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Selection of wireless communication technology for data transmission between wearable electronics devices and the receiver

Streszczenie. *Jednym z kluczowych zagadnień dotyczących elektroniki noszonej jest transmisja danych w obrębie sieci bezprzewodowych. Do najczęściej wykorzystywanych rozwiązań należą: technologia Bluetooth Low Energy (BLE), a także protokół ZigBee, charakteryzujące się niskim zużyciem energii oraz niską ceną implementacji. Funkcjonalność takich rozwiązań zależy także od energochłonności zaproponowanych rozwiązań, a także ich rozmiarów i wagi. Celem niniejszego opracowania jest analiza wybranych technik komunikacji, które zostały porównane pod względem ich zasięgu oraz energooszczędności. W pracy przedstawiono wyniki dotyczące testów komunikacji bezprzewodowej. Przedstawiono porównanie zasięgu komunikacji Bluetooth przeprowadzonych w różnych warunkach, takich jak w budynku, w którym nie było przeszkód oraz w obiekcie użyteczności publicznej. W celu porównania parametrów komunikacji Bluetooth zostały użyte różne modele telefonów. (**Dobór technologii komunikacji bezprzewodowej do transmisji danych pomiędzy urządzeniami elektroniki ubieralnej a odbiornikiem**)*

Abstract. *One of the key issues in wearable electronics is data transmission over wireless networks. Among the most commonly used solutions are Bluetooth Low Energy (BLE), as well as the ZigBee protocol, which are characterized by low power consumption and low implementation cost. The functionality of such solutions also depends on the energy consumption of the proposed solutions, as well as their size and weight. The purpose of this paper is to analyze selected communication techniques, which were compared in terms of their range and energy efficiency. The paper presents results on wireless communication tests. A comparison is presented of Bluetooth communication range carried out under different conditions, such as in a building where there were no obstacles and in a public facility. In order to compare Bluetooth communication parameters, different phone models were used.*

Słowa kluczowe: elektronika noszona; energooszczędność; BLE; ZigBee
Keywords: wearable electronics; energy efficiency; BLE; ZigBee

Introduction

Currently, with rapidly developing technologies, wireless transmission has gained in importance in many fields of technology, such as telecommunications, medicine or mechanical engineering [1-3]. The most popular consumer communication standards are Bluetooth, Wi-fi and ZigBee. These standards coexist on the same 2.4 GHz ISM frequency band, but differ in the number of available channels, bandwidth and power consumption. Bluetooth and Zigbee have significantly lower power consumption compared to Wi-Fi communication, but have much lower bandwidth [4-7]. The transmission bandwidth for BLE is 2404-2480 MHz and has as many as 40 channels (channels every 2 MHz), of which 3 channels are used for device broadcasting. In contrast, Zigbee has a transmission bandwidth of 2405-2480 MHz, where there are only 16 channels (channels every 5 MHz). Wi-Fi has 3 main non-overlapping transmission channels with the following frequency bands: 2403-2423 MHz, 2428-2446 MHz and 2453-2473 MHz (Figure 1).

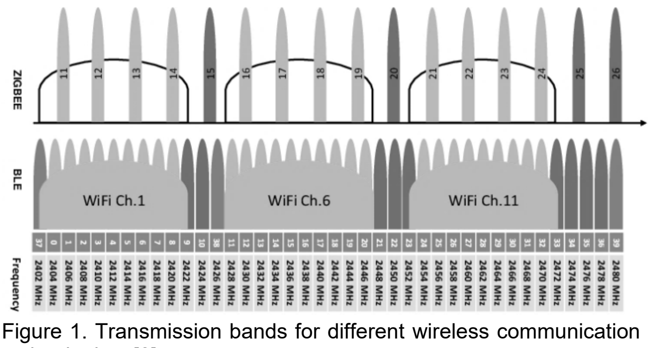

Figure 1. Transmission bands for different wireless communication technologies [8]

Despite the appearance on the market of many solutions applicable to smart clothing [9-11], finding a study that approximates the correct way to design and realize wireless communication in wearable electronics devices is a complex issue on which many research centres are working [12-14]. An analysis of the solutions available on the market shows that existing solutions often lack solutions to support their operation in the form of an application that would allow visualization of data and control of the operating parameters of wearable electronics components.

