Terahertz-based ultra-high bandwidth wireless access networks

terapod

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TERAPOD project newsletter #6

March 2021

Welcome to the final TERAPOD project newsletter!

The end of the TERAPOD project (31-May-2021) is approaching, and the team has been very busy preparing for the final demonstration. In this final newsletter we report on:

- The final online workshop date! See below!!
- A channel sounder video from TU Braunschweig
- New RTD waveguide packaging from INESC and Glasgow
- Advances in simulation of data centre networks at WIT
- The phase distribution chip developed at VLC Photonics
- Two upcoming events on THz comms in Mar-2021
- Three books and planned journal editions on THz comms.

More info is available on the project website www.terapod-project.eu

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TERAPOD final workshop

SAVE THE DATE

TERAPOD will hold its final workshop and live demonstration on WED 26-May-2021. The agenda will be released shortly, which will include live demonstrations of world-beating THz links. Registration is open; please visit the website for more info and to sign up for this free event: https://terapod-project.eu/terapod_events/terapod-final-workshop

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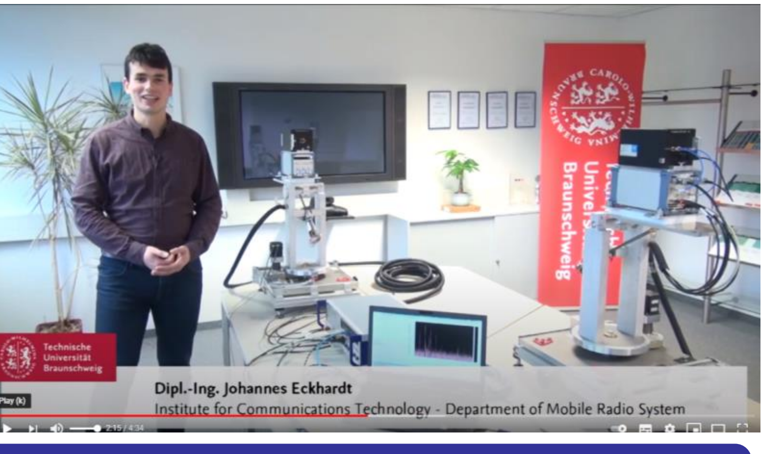
How to: Channel sounding for THz communications

Technische Universität Braunschweig

The propagation of electromagnetic waves at THz frequencies is a topic of study at TU Braunschweig, where a unique in-house channel sounder system has been developed. The team has made a video which describes the equipment and the applications for this special measurement tool:

https://www.youtube.com/watch?v=ouaCkGFkEJ0



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Waterford Institute of Technology · Technische Universität Braunschweig · VIVID Components · VLC Photonics · ACST Technology Solutions for Terahertz Electronics · NPL National Physical Laboratory · DELL EMC · UCL · INESCTEC · University of Glasgow · bay photonics

RTD waveguide package

The diverse properties of indium phosphide (InP) in the optical as well as the electrical domain makes it an ideal material for the realisation of active devices such as lasers and photodiodes, as well as high frequency sources, detectors and amplifiers. The resonant tunneling diodes (RTDs) used in TERAPOD are no exception and also take advantage of an InP-based material. The isotropic etching profile of InP presents design challenges for the implementation of waveguiding structures such as microstrip and grounded co-planar waveguide (CPW), requiring unfeasible thicknesses of the substrate. Therefore, InP based devices often incorporate transitions to effectively couple the high frequency signal into a conventional rectangular waveguide. These transitions are created by incorporating a radiating element at the end of the active device which radiates into a cavity. Such cavities require vertical placement of the InP chip within the waveguide and are more susceptible to mechanical defects in placement.

