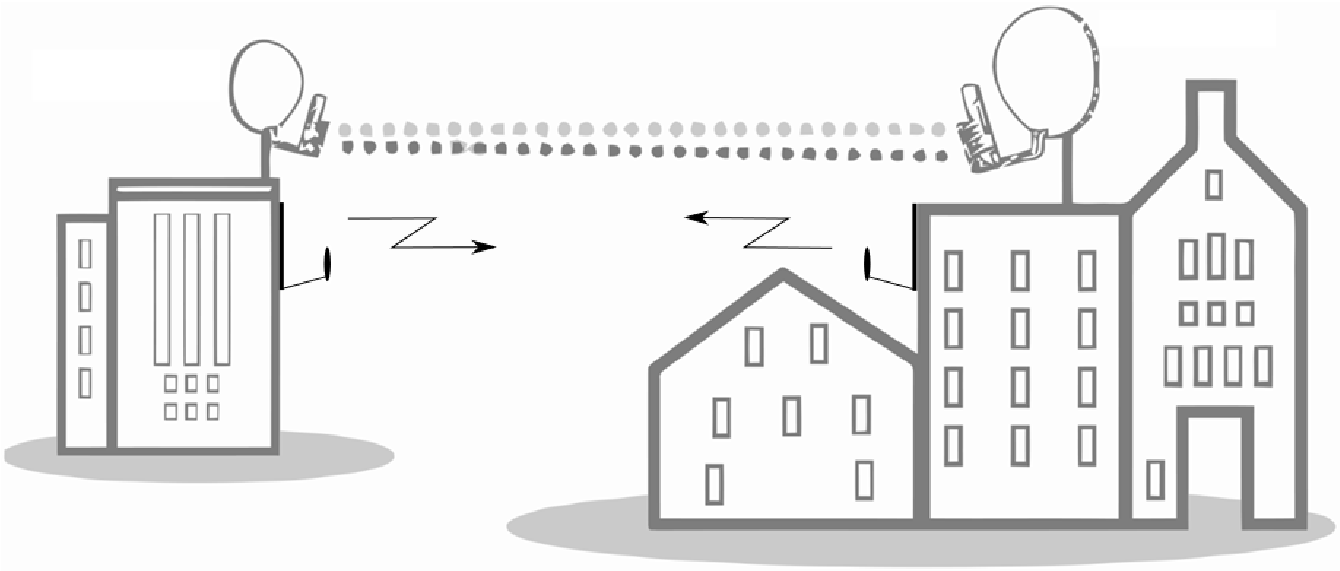
- Propagation paths are subject to blockage by persons, vehicles, trees etc.
- Further: appearance of new rays for a short time: reflections from passing vehicles, persons and smaller objects
- Analysis of several static measurements in the street canyon environment
- Peaks identified by simple threshold rule and plotted as ray bitmap diagram





Millimeter Wave Antenna Design

mmW Antennas for Back- and Fronthaul (1)

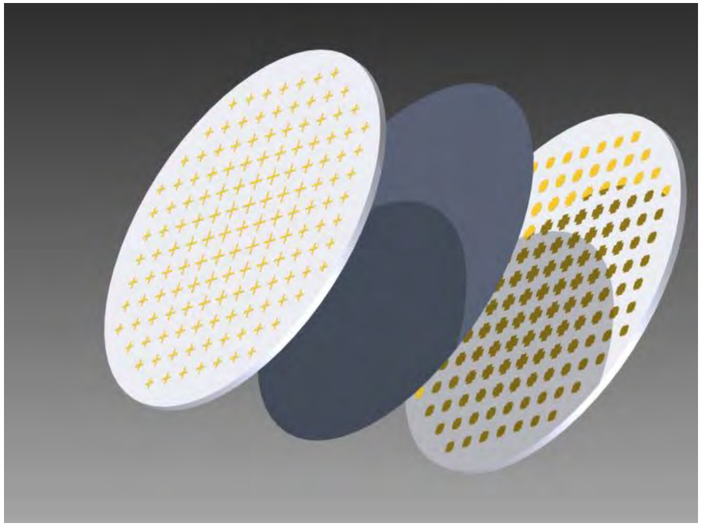


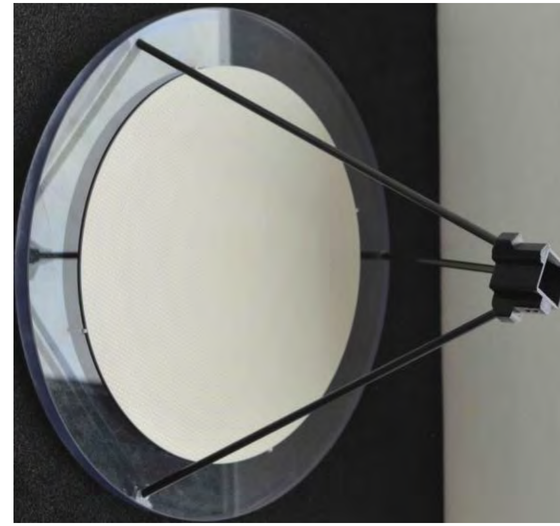
•SOTA: LOS links at huge bandwidth using parabolic antennas