For this reason, the authors of this paper analysed possible technologies that would enable wireless communication between measuring devices and the central device.

After analysing the modes of operation of Wi-Fi, Bluetooth, ZigBee, Thread, or Matter technologies that determine the operation of IoT devices, it was concluded that the greatest application potential for wearable electronics devices is Bluetooth technology, which is present in almost every consumer device such as a phone or laptop.

Measurement method

To test the functionality and measure the range, reliability and speed of Bluetooth communication, a development board based on the nRF52832 chip with BLE and 2.4 GHz connectivity was used as the transmitter.

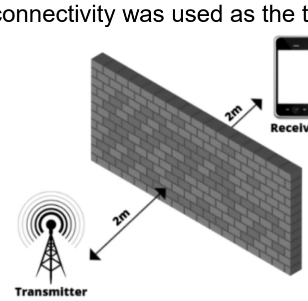

Figure 2. Measurement scheme for analysing signal strength and delay passing through a wall as a function of distance

The measurement circuit also used the nRF Connect for Mobile application, and the receivers were Xiaomi and iPhone phones. The distance between the transmitter and receiver was set using a Yato YT-73125 rangefinder. In addition, the designed measurement system was tested for noise immunity, and power consumption was analysed for Bluetooth and ZigBee.

The microcontroller chosen by the authors allows the processor to operate at 64 MHz and contains a large amount of FLASH (256-512 kB) and RAM (32-128 kB) memory. In addition, it has a 12-bit, 200 kSPS analog-to-digital converter, 5x 32-bit timers, up to 4 connections via SPI and 2 I2C connections [15-17].

Comparison of IoT (Internet of Things) technologies is presented in Table 1.

Tablw 1. Table showing comparison of IoT technologies IoT [4, 5, 18-24]

Technology	BLE	ZigBee	Wi-Fi	LoRa	LTE-M	NB-IoT
Range	< 10m	< 100m	< 100m	5-20 km	< 15 km	> 10 km
Transmission bandwidth	< 2.4 GHz	< 2.4 GHz	2.4 - 5 GHz	0.5 - 900 MHz	± 1.08 MHz	0.45 - 3.5 GHz
Reliability	Medium	High	High	Medium	High	High
Delay	< 10 ms	< 20 ms	< 10 ms	1 - 10 s	0.1 - 1 s	1.5 - 10 s
Power consumption	Low	Low	Medium	Low	Medium	Low
Data transmission	0.5 - 2 Mb/s	250 kb/s	54 Mb/s	50 kb/s	375 kb/s	200 kb/s
Availability on mobile devices	Yes	No	Yes	No	Yes	No
Implementation cost	2 - 5 USD	1 - 5 USD	1 - 10 USD	2 - 25 USD	4 - 35 USD	5 - 30 USD

Results

Example signal strength and delay measurements for the nRF52832 chip, which operates on Bluetooth Low Energy technology, are presented in Figure 3 and Figure 4.

