HORIZON 2020

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Executive summary

The Initial Research Alignment Report helps assess, validate and align the proposed technological developments of the project with the goals and requirements of the use cases. It closely aligns the work within the technical work packages to the scenarios previously specified.

The objective of this deliverable is to report on the activities of T2.2 which focuses on:

- aligning the research activities carried out with the project to the set of use case requirements that were initially defined
- validation and demonstration of the work through the demonstrators
- reporting on how the work is also aligned with recent emerging State of the Art activities in the area of THz communication.

1 Introduction

1.1 Summary

This deliverable presents the Initial Research Alignment Report for the TERAPOD project. It closely aligns and integrates the technological developments and research from other work packages (particularly WPs 3 – 5) with the use case scenarios previously specified in D2.1. The task activities for the various WPs are reviewed and each is described in detail, aligning to the aforementioned requirements. These activities are also associated with the demonstrators outlined in the TERAPOD proposal.

1.2 Structure of this document

This document is laid out as follows:

- Section 1 acts as an introduction to this deliverable, in summary, what it presents along with its relationship to other deliverables within the TERAPOD project and details what partners have helped contribute to this text.
- Section 2 provides an overview of how technical activities from the various WPs are mapped to requirements, in the form of the use case scenarios. It also aligns these activities to the respective demonstrators outlined in the TERAPOD proposal, where all activities are validated and demonstrated by at least one demonstrator.
- Section 3 presents how activities within TERAPOD align with other State-of-the-Art activities and technologies within the THz space across Europe and internationally. It details certain areas and publications related to the overall goals of the project.
- Section 4 provides conclusions and a summary of the next steps in relation to the project.

1.3 Relationships with other deliverables

The content presented in this document relates to the following deliverables:

- D2.1 – Initial Requirements and Scenario Specifications: this document presents an overview of the use case scenarios and detailed requirements

1.4 Contributors

The following partners have contributed to this deliverable:

- TSSG (Alan Davy)
- DER (Fiach O’Donnell)
- TSSG (Saim Ghafoor)

2 Research Alignment within the Project

This section will provide a bird-eye view of the mapping of requirements to WP activities and demonstrators, ensuring that all activities are tied to at least 1 requirement and that all requirements are being validated and demonstrated by at least one demonstrator.

2.1 Overview

The requirements for different use cases (mentioned below) are already discussed in detail in deliverable D2.1. It is important before developing any research alignment that each partner agrees on the broad definition of the requirements and use cases. A clear understanding of these requirements and demonstrator help in using the efforts towards the required deliverables. Therefore, initially, the requirements and demonstrators will be explained in this document, followed by the methodology to establish a mapping between the task activities, requirements and the demonstrators for each partner.

2.1.1 Use cases

There are four use cases which were finalised to establish the feasibility of Terahertz band communication within a Data Centre environment. These use cases are mentioned and discussed in much detail in Deliverable D-2.1 (Initial requirements and scenario specifications). We can summarise as follows;

1. TERAPOD-UC-01: Commercial Feasibility of THz DC Wireless Networks

   In this use case, a commercial feasibility of Terahertz band is aimed to be established within a data center environment. The functional and non-functional requirements might influence the implementation of such high transmission rate bands. Therefore, different aspects for devices, antennas, transceivers, materials, and communications are considered and established to achieve the Terahertz link expected performances. The considered factors also include the geometry of data centers, topologies, achievable rates, power consumption, channel modeling, and environmental effects. All these are considered to asses the feasibility to establish a wireless Terahertz link.

2. TERAPOD-UC-02A: Static (Layer-1) THz Wireless Data Links

   This use case is focused on the integration of static Terahertz wireless link within a Data center environment. It also includes the performance comparison of Terahertz wireless link with wired links (optical) in terms of achievable data rate and feasibility of point to point communication. The important factors in achieving the point to point connectivity are to analyse the device and transceiver characteristics with antenna alignment to establish the distance achievable with required throughput and delay.

3. TERAPOD-UC-02B: Dynamic (Multi-Layer) THz Wireless Data Link Integration

   This use case is focused on point to multipoint communications and analysis of different network aspects including network congestion, minimising link downtime, delay and maximising throughput. It is also focused on developing efficient networking protocols to implement on-the-fly and flexible solutions.

4. TERAPOD-UC-03: Wireless Data Centre Auto-Configuration

   This use case involves the full integration of wireless Terahertz link within a data center with auto-configuration which includes automated device discovery, configuration, and synchronization with existing devices. It also involves the automated re-configuration of beam-direction, range, and other appropriate parameters.

2.1.2 Requirements

Various functional and non-functional requirements are already listed in D-2.1, and therefore are not discussed here. A summary of the requirements for each use case is given below.

1. Use case 1: includes requirements for end-user; data transmission; scenario; interface including topologies, geometry, safety and workloads; and technology. Non-functions requirements include the testing and validation, cost and commercial factors and licensing considerations.
2. Use case 2A: includes the data transmission including data rate, bit error rate, and power consumption; detailed description of scenario; interface requirements including components and external systems with traffic load and links; technology including the communication layer parameters; device including transmitter and receiver devices such as RTDs or UTC-PDs; and non-functional requirements.
3. Use case 2B:

   Analogous to use case 2A.
4. Use case 3B:

   Mostly same as for use case 2A and 2B, the details about the communication parameters are outlined in D-2.1.

