

# Using Bluetooth Low Energy for Dynamic Information-Sharing in Vehicle-to-Vehicle Communication

Jian Yang and Christian Poellabauer  
 University of Notre Dame

Pramita Mitra  
 Ford Motor Company

## ABSTRACT

Bluetooth Low Energy (BLE) is an energy-efficient radio communication technology that is rapidly gaining popularity for various Internet of Things (IoT) applications. While BLE was not designed specifically with vehicular communications in mind, its simple and quick connection establishment mechanisms make BLE a potential inter-vehicle communication technology, either replacing or complementing other vehicle-to-vehicle (V2V) technologies (such as the yet to be deployed DSRC). In this paper we propose a framework for V2V communication using BLE and evaluate its performance under various configurations. BLE uses two major methods for data transmission: (1) undirected advertisements and scanning (unconnected mode) and (2) using the central and peripheral modes of the Generic Attribute Profile (GATT) connection (connected mode). This paper investigates quantitative and qualitative advantages and disadvantages of both approaches and proposes a communication framework based on the central/peripheral mode, which uses a random role switching technique to ensure frequent communication opportunities between devices. Further, experiments on BLE-equipped Android devices are used to study the impacts of different framework parameters on communication performance, loss rates, and scalability. The paper further discusses other limitations, prospects, and potential applications of a BLE-based communication framework for VANETs.

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## INTRODUCTION

Vehicles are becoming increasingly connected and over the past decade, several communication technologies have emerged to provide communications for vehicles, including Infrared, Classic Bluetooth, ZigBee, and Dedicated Short Range Communications (DSRC) [1]. One of the latest additions to these technologies is the Bluetooth Low Energy (BLE) standard, also known as Bluetooth Smart. BLE was developed as a communication technology with various applications in mind, such as healthcare, fitness, smart homes, proximity sensing, and security. While BLE was not designed specifically for vehicular communications, its simple and quick connection establishment mechanisms make it a potential inter-vehicle communication technology, either replacing or complementing other vehicle-to-vehicle (V2V) technologies (such as the yet to be deployed DSRC). Previous research has shown that BLE can maintain robust short-range communication for both static and mobile scenarios [2], while also providing low power consumption and low latency [3]. Compared to Classic Bluetooth, BLE is able to provide considerably less power consumption and cost while still maintaining a comparable communication range and quality. The widespread use of Bluetooth technology (e.g., in mobile phones, laptops, automobiles,

etc.) is expected to further fuel the adoption of BLE. However, there are only a handful of communication models or protocols for BLE-based V2V communications available to date.

In this paper, we propose a framework for V2V communications using BLE and evaluate its performance under various configurations. We first compare the data rates and latencies for BLE communications using *Advertising Events* and *Connection Events*. Then, based on the use of Connection Events, we propose a **dynamic central/peripheral role switching mechanism** to provide stable BLE-based dynamic information-sharing with low data loss and low latency. Experiments using BLE-equipped Android devices and network simulations are used to investigate the impact of different parameters that may affect the performance of the framework. Our results show an acceptable latency (less than 1s) of the framework when applied to a large number of nodes in a fixed area. The evaluation also supports our claim that BLE is a promising technology for vehicular networks.

The rest of the paper is organized as follows. In the Related Work section, we review the latest research efforts in the fields of vehicular communications and BLE technology. Then, we provide an overview of the BLE technology and discuss the data transmission modes provided by the protocol. The following sections present our proposed event-based framework for dynamic information-sharing and the evaluation results, respectively. In the Conclusion section, we discuss the potential applications of the proposed BLE-based framework for vehicular systems.

## RELATED WORK

Several approaches have been proposed to provide fast and reliable communications among vehicles over the decade. Currently deployed Vehicle-to-Infrastructure (V2I) systems [4] (such as the OnStar system [5]) allow vehicles to connect to the Internet and transmit or receive location-based information via the cellular network. Vehicle-to-Vehicle (V2V) communication is another technology that relies on Vehicular Ad Hoc Networks (VANETs), enabling more direct data exchange and information sharing. Over the past decade, the DSRC [6] standards have emerged as a realization of VANET systems. DSRC provides a number of two-way short-range to medium-range wireless communication channels specifically designed for automotive use. At the PHY and MAC layers, DSRC utilizes IEEE 802.11p Wireless Access for Vehicular Environments (WAVE), which is a modified version of the familiar IEEE 802.11 (Wi-Fi) standard. Other technologies, such as ZigBee [7], and Classic Bluetooth are also considered as potential approaches for vehicular communications, but they are limited by their short communication ranges or unacceptable latencies [8], and therefore, these technologies are not widely deployed in VANETs.

