HORIZON 2020

Terahertz based Ultra High Bandwidth Wireless Access Networks

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1.0	26.11.17	Thomas Kürner	TUBS	All review comments made by Niamh O'Mahony addressed
1.1	28.11.17	Thomas Kürner	TUBS	Typos removed

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Executive summary

This deliverable provides a preliminary list of standards, which have been identified during the kick-off phase of the TERAPOD project. The two main bodies, which have been identified so far are IEEE 802 and the World Radio Conference 2019 (WRC 2019) as well as its related bodies. TERAPOD can adopt Std. IEEE 802.15.3d™-2017 and will investigate whether any further adaptions for this standard are required for more advanced applications. The findings can be fed to IEEE 802 through IEEE 802.15 IG THz. TERAPOD can provide technical input to the preparatory process of AI 1.15 at WRC 2019 on the data center use case. In addition to contributions to these two standardisation bodies TERAPOD has identified the necessity to develop a standard in the area of device measurements and intends to produce a best practice document in this area.

1 Introduction

1.1 Summary

This deliverable provides a preliminary list of standards, which have been identified during the kick-off phase of the TERAPOD project. The content is derived from information given by consortium members participating in standardisation and regulation bodies. The two main bodies, which have been identified so far are IEEE 802 and the World Radio Conference 2019 (WRC 2019) as well as its related bodies. In addition to these two standardisation bodies TERAPOD has identified the necessity to develop a standard in the area of device measurements and intends to produce a best practice document in this area.

1.2 Structure of this document

This document describes the status of standardisation at IEEE 802 relevant for wireless links in Data Centers, in chapter 2, followed by a description of the process towards WRC 2019 and the bodies involved in that process. Chapter 3 describes the ideas to produce a document on “Recommended practice on device measurements for THz communications”.

1.3 Relationships with other deliverables

This document is the first deliverable of a set of deliverables describing TERAPOD’s activities towards standardization. Therefore there is no relation to any other document.

1.4 Contributors

The following partners have contributed to this deliverable:

- Thomas Kürner (TU Braunschweig)
- Mira Naftaly (NPL)
- Sebastian Rey (TU Braunschweig)

1.5 Acronyms and abbreviations

AI	Agenda Item
CEPT	Conférence Européenne des Administrations des Postes et des Télécommunications
CPG	Conference Preparatory Group
CPM	Conference Preparatory Meeting
ECP	European Common Proposal
EIRP	Effective Isotropic Radiated Power
IEEE	Institute of Electrical and Electronics Engineers
ITU-R	International Telecommunication Union, Radiocommunications Sector
MAC	Media Access Control
PT	Project Team
RTD	Resonant Tunneling Diode
SG	Study Group
WG	Working Group
WLAN	Wireless Local Area Networks

WSN	Wireless Specialty Networks
WP	Working Party
WRC	World Radio Conference

1.6 Change log

No change log entries.

2 Status of Standardisation in IEEE 802

Standardisation of either THz communications links or wireless links in data centers in IEEE 802 is done in the Working Groups (WG) 11 (Wireless Local Area Networks WLAN) and 15 (Wireless Specialty Networks – WSN).

2.1 IEEE 802.11

In March 2014, IEEE 802.11 has initiated the project IEEE P802.11ay on Next Generation 60 GHz communication (NG60) (IEEE, 2014) with the goal to achieve a throughput of at least 20 gigabits per second (measured at the MAC data device access point). The application of wireless inter-rack connectivity in data centers is one of the 11 usage models the project has defined and targets wireless interfaces as the secondary/tertiary interfaces in lieu of fiber optics failure (IEEE , 2017d). The first draft of the corresponding amendment has been created in November 2015 and has entered the stage of WG Letter Ballot (IEEE, 2017e). This means that there is no possibility for TERAPOD to influence the development of this standard. Since TERAPOD targets a carrier frequency at 300 GHz, there are also no possibilities to apply the outcomes of IEEE P802.11ay to the TERAPOD demonstrator.

2.2 IEEE 802.15

On 12 October 2017, a first standard for frequencies in the bands 252 to 275 GHz has been published, which was created within IEEE 802 WG15 since 2014. The corresponding Task Group has been led by Thomas Kürner from TERAPOD partner TUBS, who also chairs the IEEE 802.15 Interest group THz. In order to enable bridging in data centers for IEEE 802.15.3 standards, a small project on proper interface definitions has been initiated in July 2017.

