HORIZON 2020

Terahertz based Ultra High Bandwidth Wireless Access Networks

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Final Requirements and Scenario Specifications

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0.0	03/02/2020	Sean Ahearne	DER	Proposed table of contents.
0.1	10/02/2020	Sean Ahearne	DER	Content with provisional requirements tables.
0.2	26/02/2020	Sean Ahearne & all partners	DER and all partners	Final requirements tables with feedback. All sections complete.
0.3	27/02/2020	Alan Davy	TSSG	Final Internal Review
0.4	28/02/2019	Sean Ahearne	DER	Final document for submission.

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Executive summary

The Final Requirements and Scenario Specifications form the basis for the technological advancements in Terahertz (THz) wireless links carried out by the TERAPOD project. It finalizes the scenarios in which the technical outputs from the project will be deployed and reviews the technical requirements, ensuring that the technology artefacts produced by this project meet the needs of their eventual end users. This document represents the final iteration of review of requirements and scenarios before the end of the project.

In this document, the four use cases which were described in D2.2 are largely unchanged, as based on engagement with stakeholders they are deemed to be still accurate. They will be included for reference. These four use cases are:

- TERAPOD-UC-01: Commercial Feasibility of THz DC Wireless Networks
- TERAPOD-UC-02A: Static (Layer-1) THz Wireless Data Links
- TERAPOD-UC-02B: Dynamic (Multi-Layer) THz Wireless Data Link Integration
- TERAPOD-UC-03: Wireless Data Centre Auto-Configuration

The requirements tied to these use cases are described in detail, underpinning the technology development efforts for the TERAPOD project. These requirements have been revised and refined for this deliverable to represent the desired goals and achievements made throughout the lifetime of the project. A number of requirements have been met or achieved since the previous deliverable, with most other ongoing requirements set to be completed before the end of the project. These requirements ensure that the project produces technology for which deployment within a data centre environment is both technically viable and commercially feasible.

1 Introduction

1.1 Summary

This deliverable represents the Final Requirements and Scenario Specifications for the TERAPOD project. In this deliverable the activities undertaken to review and revise the requirements based on stakeholder and technical feedback are detailed. The requirements are presented in clear and concise tables, including both functional and non-functional requirements, with alignment to TERAPOD technology components and the responsible partner(s) assigned to each. Requirements related to THz technology standardisation and device testing and validation activities are also described.

1.2 Structure of this document

This document is laid out as follows:

- Section 1 introduces the deliverable, including its relationship with other TERAPOD deliverables and the partners who have contributed to developing the requirements of this project.
- Section 0 provides an overview of the activities undertaken to revise the use cases and requirements, along with an overview of each use case.
- Section 3 describes the detailed requirements for TERAPOD, structured according to functional, non-functional, standardisation and test/validation requirements.
- Finally, Section 4 provides conclusions and a summary of the progression of the technical requirements over the course of this project.

1.3 Relationships with other deliverables

The requirements presented in this document relate to the following deliverables:

- D2.1: This deliverable contains the initial use case specifications and requirements, which form the basis for those in this document.
- D2.2: This deliverable contains revised requirements and use case specifications based on feedback gathered throughout the project, following the same methodology and structure outlined in the previous deliverable.
- Various other technical deliverables have a relationship with this deliverable in terms of their results demonstrating that technical requirements defined in this project have progressed or are completed.

1.4 Contributors

The following partners have contributed to this deliverable:

- DER (Niamh O'Mahony, Sean Ahearne)
- TUBS (Johannes Eckhardt, Thomas Kürner)
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- VLC (Marco Garcia Porcel, Alberto Hinojosa)
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2 Revised Scenario Specifications and Identification of Requirements

Building on the previous revised requirements that were outlined in D2.2, this deliverable produces the final revision of the use case scenarios and technology requirements, with the goal of ensuring that TERAPOD technologies meet the needs of their intended market. The revisions to requirements in this iteration come mainly from two sources: (1) continued engagement with stakeholders regarding use cases and performance requirements; and (2) lessons learned from technical development efforts to date.

