mmWave 5G and Beyond

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Contents

• Self introduction
• Millimeter-wave (mmWave) 5G
• Beyond 5G
Self Introduction

• Current job
  – Tokyo Institute of Technology, Professor
  – Fraunhofer Heinrich-Herz-Institute, Consultant

• Research contributions
  – Contributions to 4G LTE about MIMO-OFDM
  – Contributions to 5G about mmWave HetNet

• Press releases
  – 2012, Cheating detection in exam using smart phone
  – 2014, Ubiquitous indoor environment using WPT
  – 2018, Birth of (pre-) 5G in PyeongChang Olympic
Question 1

Will 5G service start in 2020?

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Question 1

Will 5G service start in 2020?
History of Cellular Networks

- **2G**
  - Voice call
  - SMS
  - GSM/PDC
  - GMSK/π/4-QPSK

- **3G**
  - International
  - Mobile internet
  - Wi-Fi hotspot
  - 3GPP Rel.99
  - WCDMA

- **4G**
  - 3GPP Rel.8 (LTE)
  - MIMO-OFDM

- **5G**
  - Video chat
  - Cloud storage
  - GPS navigation

May 2, 2018
Requirement in 5G (IMT2020)

- Three applications of 5G selected in ITU-R: Enhanced MBB, Massive MTC (IoT), Ultra-Reliable LLC
- Key capabilities to realize eMBB: >10Gbps peak user rate, >1000x system rate, energy efficiency
- Key capabilities to realize URLLC: <1ms latency, >99.99% reliability

3 Key Use Cases of 5G
- Enhanced Mobile Broadband
  - Gigabytes in a second
- Massive Machine Type Communications
- Ultra-reliable and Low Latency Communications
- Smart City
- Voice
- Work and play in the cloud
- 3D video, UHD screens
- Industry automation
- Augmented reality
- Mission critical application, e.g. e-health
- Self Driving Car

8 Key Capabilities (KPIs) of 5G
- Peak Data Rate
- Area Traffic Capacity
- Network Energy Efficiency
- Spectrum Efficiency
- Ultra-reliable and low latency communications
- Latency
- Mobility
- Connection Density
- High Importance
- User Experienced Data Rate

@ Recommendation of ITU-R M.2083-0, Sep. 2015
5G Plan in T-Mobile
3GPP TSG RAN1 Meeting
ITU-R & 3GPP Roadmap for 5G

We are here!
First 5G service in Japan

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ITU-R standardization</td>
<td>Requirements</td>
<td>Call for proposals</td>
<td>Standardization</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3GPP standardization</td>
<td>Channel model SI</td>
<td>Requirements SI</td>
<td>Technology SI</td>
<td>WIs</td>
<td>WIs</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **2014**: ITU-R standardization
- **2015**: 5G system development
- **2016**: First 5G service in Japan
- **2017**: 5G service launch
- **2018**: 5G+ service launch
- **2019**: WRC19
- **2020**: WRC15
Question 2

Does mmWave improve data rate?
Does mmWave improve data rate?
Frequency & Data Rate

Channel capacity

Upper bound of data rate

\[ C = B \log_2 (1 + \gamma) \text{ [bps]} \]

- \( B \) : Bandwidth [Hz]
- \( \gamma = \frac{P_r}{P_n} \) : Receive SNR

Bandwidth & center frequency

Limitation due to spectrum allocation and RF circuits

\[ B = \alpha f_0 \]

- \( f_0 \) : Center frequency [Hz]
- \( \alpha \) : Relative bandwidth

Spectrum allocation in Japan

- 300MHz～3GHz
- 3GHz～30GHz
- 30GHz～300GHz

Bandwidth (data rate) is proportional to center frequency \( B = \alpha f_0 \)
Frequency & Coverage

Friis formula

Propagation loss in free space

\[ P_r = \left( \frac{c}{4\pi d^2 f_0^2} \right) G_r G_t P_t \ [W] \]

- \( P_t \): Tx (transmit) power [W]
- \( G_t, G_r \): Tx/Rx antenna gain
- \( c \): Velocity of light [m/s]
- \( d \): Distance [m]

