Sub-1 GHz long-range communication and smartphone connection for IoT applications

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Introduction

In today's Internet of Things (IoT) world, there is a multitude of new wireless connectivity applications entering the market each day, propelling the continuous gathering of sensors and interactions. From our smartphone telling us how many steps we have taken to our security system telling us that no windows are left open, we have a safety net of reminders helping us effortlessly move throughout our day. This trend of gathering more information creates daily interactions with different wireless devices. Within one day a person will interface with over 100 connected things using multiple wireless protocols or standards. As of now, there is very little overlap as you connect from your home security system to your car to your office. The interface is a bit awkward as you switch from wireless bands and separate networks, so how do you encourage more interaction between these networks? What is often missing is the seamless interaction from 2.4 GHz to Sub-1 GHz.

Sub-1 GHz: Long-range and low-power RF connectivity

For a lot of wireless products, range is much more important than being able to send high throughput data. Take smart metering, for example, or a sensor device in an alarm system, or a temperature sensor in a home automation system. For these applications, the Sub-1 GHz industrial scientific and medical (ISM) bands (433/868/915 MHz) offer much better range than a solution using the 2.4-GHz band. The main reason for this is the physical property of the lower frequency. Given the same antenna performance, this theory (free space) calls for twice the range when using half the RF frequency. Another important factor is that the longer RF waves have an ability to pass through walls and bend around corners. The lower data rate will also play a part since the sensitivity for the receiver is a strong function of the data rate. As a rule of thumb, a reduction of the data rate by a factor of four will double the range (free space). Lastly, due to the low-duty cycle allowed in the Sub-1 GHz RF regulations, there are fewer issues with disturbances for low-data-rate solutions in the Sub-1 GHz bands than the 2.4-GHz band (mainly due to Wi-Fi®).

The lower frequency also helps to keep the current consumption low. In addition to offering higher battery life, the lower peak current consumption also enables a smaller form factor solution using coin cell batteries. However, getting the data from the Sub-1 GHz system into your smart device can be challenging, mostly due to the fact that smart devices do not typically include Sub-1 GHz communication systems for use with ISM band communication. For this reason *Bluetooth*® low energy is the de-facto standard to use, which is where a dual-band wireless microcontroller (MCU) can act as a bridge between the two communication bands. With the **SimpleLink™ dual-band CC1350 wireless MCU** combining Sub-1 GHz and Bluetooth low energy is now possible. The CC1350 device is able to transmit +10 dBm using only 15mA, which is perfectly okay to handle for a coin cell battery. Using low-data rates—it is possible to transmit over 20 km (line of sight from an elevated transmitter) with the RF receiver consumption being only 5.4 mA using a 3.6-V lithium battery.

Challenges with the Sub-1 GHz bands

It is easy to appreciate the range and low power using the Sub-1 GHz band, but naturally there are also some drawbacks. As described earlier, one of the main tools used in our daily life, the smartphone, does not use Sub-1 GHz. Or actually, it does, it is using the licensed bands (GPRS, 3G and LTE) to get the best range, but it is not using the Sub-1 GHz ISM bands. The fact that both Wi-Fi and Bluetooth are standard features of any smartphone available on the market today offers a clear advantage for those technologies. An obvious solution to this is to combine the best of two worlds—Sub-1 GHz technology for long range and low power and a 2.4-GHz solution using Bluetooth low energy for a smartphone/tablet/PC connection. The first RF IC publicly available on the market that can do this is the CC1350 wireless MCU from Texas Instruments (TI). The CC1350 device is a single-chip solution that includes a high-efficiency ARM® Cortex®-M3 MCU, a low-power sensor controller and a low-power dual-band RF transceiver.

SimpleLink dual-band CC1350 wireless MCU

The CC1350 wireless MCU (see the block diagram below in Figure 1) is a true single-chip solution offering ultra-small PCB footprint solutions, down to 4×4 mm (QFN). If more IOs are required, it is also offered in a 7×7 mm package (QFN) with 30 IOs.

