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Building the Internet of Things with bluetooth smart

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ABSTRACT

The Internet of Things, or the IoT, is an emerging, disruptive technology that enables physical devices to communicate across disparate networks. IP has been the de facto standard for seamless interconnectivity in the traditional Internet; and piggybacking on the success of IP, 6LoWPAN has been the first standardized technology to realize it for networks of resource-constrained devices. In the recent past Bluetooth Low Energy (BLE) a.k.a Bluetooth Smart - a subset of the Bluetooth v4.0 and the latest v4.2 stack, has surfaced as an appealing alternative, with many competing advantages over available low-power communication technologies in the IoT space such as IEEE 802.15.4. However, BLE is a closed standard and lacks open hardware and firmware support, something that hinders innovation and development in this field. In this article, we aim to overcome some of the constraints in BLE's core building blocks by making three contributions: first, we present the design of a new open hardware platform for BLE; second, we provide a Contiki O.S. port for the new platform; and third, we identify research challenges and opportunities in 6LoWPAN-connected Bluetooth Smart. We believe that the knowledge and insights will facilitate IoT innovations based on this promising technology.

1. Introduction

We can automate different functions in our everyday life by embedding a tiny computer with limited storage and communication capabilities in physical objects around us. The network of these smart objects or *things* using the Internet protocol (IP) is called the 6LoWPAN [1] or IPv6 over low-power wireless personal area networks, and the interconnection of 6LoWPAN networks with the Internet form the Internet of Things (IoT). IPv6, potentially, offers unlimited address space to connect billions of uniquely identifiable smart *things* with the Internet. 6LoWPAN is an IoT enabling technology that makes it possible to run the heavyweight IPv6 protocol in resource-constrained devices, by offering compression and fragmentation capabilities. Unlike conventional wireless sensor networks (WSN), 6LoWPAN networks are being deployed in environments where people are an integral part of the system.

Low-power IEEE 802.15.4 [2] is the de facto link and physical layer standard for 6LoWPAN networks. However, new technologies are emerging; and among the few energy efficient communication technologies, Bluetooth Low Energy (BLE) is an appealing alternative. BLE, marketed as Bluetooth Smart, is a lightweight variant of Classic Bluetooth targeted for low-power resource-constrained devices. Since the introduction of BLE in Bluetooth 4.0[3,4], there has been a widespread adoption of this technology by big and small technology vendors. Currently, most high-end smartphones support BLE.

Bluetooth 4.2 [5], released in December 2014, further brings Internet Protocol (IP) capabilities to Bluetooth - which means that we are now able to connect a Bluetooth device with the Internet using standardized mechanisms. In addition to the IP support, Bluetooth 4.2 offers National Institute of Standards and Technology (NIST) standardized advanced Elliptic Curve Cryptography (ECC) based security, enhanced privacy, and increased data rate and speed. One of the main competitive advantages BLE has over other low-power wireless technologies (such as IEEE 802.15.4) is out-of-the box support in most smartphones[1], which enables seamless and infrastructure-less integration of BLE devices with the Internet. This makes BLE a potential disruptive technology for the IoT.

BLE offers many advantages over its competitors, but when it comes to the wireless technology aspect for the IoT, it is not an open standard and lacks open hardware and firmware support. IoT has a huge potential to bring enormous innovations; however, the close-source nature of the BLE firmware becomes a great hin-

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[1] The latest iPhone 6s already supports even the new Bluetooth 4.2.

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drance. In order to enable IoT innovations, it will be highly motivational for thousands of new IoT startups to have access to open BLE hardware and firmware/software. BLE also lacks some of the important communication paradigms that are integral to the IoT such as multi-hop communication, *secure* broadcast, and group communication. Currently, BLE only supports the client-server communication model where two devices that are in the direct radio range of each other can communicate. Considering that BLE is a low-power wireless technology targeted for resource constrained IoT devices, the single-hop-only topology limits the communication range to just a few meters. Therefore, new communication paradigms are needed for BLE before we can take its full advantage.

In this article, we make the following contributions.

- We describe novel BLE features that make IoT ready in congruence with the IoT architecture consisting of Internet-connected resource-constrained BLE devices.
- To foster IoT innovation, we present a novel open hardware for BLE, the first of its kind.
- We provide the open source Contiki operating system (O.S.) port for the new hardware.
- We identify and discuss research challenges and opportunities in BLE-connected 6LoWPAN networks.

The rest of the article is structured as follows. The related work is highlighted is Section 2. We describe BLE connected IoT architecture and novel BLE features in Section 3. In Section 4, we present our new BLE hardware platform. Section 5 elaborates the Contiki O.S. port for our platform. Our identified open research challenges and opportunities in the BLE based IoT are discussed in Section 6 that is followed by the conclusions in Section 7.

