**IEEE P802.15**

**Wireless Personal Area Networks**

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| Re: | [Extends content of 15-16-0636-00-0000] |
| Abstract | [This document describes the intended objectives of the Interest Group on Low Power Wide Area (LPWA) Networks] |
| Purpose | [Information on activities within IG LPWA] |
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# Introduction to Low Power Wide Area (LPWA) Networks

State-of-the-art cellular communication systems are mainly optimized for high payload bitrates with few users. As a result, they are not able to efficient cover many applications with low bitrate requirements per device, but potentially thousands of devices in a given area. Examples for such applications are water/gas metering or environmental monitoring. These applications require low-cost devices, battery lifetimes of several years, and spectrally efficient protocols that are able to support thousands of devices. On the other hand, there are no strict requirements on parameters such as latency, and the number of messages per day is limited. Low Power Wide Area (LPWA) Networks try to offer connectivity that specifically addresses the aforementioned requirements.

Figure 1: General concept of LPWA networks consisting of base-station and node

Figure 1 shows a typical configuration of a LPWA network. Low-cost nodes with low transmit power (e.g. 10mW) transmit their data to a base-station over a distance of several km. The antennas of the base-station may be mounted on highly exposed sites for increased coverage. However, the high path loss caused by the large distances can only be overcome by very low payload bitrates of normally less than 1000 bit/s.

Generally, LPWA networks do not offer higher power efficiency than other communication systems. However, due to the low payload bitrates a low transmit power is sufficient to transmit signals over large distances.

The properties of LPWA networks lead to the following technical challenges:

* Low received signal strength: The low transmit power in addition to high distances leads to low received signal strength that can only overcome by very low payload bitrates.
* Frequency offsets of the oscillators: The frequency offsets of the employed oscillators lead to frequency offsets that can be magnitudes higher than the signal bandwidth.
* Low node complexity: The requirements of low power consumption and low-cost do not allow the use of sophisticated algorithms (mainly on the nodes) that operate close to the theoretical limits.
* Hidden node problem: One node is typically not able to detect the transmission of other nodes, as the nodes are normally not equipped with exposed antennas. Therefore, other means are required to avoid or resolve collision of the signals of multiple nodes at the exposed base-station antennas.
* Restrictions due to frequency administration: The use of license-exempt frequency bands is commonly coupled to constraints on different parameters such as duty cycle, maximum transmit duration, or transmit power.
* Interference: License-exempt frequency bands are also used by other systems that may interfere with the LPWA network.

# Motivation for the Interest Group LPWA

Currently LPWA networks are a hype topic. A variety of proprietary system or quasi standards have been developed. Examples for such systems are LoRa [LORA] or SIGFOX [SIGFOX]. Furthermore, also 3GPP is working on NB-IoT (Narrow Band-Internet of Things), an extension of the 3GPP specification to cover similar application as the LPWA networks [NB-IOT]. Nevertheless, also existing IEEE specifications may be able to cover many of the LPWA applications. However, the performance of the existing IEEE solutions and other existing standards is not fully clear. This Interest Group will therefore evaluate the performance of different candidate technologies in selected use-cases for their use in LPWA networks.

Final aim of this Interest Group is a white paper that shows the potential pros and cons of different technology candidates as well as of existing standards. This will allow IEEE do decide whether the use-cases of LPWA networks are already coved by existing systems, or whether IEEE should start the development of a new specification that is able to address the identified gaps.

# Technical Characteristics of LPWA Networks

The following list shows typical technical characteristics of LPWA networks. Similar characteristics are e.g. defined in [ETSI-LTN-USECASES].

* Typical usage of 200 payload bytes per day per node
* Typical payload bitrates of < 1kBit/s
* Maximum latency ranging from ms to several seconds
* Typical transmit distance of up to 10km (city) or 40km (rural areas)
* Frequency bands below 1GHz with focus on license-exempt frequency bands (e.g. 434MHz, 868/915MHz)
* Link budget of up to 170dB and receiver sensitivity in the range of -140dBm
* Typical transmit power of 10mW, maximum transmit power of 500mW
* Uni-directional (node to base-station) or bidirectional communication
* Star topology of the network, no relaying on nodes, no multi-hop communication

# Planned Contents of the White Paper

The aim of the white paper is the analysis of the suitability of candidate technologies and systems for LPWA networks. This analysis is only possible if the requirements of the network are clearly defined. Therefore, the first part of the while paper will be the definition of detailed use-cases. Next, the regulatory aspects for these use-cases will be reviewed. The use-cases and the regulatory aspects will then be the input for the definition of suitable channel models. Furthermore, evaluation criteria will be defined that also depend on the defined use-cases. Finally, a list of candidate technologies will be evaluated and recommendations on their suitability for LPWA networks will be given. The following sub-sections will give a detailed description of the planned work.

## Definition of Detailed Use-Cases for LPWA Networks

The analysis of the performance of different candidate technologies for LPWA networks requires the definition of detailed use-cases. To illustrate this let us consider two extreme scenarios:

The first scenario is precision farming in Kansas. The farmer distributes a high number of sensors, e.g. measuring the moisture of the soil. The communication is purely uni-directional and highly delay tolerant. Additionally, a certain packet loss-rate is fully acceptable. Due to the flat landscape almost ideal channel conditions can be expected. Furthermore, no interference from other frequency users in the use licensee-exempt frequency band is present.

The second scenario is a smart metering scenario in a densely populated area. In this case a bi-directional communication may be required for updating the data encryption key on a regular basis. The indoor to outdoor communication in addition to the surrounding buildings leads to difficult propagation conditions with many signal reflections. In addition, other systems also operating within the employed license-exempt frequency band lead to strong interference.

