IOSR Journal of Computer Engineering (IOSR-JCE)
e-ISSN: 2278-0661,p-ISSN: 2278-8727, Volume 23, Issue 6, Ser. II (Nov. –Dec. 2021), PP 63-69
www.iosrjournals.org

SimulatingAssociated Routing Protocol for Bluetooth Low Energy Devices

Ahmed Said[1], Atef Galwish[2], Mohamed Assal[1], Mohamed Elgazar[3]
[1]*Faculty of Computers & Artificial Intelligent, MTI University, Egypt*
[2]*Faculty of Computing & Artificial Intelligent, Helwan University, Egypt*
[3]*Vodafone, Egypt*

Abstract:
Internet of Things (IoT) technology has attracted much attention in recent years. Bluetooth Low Energy is a highly adopted andanticipated communication solution for the Internet of Things.However, the restriction of data communication topology topoint-to-point, limited range of communications, and the lackof IP support makes Bluetooth Low Energy less attractive forInternet of Things applications. In most of the existing routing techniques wireless networks assumes that all nodes are static and do not change their positions till the end of the network. In this paper, AnAdaptive Multi Criteria Routing Protocol for Bluetooth Low Energy (BLE) is proposed.

Keywords: *Bluetooth, IoT, Routing, Connectivity, Mobility*

Date of Submission: 05-12-2021 Date of Acceptance: 19-12-2021

I. Introduction

Bluetooth low energy (BLE) is a technology for wireless personal area networks, which was added to the Bluetooth Core Specification 4.1[1]. It is designed for applications where lowering energy consumption is paramount. It operates in the same 2.4 GHz band as the Bluetooth classic. This frequency is also shared by various other wireless technologies, e.g., Wi-Fi, ZigBee, etc. Thus, coexisting communication using these technologies interfere with Bluetooth communication.

Several existing works has investigated the effects of these potential interfering communication technologies [2, 3]. However, these technologies do not use frequency-hopping mechanisms like Bluetooth. As a result, the interference from other devices operating in the same band on Bluetooth is minimal.

Bluetooth devices communicate by forming piconets, where a device posing as master device controls the simultaneous communications within a piconet. As a result, there is no chance of collision among the devices within a piconet. However, mutual interference can occur amongst the devices belonging to different piconets. Small communication range and low device density within a proximity reduces the chance of mutual interference. It is estimated that over 30 billion wireless-connected devices to be part of the Internet of Things (IoT) in 2020 [4, 5], and it is assumed that a large proportion of these devices will be Bluetooth enabled. In fact, people are using more and more Bluetooth devices in their daily life, for example in smart phones, tablets, wireless headphones, smart watches, etc. Furthermore, future applications that can employ BLE for location-based services, for example, using iBeacon Technology, in payment systems, in body area sensor networks [6], etc.[4].

In Dec. 2014, theBluetooth SIG adopted the InternetProtocol Support Profile (IPSP), which supports theexchanging of IPv6 packets between devices over BLE [7].In conjunction to the Bluetooth SIG, the IETF is almost atthe standardization of transmission of IPv6 packets overBLE, using the similar methods from 6LoWPAN[8]. Morerecently, the Bluetooth SIG announced the formation ofSmart Mesh WG, clearly showing its plans to adopt meshnetworking to BLE [9, 10].

This paper presents the results of adapting and simulating an Associative Routing Protocol for the Bluetooth Low Energy (BLE) Devices.

II. Bluetooth Low energy Devices

The BLE protocol stack consists of the two major components: a BLE Controller and a BLE Host (see Figure 1). Thosetwo components might reside either on the same physicaldevice or can be implemented by the different devices. TheController is the logical entity that is responsible for thephysical (PHY) and the link layer (LL). The Host implementsthe functionalities of the upper layers which we leave out ofthe discussion.

