A SURVEY ON: BLUETOOTH LOW ENERGY MESH BASED COMMUNICATION NETWORK

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Abstract

Bluetooth technology has evolved wireless communication between devices with its pervasive and basic features. With the advancement of technology, the classic Bluetooth transformed into Bluetooth Low Energy (BLE) in version 4.2 and 5. Initially, BLE 4.2 was featured to support star topology network provisioned with less network coverage. Subsequently, in contrast with version 4.2, BLE 5 has thecapability for mesh topology that has increased the network coverage and enhanced end to end diversity.Due to its low power and low-cost characteristics, it is competing with other IoT mesh enabled technologies. Also, BLE special features has played significant part in the fruition of its uses like high speed automotive devices, IT and medical equipment's etc. More so, BLE can be utilized in the hospitals for effective communication as Bluetooth enabled devices are easily available and reliable due to mesh topology support feature. In view of aforesaid, in this paper we have proposed a BLE (Bluetooth 5.0) mesh-basedcommunication network architecture and protocol for the hospital consisting of BLE fixed and mobile nodes.

Keywords: Bluetooth Low Energy (BLE), BLE5, Mesh Network,Ad-Hoc Network, Hospital

Introduction

Bluetooth Low Energy (BLE) has emerged to be a foremost low power wireless technology. Moreover, BLE technology was introduced in Bluetooth 4.0 version in which BLE network design followed the star topology. However, this version suffered range limitation problem due to lack of mesh topology support. Moreover, in the absence of the aforesaid feature, the technology such as IEEE 802.15.4 (ZigBee etc.) has been utilized to support the mesh network. Nevertheless, Bluetooth Sig launched Bluetooth 5.0 provisioned with meshcapability in race with other mesh technologies to support long range communication. Nowadays, the technologists are more biased towards the technologies supporting mesh topologies and low power consumption for better network efficiency. In view of aforesaid, inthis paper, we are proposing and discussing the BLE 5 Mesh Based Hospital Communication Network (B5MBHCN) protocol to support the staff as well as an indoor and outdoor patient.

The rest of the paper is organized in a way that in Section 2, the use case for B5MBHCN is discussed. In Section 3, the related works are discussed while Section 4 will debate on the potential available technologies for B5MBHCN. Moreover, Section 5 will be a brief discussion on existing topologies for mesh network. Furthermore, Section 6is about the proposed network architecture for B5MBHCN protocol. Moreover, Section 7 will be about the security in BLE networks. Subsequently, in Section 8, B5MBHCN protocol security features are described. Finally, Section 9 will give a brief related tothe proposed protocol implementation and Section 10 will conclude the paper.

1. Use Case B5MBHCN

AWireless Ad-hoc Networks (WAHN) are becoming popular day by day due its unique feature such as it requiresno infrastructure and low power for the communication. Moreover, due its exceptional characteristics, the communication can be possible in difficult situations like earthquake, fire or in case of other accidents. Additionally, in case of hospitals this infrastructure less communication is necessary to cater for with the emergency situations for example to call the staff in emergency or normal condition from one location to another, medical equipment authentication, message transfer, patient convenience for getting different kind of information after entering the hospital vicinity. Subsequently, in the event of any disaster, the communication in the hospital becomes the most important to deal with the injured people or others. For making the WAHN possible for the hospitals, there are many available technologies such as ZigBee, Z-Wave, Threads, BLE etc. (as discussed in Section 4.). In view of aforesaid, after the detailed research, in this paper, we have found Bluetooth Low Energy 5 (BLE 5) to be the best suited technology for the proposed B5MBHCN due to its easyavailability in mobile devices, low power, low cost and mesh support characteristic. Also, after deep literature review, we have come up with the conclusion that till to date there is no Pure Mesh Solution using BLE is available. In view of aforesaid, we are proposing a pure mesh based BLE protocoltargeting the hospital (being the most critical place dealing with emergencies) where efficient and reliable communication is required.

To ensure pure mesh B5MBHCN we will focus on mesh nodes mobility,message transmission controlling, topology auto-configuration, mesh connection stability and fast handovers.

2.Related Works

The use of wireless devices and equipment has increased enormously due to rapid progression in wireless technologies. Moreover, with the passage of time, the WAHNis becoming very popular as it does not require infrastructure and thus low cost for design and development. New technologies such as ZigBee, XBee, LoRA, WiMax, BLE etc are being introduced in the market to get more efficiency. BLE 5 technology is becoming a stronger candidate due its low power consumption and mesh support.

