WORTECS

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List of Acronyms

Acronym	Meaning
CSD	Criteria for standards development
DCF	Distributed coordination function
DLL	Data Link Layer
EMI	Electromagnetic interference
HCF	Hybrid coordination function
IEEE	Institute of Electrical and Electronics Engineers
ITU	International Telecommunication Union
ITU-T	ITU Telecommunication Standardization Sector
LAN	Local Area Network
LC	Light Communication
LiFi	Light Fidelity
MAC	Media Access Control
MAN	Metropolitan Area Network
MIMO	Multiple Input Multiple Output
OBSS	Overlapping basic service set
PAR	Project authorisation request
PHY	Physical layer
SAP	Service access point
TGbb	802.11bb task group
Wi-Fi	Wireless Fidelity
WORTECS	Wireless Optical/Radio TErabit CommunicationS

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1. Background

1.1. OWC

There are currently three standardisation efforts underway in LiFi. The International Telecommunications Union (ITU) has recently completed a LiFi standard ITU G.9991 (also known as G.vlc). In the IEEE there is a revision to the IEEE 802.15.7 standard underway, with two new efforts in camera communications (IEEE P802.15.7m) and high-speed communcations (IEEE802.15.13). This document focuses on the effort within IEEE 802.11 (802.11.bb), which is where WiFi standards are placed. WORTECS partner PLF plays a key role in this effort whereas partner OLD plans to get more involved in this process. An overview of the ITU telecommunication standardization sector (ITU-T) G.vlc set of specifications is also given.

IEEE 802.11

IEEE 802.11 is a set of media access control (MAC) and physical layer (PHY) specifications for implementing wireless local area network (WLAN) computer communication in the 900 MHz and 2.4, 3.6, 5, and 60 GHz frequency bands. They are created and maintained by the Institute of Electrical and Electronics Engineers (IEEE) LAN/MAN Standards Committee (IEEE 802). The base version of the standard was released in 1997 and has had subsequent amendments. The standard and amendments provide the basis for wireless network products commonly recognized as Wi-Fi©. In November 2016, the IEEE 802.11 created a Topic Interest Group on Light Communication (LC), later named TGbb, with a target to integrate this new physical link, i.e., LC, into the next evolution of the Standard.

IEEE 802.11 TGbb

IEEE 802.11 TGbb focuses on the development of Light Communications (LC or LiFi) with broad industry support from a comprehensive ecosystem of partners including chipset vendors, infrastructure providers, device manufacturers, lighting companies, telecom operators and end customers. Key envisioned use-cases are the mass market deployment in enterprise, homes, manufacturing and more as part of a truly heterogeneous network.
The following items were originally envisaged to be addressed by TGbb during the standard development process:

- Integration with and extension to 802.11 MAC
- Low-latency data delivery
- Asymmetric device capability support (power, directivity, wavelength, sensitivity, backhaul network latency timings, etc.)
- Peer-to-peer communications

One important motivation behind 802.11 TGbb initiative, as an amendment to the 802.11 standard, was the reuse of 802.11 MAC. From the beginning, the expectation was that the LC protocol can reuse the existing facilities within 802.11, such as distributed coordination function (DCF), power save modes, session establishment/tear down procedure and block acknowledgement, etc. However, the idea is to suggest specific modifications for the operation of LC that could improve the efficiency for particular implementations. In this context, LiFi specific system or scenario design considerations are identified and carefully investigated. As an example, in LiFi scenarios the station may not necessarily see interference from neighbouring stations, which will have design modification consequences.

802.11 TGbb key features

One important motivation behind 802.11 TGbb initiative, as an amendment to the 802.11 standard, was the reuse of 802.11 MAC. From the beginning, the expectation was that the LC protocol can reuse the existing facilities within 802.11, such as distributed coordination function (DCF), power save modes, session establishment/tear down procedure and block acknowledgement, etc. However, the idea is to suggest specific modifications for the operation of LC that could improve the efficiency for particular implementations. In this context, LiFi specific system or scenario design considerations are identified and carefully investigated. As an example, in LiFi scenarios the station may not necessarily see interference from neighbouring stations, which will have design modification consequences.

