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Supporting data communications in IoT-enabled Waste Management

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Abstract. The Internet of Things (IoT) enables Smart Cities with novel services. Such services demand low power, high throughput and low-cost sensor data collection technologies. The number of devices, their variety, the breadth of their distribution, and the number of standards are continuously increasing. In this paper, we explore and critically analyze emerging IoT communication technologies. LoRaWAN has been selected for deployment in the smart waste management system (SWM) for collecting data from smart garbage bins. The paper proposes an architecture for SWM data collection and delivery as part of St. Petersburg pilot of Horizon-2020 bIoTope project. Extensive experiments with actual sensors and smart garbage bins were conducted for stress-testing the LoRaWAN technology, analyzing data rates and power consumption. The paper concludes with lessons learned and LoRaWAN wider deployment feasibility and improvements discussion.

Keywords: LoRaWAN, Internet of Things (IoT), Waste Collection, Smart Cities.

1 Introduction

The Internet of Things (IoT) as a technology paradigm includes a wide variety of sensors and actuators. Monitoring of physical infrastructure, environment and virtual entities in real-time, processing of real-time and historical observations and actions that improve the efficiency and reliability of systems – all these tasks and many others can be solved with the help of IoT. IoT sets different requirements for devices: they should operate with less memory, less processing power and less bandwidth compare to traditional models. The long operation time of the device without additional maintenance and charging (measured in years), the size of the device, its value, and

adfa, p. 1, 2017.
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the data transmission overhead in terms of maintenance costs are more important for IoT devices.

In Smart Waste Management (SWM) systems, IoT helps to provide interaction between components: containers with sensors, trucks, cloud infrastructure, dumps or recycling factories and user`s devices. Smart Garbage Container (SGB) includes a set of sensors for determining the container's state, and, possibly, an actuator for locking or opening the lid on a command. SGB can also be considered as "a thing" which generates data. The authors in [1] consider waste management as an IoT-enabled service in Smart Cities.

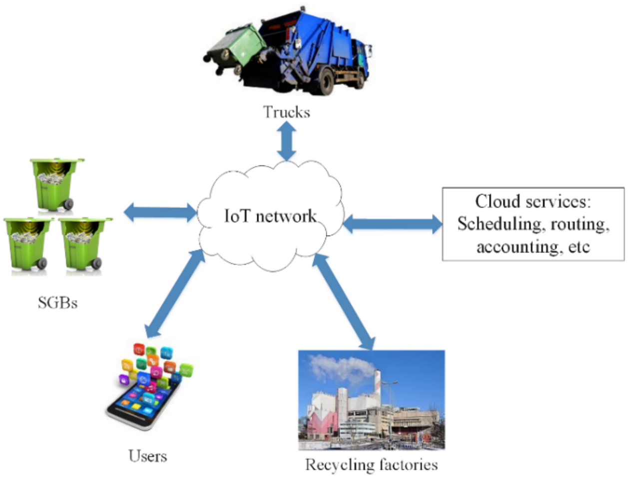

Fig. 1. Waste management system

The waste management system is presented in Fig. 1. All components of the system are linked through LPWAN technology between themselves and with cloud services. SWM systems helps to improve the waste collecting process with the utilization of an online decision process. Drivers of trucks should know when to collect waste from bins and which routes the collection trucks should follow. The route, for example, can also depend on route situation and prices on recycling factories and dumps. Users of the system are citizens and they should be aware of maintenance prices on local areas and service schedule.

The rest of the paper is structured as follows. Section 2 describes related work in communication technologies in the IoT. Section 3 discusses pros and cons of using LoRaWAN in Smart Waste management system. Section 4 represents methodology of testing and evaluating of LoRaWAN with several tests results, while Section 5 concludes the paper and discusses future work.

2 Related work

IoT market grows, and there are many use cases for which existing cellular networks are not suitable. The provided coverage, penetration through obstacles, network capacity, battery life, and device price are insufficient to meet market demands. Existing cellular networks already offer excellent area coverage in urban areas, but require the device transmitter to operate at high power, draining the battery. A battery life of several years combined with an inexpensive device cannot be realized on existing cellular standards as they do not support mechanisms of power adaptation and saving.

