Radio-frequencies technologies for local communication in cyber-physical environment

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Abstract. The paper is devoted to the Internet of Things which is becoming more popular and, in particular, to wireless connections and technologies. The paper considers two technologies that are currently most widely used on the Internet of Things: Bluetooth and Wi-Fi. The milestones of their development are considered, as well as advantages and features of each technology. Various devices that employ Bluetooth and Wi-Fi technologies and their interaction are described. The conclusion about the perspectives of development of Wi-Fi technology is made.

1. Introduction
The Internet of Things, which not only allows objects to interact with each other, but also provides interaction between objects and people, is becoming a reality and completely changing our world in many ways. Wireless connection of everyday items can automate data exchange and increase efficiency, which has a positive impact on the lives of people and organizations [1, 2]. The introduction of the Internet of Things (IoT) involves the use of wireless networks, which are present around us more and more every day.

Wireless networks mean networks in which two or more terminals can communicate without a wired connection. Wireless networks are based on radio wave connections instead of conventional cables. Each network has its own radio access technologies, for example, Bluetooth, Zigbee, Wi-Fi, WiMAX, 5G, etc. The wireless network categories are shown in Figure 1 [3].

There are two main types of radio access technologies - in licensed and unlicensed frequency spectra. The development of the Internet of Things has aroused interest in radio access technologies in an unlicensed frequency spectrum. Next, the focus will be on two technologies operating in an unlicensed spectrum of frequencies that are currently most widely used on the Internet of Things - Bluetooth and Wi-Fi. These technologies are also widely used in the Industrial Internet of Things, for example, in open-pit and underground mining operations, for the communication of autonomous drones for various purposes with the base station and among themselves [4].

Bluetooth technology is well suited for exchanging information over short distances between a large number of mobile devices (for example, to connect a smartphone to a car, headset or computer). Zigbee technology is also used at short distances.
Wi-Fi technology is better suited for transmitting large amounts of information over long distances. The following will focus on the latest developments in Bluetooth and Wi-Fi technologies. The development of Bluetooth technology has more than 20 years. The main steps in improving this technology are summarized in Table 1 [5-7].

Table 1. Bluetooth Technology Milestones

| Version | Date | Properties |
|---------|------|------------|
| 1.0     | 1998 | 1 Mbps speed. |
| 1.1     | 2002 | Standardized IEEE 802.15.1. |
| 1.2     | 2003 | Frequency hopping. |
| 2.0     | 2004 | Optionally, increase the data rate to 3 Mbps. |
| 2.1     | 2007 | Encryption, authentication methods, power reduction. |
| 3.0     | 2009 | Improved power management. |
| 4.0     | 2010 | Low power mode, encryption. |
| 4.1     | 2013 | Coexistence with mobile wireless communication. |
| 4.2     | 2014 | Connection level privacy, IPv6 support profile. |
| 5.0     | 2016 | 1, 2, or 3 Mbps, low power consumption, optional 802.11 feature for speeds up to 24 Mbps, mesh network. |
| 5.1     | 2019 | Determine the exact location of the device by analyzing the direction to connected devices. One of the devices must have an array of several antennas. |
| 5.2     | 2020 | Dynamic optimization of transmission power, timing of transmission channels. |

2. Results
There are two types of Bluetooth devices: one is called Bluetooth Classic (it is used in wireless speakers, car infotainment systems and headsets), and the other is called Bluetooth Low Energy (BLE). These two types of Bluetooth devices are incompatible with each other. This means that the Bluetooth Classic device cannot directly communicate with the Bluetooth Low Energy device.
Therefore, some devices, such as smartphones, prefer to implement both types (sometimes it is called a Bluetooth device in double mode), so they can interact with both types of devices.

**Bluetooth Low Energy (BLE)**, or **Bluetooth Smart**, is a low-power version of the well-known Bluetooth wireless technology. Low power consumption is achieved by changing the data protocol to create low duty cycle transmissions.

Bluetooth Low Energy is designed to reduce the power consumption of Bluetooth devices. BLE was introduced in 2010 with Bluetooth 4.0, and not with traditional Bluetooth radio, which consumes more energy.

With the introduction of Bluetooth 5.0 in 2016, all audio devices communicate through Bluetooth Low Energy, which means less power consumption and a longer battery life.

Since many IoT systems include small devices and sensors, BLE has become a more common protocol in IoT in terms of energy efficiency, which is very useful on the Internet of Things.

In 2017, the Bluetooth SIG Consortium (Special Interest Group) published the following three specifications of the Bluetooth mesh network:

- **Meshy 1.0 profile** - requirements of integrated mesh-network solution;
- **Mesh 1.0 model specification with node functionality**;
- **Mesh 1.0 device properties**.

