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TECHNOLOGY ASSESSMENT OF IOT WIRELESS NETWORK TECHNOLOGIES FOR THE TELECOMMUNICATION SECTOR

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Internet of Things (IoT) technologies are of particular interest for telecommunication companies that can significantly affect the interaction of economic agents. As a result of the growth in the number of connected devices, the introduction of cloud services and business applications it became possible to combine equipment, information systems and management systems into a single communication network which in turn gave impetus to the development of the Internet of Things. The basis for the development of the Internet of Things is modern data transmission technologies including IoT Wireless Networks. There are, currently, a number of wireless IoT technologies which have different characteristics. In this regard, it is of interest to identify the most promising technologies that will form the basis of the infrastructure for the development of the IoT ecosystem. This paper develops an assessment model for the application potential of IoT wireless network technologies for the telecommunication sector. LPWAN, 4G and Wi-Fi were identified as the most promising technologies. The majority of the assessment criteria are applicable to other telecommunication technologies.

Key words: technology assessment, technology management, Internet of Things, wireless networks, telecommunication companies, decision model, digital platforms.

JEL: C43, L15, L96, O14.

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1. INTRODUCTION

The transition to the fourth industrial revolution is characterized by the introduction of cross-cutting digital technologies in all sectors of economy. As a result the formation of global networks between enterprises around the world, their warehouse systems and production facilities are integrated into cyber-physical systems (CPS). The creation of CPS radically improves production, design, the use of materials, the supply chain and life cycle management (Carvalho et al., 2018).

The essence of this revolution is in technological innovation and the ability of economic actors to adapt and use them. The fourth industrial revolution includes the emergence of new markets with an emphasis on product customization and the expansion of global networks and access to them for the development of integrative processes and data exchange among economic actors (ITU, 2017). The development of global networks leads to the appearance of new business models, including the concept of the sharing economy in which cost is created by the most efficient combination of supply and demand "in the right place, at the right time" and with minimal transaction costs. Service business models do not assume possession of an asset, but the temporary use of it to meet an existing need (Albinsson and Perera, 2018).

New innovative technologies such as the Internet of Things (IoT), cloud computing, big data, artificial intelligence, machine learning and wireless telecommunication network technologies along with the development of the sharing economy have produced new opportunities for telecommunication operators, e.g. entering IoT market, using new business models (mobile virtual network operator, IoT platform integrator), creating innovative products based on big data analysis (Montori et al., 2018; Colakovic and Hadzialic, 2018). Nevertheless telecommunication companies are in danger of being thrown out of market if their business models do not change. The assessment of technologies potential in the telecommunication sector is an acute task given the new opportunities and threats that are opening up to and in this industry as a result of digitalization (Czarnecki and Dietze, 2017).

Although IoT is constantly being researched, the lack of consensus around the interpretation of this concept and the most prospective mechanisms for its development, exacerbated by the rapid change in the world economy, leaves this problem open for further research. IoT is a system of integrated data networks and connected devices equipped with sensors and software for the purpose of collecting and exchanging data, and with the possibility of controlling automatically in real time without human intervention. Given the widespread digitalization and automation, when the elements of an enterprise are integrated into a single network, many production processes can be controlled online using cloud computing principles and IoT systems.

Figure 1 shows a technology architecture for IoT, revealing data transmission in an IoT ecosystem and the role of IoT network technologies in this process.

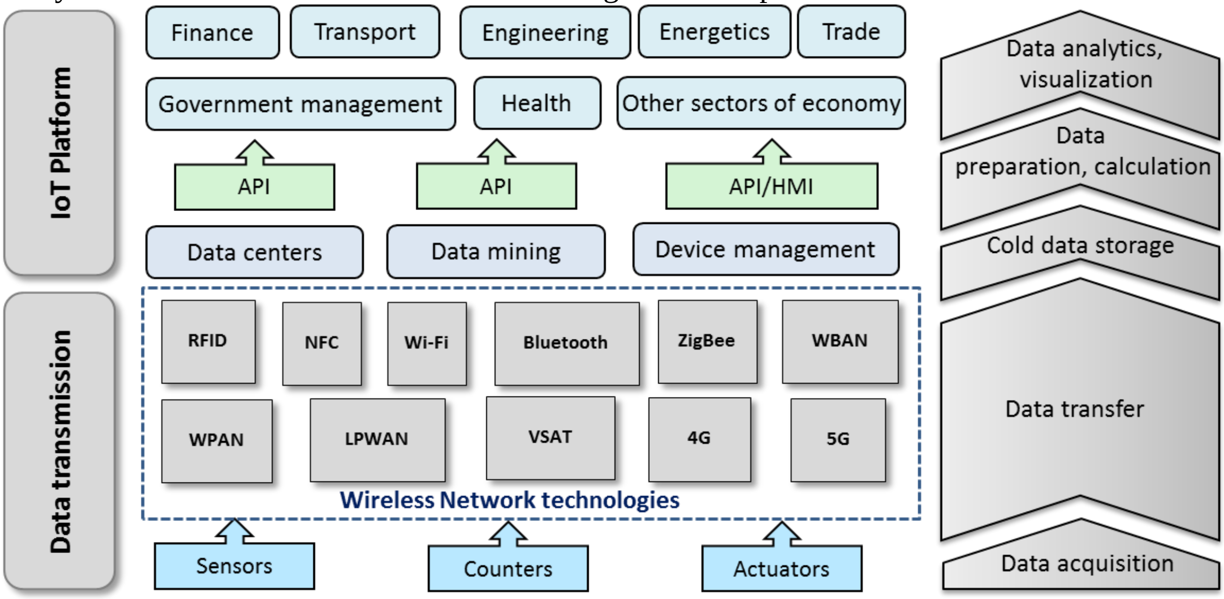

Figure 1 — Ecosystem of IoT

Source: authors.

First, data comes from different sensors, counters and actuators[4] through IoT networks to the IoT platform. There are a number of technologies in the field of data transmission, ranging from 5G wireless data transmission to energy efficient long-range technologies (LPWAN etc.). The international association 3GPP (3rd Generation Partnership Project) approved the narrowband LPWA (Low-Power-Wide-Area) standard, with which the development of IoT is connected. These technologies are designed for M2M (Machine-to-Machine) applications that require low-speed data transmission over a radio channel and unattended operation for a long period of time, possibly in remote or hard-to-reach places. Features of LPWA are low power consumption and wide territorial coverage (3GPP, 2016). Platform services are provided to various sectors of the economy from logistics to the needs of governments through data processing and analysis technologies. Data transmission carry out by API (application programming interface) — a set of standardized requests that have been defined for the program being called upon — and HMI (human-machine interface), which includes the electronics required to signal and control the state of industrial automation equipment. Identifying prospective wireless technologies in IoT becomes a significant task which can be completed through the technology assessment of IoT wireless network technologies for the telecommunication sector.

2. LITERATURE REVIEW

The range of applications for new information and communication technologies and the areas where they can be used is truly diverse (Oussous et al., 2018; Talavera et al., 2017). One of the tools to assess the application potential of innovative technologies is hierarchical modeling, widely used in works of Neshati and Daim (2017), Daim et al. (2012), Daim et al. (2018). For example, Neshati and Daim (2017) participated in the development of technology standards and created a decision model for the information and communications technology (ICT) industry.

[4] An actuator is a component of a system that is responsible for moving or controlling.

This study contextualizes technology standardization in the long-run in different areas: legal, economic, organizational and strategic (Neshati and Daim, 2017). Another example is a decision model for selecting energy storage technologies by Daim et al. (2012) which assumes implanting and using renewable energy technologies. There are also decision models for identifying robotics technologies which benefit the energy sector most. The Technology Development Envelope is a strategic roadmap to expand hierarchical solution modeling and to simulate the analytical hierarchy in the future. This procedure provides several ways for organizations to create roadmaps describing their strategies (Daim et al., 2018).

Several other authors raise technology assessment issues. Truffer et al. (2017) develop a technology assessment model based on the concept of sustainable transitions and emphasize the importance of the institutional component for technology. Cava-Ferreruela and Alabau-Munoz (2006) in broadband policy assessment determine the key factors for broadband development: technological competition, the low cost of deployment and the predisposition to use new technologies. Nazarko (2017) notes the significance of future-oriented technology assessment which is based on innovation governance.