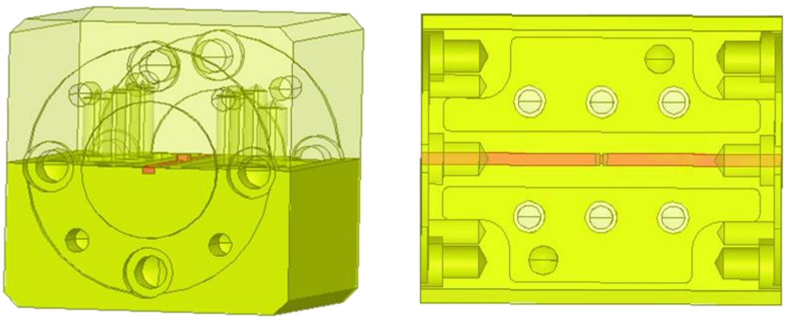

Fig. 1: (Left) 3D view of designed waveguide split block including the transition. (Right) Top view of the waveguide and CPW-to-waveguide transition (in the middle).

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INESC and University of Glasgow have been working on the development of an in-plane waveguide slot which is created at one of the open ends of the rectangular waveguide. The InP chip sits horizontally in the waveguide, thereby avoiding the mechanical instability. The proposed CPW-to-waveguide transition can operate over a bandwidth of 15 GHz (287-303 GHz). Additionally, it is optimised to interface with an RTD produced by the Glasgow team and is suitable for fabrication using split-block machining.

New techniques and models for THz data centre networks

New techniques and models for DC THz data link layer (DLL) have been developed at Waterford Institute of Technology. The advances cover a range of aspects of the DLL:

- Node sectorisation
- Optimised time slot and frame length
- DLL synchronisation
- Node discovery
- MAC techniques based on fixed time allocation and random access using re-transmission
- THz simulator

The data centre THz network is characterised by a regular arrangement of nodes and static links. However, new protocols for THz communication are required to improve data rates and reduce frame loss in a data centre THz network. WIT has shown that it is possible to achieve tens of Gbps of data throughput using sophisticated THz devices and by deploying new communication protocols. Hence, new techniques and models were proposed for data link layers of THz data centre networks including:

1. *Node arrangement and sectorisation:* THz nodes are arranged on top of the data servers (top-of-rack; TOR), and each node can support 4,6 or 8 sectors to establish a wireless link with its neighbours as presented in Figure 2.

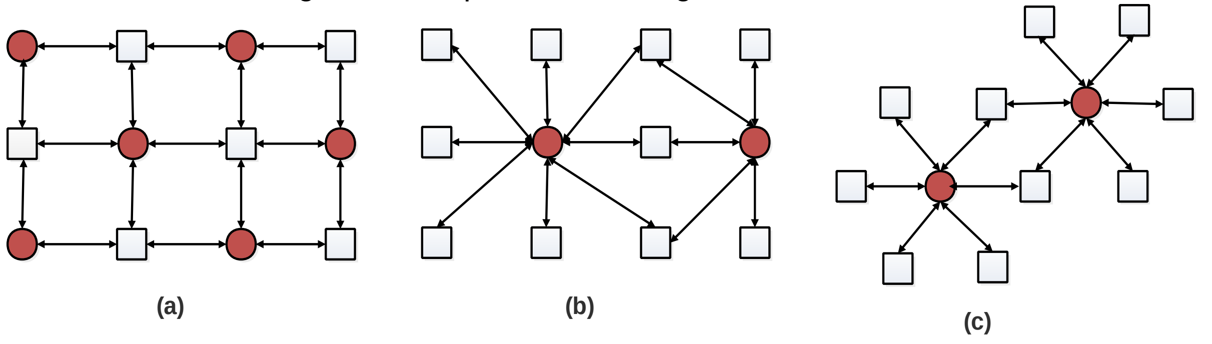

Fig. 2: Node arrangements for (a) four, (b) eight, (c) six sectors per node.

