Make: Bluetooth

The smartphone didn’t change our world because it made it easier to make phone calls—it let us connect the Internet and physical world in totally new ways. Harness the power of that technology for yourself by learning to build and control your environment with Bluetooth LE (Bluetooth Low Energy). While they share a first name, Bluetooth LE is very different from classic Bluetooth. You’ll learn the details of Bluetooth LE and how to build your own connected devices. Its extreme low-power consumption and greater reliability over longer distances make it the perfect tool for experimenters.

With this book, you’ll write code and wire circuits to connect off-the-shelf sensors and even write your own Bluetooth Services! Using inexpensive modules based on Nordic Semiconductor’s chipset such as Adafruit’s Bluefruit LE, this book takes you step-by-step through projects that build your skills as you go. Perfect for Makers who have some programming experience with Arduino or Raspberry Pi, this book greatly expands your project possibilities.

In Make: Bluetooth, you’ll:

» Construct a smart light switch you can control remotely.
» Create a lock that only your phone can open.
» Build a working weather station that measures temperature, humidity, and air pressure.
» Make a NeoPixel LED lamp you can control to change color.
» Control your computer slideshow with a Texas Instruments SensorTag remote.
» Develop a computer interfacing project using a Parrot Rolling Spider Drone.
» Control your computer slideshow with a Texas Instruments SensorTag remote.
» Develop a Bluetooth controller that can adjust your computer or phone’s volume.

This book shows you how to work with Bluetooth at all levels of your project—microcontroller board, phone, tablet, and computer. You’ll get all these devices talking to each other using software: Arduino, Node.js, and PhoneGap—and you’ll be able to mix in all kinds of sensors and external hardware, too!

Affordable, low-power projects to unwire Arduino & Raspberry Pi!
Make: Bluetooth

Bluetooth LE Projects for Arduino, Raspberry Pi, and Smartphones

Alasdair Allan, Don Coleman, Sandeep Mistry
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One of the drivers behind the recent explosive growth in the Internet of Things has been the Bluetooth Low Energy (LE) standard. What makes it so appealing is the ubiquity of smartphones—both Apple and otherwise—with support for the standard, which means that thing-makers no longer have to worry about a display or user interface. And that means that things like smart lightbulbs can look a lot more like lightbulbs rather than a computer that happens to have a light attached to it.

Bluetooth LE is very different from classic Bluetooth—in fact, pretty much the only thing that is the same is the name. You’re probably used to thinking about radios as sort of like serial connections working similarly to a phone call between two phones—once you establish a connection, each person talks as the other listens and vice versa. They stay connected, even if neither is saying anything, until one hangs up and the call is ended.

In systems like these, data is transferred using a queue, and when data is read by the receiver, it’s erased from the queue—just as once my words reach your ears over the phone, they’re out of the communications channel. Effectively, this is how classic Bluetooth works.

**What Makes Bluetooth LE Unique?**

Instead of communicating via a point-to-point connection like a phone, a *Bluetooth LE radio* acts like a community bulletin board, with each radio acting as either a board or a reader of the board.

If your radio is a bulletin board—called a *peripheral device* in Bluetooth LE parlance—it posts data on its board for everyone in the community to read. If your radio is a reader—called a *central device* in Bluetooth LE terms—it can read from any of the boards (the peripheral devices) that have information it cares about.
If you don’t like that analogy, you can also think of peripheral devices as the servers in a client-server transaction. Similarly, central devices are the clients of the Bluetooth LE world because they read information from the peripherals.

**But I Like Serial Connections!**

Most (perhaps all?) of the Bluetooth LE radios breakout boards available to makers right now—the RedBearLab BLE mini and the Adafruit Bluefruit LE, for instance—pretend to look like serial devices for simplicity’s sake and present a UART service to the user. Effectively these radios are “faking” old-style serial communication on top of the underlying bulletin board paradigm. It’s a hack, and not a bad one.

*Serial over Bluetooth LE* makes the transition from classic Bluetooth to Bluetooth LE easier for people who are used to Serial Port Profile (SPP) and UART. However, there’s a downside. It doesn’t take advantage of Bluetooth LE. These Bluetooth serial services are just stuffing data across generic transmit and receive pipes. If a device uses serial, it also needs to define a protocol for the data that is sent and received.

