

TI Designs: Reference Designs

Sub-1 GHz Connected Home Network Design Guide



TI Designs

TI Designs provide the foundation that you need including methodology, testing, and design files to quickly evaluate and customize the system. TI Designs help you accelerate your time to market.

Design Resources

TIDC-CHN	Tool Folder Containing Design Files
CC1120	Product Folder
MSP430FR5739	Product Folder
CC430	Product Folder



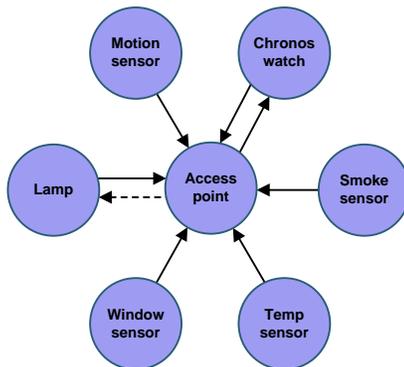
[ASK Our E2E Experts](#)
[WEBENCH® Calculator Tools](#)

Design Features

- Supports the Star Topology Wireless Network
- Runs on Low Power
- Offers a Low-Memory Footprint
- Offers a Flexible RF Setup
- Based on SimpliciTI™ Software
- Offers the Complete Source Code

Featured Applications

- Alarm and Security Networks
- Smoke Detectors
- PIR Sensors
- Window and Door Sensors



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1 Key System Specifications

Table 1. 1 Key System Specifications

PARAMETER	SPECIFICATIONS	COMMENTS
Symbol Rate	50 kbps	Configurable
Frequency Band	868 MHz	Configurable to other frequency bands. See Section 4.9 .
Modulation	GFSK	
Network topology	Full-house coverage, star network based on SimpliciTI	
Flash and RAM requirements	10kB Flash, 0.5kB RAM	
Battery life	Up to 20 years	Based on measurements in Section 8 .

2 System Description

The TI Design for the connected home network shows how to create a Sub-1 GHz star network with full-house coverage for security and sensor applications (see *Achieving Optimum Radio Range* ([SWRA479](#))). This TI Design is a pure software design using standard TI development boards from TI's Sub-1 GHz wireless connectivity portfolio. To learn more about TI's 169 MHz, 315 MHz, 433 MHz, 470 MHz, 868 MHz, 915 MHz, and 920 MHz solutions, see our [Sub-1 GHz page](#). In this network, the central device is typically powered directly while the other devices are battery powered.

2.1 CC1120 Device

The CC1120 device is a fully integrated single-chip radio transceiver designed for high performance at very low-power and low-voltage operation. All filters are integrated, rendering expensive external SAW and IF filters unnecessary. The device is intended for the industrial, scientific, and medical (ISM) usage and short-range device (SRD) frequency bands at 164 to 192 MHz, 274 to 320 MHz, 410 to 480 MHz, and 820 to 960 MHz.

The CC1120 device provides extensive hardware support for packet handling, data buffering, burst transmissions, clear channel assessment, link quality indication, and Wake-On-Radio. The CC1120 device is controlled through an SPI interface. The CC1120 device is typically used with a microcontroller and a few external passive components.

2.2 MSP430FR5739 Microcontroller Configuration

The MSP430F543xA and MSP430F541xA series are microcontroller configurations with the following:

- Three 16-bit timers
- A high-performance 12-bit analog-to-digital converter (ADC)
- Up to four universal serial communication interfaces (USCIs)
- A hardware multiplier
- DMA
- A real-time clock module with alarm capabilities
- Up to 87 I/O pins

2.3 CC430F6137 Microcontroller Configuration

The CC430F61xx series are microcontroller SoC configurations that combine the excellent performance of the CC1101 sub-1-GHz RF transceiver with the following:

- The MSP430™ CPUXV2
- Up to 32 KB of in-system programmable flash memory
- Up to 4 KB of RAM
- Two 16-bit timers
- A high-performance 12-bit analog-to-digital converter (ADC) with eight external inputs plus internal temperature and battery sensors on CC430F613x devices
- A comparator
- Universal serial communication interfaces (USCIs)
- A 128-bit AES security accelerator
- A hardware multiplier
- DMA
- A real-time clock (RTC) module with alarm capabilities
- An LCD driver
- Up to 44 I/O pins

For more information on each of these devices, see the product folders at www.TI.com.

3 Block Diagram

This explains the TI Design for the sub-1 Ghz connected home network. The following sections provide an overview of the network structure, how to send messages in the network, and how to use the interface. The network is simple star type, where an access point acts as a SimpliciTI data hub. The devices send and receive messages to and from the access point only. These messages are either broadcasted or unicast. For an illustration of the network structure, see [Figure 1](#). In this illustration, unicast messages are solid arrows and broadcast messages are dashed arrows in [Figure 1](#).

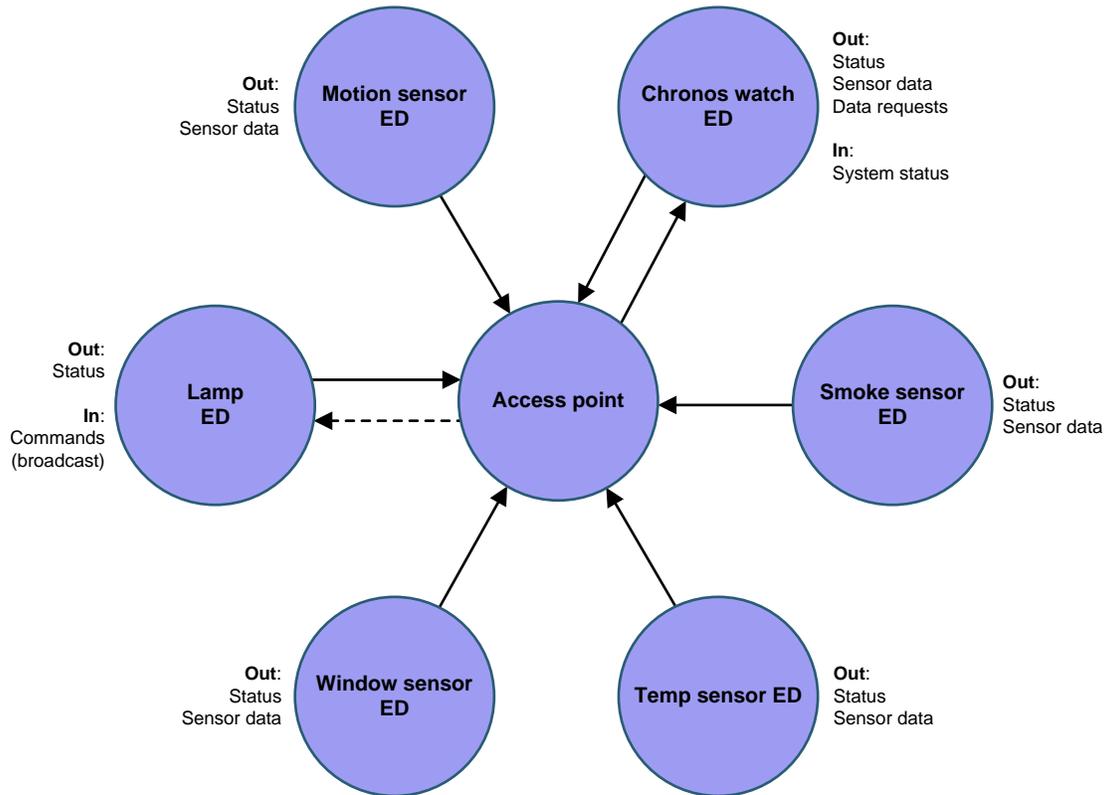


Figure 1. Network Topology

TI intends the access point (AP) to be turned off when in disuse and turned on when using the application.