2.1.3 Demonstrators

The implementation, configuration and achieved goals will be validated using the following demonstrators:

1. Simulation: Simulation for proof of concept and end-to-end performance analysis.
2. Bench-top testing: Bench-top testing for implementation of point-to-point Terahertz wireless link, beam formation, spatial configuration and other designed configurations for different devices and components.
3. DC Integration: Integration and analysis of Terahertz Wireless link within a Data Centre environment

2.2 Methodology

The main objective for this methodology is to track down the progress and research outputs and their mapping with the demonstrators and requirements, essentially through the involved task activities. The research alignment should evolve with project knowledge and progress throughout the project lifeline. The following methodology is used to track the project progress.

1. The requirements and goals for each use case scenario will be identified by each project partner individually.
2. Task activities should be identified clearly, as to how these requirements or goals can be achieved.
3. The proof-of-concept for each task activity should be shown using one of the identified demonstrators.
4. The identified demonstrators and task activities will be used to check the achievability of individual goals identified at the beginning of the project.

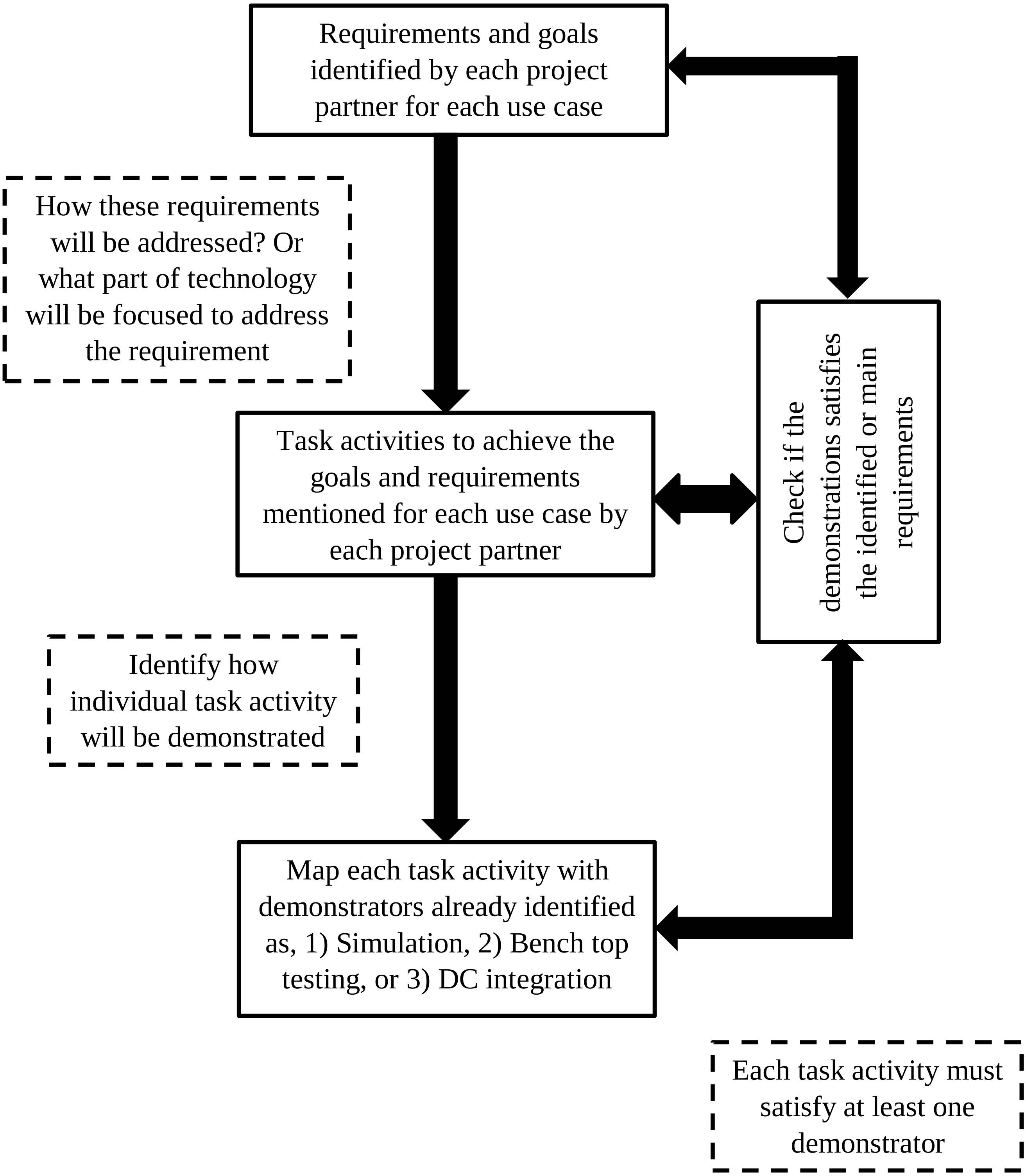

Figure 1: Research alignment methodology.