In summary, it gets obvious that these two scenarios have highly varying requirements, which will be most likely be reflected in the suitability of different candidate technologies.

Parameters for the use-cases are e.g.:

* The number of nodes and their geographical distribution
* Use of exclusive or license-exempt frequency bands, presence of interference from other services or systems
* Base-station antenna type and height
* Traffic characteristics (uni-directional, bi-directional, broadcast like)
* Properties of the environment (e.g. hilly, urban, rural, …)
* Required battery lifetime / available power source

Within the scope of this group a list of almost orthogonal use-cases scenarios should be developed that are then used for further analysis.

## Review of Regulatory Aspects

The frequency administration defines certain restrictions on specific parameters, and consequently, also on the suitability of different technology options. These restrictions also vary for different countries and regions of the world (e.g. [FCC-Part15] for the US, [ETSI-REG] for Europe). As a result, technology options that are highly suitable in one region may not be suitable in other regions. Examples for these restrictions are e.g.:

* Potentially available frequency bands
* Maximum duty cycle, maximum transmit duration
* Maximum transmit power
* Maximum channel bandwidth
* Mandated use of frequency hopping

## Definition of Suitable Channel Models

The analysis of the performance of different candidate technologies requires suitable channel models. This comprises linear channels models for modelling the propagation effects, and non-linear channel models for modeling the potential interference from other systems also operating in the license-exempt frequency bands.

Suitable channel models for modeling the propagation effects have been proposed by the 3GPP consortium in [3GPP-CHANNEL]. They are also able to model different antenna patterns and environments. Thus, they can be configured using the parameters of the developed use-cases.

Interference models for modeling the interference in license-exempt sub-GHz bands have not been in the research focus. Therefore, additional effort for defining suitable models is required.

## Definition of Evaluation Methods

The comparison of different candidate technologies requires the definition of suitable evaluation methods. These evaluation methods may also vary for the different use-cases. Classical parameters such as the required signal level for error-free decoding may not be sufficient, especially when if the reception is dominated by interference.

Potential evaluation criteria are e.g.:

* Required energy per successfully transmitted bit (including potential overhead)
* Maximum geographical size of a network cell
* Maximum number of covered users per network cell / area

## List of Candidate Technologies for LPWA Networks

The evaluation of the potential performance in different scenarios requires the listing of different candidate technologies for LPWA networks. On the one hand, this covers algorithms for the modulation, the channel access, or the forward error correction.

On the other hand, this also covers also existing open standards, such as IEEE 802.15.4k, IEEE 802.11ah or the 3GPP NB-IoT (Narrow Band-Internet of Things).

## Analysis of the Performance of the Candidate Technologies

The evaluation of the different candidate technologies with respect to the detailed use-cases will be the main outcome of the Interest Group. This evaluation will be mainly based on a literature review. A quantitative comparison between different candidate technologies will be only possible in a limited number of the candidate technologies. As a result, most comparisons will have to stay on a qualitative level.

Generally, the comparison will take place using the following steps:

1. Suitability of the candidate technology:
In many cases it is obvious that a candidate technology is not suitable for a specific use-case. If e.g. the frequency administration defines a maximum bandwidth for a specific frequency band, systems exceeding this bandwidth cannot be used. Similar considerations are also possible for other requirements defined by the use-cases.
2. Qualitative evaluation:
If a candidate technology is able to cover a specific use-case, the pros and cons of this candidate technology will be evaluated. Furthermore, the dependencies on other candidate technologies will be listed. An example is the use of frequency hopping. A pro is the improved performance in case of interference; a con is the increased complexity. In addition, frequency hopping requires the use of a forward error correction in order to offer its full benefit. As a result, frequency hopping is well-suited for scenarios with interference, but may not be required in the aforementioned precision framing example, where no interference is expected.
3. Quantitate evaluation:
The quantitative evaluation will only be possible for a limited number of candidate technologies. An example is the comparison of different forward error correction schemes. These schemes can be compared quantitatively using the required signal-to-noise ratio in specific channels in order to obtain a given maximum packet error rate.

# Planned Schedule

### September 2016 Interim (Warsaw)

* Discussion on IG objectives
* Call for contributions

### November 2016 Plenary (San Antonio)

* Fixed IG objectives
* Presentation of contributions (focus usage scenarios)
* Initial discussion on IG report

### January 2017 Interim (Atlanta)

* Fixed usage scenarios and channel models
* Presentation of contributions with focus on evaluation criteria

### March 2017 Plenary (Vancouver)

* Fixed evaluation criteria
* Presentation of contributions with focus technology options for LPWA

### July 2017 Plenary (Berlin)

* Final discussion on IG report

# Literature

[3GPP-CHANNEL] 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Spatial channel model for Multiple Input Multiple Output (MIMO) simulations (Release 13), 3GPP TR 25.996, V13.0.0, December 2015, <http://www.3gpp.org/ftp/specs/archive/25_series/25.996/>

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[ETSI-REG] ESTI; Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25 MHz to 1 000 MHz frequency range with power levels ranging up to 500 mW; ETSI EN 300 220-2, V2.4.1 , May 2012, <http://www.etsi.org/deliver/etsi_en/300200_300299/30022002/02.04.01_60/en_30022002v020401p.pdf>

[FCC-Part15] FCC CFR 47 Part 15, Telecommunication: Radio Frequency Devices, <https://www.fcc.gov/general/rules-regulations-title-47>

[LORA] <https://www.lora-alliance.org/>

[NB-IOT] <http://www.3gpp.org/news-events/3gpp-news/1785-nb_iot_complete>

[SIGFOX] <http://www.sigfox.com/>