2. *Time slot duration and frame length:* The frame length and time slot duration are optimised based on channel characteristics and the THz device properties to achieve high performance. In the TERAPOD cases studied, it may be shown that it is possible to use a channel duration of 1 µs and a frame length equal to 15000 bits.
3. *Techniques for network synchronisation using beam switching:* Nodes enter synchronisation mode to exchange information related to transmission status and node configuration. This data is captured in small frames and transmitted with short period. For the rectangular TOR layout it was proved that efficient network synchronisation may be reached within a minimum period using an alternating beam switching procedure, with an increase in synchronisation period duration as a function of network size.
4. *Node discovery using beam turning:* Node discovery in the data centre network can be performed in the networking layer as well as the DLL, under the following conditions:
    - Acceptable received power above the sensitivity threshold, which mainly depends on THz device capabilities. The new generation of THz transmitters developed in TERAPOD can transmit with acceptable Tx power.
    - The transmission range within the data centre can reach 10 m, so it is possible to decode frames from new nodes entering the network.
    - Deployment of steerable beams using THz phased array antennas, which tune to optimise link budget. Moreover, it is possible to combine beam switching with beam turning to search for new nodes, by sending discovery frames in all directions.
    - Performance of node discovery techniques using beam turning depends on the network size: discovery time increases as function of network size.
5. *Medium access techniques with and without re-transmission:* A theoretical study of new centralised access techniques under the assumption of node sectorisation and beam switching prove that it is possible to reach high data rates. The theoretical formulation of network data rate for both random and time-based access were presented and evaluated using MATLAB and ns-3 simulation. The data rate achieved by each node

depends on the number of sectors per node, the access technique and whether re-transmission is deployed. Figure 3 shows the results obtained for throughput per sector as a function of channel bit error rate for fixed slot allocation and re-transmission.

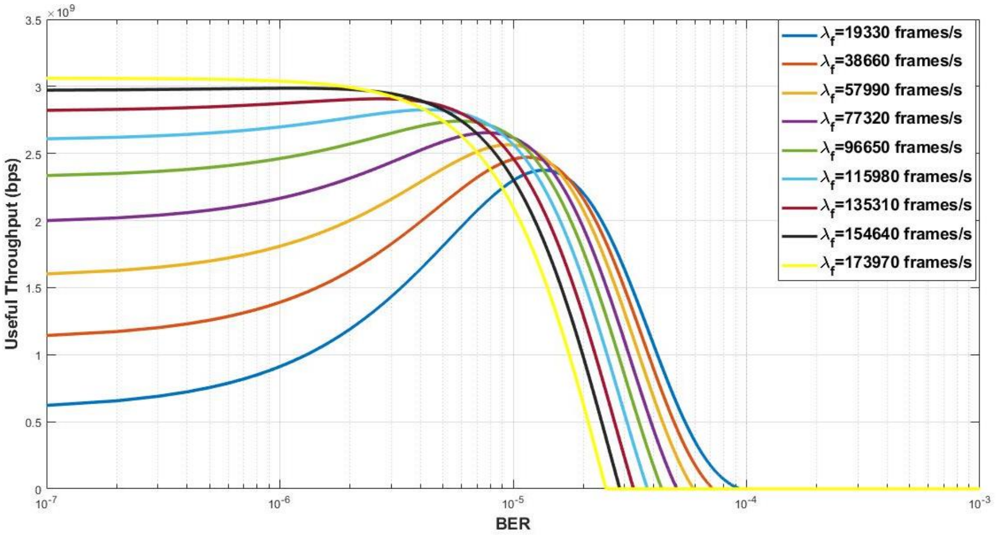

Fig. 3: Graph showing useful throughput per sector as function of channel conditions (BER). (The frame length is fixed to 8000 bits.)

6. *Network delay:* The delay was evaluated for a 5-node network and may be extended for larger networks. Figure 4 depicts the average delay recorded for four access techniques using an ns-3 simulator. For higher packet arrival rates it is possible to achieve 10 ms delay using both frame re-transmission to reduce packet loss and RTS/CTS techniques.

