

Bluetooth Low Energy Technology Simulators

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Abstract: The growing interest in Internet of Things technologies in modern life requires their active research. This can be done most easily by using a simulation product for the technology in consideration. This article presents the most famous existing simulation products of Bluetooth Low Energy technology, as well as the one developed by the authors, and presents a comparison between the considered solutions.

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1. Introduction

The Internet of Things (IoT) technologies are becoming more and more widespread in modern everyday life, which is leading to their growing worldwide distribution. The active use of IoT technologies in various industries requires the provision of a high-speed data transmission environment. Such an environment provides 4G and 5G technologies, as well as the opportunity for extensive incursion and expansion of broadband technologies for IoT [1].

Among the most common IoT technologies is Bluetooth Low Energy (BLE), which is used to: connect wearable devices such as watches, location devices, health and fitness, body sensors; access to surrounding devices such as access control bracelets, home and office automation; M2M communication with low efficiency as sensors and control devices in homes, offices and factories; communication within a closed system; connecting everything that has data to the Internet. According to statistics and sales forecasts for BLE devices, the number of devices sold is increasing by approximately half a billion per year [2]. This shows that the technology is becoming more and more used.

The widespread use of BLE technology demands offering and researching solutions to improve its performance. Simulators are a suitable tool for researching theoretical improvements to the standard. They allow preliminary study of the proposed solutions before investing resources and time for purchasing, study and configure hardware devices and make efforts to implement new specifications. Implementations of applications to simulate the operation of devices with BLE technology are limited, and most are developed as emulators.

Emulators and simulators allow experiments in software-defined environments. In this way, they ensure that experiments are performed faster than if a real hardware device had to be set up. Although simulators and emulators serve similar purposes, they do not work at

the same way.

The simulator is designed to create an environment that contains all the software variables and configurations that will exist in the actual production environment of the application. However, the simulators are not trying to emulate the actual hardware that will keep the application in use. Because simulators only create a software environment, they can be implemented using high-level programming languages. The emulator tries to mimic all the hardware features of the production environment as well as the software functions.

Simulation products provide an environment for research and study of the main functionalities of the technology in consideration, and the capabilities provided are usually based on existing standards. This allows the simulators to be actively used in the study of new theoretical solutions to improve the technology under consideration. The simplified ability to work with the provided interface, as well as the ability to make modifications to open source solutions makes the simulators an attractive tool with wide application in education. The ability of the simulators to be used on personal machines by the trainees allows for both Onsite and Online work. In addition, the issues addressed during the lesson can exercise at any time.

This article presents several simulation products which examines the basic functionality of BLE technology, as well as their advantages and disadvantages.

2. BLE simulation via MATLAB

The BLE interface in MATLAB [3], included in version 2019b [4], provides many features that allow the implementation of simple BLE applications and the ability to transmit and receive ASCII and binary data. For this implementation, it uses a Bluetooth serial port. Any Bluetooth device can be identified, and a two-way connection can be established using MATLAB. To communicate with a BLE device, the computer running MATLAB must have a built-in or external Bluetooth Low Energy adapter. This MATLAB interface is supported by the following platforms:

- macOS 10.13 High Sierra and newer versions;
- Windows 10, version 1709 and newer.



Once the device is connected, MATLAB is used to read or write data to it (Figure 1). The product allows work with both standard and custom services, features and descriptors, which play an important role in reading from and writing to a peripheral device. The interface provides examples of tracking the orientation of an end device that has a motion sensor, for the Nordic Thingy:52 device, as well as an example of collecting and visualising data from body tone tracking devices of Under Armor during exercises. There are also examples developed for the interface by researchers in the field, for the CC2541 Keyfob and CC2650 Sensor Tag BLE sensor devices [5].



```

Command Window
>> x.DataAvailableFcn=@displayCharacteristicData_x

x =

Characteristic with properties:
    Name: "Custom"
    UUID: "FFA3"
    Attributes: "Notify"
    Descriptors: [2x3 table]
    DataAvailableFcn: displayCharacteristicData_x

Show descriptors
fx >>

```

Fig. 1. Reading data from a sensor node via the MATLAB interface.

