Jakub MAJ[1], Dariusz ELJASZ[2], Krzysztof PIOTROWSKI[1]
[1]IHP – Leibniz-Institut für innovative Mikroelektronik, Frankfurt (Oder), Germany
[2]Uniwersytet Zielonogórski,Instytut Metrologii Elektroniki i Informatyki

ANALYSIS OF COMMUNICATION PARAMETERS FOR CHOSEN LP-WAN STANDARDS

This work presents both the theoretical description of popular LP-WAN standards and the description of tests of communication parameters of the LoRaWAN standard in relation to use of these standards in the data transmission on the Internet of Things technology. The tests in a simulation environment and were realized depending on the distance, the number of end devices and the spreading factor.

ANALIZA PARAMETRÓW KOMUNIKACJI DLA WYBRANYCH ENERGOOSZCZĘDNYCH STANDARDÓW O DALEKIM ZASIĘGU

W pracy opisano zarówno teoretyczny opis popularnych standardów LP-WAN, jak i opis przeprowadzonych badań parametrów komunikacyjnych standardu LoRaWAN w kontekście wykorzystania tych standardów w transmisji danych w technologii Internetu Rzeczy. Badania w środowisku symulacyjnym zostały przeprowadzone pod kątem wpływu odległości, liczby urządzeń końcowych oraz współczynnika rozpraszania.

1. MOTIVATION

The motivation to do the research presented in the paper was the very quick development of the LP-WAN (Low-Power Wide-Area Network) standards over the last decade and the development of the Internet of Things technology, which needs more and more appropriate network solutions to improve its efficiency.

LP-WAN networks are a group of wireless wide area networks characterized by low power consumption and ability to send data over very long distances. Unlike LTE or 802.11, LP-WAN networks do not focus on providing high data throughput or minimizing delays. Their task is to send small portions of data at certain intervals for many years. LP-WAN standards are most useful in the M2M (Machine-to-Machine) communication. LP-WAN networks have many advantages such as long range and good coverage inside buildings, low energy consumption, low price of devices, great scalability and the fact that one receiver or base station supports many end devices. By that, they match very well for IoT because the IoT solutions usually involve many devices located in large areas.

The Internet of Things is a technology using devices, such as sensors, to collect data from the environment in which they are located in, and then send their measurements through the network to devices that process the collected data with or without the human support, i.e., in a semiautomatic or automatic way, respectively. IoT allows people to make intelligent spaces such as intelligent cities, energy systems, or even health systems. The goal of these intelligent spaces is to make the life of their users easier because intelligent systems can automatically react for changes in the environment they monitor. According to Cisco, IoT consists of four pillars [1]: People, Data, Things, and Processes. The People pillar describes persons that are part of Internet of Things system, like the administrator, object or the beneficiary. The Data pillar describes all data such as collected raw data, transmitted data, analyzed data and the information and conclusions based on the analyzed data. Third pillar – the Things describes all devices that are involved in the IoT. The last is the Process pillar that contains all the connections on the Internet of Things technology. This pillar describes the connection type, transmission medium type, and the network standards used for the Internet of Things.

The purpose of this article is to describe and compare the most popular LP-WAN standards and to present the results of the simulations of the LoRaWAN standard in the context of using these networks for the Internet of Things (IoT). It is structured as follows. It starts with the descriptions of the three most popular LP-WAN standards for IoT, namely LoRaWAN, Sigfox and Narrowband IoT (NB-IoT). Then, the presentation of the simulation results for the LoRaWAN standard follows. The paper concludes with the plans for further research.

2. MOST COMMON LP-WAN STANDARDS

LoRaWAN is the most common network protocol that uses LoRa (Long Range) technology. LoRaWAN defines higher layers of the protocol stack, and LoRa defines the physical layer that enables long-range communication using CSS (Chirp Spread Spectrum) modulation [2]. LoRa works on unlicensed bands below 1 GHz. The most popular and most commonly used bandwidths in LoRa are 125, 250 and 500 kHz. The range in networks using LoRa depends on the Link Budget, which can be changed by modifying the bandwidth, transmission power and the spreading factor (SF). The maximum theoretical range of LoRa in an urbanized environment is about 5 km, and in open space, it can reach up to 15 km. Data rate in networks using LoRa depends on bandwidth and spreading factor. Maximum data rate is 27 kb/s using spreading factor equals to 7 and bandwidth 500 kHz. LoRaWAN uses the star architecture for its end devices, gateways, network servers and application servers. The end devices can work in three different modes depending on the needs regarding the use of Uplink and Downlink transmission. These modes differ in the number of receiving slots in the Downlink transmission and in the latency of the transmission.

