THz Communications: an overview and challenges
8 November 2019

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Presentation plan

1. THz spectrum usage and properties
2. THz Research Story
3. THz Eco-system
4. THz Uses Cases and Services
5. THz propagation signature in brief
6. THz radio-communication systems
7. Conclusions and perspectives
Terahertz waves are electromagnetic waves whose frequency range from 100 GHz to 10 THz, their wavelengths are between 30 µm and 3 mm.
• Attenuation of THz signals by atmospheric absorption

• THz frequency range involves specific THz applications (see use cases)

• THz band physical properties exhibits limitations (radio coverage) and benefits for spectroscopy/detection
  ✓ H2O absorption
  ✓ molecular finger print in the THz band
  ✓ Get through human skin (cancer detection)
  ✓ coverage enhancements with reflected hypersurfaces [IAC,2018]

Source: [NDR,2016]
1897
First research activities by Rubens in 1897 [RN,1897]

2010
Nobel Prize in Physics attributed to A. Geim & K. Novoselov. Graphene-material enabled EM communications

2014-2020 ++
Graphene and HyperSurfaces applications for integrated communication systems and Internet of Nano Things (IoNT)

1990-2000
Europe: Fraunhofer, CNRS, CEA investigate THz bands

2017-2020
H2020 and other Collaborative projects
THz standardisation

2015 and 2016 : ITU-R SM.2352 Report : deals with applications and technology trends of active services in the frequency range 275-3000 GHz
2019 : WRC’19 agenda 1.15. 275-450 GHz for applications

2008 : IEEE802.15 THz Interest Group (IG THz) creation
2014-2018 : IEEE802.15.3d , PHY layer standard in the THz band , [TU Braunschweig, NICT]. IEEE802.15.3e MAC layer with spatial beam management
2019 : TAG THz : propagation channel modeling, transceiver and receiver design. Assess the Terahertz Technology Gap for micro-scale and nano-scale applications

2018 : ECC Report 282 focuses on W&D bands. Propagation absorption, chanellization (250 MHz)

2019 : Spectrum Horizons Report [FCC_FRO,19] 95 GHz-3THz for active and passive services. License and unlicensed band use

2015 : ETSI GS mWT 002
2017-2018 : 2 Group Report publications focused on 95-450 GHz point-to-point terrestrial communications
The mmWave Coalition

Members
American Certification Body, Inc.
Azbil North America Research and Development, Inc.
Global Foundries, Inc.
Keysight Technologies
Nokia Corporation
Nuvotronics, Inc.
NYU WIRELESS
Qorvo, Inc.
RaySecur
Virginia Diodes, Inc.

NYU Wireless
Future Wireless Technologies: mmWave, THz, & Beyond seminar series, initiated in September 2018 by Pr. Rappaport

DARPA (US Defense Advanced Research Projects Agency) and a consortium of industrials partners are formed the ComSenTer center for research in THz band with US Academia and Universities are the major actors to ComSenTer center
“THz may push 5G to 6G: Terahertz Waves Could Push 5G to 6G. At the Brooklyn 5G summit, experts said terahertz waves could fix some of the problems that may arise with millimeter-wave network.”

**THz enables Macro, Micro and nano-scale** Applications. Unbiquitous connectivity and IoNT

**Massive MIMO:** Higher capacity and Adaptive MIMO for Interference cancellation by considering Graphene materials and integrated solutions

**Devices miniaturization:** Micro and Nano Scale networks
THz Uses Cases and Services

Use cases and services

Drone-based communications
- 2...10 Gbps
  - Outdoor/Stadium - <200m

Kiosk downloading
- 100-1000 Gbps
  - Indoor/Outdoor - <5m

Fixed Wireless Access
- 10 Gbps
  - Outdoor – 100/500m

Inter/intra-chip communication
- 100-1000 Gbps
  - Indoor - <few cms

Backhaul Macro
- 1 Tbps
  - Outdoor - 2km

Backhaul Mesh
- 200 Gbps
  - Outdoor – 200m

Virtual Reality
- 9 to 12 Gbps

Server farm
- 1 Tbps
  - Indoor - <10m

Source: BRAVE uses cases [BRA, 2018]: Focus on frequencies between 90 GHz and 300 GHz (bandwidth: 40-50 GHz for services except Drone-based communications).