Different communication technologies aimed at low power wireless IoT communication have been proposed and deployed. Below we provide a description of the most popular technologies and standards.

2.1 IEEE802.15.4

IEEE 802.15.4 [2] is a standard specifying the physical layer and data link layer for Low-Rate Wireless Personal Area Networks (LR-WPANs). The standard focuses on low-cost, low-speed ubiquitous communication between devices. It proposes data rates up to 250 Kbit/s and transmission distance up to 1000 m, but in most real cases, the transmission distance totals only to tenths of meters. However, the provided distance is not enough for usage in Smart City applications.

2.2 Bluetooth LE

Bluetooth Low Energy (LE) is a wireless personal area network technology designed and marketed by the Bluetooth Special Interest Group. Bluetooth LE provides rapid link establishment functions (simpler pairing) and further trades off the data rate (approximately 200kbps) for lower energy consumption, with the target to run a wireless sensor for at least one year on a single coin cell (approximately 200 mAh) [3]. Existing technology provides the possibility for Bluetooth LE devices to operate for months, even years, on coin-cell batteries

2.3 Sigfox

Sigfox is a proprietary technology, developed and delivered by the French company Sigfox, without public specification. Sigfox operates in the 868-MHz frequency band, with the spectrum divided into 400 channels of 100 Hz [4]. Sigfox wireless systems send packages with a payload size of 12 bytes up to 140 uplink messages per day at a data rate up to 100 bps and up to 4 downlink messages per day. Each message can carry a payload of 8 Bytes. Sigfox claims that each access point can handle up to a million end-devices, with a coverage area up to 50 km in optimal conditions and up to 10 km in urban areas. Sigfox concentrates on data acquisition, but it is less useful for command-and-control scenarios.

2.4 NB-IoT

Narrowband IoT (NB-IoT) is a standards-based Low Power Wide Area technology developed to enable a broad range of new IoT devices and services. NB-IoT improves the power consumption of user devices, system capacity, and spectrum efficiency, especially in deep coverage. Battery life of more than ten years can be supported for some use cases. NB-IOT guarantees over 20dB coverage, about 1000 connections and ten years using only 200 KHz bandwidth [5].

2.5 LoRa

In this paper, we focus on LoRa (Long Range), one of the most promising wide-area IoT technologies proposed by Semtech and further promoted by the LoRa Alliance [6]. LoRa Alliance has defined the higher layers and network architecture on top the LoRa physical layers and termed them LoRaWAN. LoRaWAN is primarily intended for IoT devices operating up to ten years on battery power alone in regional, national or global deployments. The intention of LoRaWAN is to provide secure bi-directional communication, mobility, and GPS-free localization services. LoRa targets deployments where end-devices have limited energy (for example, battery-powered), where end-devices do not need to transmit more than a few bytes at a time [7]. Data traffic can be initiated either by the end-device (when the end-device is a sensor) or by an external entity wishing to communicate with the end-device (when the end-device is an actuator).

3 LoRaWAN as the enabling infrastructure for SWM

The dynamic waste collection could be described as an online decision process for defining when to collect waste from bins (i.e., scheduling), and which routes the collection trucks should follow (i.e., routing). Many technologies and hardware are already used in waste management adopting different approaches in the administration of the physical infrastructure as well as the data collected in the field. Sensors enable the measurement of physical parameters and transform it to digital signals, which are transmitted wirelessly by an ad-hoc network infrastructure [8].

One of the main components of the Smart Waste Management system is an SGB. An SGB is modular and provides a different set of capabilities depending on the usage scenario. However, in any of them, data is generated from a set of sensors, and it is required to ensure the data delivery to cloud processing services. This information is used, for example, for the dynamic construction of routes, depending on SGB fullness, or garbage combustion probability and subsequent call for firefighting services.

