Thread-Based Data Glove

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Introduction

Bluetooth Low Energy (BLE) is a wireless technology introduced with the Bluetooth 4.0 Core Specification by the Bluetooth Special Interest Group (SIG). It was designed as low-power solution for extended periods of communication at low data rates. BLE connects two devices directly to each other without hops through routers, unlike some other low-power wireless technologies. As a result, BLE has seen an emergence in medical, smart energy, and consumer device applications.

Bluetooth Low Energy

BLE Technology

BLE devices are, at their simplest, radios that operate at very high frequencies. The BLE standard defines 40 Radio Frequency (RF) channels spaced 2MHz apart in the 2.4GHz Industrial Scientific Medical frequency band. The existence of multiple channels allows BLE devices to avoid interference from other signals that are being sent in the same band. Three of the RF channels are used for advertising exclusively and the remainder are for data transmissions.

Advertising is the process by which BLE devices make known they are available for connection. Basic information about the device is transmitted through these channels for potential pairings. Once two devices are connected (or, paired) to each other, further communication between the two is done in the 37 data channels.

BLE communication over the channels is done in units of data called packets. Packets have a specific format that includes headers, a payload, and security checks. Headers are sections of metadata about the transmission. The payload contains the actual data that the user of the device intended to send. The payload of a BLE packet is at least 8 bytes and no more than 27 bytes long. Anything longer needs to be split into multiple packets. The security checks validate the integrity and correctness of the packet to ensure there have been no errors. Packets are also transferred at 1Mbps, which means it would take approximately 300 microseconds to send one packet of maximum length (41 bytes) over BLE.

BLE Device Roles

Unlike traditional Bluetooth connections that work as a two-way stream of data between devices, Bluetooth Low Energy uses a "bulletin board" model of communication. Instead of both devices in a connection being able to send any kind of data back and forth, BLE devices have to decide whether they are the bulletin board (offering information) or the reader (requesting and receiving information).

Bulletin board devices can either be Broadcasters, Peripherals, or some mix of both. If a device is a Broadcaster, it immediately sends out its information to other devices that have signed up to listen to it. Peripheral devices wait until another device requests a specific piece of information before sending it.

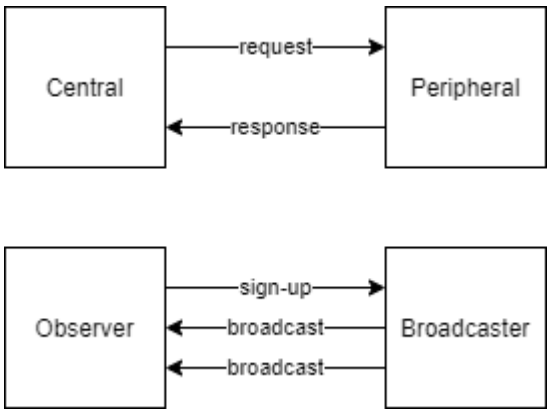

Figure 1: Visualizations of the four BLE device roles

Readers have the option of being Observers or Centrals. Observers do not consistently request information from other devices; they will only receive data from broadcasts that they have signed up for. Centrals query Peripheral devices for the specific pieces of information that are needed. Central devices also often manage connections with many Peripheral devices.

BLE Data Structure

BLE devices that offer information must place their data into structures called Services and Characteristics. Services are groups of related pieces of data. This could be all of the data from one source like a sensor (or set of sensors) or it could be information that has been obtained from different sources that are always needed together. These individual chunks of data in a Service are called Characteristics.

Characteristics can be any type of data up to 512 bytes. If there are multiple data points that need to be present in a Service, the simplest way to store them would be to place them each in their own Characteristic. However, this will require multiple transmissions of data between the reader device and the bulletin board device. BLE packets (the standard format in which data is sent) can contain up to 27 bytes of data. If a Service contains up to 27 bytes worth of Characteristics, all of that data could be put in one Characteristic and sent in one packet instead of multiple. Depending on the application requirements, the simplicity of individual Characteristics or the efficiency of larger, packed Characteristics may be preferred.