In the process of revising these requirements further engagement made with the stakeholders listed in D2.2 and below, presenting the work to date in TERAPOD and to gather their feedback and inputs on use cases and requirements. DER met with stakeholders from the following business units across the Dell Technologies organisation:

- Modular Data Centre (North America and Europe-based teams)
- TRIGr (Advanced Technology Research and Innovation Group) Hardware Team (Now part of the CTO Research Office)
- Dell EMC Industry Vertical CTOs (Telco, Finance, Healthcare, Intelligent Connected Vehicles)
- Technology Strategy Enablement (Datacentre)
- Dell Networking Engineering

Through continuing engagement with each of the above groups, DER gathered feedback regarding the use of TERAPOD technologies in the data centre and beyond and incorporated these into the revision of requirements, listed in Section 3. A summary of some recent feedback from these groups are outlined below.

1. The application of THz technology to perform as a semi-mobile high-speed solution for large-scale data archiving is of interest to certain verticals. This would entail a mobile data storage rack with a THz antenna that is capable or communicating with production server racks that also have THz antennas to quickly offload archived data and then move to the next rack.
2. The performance of the Uni-travelling carrier photodiode (UTC-PD) THz technology has led to interest in its potential ability to applied in conjunction with silicon photonics technology for future intra-rack (board to board) communications.
3. With full integration and automation of THz wireless links in a datacentre (DC), many network engineers believe that it is possible in the future for the majority of copper and optical cables in a DC network could be replaced with THz links, if they can meet the performance requirements.
4. The ability of THz devices to be compatible ("plug-and-play") with existing DC network infrastructure even if that reduces functionality, would be seen as a key benefit in adoption of the technology.
5. The application of THz technologies in mobile and outdoor use-cases is of great interest to some industry verticals, who are interested in those use-cases being the subject of future research.

The next step was to assess the status of the requirements previously defined in D2.2. These requirements were tabulated and organised according to the relevant TERAPOD technology components. The functionality technological progress of component development to date were compared with the revised requirements table to determine which of the requirements from D2.2 have been achieved. Where appropriate, lessons learned from progress to date were used to modify and refine the definition of requirements. The next section contains the use-case specifications which are largely unchanged but included for reference.

2.1 TERAPOD use cases

2.1.1 TERAPOD-UC01

Use Case Overview	
Use Case ID	TERAPOD-UC-01
Short name for the use case scenario	Commercial Feasibility of THz DC Wireless Networks
Descriptive full name of the use case-scenario	A thorough commercial feasibility case study of the role of THz based wireless links within data centre systems.
Goal(s)	The output will be an advanced business model canvas that has been iteratively developed and validated in collaboration with the target end user and stakeholder group.

This use case will be achieved through activities in WP2 and WP7, led by TSSG and UGLA. The requirements have not changed.

2.1.2 TERAPOD-UC02A

Use Case Overview	
Use Case ID	TERAPOD-UC-02A
Short name for the use case scenario	Static (Layer-1) THz Wireless Data Links
Descriptive full name of the use case-scenario	Integration of static THz wireless data links at the physical layer of the data centre network (DCN).
Goal(s)	Seamless integration of static THz wireless links within the DCN, with data transmission performance in the THz wireless links equalling or exceeding that in the existing wired links (i.e. whether transmission occurred through a wired or wireless link should be transparent to the rest of the system).

The goals of this use case have largely been achieved through the integration of THz wireless links within the data centre at Dell EMC in Cork, Ireland, which was demonstrated in D6.5. Performance requirements have been slightly revised from D2.2, to align with technical progress on the datacentre integration. Progress towards achieving all performance requirements from both THz devices are ongoing and are expected to be achieved for the final datacentre integration demo, D6.6. Feedback collected in D2.2 to define a requirement for the acceptable Bit-Error-Rate (BER) was collected and the requirement itself was achieved during the on-sit testing in Cork, Ireland for D6.5[1]. The benchtop demonstration by UCL continued to help to revise and define the relationship between link distance and other parameters such as BER, path attenuation, signal-to-noise ratio (SNR), power delay profile, etc.).

2.1.3 TERAPOD-UC02B

Use Case Overview	
Use Case ID	TERAPOD-UC-02B

Short name for the use case scenario	Dynamic (Multi-Layer) THz Wireless Data Link Integration
Descriptive full name of the use case-scenario	On-the-fly replacement or augmentation of wired links with THz wireless data links, integrated across multiple layers of the DCN.
Goal(s)	Reduction in congestion and/or link down-time due to the seamless provisioning of flexible THz wireless links to replace and/or augment wired links, as automatically determined by software.

