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# Beginning LoRa Radio Networks with Arduino

## Build Long Range, Low Power Wireless IoT Networks

Pradeeka Seneviratne

Apress®

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***Beginning LoRa Radio Networks with Arduino: Build Long Range, Low Power Wireless IoT Networks***

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# About the Author

**Pradeeka Seneviratne** is a software engineer with more than ten years of experience in computer programming and systems design. He is an expert in the development of Arduino and Raspberry Pi–based embedded systems and is currently a full-time software engineer working with embedded systems and highly scalable technologies. Previously, Pradeeka worked as a software engineer for several IT infrastructure and technology servicing companies. He is the author of several books, including *Beginning BBC micro:bit* (Apress), *Building Arduino PLCs* (Apress), and *Internet of Things with Arduino Blueprints* (Packt).

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# CHAPTER 1

# Introduction to LoRa and LoRaWAN

Radios are exciting pieces of hardware that can be used to build wireless communication links. Radios used to listen to voice and audio are known as *receivers*; your home radio, for example, can only tune into and receive radio stations. Radios that can be used to transmit voice and audio are known as *transmitters*; radio stations use transmitters to broadcast programs. Radios that can do both (transmit and receive) are known as *transceivers*; a walkie-talkie is an example of a two-way radio transceiver.

Transceivers use different types of modulations to send and receive data. The network coverage and data capacity are highly dependent on the frequency and type of modulation used. By using LoRa modulation, you can send data to long distances.

By reading this chapter, you will gain a basic understanding of LoRa, LoRaWAN, and LoRaWAN's architecture.

## What Is LoRa?

The LoRa spread spectrum is a patented modulation developed by Semtech (`https://www.semtech.com/`) based on the chirp spread spectrum (CSS) modulation. LoRa (short for "long range") provides long-range and low-power consumption, a low data rate, and secure data

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transmission. LoRa can be used with public, private, or hybrid networks to achieve a greater range than cellular networks. LoRa technology can easily integrate with existing networks and enables low-cost, battery-operated Internet of Things (IoT) applications.

Let's try to understand how the LoRa Spread Spectrum Modulation works. A plain radio signal carries no information besides the transmitter being left on. The signal must be modified in some way to convey information. There are several ways in which this can be done. Two of the most popular methods are to modify the amplitude and to modify the frequency.

## Amplitude Modulation

In *amplitude modulation* (AM), the signal strength (amplitude) of the carrier wave is varied in proportion to that of the message signal being transmitted. Figure 1-1 shows how the information signal (modulating signal) is transformed into the modulated signal. First, the information signal is mixed with the carrier signal using a mixer (indicated with an X). The carrier signal has a constant frequency and amplitude, generated by an oscillator. During the transformation, the resulting modulated signal varies its amplitude, but the frequency remains constant. This simple modulation technique simplifies the transmitter and receiver design and is cost effective.

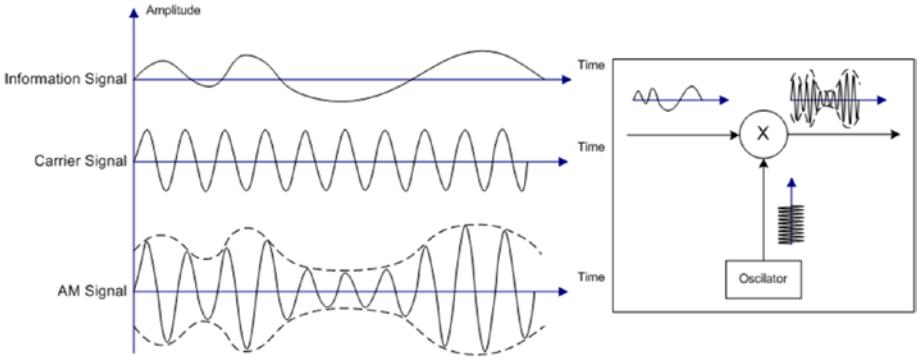


***Figure 1-1.*** *Amplitude modulation, including the information signal, carrier signal, and AM signal (source: https://en.wikipedia.org/wiki/Amplitude_modulation#/media/File:Illustration_of_Amplitude_Modulation.png by Ivan Akira, https://creativecommons.org/licenses/by-sa/3.0)*

Amplitude-modulated signals are less resistant to noise and deliver poor sound quality compared with frequency modulation. However, amplitude modulation signals can be sent over long distances.

