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An Approach to the Application of the Internet of Things in Logistics

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Abstract: The Internet of Things (IoT) is a technology of the future that is being widely applied in business environment. Companies around the world are starting to apply IoT technologies to ensure the most efficient business possible. The importance of the application of this technology has been particularly evident in improving logistics processes. This paper describes IoT applications in processes such as supply chain management, i.e. control of transport and storage of goods and materials. Examples of smart solutions offered by IoT technology are presented. Various technologies and standards are used in the implementation of the IoT. The scientific community is increasingly researching new technologies such as NB-IoT and 5G, which provide an even greater potential for IoT development. Therefore, this paper shows a comparison of these technologies and explains how IoT devices work with them.

Keywords: 5G network; Internet of Things (IoT); logistics processes; Narrowband Internet of Things (NB-IoT)

1 INTRODUCTION

The Internet of Things (IoT) is one of the most advanced technologies nowadays that is applied in almost every aspect of our lives. The IoT connects smart devices and enables them to communicate with each other and with the environment. A network consisting of such connected devices collects and exchanges data, which is later used to perform necessary actions. The IoT plays an important role in business environment, especially in logistics. According to [1], logistics as an activity is responsible for monitoring distribution networks and managing the flow of resources and final products. According to [2], logistics mission is "to get the right goods or services to the right place, at the right time, and in the desired condition, while making the greatest contribution to the firm". Logistics strives to integrate the handling of materials and information, the provision of services to consumers, logistics communications, the monitoring of warehouse locations and transport tracking. Control of the two main logistics actions, transport and warehousing, can be significantly improved through the use of IoT technology. Collecting information using sensors provides insight into important data which will be used for further work. The Internet of Things offers the opportunity to connect logistics infrastructure by all parts of the supply chain, creating a functional unit. Connecting resources, goods and devices greatly helps to create a unique environment with automated functions. The IoT ensures traceability of information and goods. Transport control, supply and shipment tracking, optimization of vehicle routes, automated maintenance of infrastructure elements are some of the applications of IoT technology in logistics. According to [3], doing business optimally means finding solutions that will provide the lowest possible costs. Acquisition, implementation and maintenance of modern and sophisticated technologies such as the IoT imply significant costs for the company, but since it provides tracking of all resources of a company, it ultimately plays a significant role in achieving savings.

According to [4-6], transport control includes determining the location of transport vehicles and tracking them on routes. Important parameters that need to be monitored are vehicle temperature, vehicle humidity, lighting conditions and the like. The goal is to get optimized vehicle routes, reduce fuel consumption, effectively and efficiently maintain the quality of transported resources, and speed up loading, reloading, and unloading. The IoT provides automation of processes and ensures a quick response to possible irregularities, since it ensures real-time monitoring of data. In addition to transport, it is important for companies to control the flow of materials and information in warehouses. The functionality of the warehouse is reflected in its management. According to [7], modern warehouse management systems require automatic identification and monitoring of data and warehouse activities in real-time. Identification of forklifts, pallets and warehouse employees is important for successful organization of all warehouse processes and their management. With the help of IoT technology, it is possible to control all warehouse parts and monitor and analyze data important for further processes.

The paper consists of three sections. The introduction is followed by a more detailed discussion of the importance of applying the IoT in transport logistics and warehouse logistics. Section 3 presents a comparison of the technologies, while Section 4 points to the future of the application of technology in logistics, the 5G network, and the challenges that the application of technology brings. This is followed by a conclusion on the lessons learned in the paper and recommendations for further research. The methods used in the paper are analysis, synthesis, induction, and deduction of knowledge and facts from available primary, secondary, and tertiary sources in which scientists and experts have presented their prior knowledge relevant to the topic of this paper.

2 DISCUSSION

The following section describes IoT technologies used in transport and storage activities. IoT solutions are realized by integrating different hardware and software. These are various wireless and network sensors, microcontrollers, microprocessors, and systems such as GMS (Global System for Mobile Communication), GPS (Global Positioning System), GPRS (General Packet Radio Service), RFID (Radio-Frequency Identification), cloud technologies, and Wi-Fi. Tracking and managing cargo in the transportation and logistics industry requires a solution that is fully mobile and can travel with cargo while staying connected and communicating back to the home servers/platform. For connectivity on a global scale, regardless of where your device moves, one of the best recognized solutions - particularly for large-scale deployments - is cellular M2M connectivity (Mobile to Mobile).