There is, however, a lack of research in modeling technology assessment in IoT. As far as IoT is concerned, there are a number of research directions. First of all, modeling dynamics of trust in the IoT sphere inasmuch as confidence is one of the most significant factors influencing the development of new technology (Fernandez-Gago et al., 2017). The second direction is the application interoperability model for embedded wireless networks and its assessment of objects that are heterogeneous and constrained in nature. The problem of constant connections among things, which are heterogeneous and constrained in nature, is that devices have diverse operating systems, processor structures, and applications in various programming languages (Vinob chander et al., 2017).

There are many multidirectional challenges for IoT. Firstly, there is the problem of standardization as there is intense competition between different standards for IoT (Gershenfeld et al., 2004). However for the interoperability of various devices it is not enough to have many different standards, and it is necessary to develop common internationally accepted standards. A key to the success of IoT is collaboration between countries and key stakeholder (providers, developers etc.) and between standards bodies to provide interoperability (Park et al., 2016).

Secondly, there are issues of cybersecurity. The variety of issues and obstacles is diverse and multifold: authorization and access, control, secure architecture, authentication and privacy (Conti et al., 2018). That is why the urgent need to develop international legal regulations in IoT and alternative approaches to addressing security problems (arising in IoT directly) has appeared (Weber and Studer, 2016). Dealing with such problems requires the creation of a framework for automating the analysis of IoT cybersecurity (Ge et al., 2017). It is necessary to implement Software Defined Networking (SDN) and Blockchain technology to IoT for improving efficiency and cybersecurity (Kouicem et al., 2018).

Thirdly, the most significant and complex challenge is technology restrictions. Most IoT difficulties are attributed to the non-interoperability of devices, scalability and energy efficiency (Nawaratne et al., 2018; Makhdoom et al., 2019; Ko et al., 2019). There is, therefore, the necessity to develop the concept of fog computing in IoT systems. This is possible due to the formation "a geo-distributed intermediary layer of intelligence between sensor nodes and the cloud because of the bridging point (i.e., gateway) between the sensor infrastructure network and the Internet" to solve the lack of interoperability (Rahmani et al., 2017). The restriction of the current TCP/IP architecture of the IoT ecosystem demands another remedy: this issue needs a LPWAN (Bello et al., 2017). An additional point is that cloud computing has been recognized as a far reaching lead-up to overcoming a number of the existing problems in IoT. Nevertheless, the integration of IoT and cloud computing has several challenges as well. The interoperability and embeddedness of these two innovations demand decision models and roadmaps which are able to overcome all the challenges connected to the integration of IoT and cloud computing including:

- reference architectures which are necessary for cloud-based IoT solutions;
- smart use of cloud resources by multiple IoT applications and smart-devices;
- the standardization of various services and data;
- the contextual information inherent in the state of the neural network;
- the security and privacy of the database;
- a high level of the heterogeneity in IoT and cloud environments;
- reliability;
- the evolution of applications and the perfection of app support;
- the creation of the models for IoT device virtualization (Cavalcante et al., 2016).

In spite of the challenges connected to implementing and expanding IoT, this innovative technology can impact businesses, organizations and individuals. For manufacturers using this technology means far fewer improvident stock glitches, for retailers — loss enhancement to sales staff (Schoenberger et al., 2002). There is also the opportunity for "the optimization of the configuration of lights and switches at home", a simplification of buildings and the facilitation of health care at home (Gershenfeld et al., 2004). All these benefits make IoT worth investing in and developing.

There are several ***research gaps*** in the area under consideration. First of all there are not enough holistic and quantitative models to assess IoT technologies. In some models, including the model of trust dynamics in IoT (Fernandez-Gago et al., 2017), IoT is evaluated from a position of trust, paying insufficient attention to the technological aspects of its development, including assessing the effectiveness of the information infrastructure. On the contrary, Vinob chander et al. (2017) created an application interoperability model for heterogeneous IoT environments in which the technical aspects of IoT are included but without paying attention to other aspects that affect IoT dissemination, including its legal framework. There is a lack of comprehensive studies covering the wide range of IoT wireless networks, which was shown in the introduction to this article. Mekki et al. (2018) developed an approach to analyzing LPWAN technologies, highlighting the following factors: frequency, bandwidth, maximum data rate, bidirectional, maximum messages/day, maximum payload length, range, interference immunity, authentication & encryption, adaptive data rate, handover, localization, allowing private networks and standardization. In this research, a number of criteria have been developed which can be used to make a decision on the implementation of LPWAN technologies. However there is a lack of clear qualitative-based technology selection criteria. There is also no clear evidence pertaining to which criteria are critical for the decision model to assess IoT technologies. Those facts stimulated us to create a model of assessment of IoT wireless network technologies for the telecommunication sector which eliminates such shortcomings and covers a wide range of indicators affecting the effectiveness of the development of IoT (Vinob chander et al., 2017).

As the technologies of IoT are relatively new and developing dynamically, there is a lack of research in the field of modeling of technology assessment of application potential of IoT wireless network technologies.

In this research, the methodological foundations of the model are based on the studies of Daim on technological assessment in various fields. In these papers the following perspectives are singled out: functionality, design, technological, user experience, electronics (Daim et al., 2018);

economic, strategic, organizational, legal (Neshati and Daim, 2017); technical, economic, environmental and social (Daim et al., 2012). The desk research identified four perspectives for the decision model which are important for telecommunication companies in the implementation of IoT technologies: ***economic*** (World Trade Organization, 2018; Neshati and Daim, 2017), ***organizational*** (Gronau et al., 2017; Neshati and Daim, 2017), ***technological*** (Atzori et al., 2010; Bello et al. , 2017; Conti et al., 2018; Ge et al., 2017; ITU, 2012; Vinob chander et al., 2017; Rahmani et al., 2017; Cavalcante et al., 2016) and ***legal*** (ITU, 2012; Park et al., 2016; Weber and Studer, 2016; Cloud Security Alliance, 2015; 3GPP, 2016) (see Figure 2).