## Frequency Modulation

*Frequency modulation* (FM) is widely used for FM radio broadcasting. In frequency modulation, the frequency of the carrier wave is changed in accordance with the intensity of the signal. The amplitude and the phase of the carrier wave remain constant. Only the frequency of the carrier wave changes in accordance with the signal.

Figure 1-2 shows the frequency modulation technique. The information signal is mixed with the carrier signal using a mixer. The carrier signal has a constant frequency and amplitude. When the information signal voltage is 0, the carrier frequency is unchanged. When the information signal approaches its positive peaks, the carrier frequency is increased to a maximum. But during the negative peak of a signal, the carrier frequency is reduced to a minimum. Therefore, the resulting modulated signal has a constant amplitude with varied frequencies.

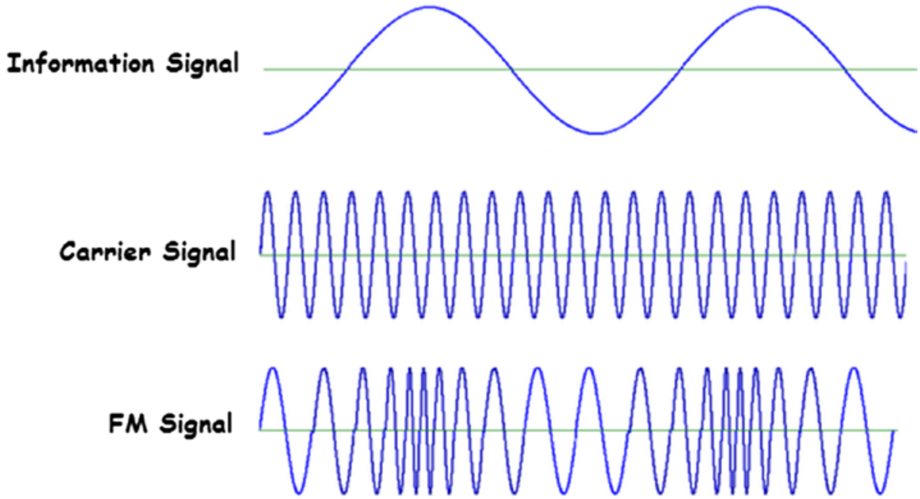


***Figure 1-2.*** *Frequency modulation, including the information signal, carrier signal, and FM signal*

Frequency-modulated signals are more resistant to noise and deliver better sound quality compared with AM. They can't travel long distances and can be blocked by tall buildings or mountains.

## Frequency Shift Keying

*Frequency shift keying* (FSK) represents a digital signal with two frequencies. One frequency could be used to represent digital 1, and the second frequency could be used to represent digital 0. Figure 1-3 shows how a digital signal is transformed into a modulated analog signal using FSK modulation. A carrier signal and two different frequencies are used to represent digital states, HIGH and LOW. The digital data signal is mixed with the carrier signal and encoded into a modulated analog signal.