BLE has been standardized by the Bluetooth Special Interest Group (SIG) under the Bluetooth 4.0 specification [9]. The recent published Bluetooth 4.1 specification [10] opened a few more interfaces for developers to fully take advantage of various BLE network features. Gomez et al. [3] provided a succinct overview of the BLE protocol stack and investigated how its energy consumption, latency, maximum piconet size, and throughput are affected under different configurations. Cho et al. [11] explored the latency performance of BLE with respect to certain network features. The experiments conducted in [11] verified the typically observed delays for GATT connections specified in the Bluetooth 4.1 protocol. Their results also showed that choosing a wide range of BLE parameters provides high flexibility for BLE devices to be customized for different applications. Mikhaylov et al. [12] developed a BLE network simulation tool based on the OMNET++ simulator to test the latency and throughput under various network types and configurations. This tool is the first and only one available so far for BLE network simulations; it is also used for the experiments in this paper.

Unfortunately, there is yet a dearth of research focusing specifically on BLE for vehicular applications. One notable exception is the work by Bronzi et al., which explored the potential of using BLE to implement V2V applications [13] and where they also developed a mobile application for iOS devices to test the communication

performance for single-hop scenarios [2]. A proof-of-concept application for the multi-hop scenario is proposed to demonstrate the feasibility in real-life driving scenarios. The event-based role switching method allows the BLE device to switch between *central* and *peripheral* roles so that the message can be rebroadcast to the whole network. Our work partly adopted that idea on peripheral/central role switching for low-latency data exchange.

## BLE TECHNOLOGY OVERVIEW

BLE is a power-efficient and application-friendly version of Bluetooth that was designed for many new applications in the field of the Internet of Things (IoT). As an addition to the Classic Bluetooth technology, BLE has been created for the purpose of transmitting small packets of data at a time, while consuming significantly lower energy than previous network solutions.

BLE operates in the 2.4 GHz Industrial Scientific Medical (ISM) band and defines 40 Radio Frequency (RF) channels with 2 MHz channel spacing. There are two types of BLE RF channels: *advertising* and *data* channels. Advertising channels (channels 37, 38, and 39) are used for message broadcast, device discovery, and connection establishment, while the data channels are mainly used for bidirectional communication between connected devices. An *adaptive frequency hopping* mechanism is used on top of the data channels to address interference and wireless propagation issues. This mechanism dynamically selects one of the 37 available data channels for communication during a given time interval.

The physical channel is sub-divided into time units known as *events*. Data is transmitted between BLE devices in packets that are positioned in these events. There are two types of events: *Advertising Events* and *Connection Events*. The former only utilizes the three advertising channels for each event, while the latter uses both the advertising and data channels – advertising channels for connectable device discovery and data channels for data transmission once a connection has been established. These two types of events determine how data packets are transmitted between BLE devices and are also utilized for the data transmission techniques in our proposed dynamic information-sharing framework, as described in the following sections.

## A BLE-BASED INFORMATION-SHARING FRAMEWORK

In this section, we explore how BLE can be used for event-based dynamic information-sharing, by utilizing the two types of BLE data packet transmission events described in the previous section. Toward that end, we first compare the advantages and disadvantages of these two data transmission events. Next, we propose a randomized mechanism for robust event-based data transmission using BLE in vehicular networks. At the end of this section, we present a conceptual framework that leverages the proposed randomized mechanism for dynamic information-sharing in V2V communications.

## BLE Data Transmission Modes

Given the advertising events and connection events defined for each physical channel, basic BLE data transmission is categorized into two modes: (1) the undirected advertisements and scanning (AD/SC) modes that together implement the advertising events; and (2) the central and peripheral connection modes that implement the connection events. Both modes can be used for common data transmission between BLE devices. However, V2V communications have high demands on data rate, packets collision, and latency requirements. In this section of the paper, we study the feasibility of utilizing these modes for V2V communications.