2.3 Research alignment based on each use case and partner activities

Table 1: TSSG, research alignment summary

						Timeline to finish task			
Use case	**Requirement**	**Work package**	**Task activity number**	**Task activities**	**Related deliverable**	**Starting time**	**Completion time**	**Status**	**Demonstrator**
UC-01	To identify issues and challenges for THz MAC layer	WP-5	T-5.2	Literature review for exiting Terahertz communication protocols	D-5.3	M12	M-14	In-progress	Simulation
	Initial Data Link Layer simulator	WP-5	T-5.2	Analyses and selection of existing simulators for Terahertz communications	D-5.3	M-08	M-13	Completed	Simulation
		WP-5	T-5.2	Initial Data Link Layer Block Diagram	D-5.3	M-08	M-13	Completed	
		WP-5	T-5.2	Physical layer parameters analyses to be used in the link layer simulator	D-5.3	M-08	M-14	In-progress	Simulation
		WP-5	T-5.2	Implementation/simulation of DLL basic functionalities on MATLAB	D-5.3	M-10	M-15	In-progress	Simulation
	Traffic modelling and work load estimation of Data Centres	WP-5	T-5.2	Theoretical Frame generation and DLL buffer modelling using Markov Chain	D-5.3	M-12	M-15	In-progress	Simulation
		WP-5	T-5.2	Capturing real traces from Data Centre environment and equivalent traffic generation	D-5.3	M-10	M-24	In-progress	Simulation
UC-2A	Initial Data Link Layer simulator	WP-5	T-5.2	Implementation of Point to point link within a Data Centre scenario using directional antennas	D-5.3	M-15	M-18	Not started	Simulation
		WP-5	T-5.2	Implementation of channel model and physical layer aspects	D-5.3	M-15	M-26	Not started	Simulation
		WP-5	T-5.2	Interfacing between Physical, MAC and Network Layers	D-5.3	M-15	M-26	Not started	Simulation
	DC Geometry	WP-5	T-5.2	Simulations for wireless topology design within a Data Centre using inter/intra rack communication	D-5.3	M-18	M-20	Not started	Simulation
	Handshaking mechanism	WP-5	T-5.2	Handshaking mechanism proposed and implemented	D-5.3	M-20	M-24	Not started	Simulation
	Data rate and transmission distance	WP-5	T-5.2	Simulations carried out for maximum distance achievability	D-5.3	M-24	M-26	Not started	Simulation
				Simulations performed to analyse the achievable data rate				Not started	Simulation
				Comparison of an optical and THz link within a Data Centre environment				Not started	Simulation
UC-2B	Final Data Link layer simulator	WP-5	T-5.2	Point to multipoint scenario implemented and simulated for a Data Centre environment within a simulator using directional antennas	D-5.4	M-26	M-30	Not started	Simulation
	DC Geometry	WP-5	T-5.2	Extended simulations performed for point to multipoint scenario with directional antennas	D-5.4	M-28	M-30	Not started	Simulation

	Handshaking mechanism	WP-5	T-5.2	Advanced Handshaking mechanism proposed and implemented with directional antennas	D-5.4	M-30	M-33	Not started	Simulation
UC 03	Autonomous algorithms for discovery, synchronizatio n and configuration	WP-5	T-5.2	Advanced algorithms for device discovery	D-5.4	M-33	M-36	Not started	Simulation
				Advanced algorithm for handshaking				Not started	Simulation
				Advanced algorithms for synchronization, antenna alignment and link configuration				Not started	Simulation
	Autonomous algorithms using dynamic traffic loads	WP-5	T-5.2	Simulation of different traffic loads to analyse the performance and achievable data rate with transmission distances.	D-5.4	M-35	M-36	Not started	Simulation

Table 2: DER, research alignment summary

						Timeline to finish task			
Use case	**Requirement**	**Work package**	**Task activity number**	**Task activities**	**Related deliv erable**	**Starting time**	**Completion time**	**Current status**	**Demonstrator**
UC-01	**End-user requirements Technology Requirements Non-functional Requirements**	**WP2**	**T2.1**	Define use case scenarios Stakeholder/end-user interviews & workshops Business Model Canvas Examine commercial opportunities for THz/DC integration Identify potential safety risks and customer/market risks	D2.1	M1	M36	Completed	DC integration Bench top End-to-end simulator
					D2.2			On-going or in-progress	
					D2.3			Not Started	
UC-2A	**End-user requirements Technology Requirements Non-functional Requirements**	**WP2**	**T2.1**	Define use case scenarios Stakeholder/end-user interviews & workshops Business Model Canvas Examine commercial opportunities for THz/DC integration Identify potential safety risks and customer/market risks	D2.1	M1	M36	Completed	DC integration Benchtop End-to-end simulator
					D2.2			On-going or in-progress	
					D2.3			Not Started	
	Interface requirements	**WP5**	**T5.3**	Embedding THz links into a comms network - DER data center Study and develop flexible models to support multiple different network simulation scenarios within the data center Design of Layer 3 routing algorithms/protocols and other (anycast/multicast) • The trial network simulator mapping traffic and THz communication across links within a datacentre	D5.3	M7	M36	On-going or in-progress	End-to-end Simulator
					D5.4				
UC-2B	**End-user requirements Technology Requirements Non-functional Requirements**	**WP2**	**T2.1**	Define use case scenarios Stakeholder/end-user interviews & workshops Business Model Canvas Examine commercial opportunities for THz/DC integration Identify potential safety risks and customer/market risks	D2.1	M1	M36	Completed	DC integration Benchtop End-to-end simulator
					D2.2			On-going or in-progress	
					D2.3			Not Started	
	Interface requirements	**WP5**	**T5.3**	Further design of routing protocols, simulation scenarios etc. Partitioning of data traffic and software-defined networking (SDN) integration	D5.3	M7	M36	On-going or in-progress	End-to-end Simulator
					D5.4				