Bluetooth LE offers device makers the ability to create Bluetooth LE devices with self-describing services. If the characteristics are well designed and the descriptors make sense, you can use services without documentation. (An example of this is using a Smartbotics Lightbulb with the LightBlue iOS app.)

Contrast this with other devices using SPP, like services where you need to learn the details of which bytes to send over the wire to turn on an LED and change its color. These devices need really good documentation and/or additional libraries to do simple stuff like set the color of a LED.

Returning to our bulletin board example, we’re creating a board (the *service*) that has a sticky note attached (known as a *characteristic* in Bluetooth LE parlance), which we can read, letting us know if the LED is on or off, or write to—allowing us to control the LED.

**Building a Custom Service**

Unfortunately, until recently, building custom services for Bluetooth LE has been fairly complicated and not for the faint-hearted. However, it’s getting simpler as several good tools now exist to do most of the heavy lifting for you.

In light of that, we decided to look at one platform—the Nordic Semiconductor radios—and figure out a complete toolchain that would allow you to build a custom service for those radios, and make use of that service from an Arduino project. We picked this particular radio because it’s readily available and there is good library support.

This book is the result.
Who Should Read This Book?

This book provides an introduction to the topic of how to build and deploy Bluetooth LE sensors and devices. It takes a hands-on approach and teaches you how to build things and how to use them, not just the protocols and architecture behind the standard.

If you’re a programmer or a maker who wants to get started with Bluetooth LE, this book is for you.

What You Should Already Know

This book is intended as an introduction to working with Bluetooth LE, and it assumes a technical background. However, we walk you through installing and using all the software and development environments you’ll need, including how to get started with the Arduino, Raspberry Pi, Node.js, and PhoneGap.

What You Will Learn

This book will guide you through building a series of connected projects—from lightbulbs, to locks, to beacons, and drones. It will walk you through your first hardware prototypes, show you how to improve them, and teach you how to build Bluetooth LE connected devices for the Internet of Things.

What's In This Book

Chapter 1, Introduction
This chapter talks about the Bluetooth LE standard and the concepts you’ll need to know about before you can start building Bluetooth LE devices.

Chapter 2, Getting Started
This chapter walks you through setting up the tools and software you’ll need to set up your development environment.

Chapter 3, Smart Light Switch
This chapter shows you how to build a smart light switch that not only lets you turn the light on or off using the switch but also remotely via Bluetooth LE. The switch knows its current status—in other words, whether the bulb is on or off—and will send out a notification if that status changes.

Chapter 4, BLE Lock
This chapter shows you how to build a lock that can be opened using your phone via Bluetooth LE. We will also walk through writing a mobile app that will run on iOS or Android using PhoneGap, which will control the lock.
Chapter 5, Bleno Lock
This chapter re-creates the Bluetooth LE lock built in the previous chapter but this time using Node.js on the Raspberry Pi. It uses the same lock service as the original Bluetooth LE lock so it can be controlled using the same mobile app.

Chapter 6, Weather Station
This chapter walks you through building a Bluetooth-LE-enabled weather station that can measure temperature, humidity, and pressure.

Chapter 7, NeoPixel Lamp
This chapter will show you how to build an RGB lamp that is controllable from your phone using an Arduino and a NeoPixel Ring with 16 LEDs.

Chapter 8, SensorTag Remote
This chapter shows you how to turn a TI SensorTag into a remote control for your computer, triggering an action on your computer when one of the SensorTag buttons is pressed.

Chapter 9, HID over GATT
This chapter explores the Human Interface Device (HID) profile and shows you how to build a Bluetooth LE volume control.

Chapter 10, Beacons
In this chapter we explore Bluetooth LE beacons, showing how to create them using Node.js and detect them using smartphones.

Chapter 11, Drones
This chapter shows you how to control a Parrot Rolling Spider drone over Bluetooth LE using a computer and Node.js.

Chapter 12, Going Further
This chapter provides a collection of pointers to more advanced material on the topics we covered in the book, and material covering some of those topics that we didn’t manage to talk about in this book.