•Due to shape → heavy and not easy to hide in street view

•Solution Approach: remodel parabolic lense effect using simple PCB reflector arrays → flat, light, variable size, low cost at high quantities

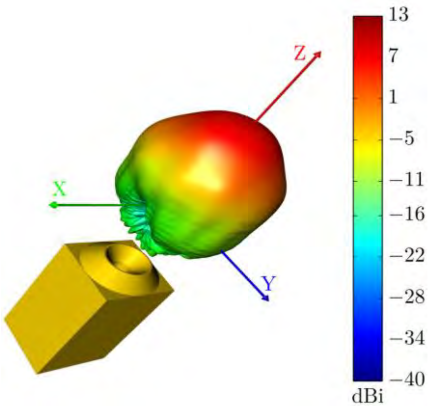
mmW Antennas for Back- and Fronthaul (2)

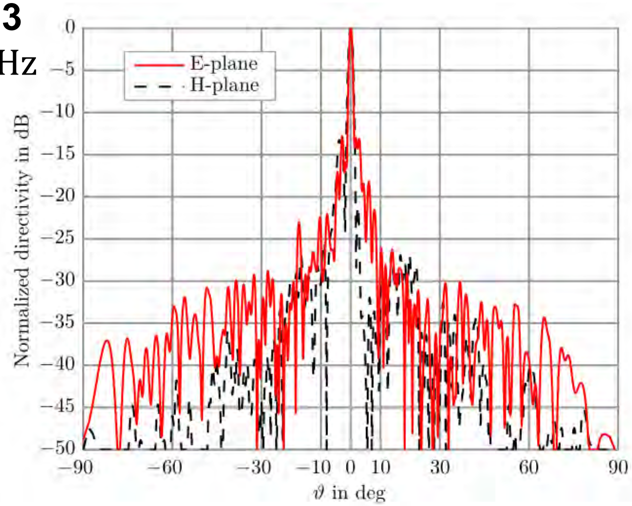


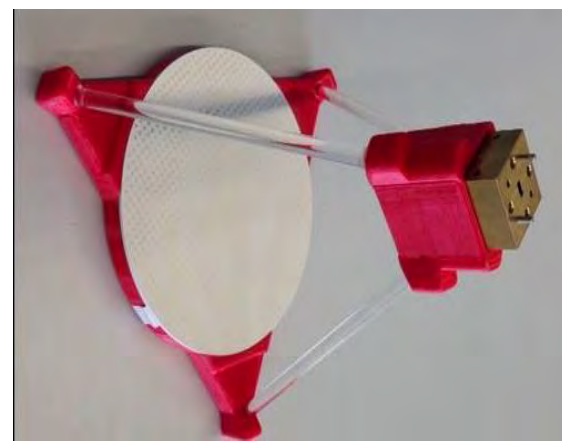


RF-material: Rogers RO3003

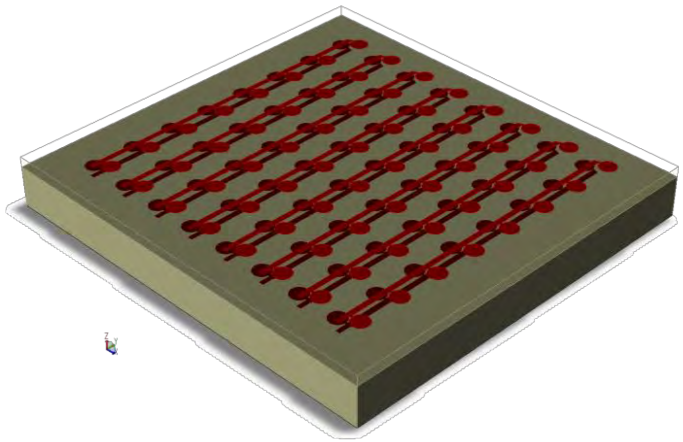
$\varepsilon_r = 3, \tan\delta = 0.0013$ @ 10 GHz