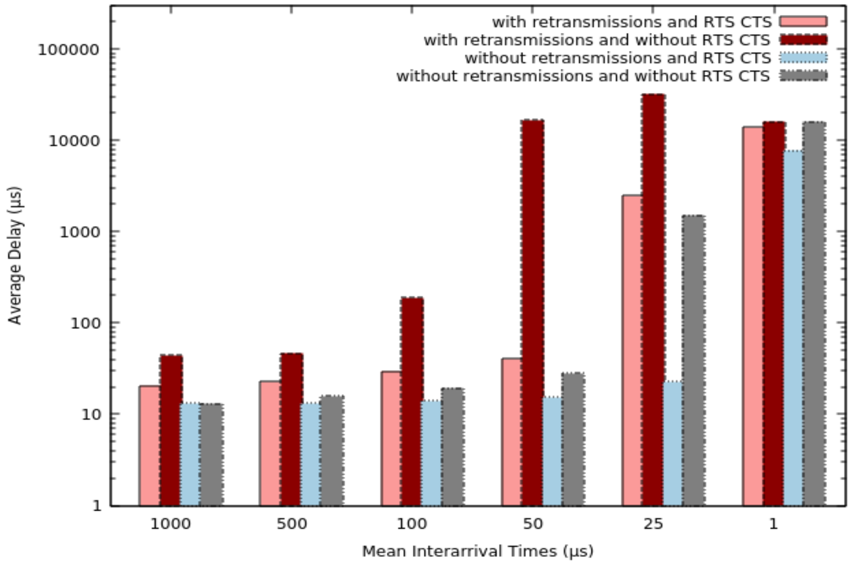

Fig. 4: Average delay in milliseconds as a function of mean inter-arrival time for a 5-node network.

7. *Simulator:* New networking models were designed and integrated in ns-3 to meet TERAPOD requirements in terms of data rate and packet loss. An appropriate simulator architecture was developed within the project based on a wireless data centre scenario.

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TERAPOD phase distribution PIC: From design to characterisation

Exploiting the photonic integration technology for terahertz systems, VLC Photonics has developed a phase distribution photonic integrated circuit to control the input laser light to four different outputs, which will be coupled into an array of four antenna elements developed by UCL and INESC TEC.

The integrated system enables the coherent addition of radiated THz signals in a specific direction while suppressing emission in undesired directions. The design of a phase distribution PIC for 100-300 GHz signals will provide beam steering capabilities for efficient and low power multi-device links.

In order to provide a true-time delay over the broadened spectra of modulated signals, the phase control and delay lines are constructed with cascaded all-pass filters based on ring resonator cavities. The phase distribution PIC was fabricated on the low-loss SiN industrial photonic Damascene process AN800 at the Ligentec foundry. The phase distribution system based on ring resonators is depicted in a GDS representation of the fabricated PIC system design presented in Fig.5.

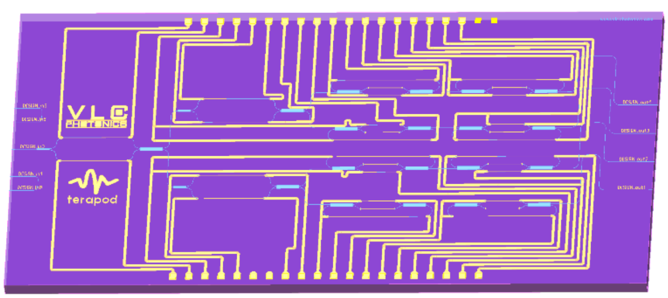
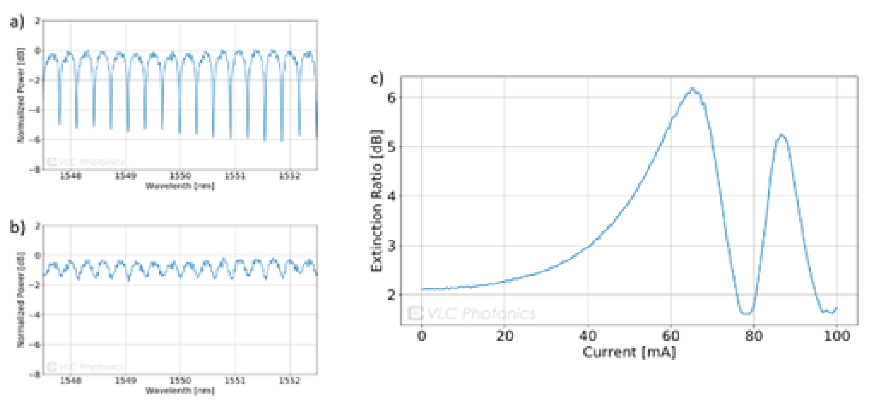