2. Related work

Prior to the introduction of IPv6 capabilities in BLE in December 2014, there were previous efforts to use BLE in resource-constrained environments [6–8]. These solutions use the legacy BLE technology that can solve the local low-power connectively problems but cannot utilize the global end-to-end connectivity and security capabilities of BLE 4.2. Even the recent BLE based architectures [9–11] do not take advantage of the IPv6 connectivity.

Due to the Internet connectivity, cyber security became a requirement in IoT. With this realization, the Bluetooth Special Interest Group (SIG) has introduced the strong ECC based security in Bluetooth 4.2. Recently, Chakrabarty and Engels propose to encrypt the BLE 4.2 metadata [12], which can further protect the source and the destination addresses and the frame sequence number against adversaries. An application layer security is also proposed for BLE [13] to bring end-to-end security in the BLE connected IoT.

BLE is also coined as a viable solution for the IoT by industry [14], which is apparent from the fact that the big industry player Qualcomm, to grow its presence in the IoT market, has bought U.K.'s CSR, a global name in the Bluetooth world[2].

There are many existing System-on-a-Chip or SoC (such as CC2540[15], nRF51822[16]) and prototyping platforms (such as BLEduino[17]) that enable the end user to develop applications over a standardized BLE stack; but platforms that provide the feasibility to alter the communication stack are not available. The BLE platform introduced in this paper addresses this gap. Currently, the platform only supports the broadcast mode of operation.

We therefore do not claim that we are the first to propose BLE for IoT; however, to the best of our knowledge, we present the first open BLE hardware platform and open source implementation of BLE physical and MAC layer. Furthermore, this is the first work that discusses the new opportunities and challenges posed by IPv6-enabled BLE.

3. Bluetooth 4.2 and IoT architecture

BLE was introduced in Bluetooth 4.0, which allows power-efficient connections between Bluetooth devices that can run for months on cell-size batteries. Bluetooth 4.0 also adds the broadcast communication mode, in addition to the legacy connection-oriented pairing mode. A major class of applications still uses the connection mode between two devices such as a remote and a TV, a smartwatch and a smartphone, and a music player and a headset. Applications utilizing the broadcast mode can use the signal from different nearby BLE dongles without creating a prior connection. BLE broadcast has enabled a number of new functionalities such as localization. Although new functionality has been included in Bluetooth 4.1, it does not offer significant improvement over Bluetooth 4.0 that enables prevalent use in new domains. In contrast, the new Bluetooth 4.2 [5] offers novel features that make BLE a favorable technology for the IoT.

In this section we discuss Bluetooth 4.2, released in December 2014, elaborate the architecture of BLE connected IoT, and highlight novel features that brand BLE one of the most promising technologies to be used in resource-constrained devices in the IoT.

3.1. Bluetooth smart connected IoT architecture

The major addition that enables IoT capabilities in Bluetooth is the introduction of the Internet Protocol Support Profile (IPSP) [18][3]. IPSP enables an IPv6-enabled Bluetooth *peripheral* and a *central*, and a mechanism to discover each other and establish a link-layer connection. The BLE Generic Attribute Profile (GATT) is used to discover if a device supports IPSP. The IP Support Service (IPSS) is used over GATT to determine the support for the IPSP's *Node* role [18]. If a device supports IPSP, the actual IP data packets are exchanged using the Bluetooth Logical Link Control and Adaptation (L2CAP) credit based flow control mode.

In Fig. 1 illustrates a BLE-connected IoT architecture: consisting of a BLE sensor node, a smartphone, and the conventional Internet host. BLE is not directly interoperable with the 802.15.4 standard. However the latest Bluetooth 4.2 profile, the IPSP, makes it possible to run IP over BLE. We can therefore argue that both are interoperable at the IP layer and above The IEEE 802.15.4 protocol is not supported in ubiquitous devices such as smartphones; therefore, an IEEE 802.15.4-based 6LoWPAN network requires a dedicated 6LoWPAN Border Router (6LBR) in order to interconnect the 6LoWPAN network with the Internet. On the other hand, most smartphones have out-of-the-box support for BLE, which eliminates the need of gateways such as 6LoWPAN border routers [19] to connect BLE devices with the Internet. However, in order to provision the 6LoWPAN communication, both the sensor node side and the smartphone side must support the 6LoWPAN header compression mechanisms, as depicted in Fig. 1.

Nieminen et al. in the IETF RFC 7668 [20] discuss the standardized way of transmitting the compressed IPv6 packets over BLE, which they also implement and evaluate [21]. The RFC explains the link between the Bluetooth specifications and the 6LoWPAN standard. This document proposes the use of the 6LoWPAN header compression mechanism [19] over BLE; however, it does not include the 6LoWPAN fragmentation mechanism but rather uses the fragmentation mechanisms already defined in the Bluetooth L2CAP.

[2] https://www.qualcomm.com/news/releases/2015/08/13/qualcomm-completes-24-billion-acquisition-csr

[3] Though IPSP is compatible with Bluetooth 4.1, it is released with Bluetooth 4.2.