Some of the requirements of this use case have been achieved through the development of appropriate simulated scenarios which were reported in D5.5. The other required network-level functionalities are currently being researched with the requirements set to be completed in the next network protocol deliverable, D5.6. Latency requirements defined in D2.2, based on VMware vCenter Server High Availability Performance and Best Practices[2], stated that THz technologies must have a maximum latency of less than 10ms to meet common DC performance requirements. This requirement was achieved based on results gathered from on-site testing in D6.5.

2.1.4 TERAPOD-UC03

Use Case Overview	
Use Case ID	TERAPOD-UC-03
Short name for the use case scenario	Wireless Data Centre Auto-Configuration
Descriptive full name of the use case-scenario	Auto-configuration of wireless networking links within a data centre, allowing flexibility, scalability and rapid deployment of replacement or additional components.
Goal(s)	Full integration of THz wireless links within the DCN, with the following features: 1. Automatic device discovery and registration when a new device is added to the network or an existing device is replaced. 2. Automatic spatial configuration of wireless links, such that a given transmitter or receiver may communicate with more than one other transmitter/receiver, through reconfiguration of its beam direction, range and other appropriate parameters.

There have been no significant updates to the requirements of TERAPO-UC-03, other than those which are inherited from the previous use cases. It has been confirmed through D6.5 that THz wireless links can integrate with existing DC network devices, providing “plug-and-play” functionality and some auto-configuration.

3 TERAPOD Revised Requirements

In this section, the requirements for TERAPOD technologies are presented. These requirements have been defined based on the needs of the use cases, lessons from the continued efforts towards developing the technologies and input from interested industry stakeholders. For the sake of clarity, the requirements have been categorised as functional (what the technology must do), non-functional (how the technology must operate), standardisation (with what standards the technology must comply) and testing/validation (what additional needs must be met to allow the technologies to be tested and/or validated). Note that the test and validation requirements are only relevant for the purposes of test/validation; these do not need to be met by the devices when they are deployed.

3.1 Functional Requirements

Table 1: TERAPOD functional requirements

Id	Requirement Description	Relevant TERAPOD Component(s)	Owner	Status	Comments
REQ -F01	Power - SBD-based detectors: No power consumption by SBDs in detectors. Power supply no larger than 1.8W is required to feed the integrated amplifiers.	SBD detector	ACST	Ongoing	
REQ -F02	Power - SBD-based mixer: No power consumption by SBDs in mixers. Most power is within the LNA and the LO. Typical requirements of the LNA would be 1.5-2W electrical power. The LO would be based in RTD or UTC-PD with similar power consumption to that previously indicated.	SBD mixer	ACST	Ongoing	To be tested with RTD/UTC in the upcoming months
REQ -F03	The package should be designed, and materials chosen such that the mm wave beam will be emitted with minimal hinderance from: - physical barriers (minimum of 90 deg beam clearance is required) - reflections - absorption	Packaging	BAY	Designed	
REQ -F04	The package will incorporate a means of fixing to a heatsink or similar	Packaging	BAY	Designed	
REQ -F05	The package design will accommodate the alignment of optical fiber to the phase distribution chip and these to the UTC PD chip array in such a way that they are fixed, and optical alignment is maintained.	Packaging	BAY	Designed	
REQ -F06	The package design will allow temperature control via a feedback element.	Packaging	BAY	Designed	
REQ -F07	Packets from layer 3 must have the structure of IP format.	NETWORK Layer	DER	Achieved	
REQ -F08	Routing algorithm is required to maximize throughput, given the available wired and wireless links.	NETWORK Layer	DER	Completed	Completed in D5.5, to be expanded in D5.6.
REQ -F09	Congestion and/or failures in the network can be detected. See also REQ-N09.	NETWORK Layer - network	DER	Partially Complete	Network fail-over completed in D5.5.