Conventions Used in This Book
The following typographical conventions are used in this book:

Italic
Indicates new terms, URLs, email addresses, filenames, and file extensions.

Constant width
Used for program listings, as well as within paragraphs to refer to program elements such as variable or function names, databases, data types, environment variables, statements, and keywords.
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Support material for the book is also available at the book’s website.

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Acknowledgements by Alasdair Allan

Everyone has one book in them, but this isn’t mine. Depending how you count them, this is my ninth book. But every book is different, and they do not write themselves. So I’d like to thank my co-authors Don Coleman and Sandeep Mistry, and my editors at Make:, Brian Jepson and Roger Stewart, for holding my hand throughout the process.

I very much want to thank my wife, Gemma Hobson, for her continued support and encouragement. Those small, and sometimes larger, sacrifices an author’s spouse routinely has to make don’t get any less inconvenient the second, or third, or the n’th time around. I’m not sure why she lets me write—perhaps because I claim to enjoy it so much. Thank you, Gemma. Finally to my son Alex who, seven years on from my first book, is actually almost old enough to read this one.

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This is the first book I’ve been involved in. I would like to thank my co-authors Alasdair Allan and Don Coleman, and the editors Brian Jepson and Roger Stewart for guiding me through the process and providing valuable feedback throughout its production.
In Chapter 2, we’ll install the tools we need to write code and deploy services. But before we do that, we need to talk about Bluetooth LE, and make sure your machine can talk to it, too.

This chapter talks about some of the jargon you’ll need to understand to work with Bluetooth LE. The following chapter walks you through installing all of the software and configuring the hardware you’ll need for the projects in this book. After working through these two chapters, you should probably proceed with Chapter 3, which is a solid introduction to working with Bluetooth and the Arduino. However, after that you should be able to pick and choose among the rest of the projects in the book.

**Talking About Bluetooth LE**

Bluetooth LE divides the world into peripheral and central devices. *Peripheral devices* are things like sensors; they’re typically small, low-powered, and resource-constrained. *Central devices* are things like mobile phones and laptops, although these can usually also operate in peripheral mode.

Peripherals can operate in two modes: either by broadcasting or being directly connected to a central device. The broadcast mechanism is one of the big differences between Bluetooth LE and classic Bluetooth; it allows data to be sent out by the peripheral to any device in range.
The real-world range of a Bluetooth LE device depends on the transmitting power of the radio. Since higher transmitting power means more battery is required, Bluetooth LE is, unsurprisingly, a short-range standard. While it’s perfectly possible to have a real-world range of greater than 30m (about 100ft), a more typical operating range is between 2 and 5m (around 5 to 15ft).

This means that a Bluetooth LE peripheral device doesn’t necessarily need to be “paired” with a central device in order to transfer data. In Bluetooth LE, we speak of it as “connected” rather than paired as we did with Bluetooth 2.1. In broadcast mode, the peripheral will periodically send out advertising packets, available to any device that’s looking for them, for devices acting as “observers.”

The standard advertising packet describes the broadcasting device and its capabilities but is also capable of including custom information—sensor data, for instance—that you want to broadcast.

Broadcasting data from your peripheral is a good choice if you’re building something like a weather station where the data isn’t sensitive. However, there is no provision for security when broadcasting, so for personal data, the central device should connect to the peripheral, not the other way around.

Connections are exclusive. This means that a peripheral cannot be connected to more than one central device at a time. When a central device connects to a peripheral, the peripheral will stop advertising itself, and other devices will not be able to see it or connect to it until the first connection is terminated. However, whereas a peripheral can only be connected to one central device, a central device can be connected to more than peripheral at the same time.

The Bluetooth 4.1 specification removed the restriction that peripheral devices can only be connected to a single central device. Going forward, a peripheral can be connected to multiple central devices simultaneously. However, there are still many devices and chipsets that remain limited in this fashion.

If you need to exchange data between the peripheral and the central device, then you need to establish a connection between the two devices.
Protocols and Profiles

On top of the protocols that make up the Bluetooth LE standard, the specification defines what are called *profiles*. These are either the basic modes of operation needed by all Bluetooth LE devices, like the Generic Access Profile and Generic Attribute Profile, or *profiles covering specific use cases* such as the Heart Rate Profile.