From the proposed Criteria for Standards Development (CSD) suggested by the IEEE 802.11 Study Group, the following key features are extracted:

- The difference between LC and the existing 802 light communications standards is the use of the 802.11 MAC as well as the reuse of associated services that are focused on wireless local area networks. This new approach will allow LC that are focused on local wireless area networks. This is in contrast to the existing (802.15.7m and 802.15.13) efforts that are focusing on deploying the technology for wireless specialty networks which have less challenging requirements on energy efficiency, form factor and cost.
- Tight integration with 802.11, the coexistence and hand-over with other 802.11 PHY types (Fast-Session Transfer). This will reduce time-to-market for LC in its potential large-volume applications, (such as when combined with lighting). Similar to the differences between the work on 60 GHz done within 802.15 and within 802.11, the use of the light spectrum with 802.11 technologies will address new use-cases having much larger volumes, in addition to the existing use-cases targeted by 802.15. Determining the technical specifications of LC in 802.11 is the primary objective of the proposed task group on LC in 802.11.
- The key difference between the ITU-T G.vlc effort compared to the proposed 802.11 LC amendment is the use of the 802.11 MAC as well as the targeted deployment of the technology in Enterprise environments, EMI sensitive environments in contrast with the focused home networking use-case for the G.vlc standardization work.

The following specifications were approved by the IEEE Standards Association Standards Board which are derived from the Project Authorization Request (PAR) highlighting the specific changes that the TGbb committee is allowed to consider.

- The amendment specifies a PHY that provides:
    - Uplink and downlink operations in an optical wavelength band from 380 nm to 5,000 nm
    - All modes of operation to achieve minimum single-link throughput of 10 Mbps and at least one mode of operation that achieves single-link throughput of at least 5 Gbps, as measured at the MAC data service access point (SAP),
    - Interoperability among solid state light sources with different modulation bandwidths.
- The amendment specifies changes to the IEEE 802.11 MAC that are limited to the following:
    - Hybrid coordination function (HCF) channel access,
    - Overlapping basic service set (OBSS) detection and coexistence,
    - Existing power management modes of operation (excluding new modes),

  - Modifications to other clauses necessary to support the above changes.
- LC systems are expected to adhere to regulation and standards such as IEC 62471:2006 - "Photobiological safety of lamps and lamp systems" as well as ITU G.664 - "Optical Safety Procedures and Requirements for Optical Transmission Systems" and others. In addition, LC systems are expected to not create any additional electromagnetic interference.
- The project will address the security of the transition between the new LC PHY and the existing 802.11 PHYs as well as the security implications in supporting Fast Session Transfer.

ITU-T G.hn and G.vlc

The ITU-T is part of the ITU and in charge of producing recommendations for all fields of information and communication technology, from video compression to network transport layers. In particular, the ITU-T has produced over the past two decades several recommendations for home networking over existing coaxial cables, telephone wiring, power lines or plastic optical fiber. This work started in 2001 with the approval of recommendation G.9951 for phoneline networking transceivers, and has progressively led to the G.hn set of specifications.
The G.hn specification is composed of several recommendations: G.9960 for system architecture and PHY, G.9961 for data link layer (DLL), G.9963 for multiple input multiple output (MIMO) extension and G.9964 for power spectral density specifications. The approval of these recommendations has been followed by the production of dedicated semiconductors by several vendors so that G.hn is now being implemented in different applications. Besides home networking, G.hn deployment is driven by factory and industrial applications, for example robot communication, and by in-car communication.
In parallel, the G.hn PHY layer has been found to be very convenient for LC so that several players in the field are using this technology. The ITU-T acknowledged this trend by approving in March 2019 the G.9991 recommendation, which forms, together with the G.9961, G.9963 and G.9964 recommendations, the G.vlc set of specifications for LC. In practice, G.9991 is very close to G.9960 so that G.vlc offers the same convenient PHY design as G.hn with a maximum achievable data rate of 2 Gbps.
However, G.vlc uses the same DLL as G.hn, which is not primarily designed for wireless communication applications. Therefore, mobility and access point handover is not as easily supported with G.vlc as with an IEEE 802.11-based MAC, although such a feature could be included in future recommendations. It may indeed be that the ITU-T has a mode of operation more flexible than the IEEE as there is no need for a PAR to start new recommendations. However, the ecosystem currently in place around the G.vlc is definitely less oriented toward mass market than the IEEE ecosystem. G.vlc also does not allow at the moment inter-operability between WiFi and LC, which is one of the goals of TGbb.