We investigated LoRaWAN as an intermediate between end-device and cloud service. Long range of operation up to 13 kilometers, small power consumption and confirmed packet delivery with bitrate up to 1 Kbit/s is enough for Smart City areas in which a gateway may be deployed in the district and communicate with multiple waste points.

Communication between end-devices and gateways is spread out among different frequency channels and so-called spreading factors (SF). It is the logarithmic ratio between the symbol rate (Rs) and the chip rate (Rc), i.e. SF = log2 (Rc/Rs). SFs enable simultaneous noninterfering communications between devices with the orthogonal nature of the set of codes. LoRaWAN data rates range from 0.3 Kbit/s to 27 Kbit/s for a 125 kHz bandwidth, depending on SF parameter. Data Rate (DR) is a parameter that determines the current mode of operation. The relationship between DR, SF and other parameters is presented in Table 1.

Table 1. LoRaWAN parameters [9]

DR	Configuration	Physical bit rate [bit/s]	Receiver Sensitivity, dBm	Range, km
0	SF12 / 125 kHz	250	-137	0-2
1	SF11 / 125 kHz	440	-134.5	2-4
2	SF10 / 125 kHz	980	-132	4-6
3	SF9 / 125 kHz	1760	-129	6-8
4	SF8 / 125 kHz	3125	-126	8-10
5	SF7 / 125 kHz	5470	-123	10+

End-devices can transmit via any available channel at any time using any available data rate, being restricted by the necessary need to implement pseudo-random channel hopping at each transmission and to comply with the maximum transmit duty cycle. There are several modes of work for specification of LoRaWAN (for EU868), with the difference in transmission power. For a number of tx values from 1 to 5, the transmission power is respectively equals 14 dBm, 11 dBm, 8 dBm, 5 dBm and 2 dBm.

The minimum set of sensors for the proposed architecture of an SGB includes:

- Level meter, which is a set of range finders HC-SR04
- Temperature sensor, DHT-22
- RFID reader for garbage and user authentication

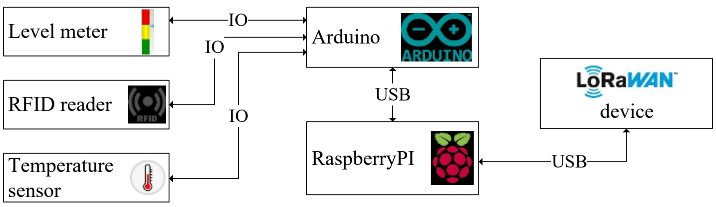

Fig. 2. Sensors connection diagram for Smart Container

This set of sensors is enough to determine the current state of the container and generate events about unexpected temperature increases. RFID reader can be used to authenticate the user in the system to calculate the amount of garbage ejected and determine its type.

Figure 2 presents the proposed architecture of interconnection between sensors and LoRaWAN device. We use Arduino board as a bridge between sensors and Raspberry Pi (RPI) platform. Its main function is to convert raw sensor information to data packets that are sent for further processing and sending to RPI. This approach ensures the modularity of the device since when adding a new sensor, the Arduino firmware can be overwritten with the RPI while not disrupting the system as a whole. If we want to add pressure sensor, light sensor, or any other sensor type, we can connect it to Arduino, and flash new firmware throw RaspberryPI, to communicate with it by UART, SPI, I2C or read raw analog signal. Such an approach is useful for models, where an additional source of information can be used for refinement existing one. RaspberryPI aggregates raw data and represent a bridge to Cloud through LoRaWAN stack.