Table 1 Application of IoT technologies in transport

Product/application	Company	Technology used	Results
SmartPORT: measuring activities in and around the river port, monitoring parameters such as temperature, humidity, wind direction, air pollution, water level, goods flow management, networked ships, bridges and other port elements	SAP in cooperation with Deutsche Telekom and the ADAC car club (Germany)	Cloud technology, mobile applications for real-time communication	Increased port permeability, connected participants in traffic and logistics, reduced CO_2, smart lighting, better driver awareness in the port, reduced waiting, improved routes, digitalization of port traffic inspections [16]
Real-time monitoring and controlling of transport distribution centres	MOST (Sweden)	GSM network, sensors, cloud technology	Improved transport actions, route optimization, better shipment control [17]
Transport and equipping with the regulation of temperature, humidity, brightness and shipment pressure, sending warnings in case of irregularities, vehicle tracking and connection to the central station, providing insight into the condition of the roads	DHL (Germany)	Sensors, GPS	Improved transport services, route optimization, better information of the traffic condition, timely warnings of obstacles [17]
TruckCam: simultaneous video and audio recording in the vehicle cabin and recording of the route	TruckCam AB (Sweden)	Cloud technology	Accident investigation during transport, safety improvement [18]
GSETrack: monitoring and tracking of luggage carts and other non-motorized equipment at the airport, sending and receiving equipment information	Undagrid (Netherlands)	LoRa, BLE	Facilitated location of equipment, more efficient transfer of goods [19]

Table 2 Application of IoT technologies in warehousing

Product/application	Company	Technology used	Results
SmartLift: tracking the location of goods in the warehouse in real-time and the speed and direction of the forklift	Swisslog (Switzerland)	Big Data, sensors, GPS	Reduced storage costs, higher productivity and efficiency and increased security of supplies and employees [16]
Smart systems installation in the energy consumption of the warehouse, sensors placed in the infrastructure of the warehouse monitor and regulate the lighting ventilation and heating level	OHL (SAD)	Sensors, cloud technology	The analysis of the collected data enables control of energy consumption, reduction of costs [16]
Supply chain monitoring, temperature, chain compliance and visibility tracking, refrigerated containers monitoring	GlobeTracker (Denmark)	Wireless sensors, Bluetooth, LoRa	The company has insight into events inside the warehouse, increased income, increased efficiency [17]
VoiceXtreme: real-time voice warehouse management	Spica (Croatia)	Wi-Fi, sensors	Improved work efficiency, speech communication leaves more room for manual handling and other tasks, easier management of industrial facilities [20]

2.1 IoT in Transport

According to [8], controlling transport means managing fleets, monitoring the vehicles used by the company, and the activities of the company's employees. The IoT finds application here in vehicle cloud monitoring. The technology needs to be built into the vehicles, and monitoring is done through any device connected to the Internet, such as a cell phone. GPS is used to determine the location of vehicles and track routes. The connection to the Internet application is established via GPRS. In fact, a GPS signal, which uses the GNSS network (Global Navigation Satellite System), provides information about the current location, direction of movement, time and speed of the tracked vehicle. Among other information collected through IoT devices, all collected data is subsequently stored in the cloud, allowing users to get reports on trips and travel expenses, cargo status and the like. The IoT also enables the execution of functions such as creating travel orders and provides control of the vehicle while driving whenever it is connected to the Internet. According to [9], in logistics, it is crucial to get information in a timely manner. That means the company can monitor its vehicles at any time. Real-time tracking brings improvements for transport by reducing delays or, for example, simply solving problems in determining the most convenient routes. In addition, when transport problems arise, a response and finding a solution by means of the IoT can be much faster than before. According to [10], it is important to monitor the condition of products during transport and RFID technology can be used for that purpose. The built-in sensors with RFID collect product data, which allows control over them. In addition, it is important to collect information about vehicle maintenance and monitor driving conditions. According to [11], this is done with the help of OBD technology (On-

Board Diagnostics). All information stored in the cloud can then be analyzed and feedback can be sent to the driver's cell phone as needed. Drivers receive instructions via special IoT applications. This way of connecting devices and using these technologies helps the effective development of the company. With the IoT, as stated in [12], transport becomes automated, and its application provides better opportunities for the development of logistics of any company.

