Application Report
SWAA168–October 2017

Designing Thermostats With CC3220 SimpleLink™ Single-Chip Wi-Fi® MCU System-on-Chip

ABSTRACT

According to the U.S. Energy Information Administration (EIA), 41% of all US residential energy cost is spent on heating and cooling. The average energy cost has increased by 4% (over the last 10 years), and the upward trend is expected to continue for the foreseeable future. This increase in energy cost is pushing end equipment manufacturers to find ways to lower energy consumption, which can benefit homeowners. Though programmable thermostats have been used for many years, a study has shown that fewer than 15% of homeowners actually program their thermostats.

A smart thermostat has advanced capabilities to learn user behaviors, which provide energy savings (estimated to be from 15 to 25%) by automatically adjusting the temperature, thus eliminating the need for users to program the thermostat. The smart thermostat also serves other functionalities external to the HVAC system by providing the following:

- Connectivity
- Remote control and programmability
- Energy usage monitoring
- Home gateway access

Many smart thermostats use Wi-Fi® for connectivity through cloud. This application report is presented for enabling customers to create a low-power, connected-MCU based thermostat that can link a variety of sensors and securely connect to the cloud and provide remote monitoring and control.

Contents

1 Introduction 2
2 Smart Thermostat Features and Generic Use Cases 3
3 Smart Thermostat Development Resources With the CC3220 Device 4
4 Summary 8
5 References and Related Collateral 8

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1 Introduction

Smart thermostats come with a variety of features to enable maximum comfort with energy savings, along with ease of use for setup and operation. Figure 1 shows some advanced use cases and features for smart thermostats.

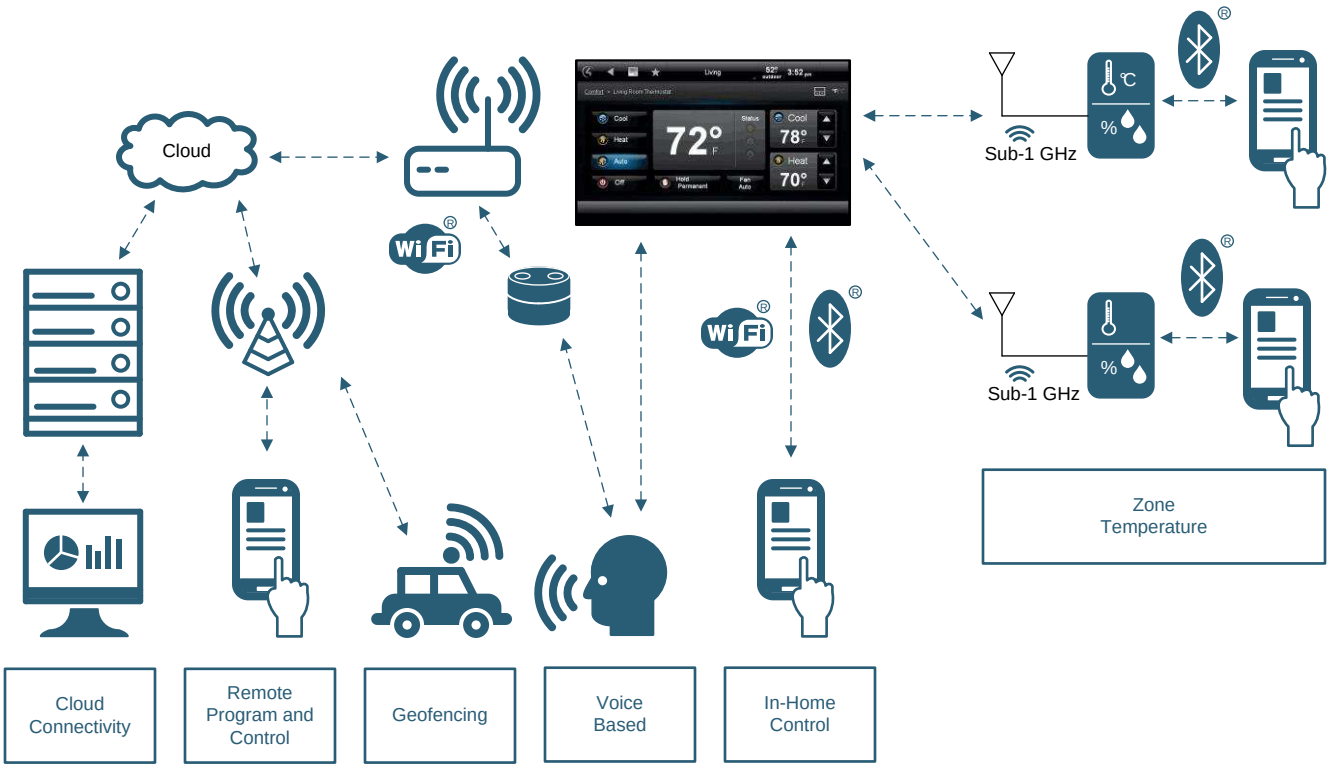

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Figure 1. Smart Thermostat Ecosystem

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2 Smart Thermostat Features and Generic Use Cases

With connectivity to the internet and cloud services, it is easy to realize many use cases that are not possible with conventional programmable thermostats. Use cases and general considerations for the essential smart thermostat are briefly explained in the following.

