THz end-to-end wireless systems
supporting ultra-high data Rate applications

ThoR project newsletter #5

March 2021

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Welcome to the fifth ThoR project newsletter!

Despite the COVID-19 restrictions, it has been a busy time for ThoR and for THz communications. In this newsletter we report on:

- 3TTCW and EuCAP 2021: both held online this month
- Automatic planning algorithms for THz comms by TU Braunschweig
- 300 GHz link design and interference study by Waseda University
- Three upcoming books or journals on THz comms
- 300 GHz sold state power amplifier development at Fraunhofer IAF
- Characterisation of ThoR demo modules by University of Stuttgart

More information is available on the project website www.thorproject.eu

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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

ThoR at EuCAP 2021

22-26 Mar-2021; online

ThoR will share an online booth at EuCAP 2021 with TERAPOD 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

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Automatic planning algorithm for 300 GHz wireless backhaul connections

Providing stable communication channels between base stations and the backbone network, known as backhaul links, is an essential requirement to ensure reliable operation of the cellular network. To date, backhaul links using cable, *e.g.* glass fibre, have been widely used and have become a general application concept for backhaul links. However, providing cable connections is time consuming and cost intensive. In some cases, underground cable connections are not feasible due to geographic issues. For this reason, *wireless* backhaul links have arisen as an alternative and can bring economic benefits as well as offering simple and swift installation.

TU Braunschweig has been developing tools for planning wireless backhaul connections, with which links of given a heterogeneous network operating at 300 GHz can be automatically arranged. As shown in Fig. 1, three different types of algorithms are currently available: star LoS (line of sight), ring LoS and star NLoS (non-LoS). An additional algorithm using ring topology with NLoS optical path is under development.

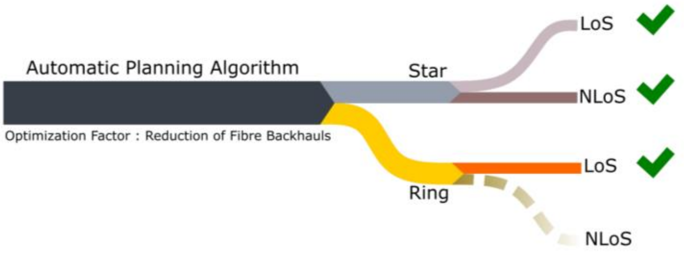

Fig. 1: Networking topologies of automatic planning algorithms.

The algorithms try to find an optimum solution for the backhaul network. The optimisation factor of the developed algorithms is set as the reduction of cable connections, so the optimum solution is a backhaul network with potentially many wireless links instead of fibre connections. The search process for the optimum solution is an NP problem from the operational point of view, which is completed using heuristic searching process with certain random decision phases.

Three available algorithms have been applied on networks in the Hanover area, where high data traffic is foreseen and densely deployed base stations will be required to support the high data traffic. Fig. 2 shows the planning results of wireless backhaul networks in Hanover using different types of networking topologies. The application of various networking topologies is scheduled to be extended further into different cities with distinct development geographies, including metropolitan, urban, suburban and rural.

Fig. 2: Planning results of wireless backhaul network: using star topology considering only LoS links (left), using star topology considering hybrid concept of LoS and NLoS links (middle) and using ring topology considering only LoS links (right).

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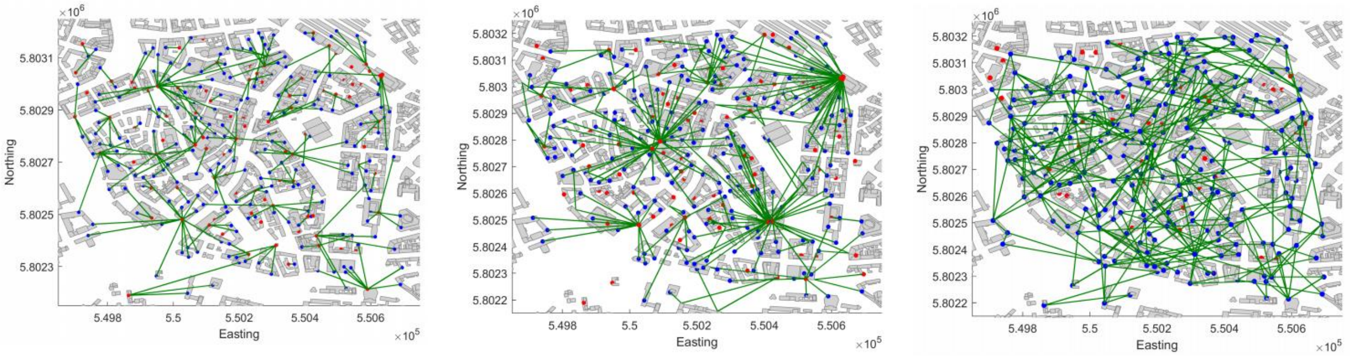