2.2 IoT in Warehousing

According to [13], traditional systems require more employees in warehouses. Today, efforts are being made to build smart warehouses that will utilize human resources exclusively to control the processes carried out in the warehouse. Based on [14], the IoT provides automated processes and networking of physical components facilitating warehouse management. Supply classification, tracking orders, monitoring the shelf life of products and parameters such as temperature, air humidity, and other conditions in the warehouse are important for its efficient functioning. According to [15], it is important to control shipping and replenishment of goods. In this way, goods can reach the right users at the right time. Supply control and availability of information about the location or quantity of goods can be realized using RFID technology. According to [16], the IoT can offer numerous benefits to warehouses such as precise control of goods and real-time management, timely detection of problems and irregularities, visibility of all processes, employees, and supplies, increased efficiency and employee safety, and monitoring the condition of goods and warehouse conditions. The information needed to control all these processes is collected using built-in sensors. By analyzing the collected data, problems in the warehouses are solved in time and an optimal response is provided. In addition to supply control, it is important to pay attention to the maintenance of equipment in the warehouse. With the help of the IoT, it is possible to monitor data on damage or defects and reduce human error, which in turn reduces the costs of the company. The sensors monitors the conditions in the warehouse and signals significant changes to the WMS (Warehouse Management System) with the appropriate software. By installing cameras on forklifts, it is possible to scan the space and thus reduce the risk of accidents, which increases employee safety. Sensors can detect the condition of pallets to better ensure proper handling. When a problem occurs, employees are notified thereof through a specific application and cane then manage warehouse processes with increased safety. Warehouse conditions are not always ideal, so it is important to monitor the health of employees. The IoT finds application here as well, for example, with devices such as smartwatches or smart wristbands. They measure heart rate or calories burnt, and timely notification of physical changes can prevent potential injuries and problems.

Tabs. 1 and 2 show different products of individual global companies and describe their application related to transport and storage. The technologies used in their implementation and the results achieved through the application of the IoT are listed.

3 TECHNOLOGY COMPARISON

Connectivity is a critical component of the Internet of Things. IoT devices rely on networks to communicate with gateways, applications, servers, routers, and other IoT devices. This communication - data transmission and reception - enables IoT devices to perform the functions they were designed for.

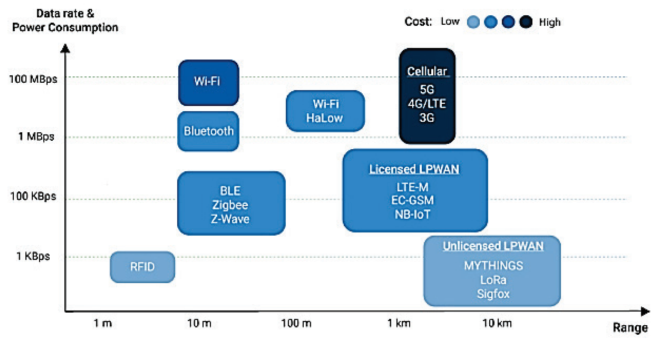

Figure 1 Comparison of IoT technologies by certain characteristics [21]

The IoT uses various protocols and technologies that enable its implementation. Different companies have different needs in relation to the IoT, and the type of technology applied depends on these needs. It is important to think about the spectrum to be used (licensed or unlicensed), the data rate required, power consumption, the number of devices that must be connected, and how much all that costs. Fig. 1 shows the relationship of different technologies by their reach, data rate, energy consumption and costs, and these are described in more detail below.

According to [22, 23, 24], one of the unlicensed networks is SigFox and it is the first global IoT network. It operates within the frequency band ranging from 915 MHz to 928 MHz (USA), at 868MHz (Europe) and at 433 MHz (Asia). It is characterized by low implementation costs and low noise levels, hence low energy consumption. It uses many devices that communicate with each other. The data rate is up to 100 bit/s. Based on [24], another unlicensed network is LoRa, which operates in the frequency band ranging between 868 MHz and 915 MHz. It enables secure data transfer with low power consumption. It covers up to 8 km in urban areas and up to 22 km in rural areas. The baud rate can be adjusted from 0.3 to 50 kbit/s. It has high noise resistance and uses SS (Spread Spectrum) and CSS (Chirp Spread Spectrum).

