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

Demand for wireless bandwidth today exceeds network capabilities

- Smart Device Proliferation
- Video Traffic Growth
- Growth of Mobile Data
- OTT Invasion
- Spectrum Crunch
Rich Requirements for 5G

- **High traffic**
  - Office

- **High density**
  - Subway
  - Stadium

- **High mobility**
  - High-speed Train
  - Freeway

**Mobile Internet services**
- UHD Video Streaming
- Cloud Storage
- Augmented Reality
- Online education

**Internet of Thing**
- ITS
- Environment protection
- Remote medicine
- Modern Agriculture
- Smart Home
The 5G Vision

- 1ms latency
- 10 Gbps
- 1000 x capacity
- 10x longer battery life
- Very high data rate
- Very dense crowds of users
- Great service in a crowd
- Ubiquitous things communicating
- Very low energy, cost, and massive number of devices
- 100 x higher number of devices
- Mobility
- Best experience follows you
- Super real-time and reliable connections

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October 8th, 2014
5G Radio Technologies

Network Densification

Spectrum Extension

Spectral Efficiency

Advanced Antennas

Interference Management

Offload and D2D
5G Public Private Partnership in Europe

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

The 5G Infrastructure Public Private Partnership
How to increase Capacity?

- **Spectral Efficiency**: Factor 5
- **Spectrum Extension**: Factor 2
- **Network Densification**: Factor 10
- **Offload**: Factor 2

Overall Gain: 200
Achieving 10,000x above 6 GHz?

- **Performance in Capacity/m²**
  - Current Performance
  - Offload
  - Network Densification
  - Spectral Efficiency
  - Spectrum Extension

- **Spectral Efficiency**
  - MIMO COMP 64 QAM
  - Carrier Aggregation
  - New Carrier Type

- **Spectrum Extension**
  - Relay HetNet Small Cells

- **Network Densification**
  - WiFi Offload

- **Offload**
  - Factor 2

- **Overall Gain**: 10,000
  - October 8th, 2014

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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)
MiWEBA – The Essentials

- Millimeter-Wave Evolution for Backhaul and Access
- European-Japanese cooperation
Millimeter-wave introduction

- 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

- **2GHz band**
  - **Macro:**
    - Center freq: 2GHz
    - BW: $\rho \times 10$ MHz
    - Tx power: 46 dBm
  - **Small-cell:**
    - Center freq: 2GHz
    - BW: $(1-\rho) \times 10$ MHz
    - Tx power: 24 dBm

### Multi-band

- **3GHz band**
  - **Macro:**
    - Center freq: 2GHz
    - BW: 10 MHz
    - Tx power: 46 dBm
  - **Small-cell:**
    - Center freq: 3.5GHz
    - BW: 100 MHz
    - Tx power: 30 dBm

- **60GHz band**
  - **Macro:**
    - Center freq: 2GHz
    - BW: 10 MHz
    - Tx power: 46 dBm
  - **Small-cell:**
    - Center freq: 60GHz
    - BW: 2.16 GHz
    - Tx power: 10 dBm
### Condition of Analysis

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

<table>
<thead>
<tr>
<th></th>
<th>Macro BS</th>
<th>3G small-cell BS</th>
<th>60G small-cell BS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center freq.</td>
<td>2GHz</td>
<td>3.5GHz</td>
<td>60GHz</td>
</tr>
<tr>
<td>BW</td>
<td>10MHz</td>
<td>100MHz</td>
<td>2.16GHz</td>
</tr>
<tr>
<td>Tx power</td>
<td>46dBm</td>
<td>30dBm</td>
<td>10dBm</td>
</tr>
<tr>
<td>ISD</td>
<td>500m</td>
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<table>
<thead>
<tr>
<th></th>
<th>AME</th>
<th>Traffic</th>
<th>Propagation model</th>
</tr>
</thead>
<tbody>
<tr>
<td>User rate</td>
<td>≤8bps/Hz × BW/coverage area</td>
<td>Present, 5 years later, 10 years later</td>
<td>Distance-dependent PL exponent: 3, Frequency exponent: 2</td>
</tr>
<tr>
<td>Interference model</td>
<td>Fluid model</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

1000 times system rate is achieved by 60GHz in 10 years

60GHz is better than 3GHz in 5 years

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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 communication & 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, ...)

Mobility & traffic of all users are managed via macro BS by user/control plane splitting

1000 times data rate via ultra-broadband small-cell BSs (3.5GLTE, 5GWiFi, 6GWiGig)

Inter connection between small-cell BSs (WiFi/WiGig) and macro BS via enhanced CPRI

Centralized radio resource management via C-RAN for efficient operation of HetNet
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, 60GWiGi 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

Reflected ray

Direct ray

Equal gains of TX antenna pattern

Equal gains of RX antenna pattern
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

Channel Impulse Response

Selected multipath components

RX antenna

TX position

RX location

TX location

RX position (25 meter)
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
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
$\varepsilon_r = 3, \tan \delta = 0.0013 \ @ \ 10 \, \text{GHz}$
mmW Adaptive Antenna Arrays (3)

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

60 GHz Active Antenna Array 8x8

- Beamforming pattern single column
- Beamforming pattern with 8 active columns

@ Intel
MiWEBA Prototypes
Hardware & Prototypes

**mm-Wave chips for UE**
- CMOS transceiver for WiGig
- 1.8Gbps at MAC throughput
- Power consumption less than 1W

**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
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
Thank you

www.miweba.eu

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