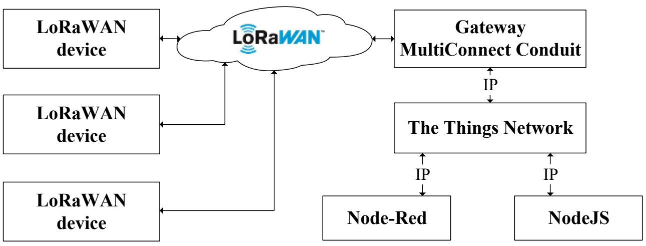

Fig. 3. Connecting diagram of SGB

Figure 3 represents the communication layer of the architecture. Each gateway serves a set of SGBs. In the proposed system, we use Multitech's MultiConnect Conduit Gateway [10]. MultiTech IoT platform includes programmable gateways, long-range RF modules, and accessory cards. Available options include a LoRaWAN mCard capable of supporting thousands of MultiConnect mDot long-range RF modules connected to remote sensors or appliances. The MultiConnect mDot is a LoRaWAN Ready, Low-Power Wide Area Network (LPWAN) RF module, capable of full duplex communication over distances more than 16 km. The main purpose of the gateway is to ensure reliable package forwarding to IP-network.

The Things Network (TTN) service is a cloud service for monitoring the queue of events from devices, decrypting packets, routing data to processing services, and sending packets back to devices. All the gateways connected to the TTN network are accessible on the map and can be used by LoRaWAN endpoint devices to communicate with the system. Packets are encrypted by endpoint devices by device key and by application key, so payload data is accessible only by the owner. Simultaneously, the openness of infrastructure is a significant step towards the spread of technology. TTN platform creators offer plug-ins for NodeRed and NodeJS for rapid prototyping of applications.

The module based on the RN2483 chip is used as an endpoint device. The RN2483 [11] is a fully-certified 433/868 MHz module based on wireless LoRa technology.

The RN2483 utilizes a unique spread spectrum modulation within the Sub-GHz band to enable long range, low power, and high network capacity.

Fig. 4 depicts the scheme of our prototype, which is developed in ITMO University for a pilot project of Smart Waste Management ecosystem in bIoTope project (Horizon2020).

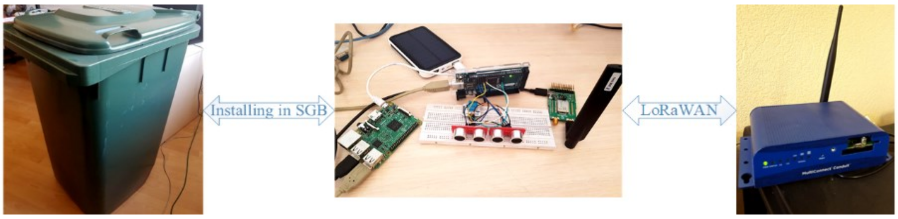

Fig. 4. Proposed architecture of Smart Waste Bin

In Table 2 we present acceptable parameters of data flows from SGB in Smart Waste Management system. Injection of packets into the network is an event-based process. When a user interacts with an SGB, a new value of the of the garbage level parameter should be calculated. The number of packets per day per device parameter depends on the number of interactions with SGB. The upstream packet contains information about level, temperature, and RFID. The downstream direction of data flow is used by RFID system for user authentication. The lid will open only after receiving an accepting message from the cloud. The latency between the user action and response should be maintained in a sub second range.

Table 2. Acceptable parameters of data flows

	Packets count per day per device	Upstream packet size (byte)	Downstream packet size (byte)	Distance to gateway (m)	Wait for answer time (ms)
Range	20 - 100	40 - 60	20 - 40	1000 - 7000	50 - 2000

The next section describes the testing of the LoRaWAN technology for compliance with the specified parameters.

4 Evaluation and testing methodology

4.1 Testing methodology

The main parameters determining the suitability of technology for use in the IoT-enable waste management scenarios are communication at long distances and low power consumption at a sufficient data rate.

In order to test the LoRaWAN workflow indicators, we developed an algorithm and implemented it as a module written in the NodeJS language. The algorithm includes the finite state machine represented in Fig. 5. Since the packets are sent to TTN, the connection to it is initialized. After the connection is established, it checks the availability of devices on the COM-port and initializes the connection to them.