If your device is turned off and the connection data has been saved to flash in the access point, do the following:

1. Turn on the device
2. Press the left or right button from the title screen
3. Use the application

TI intends devices, except for the LED lamp, to have sufficient battery life and always be on.

If a device runs out of power, do the following:

1. Replace its batteries
2. Reenter the device into the network

All devices send data to the access point or poll data periodically. If no data is available for a longer period of time, the device increases the time interval of transmissions to save battery life.

4 System Design Theory

4.1 Message Format and Types

The system has two message formats: unicast messages and broadcast messages.

4.1.1 Unicast Messages

Unicast messages are sent either from devices to access point or from access point to devices. The payload of the unicast messages is a four byte frame sent as unsigned integers. For an example of the unicast message frame, see [Figure 2](#).

Device Type	Message Type	Message	Packet Number
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Figure 2. Unicast Message Frame

The frame is split into three types:

- Device type
- Message type
- Predefined message (or a sensor value)

Sensor values are detected and parsed depending on device and data type.

The device type indicates what kind of device sent the message. Types of devices include the following:

- Access Point
- Motion Sensor
- Alarm Motion Sensor
- Temperature Sensor
- Door Sensor
- LED Lamp
- Chronos Watch

Message types indicate what kind of message is sent. Message types include the following:

- Event
- Data
- Command
- Status

The predefined messages include the following:

- Motion/No Motion
- Open/Closed
- Smoke/No Smoke
- Arm/Disarm Alarm
- Alarm Toggle
- Data Request
- Status OK

4.1.2 Broadcast Messages

The broadcast frame is similar to the unicast messages but exclude the device type. For the broadcast message frame, see [Figure 3](#).

The predefined broadcast commands include the following:

- Commands
- Alarm off (alarm disarmed)
- Alarm on (alarm triggered)
- Light on

Device Type	Message	Packet
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Figure 3. Broadcast Message Frame

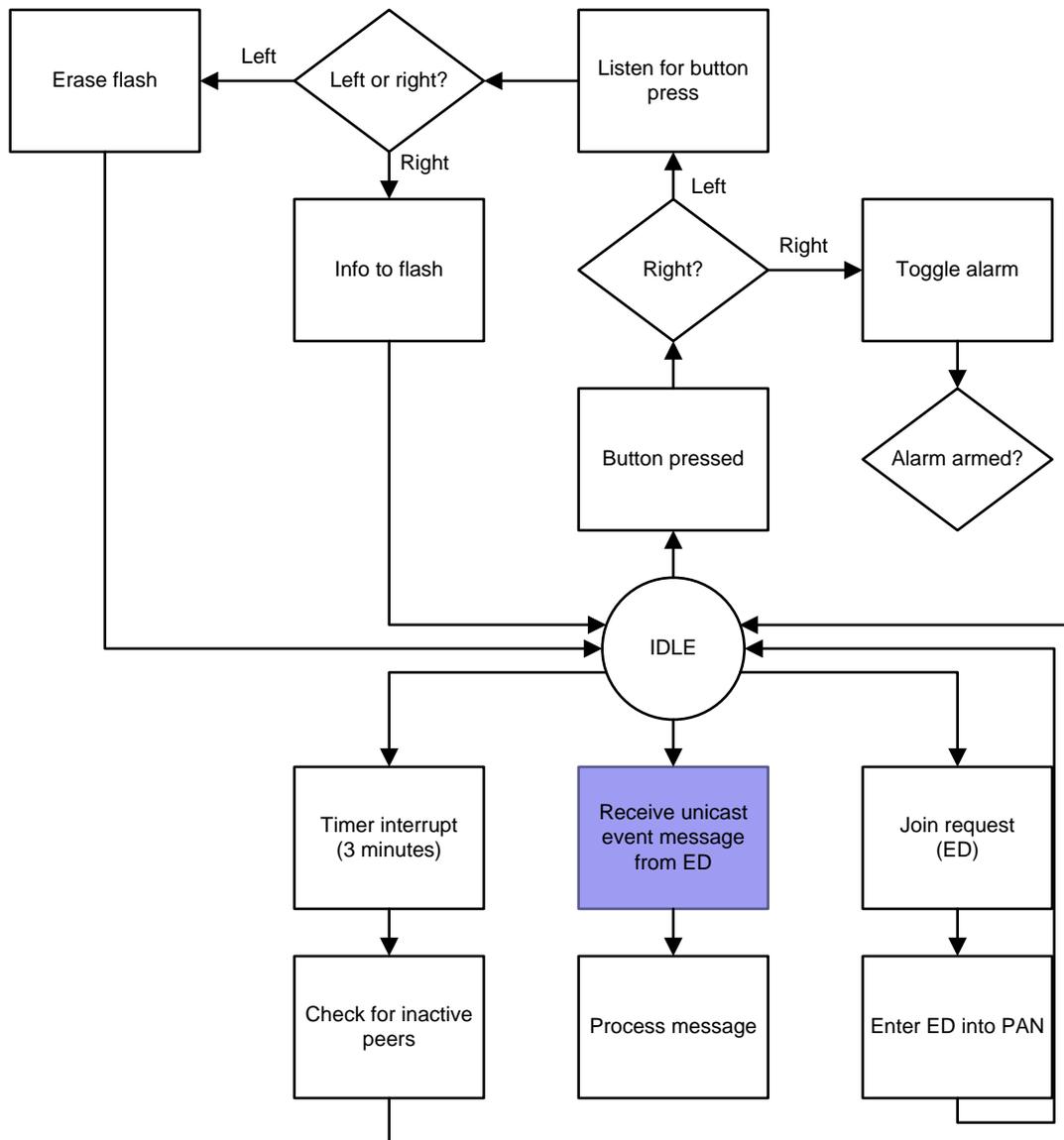
NOTE: Only the LED lamp receives broadcast command messages but many other devices such as sirens, sprinkler systems, and so forth can be added without modification.

Broadcast messages are repeated five times for each transmission.

4.2 Device Description

4.2.1 Access Point (AP)

The access point is a SimpliciTI data hub and contains most of the logic of the network. When on, the access point loads previously-saved linked devices from flash. The access point listens continuously receives devices trying to connect to the network and messages from connected devices. The access point receives messages from devices and acts according to state of alarm and content of the message. To use access point in demo applications, ensure that you save your link data to flash. For a flowchart illustrating the processes of the access point, see [Figure 4](#).



Message processing has been split up into one flowchart for each type of message.

The process that checks for inactive peers checks if a device sent status messages in the last two minutes. If not, access point sets device status on LCD to inactive.

Figure 4. Access Point Flowchart

4.2.2 Event Messages

For a flowchart regarding how access point handles incoming event messages from devices, see [Figure 5](#). The process message node refers to [Figure 4](#).

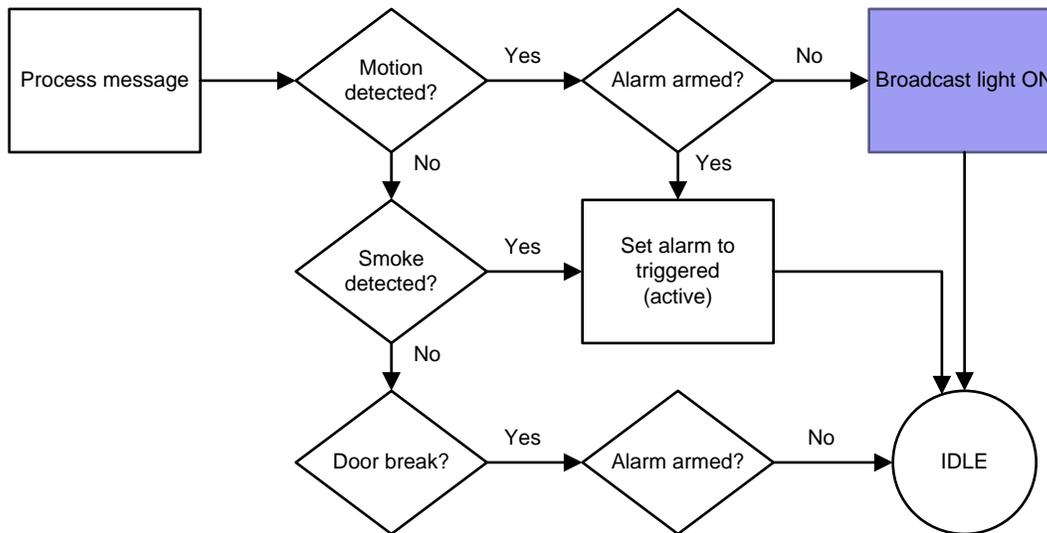


Figure 5. The Process for Event Messages in Access Point

4.2.3 Command Messages

For a flowchart regarding how access point handles incoming command messages from devices, see [Figure 6](#). The process message and alarm armed? nodes refer to [Figure 4](#).