**The GAP**

The *Generic Access Profile* (GAP) defines roles for devices, including the peripheral and central roles we mentioned in the last section, alongside advertising and discovery.

There are two ways to advertise data using GAP: advertising data and scan response packets. While both packets use the same payload format, and consist of up to 31 bytes of data, only the advertising data packet is mandatory. It is sent out at a preset advertising interval—the longer the interval, the less power used—on receipt listening devices can request the scan response packet with additional data if it exists.

Using custom advertisement data in the broadcast packets is how both the iBeacon and Eddystone standards are implemented; see Chapter 10 for more information.

Once a connection with the peripheral has been made, you will use GATT services and characteristics to communicate with the peripheral device, and advertising will stop until the connection is terminated.

**The GATT**

The *Generic Attribute Profile* (GATT) defines how Bluetooth LE transfers data back and forth between peripheral and central devices. It defines profiles, which are collections of services. Each service has characteristics, which contain data.

Roles change when moving from GAP to GATT. GATT defines two roles: client and server.

It may seem backwards, but peripheral devices are known as *GATT servers* and the more powerful central devices are *GATT clients*. Think of it this way: the server has data and the client wants data. All connections between the devices are initiated by the client.

After connecting, the client can get a list of services offered by the server. Before connecting, the central device had a potentially incomplete list of services from the advertising data.

**Services and Characteristics**

*Services* are used to break up the data into logically associated chunks, and consist of a collection of characteristics. *Characteristics* are the containers that hold the data associated with a service. Both services and characteristics are identified by a unique identifier, known as an UUID; see “UUIDs”.

Characteristics contain at least two attributes: a *characteristic declaration*, which contains metadata about the data, and the *characteristic value*, which contains the data itself. The
characteristic can also contain additional descriptors to expand on the meta data. Together, the declaration, value, and any optional descriptors form a bundle than make up a characteristic.

Characteristics can be defined as read or write. Characteristics are read by the client using a read request, with the returned value of the request being the characteristic value. Characteristic values can be written using a write request. The server returns a confirmation after the value is written. There is an additional write property called the write command. When a characteristic value is written with a write command, the server does not send any response back to the client. The write command is sometimes called write without response.

Two additional properties are notify and indicate. Both of these are server-initiated communication. A client subscribes to be notified when a characteristic's value changes. When a change occurs, the server notifies the client by sending the new value. An indication is similar to a notification, except that the client must acknowledge the receipt of the indication.

Characteristics can have multiple properties. For example, one characteristic could allow read, write, and notify.

**UUIDs**

Bluetooth uses Universally Unique Identifiers (UUIDs) for many things, including services and characteristics. Bluetooth services that have been approved by the Bluetooth Special Interest Group are assigned 16-bit UUIDs. All other services and characteristics must use 128-bit UUIDs, which can be generated with tools such as uuidgen, as shown here:

```
$ uuidgen
437121E5-A6F0-43F9-8F8F-4AB73D6CC3EB
```

In this book, we use 16-bit UUIDs. Technically we’re breaking the rules, but for us it’s a lot easier to type DCF8 than 391CDCF8-4BD4-4507-BE23-B57DFD1F870B. See Table 1-1 for a list of officially approved 16-bit UUID ranges.

<table>
<thead>
<tr>
<th><strong>UUID</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>00xx</td>
<td>Namespace Descriptors</td>
</tr>
<tr>
<td>18xx</td>
<td>Services</td>
</tr>
<tr>
<td>27xx</td>
<td>Units</td>
</tr>
<tr>
<td>28xx</td>
<td>Declarations</td>
</tr>
<tr>
<td>29xx</td>
<td>Descriptors</td>
</tr>
<tr>
<td>2Axx</td>
<td>Characteristics</td>
</tr>
</tbody>
</table>

Table 1-1. Officially approved 16-bit UUID ranges
For the LED examples, we reuse SmartBotics’ service for their RoboSmart lightbulb. For the button examples, we reused Texas Instruments’ Simple Key Service from their Sensor Tag. For the thermometer examples, we create some 16-bit UUIDs.