1.2. RF

IEEE 802.15.3d

In 2008 the IEEE 802.15 interest group IG THz was established. The main focus of this group is on communications in the THz frequencies, especially in the bands between 275-3000 GHz. The first IEEE 802 project towards 100 Gbps approved in 2014 was Task Group IEEE 802.15.3d. This project was a spin off from IEEE 802.15 IG THz. This project standardized wireless point to point physical layer for a nominal data rate of 100 Gbps in the bands from 252 GHz to 325 GHz. The IEEE 802.15.3d standard was approved on 28th September 2017. This standard defines new PHY for IEEE 802.15.3-2016, MAC based on

IEEE 802.15.3e-2017, 8 different channel bandwidths, 2 different PHY modes with 7 modulation schemes (6 quadrature and OOK) as well as 3 channel coding schemes [1][2].

References

[1] IEEE Std 802.15.3d™-2017, Amendment to IEEE Std 802.15.3™-2016 as amended by IEEE Std 802.15.3e™-2017

[2] Thomas Kürner, Sebastian Rey, “IEEE 802.15.3d and other activities related to THz Communications. Where to go next?”, Towards Terahertz Communications Workshop, European Commission, 7 March 2018

2. Period I – Review of key actions

2.1. OWC

The key actions listed in Deliverable 5.2 (Period I standardisation report) for Period II were as follow:

1. Continue attendance of WORTECS partners to Standardisation meetings. It was planned to attend the following meetings throughout Period II:

In 2018		Session	Type
January 14-19	Hotel Irvine, Irvine, CA, USA	167	Interim*
March 4-9	Hyatt Regency O'Hare, Rosemont, Illinois, USA	168	Plenary
May 6-11	Mariott Hotel, Warsaw, Poland	169	Interim*
July 8-13	Manchester Grand Hyatt, San Diego, CA, USA	170	Plenary
September 9-14	Hilton Waikoloa Village, Kona, HI, USA	171	Interim*
November 11-16	Marriott Marquis Queen's Park, Bangkok, Thailand	172	Plenary

In 2019		Session	Type
January	St. Louis, Missouri, USA	173	Interim*
March 10-15	Hyatt Regency Vancouver and Fairmont Hotel Vancouver, Vancouver, Canada	174	Plenary
May 12-17	Grand Hyatt Atlanta in Buckhead, Atlanta, Georgia, USA	175	Interim*
July 14-19	Austria Congress Centre, Vienna, Austria	176	Plenary
September 15-20	Marriott Hanoi, Hanoi, Vietnam	177	Interim*
November 10-15	Hilton Waikoloa Village, Kona, HI, USA	178	Plenary

2. Provide updates to consortium members about the progress of the relevant standards at the face to face and phone meeting. **Status:** Updates given at all project meetings
3. Prepare a presentation of WORTECs architectures and technical contributions for presentation to the IEEE WNG group and other relevant working groups. This will allow WORTECS technologies to be ‘showcased’, ensuring their relevance for future standards. **Status:** Delayed until period III (year 3) to allow results to be showcased.

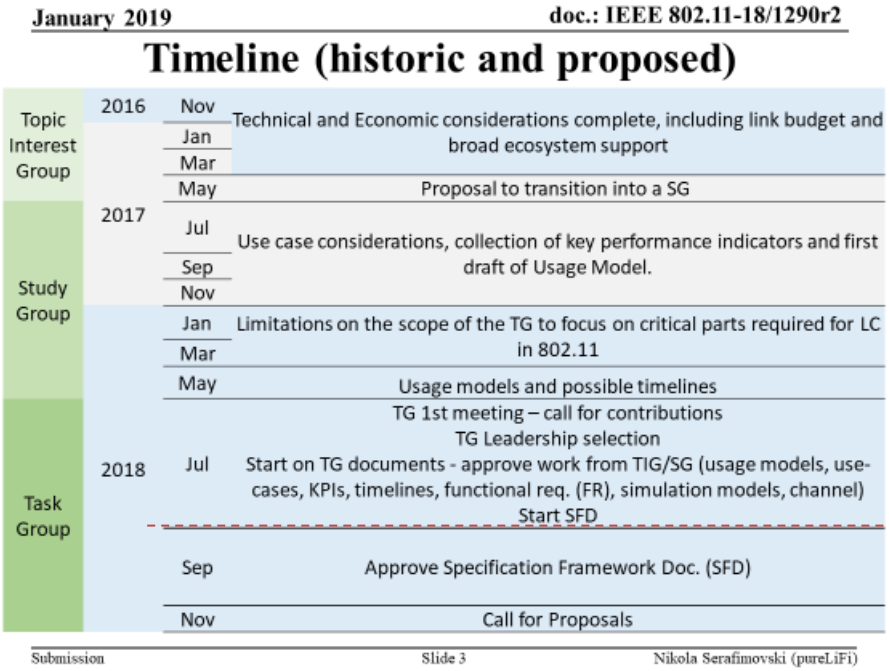
3. Period II – Roadmap and proactive contributions

This section details the envisaged roadmap and the predicted contributions for period II, as seen at the beginning of period II.