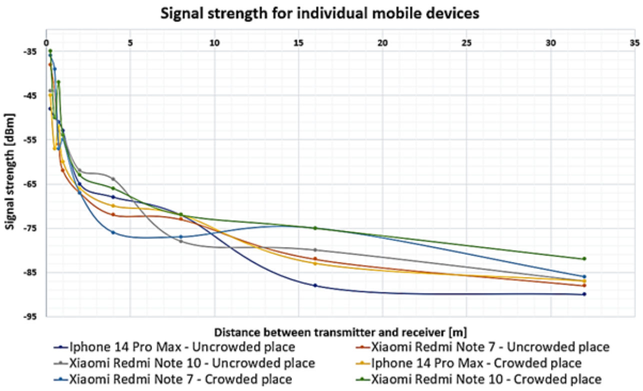

Figure 3. Signal strength for individual receivers

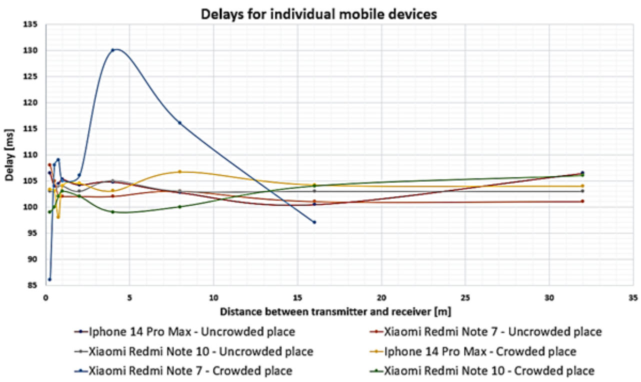

Figure 4. Delays for individual receivers

The above measurements were conducted at two different locations. One was a building with a small number of devices interfering with the signal, and the other location was where a mass event was taking place during the measurements. In the graph above, it can be seen that the signal began to weaken exponentially as the distance between the transmitter and the receiver increased. Various types of obstacles or walls that can exist between the transmitter and receiver can degrade the signal level. The signal can pass through walls and obstacles, however, the strength of the signal will be highly dependent on what material was used to build them.

In the graph of the delay for each receiver, you can see that it does not depend on the distance between the transmitter and the receiver. There are no significant changes. When measured at a mass event in a sports hall, where many devices were present, the latency data varied between 95 - 110 ms. The only more significant differences in latency occurred in the Xiaomi Redmi Note 7. Each phone has a different BLE standard. In the case of the Xiaomi Redmi Note 10, it is BLE standard 5.1, while the iPhone 14 Pro Max is 5.3.

Electricity consumption of a device operating with BLE technology

In case of the nRF52832, 3V voltage was used due to nRF52 being designed to be most energy efficient at 3V [25].

After startup current rises and for 1ms average current is equal to 3.62mA then for 120ms current drops to 120μA and after that time the same advertising signals are send in 100ms interval until peripheral device connects to the central device.

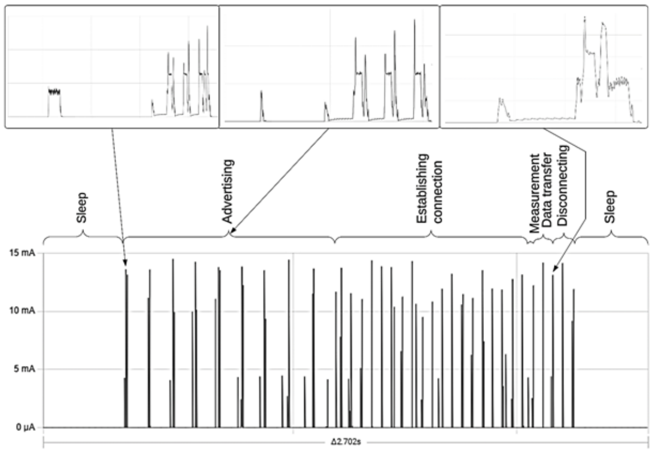

Figure 5. Current consumed by the device during operation nRF52832

Nordic semiconductor provides online power calculator and using it was possible to compare real current consumption and calculated consumption.