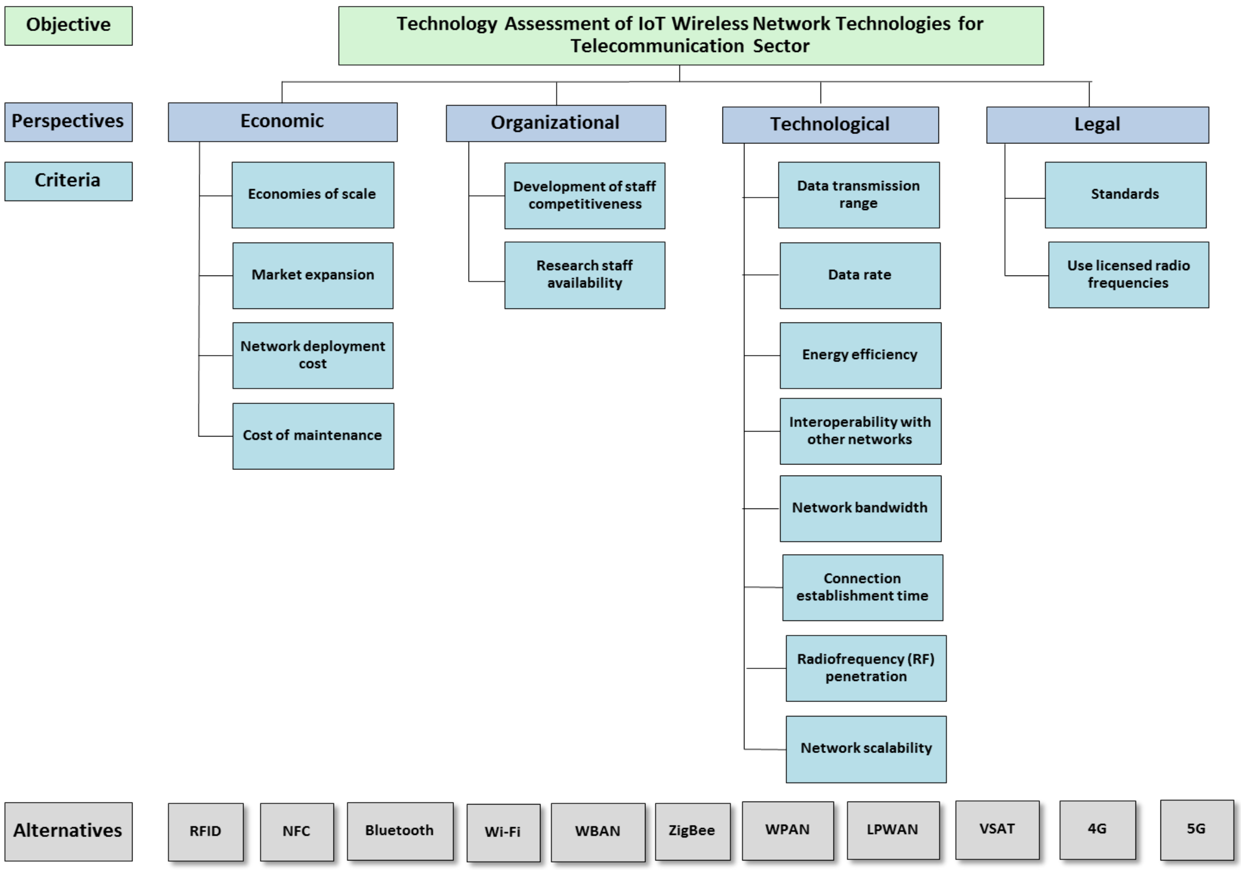

Figure 2 — A decision model for the implementation IoT wireless networks in telecommunication sector

Source: authors based on the approach of (Neshati, Daim, 2017; Daim et al., 2012; Daim et al., 2018).

From an ***economic perspective*** economies of scale are one of the most significant criteria in the telecommunication sector. Before the Uruguay round of the WTO framework, the organizational structure of national telecommunications markets were state monopolies, with the exception of the United States, where the owners of the telecommunications company were private individuals precisely because of the possibility to use economies of scale in contrast to a highly competitive market (Markova, 2009). The main reason for this organizational structure was the fact that the telecommunications industry had the inherent features of a natural monopoly based on the overwhelming advantage in costs for the existing company in the market. The technological features of the telecommunications market predetermined its organizational structure. Despite the privatization and liberalization of telecommunication markets, which started in the 1980s, economy of scale remains a characteristic feature of this market whose organizational structure is now an oligopoly in many countries (World Trade Organization, 2018). Other significant criteria for telecommunication companies from an economic perspective are market expansion, network deployment cost and cost of maintenance.

The ***organizational perspective*** (Neshati and Daim, 2017) is inextricably linked with the issue of development of staff competencies and the ability to conduct research, which is important not only for IoT, but also refers to change management, new business models and engineering. The basis for ***technological perspective*** is technical specifications, which include data transmission range, data rate, energy efficiency, interoperability with other networks, network bandwidth, connection establishment time, radio-frequency (RF) penetration, and network scalability (Atzori et al., 2010; Bello et al., 2017; Conti et al., 2018; Ge et al., 2017; ITU, 2012). From a ***legal perspective***, the most significant criteria are the degree of elaboration of standards for different IoT wireless network technologies and the necessity to use licensed radio frequencies (ITU, 2012; Park et al., 2016; Weber and Studer, 2016; Cloud Security Alliance, 2015).

The goal of the research is to validate the perspectives and criteria which should be assessed to identify the application potential of IoT wireless network technologies for the telecommunication sector and apply a decision model for the assessment of IoT wireless network technologies.
The following ***research questions*** are posed:

i. What are the weights of the perspectives and criteria of the technology assessment model?
ii. What are the requirements for the further development of the model?
iii. What are the most prospective IoT wireless network technologies according to the model?

3. METHODOLOGY

For the development of the decision model of assessment of IoT wireless network technologies for telecommunication sector we used a combination of desk research and expert procedures. The algorithm of research is shown in the Figure 3.

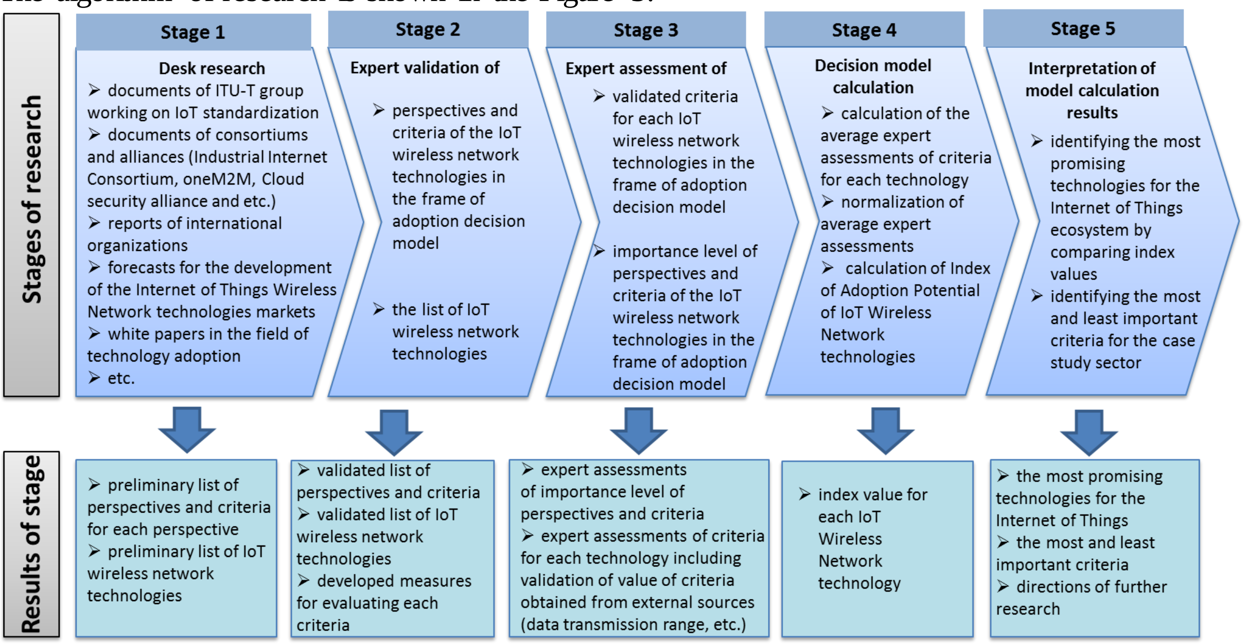

Figure 3 — The algorithm of research to assess applicable potential of IoT wireless network technologies[5,6]

[5] International Telecommunication Union developed Recommendation ITU-T Y.2060, which provides an overview of the Internet of Things.

Source: authors.

Stage 1. Desk research

Currently, there are a number of technologies in the field of data transmission for the needs of the Internet of Things, ranging from wireless data transmission technologies 5G to energy efficient long-range technologies. On the basis of desk research the list in Table 1 shows the technologies compiled for analysis.

Table 1 — The list of IoT wireless network technologies

№	IoT wireless network technology	Sources
1.	RFID	Montori et al. (2018); Mukherjee and Biswas (2018); Colakovic and Hadzialic (2018); Khanna and Kaur (2019); Bello et al. (2017); Makhdoom et al. (2019)
2.	NFC	Khanna and Kaur (2019); Colakovic and Hadzialic (2018); Montori et al. (2018); Mukherjee and Biswas (2018); Bello et al. (2017)
3.	Bluetooth	Jang et al. (2018); Montori et al. (2018); Ray (2018); Bello et al. (2017); Colakovic and Hadzialic (2018); Vinob chander et al. (2017); Makhdoom et al. (2019)
4.	WBAN	Montori et al. (2018); Viittala (2017)
5.	Zigbee	Colakovic and Hadzialic (2018); Vinob chander et al. (2017); Makhdoom et al. (2019); Noor and Hassan (2018)
6.	WPAN	Ray (2018); Colakovic and Hadzialic (2018)
7.	LPWAN	Jang et al. (2018); Mekki et al. (2018); Noor and Hassan (2018); Montori et al. (2018); Ray (2018); Vinob chander et al. (2017); Khanna and Kaur (2019)
8.	VSAT	Colakovic and Hadzialic (2018); Montori et al. (2018)
9.	4G	Makhdoom et al. (2019); Ray (2018); Colakovic and Hadzialic (2018); Noor and Hassan (2018); Khanna and Kaur (2019); Li et al. (2018)
10.	5G	Cheng et al. (2018); Noor and Hassan (2018); Colakovic and Hadzialic (2018); Li et al. (2018); Galinina et al. (2017); Ray (2018)

[6] OneM2M is a consortium the purpose of creation of which is to develop the global standards initiative for Machine to Machine Communications and the Internet of Things.