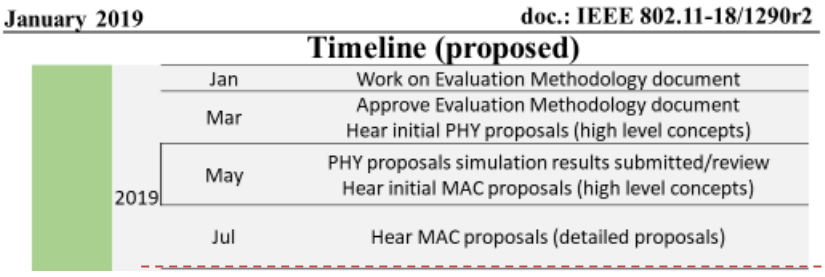
3.1. OWC

3.1.1. 802.11 TGbb roadmap

The following timeline was envisaged for the 2018-2019 period.



Start of period II



End of period II

3.1.2. 802.11 TGbb planned proactive contributions

The following list details pureLiFi's planned contributions to the 802.11bb standardisation process during period II of the WORTECS project:

- Develop and agree the use cases
    - TGbb needs to find out suitable scenarios for LC coming into use as a communication technology. Use cases are selected to demonstrate the advantages of using LC.
- Develop and agree the usage models derived from the use cases

- A number of usage models are provided to help guide standardization effort. A usage model is the combination of Pre-Conditions (Initial conditions before the use case begins), Environment (The type of place in which the network of the use case is deployed, such as home, outdoor, hot spot, enterprise, metropolitan area, etc.), Application (A source and/or sink of wireless data that relates to a particular type of user activity. Examples are streaming video and VoIP.), Traffic Conditions (General background traffic or interference that is expected while the use case steps are occurring. Overlapping BSSs, existing video streams, and interference from cordless phones are all examples of traffic conditions.) and Use case (– A use case is task oriented. It describes the specific step-by-step actions performed by a user or device. One use case example is a user starting and stopping a video stream.)

- Develop and agree the channel models
  - A realistic visible light communication channel model should take into account the effect of wavelength dependency, realistic light sources as well as different types of reflections such as specular and mixed cases of diffuse and specular. Channel models for different scenarios in terms of LC use cases are needed for the research purpose of later stage of the standard development.
- Develop and agree the evaluation methodology for PHY and MAC
  - The evaluation methodology specifies choice of process for simulation scenarios, parameters to be used, analytical front-end model, and metrics to measure in the simulations.
- Develop and agree the functional requirements
  - The functional requirements propose requirements for solutions addressing functionality to be provided by the IEEE 802.11bb amendment, referred to as the TGbb Functional Requirements.
- Develop and agree technical submissions (proposed PHY modifications, proposed MAC modifications)
  - This involves lots of activities such as new proposals for PHY/MAC modifications towards the aim of the PAR, discussions on the proposals, providing more system performance or simulation results to illustrate the benefits of the proposals.
- Develop and agree specification framework
  - The specification framework provides the framework from which the draft TGbb amendment will be developed. The document provides an outline of each the functional blocks that will be a part of the final amendment. The

document is intended to reflect the working consensus of the group on the broad outline for the draft specification.

3.1.3. Contributions during period II

This section details the contributions of pureLiFi to the 802.11bb standardisation process during period II.