		monitoring function			Expanded with congestion detection in D5.6
REQ -F10	Dynamic load control function(s) can provision wireless THz links as required to handle high volume, high priority flow. See also REQ-N10	NETWORK Layer - load control function(s)	DER	Ongoing	To be completed in D5.6
REQ -F11	Routing algorithm must implement fail-over to wireless link when a wired link fails.	NETWORK Layer - routing algorithm	DER	Completed	Completed in D5.5, to be expanded in D5.6.
REQ -F12	Network controller can add and control new and as-yet unregistered THz wireless devices.	NETWORK Layer	DER	Ongoing	Architecture Defined in D5.6
REQ -F13	If wireless links are not successfully established, failure must be notified to higher network layers.	NETWORK Layer - Reporting	DER	Ongoing	To be completed in D5.6
REQ -F14	The MAC protocol is required to support the following functions: a. A channel access mechanism is required to support multiple nodes within a data center to support inter and intra rack communications. b. A scheduling mechanism is required to support reliable communication among the nodes. c. A method to detect antenna directionality is required while accessing a channel for link establishment (handshaking) and transmissions.	LINK Layer	TSSG	Ongoing	To be completed in D5.4 Revised to reflect functionalities required
REQ -F15	Error detection field should be inserted to data link frames.	LINK Layer	TSSG	Achieved	Results in D5.3
REQ -F16	The handshaking protocol must support the following functions: a. Support link establishment and neighbor discovery with low delay and message overhead. b. Support for directional (beam-steering) antenna	LINK Layer	TSSG	Ongoing	To be completed in D5.4 Revised to reflect functionalities required
REQ -F17	Packet buffer is required.	LINK Layer	TSSG	Achieved	Modelling done
REQ -F18	An auto-configuration function is required to guarantee a THz link's data rate and reliability	LINK Layer	TSSG	Ongoing	To be defined in D5.4 Revised to reflect functionality required
REQ -F19	A function to detect link obstacle or LOS blockage by monitoring the link for packet or frame loss is required	LINK Layer	TSSG	Ongoing	To be completed in D5.4 Achieved for path diversity Revised to reflect functionality required

REQ-F20	A neighbor discovery protocol is required, required functions are: a. Detect nearby THz devices and maintain a neighbor table. b. Auto-detection of new THZ nodes. c. Node position should be included for a positioning map of all available nodes within a data center. d. A method to define the indoor node coordinates	LINK Layer - Neighbor Discovery Protocol	TSSG/DER	Ongoing	To be completed in D5.6 as an SDN solution and to be completed in D5.4 as a stand-alone solution This functional requirement has been merged with F21 and F22 Defined in D2.2
REQ-F21	Node position should be inserted in control message header to be included in the neighbor table to define the positioning map of all available nodes within a data center.	LINK Layer - Positioning Protocol	TSSG	Merged	Merged with REQ-F20
REQ-F22	Method to define the indoor node coordinates is required.	LINK Layer - Positioning Protocol	TSSG	Merged	Merged with REQ-F20
REQ-F23	Interface is required between data link and network layers for message exchange to optimize resources and link parameters	LINK & NETWORK Layers	TSSG/DER	Ongoing	To be completed in D5.6
REQ-F24	Interface is required between physical and data link layers for message exchange to optimize resources and link parameters	PHYS & LINK Layers	TUBS	Ongoing	Structure created, data shared and unified across both layers
REQ-F25	Power - UTC-PD: Typical 2V bias (about 2mW total electrical), a typical laser LO (200mW electrical) and Peltier cooling (<100 mW electrical at typical operation).	UTC-PD	UCL	Achieved	LO power - 40 mW
REQ-F26	For the data center demonstrator, the wireless transmitter and receiver must be transparent to DELL's optical network: the Tx THz box must take as an input the optical signal from DELL's optical transceivers and the Rx THz box must generate as output this same signal at a suitable wavelength (i.e., within the optical bandwidth of DELL's transceivers).	UTC-PD	UCL	Achieved	
REQ-F27	Modulation of the signal will be done at the laser source. The photonic phase distribution circuit does not include modulation capabilities.	UTC-PD Laser Source	UCL	Achieved	
REQ-F28	UTC-PD and/or RTD must act as LO for SBD heterodyne mixer.	UTC-PD/RTD & SBD mixer	UCL/UGLA/ACST	Ongoing	To be tested with RTD/UTC in the upcoming months
REQ-F29	Electrical interface is required from TERAPOD wireless THz transceivers (E-RTD and SBD envelope detector).	RTD & SBD detector	UGLA	Achieved	

