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PERFORMANCE ASSESSMENT OF BLUETOOTH LOW ENERGY

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Abstract

For a vast range of uses, lightweight, portable and integrated sensors are a prevalent technology in daily life. Wireless transmission plays a key role in this sense, and Bluetooth Low Energy (BLE) is gaining more and more prominence among the solutions available. BLE merges together strong efficiency, low-energy consumption and widespread diffusion. The goal of this work is to examine the key methodologies used to investigate BLE efficiency. An in-depth overview of the protocol, outlining the key aspects and implementation specifics, is the first section of this analysis. The second section discusses the state of the art with respect to BLE functionality and performance. In specific, throughput, maximum number of connectable sensors, power usage, latency and maximum reachable range are evaluated in order to define the existing BLE technology limits. The key findings can be summarized as follows: technically, the output can exceed the ~230 kbps limit, but the real implementations tested in this analysis reveal that the outputs are limited to ~100 kbps; the maximum reachable range depends solely on the radio capacity, and goes up to a few tens of meters; The maximum number of nodes in the network depends on the parameters of the connection, the design of the network and the particular features of the system, although it is generally less than 10; power consumption and latency are mostly modelled and evaluated, based strictly on a broad number of parameters. Much of these functions are focused on analytical simulations, but to grasp the exact boundaries, there is a need for rigorous experimental assessments.

Keywords: *Internet Engineering Task Force (IETF), Internet of Things (IoT), Internet Protocol Version 6 (IPv6), Low power Wireless Personal Area Networks (Low-PAN).*

I. INTRODUCTION

Bluetooth Low Energy (BLE, Bluetooth 4, Bluetooth Smart) is an advanced technology developed by the Bluetooth Special Interest Group (SIG) with the goal of being the best alternative to the vast range of current and widespread mainstream wireless solutions on the market, i.e. IEEE 802.11b (Wi-Fi), ZigBee, ANT+ and Bluetooth Classic (Bluetooth 3.0, Simple Rate/Enhanced Data Rate).

BLE is an ideal candidate for a wide variety of applications in the medical sector for e-health applications, e.g. in a body area network (using ECG, a heart rate monitor, a blood pressure metre,

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EMG for prothetic hand monitoring and an IMU sensor used for early diagnosis) because of the synergy between good performance and universal diffusion (nowadays, BLE is present in all PCs, smartphones and tablets) [1]; It is also used to regulate respiration, activities and falls), in automotive applications, in voice communications, kinematic monitoring, in households for healthcare environments and smart homes, in game control for the transmitting of M-IMU data, in protection systems, for the understanding of crowd dynamics, etc. It has been used successfully using beacon communication for location detection and distance measurement [2]. In this modality, various systems or sensors are designed to transmit broadcast signals, provided with the BLE interface and positioned in a structured environment, so that listener devices (e.g. the mobile device of the operator) can receive them. In this way, it is possible to give certain pieces of information about the ambient world, or to detect the location of the user, or to quantify the distance in the atmosphere between sensor devices, or to detect the presence of machines, and so on [3]. In addition, BLE has also been used in Internet of Things (IoT) technology due to its simplicity and low power consumption, such as distributing Internet Protocol Version 6 (IPv6) packets over Low-Power Wireless Personal Area Networks (Low-PAN) in health tracking applications. This was also possible due to the Internet Engineering Task Force (IETF) Low-PAN working group that suggested several specifications and draughts to define the IPv6 packet transmission header compression scheme in low-power wireless networks [4]. This has also contributed to the definition of unique feature packs, introduced in dedicated MCUs, allowing 6LowPan IoT nodes to be linked via BLE interfaces.

BLE Protocol Stack:

- The Application (App) is the stack's highest block, which contains the user's direct interface. It specifies certain profiles from which it is possible to interoperate with various applications that reuse similar functions [5]. The Bluetooth SIG defines these application profiles and supports interoperability between devices from various manufacturers. The Bluetooth specification also requires vendor-specific profiles to be specified for use cases not covered by the profiles defined by the SIG.
- The host contains the layers below:
  - I. Generic Access Profile (GAP)
  - II. Generic Attribute Profile (GATT)
  - III. Logical Link Control and Adaptation Protocol (L2CAP)
  - IV. Attribute Protocol (ATT)
  - V. Security Manager Protocol (SMP)
  - VI. Host Controller Interface (HCI)
- The Controller has the following levels of structure:
  - I. Host Controller Interface (HCI)
  - II. Link Layer (LL)
  - III. Physical Layer (PHY)

Each layer integrates the lower layer into the protocol. As a result, the raw data collected from the antenna is encapsulated in a regular BLE packet, shown by the left arrow. The BLE packet sent by the transmitter, on the other hand, is broken into raw data and then handled by the PHY sheet, as seen by the arrow on the right [6]. In order to facilitate the production of devices compliant with both standards, the BLE architecture has retained some common parts of Classic Bluetooth.