The ARM Cortex-M3 application processor has 128 kB Flash, 20 kB ultra-low power SRAM in addition to 8 kB SRAM that is used for cache (can also be allocated as regular SRAM). The RF core contains an RF front-end capable of supporting the most relevant Sub-1 GHz bands (315, 433, 470, 868, 915 MHz) as well as 2.4 GHz. The radio core includes a very flexible software-configurable modem to cover data rates from a few hundred bits per second up to 4 Mbps and multiple modulation formats from "simple" OOK (on–off keying), to (G)FSK, (G)MSK, 4-(G)FSK and shaped 8-FSK. The main advantage with a very flexible radio core is to handle the wealth of existing legacy Sub-1 GHz solutions in the market today and also to support modifications to existing standards. One good example for this is that the CC1350 wireless MCU is able to handle, with only firmware upgrades, the new long-range mode, as well as the new high-speed mode that was announced by the Bluetooth SIG in June 2016 (Bluetooth 5.0).

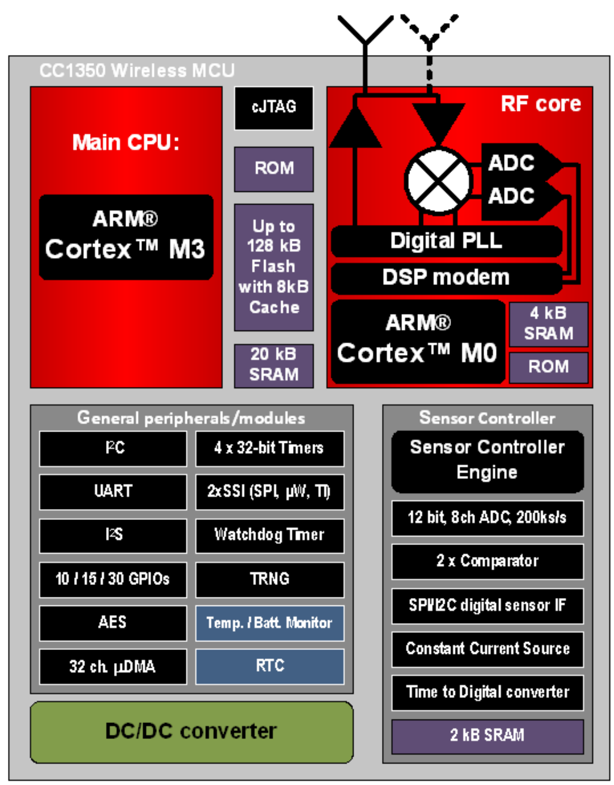


Figure 1: CC1350 wireless MCU block diagram.

The ARM Cortex-M0 in the RF core is running pre-programmed ROM functions to support both low-level Bluetooth and proprietary RF solutions. This greatly offloads time critical tasks from the main ARM Cortex-M3 application processor.

The power system tightly integrates a digital converter to digital converter (DC/DC) solution that is active in all modes of operation, including standby. This ensures low-power operation, as well as stable performance (RF range) despite drop in battery voltage.

Lowest Power Sub-1 GHz

- 5.4 mA Radio RX current
- 13.4 mA Radio TX @ +10 dBm
- 24.4 mA Radio TX @ +14 dBm
- 51 µA/MHz ARM Cortex-M3 @ 48 MHz
- 0.7 µA sleep current with RTC + retention

Sub-1GHz

Up to 20-year battery life for sensor nodes

Low Power BLE

- 6.4 mA Radio RX consumption
- 10.5 mA Radio TX @ +0 dBm

Bluetooth®

Enabling ULP smart phone connection

ROM in CC1350 wireless MCU

The SimpleLink CC1350 device contains over 200kB of ROM (Read Only Memory) with libraries covering the following functions:

- TI-RTOS (real time operating system)
- Low-lever driver library (SPI, UART, etc.)
- Security functions
- Low level and some higher level, Bluetooth stack functions

Note that ROM code can be fixed/patched by functions in Flash or RAM.

Ultra-low current consumption

The SimpleLink CC1350 and CC1310 (Sub-1 GHz only) wireless MCUs offer ultra-low current consumption in all modes of the operation both for the RF as well as the microcontroller.

The sensor controller

The sensor controller is a native, small power-optimized 16-bit MCU that is included in the CC13xx devices to handle analog and digital sensors in a very low-power manner. It is programmed/configured using the Sensor Controller Studio where users find predefined functions for the different peripherals. The tool also offers software examples of common sensor solutions like ADC reading (streaming, logging window compare functions) and I^2C/SPI for digital sensors. The sensor controller can also be used for capacitive touch buttons. Sensor Controller Studio can be downloaded from this **link**. See Figure 2 on the following page.

