# Wireless Connectivity for the Internet of Things

## Introduction

The term Internet of Things (IoT) has gained enormous popularity with the explosion of wireless sensor networks, smart meters, home automation devices and wearable electronics. The IoT spans long-range outdoor networks such as the smart grid and municipal lighting as well as shorter-range indoor networks that enable the connected home and residential security systems.

Numerous companies have introduced innovative solutions for the IoT market that provide security, status and other convenient services. A connected system architecture comprises a number of wireless nodes ranging from simple remote control devices to complex wireless networks featuring a gateway to connect to the Internet.

These networks can also provide localized system intelligence and cloud services as shown in Figure 1. In this article, we will discuss low-power, long-range wireless connectivity in the widely used sub-GHz band.

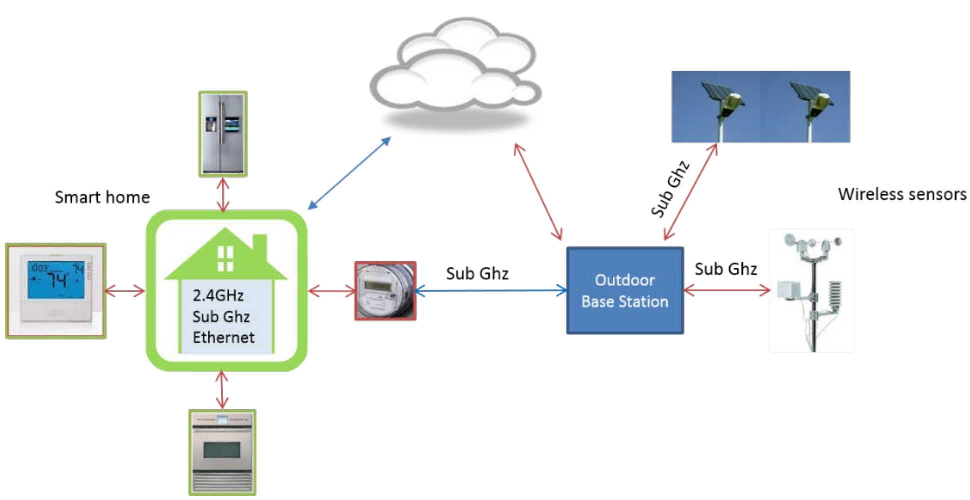



**Figure 1. Connected System Architecture**

## Choosing the Right Wireless Solution

MCU and wireless ICs are primary building blocks of an IoT system. MCUs used in connected device applications typically offer a wide selection of memory and peripheral options. The choice of wireless ICs (transceivers, transmitters and receivers) is an equally important, if not more, complex decision. Choices include sub-GHz devices running mostly license-free proprietary protocols and a plethora of 2.4 GHz devices based on standards such as ZigBee, Bluetooth Smart and Wi-Fi.

There is no "one size fits all" solution when it comes to choosing the optimal wireless protocol for a given IoT application. Each wireless option has pros and cons, and the application, such as a gateway or a battery-powered end node, drives the selection of the right connectivity technology.

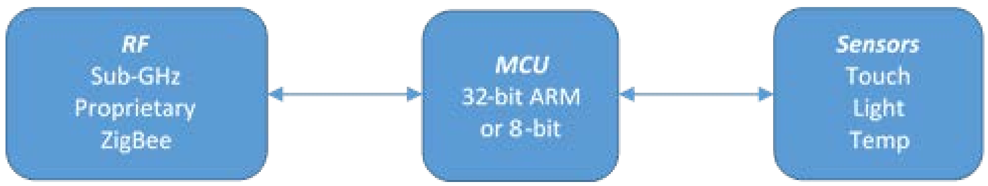



**Figure 2. Sensor Node Architecture**

Proprietary sub-GHz protocols and the open ZigBee standard are among the most commonly used wireless protocols for applications that require a combination of energy efficiency, long battery life (5-15 years depending on the battery) and extended range for remote sensor nodes. Bluetooth provides very short-range, point-to-point connectivity for smart phones and tablets without additional wireless infrastructure. Wi-Fi is the most widely used protocol for bandwidth-intensive applications such as video streaming and wireless hot-spot connectivity.

The sub-GHz band is ideal for long-range, low-power and lower data rate applications such as smoke detectors, door and window sensors, and outdoor systems such as weather stations, smart meters and asset tracking.