BLE mesh has been introduced in many areas such as homes, factories, parking lots etc.Moreover, this section will discuss the related research works done in the past in the field of BLE mesh network design.

In 2013, [1] introduced for the first time the multi-hop data transfer mechanism in BLE networks. Moreover, as per the author, the solution discussed in the paper, supposed to be the first one that has been implemented and tested in practical. Also, as per the writer, the depicted system has some limitations like security as well as the mobility of nodes. [2] developed a BLE multi-hop routing protocol based on the scatter net topology features of Bluetooth 4.1 version and implemented on real hardware to get the results. According to the author, the protocol performed well in terms of delayand resource utilization. According to [3], due to the incorporation of scatter-net topology in Bluetooth 4.1, it can support long range communication. Therefore, the technology can be used in more applications as compared to its predecessor's version. In this paper, the authorintroduced the concept of service mediation created on Named Data Networking (NDN) concept by working on GAT and ATT layers. Furthermore, [4] developed an opportunistic routing protocol for BLE mesh. Moreover, the writercompared the results with flooding and conventional routing. Subsequently, the researcher concluded that the proposed protocol works well in contrast with other routing techniques. [5] proposed a BLE Mesh Network to support mobility feature. The author developed a protype of Android Operating System for BLE Mesh Network to optimize the data routing by considering residual energy, hop count and degree. [6] compared the BLE and Wi-Fi technology in the scenario to monitor the disoriented people movement by following the region monitoring approach. Moreover, the technique was actualized as an application for android based phones. [7] introduced a system capable of disaster prediction and monitoring by using Wireless Sensor Network technologies. Also, the author designed an improved and abridged WSN routing protocol that is developed on top of trickling routing algorithm. Moreover, the protocol was deployed utilizing BLE protocol to accomplish low power consumption. Subsequently,the writer did performance analysis of the designed algorithm in disaster situation. Furthermore, the study has given acceptable outcomes related to the performance of the system. However, according to the author, there are some limitations in the system that can be improved by using 3G cellular for long distance data transfer.[8] investigated a problem that IoT devicesdo not connect to multiple gateways smoothly. However, after an in-depth research, the author proposed the gateway selection mechanism for the transmission of connection associated information to the optimum gateways. Moreover, the analysis has shown reduced overhead and low latency. [9] developed the Cluster Based on Demand Routing Protocol to support multi hop communication in BLE networks. Moreover, the author concluded that the energy consumption has reduced due to the adoption of aforesaid routing technique. [10] did research for developing the first multi-hop real time protocol on top of BLE for the industrial purpose. Moreover, the author adopted the connection-oriented approach for the utilization of all 37 data channel for the communication. The main idea in the design of the protocol was to break (subdivide) a network into clusters (small networks). The protocol was created for Industrial Wireless Sensor Networks (IWSN) to enable the BLE mesh network for provision of bounded packet delays to support real time communication. [11] developed a heterogeneous network with the combination of BLE and LoRa for the security of the operators in the industrial environment. In the paper, the author has investigated to explore key empowering IoT technologies for collaborative network in Industry 4.0 conditions.

Moreover, after the detailed discussion on available literature, the Table1 is showing the results of comparative study.

3. Potential AvailableIoT Mesh Based Technologies for B5MBHCN System

This section will discuss the potential available technologies that can be utilized for designing of B5MBHCN system.

4.1. ZigBee

ZigBee is a wireless mesh supported technology based on IEEE standard 802.15.4. Moreover, it is cost-effective with the capacity to work for months or years on batteries. Also, the technology is being utilized throughout the world in various applications due its reliability and low-cost.

ZigBee devices can be configured as ZigBee End Device (ZED), ZigBee Router (ZR) and ZigBee Coordinator (ZC).

4.1.1. Coordinator

The coordinator responsibility is to manage the overall network. Each network consists of one coordinator. It performs jobs such as starting the network, permitting the nodes (devices) to enter or leave the network, holding list of routers, channel selection for the network etc.

4.1.2. Router

ZR is a Fully Functional Device (FFD) like ZC. It performs all the jobs like the coordinator except the task of network establishment. ZR is used to increase the network range (network coverage). Moreover, its main function is to find the best possible path (route from source to destination) for data transmission.

4.1.3. End Device

End Device has the capability to communicate with the parent devices (ZR and ZC only), thus termed as Reduced Function Device (RFD). Also, it has low power consumption as it is not responsible for data traffic routing and can only perform function like joining or leaving the network and transmission of packets.

Moreover, Fig. 1 is showing the ZigBee communication flow.