Software offering and ease of use

With the Bluetooth low energy CC2540 wireless MCU, TI offered one of the first certified **Bluetooth low energy software stacks**. The stack has since been developed further to support the SimpleLink CC26xx platform that was released in 2015. This stack is now also available for the CC1350 device and has all the features that the Bluetooth 4.2

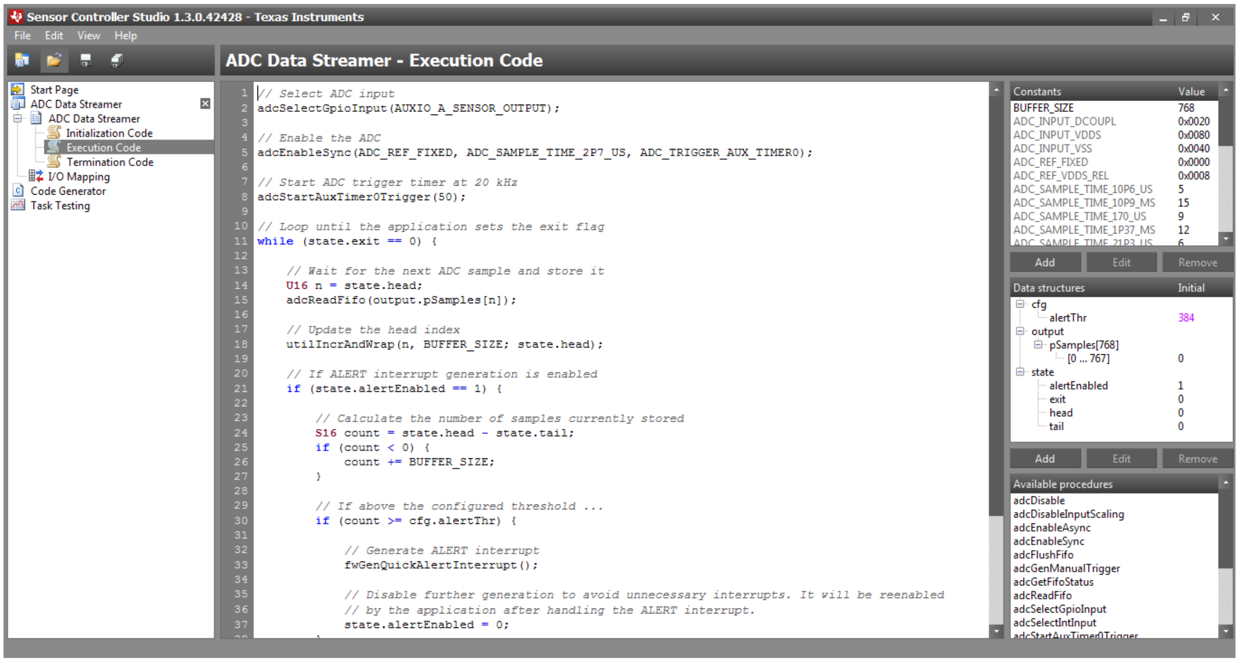


Figure 2: TI sensor controller studio

standard offers—from "simple" beacons to a fully connectable stack. All TI RF stacks are using **TI-RTOS**, a free real-time operating system from TI. TI-RTOS is distributed under the 3-Clause BSD license, meaning that full source code is provided. To further reduce the complexity of developing applications and let customers solely focus on their application development, TI provides a large set of peripheral drivers, including a performance-optimized RF driver. The TI-RTOS for CC13xx and CC26xx software development kits (SDK) offers a large set of getting started examples. The RF examples serve as a great starting point for developing proprietary systems, all software examples are provided with the purpose of showing a performance-optimized usage of the various drivers. For new product development, without the need to adhere to legacy products, a great solution is to use the new **TI 15.4-Stack** offering. TI 15.4-Stack is TI's implementation of the IEEE 802.15.4g/e standards, enabling star-type networks. It is offered (free of charge) in two versions:

1. Version optimized for European RF regulations (ETSI)—using frequency agility and LBT (Listen before talk)
2. Version optimized for US RF regulations (FCC)—using frequency hopping to enable highest output power

Sub-1 GHz and Bluetooth low energy use cases

The fact that the CC1350 wireless MCU enables both Sub-1 GHz and Bluetooth low energy in a single device opens up a lot of possibilities. Here are a few of them:

1. Installation/commissioning, maintenance and diagnostic of a Sub-1 GHz network

During installation/commissioning, the long-range capabilities of Sub-1 GHz can be a drawback. During installation, you want only your selection of devices in the network to be connected together—not nodes from e.g., the neighbor that might have the same product installed. Using a smartphone with shorter range (and also much higher data rate) using a Bluetooth connection and with a large display will make installing devices a lot easier. With the Internet-connected smartphone, it would also be easier to download new software for the node as well as collecting diagnostic information. Such a solution can be made to do it yourself as well as professionally installed products. Examples:

- Let's say you buy a two pack of pre-commissioned smoke detectors that are connected together with a Sub-1 GHz network, but then you find out that you need another device that you want to add to your network.
- Another example would be consumer or professional installation of intruder alarm systems or home automation.

Commissioning

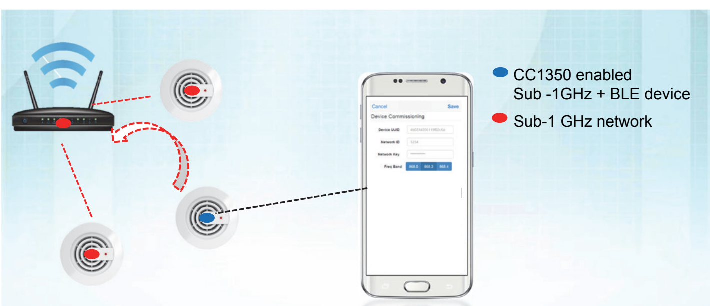


Figure 3: Bluetooth software: Fully connectable stack Sub-1 GHz software: TI 15.4-Stack or a legacy Sub-1 GHz solution.

2. Firmware updates

In order to ensure best performance over the complete lifetime of a connected product, it is critical to be able to offer over-the-air (OTA) firmware updates. Updating the firmware can also add new features to devices already deployed in the field.

Taking advantage of the higher data rates that Bluetooth low energy offers, firmware updates can be made much faster. A system can consist of devices that can be firmware updated both via the Sub-1 GHz link and the Bluetooth low energy link, offering great flexibility for the user. One example of when using Bluetooth low energy for OTA firmware updates can be the following scenario; a device gets a command via the Sub-1 GHz interface to switch to Bluetooth low energy mode, the user then connects to the device using Bluetooth low energy, once connected a new firmware image is transferred via the Bluetooth link. The device then restarts with the new firmware image loaded.

Firmware update

Figure 4: Bluetooth software: Fully connectable stack Sub-1 GHz software: TI 15.4-Stack or a legacy Sub-1 GHz solution.

3. Using the smartphone as a remote display

Making end products that are easy to use is essential for both consumer and professional products. Nice color displays are both expensive to use, develop, often mechanically weak and they increase the current consumption for the product. In many cases, the interface can be reduced greatly if a smartphone can be used as the display or alternatively an existing product can get enhanced features. Example: A wireless smoke detector that can use a smartphone to display battery status or the time since the last alarm sounded. Basically any sensor network that has data to display can benefit from using a smartphone as a remote display instead of a standard LCD.

Remote display

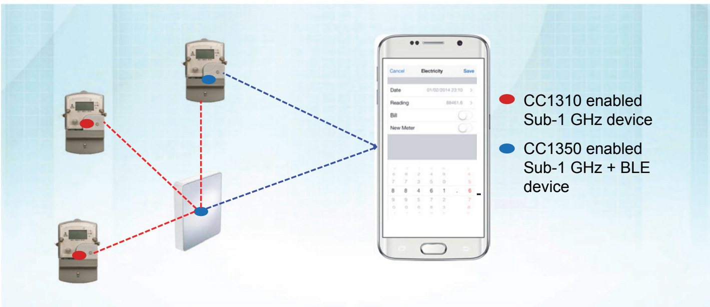


Figure 5: Bluetooth software: Beacons, no Bluetooth low energy stack needed
Sub-1 GHz software: TI 15.4-Stack or a legacy Sub-1 GHz solution.