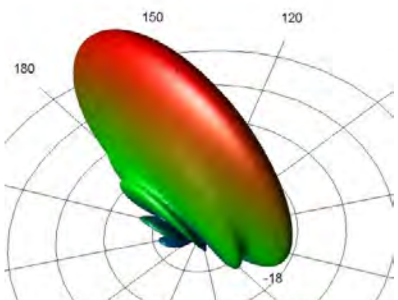




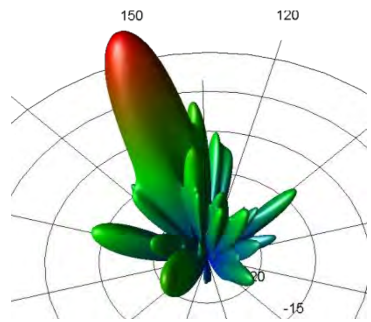
mmW Adaptive Antenna Arrays (3)



60 GHz Active Antenna Array 8x8



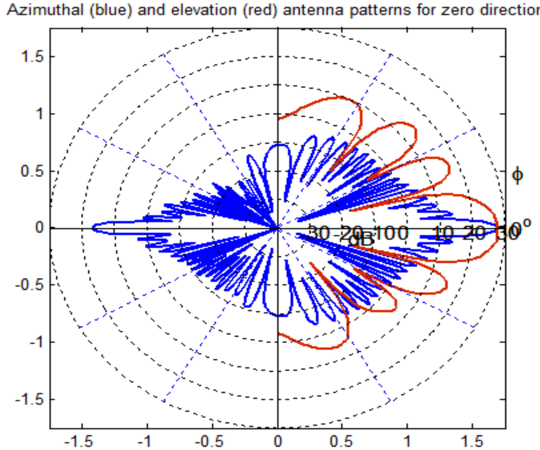
Beamforming pattern single column



Beamforming pattern with 8 active columns

- mm-wave modular array antenna
- 24dBi gain by 8x32 elements

Azimuthal (blue) and elevation (red) antenna patterns for zero direction



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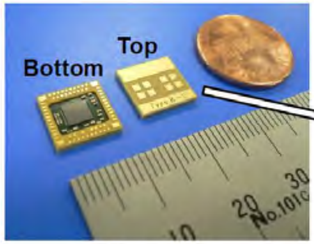
MiWEBA Prototypes

Hardware & Prototypes

mm-Wave chips for UE

- CMOS transceiver for WiGig
- 1.8Gbps at MAC throughtput
- Power consumption less than 1W



RF module

System board

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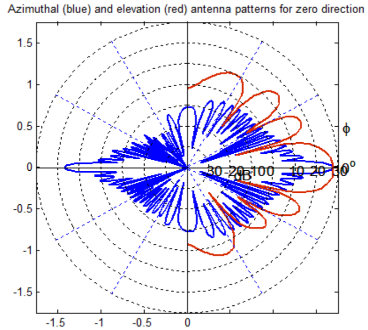
mm-Wave Arrays for BS

- mm-wave modular array antenna
- 24dBi gain by 8x32 elements



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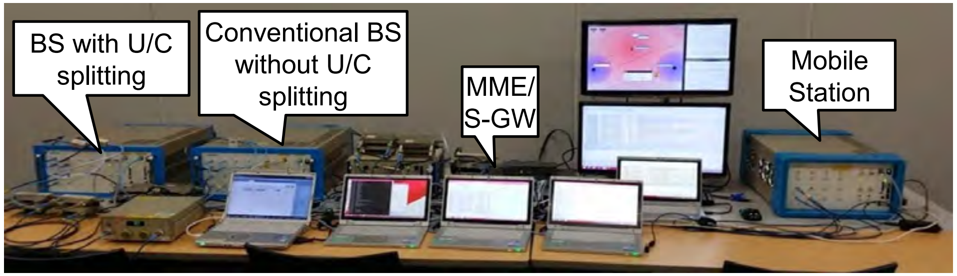
Hardware prototype for U/C splitting

- Hardware prototype for U/C splitting by using Master eNB routing
- Seamless handover between 2GHz macro & 3.5GHz small-cell BSs



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Lessons learned

Huge potential of millimeter-waves

- Provide higher data rates
- Reduce energy per bit on link level

New quasi-deterministic channel model developed

- Based on measurements & ray tracing

Heterogeneous network challenges

- Network management/reconfiguration
- Reduce energy consumption
- Enhance user experience

MiWEBA Team

Osaka, Japan, Oct. 2013

Thank you

www.miweba.eu

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