Source: IEEE Std. 802.15.3d-2017: Focus on frequencies ranged between 252 GHz and 325 GHz (different bandwidths ranged from 2.16 GHz to 69.12 GHz).
• **Path-loss models** are derived from
  - the modified Friis equation including atmospheric absorption and experimental measurement
  - **Radiative transfer theory**
    ✓ Transmission distance
    ✓ Medium molecular composition, specifically water vapor molecules
  - Measurements have been performed and published in the IEEE 802.15 THZ TAG and Research institutes (Korea University in 2009, ...)
  - Path-loss models in the MIMO context
THz propagation signature in brief

**Propagation models**

- **Multi-path models** are built on:
  - The *ray tracing Modelling* and *multi-cluster model* derived from Saleh Valenzuela & IEEE15.3d models
  - Measurements have been performed using the **TUBS channel sounder** [REP,2017] that are published in the IEEE 802.15 THz TAG

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<thead>
<tr>
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<tbody>
<tr>
<td>LOS</td>
<td>-69.39</td>
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<td>0.00</td>
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<tr>
<td>Reflection</td>
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<td>-101.00</td>
<td>0.40</td>
<td>87.10</td>
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Comparison between measurements and Ray Tracing

Source: [KPH,2019]
• Experimental measurements: an illustration

  ▪ Determination of power loss coefficients in indoor environment
    • Office environment: small office, large office and conference room
    • Corridor environment: 88m (university) and 48 m (building office)

  ▪ Investigated band 250-325 GHz
    • Using continuous wave signal at 250, 275, 300 and 325GHz

  ▪ Power Loss coefficients

<table>
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<th>Frequency (GHz)</th>
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<tbody>
<tr>
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<td>20.11</td>
<td>18.97</td>
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<tr>
<td>275</td>
<td>20.02</td>
<td>19.21</td>
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<td>300</td>
<td>20.0</td>
<td>18.93</td>
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<tr>
<td>325</td>
<td>19.80</td>
<td>19.60</td>
</tr>
</tbody>
</table>

Source: Report ITU-R P.2406-1 (05/2019)
THz radio-communication systems

THz signal Generation/detection

Heterodyning techniques

An **electro-optic crystal** receives both a THz beam and an optical probe beam, both of which are polarized.

In the presence of the THz beam, the polarization of the probe beam is rotated by the electro-optic crystal, with the degree of rotation being proportional to the THz field amplitude. The analyzed probe beam is then imaged by the optical camera.

Keysight X-series with measurements up to 1.1 THz
Integrated system using the Graphene

THz radio-communication systems

THz signal Generation/detection

- THz signal Generation/detection

- THz radio-communication systems

- Integrated system using the Graphene
THz radio communication systems

THz Technological Gap

**Metasurfaces**
- Enabled by Nanotechnology
- Additionally supports:
  - Controlled reflection
  - Polarized reflection
  - Absorption

**Reflectarray**
- Supports only:
  - Normal reflection

**Experimental Setup**
- User Location
- Base Station
- Drywall 1
- Drywall 2
- mmWave image

**HyperSurfaces**
- Access point
- Access point with UM-MIMO
- HyperSurfaces or programable metasurfaces

**THz Deployment Issues**

**THz Technological Gap**
This presentation provides an overview of THz communications and promising research challenges for macro, micro and nano scale applications for beyond 5G

- Attention is paid for healthcare, IoNT and Robotics
- Graphene would play a major role in the emerging THz technologies

Orange possibilities and challenges

- Enlarge added values on beyond 5G services with large spectrum availability and Multi-band operation with scalable distance ranges
- THz fingerprint brings advantages (spectrum, attenuation,...)
- Evaluate benefits of meta and hypersurfaces for power efficient deployment topologies
- Telecommunications
- Investigate, access and learn about:
  - THz uses cases supporting several hundred Gps and Link Budget
  - THz propagation measurements
  - Ultra Massive MIMO in THz bands
Thanks!