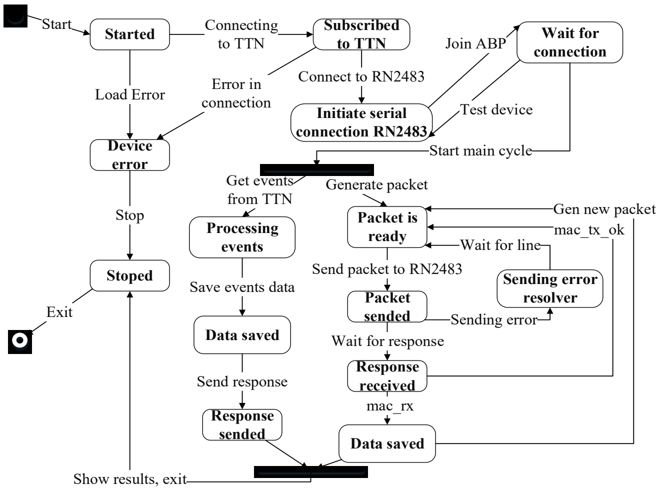

Fig. 5. LoRaWAN testing sequence diagram

The main cycle of the program with the device is as follows: a packet of the specified length (8 * N bytes) is generated, which is prepared for sending by executing the command "mac tx uncnf". The packet contains the Timestamp (the current Unix time in milliseconds) of the generation time. In the case of successful sending, the message "mac_tx_ok" comes from the device, after which the cycle proceeds to the generation of a new package. If "mac_rx" comes back, it reads the incoming data, which also contains the time of the sending, and writes them to determine the time of receiving the data packet. In the case of a send error, if there are no free channels, the data is resent. The cycle of working includes processing of incoming data and sending a response.

4.2 Packet delivery time

The data transfer rate, the number of packets transmitted per unit of time and the size of transmitted packets are the main parameters of any data transmission system. We investigated the dependence of the size of the payload and DR parameter. The packet size has a correlation with the data transfer rate, as we can send more information in single payload. However, such approach increases the needed time to send the packet, and affects the channel waiting time, as it is shown in Fig. 6.

Increasing the DR parameter reduces the delivery time of the packet (Fig. 7), significantly increasing the data transfer rate. However, this value affects the power consumption of the device, and the signal level decreases.

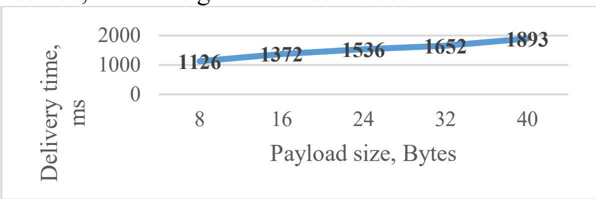

Fig. 6. Dependency between Delivery time (ms) and a packet payload (byte) with DR = 1

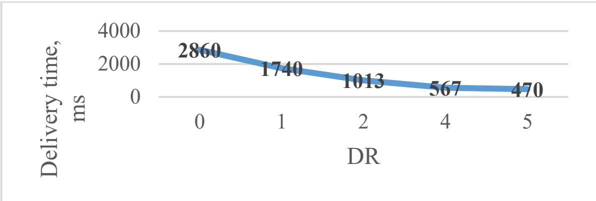

Fig. 7. Dependency between Delivery time (ms) and DR with a packet size of 40 bytes

Fig. 8 shows the dependence of the packet transfer rate (with 40 bytes payload) for different values of DR. As we can see in Fig. 8, the channel capacity correlates with the DR parameter.

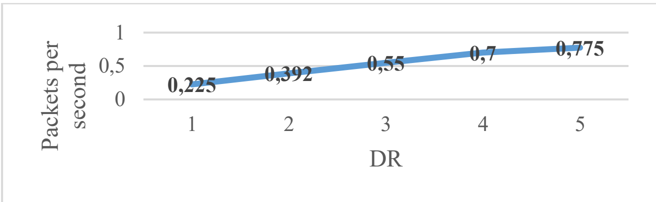

Fig. 8. The number of packets transmitted per second for DR with a packet size of 40 bytes

4.3 Power consumption

Energy consumption is one of the determinants of the use of technology in IoT. Thus, the next series of tests were aimed at determining the power consumption of the RN2483 module when sending the data packet at various parameters. It is required to select a sufficient operation mode for providing the necessary transmission power.