A wireless local area network (WLAN) is a network that provides high-speed internet and secure communication. It is also known as Wi-Fi. It is based on the IEEE 802.11 standard and used to transmit sensor data within a range of 100 m. The data rate ranges from 2 Mbit/s to 600 Mbit/s. Unfortunately, the implementation of WLAN can be very expensive for large smart grids.

According to [24], ZigBee, a low-power broadband network, is also in the unlicensed spectrum. Its implementation is simple and cheap, but it has low coverage of up to 100 m. It is based on the IEEE 802.15.4 standard. Data rates are up to 250 kbit/s in the 2.4 GHz band, 40kbit/s for 915 MHz, and 20kbit/s for 868 MHz. ZigBee technology is prone to interference and does not have large processing capabilities.

According to [24], WiMAX wireless technology is based on the IEEE 802.16 standard and it uses a 4G network. The data rate is up to 75Mbit/s, and the coverage is up to 50 km. It has a short delay of 10 to 50 ms. Its implementation is expensive, thus just like SigFox, it is not ideal for larger smart grids. Broadband low-power networks (LPWAN) are suitable for the IoT. As a result, standards have recently been considered that will enable more successful implementation of the IoT. Examples include the licensed standards NB-IoT and LTE-M. These are technologies that incline towards the 5G network, which holds the key to future communications.

According to [25, 26, 27, 28], NB-IoT is used in the transmission of small amounts of data. It is standardized by 3GPP, connected to LTE infrastructure, and based on LPWAN. Using existing cellular infrastructures, it is a good candidate for IoT implementation by providing a standardized common platform for device connectivity. An important advantage of NB-IoT technology is its compatibility with LTE frameworks, GSM, UMTS and the 5G network. It is ideal for large coverage networks with minimal complexity. One of the greatest advantages of NB-IoT is its adaptability in complex situations such as work in rural areas. It is also considered green technology due to its energy characteristics, which is very important while working with a large number of devices or sensors. It allows you to connect many devices (more than 100,000). It uses a wide frequency band (180 kHz). Data rates are not especially high, up to 250 kbit/s. However, NB-IoT is not sensitive to delays, so it is used in delay-tolerant applications. It is based on the LTE protocol whose functionality it reduces to make improvement to IoT applications. It is used, for example, in smart parking, which is part of transport activity, and for the purpose of supervision and monitoring. In contrast, LTE-M has a higher delay (100-150 ms), which makes it a more powerful option.

According to [29], there are three defined ways of operating the NB-IoT network. Stand-alone mode is an autonomous mode that uses an independent frequency band that does not overlap with the LTE band. Guard-band mode is a mode in the protected band of the LTE network. In-band mode uses the LTE band for development and requires one PBR (Physical Resource Block) LTE band. This is the most commonly used mode. The NB-IoT network consists of five parts. An NB-IoT terminal represents IoT devices that have access to the NB-IoT network. The base station refers to the stations that need to support the defined working modes. The core of the NB-IoT network is used to connect the base station to the cloud IoT platform. The cloud platform is used to process various services and provide results to NB-IoT terminals. The Vertical Technical Center receives services, stores them in its center and takes control of the NB-IoT terminals.NB-IoT technology is still in the introduction phase. It is evolving by using and upgrading existing networks and it will take some time before it becomes accepted and developed around the world. As it is not yet fully developed in practice, LoRa and Sigfox, which are mature and commercialized technologies, are often still used.

Tab. 3 shows the technologies used by the IoT and compares the values of their essential parameters.