Sigfox [3] is another popular LP-WAN technology. It uses radio technology that works in ultra-narrow band, using frequencies below one GHz. Sigfox takes 192 kHz of the available bandwidth to send messages, but each message is just 100 Hz wide. Sigfox uses two kinds of modulation, one for Uplink and one for Downlink transmission. For the former, it uses the DBPSK (Differential Binary Phase-Shift Keying) modulation. That is because of its ease of implementation, low cost of devices and high sensitivity of the base station. For Uplink, there are two options for the transmission speed and for the base station sensitivity. Depending on the region, the options are either 100 b/s with the sensitivity of -142 dBm and 600 b/s with the sensitivity of -134 dBm. The Link Budget is the same for all regions, i.e., it equals to 163.3 dB and it is balanced by the power of the devices. Because the Downlink transmission is rare and does not require such reliability as the Uplink transmission, it uses the GFSK (Gaussian Frequency Shift Keying) modulation. Transmission speed for Downlink equals 600 b/s and the sensitivity is -132 dBm. Finally, Sigfox has a limit of messages that can be send during a single day. The limit for Uplink is 140 messages, and the limit for Downlink is four (4) messages.

The third LP-WAN standard relies on mobile networks. NB-IoT [4] is included in the group of 5G technology by 3GPP. It is the NB-IoT standard based on the Long Term Evolution (LTE) technology, using most of its protocols and architecture. The similarity of these two technologies allows NB-IoT to use the existing LTE infrastructure, reducing the costs of the implementation of the technology. NB-IoT occupies just 200 kHz of the LTE radio bandwidth, with 180 kHz used for communication and two 10 kHz buffers. Because of that, transmission speed is lower than in LTE and equals to 127 kb/s for Downlink and 159 kb/s for Uplink. For Downlink communication, it uses the Orthogonal Frequency-Division Multiple Access (OFDMA) coding. This method enables simultaneous data transmissions targeting many devices using orthogonal frequencies. Another method – the SC-FDMA (Single-Carrier Frequency-Division Multiple Access) is used for Uplink communication. NB-IoT can work in three modes. In the first mode, Standalone, the NB-IoT works on a separate infrastructure created specifically for NT-IoT. The second mode, Guardband, takes advantage of the fact that there is 200 kHz bandwidth between every LTE band for protection. So the NB-IoT uses this bandwidth in the Guardband mode. In the third mode, the In-band mode, NB-IoT technology uses free frequencies within the LTE bands.

The table below compares the most important parameters of the described LP-WAN standards.

Table 1: Comparison of communications parameters of common LP-WAN networks

Name of Standard	LoRaWAN	Sigfox	Narrowband IoT
Frequency band	Unlicensed ISM band	Unlicensed ISM band	Licensed LTE bands
Bandwidth	7,8 kHz - 500 kHz	192 kHz	200 kHz
Range	Urban: 5 km Rural: 15 km	Urban:5 km Rural: 40 km	Urban: 1km Rural: 10 km
Modulation	CSS	BPSK	QPSK
Bidirectional	Yes/Half-duplex	Limited /Half-duplex	Yes/Half-duplex
Latency	Device Class Dependent	1-30 sec	< 10 sec
Cell capacity	Over 1 million	Over 1 million	About 50000
Max payload	243 bytes	UL: 12 bytes DL: 8 bytes	1600 bytes
Data rate	Maximum – 27 kb/s	100 b/s or 600 b/s	UL: maximum 159 kb/s DL: maximum 127 kb/s
Adaptive data rate	Yes	No	No
Encryption	AES 128 bit	AES 128 bit	3GPP 128-256 bit
Standardization	LoRa-Alliance	Sigfox in co with ETSI	3GPP

5. LORAWAN SIMULATION RESULTS

LoRaWAN simulations were made in the Network Simulator 3 [5]. The simulations were carried out in two environments. First environment was the FSL (Free Space Loss), while the second one was the ShU (Shadowed Urban Area). Every packet had a payload of 10 bytes. During one simulation, each device sent 100 packets in an interval of 15 minutes. The goal was to analyze the reliability (δ), expressed as a percent of received packets of the LoRaWAN network, depending on the number of end devices (N) – up to 2500, the environment type, the value of the spreading factor (SF) and the distance (d) – up to 10 km. In the simulations, only one gateway was used to receive the packets. Due to the limitations of the LoRaWAN module, the simulation was carried out only for class A devices.