All three standards and activities will be briefly described in the following.

2.2.1 Standard IEEE 802.15.3d-2017

Standard IEEE 802.15.3d™-2017 (IEEE, 2017b) is an amendment to IEEE 802.15.3™-2016 (IEEE, 2016a), which extends this standard by physical layer for point-to-point links operating in the frequency band 252 GHz to 325 GHz at ranges as short as a few centimeters and up to several 100m. The targeted nominal PHY data rate is up to 100 Gbps. The applications of the amendments are kiosk downloading, intra-device communications, wireless backhauling/fronthauling and wireless links in data centers.

The channel plan covering these frequency ranges is shown in Figure 1. Eight different bandwidths between 2.16 GHz and 69.12 GHzhave been defined. Furthermore, Standard IEEE 802.15.3d™-2017 has defined two PHY modes: a single carrier PHY and an on-off-keying mode. The latter is especially suited for the application of resonant tunnelling diodes (RTD), which are also used within TERAPOD. The media access control (MAC) is mainly based on the amendment IEEE 802.15.3e™-2017, which has been published in February 2017 (IEEE, 2017a).

TERAPOD will build on Standard IEEE 802.15.3d™-2017 and the standard will be implemented in physical layer simulation used in the project.

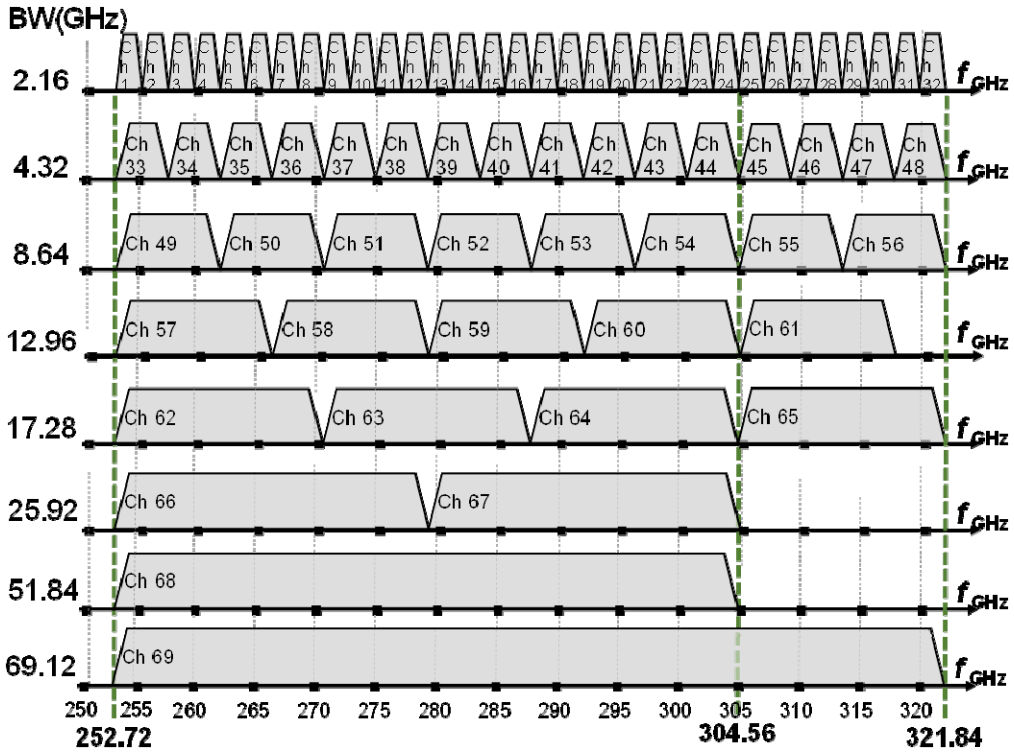

Figure 1: Channel I the frequency band 252 to 275 GHz as defined in Std. IEEE 802.15.3d™-2017 (IEEE, 2016c)