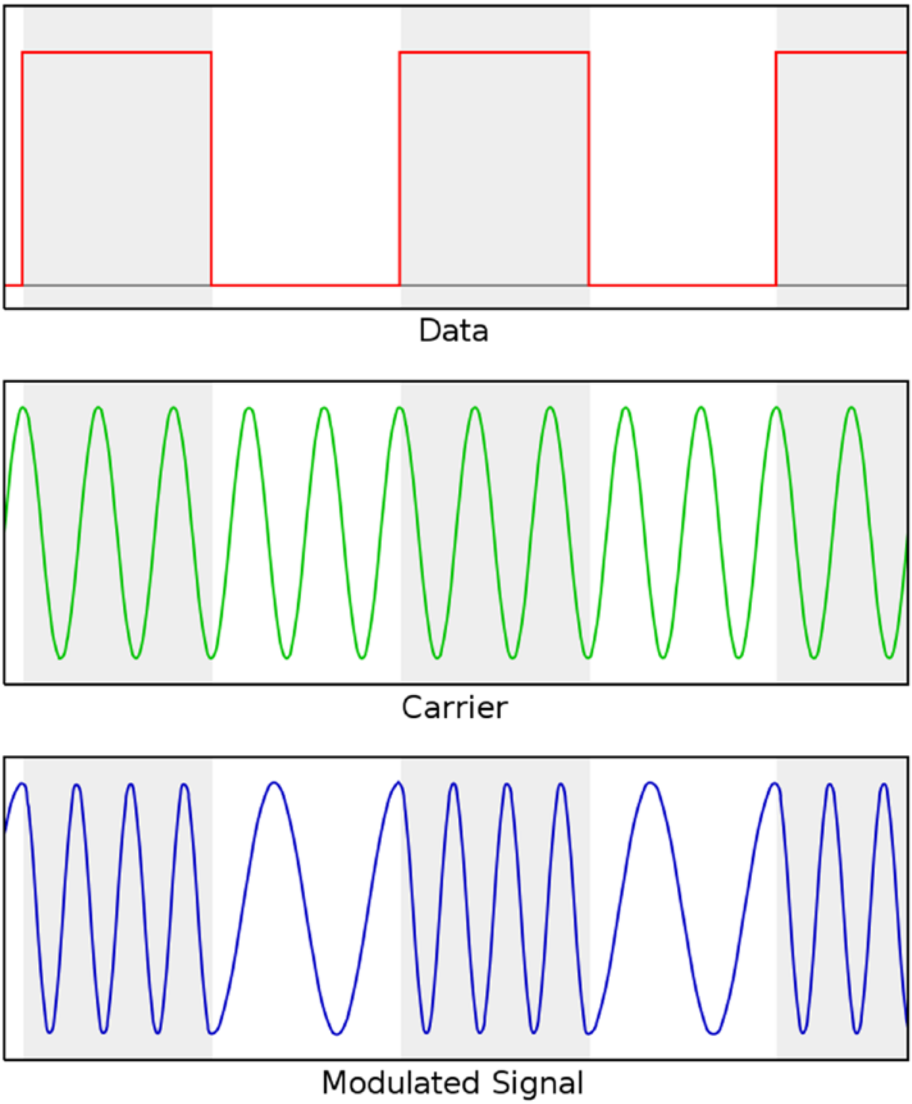


***Figure 1-3.*** *FSK modulation transformed digital signal into an analog signal using two frequencies. Each frequency represents a digital state. (Source: https://en.wikipedia.org/wiki/Frequency-shift_keying#/media/File:Fsk.svg; license: https://creativecommons.org/licenses/by-sa/3.0/)*

Figure 1-4 shows how the signal jumps between its two frequencies (1 and 0); it is known as a *waterfall display*.

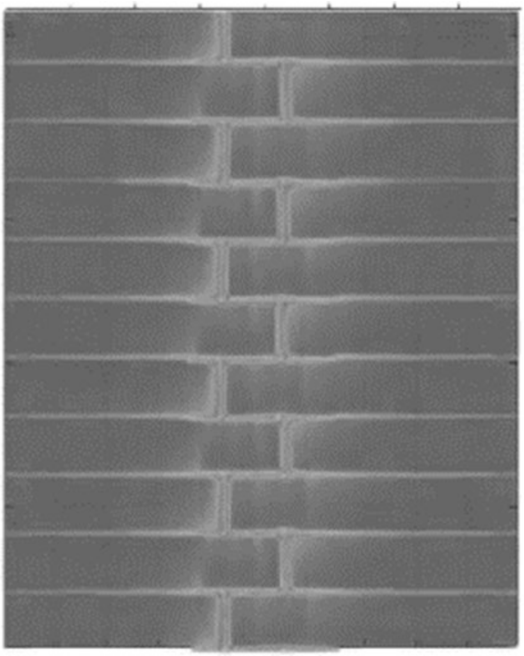

***Figure 1-4.*** *Waterfall display for frequency shift keying*

## Chirp Spread Spectrum

Chirp spread spectrum (CSS) modulation maintains the same low-power characteristics as FSK modulation. It is a spread spectrum technique that uses wideband linear frequency-modulated chirp pulses to encode information.

CSS was developed for radar applications in the 1940s. It has been used in military and space communications for decades because of its long communication distances, low transmission power requirements, and less interference.