Source: authors.

A very small energy requirement for data transmission and a long battery life is critical for embedded technology. It is projected that LPWAN will be used in a wide range of IoT applications such as asset tracking, security monitoring, water and gas consumption measurement, as well as in intelligent networks, city parking, vending machines and urban lighting. The technology can also be used to connect wearable devices.

The requirements of IoT applications are so diverse that using LPWAN with a single technology is not possible; therefore three complementary standards are being considered which along with LTE-Advanced Pro will be included in 3GPP Release 13. These are the standards for narrowband IoT devices (NB-IoT), for extended GPRS coverage (EC-GPRS) and inter-machine LTE connections (LTE-MTS). These technologies operate in the licensed frequency range and will cover all uses of LPWAN devices. The accelerated development of LPWAN-solutions is currently being carried out within the Mobile IoT Initiative project, initiated by the GSM Association. This project brings together 27 leading mobile operators from around the world, OEM Equipment manufacturers, chip and component manufacturers, including AT&T, Alcatel-Lucent, China Mobile, China Telecom, Deutsche Telekom, Ericsson, Huawei, Intel, Nokia, Qualcomm, Verizon Wireless and Vodafone (3GPP, 2016).

As part of the development of IoT technologies, it is necessary to identify promising wireless technologies for supporting IoT connections. Different characteristics of IoT devices are the small amount of traffic, dense sets of connections or data transmission over long distances, which require new wireless technologies.

Stage 2. Expert validation

Expert validation of the criteria were made in a workshop by the thirteen experts from two departments of The Bonch-Bruevich Saint-Petersburg State University of Telecommunications: Faculty of Radio Technologies of Communication and the Faculty of Info-communication Networks and Systems. The following parameters were taken into account when selecting candidates: higher technical or economic education, professional experience in research, participation in conferences, and publications in the field of information and communication technologies. For this, a questionnaire was developed, which is presented in Appendix 1. Experts in the workshop were asked to evaluate the attractiveness of a technology for IoT. As part of the discussion, in addition to the proposed list of 10 technologies identified by desk research (RFID, NFC, Bluetooth, WBAN, Zigbee, WPAN, LPWAN, VSAT, 4G, 5G), the experts decided to include Wi-Fi as having potential for IoT. The validation algorithm for the list of technologies is presented in Figure 4.

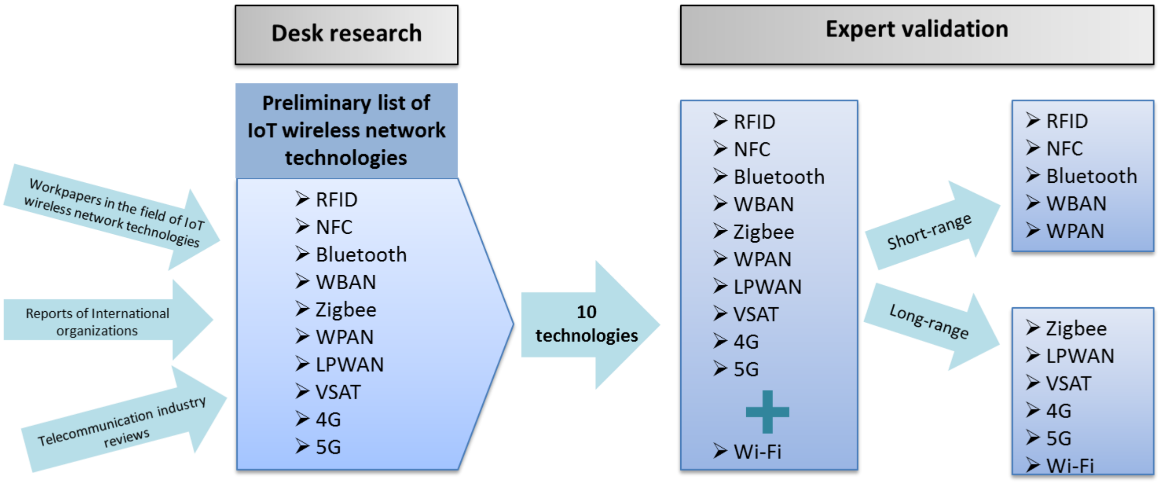

Figure 4 — Validation algorithm of IoT wireless networks technologies

Source: authors.

On the basis of the validation, criteria and the list of technologies, a decision model for the implementation of IoT wireless networks was developed. A more detailed description of the criteria and measurement units of these criteria is given in the Table 2. During stage 4 (see below) raw data were normalized for the calculation of the model.

Table 2 — Methodology of evaluation criteria for IoT wireless networks technologies for telecommunication sector

Perspectives	**Criteria**	**Description**	**Measurement Unit**
Economic	Economies of scale	For the telecommunication sector economies of scale are one of the key competitive advantages in the development of telecommunication infrastructure due to the significant costs of its development and implementation. This is quantified by 3-point scale: 0 — the introduction of technology does not lead to economies of scale; 1 — insignificant economies of scale;2 — significant economies of scale	3-point Scale
	Market expansion	Assessment of the market growth rate for each IoT wireless networks technologies.	%
	Network deployment cost	The key factors affecting the cost of network deployment are hardware costs, interoperability with existing systems, personnel costs. This is quantified by 3-point scale: 0 — very expensive network deployment cost; 1 — significant network deployment cost; 2 — there is an opportunity to update an existing network.	3-point Scale
	Cost of maintenance	Expenses for replacement of components. This is quantified by 3-point scale: 0 — high cost of maintenance; 1 — middle cost of maintenance; 2 — low cost of maintenance	3-point Scale

Organizational	Development of staff competitiveness	The need to acquire additional competencies for the staff of telecommunication companies. This is quantified by 3-point scale: 0 — need to hire new employees with the necessary competencies; 1 — it is enough to increase the level of qualification of employees within the telecommunication company; 2 — additional retraining is not required.	3-point Scale
	Research staff availability	For the development of IoT research and development must be carried out to extract additional benefits from its implementation, including the identification of new potential areas of use. This is quantified by 3-point scale: 0 — technology is new, little researches in this field; 1 — there are researchers in this field but their quantity does not cover the demand; 2 — there are enough researches in this field.	3-point Scale
Technological	Data transmission range	Physical data transfer by means of telecommunication networks	meters
	Data rate	Data volume transferred per unit time	kbps
	Energy efficiency	Improving the energy efficiency of network infrastructure is a critical factor for ensuring the necessary functionality and environmental sustainability of IoT networks. This is quantified by 3-point scale: 0 — low level of energy efficiency; 1 — middle level of energy efficiency; 2 — high level of energy efficiency.	3-point Scale
	Interoperability with other networks	The success of the deployment of the network is determined by the possibility of its interoperability both nationally and internationally. This is quantified by 3-point scale: 0 — low level of interoperability with other networks; 1 — middle level of interoperability with other networks; 2 — high level of interoperability with other networks.	3-point Scale
	Network bandwidth	The maximum allowed traffic processing speed which is determined by the network standards (peak bit rate).	kbps
	Connection establishment time	Delay in data transfer is becoming an increasingly important factor for telecommunication networks due to the operation of many IoT devices in real time. This is quantified by 3-point scale: 0 — long connection establishment time; 1 — middle connection establishment time; 2 — short connection establishment time.	3-point Scale
	Radiofrequency (RF) penetration	The radiofrequency (RF) penetration enhances with increasing of wave length. This is quantified by 3-point scale: 0 — low level of radiofrequency (RF) penetration; 1 — middle level of radiofrequency (RF) penetration; 2 — high level of radiofrequency (RF) penetration	3-point Scale

	Network scalability	The ability of the network to cope with the increase in workload when adding resources, usually hardware. This is quantified by 3-point scale: 0 — low level of network scalability; 1 — middle level of network scalability; 2 — high level of network scalability.	3-point Scale
Legal	Standards	The adoption of the standards by the International Telecommunication Union. This is quantified by 3-point scale: 0 — there are no recognized standards within the ITU or national standards; 1 — there are national standards for technology; 2 — there are standards within the ITU.	3-point Scale
	Use licensed radio frequencies	Necessity of the acquisition of a license for the radio-frequency sector. This is quantified by 3-point scale: 0 — the technology operates exclusively on licensed frequencies; 1 — the technology operates at unlicensed frequencies, but in some cases it is necessary to use licensed frequencies; 2 — technology does not require a license for the provision of radio frequency.	3-point Scale

Source: authors.