2.2.2 Project IEEE P802.1ACct

Within IEEE 802, different MAC types have been developed, which may differ in some details. Such difference may become an issue if more than one MAC technology is employed, for example, in Bridged LANs, which occur in Data Centers. To overcome such problems IEEE Std 802.1AC ™ - 2016, IEEE Standard for Local and metropolitan area networks— Media Access Control (MAC) Service Definition (IEEE, 2016b) deals with a clear definition of the MAC Service that would facilitate the definition of a common Bridging technology that could apply to all MAC types. In (IEEE, 2016b) such a service definition does not occur for IEEE 802.15.3™-2016. Therefore, in July 2017, the small project IEEE P802.1ACct (IEEE, 2017c) has been defined as a joint activity of IEEE 802 WGs 1 and 15 to amend IEEE Std. 802.1AC with respect to the definitions required to bridge the LANs with the IEEE Std. 802.15.3™-2016. The work for the project is straightforward and the amendment is expected to be ready at the end of 2018. As such, there is no need for TERPAOD to feed any input to the process. However, the output will be essential to deploy wireless links in data centers and is therefore essential for TERAPOD.

2.2.3 IEEE 802.15 Interest Group THz

The 802.15 THz Interest Groups (IG THz) has been established already in 2008 with its focus on THz communications and related network applications operating in the THz frequency bands between 275 and 3000 GHz. In its early years the IG THz monitored the early developments of THz communications and in 2013 triggered the establishment of a study group, which finally led to the creation of the IEEE 802.15. TG 3d with the goal to develop (IEEE, 2017b). Through its members the IG THz also provided significant input to the preparation process of WRC 2012, where the footnote 5.595 of radio regulation dealing with frequencies beyond 275 GHz was under discussion. For the preparation process of WRC 2019, the IG THz was a similar role and is participating in drafting liaison statements between IEEE 802 and ITU-R if required. Furthermore, the IG THz is monitoring the progress in the area of THz communications and is looking for opportunities and requirements to

establish further future Study Groups with applications different from the scope of (IEEE, 2017b). Especially the latter might reveal opportunities for TERAPOD to actively influence the development of future standards. TERAPOD will, therefore, investigate whether the technology developed in the project will require further amendments on the standards and will act accordingly. As first step, TERAPOD has been introduced to the IG THz in its November 2017 meeting (TERAPOD, 2017), see also Appendix A.

2.3 Potential Interaction between TERAPOD and IEEE 802

Based on the descriptions and findings form the previous sections, Table 1 summarizes the potential interaction with IEEE 802 standardisation groups and the use of IEEE 802 standards within the project. Thomas Kürner from partner TUBS is Chair of IEEE 802 IG THz and is regularly participating in IEEE 802.

Table 1: Summary of potential interaction with IEEE 802standardisation groups and use of IEEE 802 standards with TERAPOD

Standard / Standardisation group	Possible Interaction	Remarks
Std. IEEE 802.15.3d™-2017	Adopt the standard in TERAPOD	The standard is essential for TERAPOD and has been published in October 2017
IEEE P802.1ACct	Adopt the standard in TERAPOD once it is finished	If bridging is required the amended standard may be used. It is expected the amendment will be published EoY 2018
IEEE 802.15 Interest group THz	Provide regular input of TERAPOD results to this group	IG THz is the nucleus to spin-off a potential new Study Group/Task Group for further amendments of IEEE 802.15.3. However, this would require significant resources, which could be foreseen in a potential follow-up project.
IEEE P802.11ay	none	Although this project is on one specific application for wireless links in data centers, the project is targeting another carrier frequency (60 GHz). Furthermore, the project has already advanced to the balloting process, leaving no room for input form TERAPOD.

3 World Radio Conference 2019 (WRC19)

At the upcoming WRC 2019, the frequency band between 275 GHz and 450 GHz is considered by a specific Agenda Item (AI) 1.15 (ITU, 2015). In this section, we first describe the current situation in the Radio Regulations and the AI 1.15, followed by an overview of the bodies involved in the preparation of WRC 2019 with respect to this AI and conclude with the potential for TERAPOD to influence this process.