REQ -F30	On-chip antenna is required for UGLA 300 GHz technology	Slot bow-tie antenna; Broadband monopole antenna; Circular slot antenna	UGLA	Packaged; DC testing complete; RF testing not complete.	Currently in progress, will be tested as part of packaged device for D6.6
REQ -F31	A method to increase the scanning range of THz wireless antennas is required, for example using a phased array antenna.	Phased array antenna	VLC	Achieved	Phase array antenna with -45° to +45° scanning range designed

3.2 Non-functional Requirements

Table 2: TERAPOD non-functional requirements

Id	Requirement Description	Relevant TERAPOD Component(s)	Owner	Status	Comments
REQ -N01	The design of the photonic integrated circuit must be capable of being packaged.		BAY	Designed	
REQ -N02	The position of the thermistor (the feedback element) will be close to the active component(s).	Packaging	BAY	Designed	
REQ -N03	The preferred package connections must be of a ‘standard’ configuration (pin pitch, size and finish)	Packaging	BAY	Designed	
REQ -N04	The choice of and amount of fixing adhesive for (in particular) the UTC-PD chip requires zero to very thin underfill.	Packaging	BAY	Designed	
REQ -N05	Latency for a point-to-point wireless connection must not exceed 10ms.	NETWORK Layer - Datacenter Services	DER	Completed	Completed in D6.5
REQ -N06	Reduce network congestion by 10-50% (this target will be refined in later iterations of the TERAPOD requirements, considering the nature of the congestion and other factors).	NETWORK Layer - Datacenter Services	DER	Completed	Completed in D5.5, to be expanded in D5.6
REQ -N07	Controller must be capable of reconfiguring and establishing new wireless links in less than 1000ms	NETWORK Layer - link establishment	DER	Ongoing	To be completed in D6.6 Revised definition
REQ -N08	Security for wireless links	N/A	DER	Out of scope	

REQ -N09	Congestion and/or failures detection: a. Network monitoring function will detect congestion when the following conditions occur: jitter >= 50ms; packet loss >= 0.5% b. Network monitoring function will detect congestion within 1000 ms of the relevant conditions occurring. c. Network monitoring function will detect a link failure when the link has been unresponsive for 250 ms.	NETWORK Layer - network monitoring function	DER	Ongoing	To be completed in D5.6 Revised for more realistic performance targets
REQ -N10	Dynamic load control: Controller must be capable of reconfiguring wireless links in response to high traffic volume in less than 1000ms	NETWORK Layer - load control function(s)	DER	Ongoing	To be completed in D5.6
REQ -N11	The modulation and coding format must guarantee that the maximum permitted BER for the targeted data, from an end-user's point of view, not be exceeded.	MAC/PHY Layer - Link QoS	DER/UCL	Achieved	
REQ -N12	Link modelling and network design must be based on realistic measurements, and existing network element arrangement (racks, inter-rack distance, rack height, path loss etc.).	MAC/PHY Layer	TSSG	Ongoing	All simulations are using realistic parameters, will be completed in WP5 and Simulator Demonstrator
REQ -N13	Media Access Control (MAC) protocol for transmission via wireless THz link should be able to achieve burst data rates found in a datacenter network (up to 100 Gb/s).	MAC Layer	TSSG	Ongoing	To be completed in D5.4 Revised definition
REQ -N14	MAC Layer should report to the controller when a link failure occurs	MAC/NETWORK Layer - Reporting	TSSG	Out of scope	Will be detected by the network layer
REQ -N15	Antenna scanning range must be 90° (-45°, +45°) or greater.	All Antenna components	TSSG/INESC	Achieved	
REQ -N16	If Forward Error Correction (FEC) is used, BER must be below FEC limits (BER < 2·10-2 for SD-FEC (20% over-head) or BER < 3.8·10-3 for HD-FEC (7% over-head)) before FEC decoding and 1x10-10 after.	MAC/PHY Layer	TSSG/UCL	Achieved	
REQ -N17	If no FEC is used, BER must be below 1x10-10.	MAC Layer	DER/UCL	Achieved	Completed in D6.5
REQ -N18	Transmitted power must not exceed 10mW for safety limits for persons within the data center and/or in surrounding area	All Tx components	TUBS/NPL/UCL/UGLA	Achieved	RTD and UTC-PD Tx powers are currently below 1mW
REQ -N19	Transmission must not interfere with other electronic equipment operating within the data center and/or in surrounding areas.	All Tx components	TUBS	Out of scope	Out of scope as Tx power from current devices is too low to cause any measurable electronic interference