## LoRa Spread Spectrum Modulation

You already know that LoRa modulation uses the chirp spread spectrum to encode data. Each bit is spread by a chipping factor. The number of chips per bit is called the *spreading factor* (SF). CSS uses spreading factors from 7 to 12. Small spreading factors provide high data rates and require less over-the-air time. Large spreading factors provide low data rates and require more over-the-air time.

LoRa modulation is more complex and resilient to background noise. Rather than just use the two frequencies of SFK, it sweeps between the two frequencies, as shown in Figure 1-5. The bottom part of the image shows the frequency sweeps from up to down. The top part of the image shows the frequency sweeps from down to up.

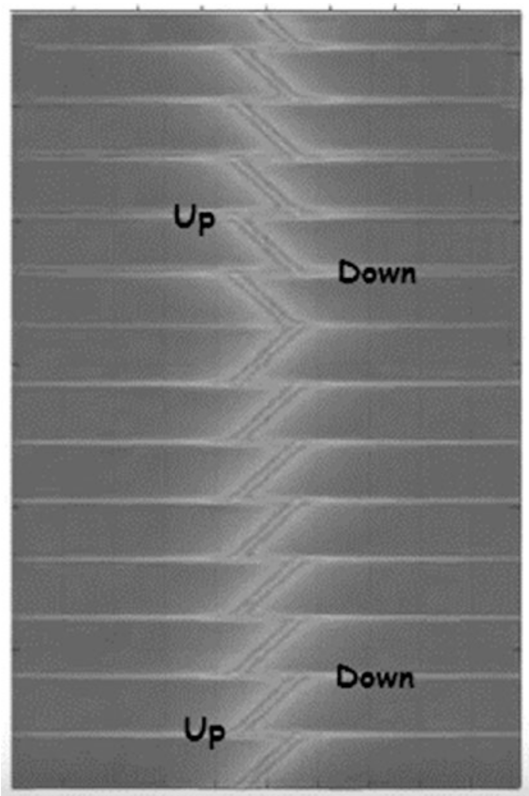


***Figure 1-5.*** *Sweeping between the two frequencies (up to down and down to up)*

The LoRa Spread Spectrum Modulation has the following properties:

- Bandwidth scalable
- Constant envelope/low power
- High robustness
- Multipath/fading resistance
- Doppler resistance
- Long-range capability
- Enhanced network capacity
- Ranging/localization

## LoRa Applications

LoRa is suitable for building long-range communication channels with low data rates. LoRa wireless sensor networks can be used to build a wide array of applications. Some of them are as follows:

- Agriculture processing
- Air pollution monitoring
- Asset tacking
- Cattle tracking
- Energy management and sustainability
- Fall detection
- Fire detection
- Fleet management
- Fleet tracking

- Home security
- Indoor air quality management
- Industrial temperature management
- Liquid presence detection
- Locating stolen vehicles and cargo
- Medical refrigerator monitoring
- Parking management
- Precision farming
- Predictive maintenance
- Radiation leak detection
- Shipment quality
- Smart home asset tracking
- Smart irrigation
- Smart lighting
- Smart parking
- Tank flow monitoring
- Waste management
- Water flow monitoring
- Water management and protection
- Wireless gas-level monitoring

## Network Coverage

A single gateway can cover entire cities or hundreds of square miles/kilometers. The coverage highly depends on obstructions (buildings, trees, hills), the environment (heavy rain), and technical factors (high-level radio interference, antenna type). Figure 1-6 shows a coverage map of LoRa gateways distributed in New Zealand by Spark Digital.