UC-03	**End-user requirements Technology Requirements Non-functional Requirements**	**WP2**	**T2.1**	Define use case scenarios Stakeholder/end-user interviews & workshops Business Model Canvas Examine commercial opportunities for THz/DC integration Identify potential safety risks and customer/market risks	D2.1	M1	M36	Completed	DC integration Benchtop End-to-end simulator
					D2.2			On-going or in-progress	
					D2.3			Not Started	
	Demonstration or proof-of-concept	**WP6**	**T6.3**	Fully demonstrate THz links in a data center environment through real-time device/link integration and through simulators	D6.3 D6.4	M4	M36	On-going or in-progress	DC integration

Table 3: TUBS, research alignment summary

						Timeline to finish the task			
Use case	**Requirement**	**Work package**	**Task activity number**	**Task activities**	**Related deliv erable**	**Starting time**	**Completion time**	**Status**	**Demonstrator**
UC-01	**Sustainability Technology requirements**	**WP7**	**T7.4**	Standardization activities to strengthen the Data Centre Scenario as an application for the THz technology	D7.5 D7.6 D7.7	M1	M36	In-progress	DC integration Benchtop End to end simulation
UC-2A	**Data Centre geometry Network Requirements**	**WP4**	**T4.2.1**	Channel measurement for Channel Characterization of Use Case Scenarios	D4.3	M1	M10	Completed	End to end Simulator
				Study of channel characteristics for different transmission scenarios (General Characterization, Top of Rack, Intra-Rack) in the data center	D4.4	M10	M20	In-progress	End to end Simulator
			T4.2.2	Bild a 3D data center model for ray tracing channel simulations	D4.4	M10	M22	Not started	End to end Simulator
				Extensive ray tracing simulations to fully characterize the channel	D4.4	M22	M28	Not started	End to end Simulator
				Creation of a model of the THz channel which will be fed to the PHY simulator	D4.4	M26	M30	Not started	End to end Simulator
	Data Rate of THz links Bit Error Rate	**WP5**	**T5.1**	First simple physical layer simulator implementing the current standard of THz communication which gives BER and PHY delay for the measured scenarios using a simple channel model	D5.1	M1	M15	In-progress	End to end Simulator
				Implementation of the THz Channel model in the PHY simulator	D5.2	M15	M33	Not started	End to end Simulator
				Implementation of forward error correction methods in the PHY simulator	D5.2	M15	M27	Not started	End to end Simulator
				Analysis of Bit Errors in the PHY simulator and Development of a Statistical Error Model	D.5.2	M15	M33	Not started	Benchtop End to end Simulator
UC-2B	**Interface requirements**	**WP5**	**T5.1**	Definition of interfaces between simulators	D5.1	M1	M6	Completed	End to end Simulator
				Development of an Error Model Generator which enables higher-level simulations employing a realistic PHY model	D5.2	M20	M34	Not started	End to end Simulator
UC-03	**Demonstration or proof-of-concept**	**WP6**	**T6.2**	Development of a simulator platform/interface which serves as a demonstration platform and illustrates how all different simulators work together (DC Geometry, Raytracing, PHY Sim, MAC Sim, Network Sim, Auto Config)	D6.3 D6.4	M1	M36	In-progress	End to end Simulator

Table 4: INESC TECH, research alignment summary

						Timeline to finish task			
Use case	**Requirement**	**Work package**	**Task activity number**	**Task activities**	**Related deliverable**	**Starting time**	**Completion time**	**Current status**	**Demonstrator**
UC-02A and UC-02B	**Technology requirement: device antenna gain higher than 20 dBi for 1 m transmission (adjacent racks).**	**WP 3**	**T 3.5**	Propose and validate by simulation a substrate integrated antenna design solution compatible with existing manufacturing limitations.	D3.4	M1	M12	Completed	Benchtop End to end Simulator
		WP 3	**T 3.5**	Improve initial substrate integrated antenna design solution with antenna feed details.	D3.6	M13	M14	On-going or in-progress	Benchtop End to end Simulator
		WP 3	**T 3.5**	Propose and validate by simulation a waveguide-based solution to interface with the substrate integrated antenna array to provide the target gain.	D3.6	M15	M20	Not started	Benchtop End to end Simulator
	Technology requirement: device antenna gain higher than 30 dBi for 10m transmission (adjacent aisles).	**WP3**	**T 3.5**	Improve initial waveguide-based interface to substrate integrated antenna array to provide the target gain.	D3.7	M21	M30	Not started	DC integration Benchtop End to end simulator
		WP3	**T 3.5**	Propose and validate by simulation a horn antenna solution to be interfaced with the SBD receiver.	D3.6 /D 3.7	M13	M16	On-going or in-progress	DC integration Benchtop End to end simulator
UC-03	**Technology requirement: device antenna compatible with beamforming subsystem.**	**WP3**	**T 3.5**	Simulate antenna array radiation patterns resulting from array excitations with phase values given by the developed PIC, considering a Si lens.	D3.6 / D3.7	M13	M16	Not started	Bench top End to end Simulator
		WP3	**T 3.5**	Simulate antenna array radiation patterns resulting from array excitations with phase values given by the developed PIC, considering an antenna waveguide output.	D3.6 / D3.7	M17	M24	Not started	Bench top End to end Simulator