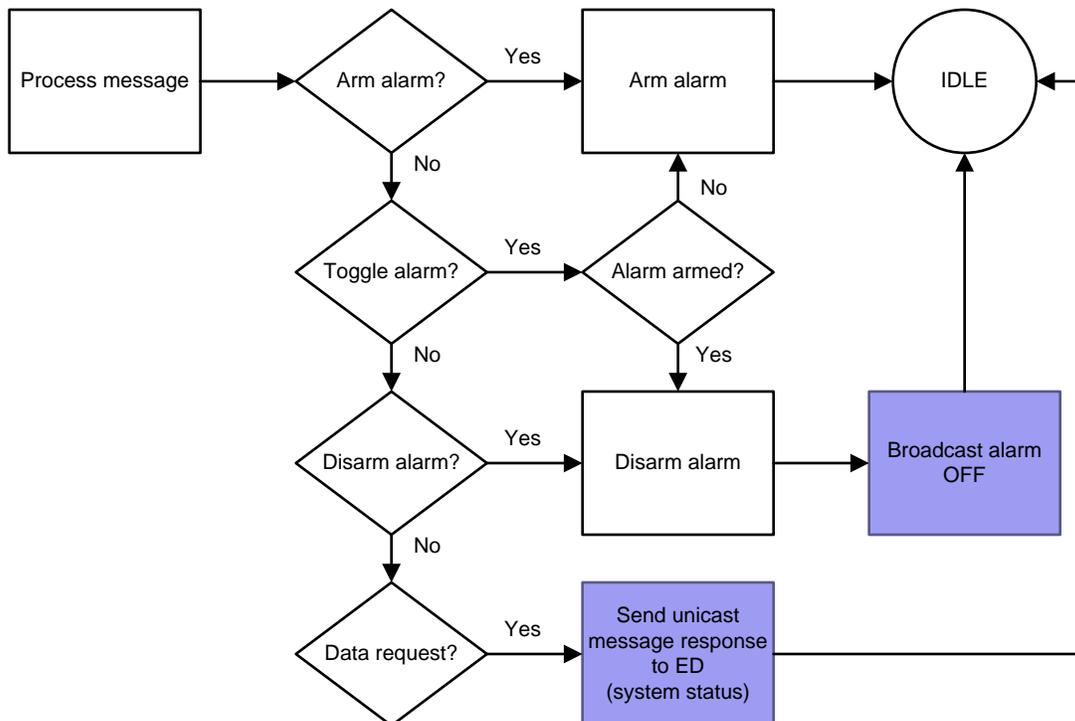


Figure 6. The Process for Command Messages in Access Point

4.2.4 Status Messages

Status messages indicate to access point if a device is active or inactive. All devices send status messages every two minutes. If the access point has not received a status message for a timeout period, the access point considers the device inactive and denotes the inactivity in the GUI. Each device linked to the access point has an activity timer. If the timer counts two minutes, the device becomes inactive. Each time the access point receives a status message, it clears the timer for that device. For a flowchart regarding how access point handles the incoming status messages from devices, see [Figure 7](#).



Figure 7. The Process for Status Messages in Access Point

4.2.5 Data Messages

Data messages contain only temperature data and print to the LCD instead of being buffered or saved. TI intends data messages to be parsed. This process depends on the type of device and type of data received. For a flowchart regarding how the access point handles incoming data messages from devices (for example, the temperature sensor), see [Figure 8](#).

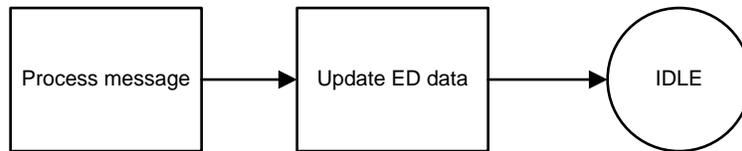


Figure 8. The Data Message Process in Access Point

4.3 Temperature Sensor

The temperature sensor operates in sleep mode after starting up (in both the radio and CPU) and wakes periodically to send status and temperature data unicasts to the access point. If using the TrxEB evaluation board, press the left button to cause a port interrupt to wake up the temperature sensor.

The device uses the built-in temperature sensor in the radio (CC112x or CC12xx) that requires one-point calibration. Set the calibration value defined in *c112x temp read.c*. The temperature value is accurate only in proximity to the temperature used for calibration. The sensor sends data as an unsigned integer causing only positive Celsius temperatures to give a correct value on the system GUI. For an illustration of operating of the temperature sensor, see [Figure 9](#).

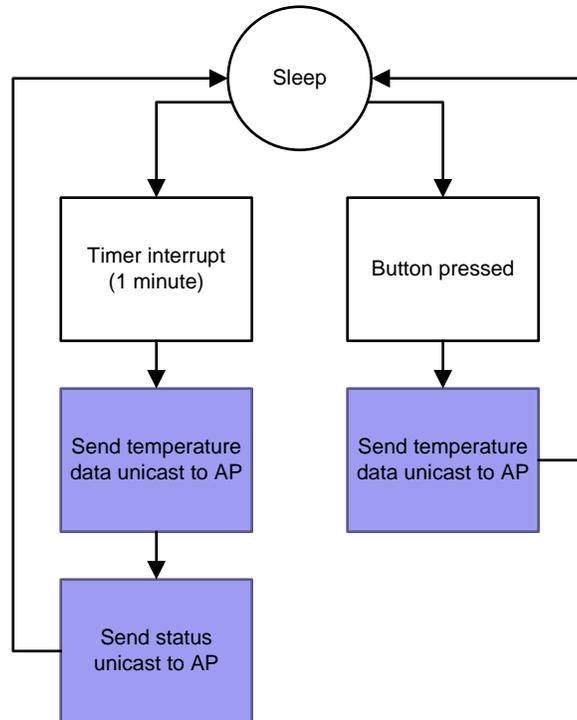


Figure 9. Temperature Sensor Operation

4.4 PIR (Motion) Sensor

The PIR sensor operates in sleep mode after starting up and wakes periodically to send its status. If an interrupt triggers from pressing the left button on either the TrxEB or from the PIR sensor, the device wakes up. After receiving an interrupt, the device sends an event unicast to the access point with the motion-detection information. The button pin that caused the device to wake up is sampled every second. When the button is released, the device sends an event unicast to the access point with the no-motion event information.

The PIR sensor usually sends multiple interrupts during one-motion detection. The PIR sensor connects from the SPI header pin 3 to pin P2.4 on the TrxEB and from pin P2.0 on the MSP-EXP430FR5739. On the PIR sensor, the pin 1 on the SPI header must be grounded on the device. For a flowchart that illustrates how the PIR sensor operates, see [Figure 10](#).