Coverage is inversely proportional to center frequency

\[ d_0 = \frac{\beta}{f_0} \]
User Experienced Data Rate

- Use experienced data rate

Channel capacity considering multiple access

\[ C_{\text{UE}} = \frac{B \log_2 (1+\gamma)}{N_{\text{UE}}} \quad \text{[bps/user]} \]

\[ N_{\text{UE}} = \pi d_0^2 \eta \quad : \# \text{ of users} \]

\[ \eta \quad : \text{User density [UEs/m}^2\text{]} \]

Substitute \( B = \alpha f_0, \quad d_0 = \frac{\beta}{f_0} \)

\[ C_{\text{UE}} = O \left( f_0^3 \right) \quad \text{[bps/user]} \quad \rightarrow \quad \text{Era of high frequency & small cell} \]
New IMT Bands

- Frequency bands identified by ITU-R (International Telecommunication Union) for International Mobile Telecommunications (IMT)

**Before WRC-15**

450 – 470 MHz, 698 – 960 MHz, 1710 – 2025 MHz, 2100 – 2200 MHz, 2300 – 2400 MHz, 2500 – 2690 MHz, 3400 – 3600 GHz

**In WRC-15**

mmWave frequency bands are identified for candidates of IMT bands

1427 – 1518 GHz band is additionally identified

**In WRC-19**

Frequency bands above 24.25 GHz will be selected from the candidates
Question 3

Did Sakaguchi contribute to 5G?

- [ ] Yes
- [x] No
Did Sakaguchi contribute to 5G?
World 5G Activities

5G-Infrastructure Public Private Partnership Association.

ITU-R WP5D.
M.2320 [Future Technology], Oct. 2014.
M.2083 [IMT.Vision], June 2015.
M.2376 [IMT.Above 6GHz], June 2015.

METIS, EU, Nov. 2012.
Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society

3rd Generation Partnership Project.
Rel. 14, 2016.
Rel. 15, 2018.

The Brooklyn 5G Summit, USA, April 2014.

IMT-2020 (5G) Promotion Group

MiWEBA, EU & Japan, June. 2013.
Millimeter-Wave Evolution for Backhaul and Access.


2020 and Beyond AdHoc.

5GMF, Japan, Sep. 2014.
The Fifth Generation Mobile Communications Promotion Forum.
MiWEBA 5G Architecture

- Millimeter-wave small-cell BSs to realize 1000x gain on system rate
- C/U splitting and C-RAN architecture to realize efficient RRM for small-cells

- Mobility & traffic of all users are managed via macro BS by Control/User plane splitting
- Inter connection between small-cell BSs and macro BS via next generation CPRI
- Centralized radio resource management via C-RAN for efficient operation of HetNet
- 1000 times data rate via mmWave small-cell BSs (e.g. 60GHz 11ay, 28GHz NR)
• System rate increases against # of small-cell BSs in high traffic scenarios
• 1000 times system rate is achieved by 30x 60G small-cell BSs in 10 years
• Performance of 60G small-cell BSs is better than that with 3G small-cell BSs
Contributions to 3GPP & ITU-R

2012
• Proposed the concept of mmWave overlay HetNet for 5G

2013
• Project started

2014
• Contribution to 3GPP RAN2 about C/U splitting
• Contribution to ESTI ORI about CPRI compression
• Contribution to 3GPP RAN2 about LTE/WLAN aggregation

2015
• Contribution to ITU-R

2016
• Developed PoC of mmWave overlay HetNet
• Project ended

May 2, 2018
K.S. Roadmap for 5G


M.2320 M.2376 M.2083

ITU-R

IEEE 802.11ay

3GPP Rel. 14 Rel. 15 Rel. 16 Rel. 17

H2020 5GPPP P1 H2020 5GPPP P2

Berlin 5G test-bed

5G-Champion

5G!Pagoda

5G-MiEdge

MIC R&D MiEdge+

MIC R&D for 5G

5GMF

First 5G deployment in Japan

First 5G deployment in Japan

May 2, 2018
Will mmWave come to 5G?
Question 4

Will mmWave come to 5G?
Trend of mmWave in 3GPP & IEEE

- Trend in 3GPP
  - Rel. 15 will finalize NR (phase 1) by June 2018
  - New NR bands include
    - 24.25 – 29.5 GHz
    - 31.8 – 33.4 GHz
    - 37 – 40 GHz

