Wi-Fi, Bluetooth, and the Internet of Things

Introduction

The Internet of Things (IoT) has an increasing number of our devices interacting with each other. When we switch on a movie, our lights dim. When we leave the house, the doors lock, the thermostat adjusts, and the lights turn off. Our EKG comes back irregular and our cell phone brings up our doctor's phone number. We want technology to simplify our lives. We want our devices to interact. To do this they need to communicate wirelessly.

IoT encompasses a vast array of products from warehouse inventory tracking to smart watches to lights that connect to the Internet. While IoT is a broad classification, the goal of this whitepaper is to help developers whose products are primarily meant for in-home or wearable use. For these types of products, the choice for wireless technology will most likely come down to Wi-Fi, Bluetooth Classic, or Bluetooth Smart aka Bluetooth Low Energy (BTLE). The major factors to consider will be power, data rate, and the types of devices that your product will need to communicate with.

Background

Although we generally recommend Wi-Fi or some form of Bluetooth, there are many other forms of wireless communication. For certain types of products with special requirements, one of these alternatives might be the best solution.

Active RFID is often used for asset tracking and inventory management in places like hospitals and warehouses. It is the underlying technology for NFC, which can be appropriate for very low-bandwidth, close-range applications.

Both ZigBee and Z-Wave are low-power mesh networking options. Mesh networks can function without a central hub or host device, so there is no single point of failure. Both are also relatively low power. Additionally, Z-Wave operates at a lower frequency than other standards, which enables it to travel through walls more effectively.

Cellular technologies including 3G, 4G, and LTE can make sense in environments where Wi-Fi or Bluetooth are unavailable. Unfortunately, a cellular connection requires a great deal of power (such as large batteries or a similarly capable power source), making it unfeasible for many applications. Currently, cellular is more commonly used in products that operate in remote locations, such as solar-powered sensors or tracking devices.

Thread is a new standard being supported by several major companies. With Google's support it looks like it could have an exciting future, but it is not yet ready for immediate use. Thread and ZigBee have announced cooperation that may create new markets for ZigBee, but the partnership is still nascent and there are few details available.

Apple's HomeKit promises to ease integration by providing a communication framework for home automation, but it still requires selecting a wireless technology such as Wi-Fi or Bluetooth for the data transmission.

Wi-Fi

Wi-Fi is extremely well established and exists in most homes and offices. Devices receive an address and can communicate with any other device on the network, which can grow to be very large. A variety of security options exist and provide a good level of safety. Gaining network credentials can be complicated, however, and joining a network can take a perceptibly long time. Most home automation devices must remain active on the network. This means that shutting down to save power is generally not an option. Wi-Fi starts to make sense especially for devices with a typical power draw of several watts, which is more common for wall-powered devices. Several companies are making Wi-Fi-based speakers, lights, and other household appliances.

Connecting a device to a Wi-Fi network (also known as provisioning or commissioning) can pose a challenge. A common strategy is to set up an ad hoc network where the device acts as a router to which a laptop or smartphone can connect and then be used to input credentials. There are also a number of other strategies including Wi-Fi Protected Setup, Universal Plug and Play, Devices Profile for Web Services, and Zero Configuration Networking that all try to automate and facilitate the setup process. Additionally, some Wi-Fi devices are now able to connect directly to each other. To the user this looks much like Bluetooth, although in actuality one of the devices is acting as a router.

Bluetooth Classic and BTLE

Bluetooth Low Energy was added to the Bluetooth 4.0 standard. Bluetooth Classic and BTLE are fundamentally different technologies, but they do share some similarities. Both work by establishing a direct connection between two devices. A host device is able to connect to multiple slaves and is usually able to act as a slave as well. Slave devices, however, are not aware of the other slaves, and each has an isolated, independent channel to its host. Both Bluetooth Classic and BTLE operate on the same hardware and within the same frequency band.

Bluetooth Classic consumes significantly more power and requires a pairing step that can be time-consuming, but it supports much higher data rates. Audio devices are a core segment for Bluetooth Classic, and many car-based applications that interact with smartphones require enough bandwidth to warrant a Bluetooth Classic connection. A Bluetooth Classic host can support a maximum of 7 slave devices, though attaching to all of them at the same time would likely degrade performance.