4.2. Wi-Fi

Wi-Fi is a widespread wireless technology that uses radio frequencies for data transmission. Wi-Fi allows wire free fast speed internet connections. It uses the standard IEEE 802.11 consisting of sub classes such as 802.11 a/b/g/n/ac. However, the version n and ac are being used nowadays for high speed data transfer with greater efficiency. Subsequently, "n" was commercialized in 2009 and boosted the market of Wi-Fi. It was embedded with the latest features such as Multiple Input and Multiple Output (MIMO), Orthogonal Frequency Division Multiplexing (OFDM), Space Time Block Coding, cyclic delay diversity etc. These additional capabilities improved the throughput and coverage up to 150 Mbps and 250 meters respectively. Also, IEEE 802.11 ac released in 2013 with additional feature of multi user MIMO.

4.3. Z-Wave

It is an interoperable, low powered Radio Frequency (RF) based wireless communication technology that supports full mesh network. It operates in the sub-1GHz band, thus impervious to interferences from other wireless technologies like Wi-Fi and Bluetooth, ZigBee that operates on 2.4 GHz frequency band. Moreover, it is designed for control and status applications. It supports data rates up to 100 kbps, IPV6 and multichannel operation with backwards compatibility to all predecessor versions.

4.4. Threads

Thread is a wireless mesh network supported protocol based on IPV6 principles. It is designed to support low power IoT devices (IEEE 802.15.4-2006). Moreover, the protocol is independent from other IoT mesh protocols like ZigBee, Z-Wave and BLE. Also, it is simple, secure, reliable and easy to scale.

4.5. Bluetooth Low Energy (BLE)

BLE is low power consumption light-weight version of classic Bluetooth [9]. There are quite number of protocols available for mesh networking but what makes BLE so much preferred is its availability in any modern mobile devices.Moreover, BLE architecture follows the same protocol stack as classical Bluetooth BR/EDR consisting of the controller and the host. More so, all applications are developed on top of GAP and GATT layers. Also, Table2 is showing the difference between BLE version 4.2 and 5. Furthermore, forthcoming subsections will discuss BLE Protocol Stack in detail as shown in Fig. 2.

4.5.1. Physical Layer

This layer is the lowest layer consists of physical analog communication printed circuit board accountable for transmission of wire free digital signal. It operates on 2.4 GHz ISM (Industrial, Scientific and Medical) frequency band with 40 Radio Frequency (RF) channels [10]. Moreover, these are sub divided into 3 Advertising Channels (AC) and 37 Data Channels (DC). Subsequently, AC has the responsibility of device discovery, connection establishment and transmitting broadcast messages. Whereas, DC enables two-way communication among the connected devices and Adaptive Frequency Hopping (AFH) for consequent connection events.

4.5.2. Link Layer (LL)

BLE LL defined paired roles constitutes as Advertiser/Scanner, Slave/Master and Broadcaster/Observer [9]. To begin with, for instance the BLE hosts has Standby/Unconnected state. Moreover, they get into the Discovery state in which the host device desiring to be discovered becomes the Advertiser and the device wishing to be connected becomes the Scanner. The advertising device will send advertising packets holding basic information about itself while all the scanning devices will receive those packets. The Fig. 3 is depicting the scenario. Moreover, the scanner will analysethe advertisement packet on receiving. Subsequently, the scanner may become the Initiator by initiating the connection with the specific advertiser and goes into the Connecting phase. In this state, the initiator will send the CONNECT REQ advertising packet to the advertiser. Moreover, finally it accepts a connection invitation and becomes the slave and initiator will act as a master.

4.5.3 L2CAP

L2CAP resides in data link layer and provides connection-oriented and connectionless data services to upper layer along with multiplexing, segmentation and reassembly capabilities.

4.5.4 GAP

GAP characterizes the general topology of the BLE network stack. Moreover, it defines the guidelines as how BLE devices can make themselves available (broadcasting mechanism). Also, how the two devices can communicate with each other (connection mechanism).

4.5.5 GATT

GATT depicts in detail how attributes/data are exchanged once BLE devices have a dedicated connection. Like GAP, the GATT defines the roles which communicating devices can adopt such as client or server. Client can read as well as write the attributes on the server while server has the responsibility of making those attributes available for the client.

Moreover, after the detailed discussion on the technologies available for B5MBHCN, the Table3 is showing the comparison of all the technologies.