4. Managing Bluetooth low energy beacon payloads

One major benefit with using Sub-1 GHz is the longer range using the same output power. When updating a large set of Bluetooth low energy beacons with new payload information, having to physically approach each and every beacon might not be a manageable task. In this case, the Sub-1 GHz link can be used to connect to the beacon and give it new Bluetooth low energy payload information. This section describes a few use cases.

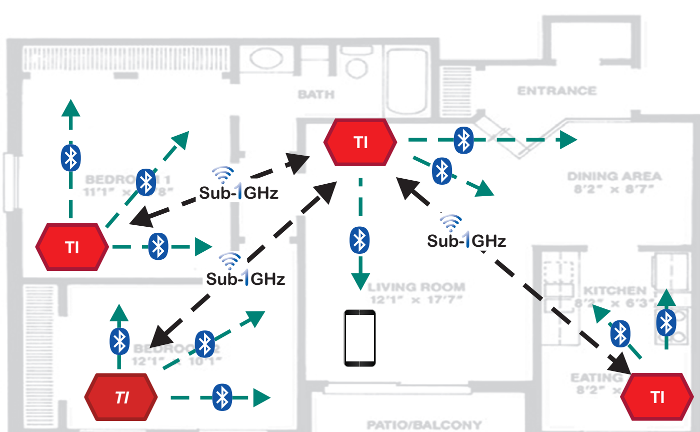


Figure 6: Bluetooth software: Beacons, no stack needed
Sub-1 GHz software: TI 15.4-Stack or a legacy Sub-1 GHz solution.

Google Physical Web

In the Google Physical Web concept, beacons are used to transmit a simple URL that is easily opened in a standard web browser. The advantage of this is the ease of use – no special app is needed, one just needs to create a web page that the Bluetooth beacon is pointing to. The Sub-1 GHz link is used to manage the beacon, which basically is used to change the web link.

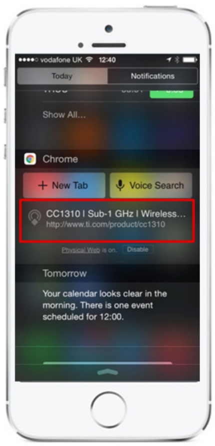
Google Physical Web is using the open source **Eddystone** specification for the Bluetooth low energy beacon frame format. A few different frame formats are specified:

1. URL, broadcast a standard URL
2. TLM, Type Length Message used to broadcast sensor data like battery level, time since reboot, etc.
3. UDI, Unique Device Identifier, used for proximity use cases.

Examples: A movie theater that announces the next movie using a Bluetooth beacon in multiple places around the movie theater. The Sub-1 GHz link is used to update the “digital posters” every time there is a new movie showing.

Proprietary beacons

When there is no need to be interoperable with other applications, you might consider implementing your own Bluetooth low energy beacon frame format. One example is the TI SimpleLink SensorTag kit application, where a proprietary frame format is used to interact with devices from the smartphone application.



Getting started

The out-of-the-box software for the CC1350 wireless MCU demonstrates many of the use cases described in this paper. The software can be found at this **link**.

The **SimpleLink dual-band CC1350 wireless MCU LaunchPad™ development kit** is pre-programmed with the TI BLE-Stack, allowing you to connect to the device using the SensorTag iOS/Android smartphone app. When connected, the CC1350 device offers the same functionality as the SimpleLink multi-standard CC2650 LaunchPad kit. Using the built-in Bluetooth low energy OTA download, one can easily convert the CC1350 device from a Bluetooth low energy device into a Sub-1 GHz device, due to the dual-mode capabilities. The step-by-step guide on the above link will show you how to download new application images to create a small wireless sensor network. The sensor network includes a concentrator that receives Sub-1 GHz data and nodes that send data over the Sub-1 GHz link to the concentrator and in addition reconfigures the radio core on the fly to send out Bluetooth low energy advertisement packets.

Additional resources:

- Development kits:
  - Dual-band CC1350 LaunchPad development kit (**LAUNCHXL-CC1350**)
  - CC1350 SensorTag demo kit (**CC1350STK**)
  - CC1310 LaunchPad kit (Sub-1 GHz only) (**LANUCHXL-CC1310**)
- Software:
  - **TI BLE-Stack** software development kit
  - **TI-RTOS for CC13xx/CC26xx software examples**
  - **TI 15.4-Stack** software development kit
  - **SmartRF™ Studio**
  - **SmartRF Flash Programmer**
- Support
  - **TI E2E™ community forums**

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