802.11bb

pureLiFi has authored or co-authored the following documents:

- Proposed simulation scenarios. (https://mentor.ieee.org/802.11/dcn/18/11-18-1423-08-00bb-tgbb-simulation-scenarios.docx)
- Commented on simuation scenarios contributions. (https://mentor.ieee.org/802.11/dcn/18/11-18-1700-00-00bb-comments-against-simulation-scenario-document.docx and https://mentor.ieee.org/802.11/dcn/18/11-18-1760-04-00bb-comments-tgbb-simulation-scenarios.xlsx)
- Proposed evaluation methodology (https://mentor.ieee.org/802.11/dcn/18/11-18-1429-04-00bb-evaluation-methodology-docx.docx)
- Provided the process document outlining the selection and operation procedure for technical contributions presented within TGbb.(https://mentor.ieee.org/802.11/dcn/18/11-18-2036-01-00bb-tgbb-process-document.pptx)
- Proposed time line for TGbb. (https://mentor.ieee.org/802.11/dcn/18/11-18-1290-03-00bb-timeline-for-lg-tg.ppt)
- Proposed PHY evaluation methodology simulation calibration. (https://mentor.ieee.org/802.11/dcn/19/11-19-0272-01-00bb-phy-evaluation-methodology-simulation-calibration.docx and https://mentor.ieee.org/802.11/dcn/19/11-19-0877-00-00bb-updated-phy-evaluation-framework.docx)
- Proposedd way forward on TGbb PHY. This presentation aims to provide an overview on how to gradually integrate the physical layer capability for LC into 802.11. (https://mentor.ieee.org/802.11/dcn/19/11-19-0388-00-00bb-proposed-way-forward-on-phy-in-tgbb.pptx)
- Contributed to the Call for Proposals IEEE 802.11bb Task Group. (https://mentor.ieee.org/802.11/dcn/18/11-18-2039-03-00bb-tgbb-call-for-proposals.doc)

- Proposed evaluation methodology for PHY (https://mentor.ieee.org/802.11/dcn/19/11-19-0187-04-00bb-evaluation-methodology-for-phy-and-mac-proposals.docx)
- Proposed MAC channel access features for TGbb. (https://mentor.ieee.org/802.11/dcn/19/11-19-0846-01-00bb-proposed-mac-channel-access-features-for-tgbb-pptx.pptx)
- Proposed PHY pre-proposals and collect feedbacks in the IEEE meetings. (https://mentor.ieee.org/802.11/dcn/19/11-19-0847-01-00bb-proposed-phy-for-tgbb-pptx.pptx)
- Presented PHY simulation results for TGbb are submitted. (https://mentor.ieee.org/802.11/dcn/19/11-19-1224-01-00bb-simulation-results-for-802-11a-phy-in-lc.ppt)
- Proposed the Evaluation Methodology for the MAC. (https://mentor.ieee.org/802.11/dcn/19/11-19-0848-02-00bb-proposed-evaluation-methodology-for-mac-proposals-docx.docx)
- Link Performance Models for System Level Simulations has been provided to the group. (https://mentor.ieee.org/802.11/dcn/19/11-19-1000-01-00bb-mac-evaluation-simulation-method.docx)
- Proposed common PHY mode. (https://mentor.ieee.org/802.11/dcn/19/11-19-1206-01-00bb-proposed-common-mode-phy-for-tgbb.pptx)

Oledcomm has co-authored the following document:

- LC-optimized PHY proposal for TGbb. (https://mentor.ieee.org/802.11/dcn/19/11-19-1053-02-00bb-lc-optimized-phy-proposal-for-tgbb.pptx)