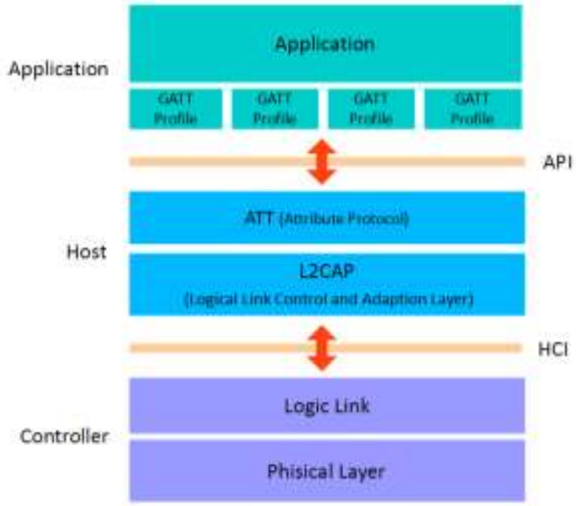

Figure 1. BLE Stack

On the physical layer (PHY) BLE uses the Gaussian Frequency Shift Keying (GFSK) modulation with a bandwidthbit period product equal to 0.5 and the symbol rate of 1mega-symbols per second. To simplify the transceiver design,BLE uses very short data packets with the maximum lengthof 47 bytes[11]. The power of output radio signal for BLEtransmitters range from -20 to +10 dBm. The sensitivity level of the BLE receiver is below -70 dBm [1]. Likewise, theprevious version of Bluetooth, BLE operates in the license-free2.4 GHz industrial, scientific, and medical (ISM) band, whichthe protocol divides into 40 2-MHz wide channels. Three ofthose, which reside between the typically used wireless localarea network channels, are called *advertising channels* and areused for advertising and service discovery. The remaining 37*data channels* are used for establishing the P2P links betweenthe devices. The data transmission of BLE devices is boundto time units known as advertising and connection events.

The advertising events might be used by the transceivers tobroadcast small blocks of data, or to request and to specifythe parameters of the connections to be established in the datachannels. The period between the starts of two consecutivesadvertising events is defined as:

$$T_{advEvent} = advInterval + advDelay$$

where *advInterval*is an integer multiple of 0.625ms in therange of 20ms to 10.24 s, and *advDelay*is a pseudo-randomvalue generated anew for each advertising event, which takes values in the range from 0ms to 1ms [1].

At the beginning of an advertising event the advertiser, i.e., the device which has some data to transmit, sends an advertising frame. Using the different advertising frame types, the advertiser might encapsulate up to 31 bytes of data straight in the advertising frame or might indicate its capability to start a connection in data channels. In the latter case, after sending a frame, the advertiser switches to receive and waits for possible connection establishment requests. If the connection request from a device (which is referred to as an initiator) is received, the two devices start peer-to-peer connection in the data channels.

Depending on the specifics of the implementation and the requirements of the application, the BLE advertiser might either send the advertisements in a specific advertising channel or switch sequentially between few of those. Once a connection in data channels is established, the *initiator* becomes the *master,*and the *advertiser* becomes the *slave*. Note, that BLE assumes, that a master is richer on resources than a slave. In the start of a connection event (referred to as the connection event anchor point), the used radio channel is changed following the pre-agreed sequence.

The communication in each connection event is started by the master sending a frame to the slave. Then, the slave and the master alternate sending the frames on the data channel while at least one of the devices has data to transmit or until the current connection event ends. If either of devices receives two consecutive frames with CRC errors, the connection event is closed. The same happens if either of the devices misses a radio frame. The period between the frames on a data channel equals to the Interframe Space period (IFS) = 150 μs. The maximum LL payload of a BLE data frame is just 27 bytes [11], [12].

Once the connection event is closed, to save the energy, the devices might switch to a low-power sleep mode and wait until the start of the next connection event. Theparameters of connection (e.g., the connection event interval

Figure 2. Illustration of advertising, connection establishing, data transferring and connection terminating in BLE - *connInterval*or the list of used data channels) are defined by the master and reported to the slave in the connection request (CONNECT REQ) packet. Then, if required and if supported by both devices, *some* connection parameters (e.g., *connInterval*, *connSlaveLatency*, *supervisionTimeout*) might be modified without re-establishing the connection.