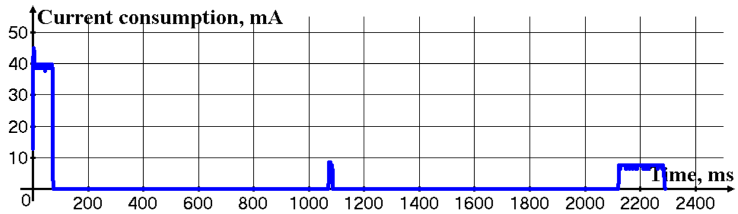

Fig. 9. Current consumption for DR = 5 and 40 bytes payload with TX Power = 1

In case of sending a single packet, we can see three time windows when the device is operating: the first window is used for sending a packet, and two other are used for receiving information back. The curve shown in Fig. 9 varies depending on the settings of the target device:

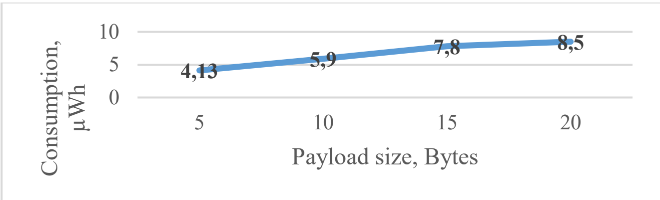

Fig. 10. Dependency between power consumption (µWh) and Payload size (bytes) with DR = 5

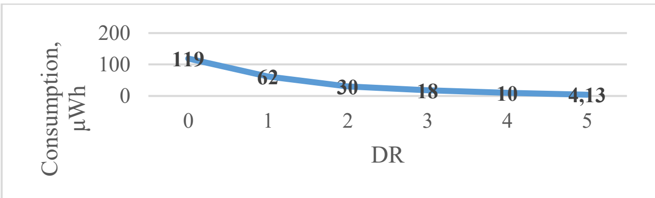

Fig. 11. Dependency between power consumption (µWh) and DR with 40 bytes Payload

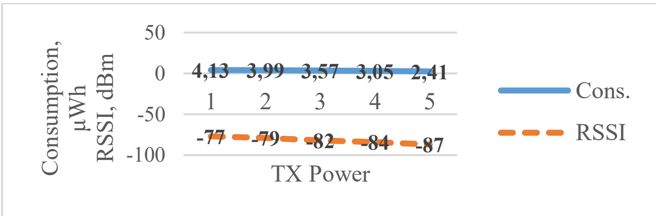

Fig. 12. Dependency between power consumption (µWh), RSSI (dBm) and TX Power with 40 Bytes Payload and DR = 5

Fig. 10 shows the dependence of power consumption on payload size for TX Power equals one. As the packet size increases, the packet sending period and the width of the first section increases. The power consumption also increases for a single packet.

As the value of DR increases, the sending period decreases: the width of the first segment decreases. The power consumption decreases for a single packet (Fig. 11).

As the value of TX Power increases, the transmission power decreases according to specification: peak current value of the first section decreases. The power consumption also decreases for a single packet (Fig. 12).

After all, the power used for delivery of a single packet depends on several parameters, and the developer is responsible for choosing the optimal values for concrete purposes. The increase in the DR value is beneficial for the system, but this parameter affects the signal level in the network. As the DR value increases, the distance of communication decreases, as we have shown in the previous section. Consequently, the proper selection of the DR parameter is the determining factor in the use of the LoRaWAN device, influencing the relationship between range, consumption, and network bandwidth.

