Radio Technologies for 5G Using Advanced Photonic Infrastructure for Dense User Environments

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Radio Technologies for 5G using an Advanced Photonic Infrastructure for Dense User Environments

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www.rapid5G.eu

Photonic-Based 5G technology
- MMW/MW heterogeneous cell
- WDM-based C-RoF
  - Wireless resource control
  - Beam forming
  - SDM/MIMO
- Field trials in stadium & mall

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RAPID’s Vision

Optimization of resources allocation by dynamic physical layer connection between central station and RAUs

60GHz wider band for HD/3D video downloading

-> Save resources for legacy system (3G/LTE/WiFi)

Realization of efficient use and security by IEEE802.11ai

Trials under stadia, trains, aircraft investigated in the example of the densely user situation

Simulation will predict availabilities for large number of terminals

Optical networking with WDM

Spot service by directive MMW antenna

3G/LTE/WiFi

MMW (60GHz)

Densely located users

MMW transceiver

Low cost device HetNet

RAU

Remote Access Unit

Internet

Local server

Central Station

Optical backbone

RAU

: HD/3D video terminal

: Web, low resolution video streaming

: Remote Access Unit

5G

A Europe-Japan Cooperation
RAPID’s Heterogeneous WDM-CRoF Network Architecture

optical WDM-CRoF access network for connecting cells
Participants of RAPID

**European Participants**

<table>
<thead>
<tr>
<th>Participant No *</th>
<th>Participant organisation name</th>
<th>Country</th>
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<tbody>
<tr>
<td>E1 (Coordinator)</td>
<td>Universität Duisburg-Essen</td>
<td>Germany</td>
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<tr>
<td>E2</td>
<td>University of Kent</td>
<td>United Kingdom</td>
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<td>E3</td>
<td>Corning Corporation</td>
<td>Germany</td>
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<td>E4</td>
<td>Siklu Inc.</td>
<td>Israel</td>
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<td>E5</td>
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<td>Poland</td>
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**Japanese Participants**

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<td>J1 (Japanese Coordinator)</td>
<td>Osaka University</td>
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<td>J2</td>
<td>Doshisha University</td>
<td>Japan</td>
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<td>J3</td>
<td>Electronic Navigation Research Institute</td>
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<td>J4</td>
<td>Hitachi Limited</td>
<td>Japan</td>
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<td>J5</td>
<td>Central Research Institute of Electric Power Industry</td>
<td>Japan</td>
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<td>J6</td>
<td>Koden Techno info</td>
<td>Japan</td>
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RAPID’s Consortium at a Glance

System Layers
- Security
- Protocol/Channel
- Network
- Cable/Link
- Module/Device
- Material/Process

Technology
- MW/MMW
- Photonic

RAPID Consortium
- KODEN
- KENT
- EXATEL
- CRIEPI
- ENRI
- Corning
- Siklu
- HITACHI
- Doshisha
- UDE
- OSAKA
Technical Topics in RAPID

- **MMW/Photonic device & sub-system**
  - 60GHz radio transceiver with high SNR MMW signal
  - Steerable 60GHz antenna technologies
  - 60GHz signal receiver
  - Photonic-based MMW signal generation/control
  - Optical-Electrical conversion/SNR analysis

- **System & Life-cycle test**
  - Photonic-based MMW distribution network
  - Mobile terminal localization
  - MMW experiments in fields
60GHz radio transceiver with high SNR MMW signal
Schematic set-up for interfacing the transceiver with a WDM-PON network

System architecture of RoF-based wireless link

AWG: Arrayed waveguide grating (for WDM MUX and DEMUX)

DSO: digital sampling oscillator, AWG: Arbitrary waveform generator
Measured results

- IQ wireless data transmission was conducted achieving a spectral efficiency of:
  1. ~ 9 bit/s/Hz (9.8 Gbit/s over 1 GHz signal bandwidth)
  2. 6 bit/s/Hz (21 Gbit/s over 3.5 GHz signal bandwidth)