### AD/SC Mode

In the AD/SC mode, *advertiser* and *scanner* are the two major roles that a BLE device can play. Devices that transmit advertising packets on the advertising physical channels are referred to as advertisers. Devices that receive advertising packets on the advertising channels without the intention to connect to the advertising device are referred to as scanners. Transmissions on the advertising channels occur via payloads in the advertising events. As shown in Figure 1, at the start of each advertising event, the advertiser sends an advertising packet corresponding to the advertising event type (connectable or non-connectable). Depending on the type of advertising packet, the scanner may make a request to the advertiser on the same advertising channel, which may be followed by a response from the advertiser on the same advertising channel. The advertising channel changes on the next advertising packet sent by the advertiser in the same advertising event. The advertiser may end the advertising event at any time during the event. The first advertising channel is used at the start of the next advertising event.

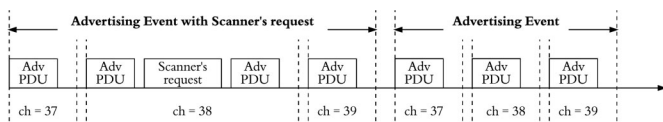


Figure 1. Advertising events. [9]

For applications using the AD/SC mode, the advertising packets are usually set as non-connectable and will not respond to any request from scanners. In the AD/SC mode, each device can maintain two roles simultaneously – the scanner is set as always active in order to receive all incoming packets, and the advertiser will be activated when there is a need to transmit data.

The size of each Packet Data Unit (PDU) is limited to 32 bytes. For each advertisement, the packet may contain configuration data as well as user-defined payload (up to 20 bytes). Usually, such small payload is used for transmitting simple and small data (e.g., location, temperature, and speed). For larger data that cannot fit into a single PDU, it will be segmented into multiple packets and an index number will be attached to each packet. Then the set of packets will be advertised repeatedly in sequence. On the scanner side, due to packet loss or interference, packets may not arrive in order and need to be sorted using the index number of each packet to retrieve the original data block. Figure 2 illustrates the procedure of transmitting larger data blocks using the AD/SC mode.

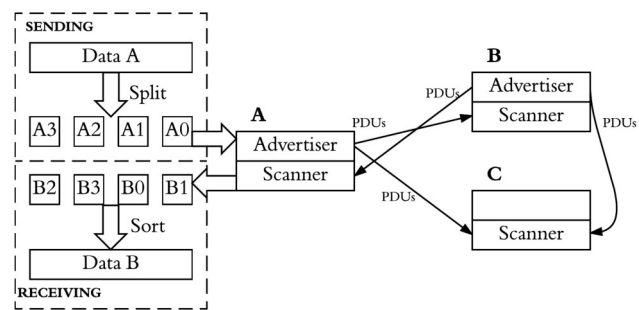


Figure 2. Fragmenting in the AD/SC mode for large data transmissions.

The AD/SC mode provides a simple and fast way of data transmission and is a good fit for broadcasting real-time information with small size, such as a vehicle's location, real-time speed, and local weather data. Since the BLE device can be both an advertiser and a scanner simultaneously, a vehicle in the AD/SC mode can easily notify their surrounding vehicles of its current status and keep track of its neighbors' states. However, the limited size of the packet payload in the AD/SC mode may limit the number of potential applications enabled by this mode. Splitting a large data block into multiple packets is a possible solution, but may result in heavy network traffic and increased data loss rates, especially in dense areas where a large number of fragmented data are broadcast over the network.

When advertising non-connectable packets, the advertising and scanning activities do not work simultaneously as we discovered when implementing the AD/SC mode on BLE-equipped Android devices. Theoretically, the advertising activity will not affect the scanning activity, but when the advertising activity is invoked, the scanning may be temporarily paused, thus causing a "dead zone", which prevents the reception of incoming packets. This dead zone problem is further explored in the Evaluation section of this paper.

### C/P Mode

To overcome the shortcomings of the AD/SC mode, the C/P mode can be considered as an alternative to AD/SC. The C/P mode is based on connection events and there are two roles for each BLE device: *central* and *peripheral*. A device that initiates an outgoing connection request to an advertising connectable PDU is referred to as a central device. The BLE device that accepts an incoming connection request after advertising connectable PDUs is defined as a peripheral device.

In the C/P mode, a peripheral device will periodically broadcast connectable PDUs and a central device will scan for such connectable packets to initiate a connection request on the same physical advertising channel. Once the peripheral device accepts the request, a connection is established between a central and a peripheral, and the data will be transmitted from the peripheral to the central based on the GATT profile. Both roles can end the connection at any time.

The GATT profile defines a framework that uses the Attribute Profile (ATT) for the discovery of services and the exchange of characteristics from one device to another. A characteristic is a set of data, which include a value and properties. The data are organized into services and characteristics are stored in attributes. The hierarchy of