3.2. RF

3.2.1. 802.15.3d roadmap and proactive contributions

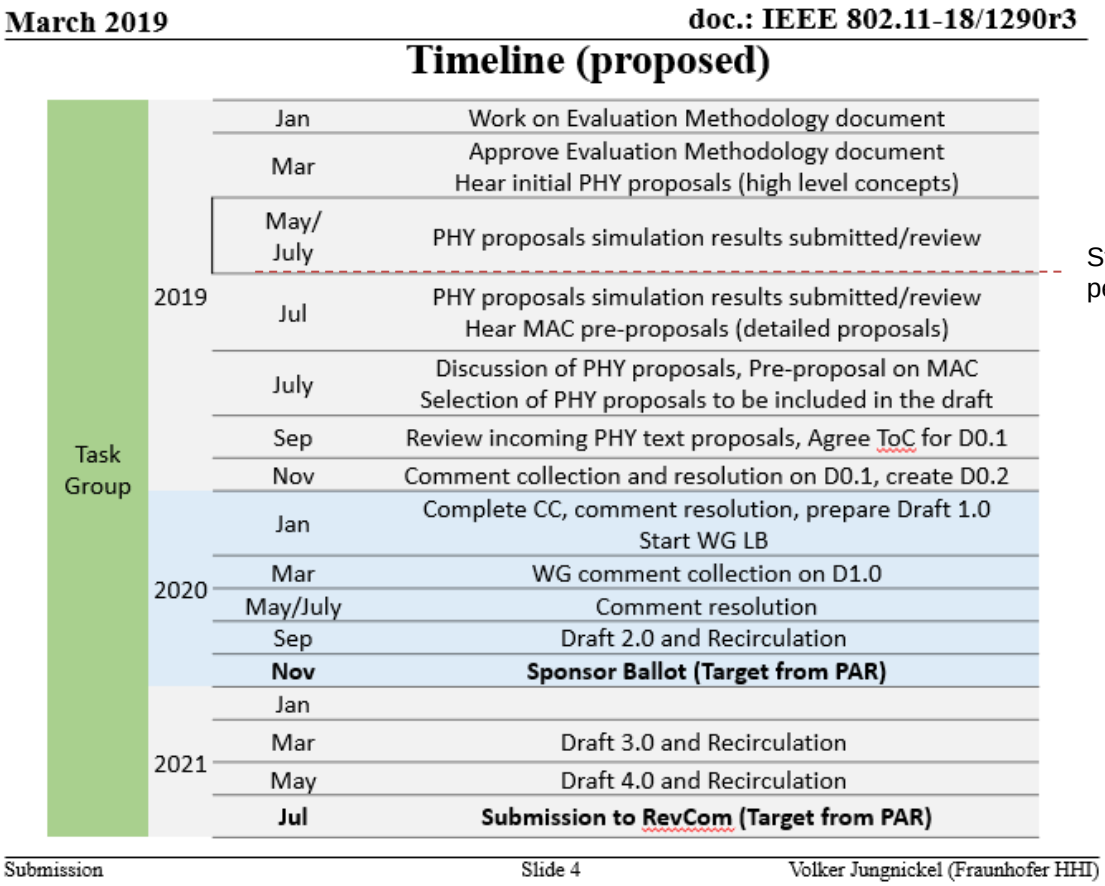
At the moment, IHP is designing and producing the terahertz chips. Some parts of the chips are produced and tested. They are being integrated in the main transceiver chip which is not yet fully finished.
In the period II the main activities would be monitoring of the activities of the IEEE 802.15 TAG. There is no new THz standard development where WORTECS can actively contribute.

4. Period III – Roadmap and proactive contributions

4.1. OWC

4.1.1. 802.11bb roadmap

The following timeline is proposed for the 802.11 TGbb for Period III:



4.1.2. 802.11bb proactive contributions

The following contributions are planned during period III of the project:

- MAC evaluation methodology
    - In order to demonstrate the simulation results for MAC designs, a systematic guidance and requirements are to be developed and agreed. All measurement shall be done under the same assumptions and requirements.
- Common mode PHY submission
    - The group is seeking a common PHY mode which will be the default PHY mode whenever the station is powered on or loses connection due to any failure.
- Common mode MAC proposal

- The group is seeking a common MAC mode which will be the default MAC mode whenever the station is powered on or loses connection due to any failure.

- Prepare simulation results for MAC proposals
  - Following the lead of MAC evaluation methodology, the proposers shall provide simualtion results for their proposed MAC schemes in order to demonstrate the performance of the proposals in specific scenarios.

4.1.3. Other standardisation related activities

- Initial contacts have been made with the ELIOT (Enhanced Lighting for the Internet of Things) project, which contains partners involved in IEEE 802.15.13 and ITU G.vlc efforts, and further conversations are planned for period III. Whilst there are no specific aims this will allow a greater understanding of the standardisation landscape.
- The presentation on WORTECS capabilities to the IEEE WNG delayed from period II will be undertaken in period III.

4.2. RF

4.2.1. IEEE 802.15 TAG roadmap and proactive contributions

For the period III, IHP is planning to contribute to the IEEE 802.15 TAG, since the future plans of this group are strongly aligned with the WORTECS activities [2]. The IEEE 802.15 TAG is monitoring the progress in the THz communications in order to evaluate the possibility for forming new Study Groups for applications like WLAN, requiring beam steering or advanced methods for device discovery.

In the period III, the beam steering chips for frequencies of 240 GHz should be produced at IHP and should be also measured. These results can be presented in the IEEE 802.15 TAG. Additionally, the other 240 GHz circuits developed under the WORTECS project can be presented on of the IEEE 802 meetings.

At this moment, the IEEE 802.15 TAG meeting plans are not published, therefore, no precise time schedule can be proposed for period III.