Link design and interference study

The ThoR project aims to offer high-speed THz wireless transmission which can be used for land mobile services (LMS) as well as for fixed services (FS). It will demonstrate a high-speed point-to-point link which will be used for connection between base stations and remote antenna units. Rainfall, fog, and snow effects must be taken into account, for THz radio systems designed for outdoor use. Fig. 3 shows the numerically calculated signal-to-noise ratio (SNR) of 300 GHz THz links, where the antenna gain and transmission power are assumed to be 50 dBi and 20 dBm, respectively [1]. The atmospheric attenuation at 300 GHz is assumed to be 5.24 dB/km. Additional attenuation due to rainfall is also taken into account: attenuations are assumed to be 4.47 dB/km and 8.99 dB/km for 5 mm/h and 50 mm/h rainfalls respectively. The bandwidth (BW) is assumed to be 100 GHz or 2 GHz. The noise level is defined as the thermal noise (-64.00 dBm for 100 GHz BW, and -80.99 dBm for 2 GHz BW). The required SNR for QPSK is approximately equal to 10 dB. Thus, the noise figure (NF) of the total transmission system is assumed to be 15 dB. The expected transmission distance for a 100 Gbps signal whose BW is 100 GHz is 800 m. This is sufficient for FS connecting base stations and remote antenna units in beyond 5G or 6G systems which have many small cells.

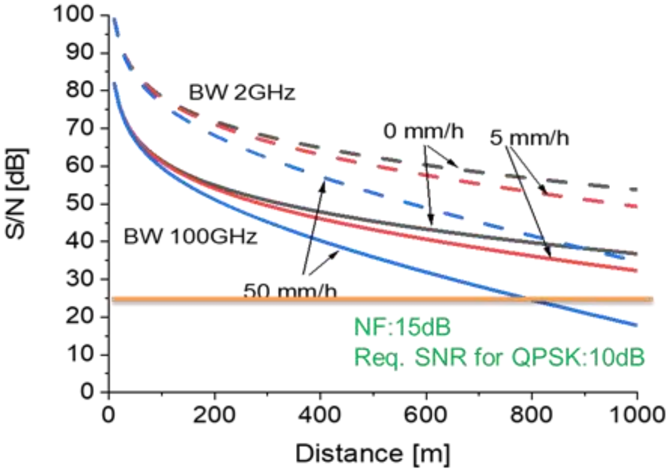

Fig. 3: SNR of 300 GHz radio links. Solid and dashed lines represent 100 GHz and 2 GHz bandwidth links respectively.

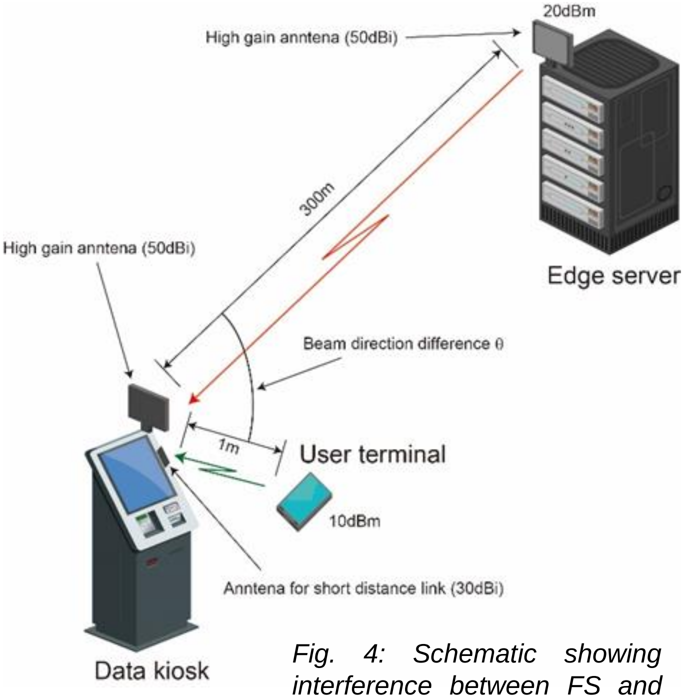

Fig. 4: Schematic showing interference between FS and LMS in the 300 GHz band.