3.1 Current Situation in Radio Regulations

The situation for the use of frequencies in the band beyond 275 GHz is described in footnote 5.565 of the current version of the radio regulations (ITU, 2016):

"**5.565** A number of bands in the frequency range 275-1 000 GHz are identified for use by administrations for passive service applications. The following specific frequency bands are identified for measurements by passive services:

– radio astronomy service: 275-323 GHz, 327-371 GHz, 388-424 GHz, 426-442 GHz, 453-510 GHz, 623-711 GHz, 795-909 GHz and 926-945 GHz;

– Earth exploration-satellite service (passive) and space research service (passive): 275-286 GHz, 296-306 GHz, 313-356 GHz, 361-365 GHz, 369-392 GHz, 397-399 GHz, 409-411 GHz, 416-434 GHz, 439-467 GHz, 477-502 GHz, 523-527 GHz, 538-581 GHz, 611-630 GHz, 634-654 GHz,657-692 GHz, 713-718 GHz,729-733 GHz, 750-754 GHz, 771-776 GHz, 823-846 GHz, 850-854 GHz, 857-862 GHz, 866-882 GHz, 905-928 GHz, 951-956 GHz, 968- 973 GHz and 985-990 GHz.

The use of the range 275-1 000 GHz by the passive services does not preclude use of this range by active services.

Administrations wishing to make frequencies in the 275-1 000 GHz range available for active service applications are urged to take all practicable steps to protect these passive services from harmful interference until the date when the Table of Frequency Allocations is established in the above-mentioned 275-1 000 GHz frequency range.

All frequencies in the range 1 000-3 000 GHz may be used by both active and passive services. (WRC-12)."

3.2 Agenda Item 1.15

Although (ITU, 2016) allows the use of the frequency range by active services, which THz communications is, it is up to the national administrations to decide on this. Also, the technical constraints, under which use is possible, are not clearly defined except for the protection of the passive services by all means. On the other hand, from the frequency bands listed in footnote 5.565 of the radio regulations, it is obvious that sharing between passive and active services is required from a THz communications point of view. Therefore, in the final acts of WRC 2015 resolution 767, it was agreed upon (ITU, 2015):

"(…) to have an agenda item for WRC 2019 to consider identification of spectrum for land-mobile and fixed active services in the range of 275 GHz to 450 GHz while maintaining protection of the passive services identified .

(…)

ITU-R is invited to

- identify technical and operational characteristics
- study spectrum needs
- develop propagation models

- conduct sharing studies with the passive services
- identify candidate frequency bands"

3.3 Bodies related to WRC AI 1.15

ITU-R Working Party (WP) 1A is the leading working party within ITU-R, because several WPs of the Study Groups (SG) 3, 5 and 7 are involved in AI 1.15. Specifically, WP 5A, 5C, 7C and 7D are the contributing groups with respect to land-mobile, fixed, earth-exploration satellite and radio astronomy services. WP 1A (coordinating the sharing studies), SG 3 (propagation models) and WP 5A (land-mobile services) are the relevant groups for TERAPOD. WP 5A addresses the use cases of close proximity (intra-device, inter-chip communications, ticket downloading) and wireless links for data centers.

WP 5A is working towards a draft new report, which includes the technical parameters for the sharing studies like frequency range, modulation, EIRP, deployment densities, antenna patterns and spectrum need. It is expected that the new report will be finalised in early 2018.

SG 3 provides guidance on the propagation models to be used for the sharing studies. However SG 3 only extrapolated existing models to the 300 GHz range and is continuously looking for new insights into propagation characteristics. There might be a chance for TERAPOD to feed in some results on channel measurements and channel modeling in the future.

WP 1A leads the preparation of AI 1.15 above 275 GHz and is also working towards a report on sharing studies and develops some text for the upcoming conference preparatory meetings (CPM) for WRC-19 AI 1.15, which will contain possible actions with reasoning for the agenda item in WRC19 and represents the view of all administrations (each administration can have its own view in there).

The view of the administrations is defined in individual national processes. For instance, in Germany there are national preparatory groups open to interested parties. In Europe (CEPT), there is the CPG (Conference Preparatory Group) which tries to combine the national positions into European Common Proposals (ECPs) to ease the workflow in the international regulatory meetings. The workload of CPG is distributed over several Project Teams (PT). For AI 1.15, PT A is the responsible team and its progress is reviewed in the CPG meetings.