The performed tests show that all factors listed above have an influence on reliability of the LoRaWAN. The impact of the number of devices on the network reliability is evident – during the tests at a constant distance and constant spreading factor, increasing the number of end devices resulted in the reduction of the number of received packets. This situation occurs because the packets were sent at the same time from all terminal devices, and the more devices sent packets, the greater chance that the packets collide or the gateway's receiving channel will be occupied.

The tests also showed that distance, especially in an urban environment, has a significant impact on the reliability of the LoRaWAN. This is because receivers have different levels of sensitivity depending on the spreading factor and the increased distance causes an increase in link loss. Therefore, once the transmission falls below the level of sensitivity, the packet will not reach the gateway anymore. Simulation shows that in free space environment, the number of received packets is at a constant level for the distances between one and ten km. It is because in free space/rural environment, the LoRaWAN can theoretically reach up to 15 km.

Another parameter that affects the number of successfully received packets is the spreading factor. It is a configurable parameter. Correct configuration of this parameter helps to improve the area coverage in large network deployments. There is a trade-off between the achievable distance and the data throughput, so for smaller networks smaller SFs can be used. This is because higher SFs provide the receiving device with additional sensitivity, but also induce the need for more time to send the packet. On the other hand, lower SFs require less time to send data, but the sensitivity of the receiving devices is lower. An additional test related to the SF, carried out in the simulation, was to check the time needed to send a packet. Five different payloads were used: 1 byte, 10 bytes, 25 bytes, 40 bytes and 53 bytes. The 53 bytes payload is the maximum payload supported by the spreading factor 12. Time needed to send a packet increases logarithmically with the SF increase. Tests show that the time difference between the smallest payload and the largest payload for SF equal to seven (7) is only 0.07 seconds, but for SF equal to 12 the difference is 1.5 seconds, so is almost 21 times more than for first case. For the largest payload (53 bytes), time needed to send a packet equals 0.11 seconds for SF equal to seven (7) and 2.46 seconds for SF equal to 12. This shows that it is crucial to choose the optimum value of the spreading factor when configuring the LoRaWAN network, so that the packets do not interfere with each other.

6. CONCLUSIONS

The presented results show that the best reliability for LoRaWAN networks can be achieved for a small number of devices at distances up to 5 km using low SF of seven (7) or eight (8). In larger networks where the distances exceed 5 km, the use of low SF causes a large decrease in the value of successfully received packets. Therefore, for these networks the most suitable solution is to use SF equal to nine (9) or ten (10). Due to low throughput, SF values of 11 and 12 are not good for networks with a large number of devices, because of the increased packet interference. Simulations also shown that the LoRaWAN can work well in an urban environment on 5 km distance, but it can also send data up to 7.5 km in the urban environment on a decent level.

Further, the simulations show that LoRaWAN can handle transmission in large areas with many devices, both in an urban environment and in free space. That means that LoRaWAN fits into the IoT pillar responsible for data transmission, and the network standard can be used both for the creation of intelligent cities and intelligent systems deployed in large uninhabited areas.

The LoRaWAN module used in the simulation is constantly under development. Enhancements in the model will allow enriching the study with additional functionalities and will allow further research. One of the interesting aspects is the impact of duty cycle restrictions in the 868 MHz band and the impact of other networks on the LoRaWAN network reliability. Another interesting option is to use a real environment and physical devices to perform similar tests. Such studies would be more realistic due to the fact that the simulator only abstracts the real environment.

ACKNOWLEDGMENTS

This work was supported by the European Regional Development Fund within the BB-PL INTERREG V A 2014-2020 Programme, “reducing barriers – using the common strengths”, project SmartRiver, grant number 85029892 and by the by the German government under grant 01LC1903M (AMMOD project). The funding institutions had no role in the design of the study, the collection, analyses, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

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