REQ -N20	Transmission must be possible through semi-transparent "curtains" which separate hot and cold aisles within data center.	All Tx components	TUBS	Achieved	Confirmed in TUBS measurement campaign.
REQ -N21	An Equivalent Isotropic Radiated Power (EIRP) of 26 dBm is required so that the received power is always higher than the device sensitivity. EIRP chosen based on field measurements and antenna characteristics.	All Tx/Rx components	TUBS/INESC	Ongoing	
REQ -N22	Antenna side lobe level must be greater than 10dBm, maintaining the necessary gain and steering range.	All Antenna components	TUBS/INESC	Ongoing	
REQ -N23	Data rate >= 10 Gb/s for typical compute and storage traffic	UTC-PD	UCL	Benchtop - achieved; Demo ongoing	To be completed in D6.6 - Sean
REQ -N24	Data rate >= 25 Gb/s for real time analytics platform traffic	UTC-PD	UCL	Benchtop - achieved; Demo ongoing	Aim to complete for D6.6
REQ -N25	Laser source: The coupling must be optimal for all the possible wavelengths at C-Band.	UTC-PD	UCL	Achieved	
REQ -N26	Laser LO: laser LO must offer some degree of wavelength tuneability in order to have some control over the wireless frequency. This wavelength tuneability must also enable a wavelength offset from the signal laser of around 2.4 nm, which in the C-band corresponds to 300 GHz.	UTC-PD	UCL	Achieved	
REQ -N27	Bandwidth must be high enough that the minimum required data rate is achieved. - 40 Gbps using 16-QAM (4 bits/symbol) and 10% roll-off: 11 GHz (already demonstrated in benchtop) - 100 Gbps using 16-QAM (4 bits/symbol) and 10% roll-off: 27.5 GHz - 100 Gbps using 64-QAM (6 bits/symbol) and 10% roll-off: 18.3 GHz	UTC-PD	UCL/INESC	Achieved	
REQ -N28	Transmit power must be high enough that transmission is possible at a range of 4.5m through plastic curtains as these conditions are found in a datacenter environment.	All Tx components	UCL/UGLA	Ongoing	Redefined with conditions, will be tested with UTC and RTD in characterization and on-site testing
REQ -N29	Data rate >= 1 Gb/s for host management traffic	RTD	UGLA	Benchtop - achieved; Demo ongoing	To be completed in D6.6 - Sean

REQ-N30	Achieve power consumption of 100 mW for 300 GHz RTD source.	RTD	UGLA	Achieved	Changed from 50 to 100 mW as close to SoTA, focus on packaging devices over lower power consumption
REQ-N31	Power consumption per capacity of data center must not increase with the deployment of THz wireless links	All HW and SW components	UGLA / DER	Ongoing	Comparison of RTD power usage vs traditional optical SFP to be performed for D6.6
REQ-N32	Laser source: The power delivered by the laser will be delayed between different elements of the array.	UTC-PD	VLC	Achieved	
REQ-N33	Laser source: The power delivered by the laser will be divided between different elements of the array.	UTC-PD	VLC	Achieved	

3.3 Standardisation Requirements

Table 3: TERAPOD standardisation requirements

Id	Requirement Description	Relevant TERAPOD Component(s)	Owner	Status	Comments
REQ-S01	A license to access the 300GHz spectrum must be acquired.	All Tx/Rx components	TSSG	Achieved	
REQ-S02	The Physical Layer must comply with the requirements stated in the Std. IEEE 802.15.3dTM-2017.	PHYS Layer	TUBS	Achieved	Will be reported in D5.2
REQ-S03	The whole TERAPOD wireless communication system must comply with the IEEE 802.15.3dTM-2017 standard regarding operation frequency, modulation bandwidth, output power, etc.	All components	TUBS/ HW partners	Ongoing	Included as part of the global parameter list used for simulation and testing
REQ-S04	MAC technologies must conform to a new standard IEEE P802.1ACct, when it becomes available.	LINK Layer	TUBS/TSSG	Out of Scope	Due to issues outside of TERAPOD's influence, the publication of this standard has been delayed until after completion of TERAPOD
REQ-S05	TERAPOD technologies must comply with any relevant regulations that may be enacted following Agenda Item 1.15 of the World Radio Conference (WRC-19), addressing the allocation of spectrum above 275 GHz in November 2019. The THz communication bands are:	All components	TUBS	Ongoing	Updated with permitted bands. UTC and RTD Tx frequency can be tuned to comply with these bands