- 64 QAM signal achieving 6 bit/s/Hz in spectral efficiency
- EVM = 11.57% which translates to a BER < 2 x 10^{-6}
Measured results

Steerable 60 GHz antenna technologies
Beam-forming using an array-antenna based EO modulator

Direct EO conversion on antenna

- Laser
- EO material substrate
- Modulation electrode
- Optical waveguide
- Optical signal
- mmW signal
60-GHz band beam-forming using an EO modulator

\[ f_m = 57.3 \text{ GHz} \]
Beam steering SIW leaky-wave antenna

Direct feed from PD

Compact and low cost PCB based antenna structure

High directivity and beam steering experimentally
Lens assisted beam switching RFIC

Dimensions: 20mm x 40mm

32 radiating elements

mm-wave lens

LTCC with radiating elements

Main RFIC

Secondary RFIC for testing

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Lens assisted beam switching RFIC

Graph: Horizontal beam steering action

- Lens-A, H-pol, 61G
- Lens-E, H-pol, 61G
- Lens-F, H-pol, 61G
- Lens-B, H-pol, 61G
- Lens-H, H-pol, 61G
- Lens-G, H-pol, 61G

Gain (dBi)

Angle (degree)
Photonic-based MMW signal generation/control
60 GHz signal generation using photonic two-tone

MMW data transmission experiment
using array-antenna electrode EO modulator

QPSK signal: SR~500 MHz

OBPF: Optical Bandpass Filter
LD: Laser Diode
SG: Signal Generator
LNM: LiNbO3 Modulator
PC: Polarization Controller
EDFA: Erbium Doped Fiber Amplifier
PD: Photodiode
SA: Spectrum Analyzer
(B) 60GHz signal from PD with optical 2-tone input

Symbol Rate: 250 MHz
Frequency: 58 GHz
EVM: 6.0%

(C) Transmitted 60GHz-band signal (after LW-MMW signal reconversion)

Symbol Rate: 250 MHz
Frequency: 58 GHz
EVM: 15.8%
Terminal Localization
Processing of radio signal in optical domain

• Mobile terminal location using time domain difference of arrival (TDOA) method
• Method estimates distance using hyperbolic curve calculation

[Diagram showing TDOA method with hyperbolic curves for RAU 1, RAU 2, and RAU 3, and time differences T1, T2, T3, and T3-T1.]
Processing of radio signal in optical domain

• Using a distributed antenna system has following advantages:
  – Distribution loss is low
  – TDOA measurement accuracy is very high
  – Position of mobile terminal can be calculated before handshake
• Simulation of position error distribution is shown below
  • Here 4 RAUs were used having a distance of 30m
Preparation for demonstration in dense user environments
1st Demonstration at GAMBA OSAKA stadium

Friendship agreement between Osaka University and GAMBA Osaka football company realizes our 1st demonstration at densely environment
Experimental set-up

MMW transceiver & controller
Transceiver installed at cat-walk
Looking down on the seat from the cat-walk
Transceiver and spectrum analyzer
Transceiver Set-up at Cat-walk of Stadium

User down-link experience: > 800Mbps
Signal intensity distribution at Stadium seat

Antenna profile and seat configuration affect signal intensity

Relatively less signal intensity was observed at lower seat

Contour Plot

3D Contour Plot

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Dense area with low mobility – shopping districts

- Finalization of testbed (mall) selection
  - Stary Browar (Poznań)
  - Blue City (Warszawa)
Conclusion

- RAPID for centralized 5G radio access network
  - Fusion of advanced photonic & MMW technologies
    - MMIC / Beam forming / E-O&O-E conversion
    - MMW wireless front-end
  - WDM C-RoF based heterogeneous network

- 11 EU & Japan partners
  - Developing key technologies with good collaboration

- Field trials
  - Big football stadium => Olympic/Paralympic games
  - Shopping center
  - Aircraft, Train etc.
Thank you for your kind attention.