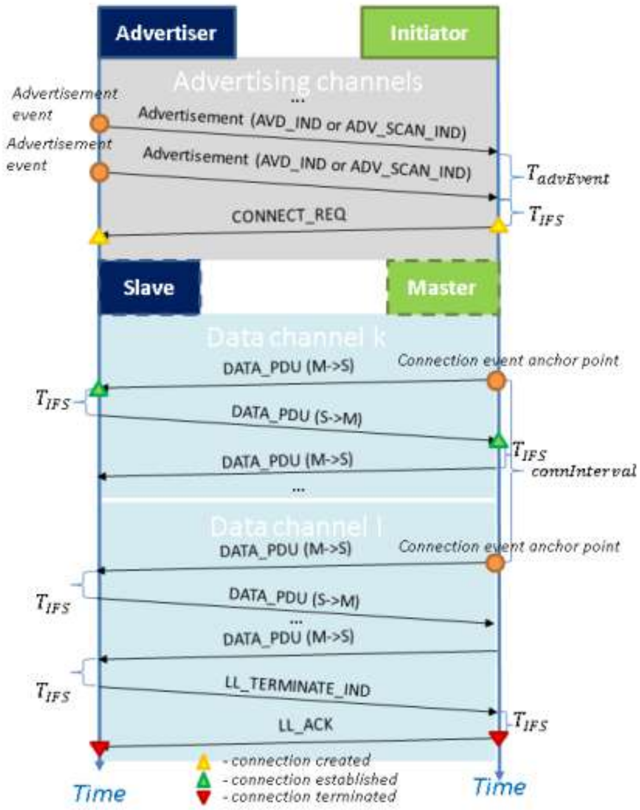

Figure 2.BLE Connection

The timing of connection events is determined through twoparameters, namely the *connInterval*, and the slave latency(*connSlaveLatency*). The *connInterval*is a multiple of 1.25msand has values ranging from 7.5ms to 4.0 s. The *connSlaveLatency*($connSlaveLatency \leq 500$) defines the maximumnumber of consecutive connection events in which a slavedevice is not required to listen.

The connection might be terminated at any time by either ofthe devices. Also, the connection is terminated automaticallyon connection supervision timeout (*supervisionTimeout,* whichranges from 100ms to 32 s).The whole procedure including advertising, connection establishing, data transferring, and connection terminating isillustrated in Figure 2. Note, that neither on the advertisingchannels nor on the data channels the BLE devices do notuse any sort of listen before talk mechanism[13].

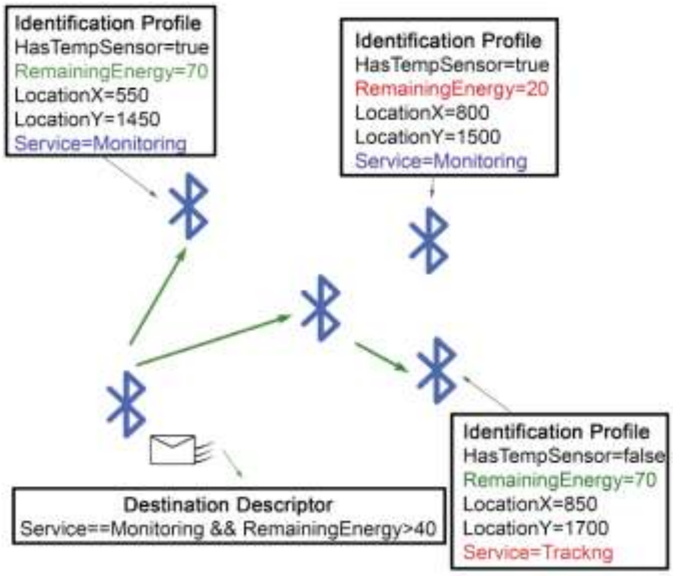

Figure 3. Identification and Addressing in Associative Routing

III. Associative Routing for Bluetooth Low Energy (BLE) Devices

In this section, a fully distributed routing protocol based on an associative routing framework presented in [14]. Associative routing replaces the semantics-free destination addresses with semantics-rich *destination descriptors* that dynamically bind to nodes at **routing time**. Destination descriptors provide qualitative descriptions of the destination nodes where a packet should be delivered.

A. Associative Routing

Associative routing does not require nodes to have unique identifiers, instead nodes identify themselves by the services they are willing to provide, resources they are willing to share, data they store, or any other attributes of relevance to applications. Network nodes maintain identification profiles that can by checked against destination descriptors of network packets by the routing protocol to determine the path along which a packet should travel. The support for associative routing only requires minimal change in the transport layer protocols to allow passing of destination descriptors from applications to the routing protocol.there is no direct mapping between the data packet destination specified by the sender and the physical nodes the packet will be delivered to. Multiple different destination descriptors may lead to the same node (or same group of nodes). Also, at different times, the same destination descriptor may lead to different nodes (or groups) as their attributes change.
For example, the battery energy level of a node could be part of its identification profiles, so if the energy level dropped, the node disqualifies for a descriptor that it used to qualify for in the past. Such highly dynamic nature of addressing in associative routing makes it an attractive solution to routing in large scale networks of dynamic topologies, like sensor networks. Figure 3 illustrates identification and addressing in associative routing.