The data transmission range and data rates of IoT wireless networks technologies are shown in Figure 5 taking into account the classification of technologies proposed by experts.

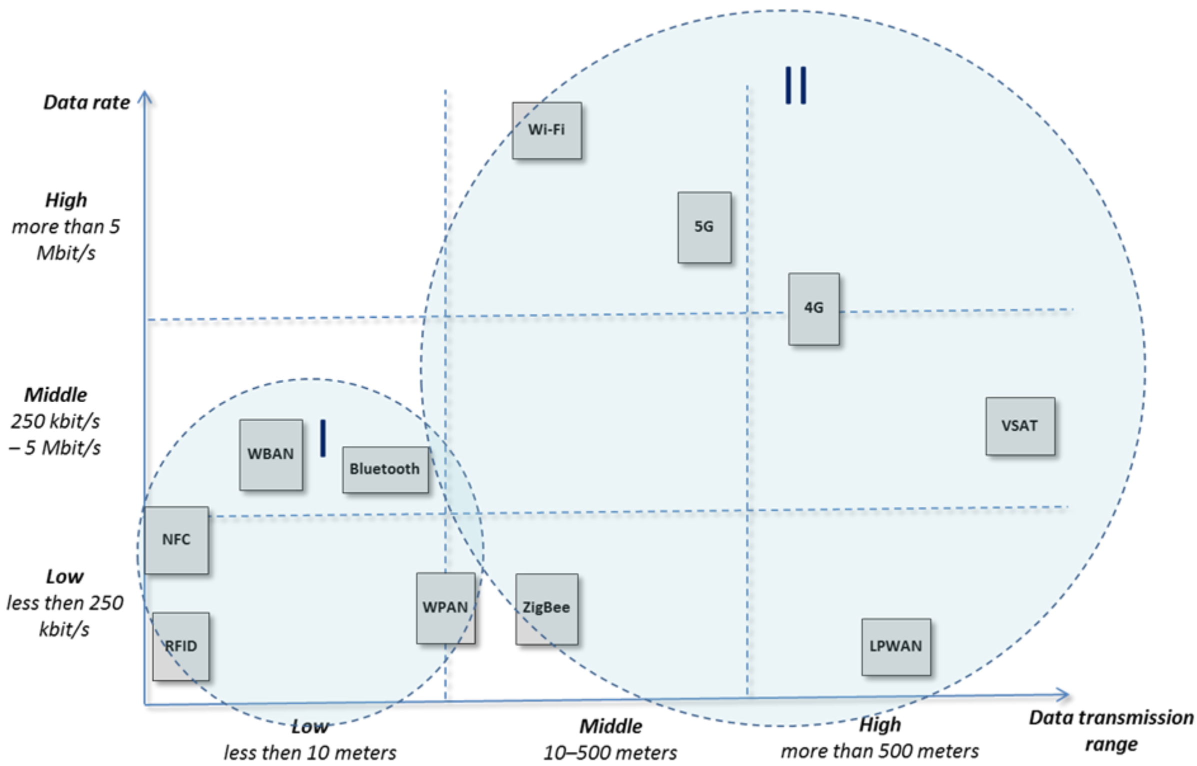

Figure 5 — Technical features of IoT wireless networks technologies

Source: authors.

Experts classified IoT wireless networks technologies by selecting data transmission ranges (Mekki et al., 2018) as a criterion since this partition will allow telecommunication companies to use the advantages of both short- and long-range technologies (see Figure 3). Such a classification can combine various technologies of data transmission for different needs of the Internet of Things. For example, when developing a smart home system in one apartment, it is possible to use short-range technologies for interaction between the devices inside the flat and long-range — for remote control by the user.

Stage 3. Expert assessment

The expert assessment consisted of two parts. Within the framework of the first direction, it was necessary to assess each technology from the list in accordance with the approved criteria. For this purpose, a questionnaire was developed, which is based on Table 2 and presented in Appendix B (see B1–B5). The questionnaire was sent to the same thirteen experts from The Bonch-Bruevich Saint-Petersburg State University of Telecommunications, who participated in the expert validation of the IoT wireless network technologies, perspectives and criteria in the workshop. Expert estimates of CAGR (Compound Annnual Growth Rate) of different IoT wireless network technologies were taken from industry reports to assess such indicators as market expansion (Grand View Research (2017); Statista (2018a); Statista (2018b); Credence Research (2017); PR Newswire Association (2018); Market Research Future (2018); Web-scale Networking (2018); MarketsandMarkets (2016); Business Wire (2016); Persistence Market Research (2016); Business Wire (2018); MarketsandMarkets (2018)).

The second part of the expert survey assessed the significance of the perspectives and criteria. So it was proposed to experts to assess the significance of different criteria affecting the potential for implementation wireless network technologies into the Internet of Things ecosystem, assuming that the sum of the importance levels of:

- economic criteria is 100%.
- organizational criteria is 100%.
- technological criteria is 100%.
- legal criteria is 100%.
- four perspectives (economic, organizational, technological, legal) is 100% (see Appendix B (B6–B10)).

Stage 4. Decision model calculation

The expert evaluations were processed in order to obtain the average assessment of the criteria for each IoT wireless network technology, using the following formula:

$$AA_k = \sum_{i=1}^{n} \frac{A_{k1} + \cdots + A_{kn}}{n}$$

where n is the number of observations,
k is criteria number,
A_{kn} is the assessment of criteria (k) by specific expert (n),
AA_k is average assessment of criteria (k).

The weighted average was normalized: the meaning is in bringing something to the standard form. In other words, normalizing the indicators means by multiplying its terms so that the maximum (in absolute terms) of this sequence is one. The Normalized Average Assessment was calculated by:

$$NAA_{kl} = \frac{AA_k}{\max_l AA_k}$$

l is the number of the IoT wireless network technology.

For example this indicator for data rate can be calculated as follows:

$$NAA_{datarate for 5G} = \frac{Datarateof5G}{\max_l(DatarateofRFID, DatarateofWi-Fi, \ldots Datarateof5G)}$$

$$NAA_{datarate for 5G} = \frac{Datarateof5G}{DatarateofWi-Fi}$$

$$NAA_{datarate for 5G} = \frac{10000kbit/s}{1000000kbit/s} = 0{,}1$$

The same approach was applied to normalize the indicators evaluated by experts. For example, for radio-frequency penetration (RF), the calculation will be as follows:

$$NAA_{RF for 4G} = \frac{Datarateof4G}{\max_l(DatarateofRFID, DatarateofWi-Fi, \ldots Datarateof5G)}$$

$$NAA_{RF for 4G} = \frac{Datarateof4G}{Datarateof4G} = \frac{2}{2} = 1$$

Thus, 4G is evaluated by experts as the technology of a high level of radio-frequency penetration and this indicator ($NAA_{RF for 4G}$) is 1, which is the maximum.

As a result of such normalization of all indicators for assessing technologies will be in the range from "0" to "1", where "1" characterizes the most desirable criteria parameters for the application of IoT wireless network technologies.

The perspectives and criteria for each technology are also found by calculating the arithmetic average of expert estimates for each of the indicators:

$$Criteria_k = \sum_{i=1}^{n} \frac{Criteria_{k1} + \cdots + Criteria_{kn}}{n}$$

$$Perspective_m = \sum_{i=1}^{n} \frac{Perspective_{m1} + \cdots + Perspective_{mn}}{n}$$

where *n* is the number of observations,
m is the number of perspectives.
k is the number of criteria.