Table 5: VLC, research alignment summary

						Timeline to finish task			
Use case	**Requirement**	**Work package**	**Task activity number**	**Task activities**	**Related deliverable**	**Starting time**	**Completion time**	**Current status**	**Demonstrator**
UC-03	**Beam steering mechanism for dynamic allocation of devices and of bandwidth**	**WP3**	**Task 3.4**	Design a phase distribution Photonic Integrated Circuit for dynamic reconfiguration of the emission profile. The PIC design has been fabricated.	D3.3	M1	M24	Completed	Simulations Benchtop
				Test and characterization of the Phase Distribution PIC. Test building blocks and their effect on the system. Test system and the range of tuning for each element.	D3.5	M8	M24	On Going	Benchtop

Table 6: NPL, research alignment summary

						Timeline to finish task			
Use case	**Requirement**	**Work package**	**Task activity number**	**Task activities**	**Related deliverable**	**Starting time**	**Completion time**	**Status**	**Demonstrator**
UC-01									
UC-02A	**Physical Layer TERAPOD components Testing and validation**	**WP-4**	**T4.1**	Measure emitted power of transmitters	D4.1	M1	M12	Completed	Benchtop
				Measure the power spectrum of the transmitter		M1	M12	Completed	Benchtop
				Measure responsivity of receivers		M1	M12	Completed	Benchtop
				Measure radiation pattern and polarisation in the far field		M1	M12	Completed	Benchtop
				Measure emitted power of transmitters	D4.2	M13	M33	Not started	Benchtop
				Measure the power spectrum of the transmitter		M13	M33	Not started	Benchtop
				Measure responsivity of receivers		M13	M33	Not started	Benchtop
				Measure radiation pattern and polarisation in the far field		M13	M33	Not started	Benchtop
	Environmental conditions	**WP-4**	**T4.2.1**	Channel measurements in real(istic) ambient conditions using mock-up	D4.4	M12	M24	Not started	Benchtop

				environment at NPL for systematic channel measurements and demo purposes					
UC-02B									
UC-03	**Physical Layer - THz transceivers which support beam-steering TERAPOD components - Beamforming sub-system Testing and validation**	**WP-4**	**T4.1**	Measure emitted power of transmitters	D4.1	M1	M12	Completed	Benchtop
				Measure the power spectrum of the transmitter		M1	M12	Completed	Benchtop
				Measure responsivity of receivers		M1	M12	Completed	Benchtop
				Measure radiation pattern and polarisation in the far field		M1	M12	Completed	Benchtop
				Measure emitted power of transmitters	D4.2	M13	M33	Not started	Benchtop
				Measure the power spectrum of the transmitter		M13	M33	Not started	Benchtop
				Measure responsivity of receivers		M13	M33	Not started	Benchtop
				Measure radiation pattern and polarisation in the far field		M13	M33	Not started	Benchtop
	Environmental conditions	**WP-4**	**T4.2.1**	Channel measurements in real(istic) ambient conditions using mock-up environment at NPL for systematic channel measurements and demo purposes	D4.4	M12	M24	Not started	Benchtop

Table 7: UGLA, research alignment summary

						Timeline to finish task			
Use case	**Requirement**	**Work package**	**Task activity number**	**Task activities**	**Related deliverable**	**Starting time**	**Completion time**	**Status**	**Demonstrator**
UC-01									
UC-2A	**Terahertz Device components (RTDs and SBDs)**	**WP-3**	**T-3.2**	Realisation of 150 GHz RTD in chip form with adequate output power (0.5 – 1 mW) and tunability (a few GHz) for use as local oscillators in coherent Schottky Barrier Diode (SBD) based THz receivers being developed partner ACST.	T-4.3 and T-3.5	M-1	M-15	In-progress	Bench top and DC integration
				Realisation of 300 GHz RTD sources with on-chip antennas and their packaging (for use with a silicon lens, which is a classical approach that is employed for some other semiconductor sources)	T-4.3 and T-3.5	M-1	M-20	In-progress	Benchtop and DC integration
				Realisation of 300 GHz RTD sources in substrate-in-waveguide (SIW) technology (as an alternative approach which employs proven high gain waveguide horn antennas)	T-4.3 and T-3.5	M-1	M-24	In-progress	Benchtop and DC integration
				Realisation of high power (>3 dBm) 300 GHz sources and their packaging as noted above	T-4.3 and T-3.5	M-1	M-30	In-progress	Benchtop and DC integration