Currently, spectrum congestion is not very significant in THz bands. However, interference studies will become increasingly important even in THz bands, because various types of wireless systems will be available using >100 GHz carriers. Fig. 4 shows a simple interference model between FS and LMS in the 300 GHz band [1]. The short-distance (1 m) LMS between a data kiosk and user terminal would suffer interference from the 300 m FS link from the data kiosk and an edge server. Transmission powers of the LMS and the FS are 10 dBm and 20 dBm respectively. A data kiosk has a 30 dBi antenna for the LMS connecting user terminals.

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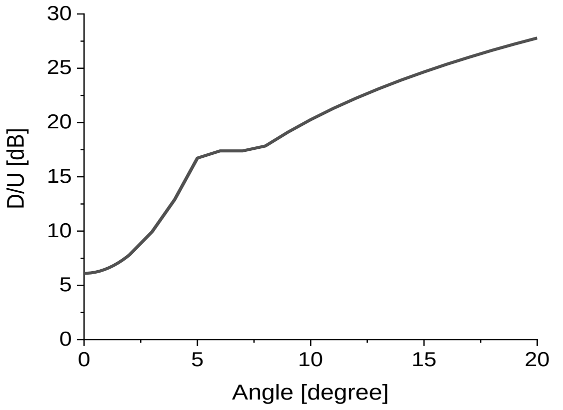

Fig. 5: Desired and undesired signal ratio.

Fig. 5 shows the ratio between desired and undesired signals (D/U) as a function of the main beam direction difference between the LMS and FS signals (θ in Fig. 4). An antenna pattern offered in [2] was used to calculate the interfering signal detected by the antenna for the LMS. The required SNR for 32-QAM is approximately 20 dB. When the direction difference angle is larger than 10°, the interference signal is small enough to ensure the SNR is larger than the required SNR. (Please see [1] for more details.)

[1] Kawanishi, T., Inagaki, K., Kanno, A., Yamamoto, N., Aiba, T., Yasuda, H., & Wakabayashi, T., "Terahertz and photonics seamless short-distance links for future mobile networks," Radio Science **56**, e2020RS007156 (2021). https://doi.org/10.1029/2020RS007156

[2] Recommendation ITU-R F.699-8, "Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to 86 GHz."

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 by ThoR and B5G partners.

THz Communications-Paving the Way Towards Wireless Tbps

Edited by Thomas Kürner, Daniel Mittleman and Tadao Nagatsuma. This new book will appear soon in the Springer Series in Optical Sciences and describes the fundamentals of THz comms, spanning the whole range of applications, propagation and channel models, RF transceiver technology, antennas, baseband techniques, and networking interfaces. It contains numerous chapters written by ThoR partners.

https://www.springer.com/gp/book/9783030737375

Applied Sciences Special Issue on THz Communications

TERAPOD partner Mira Naftaly (NPL, UK) is guest editing a special issue of Applied Sciences on THz comms, which will also be published as an 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_

IEEE Journal on Selected Areas in Communications: Special issue on THz comms and networking

The ThoR Japan Coordinator, Tetsuya Kawanishi (Waseda University), is one of the guest editors on a special issue on "Terahertz Communications and Networking" due Q2 2021. Please keep an eye on the ThoR website for more info soon!

300 GHz solid-state power amplifier development

As a key component of the 300 GHz ThoR front end, solid-state power amplifiers (SSPAs) with more than 10 mW saturated output power have been successfully implemented. The SSPA modules are based on a highly-compact power amplifier MMIC, which is realised in Fraunhofer IAF's 35 nm mHEMT technology and assembled in a split-block packaging technology. Photographs of the developed H-band waveguide module with WR-3.4 waveguide flanges are depicted in Fig. 6. The outer module dimensions are 15×32×35 mm³, excluding the SMB connector for the DC supply. With the integrated power conditioning unit, a single supply voltage in the range of 3.3 to 5 V is sufficient to operate the SSPA, consuming an overall DC power in the range of 1.3 W.