	275-296 GHz, 306-313 GHz, 318-333 GHz and 356-450 GHz				
REQ-S06	TERAPOD technologies must meet the reference levels for general public exposure to time-varying electric and magnetic fields, which is given for frequencies from 2 GHz to 300 GHz as 10 W/m², as published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).	All Tx components	TUBS	Achieved	

3.4 Test and Validation Requirements

Table 4: TERAPOD test and validation requirements

Id	Requirement Description	Relevant TERAPOD Component(s)	Owner	Status	Comments
REQ-T01	Devices must be configured for free-space operation (e.g. with antennas or lenses).	All Tx/Rx components	UCL/ UGLA/ INESC	Achieved	
REQ-T02	Devices must be packaged and portable.	All HW components	BAY	Ongoing	Achieved for UTC Achieved for W-band RTD, in progress for 300Ghz RTD
REQ-T03	Standard connectors must be provided for power supplies, as needed.	All HW components	UCL/ UGLA/ INESC/ ACST	Achieved	Yes, from all partners
REQ-T04	Standard connectors must be provided for any necessary inputs.	All HW components	UCL/ UGLA/ INESC/ ACST	Achieved	Yes, from all partners
REQ-T05	Due to the limitations of power detectors, the minimum emitted power must be at least 10 μW, and preferably 100 μW.	All Tx components	UCL/ UGLA	Ongoing for packaged modules	60uw @ 300Ghz unpackaged, 6uw packaged for UTC-PD 500uw @ 300Ghz, to be characterized for packaged - RTD Correct as of 25/02/2020

REQ-T06	Due to the lack of high-power sources, the minimum power level detectable by the SBD receiver with acceptable SNR (>10) must be no less than 10 uW, and preferably 50 uW.	All Rx components	UCL /UGLA /INESC /ACST	Ongoing	Revised to improve definition, to be tested in the coming months
REQ-T07	Design requirements for the environmental test chamber: • Length: Minimum: 1 m; Maximum: 10 m • Humidity range: 20% - 80% RH. • Temperature range: 18 – 27 deg C. • Air turbulence/ noise: Initial testing in the environmental chamber will use a variable speed fan to create a range of turbulence conditions; Characterisation of air turbulence within the data centre must be investigated further. • Wall reflectivity: 1 (metallic); <0.05 (anechoic); typical walls – variable; Semi-reflective wall panels will be made from materials similar to actual wall coatings in a DC, in order to replicate both reflections and scattering of the THz beams.	Environmental test chamber	NPL	Achieved	
REQ-T08	The test chamber will be designed to have changeable wall linings that can be varied from wholly absorbing (anechoic) to partially reflecting/scattering (emulating indoor walls) to wholly reflecting (metallic)	Environmental test chamber	NPL	Not required	we now have seen that we don't get reflections from the walls into the detector – which makes these wall panels entirely irrelevant

4 Conclusion/Further work

In this document, the TERAPOD use cases, and their detailed requirements have been finalized. These requirements represent and motivate the technology development efforts for the TERAPOD project, and each requirement has been assigned to the partner(s) responsible for ensuring that it is achieved and aligned to the relevant technology component. Progress has been made towards achieving the requirements outlined, with significant progress made since D2.2. This progression is expected to continue with the majority if not all requirements expected to be achieved by the end of the project.

5 References

[1] Dawe, P. et al. (2003). *Error Rates and Testability.* [online] Ieee802.org. Available at: http://www.ieee802.org/3/efm/public/may03/optics/dawe_optics_1_0503.pdf [Accessed 20 Feb. 2020].

[2] VMWare (2016). *VMWare VCenter server high availability performance and best practices*. [online] Available at: https://www.vmware.com/content/dam/digitalmarketing/vmware/en/pdf/techpaper/vcha65-perf.pdf [Accessed 20 Feb. 2020].