Table 8: ACST, research alignment summary

						Timeline to finish task			
Use case	**Requirement**	**Work package**	**Task activity number**	**Task activities**	**Related deliverable**	**Starting time**	**Completion time**	**Current status**	**Demonstrator**
UC-01	**Requirements, challenges and technical inputs**	**WP2**	**T2.1**	Provide support in the definition of technological aspects and technologies compatibility. Identify technological requirements for the THz TERAPOD receiver.	D2.1	M1	M6	Completed	
UC-2A	**Delivery of SBD-based THz detectors and mixers for TERAPOD receiver part**	**WP3**	**T3.3**	Provide SBD quasi-optical detectors able to work from 0.05-2.5 THz	D3.1	M1	M3	Completed	DC integration, Benchtop
			T3.3	Development of a preliminary 300 GHz Frequency mixer based on SBD technology.	D3.2	M1	M13	Completed	DC integration, Benchtop, simulation
			T3.3	Development of an SBD-based 150 GHz doubler to provide local oscillator power for the 300 GHz mixer.	D3.6	M11	M18	Designed ready for fabrication	Benchtop
UC-2B	**Delivery of SBD-based THz receiver at 300 GHz able to provide 100 Gbps**	**WP3**	**T3.3**	Delivery of a 300 GHz receiver System for preliminary demonstration of use case in Data Centre.	D3.3	M11	M18	On-going	DC integration, Benchtop, simulation
			T3.3	Development of a 300 GHz mixer based on low barrier SBDs to reduce LO power requirements	D3.7	M17	M24	Not started	DC integration, Benchtop, simulation
			T3.5	Development of a 150 GHz Oscillator using RTDs and/or UTCs	D3.6	M15	M20	Not started	DC integration, Benchtop, simulation
			T3.5	Mechanical design of a 300 GHz horn antenna in collaboration with INESC	D3.6	M15	M18	Not started	Benchtop, simulation
		WP4	**T4.1**	Characterisation of a preliminary SBD 300 GHz Mixer	D4.2	M7	M13	Completed	DC integration, Benchtop

				Characterisation of SBD 300 GHz Doubler	D4.2	M16	M18	Not started	Benchtop, simulation
				Characterisation of 150 GHz Oscillator based on RTDs and/or UTCs	D4.2	M18	M24	Not started	Benchtop
				Characterisation of the Low barrier SBD 300 GHz mixer	D4.2	M20	M24	Not started	Benchtop, simulation
			T4.2	Characterisation of the preliminary 300 GHz receiver	D4.3	M16	M18	Not started	DC integration, Benchtop, simulation
				Characterisation of low barrier SBD-based 300 GHz Receiver using RTD/UTC oscillator	D4.4	M20	M24	Not started	DC integration, Benchtop, simulation
UC-03									

3 Research Alignment with State of the Art

This section will provide an overview of where the activities within TERAPOD sit in relation to other activities being pursued within Europe and Internationally within the THz communication space.

There is a sharp increase in recent years in the research funding by the bodies like Horizon 2020 (H2020) of European Union and National Science Foundation (NSF) of the USA and NTT of Japan. This funding ranges from enhancing research on the device technology to communication aspects including channel, physical, MAC and Network layer characterization. The projects related to these aspects are mentioned in Table 2. Some of the projects are based on establishing the feasibility of communication windows within Terahertz Gap like Ultrawave [1], Dream [2], EPIC [3], and WORTECS [4]. Each project is looking at a specific scenario. For example, the TERAPOD project is aiming to design a communication methodology for a Data Centre environment, which involves potentially the channel, antenna, device and Physical layer considerations for an indoor environment only. The TERRANOVA [5] on the other hand focuses on the backhaul point to point scenario for outdoor long-range environment including small cells. Each scenario requires a different modelling approach for antenna, channel and propagation model and therefore requires different strategies to access the channel and communication establishment. Similarly, Thor [6], is also looking at high speed link up to 100 Gbps over 300 GHz band for backhaul with partial involvement of point to point scenario for MAC layer channel access.

The TERAPOD project is part of a Terahertz cluster, which includes projects focusing on different aspects and application areas within Terahertz communications domain. These projects are mainly funded for Networking beyond 5G and are working together to progress and share information among a wider audience and each other. Depending on the application area and requirements, each project has different requirements, aims, and objectives.

The projects under the Terahertz cluster platform are highlighted here with their deliverables, aims, and objective. There potential differences with TERAPOD deliverables and outputs are also discussed and highlighted here. The state of the art and Terahertz cluster projects are shown in Figure 2.

Figure 2: Terahertz cluster projects.