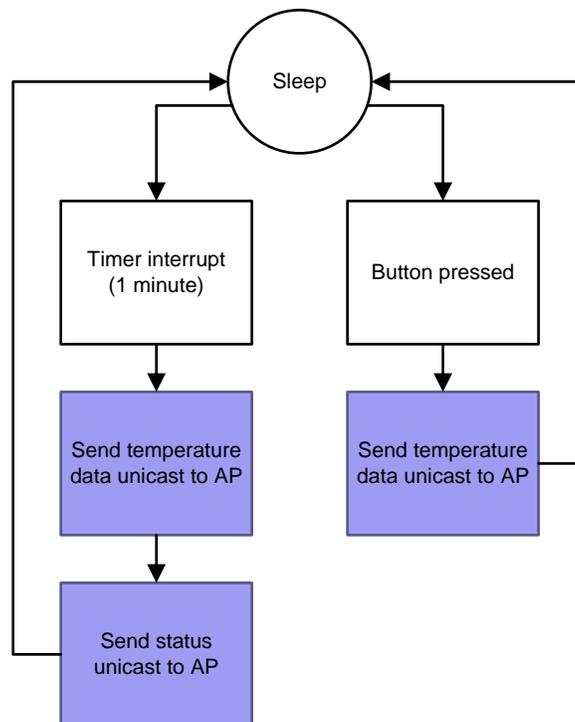


Figure 10. PIR Sensor Operation

A coin-cell battery or the external JTAG header can power the PIR sensor. TI recommends powering the sensor directly to avoid errors caused by low battery power. The sensor causes this device to consume more power than other devices (except for the LED actuator).

4.5 Smoke Sensor

The smoke sensor operates in sleep mode after starting up and wakes every minute and sends a status unicast to the access point. If you press the left button, an interrupt wakes the device. This interrupt sends a event unicast indicating that smoke is detected to the access point. When the device registers as released, the button pin is sampled each second. The device registers the sample when smoke is no longer detected and a sends a unicast event message of no smoke indicated to the access point. For an illustration of how the smoke sensor operates, see [Figure 11](#).

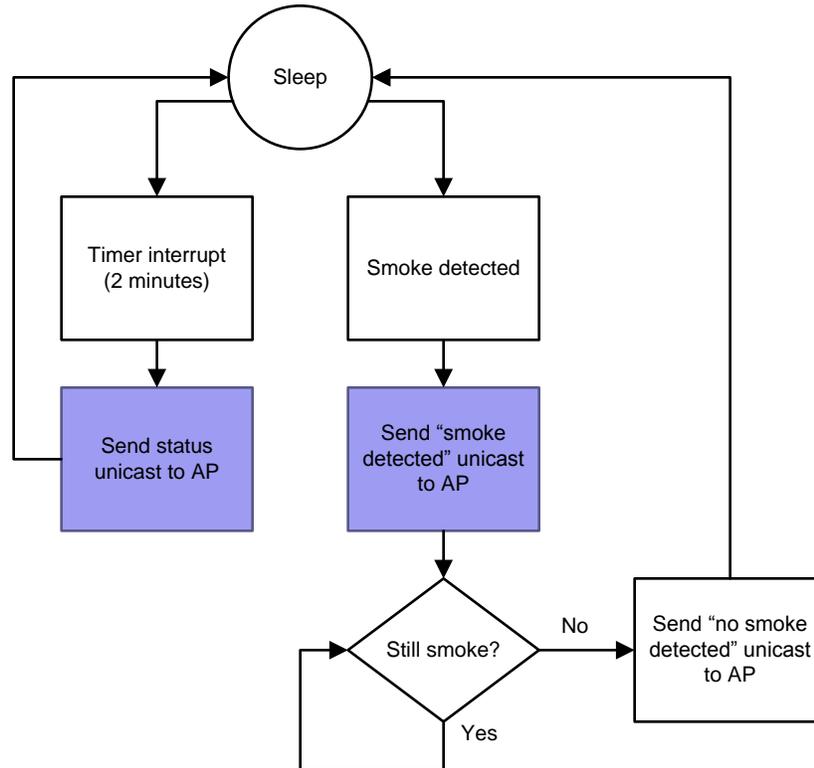


Figure 11. Smoke Sensor Operation

4.6 Door and Window Sensor

The door and window sensor is similar to the smoke sensor. The door emulates door breakage with the left button like the smoke sensor emulates smoke detection. The door and window sensor can send the alarm toggle command unicast to the access point by pressing the right button. For an example of how the door and window sensor operates, see [Figure 12](#).

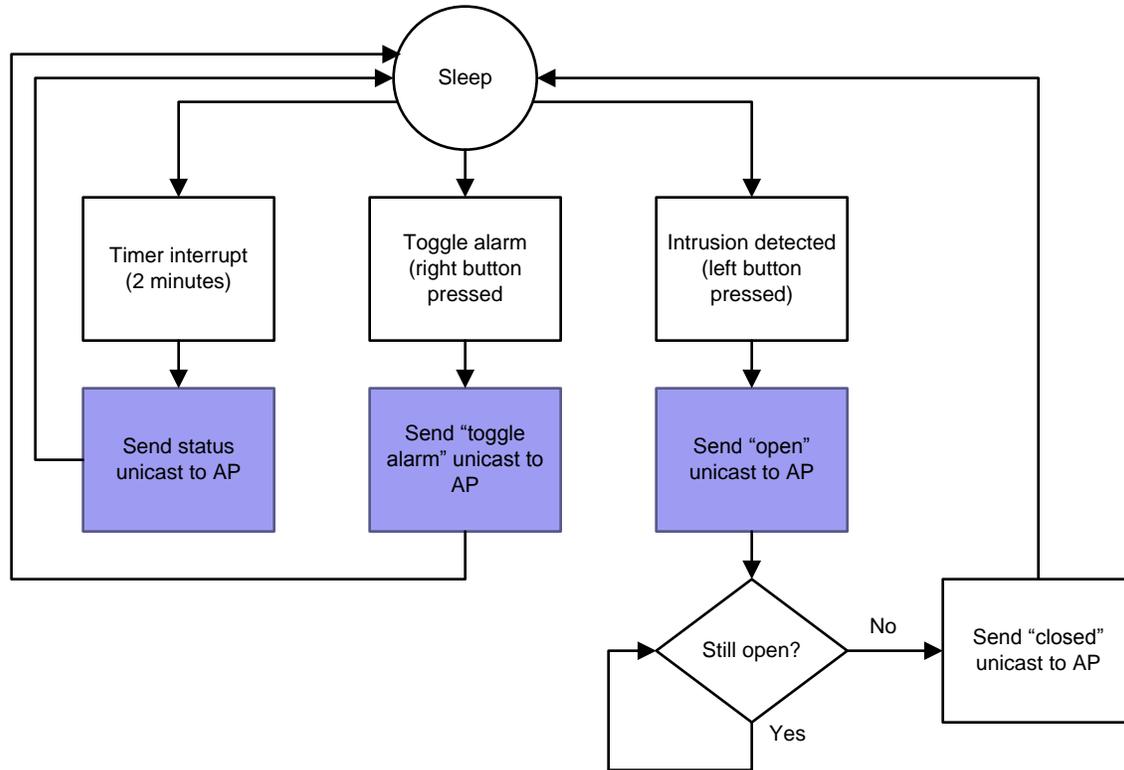


Figure 12. Door and Window Sensor Operation

4.7 LED Lamp Actuator

After starting up the LED lamp actuator, the MCU is always on and the radio is always in RX. If the LED lamp actuator detects a message, it checks if the message was broadcasted. If the message was broadcasted, it reads the message and follows the process in the flowchart in Figure 13. The LED lamp actuator sends status unicasts to the access point every minute.