Fig 5 : Layout illustration of the TERAPOD phase distribution PIC. Die area 5×10 mm².

Characterisation of building blocks shows promising performance. The 50:50 multimode interference splitters exhibit an imbalance below 2 % along a bandwidth of 40 nm, presenting excess losses up to 0.3 dB for fundamental quasi-TE mode. The MZIs for power switching operate in a current-bias range of 35 mA (between 30 to 75 mA) to tune the splitting ratio at the outputs. The MZI-based ring resonators have heating elements to control the coupling. The resonance can be varied from over-coupled to critically coupled, achieving a maximum extinction ratio of above 5 dB in critical coupling (at 65 mA) on each ring independently. This corresponds to a phase delay of the sub-THz signal from 0 to 12π rad. The optical spectral response is depicted in Fig. 6. The packaging demonstration of the coherent transmission is ongoing and the optical phase distribution system performance will be measured by NPL/UCL soon.

Fig. 6: Spectral response of a single ring at (a) critical coupling operation and (b) fully coupled, respectively. (c) Extinction ratio by current steps of 1 mA at 1550 nm.



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3rd Towards THz Comms Workshop

12 Mar-2021; online

3TTCW has been moved to an online event, so it will be easy for attendees from all over the world to join. Registration is open and the full agenda is available on the workshop website:

https://terapod-project.eu/terapod_events/3rd-towards-thz-comms-workshop

TERAPOD at EuCAP 2021

22-26 Mar-2021; online

TERAPOD will share an online booth at EuCAP 2021 with ThoR and METERACOM. The projects will also present Scientific Workshop SW03: *Antennas and Propagation Aspects for THz Communications* on FRI 26-Mar-2021 09:00 CET. This will feature technical presentations from each project as well as guest speakers. Registration is open at:

https://www.eucap2021.org

THz communications publications

The growing interest in THz comms is reflected in the fact that there are three different activities to report regarding books and journals on the subject.

ITU J-FET Special Issue on THz Communications

The ITU Journal on Future and Evolving Technologies is planning a Special Issue on THz Communications. The call for papers is open and the submission deadline has been extended to 12-Apr-2021. More info can be found on the dedicated page on the ITU website.

https://www.itu.int/en/journal/j-fet/2021/003/Pages/default.aspx

Applied Sciences Special Issue on THz Communications

Mira Naftaly (NPL, UK) is guest editing a special issue of Applied Sciences on THz Communications, which will also be published as a stand-alone e-book. The submission deadline has been extended to 30-Apr-2021. For more details see:

https://www.mdpi.com/journal/applsci/special_issues/Terahertz_Communications_

Next Generation Wireless Terahertz Communication Networks

Edited By Saim Ghafoor, Mubashir Husain Rehmani, Alan Davy. This new book, including four chapters from TERAPOD authors, is now available online for pre-order and will be shipped in hardcover after Jul-2021.

https://www.routledge.com/Next-Generation-Wireless-Terahertz-Communication-Networks/Ghafoor-Rehmani-Davy/p/book/9780367430726