In view of aforesaid discussion on IoT technologies and the literature review, the BLE technology is best suited for B5MBHCN due to its easy availability in mobile devices, low power consumption and support for mesh topology

4. Topologies in Mesh Network

5.1 Mesh Ad-Hoc Network (MeshNet)

This kind of design is only for the communication between mesh ad-hoc networking devices. In this topology, the nodes communicate with each other for data transmission without any gateway.

5.2 MeshNet connected with Gateway

It is a mesh ad-hoc network of devices communicating with each other for message passing. Moreover, for the communication with other network (long or short range), the MeshNet will be connected to the gateway.

5.3 MeshNet connected and to the Gateway

There are more than one MeshNet communicating with each other for message passing. Also, in the presence of gateway, the network gets the capability to pass on the messages to different network.

Moreover, for B5MBHCN, we will consider simple MeshNet for network communication.

5. Proposed Network Architecture for B5MBHCN Protocol

The proposed communication network architecture for B5MBHCN is shown in Fig. 4. The network will have fixed BLE MeshNet in the hospitalcomprised of fixed nodes (BLEFixed Nodes (BFN), BLE Beacon (BB)). Moreover, B5MBHCN will have the ability to deal with the moving nodes as well. Subsequently, in the network architecture, there aretwo categories ofBLE 5 enabled MobileNode (BMN) consisting of Staff Mobile Node (BSMN) and Guests Mobile Node (BGMN). Furthermore, Fig. 5 is showing the message passing diagram related to the nodes. More so, following sub-sections will explain different processesas how the node will join the mesh network, node message transmission process and the procedure for the node to leave the network

6.1 BLE Node JoinsB5MBHCN

BSMN's will be permanently part of B5MBHCN. Initially, as per the protocol all nodes will be considered as BGMN by B5MBHCN. When the node will enter the network, it will be authenticated with the help of BGMNSerial and IMEI number. Moreover, if the node verification will be positive then it will become part of B5MBHCN being BSMN. Also, the protocol will do the topology auto configuration and management. More so, if the system will not authenticate the device then it will be designated as BGMN (not part of B5MBHCN) and can only play with the beacons. Subsequently, the Fig. 6is showing the process.

6.2 BLE Nodes Message Transmission in B5MBHCN

In the proposed protocol, the message transmission is segregated as authentication such as medical equipment (BLE enabled Equipment (BE))authentication messagesand simple messages like emergency call etc. For instance, when BSMN will send an authentication message toBE,according to the protocol, BE will check the serial number in its flash memory. Moreover, if the sender node is authorized to operate the equipment, the operation will be performed else the task will be finished. Subsequently, simple message transmission will occur except BE authorization messages. The flow chart in Fig. 7is depicting the scenario.

6.3 BLE Device Leave B5MBHCN

According to the proposed protocol, the node traceability is only up to BSMN (not for BGMN). If some BSMN will leave the network, its serial number will be deactivated from the nodes databases.

6. Security in BLE Networks

In comparison with the predecessor versions of Bluetooth, the version 5 came up with the new advanced features to strengthen the capabilities of IoT based equipment. Due to the enhancement in Bluetooth specifications like more range (up to 200 meters) and data rate (2 Mbps) have also increased the security risks. Likewise, with the improved range, the attackers can access the connection even from more distance. Furthermore, with enhanced data transmission speed, the hackers can quickly get the data they require and go offline with in no time.

BLE was introduced in the market as low power consumption technology. Due to this feature its security mechanism is quite different from Bluetooth BR/EDR/HS. BLE device pairing results in the generation of Long-Term Key (LTK) instead of the Link Key (LK) as in case of its predecessor versions. For Low Energy versions, the pairing can be done in one of the two ways i.e. Legacy Pairing or Secure Connection (introduced in version 4.2).

7.1 Low Energy Pairing

Low Energy Pairing is further subdivided into categories described in forthcoming sub-sections.

7.1.1 Low Energy Legacy Pairing (LLP)

Low Energy Pairing (LP) changed to Low Energy Legacy Pairing (LLP) with Bluetooth 4.2 specifications. For Low energy Legacy Pairing (LLP), the LTK is first generated. Moreover, it is disseminated with Transport Protocol (TP) instead of key agreement as in case of BR/EDR. In LLP, LTK is generated by one device and securely transported to the other device during the process of pairing rather than both devices generates the key independently. Also, as the keys such as (LTK, Identity Resolving Key (IRK) and Connection Signature Resolving Key (CSRK)) must be transported to the other device, thus an additional step is required for their distribution. Moreover, LLP uses same pairing method as BR/EDR/HS and accordingly prone to eavesdropping attacks except the method Out of Band (OOB) with 128-bit Temporary Key (TK).