You can connect an additional RGB, LED, or LED strip. When you connect a strip, P10.1 is red, P10.3 is green, and P10.5 is blue. Red and green are available. The LED lamp actuator can receive three different commands: alarm off, alarm on, and light on. Alarm on indicates that an alarm has been triggered. When the alarm has been triggered, the LED lamp actuator will start flashing its light and RGB LED light if connected. If the command is alarm off, actuator disarms the alarm and stops flashing its light. If the RGB LED light is connected, it will turn green for a few seconds before turning off. The light on command will turn the light on for five seconds. You must use the buttons on the actuator to continue from the title screen.

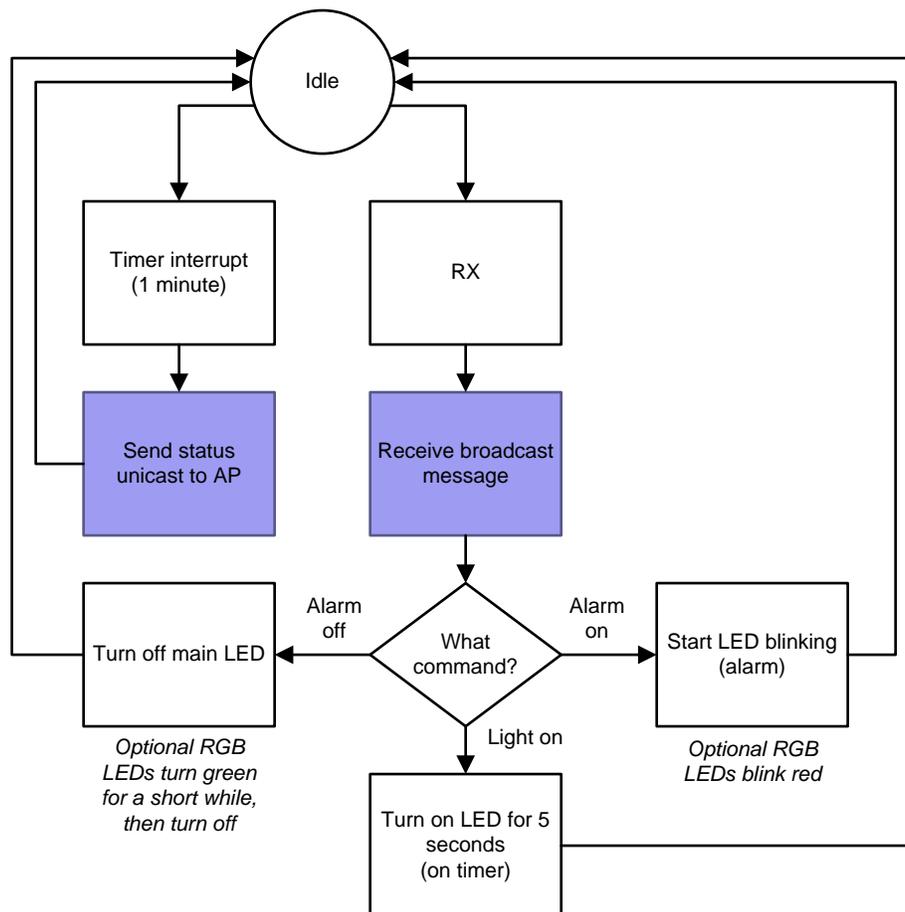


Figure 13. LED Lamp Actuator Operation

If the device is turned off, it will reenter the network after starting up (continue from title screen) if an access point is present. The LED lamp actuator consumes more power than other devices and TI recommends powering it directly.

4.8 Chronos Watch

After starting up, the Chronos watch operates in sleep mode. Interrupts wake the watch each second to increase the clock counter. The Chronos watch polls data from the access point every two seconds to get the alarm status.

By using the three buttons on the right, the Chronos watch can emulate the three alarm types, the arm, and disarm commands. The watch tries to relink five times. If unsuccessful, the device will no longer link to any access point or device. To reenter the network, reenter relink mode. After a successful relink, the watch will display a heart.

If the watch is unable to poll data for five consecutive polls, the device increases the poll interval to one minute to save battery life and clears the bottom line on the display. If the watch is unable to poll data, the device might be out of the range of the access point or the access point might be off. When in range of an active access point, the watch will poll data, update its display, and change the polling interval to each two seconds.

An example of the process of button events for the Chronos watch, see [Figure 14](#). For an example of the process of timer events in the Chronos watch, see [Figure 15](#).

