Terahertz Band for Next-Generation Mobile Communication Systems (TMCS)

https://www.teralinks.eu/

Meeting, Bucharest April, 03-04, 2019

G. Ducournau & al.

TMCS 2015

Partner

Industrial support

UC Davis/DMRC:

(USA)

Partner
TMCS 2015

Terahertz Band for Next-Generation Mobile Communication Systems (TMCS)

Outline

- Scientific background
- Key challenges and potential impact of the project
- Presentation of each partner of the consortium with their specificity and added value
- Main scientific results, dissemination and other output
- Sustainability/Valorisation

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G. Ducournau & al.
- **Scientific background: why THz frequencies?**

  - **Context:** Possible interest for THz?

  “We will use THz carrier frequencies by 2020”, after T. S. Bird, Keynote talk at Asia-Pacific Microwave Conference, Melbourne, Australia, December 2011.

Adapté de [P.J. Winzer; IEEE Proceedings]
- **Scientific background: why THz frequencies?**

  Liens point à point (P2P)

  - 1km
  - 100 Gbit/s

  Réseau local THz

  - 10 m
  - 10...100 Gbit/s

  Quelques 10 cm
  Board to board coms

  Fiber-optic compatible (1.55 µm).

  Alternatives

  « FSO »
  (Free Space optics, 0.4 / 0.78 µm)
  (ex: Intellimax) ~ Gbit/s

  Compete with:

  Backhaul Q & E-band

  ELVA: 10 Gbps / 10 km (clear sky)

  Indoor THz: small cells, frequency re-use.
- **Scientific background: why THz frequencies?**

![Graph showing attenuation vs frequency](image)

**Point to point**

**Major interest in 300 GHz-band:**

- Technologies start to be available
- Link budget is ok for km-range links
- Frequencies not allocated > 275 GHz

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**Reference:**

T. Nagatsuma, G. Ducournau, C.C. Renaud

doi:10.1038/nphoton.2016.65

[Link to website](https://www.teralinks.eu/)

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G. Ducournau & al.
- **A new paradigm at THz frequencies?**

**THz frequencies**: one (big) difference with usual radio waves:

From Shannon theorem: \( C = B \log_2 \left(1 + \frac{S}{N}\right) \)

**RADIO**: Small \( B \), thus high \( S/N \) required/complex modulations

**THz**: Huge \( B \), thus more margin on \( S/N \) (in theory)...

However THz power is often limited

\( \Rightarrow \) **Importance** of amplifiers, as SSPA, Tube, LNAs...

**TERALINKS**

Combine photonics bandwidth \( (B) \) + Tube power \( (S/N) \)
Potential impact of the project: where we want to go within TERALINKS?

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G. Ducournau & al.
- **Potential impact of the project: strong interest for THz datacoms, as a new IEEE standard has been released**

IEEE Standard for High Data Rate Wireless Multi-Media Networks

Amendment 2: 100 Gb/s Wireless Switched Point-to-Point Physical Layer

300 GHz coms... are on the way

Window = 250-320 GHz

=> IEEE 802.15.3d

F.A.Q. (Frequently asked questions)

Do we really need this?

**5G: 10 Gbps per mobile user (expected)**

100 users in a cell => 1 Tbit/s to be aggregated...

So we need THz bands
Presentation of each partner of the consortium with their specificity and added value: system-view of teralinks project

Complementary know-how associated towards THz links
- TERALINKS Tx/Rx in a nutshell

<table>
<thead>
<tr>
<th>Frequency</th>
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<td>up to 1 mW / packaged</td>
</tr>
<tr>
<td>TWT power</td>
<td>Gain &gt; 30 dB</td>
</tr>
<tr>
<td>amplifier</td>
<td>Power: 3-4 W</td>
</tr>
<tr>
<td>Antenna</td>
<td>50 dBi (high gain)</td>
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<td>&gt; 20 dBi, beam-steering</td>
</tr>
<tr>
<td></td>
<td>capable (indoor)</td>
</tr>
<tr>
<td>Receiver (direct)</td>
<td>Zero bias detector</td>
</tr>
<tr>
<td></td>
<td>Schottky ~ 1 kV/W</td>
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<tr>
<td>Rx bandwidth (GHz)</td>
<td>40 GHz, including</td>
</tr>
<tr>
<td></td>
<td>baseband amplifier</td>
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<tr>
<td>Modulation</td>
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<tr>
<td></td>
<td>40 Gbit/s</td>
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<td>Link budget (outdoor)</td>
<td>140 dB (1 km)</td>
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<td>antennas</td>
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Photonics-based
Associated to photodiode (waveguide)
Initial BW: center 240 GHz
Adjusted to 230 GHz

Indoor & outdoor antennas
Indoor: different topologies + beam-adjusting antennas

Under final validation (May, 2019)
At IEMN, on the TERALINKS testbed
- TERALINKS Tx/Rx: progresses in year #2

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**Photodiode linearity**
- TERALINKS Tx/Rx: progresses in year #2

Photodiode integration: final structure to be chosen according to the device final electrical performances

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TERALINKS Tx/Rx: progresses in year #2