Physical Layer:

The BLE infrastructure is intended to work in the 2.4-2.5 GHz Commercial, Science and Medical (ISM) band, the same as BR/EDR and Wi-Fi. The BLE radio band ranges from 2.4000 GHz-2.4835 GHz in particular, and is split into 40 channels. The central frequency of these channels is 2402 + k * 2 MHz, where k = 0... 39. Three of these channels (37, 38 and 39) are reserved for advertisement packets, while the remaining 37 are reserved for the sharing of connected data packets.

Link Layer:

The LL is the part of the stack that interacts directly with the PHY; indeed, it consists of a mixture of part of hardware (HW) and part of software (SW). The LL specifies the form of communication that can be produced by the management of the connection state of the radio between BLE devices [7]. The numerous roles a computer may perform, i.e., master, slave, advertiser and scanner, are also described by LL.

Currently, to prevent overloading the Central Process Unit (CPU) responsible for handling all the SW layers of the stack, the LL is implemented in HW by silicon vendors. Its functions are conveniently automated, however pricey to calculate, and they are usually:

1. Preamble, Access Address and air protocol framing.
2. Cyclic Redundancy Check (CRC) generation and verification.
3. Data whitening.
4. Random number generation.
5. Advanced Encryption Standard (AES).

Host Controller Interface:

The HCI is a standard protocol that takes care of the communication with the Controller, i.e. the heart of the BLE protocol stack that handles the communication between the HW and the user application, which is the lowest component of the protocol and the Host [8]. Its function, therefore, is to define a series of commands and events to convert raw data into data packets to be sent to the host layer through the serial port, and vice versa. This was important because the protocol is modular and does not contain the Handler, Host and Device in a single bundle for this purpose.

Logical Link Control and Adaptation Protocol:

The L2CAP is a multiplexer protocol common to BR/EDR; it manages data from lower layers (LL for BLE and LM for BR/EDR) and encapsulates them according to upper layers (ATT and SMP for BLE and RFCOMM for BR/EDR) into the normal BLE packet format, and vice versa; these processes are referred to as recombination (or encapsulation) and fragmentation, respectively.

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Security Manager Protocol:

In order to encrypt and decrypt data packets, the SMP is composed of many protection algorithms. During the creation of a relation, it identifies two key roles: the initiator and the responder, who would refer to the master and the slave respectively, until the connection is formed. Further information can be found in the SMP procedures, such as matching, bonding and re-establishment of encryption.

Attribute Protocol:

The ATT describes the client-server architecture features, where the client is the one that requests data from the server, which in turn sends data to the client. Typically, these functions refer to the master and the slave described in the LL, respectively, but in general, regardless of whether it is a master or a slave, a computer could be a client, a server, or both [9]. The ATT also conducts the organization of data into attributes of which a handle, a Universally Unique Identifier (UUID), a permission set and a value are allocated. This protocol is encapsulated in the GATT, which uses the ATT-defined roles for link execution.

Generic Attribute Profile:

The GATT encapsulates the ATT layer and its primary function is to decide how the knowledge and data in both profiles will be shared in a BLE relation. Profiles are definitions of potential implementations that define common habits that are used by Bluetooth devices to connect with other Bluetooth devices. To more specifically describe what kind of data a Bluetooth module is transmitting, profiles are based on the Bluetooth standard [10]. This data are arranged in a hierarchical system consisting of parts called resources, which in turn group data into containers called features.

Generic Access Profile:

In the BLE stack, the GAP is collocated at the highest level of its core; it defines system functions, modes and procedures, in addition to managing the link establishment and the security. It communicates directly with the Application layer and thus to the user, who may specify all the parameters that the network needs. In addition, it provides the relation between the user and the whole stack protocol; indeed, all the lower protocols are applied and managed by it. All the functions and procedures found in the Void are specified.

II. CONCLUSION

The aim of this analysis is to define the BLE stack and the application of this wireless communication technology protocol. Then, the details already present in the literature are displayed, the agreements and the comparisons of the findings are illustrated and the key topics are presented for in-depth analysis in order to gain full knowledge of them. Finally, it was possible to find the necessary parameters helpful from the literature review to explain how to set BLE based on the individual application. The literature offers a large number of articles about energy use that provide results during the various forms of contact with BLE. Studies usually agree on the amount of energy BLE absorbs, and they determine how it changes, altering the settings of the various protocols. One significant factor currently absent in the literature is the precise calculation of intake during all the various operations. In addition to this, it is important to note that starting from the known waveform of a BLE contact; energy consumption is simple to model.

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