7.1.2 Low Energy Secure Connection (LESC)

In LESC (introduced in Bluetooth version 4.2), the LTK key is produced and stored by each device locally with mutual key agreement and therefore does not require to be dispersed over the link. Moreover, unlike LLP, LTK is generated during the process of pairing instead of STK. Subsequently, after the generation of LTK, the encryption key will be derived from LTK to secure the link. Afterwards, like LLP, the IRK and CSRK will be distributed by both devices. Subsequently, in contrast with LLP, the LESC security has improved with addition of Elliptic-curve Diffie–Hellman(ECDH) public key cryptography (P-256 Elliptic Curve) feature to protect against the eavesdrop and MITM attack.

7.2 Low Energy Pairing Association Models (LEPAM)

This section will discuss the LEPAM for LLP and LESC. Like in the classic Bluetooth, the LEPAM was adopted, depending on the input and output capabilities of both devices. The version 4.0 and 4.1 is designed for three method such as Out of Band (OOB), Pass Key Entry (PKE), Just Work (JW). Moreover, 4.2 and 5 specification added a device pairing feature i.e. Secure Connection. Also, the paring methods are described in following sub-section.

7.2.1 Out of Band (OOB)

OOB pairing method is designed for the purpose, where OOB mechanism is being used for the device discovery and exchange of cryptographic data to be used in pairing process. Moreover, the aforesaid method is designed to support the devices embedded with technology for example Near Field Communication (NFC). Also, OOB is most secure among (PKE and JW). Furthermore, the security of OOB model depend on the OOB method that is being utilized.

7.2.2 Pass Key Entry (PKE)

This mechanism is designed for the scenario where one device has the display capability (no keyboard) while other one having a keyboard only. The six-digit pass key will be displayed on the screen and will be used in the device having keyboard. Moreover, as there is no incorporation of the pass key in link key generation during the process, thus eavesdropping attack is not a possibility in this model. Moreover, it can get secure from passive attacks if ECDH is used.

7.2.3 Just Work (JW)

JW is designed for the situation where one of the pairing devices does not have typing (keyboard) and display (screen) capabilities for e.g. headset, mouse etc. In this model the device must accept the connection without verification, therefore there is no protection against the MITM attack. However, some passive attacks can be prevented in case ECDHkey agreement protocol has been implemented.

7.2.4 Numeric Comparison (NC)

NC is designed for the scenario where both the pairing devices has the capability of displaying six-digit number and user can enter their response like 'yes' or 'no' in reply to the display. During the process of pairing, the six-digit number is displayed on each screen. Likewise, the user can enter the 'yes' response in case the number matches and 'no' if for instance it does not match. Thus, an eavesdropper who can see or catch the shown digits couldn't utilize it to get encrypted link key.

7.B5MBHCN Protocol Security Features

For B5MBHCN, we will utilize NC (as the proposed system requires security) pairing mechanism as it supports LESC. Also, it has some built-in specified security features to cater for against different attacks like eavesdropping. Likewise, the BLE 5 enabled devices utilized in the proposed system will be having displaying as well as typing capability.

Moreover, Bluetooth being the wireless technology is vulnerable to some popular security attacks like MITM, Eavesdropping. In view of aforesaid, for the proposed protocol design, we will research to make it more secure in comparison with the present specifications. Subsequently, it will be more effective against MITM attacks by providing user authentication, ensuring more secure storage of link key and proper handling of the continuous device discovery mode.

8.B5MBHCN Proposed Protocol Implementation

The proposed protocol will be tested with the help of simulation software NS2. Moreover, we will further experiment on the protocol with the help of test bed by using Software Development Kit (SDK) CC253A and Contiki (an open source Operating System (OS)). Also, for the physical implementation of the system in the hospital, there will BLE enable fixed devices and mobile devices such as wrist watches, mobile phones will be utilized to check the precision of the system.

9.Conclusion

In this paper, we have done comparative studyrelated to BLE mesh networking.According to literature review, BLE 5 suits best for our proposed system as it requires commonly available Bluetooth enabled wearables and mobile phones. Moreover, the network needsreliability and long range which can be achieved with BLE 5 mesh support. Likewise,we have proposed B5MBHCNprotocol and network architectureafter a detailed review of wireless mesh technologies. Subsequently, we have discussed the proposed protocol functions likeBMN entering or leaving the network andhow themessage transmission will occur. Finally, we have discussed briefly the implementation steps for B5MBHCN protocol.

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