Journal of The Gujarat Research Society
ISSN: 0374-8588
Volume 21 Issue 9, September 2019

# A SURVEY OF BLE MESH NETWORKS

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***Abstract***

*Important momentum was obtained by Bluetooth Low Energy (BLE). BLE's initial architecture, however, centred on star topology networking, which reduces the extent of network coverage and precludes diversity of end-to-end routes. Some rival technologies, on the other hand, resolve those limitations by endorsing the topology of the mesh network. Academia, business, and standards implementation organizations have been developing technologies to make BLE mesh networks for these purposes. The literature, however, lacks a consolidated perspective on this emerging field. This paper explores state-of-the-art BLE mesh networking comprehensively. Second, we have taxonomy of solutions from the BLE mesh network. We then evaluate the solutions, explaining the spectrum of methods that exploit existing BLE features to enable BLE mesh networks. We describe main features of solutions for BLE mesh networks and address their benefits and disadvantages. Finally, we are highlighting transparent problems at present.*

***Keywords:*** *Bluetooth Low Energy (BLE), Internet Engineering Task Force (IETF), Internet Protocol version 6 (IPv6), Wireless Home Automation Networks (WHANs).*

## I. INTRODUCTION

A new low-power wireless technology, Bluetooth Low Energy (BLE), also marketed as Bluetooth Smart, has appeared. BLE has achieved a leading role in smartphones by exploiting a feature that can reuse classic Bluetooth circuits to a large degree. This facilitates contact between the above and other instruments such as sensors, actuators, wearable's and so on with low energy. In addition, the Internet Engineering Task Force (IETF) has recently built an adaptation layer that supports Internet Protocol version 6 (IPv6) over BLE, making it easier for BLE devices to connect to the Internet of Things (IoT) [1]. While BLE is presently showing strong traction, it is also facing major challenges. As BLE was planned to adopt the topology of the star network, a major downside of a BLE network is the narrow coverage area. Wireless Home Automation Networks (WHANs), for example, often require mesh topologies to allow connectivity in a home between two end devices [2]. For this purpose, in WHANs, systems such as IEEE 802.15.4 (and therefore Zigbee or Thread), Z-Wave, or Insteon are used, both of which support mesh networks. BLE will, however, be used in such a relevant domain only for point-to-point, single-link applications. In any case (e.g. manufacturing, rural, urban, etc.) where direct communication between any two endpoints may not be feasible, a similar problem may be found [3]. Two major methods have been suggested by the group in order to deal with BLE network coverage limits. In order to expand the link range while retaining the star topology network architecture, the first one is based on reducing BLE Physical Layer signal bandwidth, as in the recently released Bluetooth 5.0 specification. However, this system also suffers from a star topology's hard coverage restriction, i.e. it is not feasible in such topology to expand the network coverage beyond one hop. In addition, in order to deal with radio transmission impairments and node errors, a star topology network does not provide direction diversity, which is a critical property in wireless networks [3]. The second solution depends on allowing a network of BLE mesh. While this paradigm entails the difficulty of needing end-to-end connectivity mesh network structures, it helps the limitations of a star topology's coverage and route diversity to be resolved. These characteristics have drawn the attention of organizations for the advancement of academia, business, and standards that have established or are implementing multiple BLE mesh network solutions by adopting various techniques. To the best of our understanding, however, literature lacks a consolidated perspective on this emerging field. BLE mesh network ideas are comprehensively surveyed in this article.

For BLE mesh network solutions, we offer taxonomy, dividing the solutions defined into three major categories: structured solutions, academic solutions, and proprietary solutions. In this article, the taxonomy serves as the key framework for defining BLE mesh solutions. Given the essence and the availability of knowledge in each situation, this arrangement provides the reader with homogeneous material in each key category [4]. We thoroughly discuss their key advantages and weaknesses after evaluating the BLE mesh strategies considered, and we raise open problems at the moment.

*The Overview of BLE*

As part of the Bluetooth 4.0 specification, BLE was specified for the first time in 2010 by the Bluetooth Special Interest Group (SIG). The following Bluetooth revisions have been released since then: Bluetooth 4.1, Bluetooth 4.2, and Bluetooth 5.0.0. The key features of BLE for the above Bluetooth specifications are defined in this section, highlighting the aspects related to support for mesh network topology.