## Sub-GHz Wireless Connectivity

Sub-GHz technology is an ideal choice for wireless applications requiring long range and low power consumption. Narrowband transmissions can transmit data to distant hubs, often several miles away, without hopping from node to node. This long-range transmission capability reduces the need for multiple expensive base stations or repeaters. Proprietary sub-GHz protocols allow developers to optimize their wireless solution to their specific needs instead of conforming to a standard that might put additional constraints on network implementation. While many existing sub-GHz networks use proprietary protocols, the industry is slowly adding standards-based, interoperable systems. For example, the IEEE 802.15.4g standard is gaining popularity worldwide and is being adopted by various industry alliances such as Wi-SUN and ZigBee. As with any standard, there are several mandatory and optional specifications, and identifying the right parameters upfront helps with device selection. Now let's take a closer look at power efficiency and wireless range in the context of sub-GHz wireless networks.

## Low-Power Consumption

Engineers designing wireless solutions for power-sensitive and battery-powered applications must consider the standby current, low power modes and wakeup times of a wireless IC. For example, Silicon Labs' EZRadio and EZRadioPRO sub-GHz transceivers are ideal choices for these applications because these energy-friendly wireless devices consume 40 nA current in standby mode with full memory retention and require only 440 µs to wake up from standby/sleep to receive mode. Autonomous features such as low duty cycle mode help to further reduce the average receive current consumption especially in time-slotted systems. In this case, the radio automatically wakes up from sleep and enters receive mode based on a programmable, integrated 32 KHz sleep clock. The radio evaluates the channel and only wakes up the host MCU if a packet is found. The decision is typically made based on preamble detection or receive signal strength indicator. If there is no valid packet, the radio automatically returns to sleep mode without interrupting and activating the host MCU.

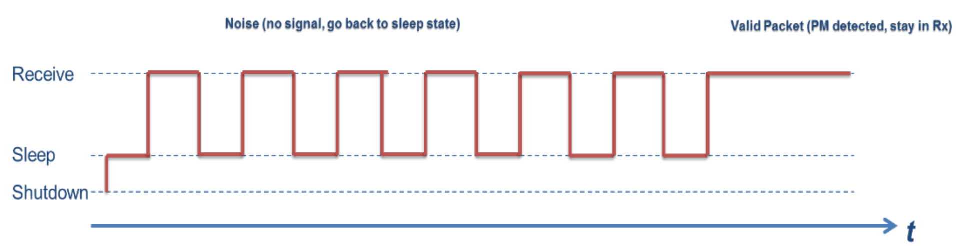



Figure 3. Receiver Autonomous Duty Cycling

Three main factors determine the current consumption of a duty cycling application: the energy required to transition from sleep to receive mode, the time required to evaluate the channel for a valid packet and the sleep mode current. The preamble sense mode of EZRadio and EZRadioPRO transceivers greatly reduces the channel access time with no degradation in sensitivity while significantly reducing the average receive current. These radios require only 8 bits of preamble to detect a valid preamble, compared to 32 bits in other traditional sub-GHz transceivers. The improvement in average receive current is greater for longer preamble lengths and lower data rates. The power amplifier (PA) consumes the highest current in these sub-GHz transceivers so an efficient PA design is also critical to achieve long battery life. EZRadio and EZRadioPRO ICs integrate an efficient +20 dBm PA that consumes only 85 mA, which is 40 mA lower than competing solutions. With a +10 dBm output power, the PA consumes only 18 mA, which enables coin cell battery operation.

## Wireless Range

One of the primary advantages of using sub-GHz wireless technology in any application is the long-range capability of this frequency band, even in obstructed conditions. Long-range systems reduce the cost of deployments as fewer base stations and repeaters are required to serve the same number of devices. Low frequency transmissions can travel longer distances for a given output power. Governed by the laws of physics, this phenomenon can be seen by using the Friis formula for path loss.

$\mathrm{Pr} = PtGtGr \left(\frac{\lambda}{4\pi R}\right)^2$ where Pr is the received power, Pt is the transmitted power, Gt and Gr are the antenna gains at the transmitter, and receiver, R is the distance between antennas and λ is the wavelength.