B. Adaptive Multi Criteria Routing Protocol

Adaptive Multi Criteria Routing Protocolframework for associative routing adopts a targeted messaging model that allows the exchange of messages between a source node and a targeted group of nodes. The routing agent defines schemas for the destination descriptor and the identification profile.

The source node creates a destination qualifierobject specifying its targeting criteria. A **Targeted Message (TM)** is a network packet carrying application data in its payload and the destination qualifierin its variable-length header. The application agent at the sender side instantiates a destination qualifierand configures it according to its targeting needs.

The application controller then passed the destination descriptor to the BLE controller as the destination address. The BLE controller constructs a targeted message and pass it to the routing controller . The routing controller decides how the packet is forwarded according to the protocol it implements and/or the routing tables it maintains.

When a message is received by a routing controller from lower layers, it extracts the destination qualifier from the messages and verifies it against the node's identification profile. If the profile matches the description in the destination qualifierthe message is passed to the local transport agent to be delivered to the application agent, otherwise forwarding decision is made. Routing agent may still forward target messages that it matches the local identification profile if it implements multicast functionality. Figure 4 illustrates the basic interactions in the associative routing framework.

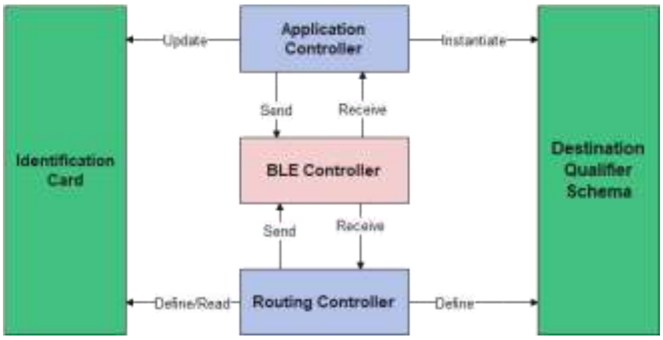

Figure 4. Associative Routing Framework

Location-aware affinity propagation (LAP) algorithm[15] is used to build a fully connected set of router nodes and establish BLE device lists. Each resource node registers with only one routing node, reachable in a single hop, that represents its gateway to the BLE network. The average number of resource nodes per gateway is referred to as **RoutingPacking Ratio (RPR)**. The protocol uses criteria indexes to speed up routing of messages to frequently targeted groups. An **Index Working Set (IWS)** by router nodes containing actively used indexes. Adaptability is achieved through monitoring runtime performance metrics and automatically modify the **IWS** accordingly.The destination descriptor used is a Boolean predicate that we refer to as **Target Predicate (TP)**.

The core of the protocol is implemented in as a Routing Controller for the associative routing framework. Each node participating in the constructed network has one or more Routing Controllers. Routing Controller is responsible for routing TMs to their destination groups and optionally routing responses back to the source. Figure 5 shows the general architecture of Routing Controller.

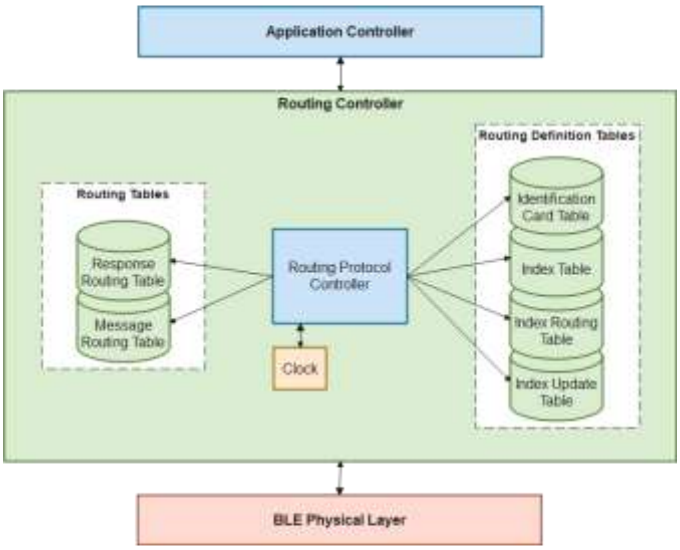

Figure 5. Routing Agent

The protocol this wayaccepts the heterogeneity in node capabilities and maintains an identification profile for the WSN node based on its abilities, spatial location, and other criteria's. The node profile is a collection of criteria. Each criterion is key/value pair. Values are either Boolean, real numbers, or text strings.
A criterion may represent capability possessed by the node, context information, administrative configuration, or application data. Addresses in are predicates referencing nodes' criteria that evaluate to true only for the target node(s). The protocol enables applications to efficiently group resources according to application defined criteria to support collaboration-oriented tasks.