The power amplifier (PA) circuits have been developed in the first two years of the ThoR project and demonstrate an operational bandwidth in excess of 275 to 325 GHz in the assembled waveguide package. More than 20 dB gain and 7 dBm output power performance has been achieved over this 50 GHz bandwidth around 300 GHz; advancing the state-of-the-art of broadband SSPA modules at the lower THz frequency band with a peak output power above 10 dBm around 300 GHz.

A summary on the SSPA results will be published soon as an article in the IEEE Microwave and Wireless Components Letters. Following on from the development of this first generation of SSPAs, Fraunhofer IAF is currently working on 300 GHz amplifier modules where several PA MMICs will be integrated in a single SSPA. This will further increase the achievable output power on waveguide level. To realise a balanced PA topology, WR-3.4 branch-guide couplers have been developed within the ThoR project, which are implemented in the SSPA modules. This next generation of 300 GHz SSPAs should be available in late 2021.

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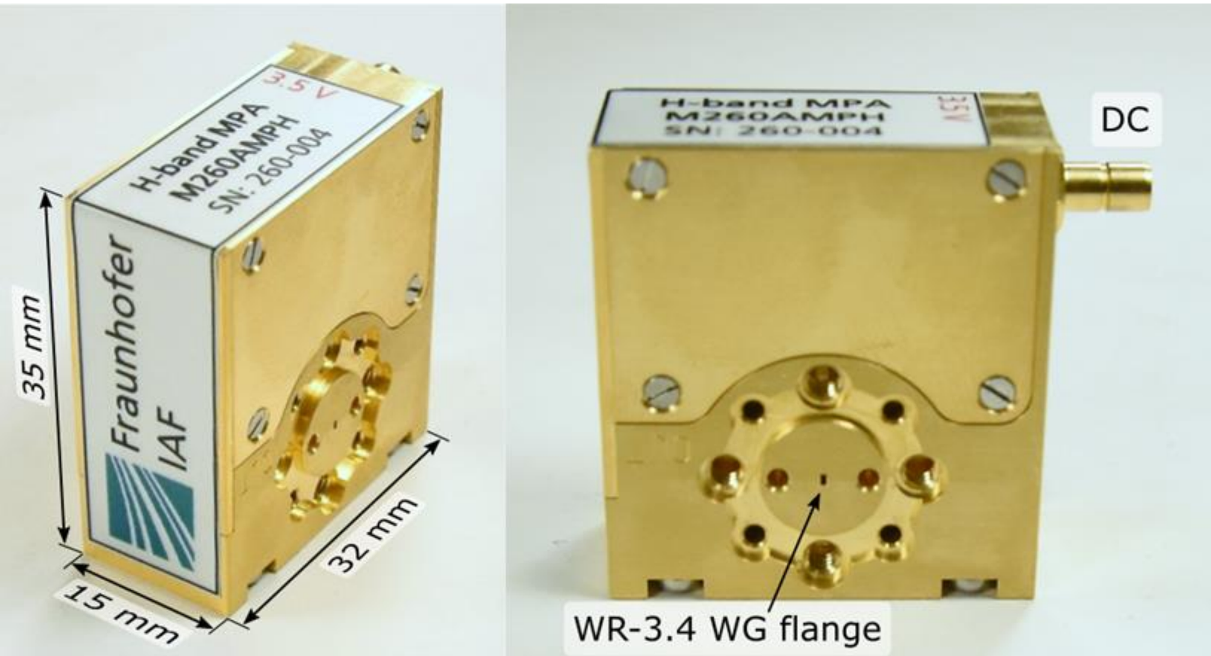


Fig. 6: Photographs of the developed WR-3.4 300 GHz solid-state power amplifier.