- Trend in IEEE
  - 802.11ad standardized in 2012
  - FCC expanded 60GHz unlicensed band up to 71GHz for 5G
  - Wi-Fi certified WiGig (11ad) from Oct. 2016
  - First commercial 11ad router and smart phone in 2017
PoC of mmWave HetNet

- Integration of mmWave access & backhaul over LTE networks (PDCP split)
- World 1st PoC of LTE/WiGig(Wi-Fi) aggregation with mmWave backhaul
PoC of WiGig Spot in Narita

When you open it, you will find 3 wireless modules inside.
PoC of mmWave GATE in TTech
PoC of mmWave for Vehicle
Will mmWave assist automated driving?
Will mmWave assist automated driving?
Automated Driving

- Automated driving car uses HD (High Definition) dynamic map
- Google car uses LiDAR to measure dynamic map (layer 4)
LiDAR for Perception

- Point cloud measured by laser radar with rotating mirror
- Larger detection range with larger number of laser points
- Egoistic perception using self LiDAR is easily blocked by surrounding vehicles, objects, buildings, etc.

LiDAR (Light Detection And Ranging)  Dynamic MAP measured by LiDAR
Cooperative Perception

• Blocking of egoistic perception due to blocking vehicles
• Cooperative perception using extended sensors over V2V link
• Cooperative perception assists safety (automated) driving

Scenario of cooperative perception

Driving w/wo cooperative perception

Braking Distance

- Moving distance from object detection (by LiDAR) to stop
- Braking distance depends on square of velocity of vehicle
- Higher velocity of vehicle should have larger detection range

Comfortable braking distance

\[ d_{\text{brake}} = 0.039 \frac{v^2}{3.4} \]

Safety Driving Measure

- Required data rate (# of laser points) to ensure safety driving

**Required # of laser points of LiDAR**

\[
N_{\text{req}} = \arg\min N \\
\text{s.t. } \tilde{N}_{\text{coop}} \geq \tilde{N}_{\text{th}} \text{ when } d_{\text{oe}} = 2 \times d_{\text{brake}}
\]

- \(N\): # of laser points of LiDAR
- \(N\): # of reflected laser points (w/wo cooperative perception)
- \(\tilde{N}_{\text{th}}\): threshold for detection

**Required data rate of V2V**

\[
R_{\text{req}} = \frac{B_{\text{laser}} N_{\text{req}}}{T}
\]

- \(B_{\text{laser}}\): bits per laser point
- \(T\): scan period of LiDAR
• Egoistic perception has limitation on safety driving velocity
• Cooperative perception improves safety driving velocity
• > 1 Gbps V2V is required to ensure safety velocity of 70 km/h
HD map for automated driving in real-time

Application
1. Automated driving (car, drone)
2. Road safety service (collision avoidance, etc.)
3. Smart city (navigation, city guide, car parking)

- High rate & low latency V2V2X using mmWave D2D
- Real-time exchange of sensor data between vehicles & RSUs
- Heterogeneous architecture with legacy V2V and V2X
- Integration with other services (road safety service, smart city)
Summary of mmWave 5G

Original 5G KPIs can be achieved by
• 10 Gbps user rate by mmWave access & beamforming
• 1000x system rate by HetNet with C/U splitting
• mmWave spectrum and devices are almost ready for commercialization

Challenges to beyond 5G

Practical deployment and key use case for mmWave 5G
• Joint design of mmWave access & mmWave backhaul
• Combination of mmWave access & mobile edge computing
• mmWave V2V/V2X for safeness of automated driving
Analysis on Energy Efficiency

- Dynamic small-cell BS ON/OFF and cell association based on traffic demand
- Maximization of energy efficiency [bps/W] while maintaining user satisfaction