Its functionalities are the following:

- scanning nearby BLE peripherals;
- connecting to BLE peripheral;
- access to a characteristic of the peripheral device with BLE technology;
- access to a descriptor of peripheral device with BLE technology;
- reading characteristics or descriptor data of a peripheral device with BLE technology;
- writing data in a characteristic or descriptor of a peripheral device with BLE technology;
- subscribing for a characteristic notification or indication;
- unsubscribing from a characteristic notice and indication.

The MATLAB interface requires the use of a real physical device with a Bluetooth module that supports BLE. The actions in the environment are performed with a sequence of commands, as there is a realised graphic visualisation for the provided sample solutions.

3. The BLE Peripheral Simulator

The BLE Peripheral Simulator application, written in JavaScript, is for Android (Figure 2) services [6], which allows developers to try out new features of Web Bluetooth without the need for a BLE peripheral. The program code can be used to launch the application and can be compiled or installed from the Google Play Store.

The application can be used to simulate BLE peripherals with one of three services:

- battery service;
- heart rate service;
- thermometer service.

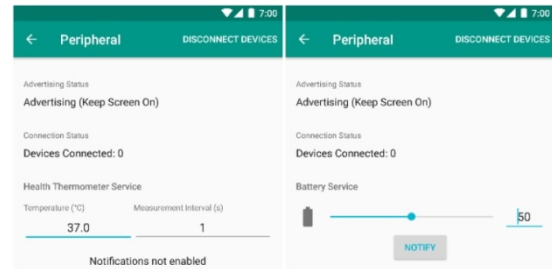


Fig. 2. BLE Peripheral Simulator user interface.

The developer can use the new features of Web Bluetooth to connect to the application to read and write characteristics, subscribe to characteristics change notifications, and read and write to descriptors. The developer can also set characteristics values, send notifications, and disconnect. The application must be installed on a device that has a Bluetooth module and supports BLE. It also has limited opportunities to manage only three types of services.

4. BLE Simulator of Mikhaylov

The Mikhaylov's simulation tool [7] allows simulate the communication between BLE devices in the constructed network (Figure 3). The simulation environment provides an opportunity to study the network aspects of the BLE protocol.

The MiXiM framework (v2.2.1) based on OMNeT ++ (v4.2.2), used as an application development environment. In order to enable multi-channel communication, the physical layer model (PHY) has been extended. The implementation of the Link Layer (LL) model in the devices is realised with the possibility of their operation in five states (Standby, Advertising, Scanning, Initiating and Connection), based on the BLE specifications.

The simulator does not support HCI (Host-Controller Interface) and host layers of the BLE stack, and packets are generated at the LL layer, which does not affect the accuracy of the communication simulation. All parameters of BLE communication (advertising and connection intervals, timeout tracking, frequency hop change, list of used data and advertising channels) are defined in a simulation initialisation file and remain constant during the simulation. Another limitation is that only one active connection is maintained for each simulated device at a time. The developed version does not include security realisation and Ping command.

The environment allows simulating the functionality of BLE devices in several modes: transmitting advertising packages on one or more advertising channels, listening to one or more advertising channels, establishing a connection, maintaining and terminating the connection. The data collected during the simulations include the number of packets sent/received by each node, the status of each node and the radio channel used at each time, energy consumption, and more. When simulating the power consumption of the radio transmitter, the consumption of the microcontroller for packet preparation and data processing is not taken into account. However, the simulator provides realistic values in terms of throughput and power consumption.