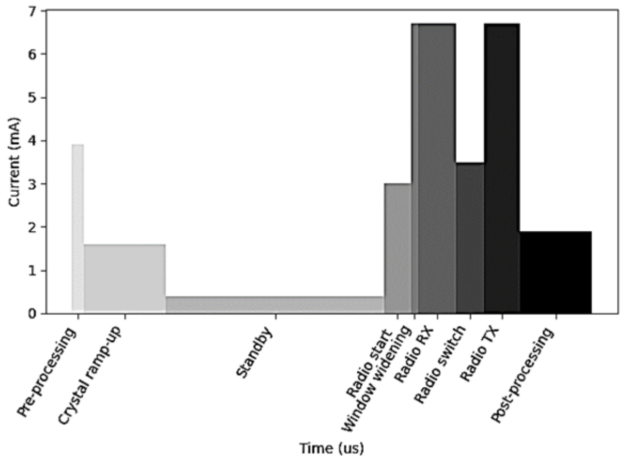

Figure 6. Current consumption calculated by Nordic Semiconductor Online Power Profiler

Calculated current consumption during advertising using Nordic Semiconductor Online Power Profiler [26] (Figure 6) was very similar to the measured one (Figure 5). Additionally, Online Power Profiler provides information what is source of current consumption in given times.

Measured values are slightly lower than those given by Online Power Profiler due to additional capacitances which are present in the circuit.

At the beginning, the peak of the 4.74mA current is observed, during which the pre-processing is done. Then crystal ramps-up mode is observed and during that time maximal current was equal to 1.97mA. Then microcontroller goes into standby mode with average current of 327μA. The current increases to 2.71mA when radio process starts. The next step of communication is transmitting data with the maximum current of 7.24mA and it is followed by the receiving mode with smaller value of average current (3.7mA). In the process of receiving data the current increases up to 14.03mA. Finally, the post processing mode needs the average current of 2.8mA to work properly.

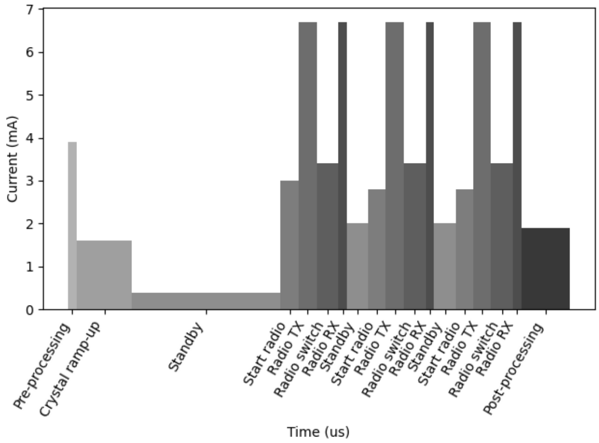

Figure 7. Current consumption during data transmission according to Nordic Semiconductor Online Power Profiler

Current consumption during data transmission was changing and shape of the current consumption chart (Fig. 5) was very similar to the calculated chart (Fig. 7). Values are not exactly the same, but it could have been caused by additional capacitances and inductances present on the test board.

From those current consumption graphs it was possible to calculate which part of consumed the most energy.

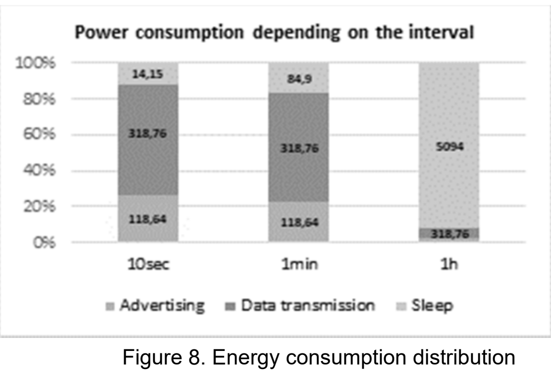

Figure 8. Energy consumption distribution

Figure 8 shows energy consumption and it is possible to observe that depending on frequency in which data was send, the different parts of the communication had different impact on overall current consumption.

In case of frequent data transfers the most energy is consumed during data transmission. Then by decreasing frequency of the data transfers more and more power is consumed during sleep. It can be observed that for the frequent data transfer the most important part of the process is optimization of data transfer current consumption but with the less and less frequent measurements current consumption between data transfers consumed major part of the charge.