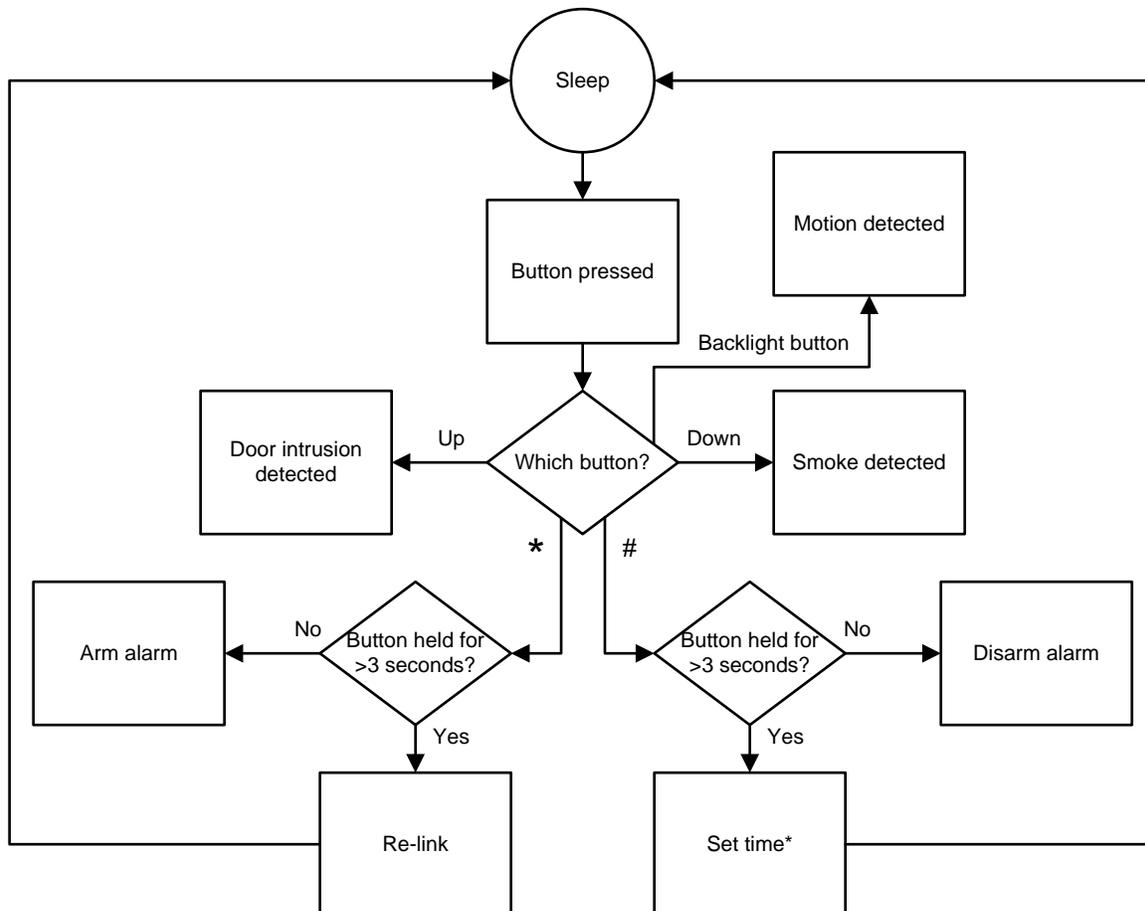


Figure 14. The Process of Button Events in the Chronos Watch

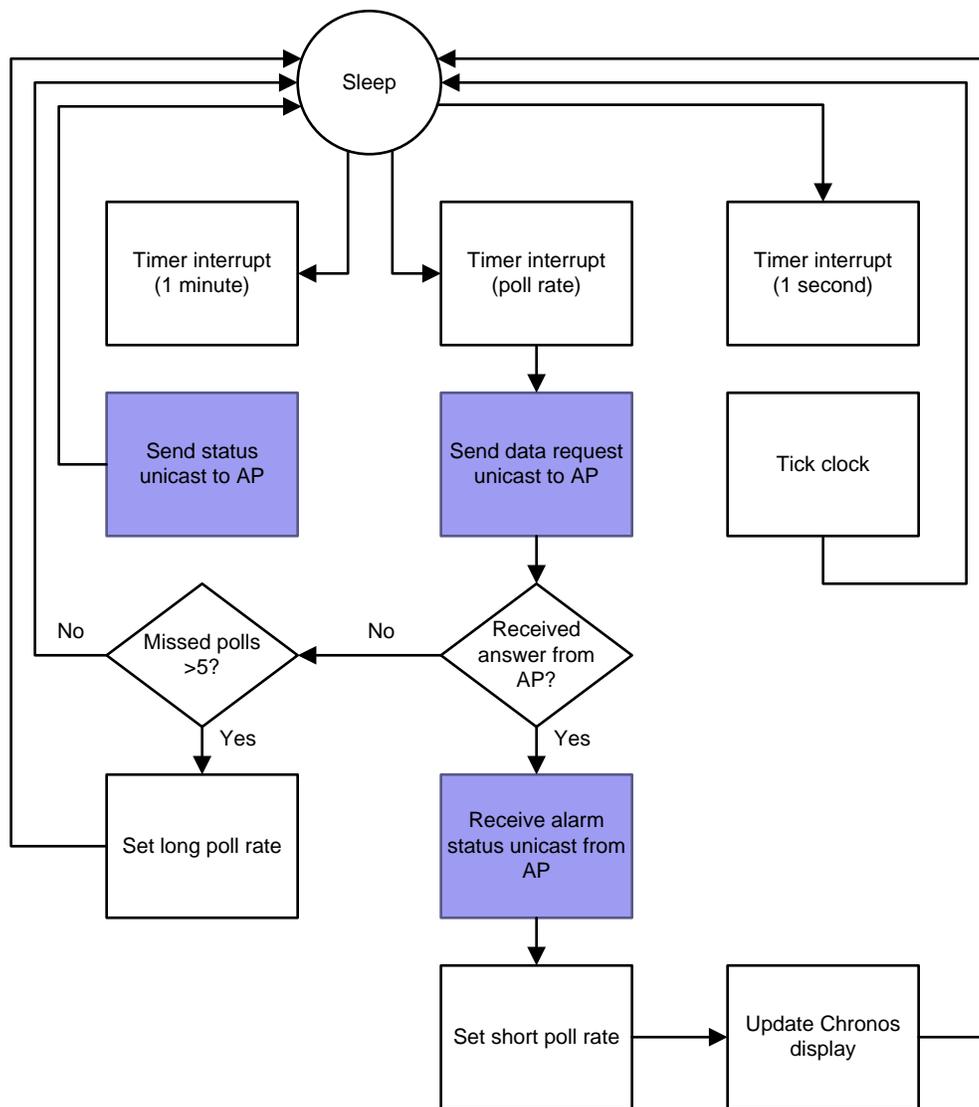


Figure 15. Process of Timer Events in the Chronos Watch

NOTE: A variant of the Chronos project in the TI Design software exists that TI intends to be used as a monitor instead of a watch.

That device shows a static message on the top row of the display instead of the time.

4.9 Physical Layer Configuration

This TI Design uses the physical layer and radio configuration. For the information regarding the settings of the physical layer and radio configurations, see [Table 2](#). These settings are the same as those in the EasyMode software in *TI LPRF EASYMODE* ([SWRA472](#)).

Table 2. Physical Layer and Radio Configuration

Modulation format	2-GFSK
Deviation	25 kHz
Bit rate	50 kbit/s
RX filter bandwidth	100 kHz
Center frequency	868 MHz
TX output power	15 dBm
Sync Word	0x55557A0E

The physical layer and radio configuration can be changed by using SmartRF™ Studio 7 to complete the following steps:

1. Start SmartRF Studio 7.
2. Choose CC1120.
3. Select either the Packet TX or Packet RX tab.
4. Set the physical parameters.
5. Press Register Export.
6. Under Templates, select SimpliciTI Settings.
7. Under Template View/Edit, check the Parameter summary.
8. Under registers, press Select.
9. Press >>> to add all registers to the export.
10. Press Ok.
11. Press Export to file.
12. Navigate to the project root .
13. Navigate to *Components\mrfi\smartrf\CC1120*.
14. To save the old configuration, rename the *smartrf_CC1120.h* file (TI recommended).
15. Save the exported file as *smartrf_CC1120.h*.
16. Recompile all nodes in the network.

The new configuration should affect all nodes.

5 Getting Started

5.1 Hardware

To evaluate this TI Design, you need at least one Performance Line Development Kit (CC1120DK). This kit contains everything to make an access point and one device based on both the TrxEB and CC1120 evaluation module.

The software provided as a part of this TI Design also supports the EXP430FR5739 LaunchPad for all devices except the LED lamp. This device has a few LEDs, instead of an LCD, and offers less visual feedback.

The PIR sensor used in the motion sensor design is based on *Ultra-Low Power Motion Detection Using the MSP430F2013* (SLAA283A). The hardware used in this TI Design is available from Olimex™.

The hardware to run the complete TI Design with eight devices and one access point follows:

- 1 × CC1120DK
- 6 × MSP-EXP430FR5739
- 3 × CC1120EMK (868-915 MHz)
- 1 × eZ430-Chronos™
- 2 × MSP430-PIR

CC1120DK – Performance Line Development Kit

<http://www.ti.com/tool/cc1120dk>

The CC1120DK consists of the following:

- Two TrxEB evaluation boards
- Two CC1120 evaluation modules for 868 MHz with antennas
- A MSP430 Debug Probe
- All cables

MSP-EXP430FR5739 Experimenter Board

<http://www.ti.com/tool/msp-exp430fr5739>

The experimenter board consists of the following:

- The experimenter board
- A native connector for adding a CC1120 evaluation module
- A CC1120EMK

CC1120EMK – Evaluation Module Kit 868-915 MHz

<http://www.ti.com/tool/CC1120EMK-868-915>

CC1120 evaluation module kit consists of the following:

- Two CC1120 evaluation modules and antennas
- An evaluation or experimenter board

eZ430 Chronos Wireless Development Tool

<http://www.ti.com/tool/ez430-chronos>

The Chronos development kit is a self-contained development kit that contains everything to get started with the CC430 platform. The Chronos watch can be used to view the status of the system, send test messages, and disarm the alarm.

MSP430-PIR Motion Sensor

<https://www.olimex.com/Products/MSP430/Starter/MSP430-PIR/>

The MSP430-PIR device is based on *Ultra-Low Power Motion Detection Using the MSP430F2013* (SLAA283). The TI Design software packet includes software to program this device.

6 Firmware

The MSP430 device supports the IAR Embedded Workbench. The software in this TI Design has been tested with a IAR Embedded Workbench for the MSP430 version 6.10.5.