[BRA,2018] ANR BRAVE project, – “5G wireless Tbps Scenarios and Requirements - v1-1”, D1.0 deliverable


THz Uses Cases and Services

Holographic Imaging and Spatial cognition

Robotics

THz applications beyond 5G

Autonomous car applications

mmWave imaging and communications for Simultaneous Localization And Mapping (SLAM)
THz Uses Cases and Services

Spectroscopy
Graphene enables clock rates in the terahertz range

THz applications beyond 5G

Healthcare applications

THz security

Fig. 4 – Terahertz image of men with hidden knife.
Michelson interferometer to spectrally analyze THz signals

The operational bandwidth of the interferometer is determined by the number \( N \) and height \( h \) of the lamella mirror.

The frequency resolution of a Michelson interferometer is determined by the scanning length of the moveable mirror, and is given by \( \Delta f = c/2L \), where \( c \) is the speed of light in air and \( L \) is the scanning length.
THz radio communication systems

Propagation models

Parameters:
- $P_{Tx} = 0$ dBm
- Target SNR = 5 dB
- 10 GHz bandwidth

Effective communication range:
- Dir + Omni: <2 m
- Dir. + Dir.: <50 m
IEEE802.15.3d PHY layer system based on single carrier and OOK (On Off Keying) modulation and 8 channel bandwidth sizes multiple of IEEE802.11 ad/ay channel size [IEEE15.3d_1,16]

95 MCS to go up to 320 Gbps

<table>
<thead>
<tr>
<th>MCS identifier</th>
<th>bandwidth (GHz)</th>
<th>modulation</th>
<th>FEC rate</th>
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<tr>
<td>0</td>
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<td>BPSK</td>
<td>11/15</td>
</tr>
<tr>
<td>1</td>
<td>2,16</td>
<td>BPSK</td>
<td>14/15</td>
</tr>
<tr>
<td>2</td>
<td>2,16</td>
<td>QPSK</td>
<td>11/15</td>
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<tr>
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<td>QPSK</td>
<td>14/15</td>
</tr>
<tr>
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<td>2,16</td>
<td>8-PSK</td>
<td>11/15</td>
</tr>
<tr>
<td>5</td>
<td>2,16</td>
<td>8-PSK</td>
<td>14/15</td>
</tr>
<tr>
<td>6</td>
<td>2,16</td>
<td>8-APSK</td>
<td>11/15</td>
</tr>
<tr>
<td>7</td>
<td>2,16</td>
<td>8-APSK</td>
<td>14/15</td>
</tr>
<tr>
<td>8</td>
<td>2,16</td>
<td>16QAM</td>
<td>11/15</td>
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<tr>
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<td>2,16</td>
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<tr>
<td>10</td>
<td>2,16</td>
<td>64-QAM</td>
<td>11/15</td>
</tr>
<tr>
<td>11</td>
<td>2,16</td>
<td>64-QAM</td>
<td>14/15</td>
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</table>

Bandwith (GHz)

- 2.160
- 4.320
- 8.640
- 12.960
- 17.280
- 25.920
- 51.840
- 69.120
1. **300 GHz transceiver using MMIC:** 20 Gbit/s ASK signal (300 GHz) at the power amplifier output terminal with waveguide technology and antenna Horn. photonic approach: an uni-travelling-carrier photodiode, from which the output is then radiated over a beam-focusing antenna.

2. **300 GHz transceiver using RTD:** resonant tunneling diode (RTD), 300-GHz carrier signal is modulated as ON and OFF depending on the amplitude of the bias voltage. Receiver, the direct-detection receiver is used.