IV. Experiments and Discussions

This section discusses the experimental results. As discussed, BLE devices have various modes of operation and the protocol is rather complex, which makes it hard to use the analytical methods for studying BLE networks.A modified version of a BLE simulation tool developed in [16] is used to test the connectivity and the validity of the proposed routing algorithm.

The Simulation tool use the MiXiM framework (v2.2.1) [20] based on the popular OMNeT++ engine (v4.2.2). In order to enable the multichannel communication, the tool extended the model of the PHY layer. The LL model was implemented as a state machine with five states (i.e., Standby, Advertising, Scanning, Initiating and Connection) as prescribed by the BLE specification v4.1 [1]. Although in the current version of the simulator the HCI and the host layers are not implemented and the packets are generated at the LL, this should not affect the accuracy of the communication simulations. All the parameters of the BLE communication (e.g., advertising and connection intervals, supervision timeout, frequency hop increment, the lists of the used data and advertisement channels) are defined in the simulation initialization file and remain constant during the simulation. The other restriction is the support of only one active link at a time for each simulated device. The security and the Ping command are not implemented at a time [16].

The developed tool enables one to simulate the operation of the BLE devices in various modes including: advertising in one or multiple advertising channels, scanning one or multiple advertising channels, establishing the connection, connection upkeep and terminating. The collected during the simulations data include, but are not limited to: the number of sent/received packets by each node, the state of each node and the used radio channel at each moment of time, consumed current and energy [16].

We perform a set of experiments in order to evaluate the quailty of our network formation and routing approach. In each experiement a number of BLE nodes are placed randomly in an area of 10 by 10 meters. Over the set of experiments the number of BLE nodes vary from 5 to 10. For each experiment different metrices has been measured including connectivity, average message delay (source to destination) and average network throughput.

In all experiments, the network achieve full connectivity between all the BLE nodes. While the delay in the network vary depend on the network of BLE nodes placed in the experiment. The delay in a network is the time taken for a data packet to traverse through the network and reach the destination. The average delay for a source node to send a targeted message to a destination node is shown in Figure 6.Figure 7 shows the network throughput achieved using the porposed routing protocol.