As a general rule of thumb, a 6 dB increase in link budget will double the range in an outdoor, line-of-sight environment. Thus, the achievable range in the 169 MHz band is better than the 868/915 MHz bands assuming all else is equal. As range tests are highly sensitive to the environment and device parameters, it is often tricky to achieve an accurate, apples-to-apples comparison between RF transceiver solutions from different vendors. Care should be taken to ensure that the radio parameters such as frequency, transmit power, bandwidth, packet structure, antenna, and the method of calculating Bit Error Rate (BER) or Packet Error Rate (PER) are all comparable. In an outdoor line-of-sight field test, EZRadioPRO devices have shown 8-10 miles (13-16 km) of range in both high-frequency bands and low-frequency bands using standard Gaussian frequency-shift keying (GFSK) modulation.

Table 1 shows a link budget for different data rates based on EZRadioPRO transceivers.

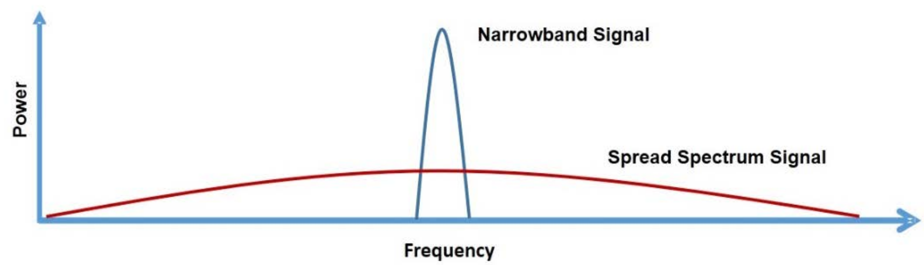
**Table 1. Wireless Link Budget**

| **Data Rate** | **Link Budget with +20 dBm Tx** |
|---|---|
| 500 kbps | 117 dB |
| 100 kbps | 126 dB |
| 9.6 kps | 136 dB |
| 100 bps | 153 db |

System range is a function of the receiver sensitivity as well as the transmission frequency. The sensitivity is inversely proportional to channel bandwidth, which means a narrower bandwidth results in higher receiver sensitivity. The channel bandwidth depends on three factors: data rate, deviation and crystal oscillator accuracy. For the application to efficiently transmit and receive, the channel bandwidth must be set just wide enough to account for these three factors. EZRadioPRO devices have fully programmable receiver bandwidths ranging from 200 Hz to 850 KHz, enabling ultra-narrowband data rates of 100 bps with -133 dBm sensitivity, which is ideal for long-range outdoor sensor applications. Some implementations use spread spectrum mechanisms instead of standard narrowband GFSK modulation. Spreading a low data rate signal requires a wider bandwidth and is spectrally inefficient but allows transmission with a lower power spectral density. The loss of sensitivity due to the increased bandwidth is compensated by coding gain where each data bit may be coded to multiple bits and sent over a wider bandwidth. This means that for the same net data rate, there is no direct sensitivity improvement compared to narrowband GFSK implementations.

Recovery of the desired data from the spread signal typically requires a longer preamble for synchronization, which increases the transmission time of the packet and further reduces battery life.

Narrowband systems provide excellent adjacent channel rejection in the range of 60 dB to 70 dB depending on the frequency band. Spread spectrum signals are less susceptible to interference. However, several narrowband signals in or around the same frequency as the wideband spread spectrum signal will reduce the range of the coded system significantly. One benefit of spreading systems is the ability to use a lower cost crystal instead of a higher priced temperature-compensated crystal oscillator (TCXO). GFSK-based narrowband systems typically require a TCXO to ensure frequency accuracy and extend range. While the cost difference between a standard crystal and a TCXO is shrinking, advanced transceivers such as the EZRadioPRO also provide mechanisms that support automatic frequency compensation (AFC) to minimize the impact of frequency offsets.




## Conclusion

Low power consumption and long range are key factors that determine the direction of a sub-GHz wireless system design. Fast signal detection, ultra-low power standby currents in the tens of nanoamps and faster state transition times combined with a robust software solution are critical building blocks that enable improved system-level efficiency for connected device applications. The IoT market is evolving quickly as a wide range of highly integrated, ultra-low-power semiconductor components become widely available at cost-effective price points. Ultra-low-power MCUs and wireless ICs with flexible architectures supporting multiple protocols will lead the way in enabling a smart, connected and energy-friendly IoT world.

Learn more about Silicon Labs' wireless solutions at [www.silabs.com/wireless](www.silabs.com/wireless)

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