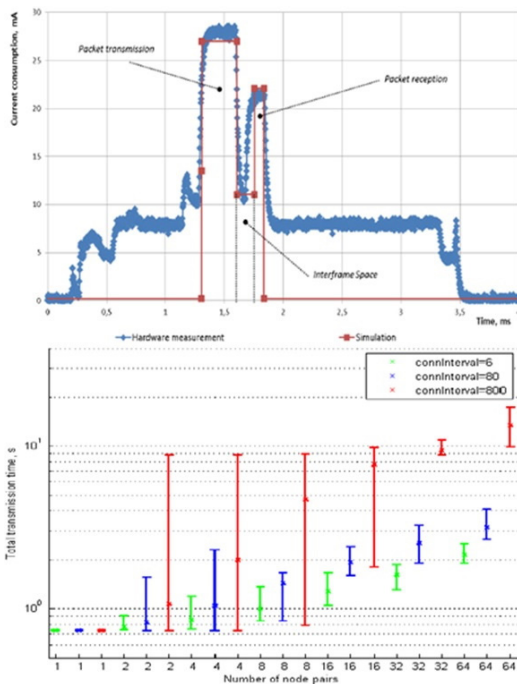


Fig. 3. Results of the Mikhaylov simulator.

5. Advantages and disadvantages of the considered BLE simulators

Based on the review of existing solutions for simulating BLE technology, the most common and used ones are presented. Table 1 describes the main advantages and disadvantages of the considered solutions.

In order to overcome some of the disadvantages of the existing solutions for simulating BLE technology and providing a wide range of opportunities for investigation of technology, to the open source simulation product

presented in [8], functionality extensions have been implemented. The product was developed in the Computer Science and Engineering Department at Technical University - Varna, Bulgaria. Extensions are expressed in providing the opportunity to study the measured RSS and RSSI values of the received signal.

6. Developed simulator for BLE

The product for simulation of BLE technology [8] developed in the Computer Science and Engineering Department at Technical University - Varna, Bulgaria, provides an easy-to-use user interface (Figure 4) for studying the main functionalities of the standard. Java, Apache Maven, JavaFX & Scene Builder and Lauch4j technologies were used to develop the environment. It has a modular architecture and the operation of all processes is controlled by the application core. The application is open source, free to use and does not require installation (only Java is required on the machine on which it runs).

The functionalities of the environment include: adding a Master and Slave device, with the ability to select and modify the parameters of Slave; visualisation of the connection topology in the network, as well as its modification; research of the used communication channels; tracking of the conducted communication and the transmitted information between the devices; presentation of statistical information on terminal devices; visual presentation of the messages exchanged between Master and Slave when establishing a data transmission connection and its termination. The product provides an opportunity to study the measured RSS and RSSI values of the received signal.

Table 1. Advantages and disadvantages of the considered simulators of BLE technology.

Simulator	Advantages	Disadvantages
MATLAB	Allows the implementation of simple BLE applications and the ability to transmit and receive ASCII and binary data. Works with both standard and custom services, characteristics and descriptors of peripherals. The interface provides examples of different applications that have implemented graphical visualisation. There are also examples developed by researchers in the field. Provides easy installation.	Requires Bluetooth serial port. There is a need to purchase a BLE transceiver if it is not built-in. The interface is supported on macOS 10.13 High Sierra and Windows 10 operating systems, as well as their newer versions. Requires physical end devices. The examples provided are applications for Nordic Thingy:52 and Under Armor devices. Requires payment of a license to use.
BLE Peripheral Simulator	Allows operation of Web Bluetooth functions without the need for BLE peripherals. Allows reading and writing of characteristics, subscribing to notifications for changes of characteristics and reading and writing of descriptors, disconnection. The application is easy to install and free.	It is a mobile application. Allows operation of a limited number of services (3). It is necessary to use a physical device that has a Bluetooth transceiver and supports BLE.
BLE Simulator of Mikhaylov	Enables simulation of communication between BLE devices in a network. Does not require work with physical devices. Allows research into the network aspects of the BLE protocol. Provides simulation of the operation of end devices in five different states. Allows metering of consumed energy. The application is open source and free access.	The simulation parameters are defined in a simulation initialisation file and cannot be changed during the simulation. Provides limited simulation capabilities. There are no operating instructions available. Difficult installation.