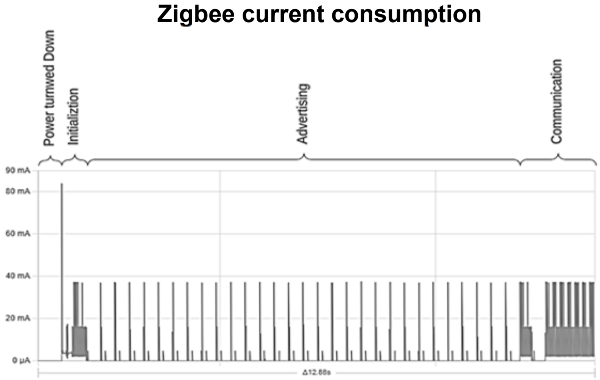

Figure 9. Current consumed by xBee module communicating via ZigBee protocol

Table 2 Maximum current consumption by individual modules (measurement results are given in the mA unit)

Module Type	Initialization	Advertising	Transmission	Average
BLE	13.73	13.72	14.28	14.48
ZigBee	83.82	37.58	37.63	83.82

Table 3 Average current consumption by individual modules (measurement results are given in the mA unit)

Module Type	Initialization	Advertising	Transmission	Average
BLE	0.43	0.14	1.02	0.59
ZigBee	5.74	0.33	7.35	1.68

As can be seen from Figure 9, the energy consumed by the XBee module communicating via the ZigBee protocol as a result of turning off the power to the XBee module, very low power consumption can be observed during the initial transmission phase. In the next stage of the module's operation, after the power is turned on, the module is initialized, which involves loading the device's configuration, which consists of items such as the role of the device, signal strength, sleep mode settings, transmission rate, etc. The next step involves the module's broadcasting. The frequency and length of the broadcast period are set in the device's configuration, which is initialized during startup. At the very end, communication between two ZigBee was presented, where one took the role of coordinator, while the other was the terminal device. In addition, the communication itself took place on the basis of checking the distance and range between the modules, as well as the quality of the connection (the number of data packets sent, received and lost). All this process was done through the XCTU application (a program that allows configuring, testing and mapping XBee devices) and Nordic Semiconductor's Power Profiler (a program that allows charting the power consumption of an individual device).

Analysing Tab. 2 and Tab. 3 it can be seen that BLE technology, compared to ZigBee, draws about 3 times less current for an averaged measurement, and as much as 6 times less current for a pickup measurement.

Discussion and conclusions

The authors in the following article focused on the choice of energy-efficient and wireless communication, through which it is possible to transfer data to a computer or connect the system to a mobile device such as a smartphone.

The Thread protocol was not chosen due to the fact that:

→ it does not support very high data speeds and range, unlike cellular wireless technologies,

→ the maximum number of supported devices (~250) is smaller than that of Bluetooth, which, with proper implementation and configuration of appropriate protocol stack parameters, can support the operation of dense networks with potentially thousands of devices.

In contrast, the Matter standard was rejected because, as with any new technology, there is a greater possibility of security vulnerabilities. However, the main disadvantage that was considered was that it has limited support for older devices that are unable to support the standard. Bluetooth technology is used in mobile devices as well as in desktop devices. In addition, Bluetooth modules used in modern microcontrollers such as the nRF52 are low-current, provide long range, as well as stable communication with low latency and low power consumption.

Based on the analysis of the literature, measurements made by the authors and data provided by manufacturers, presented by Nordic Semiconductor [27], among others, it was determined that the nRF52832 development board meets the requirements for correct communication between the transmitter and receiver over several rooms with energy efficiency. Considering the latency of the signal transmission, as well as the energy efficiency of the proposed solution, it is suggested to use Bluetooth technology for the communication between the transmitter and receiver due to the general availability of Bluetooth technology in every phone which reduces the cost of use.

It is worth noting that different values were obtained for each measuring device used as a signal receiver. Therefore, it is planned to lean on this issue to analyse the exact nature of interference and determine how it affects the system, which is important when using the indicated system solutions for structures used in wearable electronics.

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