Table 3 Comparison of IoT technologies

	SigFox	LoRa	WLAN	ZigBee	WiMAX	LTE-M	NB-IoT	GSM	RFID
Spectrum	Unlicensed	Unlicensed	Unlicensed	Unlicensed	Unlicensed	Licensed	Licensed	Licensed	Unlicensed
Cellular	No	No	No	No	No	Yes	Yes	Yes	No
Range	Urban: 3-10 km Rural: 30-50 km	Urban: 8 km Rural: 22 km	10 m	100 m	50 km	Urban: 2-5 km	Urban: 1-5 km Rural: 10-15 km	<35 km	20 cm
Max data rate	100 bps	50 kbps	600 Mbps	50 kbps	75 Mbps	1 Mbps/1Mbps	250 kbps	<500 kbps	106-424 kbps
Bandwidth	100 Hz	500 kHz	20 MHz	2 MHz	20 MHz	20 MHz	180 kHz	200 kHz	200-400 kHz
Frequency band	868MHz (Europe), 915-928 MHz (USA), 433MHz (Asia)	868-915 MHz	2.4-5 GHz	868 MHz-2.4 GHz	2.3, 2.5, 3.4 GHz	1.4-20 MHz	700, 800, 900 MHz	850, 900, 1800, 1900 MHz	13.56 MHz
Standardization	Collaboration of ETSI	LoRa Alliance	IEEE 802.11	ZigBee alliance	IEEE 802.16	3GPP	3GPP	2G, 3G, 4G, LTE, CDMA	ISO
Interference immunity	Very high	Very high	Low	Low	High	High	High	Low	Low
Energy consumption	Low	Very low	High	Low	Medium	Low	Low	Medium	Medium
Cost	Low	High	High	Low	High	High	High	Medium	Low

After analyzing all options, the question arises as to how to choose the technology that will be most effective for the application of IoT. The parameters on which network quality depends are quality of service (QoS), battery life, latency, network coverage, scope, development model, and cost.

- **Quality of service**

QoS depends on the spectrum that is involved and the protocols that are used. For example, LoRa and SigFox use unlicensed bands and are based on the ALOHA asynchronous protocol. While they deal well with interference, they do not provide a very high quality of service. NB-IoT, which uses a licensed spectrum and the LTE protocol, stands out here. However, seizing the spectrum is very expensive. Therefore, when there is a need for better QoS, NB-IoT technology will be used, and otherwise, it is better to use e.g. LoRa.

- **Battery**

Battery life depends on power consumption of the device. NB-IoT has high power consumption, so SigFox or LoRa is a better option if battery life is an essential parameter in IoT applications. Due to the asynchronous LoRa protocol, devices can idle for as long as necessary and thus save battery power.

- **Delay**

NB-IoT applications require a small delay when transferring large amounts of data. If applications are sensitive to latency and do not send large amounts of data, e.g. LoRa would be a better choice.

- **Scalability**

The IoT needs to be able to connect an enormous number of devices, and all technologies applying it enable this. But NB-IoT provides an incomparably greater advantage, where it also achieves connectivity of up to 100,000 devices per base. It sends a much larger amount of data at the same time compared to other technologies.

- **Coverage and range**

Although NB-IoT is much more convenient when it is necessary to send a large amount of data, its coverage is only up to 10 km. It is deployed only within LTE infrastructure and not adapted for regions like rural areas that do not have LTE coverage. LoRa is a bit more flexible and has a range of up to 20 km, while SigFox has an even bigger range of up to 40 km.

- **Costs**

There are several cost types to consider. These are spectrum license costs, network setup and development costs, and end-device costs. Accordingly, NB-IoT is the most expensive option.

When it comes to logistics processes, it is necessary to enable machine automation, i.e. continuous monitoring and data collecting using sensors. According to [30], this requires continuous communication and a service of high quality. So, NB-IoT would be a good solution. However, if this is a large area, where many sensors are needed, and it is important to make sure that long-lasting batteries are used, then technologies such as LoRa and SigFox have an advantage. When it comes to warehouses, it is important to control parameters such as temperature, humidity, safety, goods flow, energy consumption, etc. For this, you need to use a lot of cheap sensors with good batteries, so LoRa and SigFox are the best options. As each technology has more multiple benefits, it is good practice to use hybrid solutions.

4 THE FUTURE OF LOGISTICS, THE 5G NETWORK AND OTHER TECHNOLOGICAL CHALLENGES

According to [31], the most advanced technologies such as NB-IoT are based on LTE, i.e., the 4G network. The more devices that need to be connected, the harder it is for the 4G network to provide full support. It is crucial to achieve a high data rate, which can go up to 1Gb/s maximum. It is possible to connect about 4,000 devices within a square kilometer, which contradicts the IoT idea (millions of devices connected in the same place). This creates the need for an even more efficient network, hence 5G. According to [32], 5G is a heterogeneous system that includes 4G, Wi-Fi, millimetre waves, and other wireless technologies. 5G offers high data rates between many connected devices, with an extremely small delay. That is very important for the development of IoT applications. The frequency band used by mobile networks (up to 3.5 MHz) is slowly becoming overcrowded. According to [33], 5G will allow operation ranging about 26 GHz.