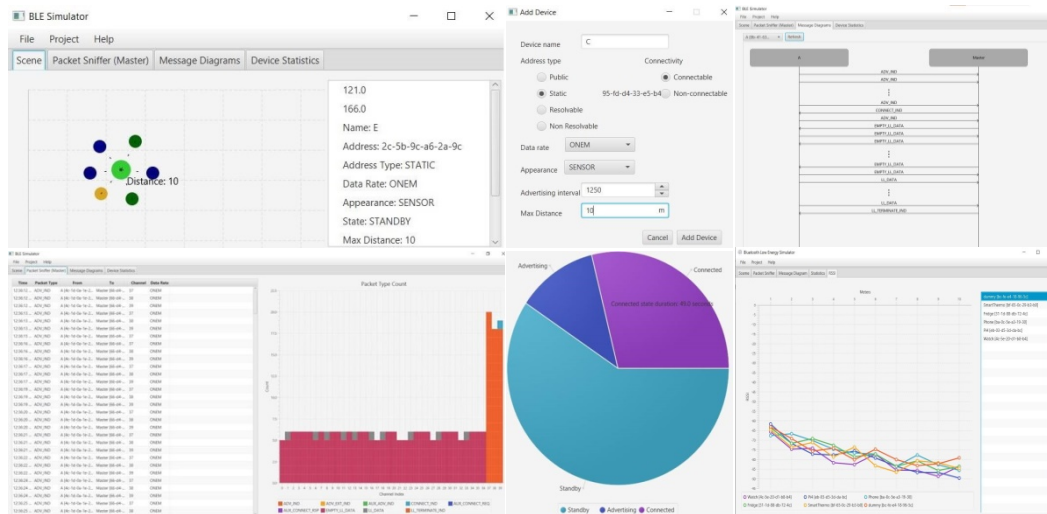


Fig. 4. User interface of the developed product.

7. Comparison of simulators for BLE

There are various studies [9, 10] that compare wireless network simulators for IoT. Based on these studies, a comparison made between the considered simulation products for BLE technology. Table 2 presents a compilation of the criteria used in the studies in

consideration, in order to more accurately compare the considered simulators, omitting the criteria that are not applicable.

The presented comparison gives reason to claim that the developed simulation product is not inferior in quality and capabilities to existing ones.

Table 2. Comparison of BLE network simulators.

Comparison criteria for BLE simulators	Researched simulators			
	MATLAB	BLE Peripheral Simulator	Mikhailov	Developed
Possibility to build different network architectures	✓	✗	✓	✓
Possibility for implementation and design of protocols	✓	✗	✓	✓
Deriving statistical results for the experiments performed	✓	✓	✓	✓
Maintaining a graphical user interface	✓	✓	✓	✓
Availability of a guide for users and developers	✓	✓	✓	✓
Supported operating system	Linux, MAC OS, Windows	Android	Linux, MAC OS, Windows	Linux, MAC OS, Windows
Scalability	✓	✓	✓	✓
Possibility for expansion	✓	✓	✓	✓
Battery/lifetime evaluation	✓	✗	✓	✗
Modelling of energy consumption	✗	✓	✓	✗
Programming language	Matlab script, Python	JavaScript	C++	Java
License	Paid standard and academic	Free	Free	Free

8. Conclusion

This article provides an overview of existing solutions for simulating BLE technology. Some of the most known simulators for the technology are discussed, and their advantages and disadvantages are presented. In order to overcome some of the disadvantages of the considered solutions, improvements have been added to the simulation product for BLE technology developed by the authors. The presented simulators are compared on the example of other researchers, using a compilation of criteria for comparing simulators for wireless networks for IoT. The obtained results show that the developed

simulation product is not inferior in quality and capabilities provided to the existing ones.

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