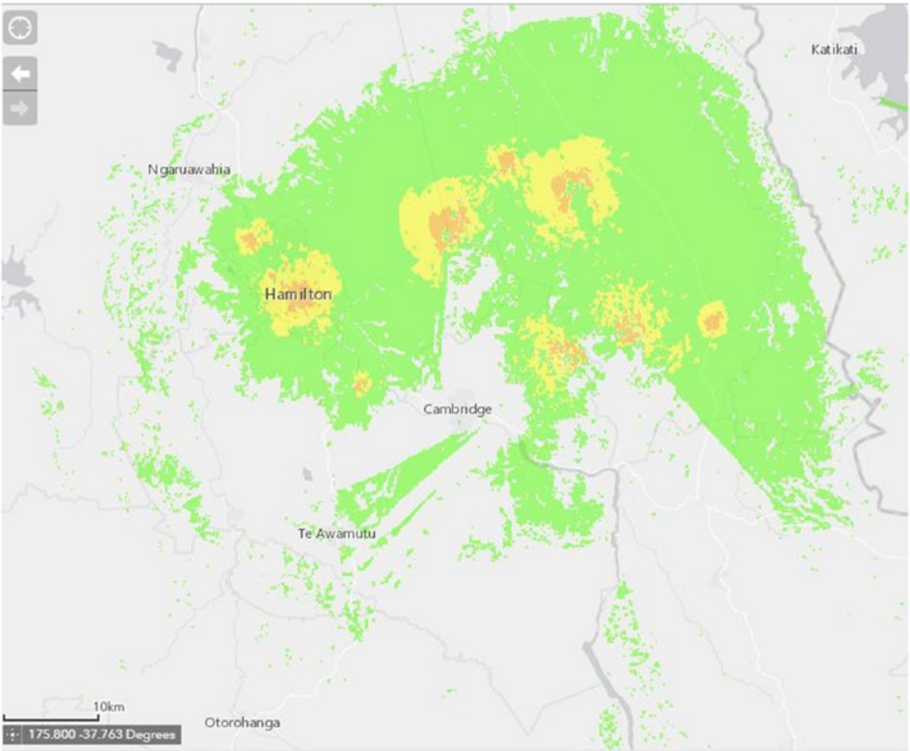


***Figure 1-6.*** *Source:* *https://www.SparkDigital.co.nz/solutions/mobility/iot/loracoverage/*

The coverage is greater than any other standardized communication technologies such as Bluetooth, ZigBee, Wi-Fi, or cellular. The link budget is the primary factor in determining the range in a given environment for any communication link, typically given in decibels (dB). LoRa modulation can be used to replace some parts of new or existing IoT networks that require small payloads and data rates.

## Example

Let's assume we have a vehicle tracking system based on traditional GPS trackers. Each vehicle transmits its current geographical location periodically to a GPS server through a cellular network. Each GPS tracker has a data plan. Let's also assume an organization has 100 vehicles, so they should pay $100 for the Internet plan.

If we replace each GPS tracker with a LoRa sensor node and a few LoRa gateways, we will only require cellular data plans for the gateways. Let's say we installed ten gateways to cover the entire geographical area. With this implementation, we can highly reduce the cost for cellular data and increase the portion of ownership of the network.

# Low-Power Wide Area Networks

LoRa networks are considered low-power wide area networks (LPWANs). The nodes can be battery powered, and the lifetime of the battery is about ten years. The nodes transmit data in small amounts over long distances and a few times per hour (for example, every ten minutes).

## What Is LoRaWAN?

Long Range Wide Area Network (LoRaWAN) is the communication protocol and system architecture for the network, while the LoRa physical layer enables the long-range communication link. LoRaWAN has the capacity to have an effect on the following:

- Battery lifetime of the node
- Network capacity
- Quality of service
- Security
- Applications served by the network

LoRaWAN consists of end nodes (end devices), gateways (concentrators), a network server, and application servers (Figure 1-7). In a LoRaWAN network, data transmitted by an end node is typically received by multiple gateways. Once the data is received, each gateway will forward the received packet to the network server through cellular, Ethernet, Wi-Fi, or satellite. The software running on the gateway is responsible for forwarding any incoming data packet to the network server. This software is known as a *packet forwarder*.

The network server sends and receives LoRaWAN messages to and from devices and communicates with upstream application servers. The application server is the destination for device application data sent as the payload in LoRaWAN messages.