- **TWT**

- State-of-the-art TWT targeted for TERALINKS
- Design completed (Band adjusted 220-260 => 210-250 GHz)
  (Still 40 GHz bandwidth, in accordance to targeted data-rate)
- Fab is on-going, slow-wave structure ok, electron-gun
- Risk mitigation: single section of SWS/high gain

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G-band TWT rendering
- **TERALINKS Tx/Rx in a nutshell**

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| Rx bandwidth (GHz) | 40 GHz, including baseband amplifier |
| Modulation  | ASK (real-time)  
              | 40 Gbit/s |
| Link budget (outdoor) | 140 dB (1 km)  
                        | 40 dB with 50 dBi antennas |

Indoor & outdoor antennas

Indoor: different topologies + beam-adjusting antennas

+ Radiation pattern setup (Full 3D) developed during TERALINKS
TERALINKS 3D radiation pattern setup

Operation: 220-350 GHz
50 dB dynamic with 2x25 dBi
Example of measurement of 25 dBi antenna (for indoor links)
Main scientific results, dissemination and other output

Antennas;

Year #1:
240 GHz horns, characterized n 2D for THz links

Normalized Antenna Radiation Pattern at 240 GHz

Year #2:

Risk mitigation we pursued two ways:
“Risk limited designs” to secure links
“Advanced design” to make proof of concepts

Low risk designs
- High gain structures (lens structures)
- Large mirror for long distance link

Advanced structures
- Luneburg lenses fed by near-field probe: enabling beam adjustment
- **Main scientific results, dissemination and other output**

*Antennas;*

Year #2:  
**Low risk designs (final required gain will depend on TWT power)**

- Achievable gains

<chart>
Main scientific results, dissemination and other output

Antennas;

Year #2:
Low risk designs (final required gain will depend on TWT power)
- High gain structures (lens structures or Cassegrain)
  > 35 dBi
- Large mirror for long distance link (> 50 dBi)
Main scientific results, dissemination and other output

Antennas;

Year #2: Advanced structures

- Luneburg lenses fed by near-field probe: enabling beam adjustment

Figure: The design and the fabricated prototype of the 3-layered 3D-printed Luneburg Lens. The lens is fed using a WR-03 waveguide probe.
Main scientific results, dissemination and other output

Antennas;

Year #2:

Advanced structures

- Luneburg lenses fed by near-field probe: enabling beam adjustment

Join work IEMN/QMUL (UK)

To be submitted to journal paper

Figure. Beam-steering demonstration at 245 GHz
- **Main scientific results, dissemination and other output**

Examples of dissemination

- 2018, Q2 (April 2018)
  
  Single channel 100 Gbit/s transmission using III-V UTC-PD photodiodes for future IEEE 802.15.3d wireless links in the 300 GHz band

- 2019 (submitted to IRMMW conference)

  First achievement of 50 Gbit/s 300 GHz link using silicon photonics!

  (Technology from IAB partner ST Micro, joint work IEMN/Univ Nice)

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Several collaborations

**THz source: Collaboration IEMN-UPNA** On the THz source, IEMN and UPNA

**Tube amplifier: Collaboration with USA (TERALINKS AISG)**
Prof. Luhmann, University of California, Davis, supports the project with his research group and state of the art facilities.

**Collaboration IEMN-LU**
On the use of a TWT amplifier towards THz communications, almost no data is actually available on the literature. In TERALINKS, we will get the opportunity to combine the THz modulated signals with the TWT, for the first time, thus we expect strong outcome of the transnational collaboration.

**Collaboration IEMN-Univ Nice-UPNA-QMUL**
In TERALINKS we have collaboratively established a full 3D antenna measurement system, and already used it for first antenna prototypes, at 240 GHz.

**Overall Collaboration of all partners**
The final goal of TERALINKS is to achieve, for the first time, a real-time transmission system combining all technologies delivered by partners. We again consider that this is a strong added value as all sub-system and partner expertise is required for the whole system demonstration.
Within TERALINKS consortium, new connections are currently ongoing for European-level research projects for THz communication developments, all of these enabled projects falls in the H2020 EU program.

We can also mention that a join ANR-DFG project, “TERASONIC”, which investigates the combination of photonics emitters and solid-state receivers has been granted by IEMN partner in 2018.

**EU THOR PROJECT (ICT 2018, H2020) 2018-2021 (IEMN Partner)**

Join initiative between Europe and Japan will enable real implementation of THz communication systems towards future 5G and beyond new network architectures.

**EU ULTRAWAVE PROJECT (ICT 2017, H2020) 2017-2020 (LU PI)**

The ULTRAWAVE project (LU partner involved) is aimed at developing a high capacity backhaul that enables 5G cell densification by exploiting bands beyond 100 GHz.
Dissemination list (8 papers (journal), 15 international conferences)

International publications on scientific journals:


- Last part of the project (-> 2019 Sept.)

The TERALINKS project is working towards the demonstrator of the THz links (in & outdoor)!

**Outdoor:**

- Use of the TWT
- Use of the photodiode to feed the TWT
- Using large antennas (reflectors), we forecast large transmission distance according to the TWT power design. *(never demonstrated yet in the community)*

**Indoor:**

- Use of the « advanced » antennas in data com link *(never demonstrated yet in the community)*

In a nutshell: many challenges!
THANK YOU