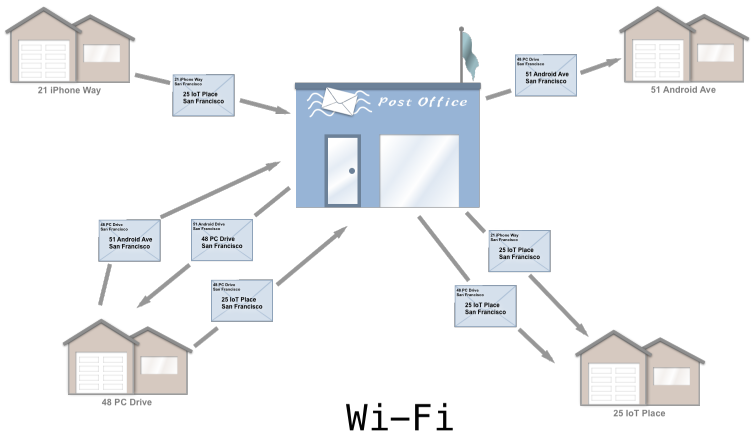
BTLE is the smaller, lighter, easier version of a device-to-device connection. Establishing a connection is very simple, with no security required. This means that a BTLE device can go into an extremely low-powered state when not actively transmitting. It would be possible, for instance, to create a BTLE keychain that has a button for triggering actions on a smartphone and runs for a year on a coin cell battery. Additionally, even during active transmission the power consumption is relatively low. While this results in a lower data rate, BTLE remains an excellent choice for low-bandwidth, low-power devices such as wearables. BTLE hosts can pair to a theoretically unlimited number of devices,

although some manufacturers limit this based on memory. Since the amount of data from any single device is small, there is a low impact in increasing the number of slave connections.

Types of Networks

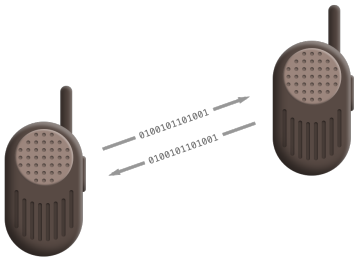
When deciding between Wi-Fi and Bluetooth, an important factor to consider is the type of communication that is needed between your device and other devices.

Traditionally, devices on a Wi-Fi network use an address to communicate to another device on the network via a router. This router is like the post office. Each house has an address, which the post office uses to route mail from one house to another.



Wi-Fi Topology

On the other hand, Bluetooth provides a direct connection between devices. This is like a walkie-talkie. A Bluetooth host device is able to communicate with multiple clients, but each channel of communication is isolated. Clients are not able to communicate with each other and are not even aware that other clients exist. Some devices are able to act as both a host and a client, but still each channel is independent. Ergo, if you need each device to talk with many other devices rather than only with a single host, then Wi-Fi is the more appropriate solution.



Bluetooth Topology

Comparison

Technology	Topology	Data Rate	Range	Peak Power
Wi-Fi	Address-based	Up to 600 Mbit/s	30m typical Miles in theory miles but limited by power, antenna, and legal restrictions	>600mW
Bluetooth Classic	Direct connect	Up to 3 Mbit/s	10m typical 100m in theory	<150mW
BTLE	Direct connect	Up to 1 Mbit/s	10m typical 100m in theory	<75mW

Selection Criteria

Each product has unique requirements and considerations, but there are some general factors to consider.

Products that need to interact with an app on a smartphone will most likely use some form of Bluetooth, due to the ease of setup and widespread support. Even when the primary interaction is not through an app, Bluetooth can provide a convenient bridge to the Internet through a user's smartphone or tablet, for instance enabling communication with a remote backend. Bluetooth, particularly BTLE, is also a good fit for portable devices that must be low power, such as wearables like activity trackers and health-monitoring devices. BTLE may not provide enough bandwidth for certain applications, however, in which case Bluetooth Classic or Wi-Fi could be better options.

Wi-Fi can be appropriate for products that are meant to be stay in a location where Wi-Fi infrastructure is already in place, such as a home or office. Wi-Fi is more power hungry and difficult to support in small, battery-powered devices, but it can be a good fit especially for wall-powered appliances that already draw a lot of power. Wi-Fi is also the better option for products that need an Internet connection even when a smartphone or other networked device is not physically present. While neither Wi-Fi nor Bluetooth travels through walls well, Wi-Fi does tend to have a longer range.

The table on the following page outlines some broad product categories and corresponding recommendations for wireless technologies.

Application	Recommendation	Rationale	Notes
Entertainment	Wi-Fi or Bluetooth Classic	Need high data rate to preserve quality of audio and video.	Wi-Fi for devices that will get their content from the Internet, but Bluetooth is better for a portable speaker or audio headset getting content from a smartphone or tablet.
Wearables	BTLE	Small size requires low power. Usually desirable to connect to user's smartphone for app interaction and as a bridge to the Internet.	Wearables largely track human-scale information like heart rate, steps, etc. These signals are slow and as such BTLE provides plenty of bandwidth. There are exceptions like EEG and sleep-monitoring devices, however, that might generate more data than BTLE can handle.
Home Automation	Wi-Fi	Home Wi-Fi networks are ubiquitous and can easily support the addition of more devices. Power is usually less of a concern because most appliances are wall powered.	Many use cases do not include a user physically present with their smartphone, so the device would have to support its own connection to the Internet. This enables features such as turning on the lights to give the appearance that someone is at home or remotely checking the contents of the fridge.
Remote / Tracking	Cellular	These devices need to communicate independently from anywhere.	This market is currently rather small. Devices that need to work in remote locations are likely to run on batteries, so power management becomes an important issue.