Further, to identify the most promising technologies of the Internet of Things, an Index of technology assessment of IoT Wireless Network technologies for Telecommunication Sector was calculated for each technology: RFID, NFC, Bluetooth, Wi-Fi, WBAN, Zigbee, WPAN, LPWAN, VSAT, 4G, 5G.

$$Index = \sum_{i=1}^{m} Perspectives \sum_{i=1}^{k} Criteria \times NAA_{kl}$$

where m is the number of perspectives.

Thus, the maximum possible value of the index is one.

Stage 5. Interpretation of model calculation results

Based on a comparison of the index values for the analyzed IoT wireless network technologies, it is possible to choose the most promising ones for the Internet of Things ecosystem by comparing index values. The most relevant technology has index values closest to 1.

Comparing coefficients with the criteria obtained on the basis of expert assessment, it is possible to determine the most and the least significant criteria. Thus, the greater the coefficient for the criteria, the more significant the criteria is. This stage is presented in more detail in the results section.

4. RESULTS

Using the model proposed by the authors above, key technologies were assessed based on the expert assessment during the stage 3 of research described in methodology part (Figure 6).

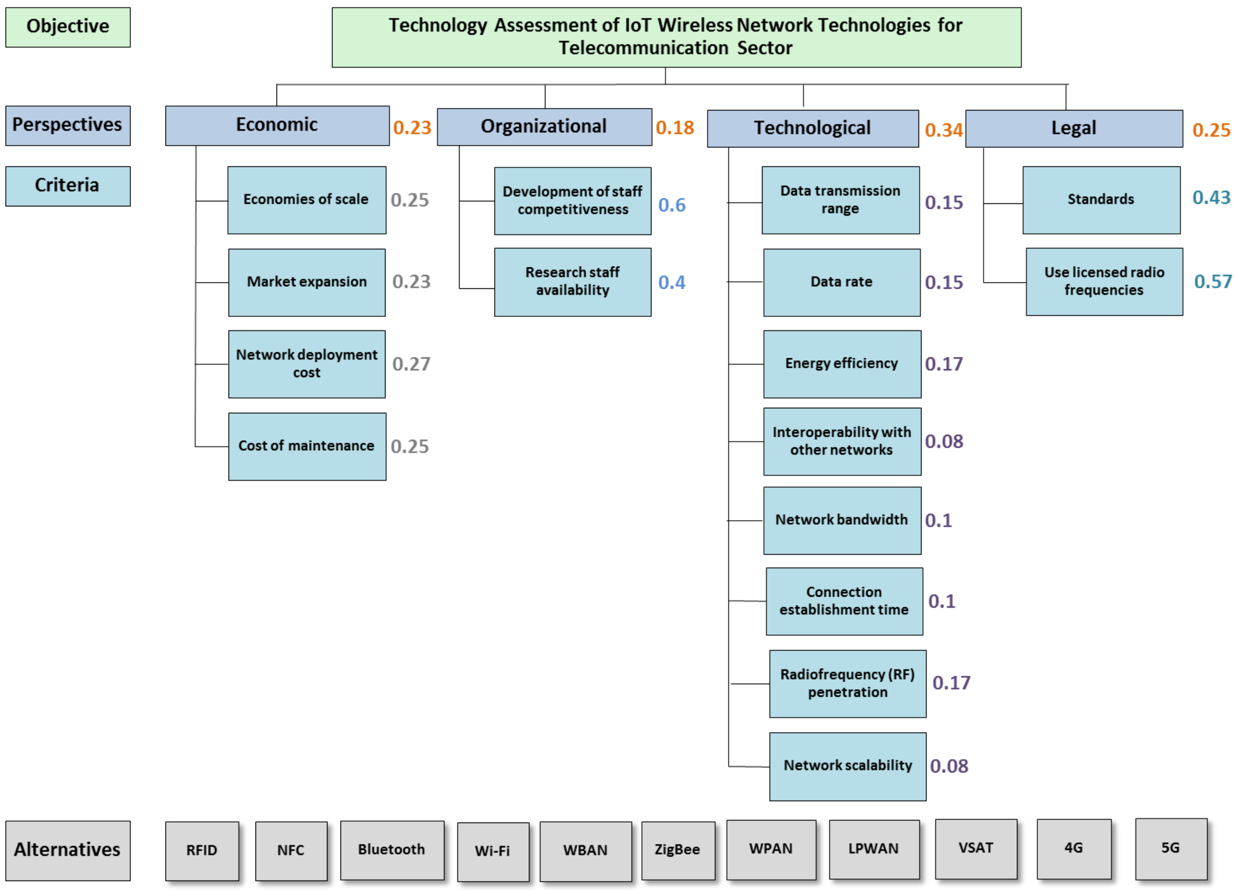

Figure 6 — Relative weights for the model

Source: authors.

On the basis of the expert survey, the most significant perspective is technological, affecting the prospects of implementing a particular IoT wireless network technology. Among the technological perspective, the most essential criteria that affect the application potential of the particular IoT wireless networks technologies are energy efficiency, radiofrequency (RF) penetration, data transmission range and data rate. To a lesser extent, organizational perspective such as development of staff competitiveness and research staff availability affect the potential of IoT wireless network technologies. Despite this, in the framework of the workshop, the experts retained this indicator, confirming it, although less important, but still significant for application potential of IoT wireless network technologies.

Further, to identify the most promising technologies of the Internet of Things, an Index of technology assessment of IoT wireless network technologies for telecommunication sector was calculated for each technology: RFID, NFC, Bluetooth, Wi-Fi, WBAN, Zigbee, WPAN, LPWAN, VSAT, 4G, 5G. The methodology for calculating the index was described earlier in the fourth stage of the research.

Figure 7 shows the values for the analyzed technologies. The maximum possible value for the index is 1.

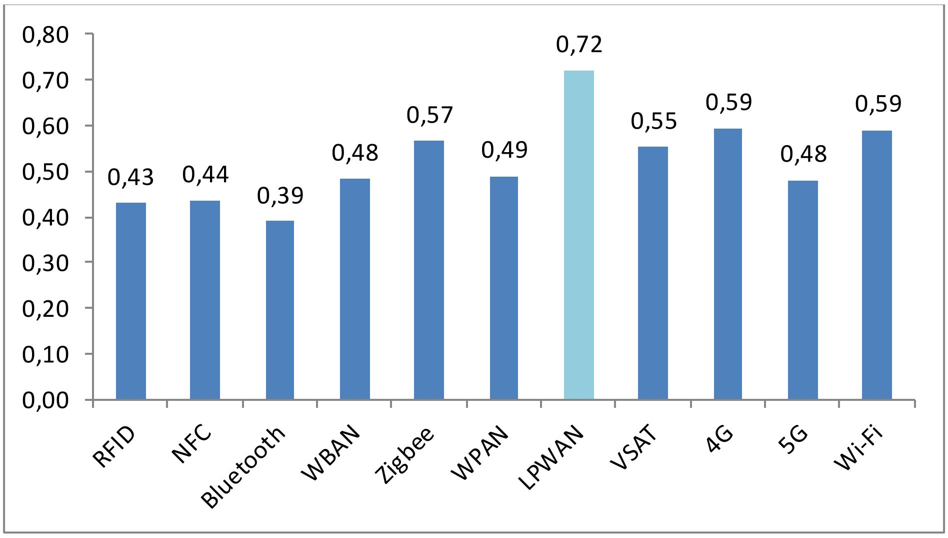

Figure 7 — Index of technology assessment of IoT wireless network technologies for telecommunication sector (maximum possible index value is 1)

Source: authors.

The most promising technology for the IoT ecosystem, according to the developed model, is LPWAN. A comparison of the estimates of the three technologies with the largest value of the Index of technology assessment of IoT wireless network technologies for telecommunication sector is shown in Figure 8 (LPWAN, Wi-Fi and 4G).