3.1 Alignment of TERAPOD project with other projects

The sections will be aligned with the activities of TERPAOD and will depict similar activities within these groups, to show how TERAPOD is progressing in comparison to these activities. In Table 9, the overall focus of each project is mentioned and their relation to TERAPOD project is highlighted. Mainly, these projects focus on different application scenarios. Therefore, each one has a significant difference in requirements and objectives. Table 10 presents the comparison of functionalities, architectures, target KPIs, and requirements for TERAPOD and other cluster projects. The detailed technical requirements and outcomes for each project are mentioned in Table 11.

Each project is focused on a different application area, and therefore each one has different technical requirements and objectives. For example, Terranova, Ultrawave, and Thor are focussing on backhaul networks. They require channel and propagation model for outdoor environments. Whereas, TERAPOD focuses on indoor Data Centre networks with short-range communication up to 10 m. The indoor scenarios require different channel model and antenna design. Each project has different technical requirement mentioned in Table 9, 10 and 11. However, for simulator and physical layer combined models can be used for antenna and beam management with simulation platform which can capture Terahertz band features.

Table 9: Alignment of TERAPOD project with other projects.

Project	Region	Focus	Alignment to TERPAOD
ULTRAWAVE	EU H2020	High capacity backhaul links to enable 5G cell densification by exploiting bands beyond 100 GHz	High capacity point to point and multipoint links within a Data Centre environment by exploiting bands beyond 300 GHz
TERRANOVA	EU H2020	System architecture for embedding broadband THz wireless links into fiber optic links for beyond 5G networks by exploiting 270 and 330 GHz band. Mainly, focused on electro-optical baseband interfaces, Integrated THz front-ends and correction schemes for hybrid fiber optic and wireless links	A full system integration within a Datacenter environment with wireless and hybrid (optical and wireless) links by focusing on RTDs, STDs, UTC-PDs, and communication architecture
EPIC	EU H2020	Forward error correction codes and design	FECs are also part of TERAPOD aims and objectives
DREAM	EU H2020	Exploiting radio spectrum bands like 130-174.8 GHz with beam steering functionality to reach optical systems speed	Exploiting radio spectrum beyond 300 GHz to provide higher data rates for a Data Centre environment.
WORTECS	EU H2020	Optical wireless communication and radio over 90 GHz Proof of Concept with Gbps throughput.	One of the use cases in TERAPOD is also focusing on optical wireless integration within a Data Centre
NTT & Tokyo Uni.	JAPAN	IC capable of 100Gbps at 300GHz. Target source is InP-HEMT. Single carrier.	TERAPOD is focusing on RTD and UTC-PD technologies, also at 300GHz and 100Gbps.
TERANOVA: A testbed for Terahertz communication	US, Buffalo NSF.	Developing a fully integrated THz communication testbed targeting 1THz.	TERAPOD demonstrators are focusing on 300 GHz and will be fully integrated into a DC deployment. I.e. not a testbed.
Hybrid Graphene/Semiconductor Plasmonic Nano-Transceiver and Nano-Antenna for Terahertz-Band Communication	US, Buffalo US AFOSR	Development of a Plasmonic THz source coupled with a graphene antenna. This is a fundamentally new approach to THz generation.	TERAPOD focuses on RTD and UTC-PD with aims of advancing TRL.

Table 10: Terahertz cluster projects functionalities, KPIs and requirements.

Project	Scenarios	Bands	Distance/ Coverage	Features/ connectivity	Data rate	Latency	Mobility	Antenna	antenna gain	Channel/Propagation model	Devices	Physical layer	MAC layer	Network layer
TERRANOVA	Backhaul	270 to 320 GHz	1 Km	Optical and wireless, Small cells	100 Gbps	Yes	Yes	Phased array/Horn antenna	55 dBi is assumed	Yes	X	Yes	Yes	X
IBROW [7]	Femtocell, Wireless portable devices	60 GHz - 1 THz	10 m	Wireless transceiver design	10 Gbps	X	X	X	X	X	RTDs	X	X	X
ULTRAWAVE	Backhaul	141-148.5 GHz (Backhaul) 275-305 GHz (Fronthaul)	Fronthaul: 600-700m Backhaul: 600 m	P2P (fronthaul), P2MP (Backhaul)	100 Gbps	Yes	X	sector/terminal	20 and 39 dBi	X	X	Yes	X	X
EPIC	Indoor and outdoor, short, medium and long-range chipset design	X	X	FEC Techniques	1 Tbps	X	X	X	X	X	CMOS	X	X	X
DREAM	Backhaul/ Mesh network	D-band	300 m	P2P	100 Gbps	X	X	X	X	X	X	X	X	X
WORTECS	Virtual reality Office Stadium and Theme park	90 GHz	10 m	P2P	VR (210 Gbps) Office (25 Mbps to 1 Gbps) Stadium (20 - 50 Mbps)	Yes	Yes	X	X	X	X	X	X	X
THOR	Backhaul	252-325 GHz	1 Km	P2P, P2MP	100 Gbps	X	X	X	X	X	X	Yes	X	X
NTT	Wireless downloading system	300 GHz	10 m	P2P	20 Gbps	X	X	X	X	X	X	X	X	X
TERAPOD	Data centers	300 GHz	10 m	P2P, P2MP, Autonomous connectivity	100 Gbps	Yes	X	Horn	24 dBi	Yes	RTDs, SBDs, UTC PDs	Yes	Yes	Yes

Table 11: Terahertz cluster project scenarios, technical requirements and outcomes.