It’s fine to reuse UUIDs if existing services and characteristics meet your needs. If you’re making your own services, use 128-bit UUIDs. See the Bluetooth Developer Site for more information.

**An Example Service**

Pulling this together, let’s look at a typical example service for a lightbulb, as shown in Table 1-2 and illustrated in Figure 1-1.

This is part of the service definition advertised by a RoboSmart Light Bulb. As you can see, despite not being an officially approved service definition, like many other manufacturers, RoboSmart uses 16-bit UUIDs.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>UUID</th>
<th>Property</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light switch</td>
<td>FF11</td>
<td>Read, Write</td>
<td>1</td>
<td>1 on, 0 off</td>
</tr>
<tr>
<td>Dimmer setting</td>
<td>FF12</td>
<td>Read, Write</td>
<td>0x7F</td>
<td>0x00 to 0xFF</td>
</tr>
<tr>
<td>Power consumption</td>
<td>FF16</td>
<td>Read</td>
<td>340</td>
<td>Watt Hours</td>
</tr>
</tbody>
</table>

This is part of the service definition advertised by a RoboSmart Light Bulb (see Figure 1-1).
Support for Bluetooth LE is available on most major OS platforms. However, if your laptop or desktop hardware doesn’t support Bluetooth LE, there is a large number of Bluetooth LE USB dongles available. Many are based around the same Broadcom BCM20702A0 chipset; for this book, we used the IOGEAR GBU521 Bluetooth 4.0 USB Micro Adaptor, which can be picked up for about $10 to $15 on Amazon and other online retailers. USB adapters with the CSR8510 chipset also work well.

**OS X**

All Apple laptop and desktop machines built after 2011 have Bluetooth LE hardware built-in, though if you’re using a Mac built before that and running Mountain Lion or later, you’re probably still okay. You can pick up a Bluetooth LE USB adaptor and it should work out of the box.

If you’re running a pre-Mountain-Lion distribution of OS X, it’s still possible to get most Broadcom-based Bluetooth LE adaptors to work, but it’s probably going to be a lot harder. For Lion, you’ll have to go into the `/System/Library/Extensions/` folder and make changes inside the `IOBluetoothFamily.kext`, adding the current Product ID and Vendor ID.
values of your USB dongle before reloading the kernel extension. For those running Pre-
Lion distributions of OS X, things are even more difficult.

**Apple iOS**
Support for Bluetooth LE on the iPhone and iPad has existed since iOS 5, although we'd recommend iOS 7 as the minimum version because it introduced iBeacon support to the operating system. Hardware support for Bluetooth LE was introduced with the iPhone 4s, iPad (third generation), and the iPod touch (fifth generation). All current Apple iOS devices support the standard.

**Linux**
Linux uses the BlueZ service to talk to Bluetooth devices, and Bluetooth LE has been supported since version 4.93.

Linux users should take a look at the instructions in “Setting Up Raspberry Pi” where we talk about installing the BlueZ service to work with the Bluetooth 4.0 USB adaptors.

**Android**
Support for Bluetooth LE in the core Android OS was introduced in Android 4.3, although version 4.4 introduced numerous bug fixes and is probably the minimum recommended version. Before this, though some manufacturers shipped hardware that was Bluetooth-LE-compatible, there was no software support, which caused many manufacturers to introduce their own libraries to support it—which were unfortunately all incompatible.

**Microsoft Windows**
Microsoft Windows 8 and above has built-in support for Bluetooth LE. Unfortunately, Windows XP, Vista, and Windows 7 only support Bluetooth 2.1, and while it’s theoretically possible to get these earlier versions to talk to Bluetooth LE devices—at least for Windows 7, it’s an extremely challenging problem that’s well beyond the scope of this book. If you’re working with Bluetooth LE under Windows, you should at least be running Windows 8.

**What Haven’t We Told You About Bluetooth LE?**

Lots. The Bluetooth LE specification is a sprawling mess of interlocking documents that runs to thousands of pages; the core standards document is over 2,700 pages on its own. What we’ve given you here is the barest outline, a sketch, of how the standard works.

However, it’s enough that you should now be able to go and confidently build projects using Bluetooth LE to actually do things in the real world. You can pick up the architecture and theory behind the protocols as you go along. But you have enough to get started.