Characterisation of H-band transmit and receive modules (DEMO-2-1)

Fully integrated transmit and receive MMICs including a frequency multiplier and a buffer amplifier in the LO path as well as an up-conversion mixer and a power amplifier in the transmitter or a low-noise amplifier (LNA) and down-conversion mixer in the receiver have been fabricated using the 35 nm InGaAs mHEMT technology from Fraunhofer IAF (see pg 5). After basic on-wafer characterisation, the chips with the most promising performance have been chosen for integration into split-block waveguide modules. Using available modules, a consecutive series of demonstration experiments which will be performed by several ThoR partners over the remaining project period was started in Q4 2020.

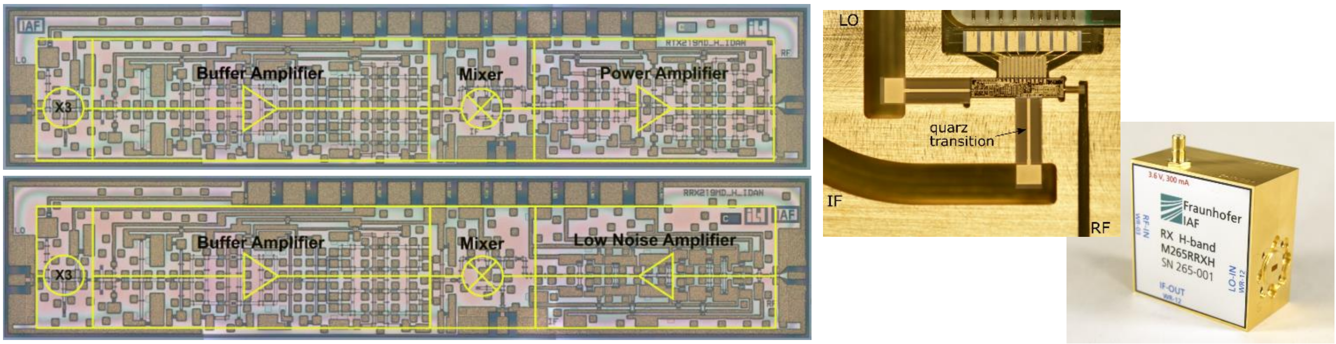
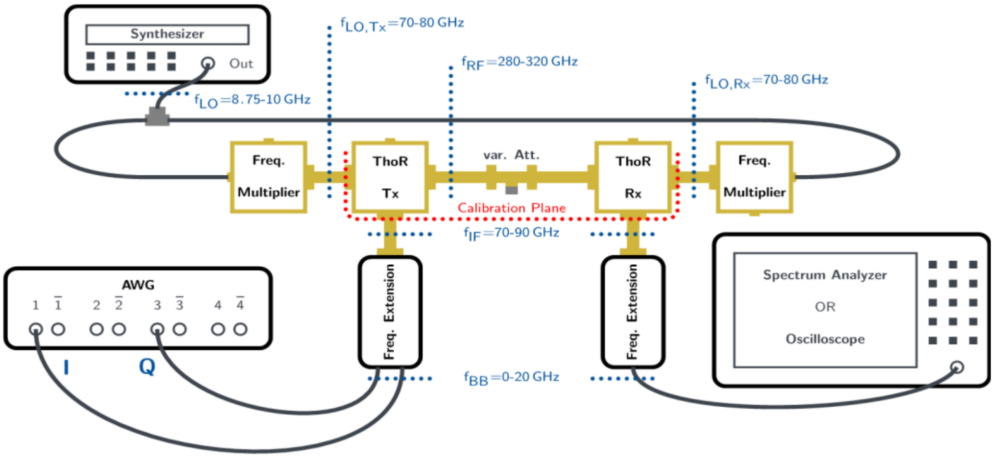


Fig. 7: Chip photos of the transmitter (top) and receiver (bottom) MMICs packaged in a split-block waveguide module (right).

The first demonstration (DEMO-2-1) was performed at the University of Stuttgart in a laboratory environment and focuses on the performance characterisation of the 300 GHz link consisting of the transmitter and receiver modules which are operated in a back-to-back configuration as shown in Fig. 8. Using modulated signals with various data rates and modulation schemes, the capability of the link is carefully evaluated in order to provide the optimum operation conditions for the following demonstrations with increased hardware complexity *e.g.* adding photonic LO generation or modems as data signal sources.

The measurements have proven the functionality of the modules and the system architecture. The results are in the process of being submitted for publication and will be reported publicly in due course.

Fig. 8: Block diagram of the measurement set-up used for ThoR DEMO-2-1.



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