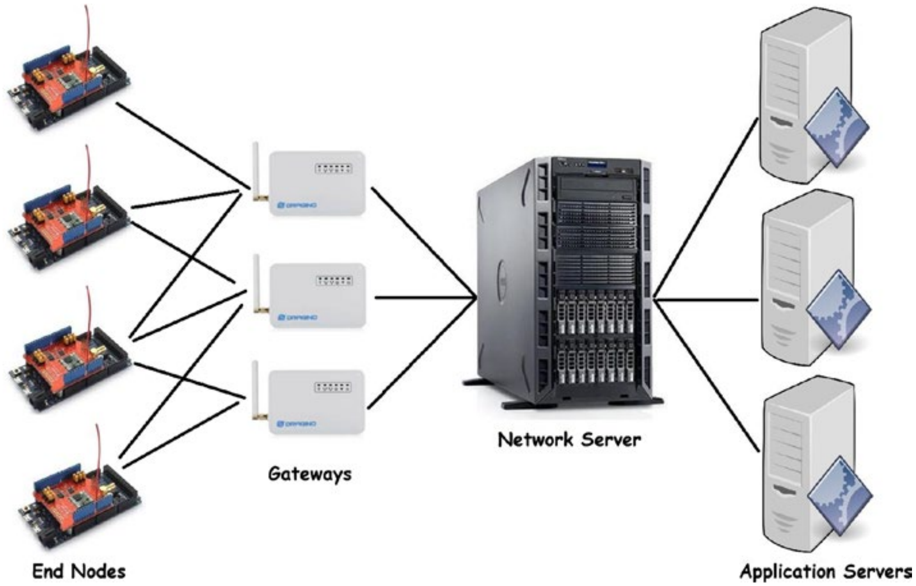


***Figure 1-7.*** *Elements of LoRaWAN*

## Packet Forwarders

A *packet forwarder* is software running on the LoRa gateway. It allows the LoRa concentrator to transmit and receive LoRa packets for both uplinks and downlinks from end nodes to network servers and from network servers to end nodes. Packet forwarders can be categorized into single-channel packet forwarders and multichannel packet forwarders. Only multichannel packet forwarders are LoRaWAN compatible.

Usually a packet forwarder does the following:

- Forwards LoRa packets received by the concentrator (LoRa module) to the network server through the IP/UDP link
- Emits LoRa packets that are sent by the network server

The following are some of the packet forwarders available for different platforms. But they are still developing, and more should be available soon.

- Semtech UDP packet forwarder (https://github.com/Lora-net/packet_forwarder): The Semtech packet forwarder code can be compiled with the Semtech Lora library (https://github.com/Lora-net/lora_gateway). See https://github.com/Lora-net/packet_forwarder/wiki/Use-with-Raspberry-Pi for compile options. It works with the Semtech SX1301 chipset.
- TTN packet forwarder (https://github.com/TheThingsNetwork/packet_forwarder): This works with Multitech Conduit, Kerlink IoT Station, and Raspberry Pi and iC880a setups.
- Dragino single-channel packet forwarder (www.dragino.com/downloads/index.php?dir=motherboards/lg01/sketch/&file=Single_pkt_fwd_v004.ino.hex): This software is written for Dragino LoRa gateways. It works with Semtech SX1272, SX1276, and SX1278 chips.
- Raspberry Pi single-channel packet forwarder (https://github.com/tftelkamp/single_chan_pkt_fwd): This works with the Semtech SX1272 transceiver (HopeRF RFM92W) and SX1276 (HopeRF RFM95W).

# Hardware for End Devices

Semtech offers a wide range of chipsets for building end devices to work with different frequency ranges. Table 1-1 shows some of the popular chipsets that can be used to build end devices with the Arduino and Raspberry Pi.

*Table 1-1. Chipsets for End Devices /End Nodes*

| Part Number | Description | Source |
| --- | --- | --- |
| SX 1272 | Long-range, low-power RF transceiver 860–1000 MHz with LoRa technology | https://www.semtech.com/products/wireless-rf/lora-transceivers/SX1272 |
| SX 1276 | 137–1020 MHz long-range, low-power transceiver | https://www.semtech.com/products/wireless-rf/lora-transceivers/SX1276 |
| SX 1278 | 137–525 MHz long-range, low-power transceiver | https://www.semtech.com/products/wireless-rf/lora-transceivers/SX1278 |

Some transceiver modules are available for building end devices without heavy soldering and additional electronic components. Figure 1-8 shows a LoRa transceiver breakout based on the SX1276/SX1278 chipset. It can be easily used with the Arduino or Raspberry Pi to build end nodes and single-channel gateways.