4.4 Evaluation results

We evaluated various operating modes of the LoRaWAN data transmission system. Taking into account the limitations on the required range of the system, the parameter DR should be chosen depending on the range equal to either 2 or 3. The "Packets per day per channel" parameter is based on information presented in section 4.2 taking into account that every device operates with 3 channels. The delay of receiving an answer from the cloud system is discussed in section 4.2. The power consumption is discussed in section 4.3. The results of the evaluation results are presented in Table 3. We can see that LoRaWAN technology is appropriate for data collection in SWM.

Table 3. Parameters of data flows

	Packets per day per channel	Packets per day per device for fleet of 100 devices	Packet size (byte)	Distance to gateway (m)	Wait for answer time (ms)	Power per packet (µWh)	Power per day per device (mWh)
Min	11000	330	40	4000	567	18	6
Max	16000	480	60	7000	1100	30	15

5 Conclusions and future work

This paper proposed and discussed the challenges of architecting the communication layer in a Smart Waste Management system for St. Petersburg pilot as part of the international Horizon-2020 project bIoTope. We critically surveyed the existing IoT technologies and identified the LoRaWAN technology as the most appropriate. We discussed usability of and evaluated LoRaWAN devices in SWM systems based on the core architecture, power consumption and packet rate. We developed the architecture of an SGB with modification possibilities while maintaining the system modularity. We developed an algorithm for the evaluation of network parameters. We defined ways for reducing power consumption and increasing the data transfer speed by properly configuring LoRaWAN devices.

The future work will address the challenges of processing data in the cloud, interacting with one of the research IoT platforms, for example, OpenIoT and/or FIREWARE and optimizing the structure of packets transmitted over the LoRaWAN network. We will work on the analysis and performance evaluation of the system's backend as well as performing the evaluation of overall Smart Waste Management system with LoRaWAN devices.

Acknowledgments

Part of this work has been carried out in the scope of the project bIoTope which is co-funded by the European Commission under the Horizon-2020 program, contract number H2020-ICT-2015/ 688203 – bIoTope. The research has been carried out with the financial support of the Ministry of Education and Science of the Russian Federation under grant agreement RFMEFI58716X0031.

References

1. A. Medvedev, P. Fedchenkov, A. Zaslavsky, T. Anagnostopoulos, and S. Khoruzhnikov, "Waste Management as an IoT-Enabled Service in Smart Cities", *Springer, Lecture Notes in Computer Science (LNCS)*, vol. 9247, 2015, pp. 104-115.
2. IEEE 802 Working Group and Others. IEEE Standard for Local and Metropolitan Area Networks—Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs); IEEE Std 802.15.4-2011: New York, NY, USA, 2012.
3. Want, R.; Schilit, B.; Laskowski, D. Bluetooth le finds its niche. IEEE Pervasive Comput. 2013, 12, 12–16.
4. Margelis, G.; Piechocki, R.; Kaleshi, D.; Thomas, P. Low throughput networks for the IoT: Lessons learned from industrial implementations. In Proceedings of the 2015 IEEE 2nd World Forum on Internet of Things (WF-IoT), Milan, Italy, 14–16 december 2015; pp. 181–186.
5. http://www.huawei.com/minisite/iot/img/nb_iot_whitepaper_en.pdf [Assessed on 17 March 2017]
6. N. Sornin, M. Luis, T. Eirich, T. Kramp, and O. Hersent, "LoRaWAN Specifications" LoRa Alliance, 2015.
7. LoRa Alliance. White Paper: A Technical Overview of Lora and Lorawan; The LoRa Alliance: San Ramon, CA, USA, 2015.
8. J. Ma, "Internet-of-Things: Technology evolution and challenges", IEEE MTT-S International Microwave Symposium (IMS), 2014, pp. 1-4.
9. https://www.researchgate.net/publication/309207302_Low_Power_Wide_Area_Network_Analysis_Can_LoRa_Scale [Assessed on 10 April 2017]
10. http://www.multitech.com/brands/multiconnect-conduit [Assessed on 10 April 2017]
11. http://www.microchip.com/wwwproducts/en/RN2483 [Assessed on 23 April 2017]

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