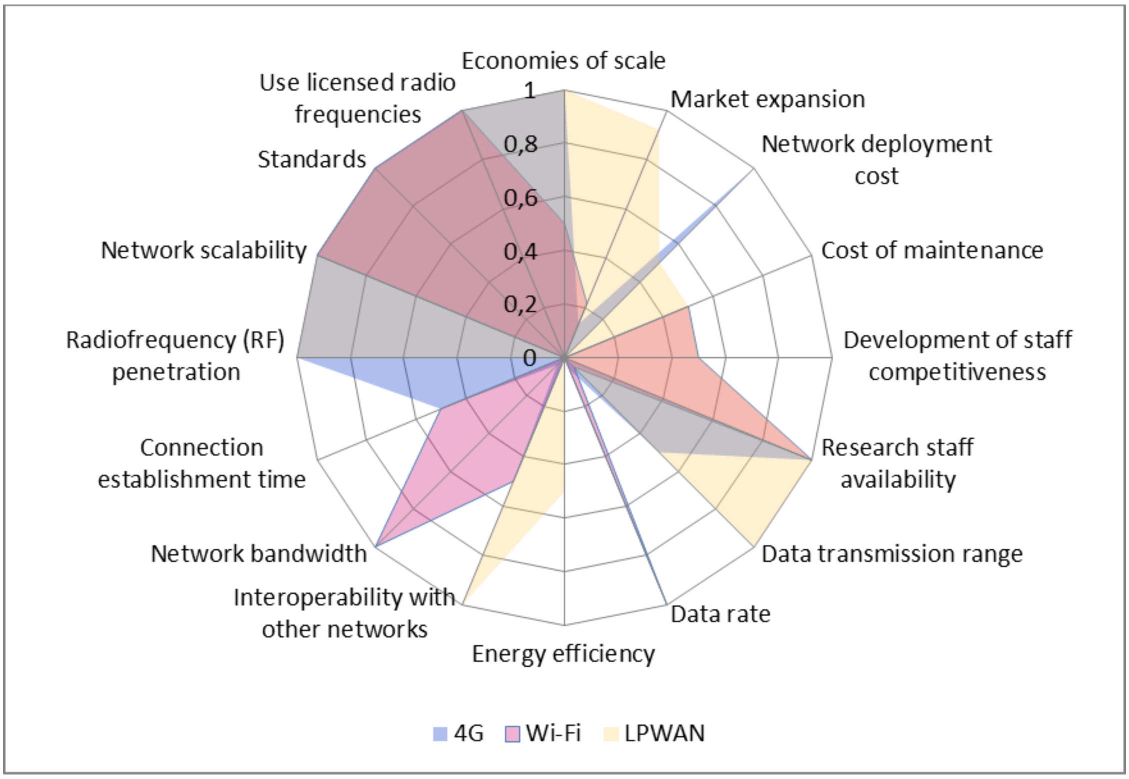

Figure 8 — Top 3 IoT wireless network technologies for telecommunication sector through the criteria prism of decision model

Source: authors.

Among the three leaders, LPWAN technology is highlighted by such indicators as the data transmission range, energy efficiency and the projected high rates of market expansion. Nevertheless according to the network bandwidth it is significantly inferior to Wi-Fi. However, for the needs of IoT, it still seems advisable to use more than one single IoT wireless network technology to combine short-range and long-range technologies, depending on the location of the connected devices relative to each other. Thus, the best technologies within each cluster are shown in Figure 9.

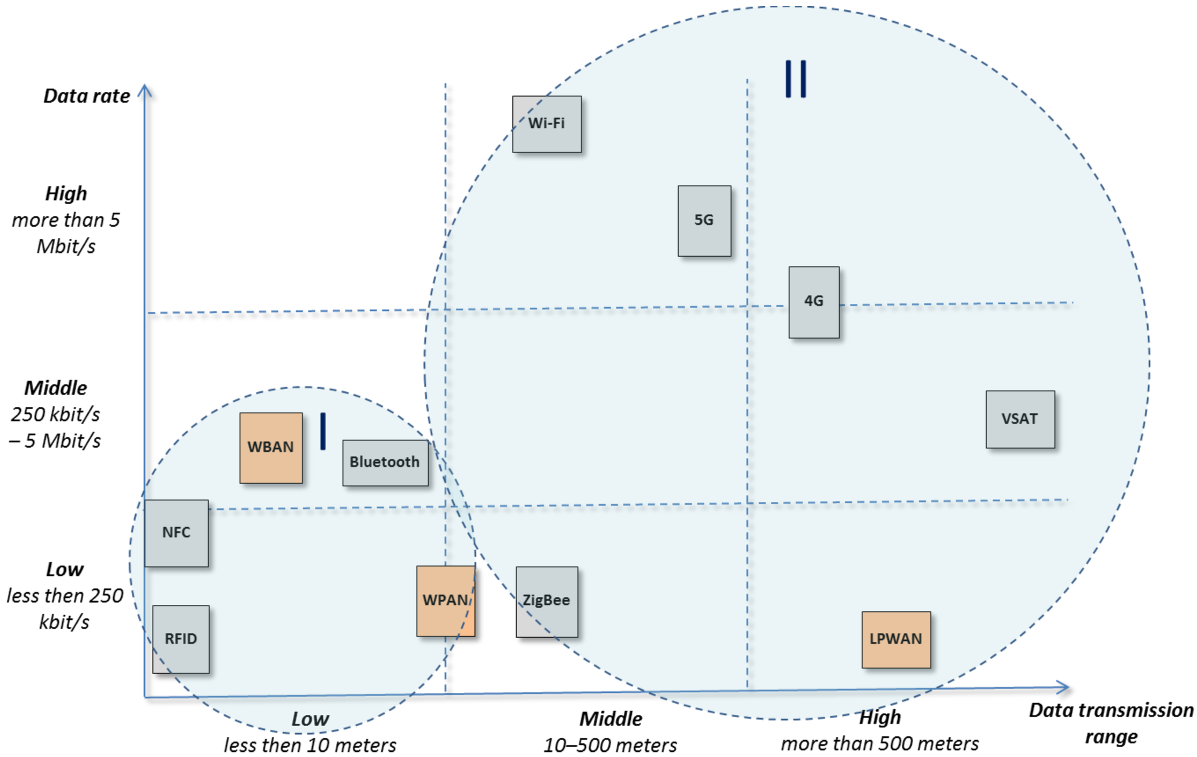

Figure 9 — Two groups for building technology portfolios for the implementation to IoT ecosystem

Source: authors.

The best combination is WBAN (Index of technology assessment of IoT wireless network technologies — 0.48) and WPAN (0.49) from the first group (short range) and LPWAN (0.72) from the second group (long range).

Concerning the advantages of LPWAN, it is necessary to allocate a moderate range, very modest energy requirements for endpoints of the network, as well as the existence of a whole family of these technologies that imply the possibility of radio access in different frequency bands. At the same time, the group of LPWAN technologies has an obvious drawback, expressed in the private character of the representatives of this group (proprietary technology) and the poor development of standards at the level of international organizations. However, this feature of the technology family is, rather, a feature of the process of growing the ecosystem of the Internet of Things and will be overcome in the future.

5. CONCLUSION & DISCUSSION

This study proposes a model for the assessment of IoT wireless network technologies for telecommunication sector in order to identify the most relevant technologies for the development of an IoT ecosystem, based on a wide range of perspectives, including economic, technological, organizational and legal. The study identified the key economic perspectives: economies of scale, market expansion, network deployment cost, and cost of maintenance. Key organizational perspectives include the development of staff competitiveness and research staff availability. Technological perspectives include a wide range of the most significant characteristics of the development of IoT wireless network technologies: data transmission range, data rate, energy efficiency, interoperability with other networks, network bandwidth, connection establishment time, radio-frequency (RF) penetration and network scalability. Legal perspectives are also important, which include standards and the use of licensed radio frequencies.

Answering the second research question, the identified perspectives are relevant for both wireless and wired technologies. However, some criteria within the framework of technological and legal perspectives require clarification when trying to generalize the model for all data transmission technologies.

There are some limitations in this model that can be the basis for the further development and improvement of the proposed model. The expert evaluation involved perspectives and criteria which were assigned a level of significance, calculated in percentage terms. However, the more common practice is to evaluate the criteria by setting the level of significance from 1 to n. Another limitation of the model is the use of different normalized measurement units to assess criteria. In the future, it would be possible to carry out the initial harmonization of measurement units in order to avoid the need for normalization.