*Bluetooth 4.0*

With the goal of allowing low power communication between devices, BLE specifies a full protocol architecture. There are two major components in the architecture; the Controller, which executes radio interface functions, and the Host, which provides higher layer features and serves applications [5]. The Physical Layer and Link Layer are the controllers, while the host consists of the Logical Link Control and Adaptation Protocol (L2CAP), the Attribute Protocol (ATT), the Generic Attribute Profile (GATT), the Protection Manager Protocol and the Generic Access Profile (GAP). The Host and the Controller connect via the Interface of the Host Controller (HCI).

*Bluetooth 4.1*

In 2013, the Bluetooth 4.1 standard was announced. With respect to BLE mesh network support, Bluetooth 4.1 implements a fundamental change; a system can run multiple Link Layer instances concurrently without restriction, regardless of its Link Layer function. A slave is thus permitted to be linked to more than one master concurrently [6]. Furthermore, one system will function at some intervals as a slave and at others as a master, establishing simultaneous communications with its Neighbours. This opens the door to the development of extended topologies of the network beyond star topology, such as mesh topology. However, in the Bluetooth 4.1 specification, the design and mechanisms for the creation and application of a BLE mesh network are not specified.

*Bluetooth 4.2*

Released in 2014, Bluetooth 4.2 implements enhancements specifically in three areas: Internet access, increased stability, and higher throughput [7]. These updates are planned to maximize the capacity of BLE as an IoT technology. However, to support BLE mesh networks, Bluetooth 4.2 does not offer extra features.

*Bluetooth 5.0*

Bluetooth 5.0 was the last Bluetooth standard announced as of the writing of this piece, written in late 2016. In terms of range, data rate, and advertisement channel features, this new Bluetooth standard provides enhancements. The latter involves an improvement in the capability of advertisement communications, along with the concept of two forms of advertising platforms, main and secondary. The primary advertisement channels are the same three advertising channels available in earlier versions of BLE, while the other 37 BLE channels are used for secondary advertising channels (formerly defined solely as data channels) [8]. Note that secondary advertisement networks, as data channels do in either BLE version, will manipulate frequency hopping. Like Bluetooth 4.2, however, it does not have extra capabilities beyond that in Bluetooth 4.1 to support BLE mesh networks. This opens the door to the development of extended topologies of the network beyond star topology, such as mesh topology. However, in the Bluetooth 4.1 specification, the design and mechanisms for the creation and application of a BLE mesh network are not specified.

*Routing Approach*

Routing-based BLE mesh network systems make use of two major types of routing solutions:

- tree/DAG proactive-routing
- Routing, on-demand.

First-class systems are ideal for sensor data collection applications where one key endpoint (i.e. the tree/DAG root) occurs, which can be a sink node and/or a portal to other networks. This arrangement is therefore ideal for connectivity between a central computer (e.g. a remote control) and the rest of the network equipment [9]. However, connectivity with any pair of devices on the network is not configured. On-demand routing is not limited to any fixed underlying configuration, so optimal routes for any two nodes can be sought. With this model, however, the size of the routing table increases with the number of destinations to which data is sent. Routes are looked for in this routing group only when data needs to be submitted. Remarkably, constructive routing is only used as part of tree/DAG-routing solutions, because otherwise, with the total number of network nodes, the routing state would increase.

*Security*

In IoT networks, security is of the utmost importance, considering the effect that breaching those networks can have on physical world operations. In BLE mesh networks, though, protection is actually a problem. Due to the absence of SMP services over advertisement packets, only packets sent via data channels are encrypted [10]. In addition, authentication is only carried out within a connection. Thus, unless the application layer has a protection solution, routing and data packets which are distributed via advertisement networks are not protected. On the other hand, because BLE was initially developed for networks with star topology, per-hop protection protects the data channels. BLE mesh networks officially do not allow end-to-end encryption and authentication.

## II. CONCLUSION

BLE mesh networking is a developing region that has the potential to extend the space for BLE applicability. In the last few years, academic solutions have been proposed for the BLE mesh network, and proprietary solutions have been published. Standards for BLE mesh networking are being developed as of the writing of this paper. Solutions for BLE mesh networking are numerous. Flooding-based systems prefer simplicity, whereas more elaborate are routing-based implementations. For data transfer, these two solution types use advertisement networks and data channels, respectively. This approach enables BLE Physical Layer features (e.g. adaptive frequency hopping), Link Layer features (bidirectional connectivity & reliability), and L2CAP layer features (segmentation and reassembly) to be exploited when using data channels, many of which are not possible for advertising-channel-oriented data transmission. There is a variety of open BLE mesh networking problems. In order to provide stable and high quality BLE mesh networks, we recommend that the group should concentrate on solving stability, multicast, and interoperability problems.

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