3.4 Potential Involvement of TERAPOD in the WRC 2019 Process

Sebastian Rey from project partner TUBS is the coordinator of AI 1.15 at the national preparatory group of Germany and at the European, CEPT, level and TUBS is participating in all bodies listed in Table 2. In case the preparation process of WRC 2019 requires further technical input on the data center use case, TERAPOD could feed this information into this process via partner TUBS.

Table 2 Bodies related to the WRC 2019 Process which are of relevance for TERAPOD

Body	Possibility for potential input
National Preparatory Process	Technical input for the data center use case, if required Input to sharing studies, if required
CEPT: CPG – PT A	Technical input for the data center use case, if required Input to sharing studies, if required
CEPT: CPG	Same as CPG PT A
ITU-R WP 5A	Technical input for the use case data center, if required

Body	Possibility for potential input
ITU-R WP 1A	Technical input for the use case data center, if required Input to sharing studies, if required
ITU-R SG 3	Input on propagation models in data centers
WRC / CPM	Technical input for the data center use case, if required

4 New Document on Recommended Practice on Device Measurements

In recent years, terahertz metrology has been attracting increasing attention, focusing primarily on calibration of time-domain spectrometers and on methodologies for parameter extraction (Y. Shimada, 2015), (Y. Deng, 2014) , (H. Iida M. K., 2013) , (H. Iida, 2017) , (T. Wang, 2016), (M. Kinoshita, 2014), (D. Molter, 2017), (A. Rehn, 2017), (M. Naftaly, 2017), (Naftaly, 2013). In contrast, little consideration has been given to techniques for characterising and specifying other types of THz devices, and in particular devices for THz communications (Naftaly, 2017). It is widely recognised that industrial-scale implementation of THz wireless links will necessarily require device standardisation, adoption of commonly agreed specification criteria, and provision of calibration services. As a preparatory step, it is urgently advisable to develop an agreed “recommended practice on device measurements for THz communications”. TERAPOD will prepare such a document.

5 Conclusion/Further work

TERAPOD has identified three areas to contribute to standards:

- TERAPOD can adopt Std. IEEE 802.15.3d™-2017 and will investigate whether any further adaptions for this standard are required for more advanced applications are required. The findings can be fed to IEEE 802 through IEEE 802.15 IG THz. Since it can be expected, that similar situations are also relevant for the other Horizon 2020 projects working in the area of “Networks beyond 5G” an invitation has been sent out to these projects for joint participation the upcoming meeting of the IG THz in May 2018 in Warsaw. During this meeting, a series of presentations from the corresponding H2020 projects is foreseen, followed by a focused assessment of the standards requirements related to these projects: “What already exists, what is missing, and when is it needed?”
- TERAPOD can provide technical input to the preparatory process of AI 1.15 at WRC 2019 on the data center use case.
- TERAPOD will provide a new document on “Recommended practice on device measurements for THz communications”

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Appendix A: Contribution from TERAPOD to IEEE 802.15

Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: TERAPOD - Terahertz based Ultra-High Bandwidth Wireless Access Networks
Date Submitted: 6 November 2017
Source: Thomas Kürner TU Braunschweig
Address Schleinitzstr. 22, D-38092 Braunschweig, Germany
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Re: n/a

Abstract: The TERAPOD project aims to investigate and demonstrate the feasibility of ultra high bandwidth wireless access networks operating in the Terahertz (THz) band. The proposed TERAPOD THz communication system will be developed, driven by end user usage scenario requirements and will be demonstrated within a first adopter operational setting of a Data Centre. In this presentation, we define the full communications stack approach that will be taken in TERAPOD, highlighting the specific challenges and aimed innovations that are targeted.

Purpose: Information of the IG THz

TSSG

DELL EMC

UCL

University of Glasgow

Technische Universität Braunschweig

NPL National Physical Laboratory

bay photonics

VIVID COMPONENTS

VLC PHOTONICS

INESCTEC TECNOLOGIA E CIÊNCIA | LABORATÓRIO ASSOCIADO

European Commission

TERAPOD

Terahertz based Ultra High Bandwidth Wireless Access Networks

terapod

To investigate and demonstrate the feasibility of ultra high bandwidth wireless access networks operating in the Terahertz (THz) band.

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TERAPOD Objectives

- Advance the Technology Readiness Level of THz communication devices and systems.
- Fully integrated ‘first adopter’ Data Center demonstrator.
- Regulation and Standardisation.
- Promote THz communications systems science.