According to [34], various parameters must often be monitored in logistics activities, which requires a large number of sensors. 5G will support for every meter of coverage up to 1,000 times more devices than the 4G network could with a 100 times higher data rate. High speeds, low delays, higher coverage, lower power consumption, and real-time actions execution are essential factors for the successful implementation of the IoT. Thus, the IoT becomes the key to the future development of logistics. A major challenge for logistics is the visibility of the supply chain. Without good enough supervision, information on the condition or location of goods is lost. With 5G it will be possible to monitor all data in real-time. Extremely low delays in 5G will be very suitable for autonomous transport actions that need fast feedback to execute all decisions promptly. Human errors that lead to loss of goods, mismanagement, and inefficiency are also common during the monitoring of logistic actions. Such problems will disappear with the implementation of IoT systems based on the 5G network. Amounts of data are rapidly growing, as well as customer demands. Those circumstance will demand applications that need faster and smarter, but also reliable architecture. It is very probable that the current IoT architecture will not be sufficient for next-generation IoT applications and upcoming services. Nowadays, most of the architectures are implemented in industry or smart cities, and by [35], these architectures are suitable for the time being, but they will not no longer be promising in terms of reliability and performance due to future challenges and therefore need to be re-examined. The fifth generation (5G) networks are taking into consideration the growth of IoT applications. Important contributions are made to the next generation of the IoT by connecting billions of intelligent devices which will allow the desired growth. For example, the existing cellular networks are not able to support the MTC communications (Machine Type Communication), but the 5G-IoT networks could provide this. In addition, 5G-IoT provides the fastest cellular network data rate with very low latency and improved coverage for M2M communication.

According to [36], the application of the IoT in logistics is expanding more and more. Therefore, it continues to face numerous technological challenges. An example of the current problem is the sensitivity of RFID technology to electromagnetic interference. In addition, there is also collision of containers that contain sensors. Thus, the location and identification of goods is difficult. Other problems such as signal attenuation or limited sensor battery life may interfere warehouse activities. Delays and data losses create low efficiency and high energy consumption. IoT technology is limited by vehicle selection and cargo optimization during transport. Attention should also be paid to working with data.

For huge amounts of data, there are also large requirements based on complex logistics processes. A particular challenge for the IoT is to preserve information to avoid privacy violation or data theft.

Today, efforts are being made to develop better algorithms against RFID sensors collisions, and new protocols are being proposed to identify unread data. Scientists are also working to optimize communication protocols to prolong sensor battery life. New technologies, like the 5G network, allow less latency and more coverage. With cloud technology, it is possible to solve complex situations in supply chain management, which provides flexibility and automation, and facilitates data review and sharing. In order to make logistics IoT systems as efficient and secure as possible, it is necessary to include new protocols and technologies such as M2M (Machine to Machine), BLE (Bluetooth Low Energy), Z-Wave, artificial intelligence, cloud technologies, Big Data, and others.

According to [37], IoT technology is reforming logistics and consequently driving profit. Improving logistics processes is key to the progress of any company. Therefore, the development of communication, sensor and mobile technologies is really important. Thus, the integration of logistics processes with the advancement of IoT technology will become more and more optimal.

5 CONCLUSION

As one of the most advanced technologies today, the IoT is widely applied in various scientific fields and economic activities, including logistics. Efforts are being made to optimize logistic processes, and this includes better control of goods and assets, monitoring the operation of warehouses, introducing automated work, monitoring the transport of goods and determining the best routes. Collecting a large amount of information, timely responses, automated device management, real-time data processing are the benefits that the IoT brings. All this significantly changes the flow of logistic processes and leads to increased efficiency as well as reduced costs. Companies around the world are trying to introduce the IoT as much as possible and use all its benefits for the advancement of logistics. Various technologies and standards can be used in the implementation of IoT systems, depending on the application needs. In logistics, the most common is the usage of wireless sensors, RFID technology, cloud technology, GPS, WLAN, and mobile networks. Wireless technologies such as SigFox, LoRa, ZigBee, and WiMAX are often applied in IoT systems. In recent times, efforts have been made to incorporate NB-IoT technology, which offers even better advantages for the further development of the IoT. The 5G network will bring great changes as it will enable the connection of an extremely large number of devices at high data rates. It will be a revolution in IoT technology, and thus in logistics.

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