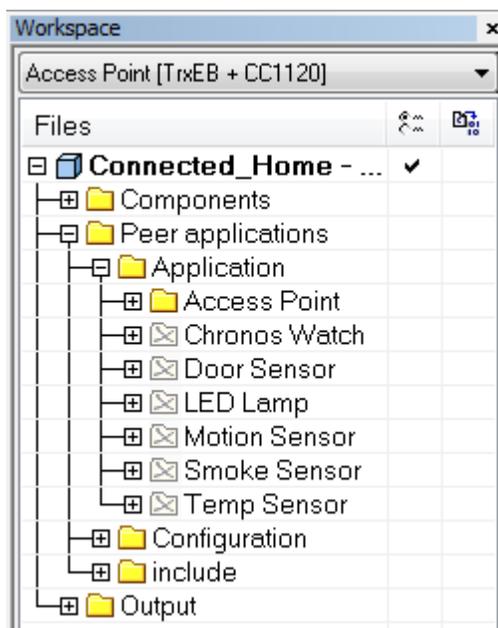
Get a 30-day trial version from IAR at: <http://www.iar.com/Service-Center/Downloads/>

6.1 Installing the Firmware: Setting up the IAR

To get started with this TI Design using IAR Embedded Workbench, you need a TrxEB device, a CC1120EM device for the access point, and hardware for one device. The device can either be another TrxEB device and a CC1120EM device, a EXP430FR5739 device and a CC1120EM device, or a eZ430-Chronos device.

To program a board, do the following:

1. Open the IAR Embedded Workbench for the MSP430 device.
2. Go to File.
3. Go to Open.
4. Go to Workspace.
5. Find the directory with the TI Design software package.
6. Go to *Projects\Examples\TrxEB\Connected_Home\IAR*
7. Open *Connected_Home.eww*
8. In [Figure 16](#), select device compile.



Selecting the device will include only the source files and configuration file for that device.

Figure 16. Connected Home IAR Project Workspace

9. Go to Project.
10. Press F7 to Make.
11. Connect the board.
12. Go to Project.
13. Press Shift-D to download and debug.

The software for the MSP430-PIR device can be found in *Projects\Examples\Applications\TI_Design_Sensor_Application\PIR-sensor*. Program this device using the steps in this section.

6.2 Running the Firmware: Quick Start

To start the firmware, do the following:

1. Ensure all devices are off.
2. Turn on the access point.
3. Press the left or right button to continue from title screen on the access point.
4. Start the devices one at a time (On TrxEB devices, press the left or right button to continue from the start screen. On the Chronos, press *up*. On EXP430FR5739, press nothing).

If some devices are labeled as inactive or do not appear on the access point display, restart the device and check the batteries.

Using the Access Point Interface

- Press the right button to toggle the arm or disarm status of the alarm.
 1. Press the left button to enter the menu for to erase or save data to flash.
 2. Press left button again to erase data on the flash.
 3. Press the right button to save the device information to the flash.
- Save the information of the device to flash to avoid having to restart all devices to relink to access point the next time you use the system.

Using the PIR Sensor Interface

- Move in front of the PIR sensor to turn on the light or trigger the alarm (depending on alarm and project setting).
- Press and hold the left button to emulate the motion detection from the PIR sensor (if no PIR sensor is present or if the batteries of the sensor are dead).

Using the Door and Window Sensor Interface

- Press and hold the left button to emulate the door or window being open or closed (while button is pressed, the device considers the door or window open).
- Press the right button to toggle the arm or disarm status of the alarm.

Using the Smoke Sensor Interface

- Press and hold the right button to indicate that smoke is detected (while the button is pressed, the device considers smoke detected).

Using the Chronos Watch Interface

- Press * to arm the alarm.
- Press # to disarm and deactivate the alarm.
- Press and hold *up* to emulate detecting a door intrusion.
- Press and hold the backlight button to emulate detecting a motion (middle right button).

6.3 Quick Event Reference

6.3.1 Emulating a Broken Door or Window

On the door and window sensor and the access point, the display will show door open or window open while the button is pressed. When the button is released, the display will show door closed or window closed. If the alarm is armed, the LED lamp actuator will blink until the alarm is disarmed.

6.3.2 Emulating Smoke Detection

On the smoke sensor and the access point, the display will show smoke while button is pressed and no smoke when the button is released. The alarm will trigger and the LED lamp actuator will blink until the alarm is disarmed.

6.3.3 Toggling the Alarm Status

You can toggle the alarm status from armed to disarmed on the door sensor, the Chronos watch, and the access point. If the alarm is triggered, toggling the alarm status will deactivate the alarm.

6.3.4 Arming and Disarming the PIR Sensor

On the PIR sensor and the access point, the display will show motion when the device detects it, and no motion when the device detects nothing. The device checks for motion every second. If the alarm is armed, the LED lamp actuator will blink until the alarm is disarmed. If the alarm is not armed, the LED lamp actuator will turn the light on for 5 seconds on a timer. To turn the light off sooner, send a command to disarm the alarm from the access point, the Chronos watch, or the door sensor.

6.3.5 Setting Periodic Events

Every two minutes, all devices send a status message to the access point. If the access point does not receive a status message from a device after three minutes, the access point sets the device status as inactive on the LCD. The temperature sensor sends the temperature value to the access point every minute. The access point and temperature sensor LCD display this value.

6.3.6 Using the Chronos Watch to Emulate Events

To emulate the door, motion sensor, and smoke alarm, do the following:

1. Press and hold *up* to emulate the door opening and closing.
2. Press and hold *⌘* to emulate the motion sensor.
3. Press and hold *down* to emulate the smoke alarm.

To set the time, do the following:

1. Press and hold *** to relink the watch to the access point.
2. Press and hold *#* to set the hour.
3. Toggle *up* and *down* to set the hour.
4. Press *#* to set the minutes.
5. Toggle *up* and *down* buttons to set the minutes.
6. Press *#* to exit.

6.3.7 LED Lamp Actuator

The actuator receives messages from the access point to turn on light or activate the alarm. This device consumes power at a higher rate than the other devices and should be powered directly.

7 Test Setup

We used a USB cable to connect a Agilent N6705B DC Power Analyzer to a PC to record the measurements. A USB connection to the PC powered the MSP430FR5739 device.

We used the setup in [Figure 17](#) when measuring the radio. When we measured the MSP430 device, we used the MSP_PWR jumper instead of the RF_PWR jumper.

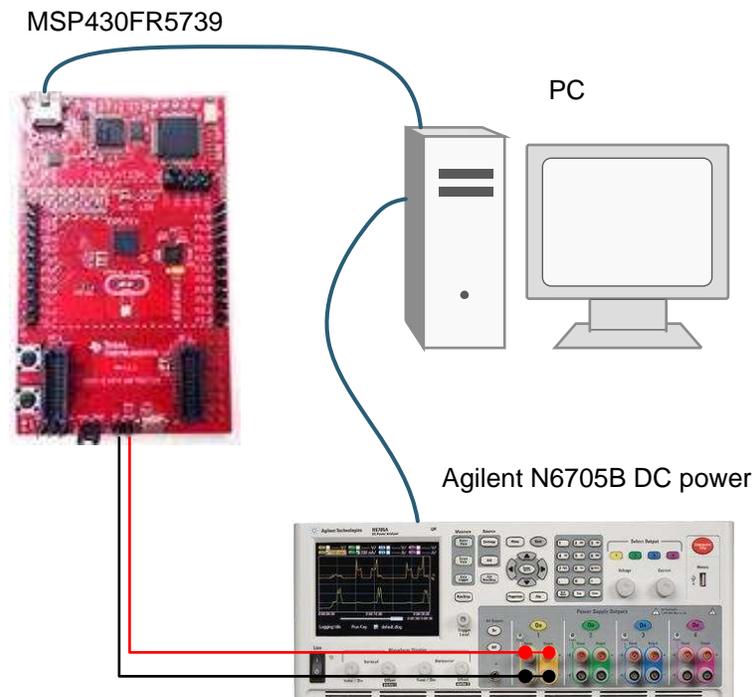


Figure 17. Radio Measurement Setup

8 Test Data

Most nodes in the connected home network are battery-powered but must last a long time. Because the connected home network has an asymmetric power budget, the battery nodes can operate at low power and assume the access point is always on. The nodes can send a message at anytime and assume that the access point will receive it.