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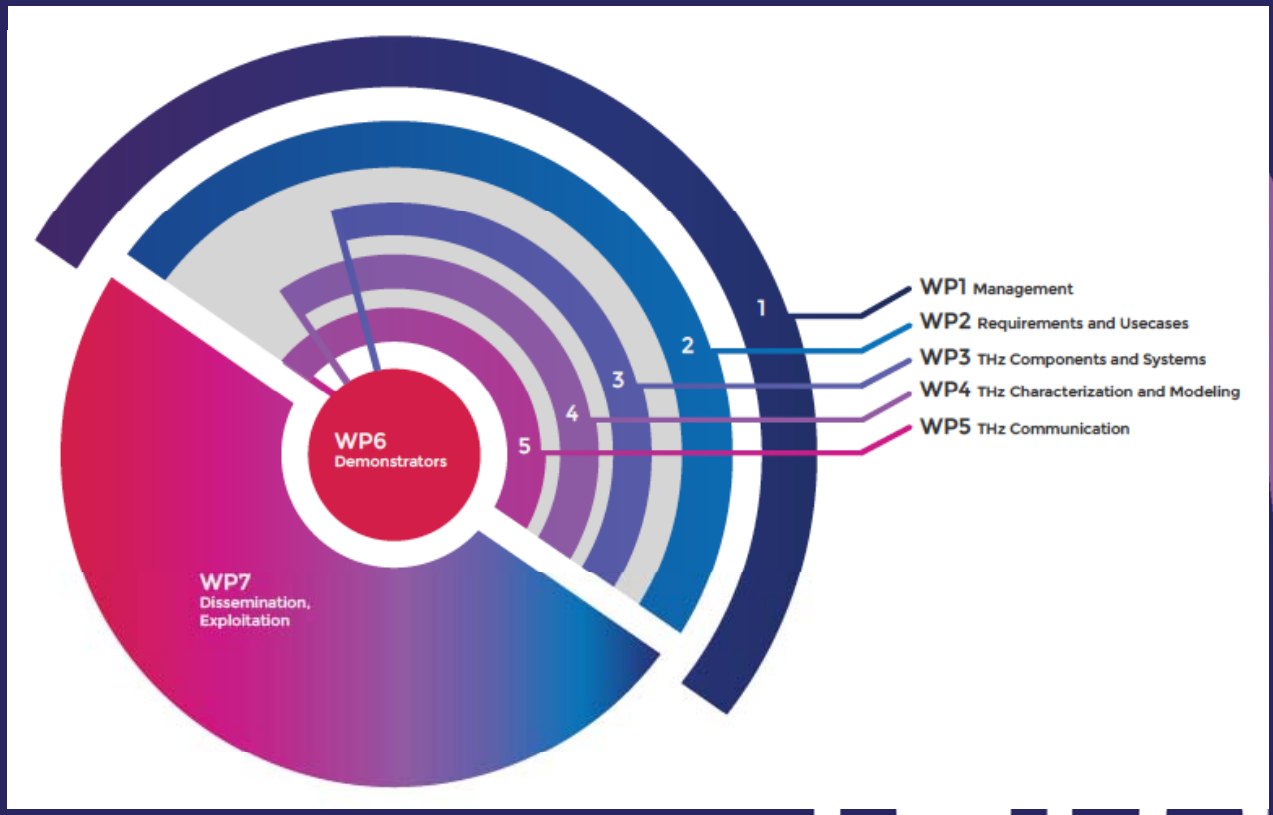
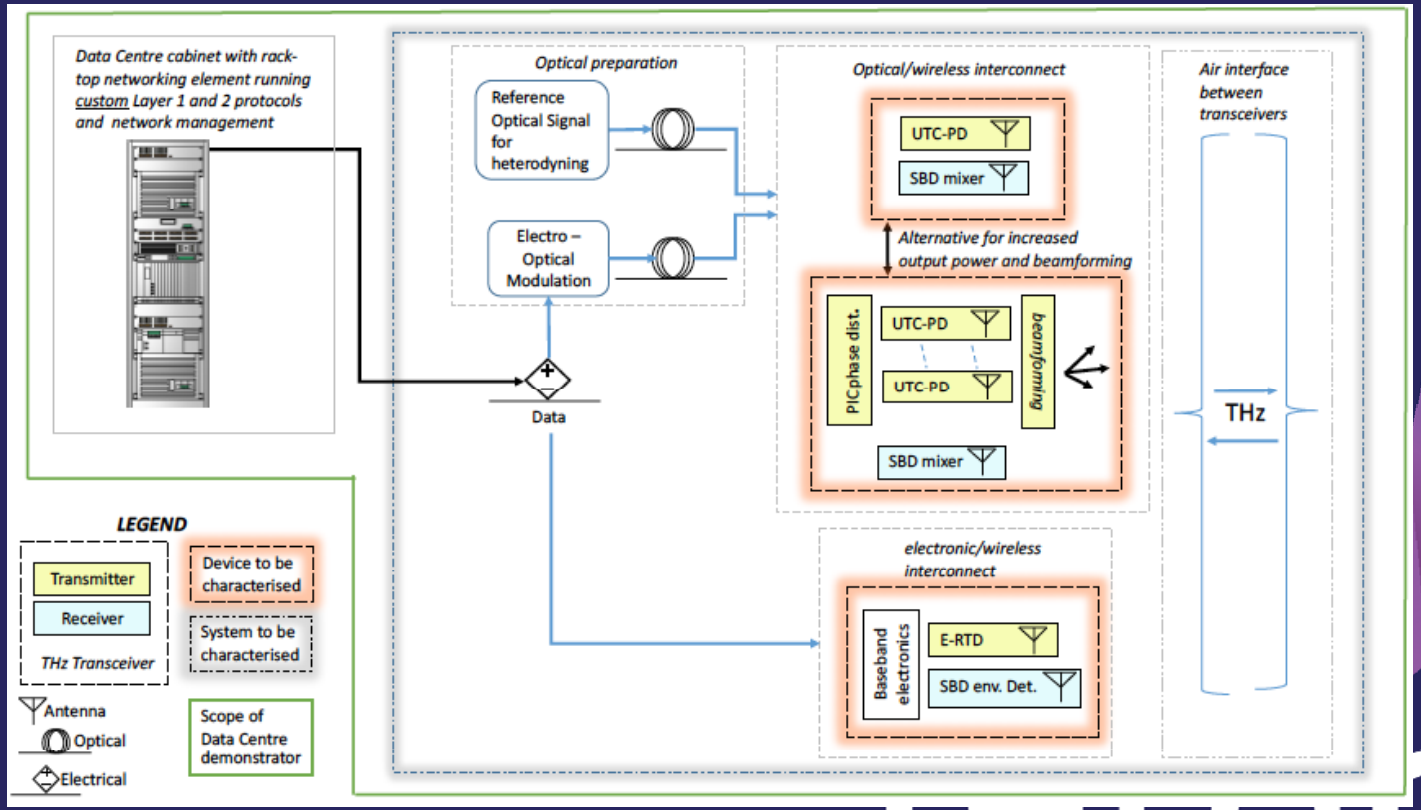
Work Packages



Approach


Data Centre cabinet with rack-top networking element running custom Layer 1 and 2 protocols and network management
Optical preparation
Reference Optical Signal for heterodyning
Electro – Optical Modulation
Data
Optical/wireless interconnect
UTC-PD
SBD mixer
Alternative for increased output power and beamforming
PIC phase dist.
UTC-PD
UTC-PD
beamforming
SBD mixer
Air interface between transceivers
THz
electronic/wireless interconnect
Baseband electronics
E-RTD
SBD env. Det.
LEGEND
Transmitter
Receiver
THz Transceiver
Device to be characterised
System to be characterised
Antenna
Optical
Electrical
Scope of Data Centre demonstrator

Technology Innovations for demonstration

- Reliable, high efficiency and high-power THz RTD sources
- Low-barrier diodes for operation as THz mixer
- Power combination of multiple THz sources
- Novel measurement and characterisation techniques for THz devices
- Novel substrate integrated THz antennas
- PHY and MAC layer THz communications protocols targeting various Use Cases

teraPod

Project Details

Coordinator: Dr. Alan Davy (Waterford Institute of Technology)

11 Partners (UK, Germany, Ireland, Spain, Portugal, Germay)

€3.4M

3 Years from 1st Sept 2017.

www.terapod-project.eu

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