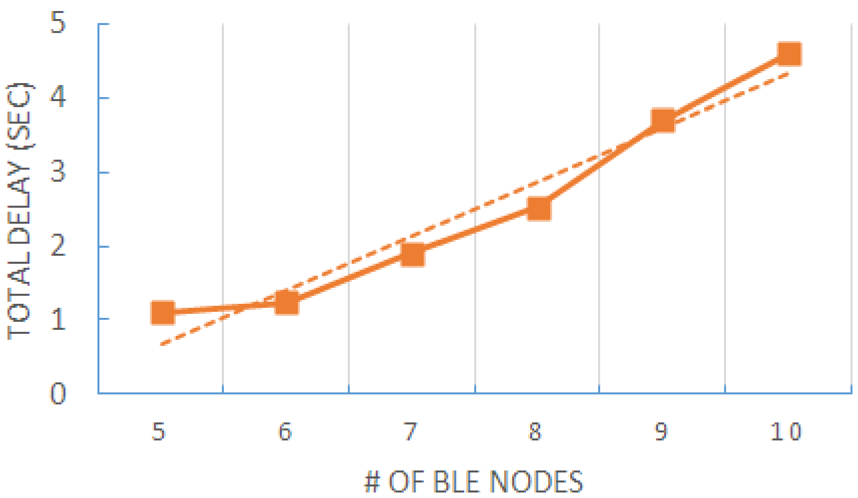

Figure 6 Average delay

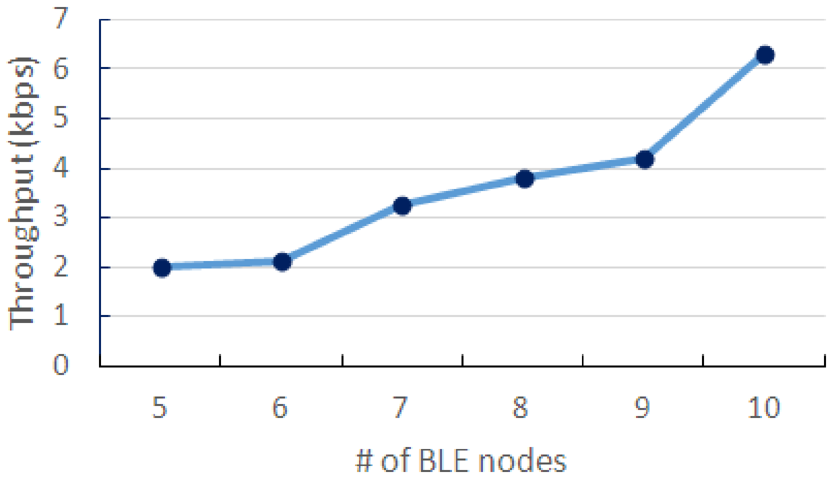

Figure 7 Network Throughput

V. Conclusion

The paper presented an Adaptive Multi Criteria Routing Protocol for Bluetooth Low Energy (BLE). The expirements on the simulator its obvious, that algorithm successfully route the targeted message in all experiments with a great network throughput and reasonable delay. Both increase approximatley linear with more BLE nodes added to the network.Experiments using real deives are necessary to prove the validity of the proposed routing algorithm.

References

[1] Bluetooth Special Interest Group, Bluetooth specification version 4.1, Kirkland, WA, USA: Bluetooth Special Interest Group, 2013.
[2] J.-S. Lee, Y.-W. Su and C.-C. Shen, "“A comparative study of wireless protocols: Bluetooth, uwb, zigbee, and wi-fi,” in Industrial Electronics," in IECON 2007. 33rd Annual Conference of the IEEE, 2007.
[3] M. Davies, E. Furey and K. Curran, "Improving compliance with bluetooth device detection," TELKOMNIKA (Telecommunication, Computing, Electronics and Control), vol. 17, no. 5, p. 2355~236, October 2019.
[4] J. J. Treurniet, C. Sarkar†, R. V. Prasad and W. d. Boer, "Energy Consumption and Latency in BLE Devices under Mutual Interference: An Experimental Study," in 3rd International Conference on Future Internet of Things and Cloud, 2015.
[5] H. Motlagh, N. M. rezaei, M. Hunt and B. Julian Zakeri, "Internet of Things (IoT) and the Energy Sector," Energies, vol. 13, no. 2, p. 494, January 2020.
[6] M. Jacobsson, R. Venkatesha Prasad and C. Guo, "Packet forwarding with minimum energy consumption in body area sensor networks," in Consumer Communications and Networking Conference (CCNC), 2010 7th IEEE, 2010.
[7] Bluetooth Special Interest Group, Bluetooth Internet Protocol Support Profile Specification Version 1.0.0, December, 2014.
[8] J. Nieminen, T. Savolainen, M. Isomaki, Z. S. B. Patil and a. C. Gomez, "Transmission of IPv6 Packets over BLUETOOTH® Low Energy," IETF, April, 2015.
[9] K. Chang, "Bluetooth: A Viable Solution for IoT?[Industry Perspectives]," IEEE Wireless Communications, vol. 21, no. 6, pp. 6-7, Dec. 2014.
[10] S. Baker, W. Xiang and I. M. Atkinson, "Internet of Things for Smart Healthcare: Technologies, Challenges, and Opportunities," IEEE Access, p. 1, November 2017.
[11] K. Mikhaylov, N. Plevritakis and J. Tervonen, "Performance analysis and comparison of Bluetooth Low Energy with IEEE 802.15.4 and SimpliciTI," J. Sens. Actuator, vol. 2, no. 3, pp. 589-613, 2013.
[12] K. M. a. J. Tervonen, "Multihop Data Transfer Service for Bluetooth Low Energy," in 13th Int. Conf. ITS Telecommunications, Tampere, Finland, 2013.
[13] M. &. B. M. Nikodem, "Experimental Evaluation of Advertisement-Based Bluetooth Low Energy Communication," Sensors (SENSORS-BASEL), vol. 20, no. 1, December 2019.
[14] R. M. Eltarras, "BioSENSE: Biologically-inspired Secure Elastic Networked Sensor Environment," Faculty of the Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 2011.
[15] M. Elgammal and M. Eltoweissy, "Location-aware Affinity Propagation Clustering," in IEEE International Conference on Wireless and Mobile Computing, Networking and Communications, 2009.
[16] K. Mikhaylov, "Simulation of Network-Level Performance for Bluetooth Low Energy," in IEEE 25th International Symposium on Personal, Indoor and Mobile Radio Communications, 2014.