For an illustration of the active power consumption of the CC1120 transceiver of a door and window sensor during the transmission of a device status, see [Figure 18](#). [Figure 18](#) illustrates the stages where the device wakes up, enters TX, changes mode to RX, waits in RX for an ACK, and then goes to sleep. Sending a status and getting an acknowledge takes about 11.1 ms. The average power consumption during this period is approximately 28.5 mA.

For the average current of the CC1120 device when the radio is in sleep mode, see [Figure 19](#).

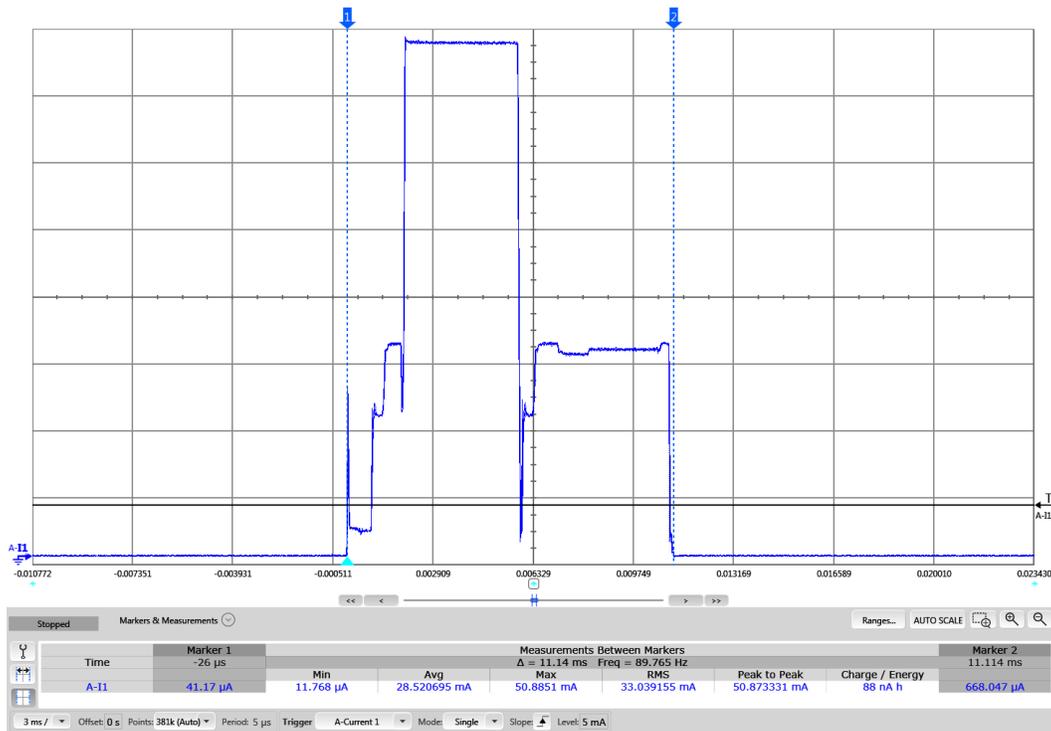


Figure 18. Door and Window Sensor Average Power Consumption While Active, CC1120 Radio Only

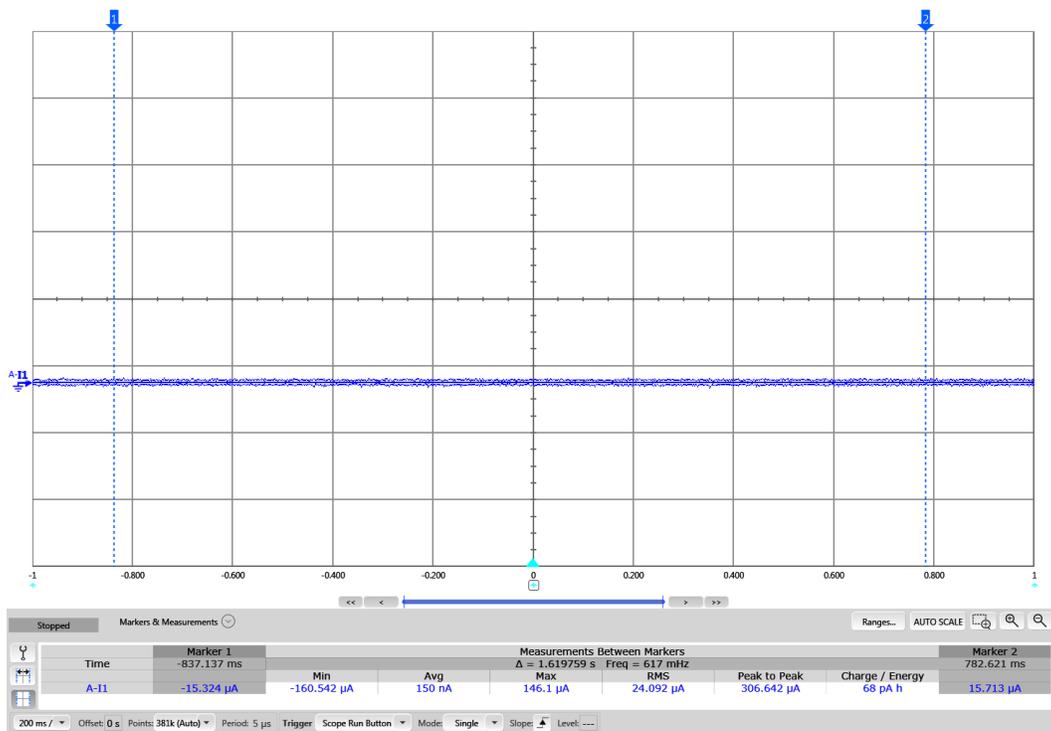


Figure 19. Window and Door Sensor Power Consumption During Sleep Mode, CC1120 Radio Only

The nodes send a status message every two minutes by default. For a calculation of the average power consumption, see [Table 3](#). This average power consumption is based on real power measurements on the CC1120 device and the MSP430FR5739 device, where sleep means power mode 3 (PM3). To have all pins of the MSP430FR5739 device in a configuration that draw the least power, we took special considerations. The exact pin configuration will depend on the board and what pins are used.

The calculations in [Table 3](#) assume the added asynchronous radio activity created when sensor values are triggered to be sent will be less than the contribution of the status messages over time.

With the average current in [Table 3](#) and two AA batteries connected with 2100 mAh capacity, the average battery time of the node is approximately 20 years.

NOTE: The MSP in [Table 3](#) has 9 μA sleep current which consumes the majority of power budget.

With a sleep current of approximately 1 μA , the MSP430FR4133 device has a higher battery life.

Table 3. Average Power Consumption

	Time [ms]	CC1120 [mA]	MSP430	Time x Current
Active	11.10	28.5	0.8	325.23
Sleep	119988.9	0.00015	0.009	1097.9
Average Current [μA]				11.9

Example End Device Life Time

(1)

9 Design Files

Hardware reference designs in this software reference design are available for the different platforms in the following reference designs:

[CC1120EM 868/915MHz reference design](#)

[CC430 Chronos reference design](#)

9.1 Bill of Materials

To download the bill of materials, see the following reference designs:

[CC1120EM 868/915MHz reference design](#)

[CC430 Chronos reference design](#)

9.2 Software Files

To download the software files, see the design files at [TIDC-CHN](#).

10 References

1. *TI LPRF Easy Mode Application Note* ([SWRA472](#))
2. *Achieving Optimum Radio Range* ([SWRA479](#))

11 About the Author

NIKLAS NORIN is an applications engineer at TI, where he works with software and firmware for the wireless connectivity team. Niklas holds an M.Sc in Electronics Engineering.

TORSTEIN ERMESJØ is an applications engineer at TI, where he works with hardware setup and system design for the wireless connectivity team. Torstein holds an M.Sc in Electronics Engineering.

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