Project	Scenarios	Technical requirements	Description of outcomes
TERRANOVA	1. Outdoor fixed P2P 2. Outdoor/Indoor P2MP 3. Indoor/Outdoor Quasi Omni-directional	**Scenario 1** requirements: Link type: LOS, FD, symmetric Expected throughput: 200 Gb - 1 Tbps Frequency: 220 -300 GHz Optical channel: SSMF Optical transceiver: XFP, CFP2-Aco Optical modulation: Single carrier PDM, QAM, NxNRZ THz Modulation: Single carrier (PDM, QAM), multicarrier (OFDM), PAM4 THz Bandwidth: 40 GHz, 80 GHz THz antenna: two polarizations Beamforming: High gain, small angel **Scenario 2: r**equirements: Multiple channel acces: space and time division mulitple access UP and DL throughput: 500 Gbps THz bandwidth: 40 GHz THz antenna: 2 polarization Beamforming type: High gain space div multiplexing Beam steering: Large angle Synchronization: required UE discovery: fast and accurate with low discovery overhead **Scenario 3:** Indoor Omnidirectional NLOS, half duplex, TDMA Throughput: 400 Gbps, 256 QAM single carrier Bandwidth: 80 GHz Antennas: M antennas **Link performance requirements:** Aggregated throughput - Tbps P2P throughput Wireless/optical - Tbps Link latency - 0 ms Range - km Reliability - target BER PER	PHY layer functionalities • Characteristics of THz band • Pencil beamforming • Modulation and coding • Multiple frequency window Tx • Multiplex transmission MAC/RRM functionalities • Directed THz channel • Heterogeneity of spectrum and deployment • Control channels • UE detection and tracking • Interference management • Multiple access channel • Caching • Handovers Front end components • 60 GHz & E band front end chipset and key parameters • First generation THz frontend prototype • The phased array • Baseband up/down conversion Optical link and THz media converter design, Optical transceiver RF frontend and antenna prototypes, Baseband digital signal processing Phased array beamforming, Beamforming implementation issues Phased array antenna caliberation techniques Channel measurements: THz band Channel LOS, 200 to 400/450 GHz channel model, Transmission windows, Channel measurements for different materials and losses in environments, Measurements for indoor/outdoor environments, for noise, scattering, reflections, and noise fading, Ray tracing

ULTRAWAVE	Point to point Point to multipoint	**G-BAND Fronthaul:** Link budget analysis with modulation schemes high order modulation scheme 64 and 16 QAM 802.11ad QPSK Range: 600-700 m Cell size for backhaul: 50-200 m Cell capacity: 500 m Bandwidth 30 GHz Frequency: 275-305 GHz Throughput 30Gbps Transmit power, IW Antenna gain: 39 dBi channel size: 440,880,1760 MHz Modulation QPSK, BPSK antenna: sector antenna 20 dBi **G-BAND Backhaul:** Frequency: 141-148.5 GHz Block allocation: 8 GHz effective throughput: 5.3 Gbps Range: 600-650 m Tx power: 4 W antenna gain: 21 dB 30 degree Modulation: qpsk, bpsk terminal/sector antenna 36 dBi	Scenario definition system specification for fronthaul system specification for a backhaul D-band and G- band for fronthaul and backhaul communication Demonstration of fronthaul and backhaul communications MMIC chipset specification G-band photonics transmitter specification
EPIC		Different for each application area	This report determines the FEC performance requirement set for the EPIC project and wireless Tb/s use-cases in general. This report sets the performance targets for the FEC development work in the rest of the project. This report will present the differently proposed refinements and optimizations related to the architectural templates for the Turbo, LDPC, and Polar codes.
DREAM	Confidential	Confidential	• System architecture and design • D-band radio front end stage design, D-band transceiver, D-band frequency synthesis test • Optimal antenna configuration, • Optimised antenna array design with simulation and measurement results for final integration • Test system for digital control of beam steering demonstrators. • Prototype design and assembly • Design of testbed architecture, spec. and planning

WORTECS		Based on application throughput and latency requirements are mentioned with the target density	Not available
THOR	Point to point Point to multipoint	Not available	Not available
TERAPOD	Point to point Point to multipoint Autonomous connectivity	Throughput up to 100 Gbps Latency: below 1 ms Antenna gain: 24 dBi (substrate antenna) BER: 10^-9 Channel/propagation model with ray tracing RTDs, SBDs, UTC PDs, Device packaging 300 GHz transmitter and receiver design Communication protocols	• System and device technical and functional requirements • Device design, antenna arrays • Channel and propagation measurement • Physical, Mac and Network layer protocols for proof of concept • Demonstration of ideas and innovations

4 Conclusion/Further work

In this report, the requirement and task activities are highlighted for different use cases by each project partners. The aim is to align the research for each use case according to work package progress in terms of the requirement and deliverables. A methodology is presented to track the progress and align different tasks. The goal is then to track down the progress, match the deliverable and demonstrator with the identified requirements of each use case, and if required then to rectify them ahead of a time.

5 References

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