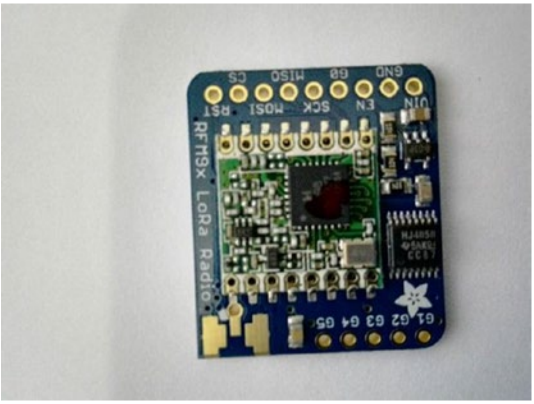


***Figure 1-8.*** *Adafruit RFM96W LoRa radio transceiver breakout, 433 MHz*

# Hardware for Gateways

LoRa gateways can handle data coming from many end devices simultaneously. These gateways can be built from scratch with Semtech chipsets.

Semtech offers the chipsets in Table 1-2 for designing and building multichannel LoRa gateways.

***Table 1-2.*** *Chipsets for Multichannel Gateways*

| Part Number | Description | Source |
|---|---|---|
| SX 1301 | Digital baseband chip for outdoor LoRaWAN macro gateways | https://www.semtech.com/products/wireless-rf/lora-gateways/SX1301 |
| SX 1308 | Digital baseband chip for indoor LoRaWAN pico gateways | https://www.semtech.com/products/wireless-rf/lora-gateways/SX1308 |

However, single-channel LoRa gateways can be built with the same chipsets designed for the end devices (Table 1-3).

***Table 1-3.*** *Chipsets for Single-Channel Gateways*

| Part Number | Description | Source |
|---|---|---|
| SX 1272 | Long-range, low-power RF transceiver 860–1000 MHz with LoRa technology | https://www.semtech.com/products/wireless-rf/lora-transceivers/SX1272 |
| SX 1276 | 137–1020 MHz long-range, low-power transceiver | https://www.semtech.com/products/wireless-rf/lora-transceivers/SX1276 |
| SX 1278 | 137–525 MHz long-range, low-power transceiver | https://www.semtech.com/products/wireless-rf/lora-transceivers/SX1278 |

Also, there are hundreds of ready-to-use LoRa gateways available on the market. Some of them are as follows:

- Dragino LG01-P IoT gateway (www.dragino.com/products/lora/item/117-lg01-p.html): This is a single-channel, indoor gateway (Figure 1-9) and is available in different frequencies such as 868, 915, and 433 MHz.


***Figure 1-9.*** *Dragino LG01-P IoT gateway (courtesy of Dragino, www.dragino.com)*

- Dragino LG02 Dual Channels LoRa IoT gateway (www.dragino.com/products/lora/item/135-lg02.html): This gateway can simultaneously receive two channels. It also can transmit data on a single channel (Figure 1-10). It is available in different frequencies such as 868, 915, and 433 MHz.


***Figure 1-10.*** *Dragino LG02 Dual Channels LoRa IoT gateway (courtesy of Dragino, www.dragino.com)*

- Waspmote gateway SX1272 LoRa module SMA 4.5 dBi, 868 MHz (https://www.cooking-hacks.com/waspmote-gateway-sx1272-lora-sma-4-5-dbi-868-mhz): See Figure 1-11.

***Figure 1-11.*** *Waspmote gateway SX1272 (courtesy of https://www.cooking-hacks.com)*

- Waspmote Plug & Sense (www.libelium.com/products/plug-sense/): See Figure 1-12.


***Figure 1-12.*** *Waspmote Plug & Sense (courtesy of www.libelium.com)*

- The Things gateway (https://www.element14.com/community/docs/DOC-83605/l/things-gateway-use-a-long-range-and-low-power-radio-frequency-protocol-called-lorawan-and-for-short-range-bluetooth-42): See Figure 1-13.


***Figure 1-13.*** *The Things gateway (courtesy of https://www.element14.com/)*

- Cisco Wireless Gateway for LoRaWAN (https://www.cisco.com/c/en/us/products/routers/wireless-gateway-lorawan/index.html): See Figure 1-14.