Each Service and Characteristic is required to have a 128-bit identifier known as a Universally Unique Identifier (UUID). These UUIDs are what reader devices connected to bulletin boards see and how they request information. This means that in order for two devices to communicate effectively, there needs to be a mutual understanding of what each Service and Characteristic represents. This is occasionally done through standard UUIDs (e.g. battery level, heart rate), but if no standard Service exists, both the reader and the bulletin board must know what UUIDs correspond to the information available and in what form the data is stored.

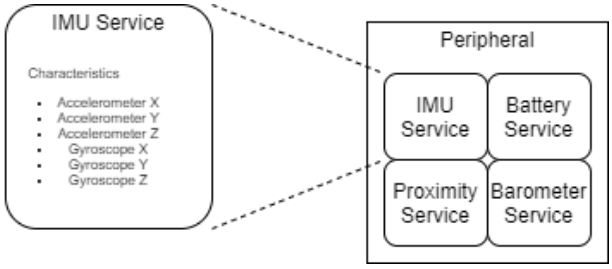

Figure 2: Visual Representation of the BLE Service and Characteristic data structure

Characteristic Options

Each Characteristic on a BLE device has a set of access permissions that dictate how other devices can interact with that Characteristic. The simplest are Read and Write; they allow other devices to perform that action on the value of the Characteristic. The UUID and other metadata about the Characteristic cannot be changed. There is also an alternate Write permission: Write without Response. This permission allows the Central device to send a new value to the Peripheral's Characteristic without needing that write acknowledged by the Peripheral. This can be useful for Characteristics that are updated frequently or ones that

are not critical in order to expedite communication between devices.

Other permissions allow Characteristics to be provided to connected devices immediately. The Notify option works similarly to Write without Response. When a new value is written to a Characteristic, the Peripheral or Broadcaster device will automatically send that new value to the Observer or Central device without expecting a response back. If confirmation of delivery is not important, this can be a quicker way to obtain information than requesting the information every time it is needed. The Indicate option is the same as Notify except that a response from the Central or Observer is required.

The Broadcast option is different than the previous five. Characteristics with the Broadcast option enabled are put into the Peripheral device's advertising packets. This means that a pair with the device is not required to get the values of this Characteristic. If any information about the device is necessary to know before establishing a connection, this is one way to accomplish that. Depending on when, where, and how frequently the value of a Characteristic is needed, one or more of these options may be enabled at a time.

Benefits of BLE

Using BLE in a device has a number of advantages over traditional Bluetooth connections. The itemization and categorization of data allows for more specific communication between two devices. With a standard Bluetooth connection, data can be sent either way that is not important to the other device. With BLE, data is not provided to a device unless it is requested. This assists with the low-energy aspect of BLE technology, since the ability to pause communication between devices lets the devices do less work.

BLE also has significantly better latency than a standard Bluetooth connection. The specification for traditional Bluetooth lists its latency as typically 100 milliseconds, while BLE comes in as quick as 3ms; almost two orders of magnitude quicker. This makes BLE more advantageous for one-time or brief connections between devices, since the setup and communication time is much quicker.

Applications in Data Glove

The data glove being built by Team Salmon relies on BLE for its wireless communication between the glove and computer it needs to communicate with. The glove has one Service and one Characteristic. As was mentioned earlier, packing all of the data into a single Characteristic reduces the number of times the computer and the glove need to send packets back and forth so that the majority of the communication will be substantive. The Characteristic is 34 bytes long and contains five short integers and six floating point numbers. Using this wireless communication method ensured that there is no confusion concerning the order in which data arrives to the computer.

The low-power aspect of BLE is also crucial to the glove. The glove would be significantly less useful if it could not operate for a long period of time. By using a low-power wireless technology, the glove will be able to operate for a long time before needing to be recharged.

Conclusion

Bluetooth Low Energy is a wireless technology built on Radio Frequency communication between two paired devices. It differs from its predecessor and contemporary standard Bluetooth counterpart in its defined roles for each device. BLE also provides the infrastructure to organize and categorize different data values into Services and Characteristics. Devices are able to interact with these Characteristics in a number of different ways, from reading and writing to being informed when the value is changed. As a result of

these features and its low-power design, it is being used in a wireless data glove application.

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