The best result in the framework of the proposed model was shown by LPWAN technology. LPWAN includes a whole set of technologies operating in different frequency bands. Therefore, in further research, we recommend analyzing these technologies taking into account the frequency bands, since they strongly influence the data transmission range and frequency penetration. By including the frequency bands, one could apply this model of technology assessment to a more detailed study of LPWAN. The frequency band is an important criteria affecting the transmission range. So, for example, using LoRa, which is a part of the group of energy-efficient long-range technologies, it is very difficult to get a distance of 10 km in practice, and if there is a spruce forest in the way of the wave, it is completely impossible for a range of frequencies.

The development of the Internet of Things is inextricably linked with the need to increase consumer confidence in new innovative products and services. Such confidence which is based on the confidentiality and security of data generated from various devices. The absence of reliable connections among components such as sensors and actuators can create security issues. A malfunction in the system could result in property damage or injury. A clear definition of the rules, procedures and distribution of responsibility along the value chain is an integral component of trust in IoT technologies. In connection with this, the further development of the assessment model for IoT wireless network technologies for telecommunication sector, the authors propose considering the perspectives and criteria which reflect the attitude of different users to the Internet of Things, as well as characteristics in the field of cybersecurity.

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APPENDIX. QUESTIONNAIRE

Appendix A. First stage of expert procedures: expert validation of perspectives and criteria of the IoT wireless network technologies in the frame of decision model and the list of IoT wireless network technologies

A.1. Please rate the prospects for implementing wireless technologies into the Internet of Things ecosystem.

№	IoT Wireless Network Technologies	**The level of prospects for the implementation of wireless network technologies in the IoT ecosystem** 1 – the most promising technology for the Internet of Things, 10 – least promising technology for the Internet of Things, 0 – wireless network technology cannot be used for the needs of the Internet of Things.
	RFID	
	NFC	
	Bluetooth	
	WBAN	
	Zigbee	
	WPAN	
	LPWAN	
	VSAT	
	4G	
	5G	

Please, if necessary, add or adjust the submitted list.

A.2. Please add or adjust (if necessary) the submitted list of perspectives and criteria influenced the potential of IoT wireless network technologies.

Perspectives	Criteria
Economic	Economies of scale
	Market expansion
	Network deployment cost
	Cost of maintenance
Organizational	Development of staff competitiveness
	Research staff availability
Technological	Data transmission range
	Data rate
	Energy efficiency
	Interoperability with other networks
	Network bandwidth
	Connection establishment time
	Radiofrequency (RF) penetration
	Network scalability
Legal	Standards
	Use licensed radio frequencies

Appendix B. Second stage of expert procedures: expert assessment of perspectives and criteria of the IoT wireless network technologies in the frame of decision model

B.1. Please assess the **economic criteria** for the following IoT wireless network technologies when they are introduced into the Internet of Things ecosystem.

№	IoT Wireless Network Technologies	**Economies of scale** 0 — the introduction of technology does not lead to economies of scale 1 — insignificant economies of scale 2 — significant economies of scale	**Network deployment cost** 0 — very expensive network deployment cost 1 — significant network deployment cost 2 — there is an opportunity to update an existing network	**Cost of maintenance** 0 — high cost of maintenance 1 — middle cost of maintenance 2 — low cost of maintenance
	RFID			
	NFC			
	Bluetooth			
	WBAN			
	Zigbee			
	WPAN			
	LPWAN			
	VSAT			
	4G			
	5G			
11.	Wi-Fi			

B.2. Please assess the economic **organizational criteria** for the following IoT wireless network technologies when they are introduced into the Internet of Things ecosystem.

№	IoT Wireless Network Technologies	**Development of staff competitiveness** 0 — need to hire new employees with the necessary competencies 1 — it is enough to increase the level of qualification of employees within the telecommunication company 2 — additional retraining is not required	**Research staff availability** 0 — technology is new, little researches in this field 1 — there are researchers in this field but their quantity does not cover the demand 2 — there are enough researches in this field
	RFID		
	NFC		
	Bluetooth		
	WBAN		
	Zigbee		
	WPAN		
	LPWAN		
	VSAT		
	4G		
	5G		
11.	Wi-Fi		

B.3. Please assess the **technological criteria** for the following IoT wireless network technologies when they are introduced into the Internet of Things ecosystem.

№	IoT Wireless Network Technologies	**Energy efficiency** 0 — low level of energy	**Interoperability with other networks** 0 — low level of interoperability with	**Radiofrequency (RF) penetration** 0 — low level of radiofrequency (RF)	**Connection establishment time** 0 — long connection	**Network scalability** 0 — low level of network scalability

		efficiency 1 — middle level of energy efficiency 2 — high level of energy efficiency	other networks 1 — middle level of interoperability with other networks 2 — high level of interoperability with other networks	penetration 1 — middle level of radiofrequency (RF) penetration 2 — high level of radiofrequency (RF) penetration	establishment time 1 — middle connection establishment time 2 — short connection establishment time	1 — middle level of network scalability 2 — high level of network scalability
1.	RFID					
2.	NFC					
3.	Bluetooth					
4.	WBAN					
5.	Zigbee					
6.	WPAN					
7.	LPWAN					
8.	VSAT					
9.	4G					
10.	5G					
11.	Wi-Fi					

B.4. Please assess the **legal criteria** for the following IoT wireless network technologies when they are introduced into the Internet of Things ecosystem.

№	IoT Wireless Network Technologies	**Standards** 0 — there are no recognized standards within the ITU or national standards 1 — there are national standards for technology 2 — there are standards within the ITU	**Use licensed radio frequencies** 0 — technology is included in the list of technologies for which a license is required 1 — technology does not require a license for the provision of radio frequency
1.	RFID		
2.	NFC		
3.	Bluetooth		
4.	WBAN		
5.	Zigbee		
6.	WPAN		
7.	LPWAN		
8.	VSAT		
9.	4G		
10.	5G		
11.	Wi-Fi		

B.5. Please specify the values of indicators for IoT Wireless Network technologies.

№	IoT Wireless Network Technologies	Data rate (kbit/s)	Network bandwidth (kbit/s)	Data transmission range (meters)
1.	RFID			
2.	NFC			
3.	Bluetooth			
4.	WBAN			
5.	Zigbee			
6.	WPAN			
7.	LPWAN			
8.	VSAT			
9.	4G			
10.	5G			
11.	Wi-Fi			

B.6. Please assess the significance of **economic criteria** affecting the potential for implementation wireless network technologies into the Internet of Things ecosystem, assuming that the sum of importance levels of economic criteria is 100%.

Economic criteria	**Economies of scale**	**Market expansion**	**Network deployment cost**	**Cost of maintenance**
Importance level, %				
	The sum of the importance levels of economic criteria is 100%. *(For example: 20% (Economies of scale) + 35% (Market expansion) + 25% (Network deployment cost) + 20% (Cost of maintenance) = 100%)*			

B.7. Please assess the significance of **organizational criteria** affecting the potential for implementation wireless network technologies into the Internet of Things ecosystem, assuming that the sum of importance levels of economic criteria is 100%.

Organizational criteria	**Development of staff competitiveness**	**Research staff availability**
Importance level, %		
	The sum of the importance levels of organizational criteria is 100%.	

B.8. Please assess the significance of **technological criteria** affecting the potential for implementation wireless network technologies into the Internet of Things ecosystem, assuming that the sum of importance levels of economic criteria is 100%.

Technological criteria	**Data transmission range**	**Data rate**	**Energy efficiency**	**Interoperability with other networks**	**Network bandwidth**	**Connection establishment time**	**Radiofrequency (RF) penetration**	**Network scalability**
Importance level, %								
	The sum of the importance levels of technological criteria is 100%.							

B.9. Please assess the significance of **legal criteria** affecting the potential for implementation wireless network technologies into the Internet of Things ecosystem, assuming that the sum of importance levels of economic criteria is 100%.

Legal criteria	**Standards**	**Use licensed radio frequencies**
Importance level, %		
	The sum of the importance levels of legal criteria is 100%.	

B.10. Please assess the significance of **perspectives** affecting the potential for implementation wireless network technologies into the Internet of Things ecosystem, assuming that the sum of importance levels of all perspectives is 100%.

Perspectives	**Economic**	**Organizational**	**Technological**	**Legal**
Importance level, %				
	The sum of the importance levels of economic, organizational, technological and legal perspectives is 100%. *(For example: 25% (economic) + 15% (organizational) + 35% (technological) + 25% (legal) = 100%)*			

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