A mesh network is a distributed, peer-to-peer, self-organizing network with a mesh topology. In a mesh network, all nodes are peer, each node is both a provider, router, and switch. According to the Mesh 1.0 specification, the maximum number of mesh network nodes can be 32,767, the maximum lifetime (TTL) is 127. If the message is received by the node and then retransmitted, the TTL is reduced by one. This prevents infinite cycles.

Features of mesh networks:

- The "intelligence" of the network means that when connected, each node automatically receives information about all other access nodes in the network and "finds out" its role;
- self-healing and self-adaptation. When a network is turned on, each device automatically determines the state of its neighbors and its role in the common topology. Therefore, when one of the nodes fails, the network is able to redirect data - redefine routes automatically;
- quick deployment. Deploying a mesh network does not require expensive infrastructure. Due to self-healing and self-adaptation abilities, this network is economical to operate;
- concept of network filling. Each incoming packet is sent through each outgoing communication, except for a reference to the parent of the message. The node automatically finds the shortest route.

Another wireless personal area network (WPAN) standard is IEEE 802.15.4. The standard defines only the physical and channel layers. The model was ratified in 2005. The goal of 802.15.4 and the protocols that are on it is an inexpensive WPAN with low power consumption. One of the latter is the IEEE 802.15.4e specification ratified in 2012. The protocol operates in an unlicensed spectrum in three different radio frequency bands: 868.3 MHz, 915 (902-928) MHz, 2,405-2480 MHz. The 2.4 GHz band is the most commonly used. The radius of the 802.15.4 protocol with direct visibility is about 200 meters, in the room - about 30 m. The data transfer rate reaches 250 kbit/s.

The Zigbee protocol is a WPAN protocol based on IEEE 802.15.4 for low-power networks. It is Bluetooth-like, but designed for the Internet of Things. It consumes little and is designed to send small amounts of data (for example, turn on the light in the bedroom).

The Zigbee Alliance approved specification 1.0 in 2004. The protocol is a private and closed standard. The Zigbee network has three main components:

- a controller for forming and starting network functions. Once the network is formed, the controller can act like a router;
- the router is involved in routing multi-hop messages, assigning logical network addresses, and allowing nodes to join or leave the mesh network;
the final device, for example, a light switch or a thermostat. It has sufficient functionality to communicate with the controller. Zigbee endpoints do not participate in routing.

The protocol operates in the 2.4 GHz band, but also at 868 MHz in Europe and 915 MHz in the United States.

Wi-Fi wireless LAN technology is developed on the basis of IEEE 802.11 protocols and provides high data transfer speed in a reliable and secure way. However, it consumes a lot of energy, and its range is relatively limited (35 m), more through obstacles, such as thick walls. To solve the problem in terms of high power consumption taking into account IoT applications, Wi-Fi 6, also called Wi-Fi ax, was released in 2019.

Wi-Fi ax improves the connectivity of objects, and at a speed of 10 Gb/s it is also used to more efficiently manage more devices with less power consumption.

The protocol was first developed in 1991 for cash registers. In 1999, the Wi-Fi Alliance was created (from the phrase Wireless Fidelity - wireless accuracy). The Wi-Fi logo is a trademark of the Wi-Fi Alliance. Equipment that complies with the IEEE 802.11 standard can be tested in the Wi-Fi Alliance, obtain the appropriate certificate and the right to apply the Wi-Fi logo.

The improvement of the IEEE 802.11 standard goes in the direction of increasing the transmission rate using the unlicensed frequency spectrum of 2.4/5 GHz (Table 2).

| Protocol | IEEE 802.11 | Date   | Frequency, GHz | Bandwidth, MHz | Transmission rate min-max, Mbps | Range indoor/outdoor, m |
|----------|-------------|--------|----------------|----------------|---------------------------------|------------------------|
| 802.11 n (Wi-Fi 4) | 2009 | 2.4/5 | 20 | 7.2 - 72.2 | 70 / 250 |
| ac (Wi-Fi 5) | 2013 | 5 | 20 | 7.2 - 96.3 | 35 / 35 |
| ax (Wi-Fi 6) | 2019 | 2.4/5, 20, 40, 80, 160 | 450 - 10 000 | 35 / 35 |
| be (Wi-Fi 7) | 2024 | 7 | 320 | 30 000 | 35 / 35 |

3. Conclusion
The promising development of Wi-Fi 7 involves support for real-time applications, coexistence with the technologies of cellular mobile networks 4G/5G. Consortium 3GPP continues development and standardization of a radio network of access for the fifth generation 5G NR (New Radio) where one of functionality, as well as in 4G of LTE, is put work in not licensed frequency ranges.

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