2.1 Ease of Setup and Control

Primary necessities of a smart thermostat are ease of setup and control. Ease of configuration and connection to the internet are crucial, which enable remote configurability and monitoring of smart thermostats through cloud connectivity. The algorithms in the cloud can provide tips on energy saving as well as provide a wide range of analytics for self-learning (understand the user behavior, learn about the home setup, adjust to comfort settings as occupant approaches).

Smart thermostats can also compare the history energy usage of others in the neighborhood to provide information about the pattern of energy consumption. With HomeKit™ hardware and software technology, end equipment manufactures can easily connect their thermostat to any Apple® device. Other software plugins [for example, Amazon Web Services™ (AWS), Microsoft® Azure™, and IBM Watson®] are provided, which enable connection to other cloud and internet services. A host of internet protocols are also provided:

- MQTT
- HTTP
- HTTPS
- DHCP
- SSH
- TLS/SSL
- SMTP
- SNMP

2.2 Security

Security is an important consideration for all devices connected to the internet of things (IoT). Because the IoT device is a *connected device* by nature, it can be a gateway to malicious access and sensitive information (for example: control over actuator, user settings, user network information, and so on).

In addition to network security, local area network (LAN) security and physical device level security are also required. The devices used in IoT applications also must prevent application code tampering, they must provide cloning protection to the application code, and allow the thermostat manufacturer to protect the investment of their software intellectual property.

2.3 Remote Control and Monitoring

Remote control and monitoring provide an easy-to-use interface for end users to monitor energy usage and adjust the settings as needed. The thermostat can also be controlled in the home through local Wi-Fi connectivity using mDNS. Some thermostats are also equipped with *Bluetooth*® and Bluetooth low energy (BLE) to provide additional interface options for in-home control and provisioning.

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2.4 Geofencing

The user's phone location information is used to define geographical boundaries in geofencing, so a smart thermostat can determine how close to home the user is located. Based on this location information, the smart thermostat can then provide additional comfort by turning on the heating or cooling system before the user arrives at home. These operations require periodic internet and cloud connectivity. For battery powered thermostats, it is essential to implement smarter ways to connect to the internet without significantly affecting the battery life.

2.5 Voice Activation

Voice activation allows for adjustment of thermostat settings through voice control by the user. The thermostat can detect a trigger phrase and perform the rest of the voice processing in the cloud. This feature enables control of the smart thermostat within the home through simple voice commands.

2.6 Zone Temperature Sensing and Control

Traditionally, the thermostat with the ambient temperature sensor was placed only in the main room. Because the temperature of the whole house was controlled using only the sensor readings from the room where the thermostat was located, hot and cold regions were created in other rooms as a result.

The newer features of zone temperature sensing and control can provide additional information for temperature in each room of the house. The smart thermostat uses occupancy detection from remote rooms to maximize the comfort level for all rooms. Each of the zones can be controlled more efficiently through the availability of controllable dampers. Zone sensor nodes can be connected to the thermostat with Bluetooth low energy or Sub-1 GHz.

3 Smart Thermostat Development Resources With the CC3220 Device

To achieve the intended functionality, most available smart thermostats on the market today use a microprocessor control unit (MCU) and a separate Wi-Fi device. To reduce both the bill of materials (BOM) and the power requirements for smart thermostat devices, a single-chip MCU plus Wi-Fi solution with rich features is a requirement. Additionally, there is a greater need for single-chip Wi-Fi system-on-chip (SoC) devices because more low-end and mid-range programmable thermostats are moving toward becoming internet-connected thermostats. The CC3220 SimpleLink™ Wi-Fi CERTIFIED™ device from Texas Instruments is a single-chip MCU with Wi-Fi that is designed to fill this need.

The CC3220 device is a dual-core wireless MCU. The embedded Wi-Fi Network Processor (Wi-Fi NWP) contains all the Wi-Fi and internet protocols. A separate, dedicated Arm® Cortex®-M4 processor is available for application development. The SimpleLink CC3220 device also offers the SimpleLink™ Software Development Kit (SDK) with many ready-to-use features, examples, and Plug-ins (cloud connectivity, HomeKit, Power Management, and so on) to reduce the development effort for system developers.

Customers can use the SimpleLink™ CC3220 LaunchXL LaunchPad™ Development Kit for all initial development and Wi-Fi performance evaluation. The LaunchPad (LP) also serves as the hardware platform to develop proof-of-concept designs before initiating the production design. The SimpleLink SDK provides the software drivers and code examples that illustrate critical features required for the smart thermostat. End equipment developers can easily realize these features with the SimpleLink CC3220 device.

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Figure 2 shows a typical system block diagram for the smart thermostat using the CC3220 device.

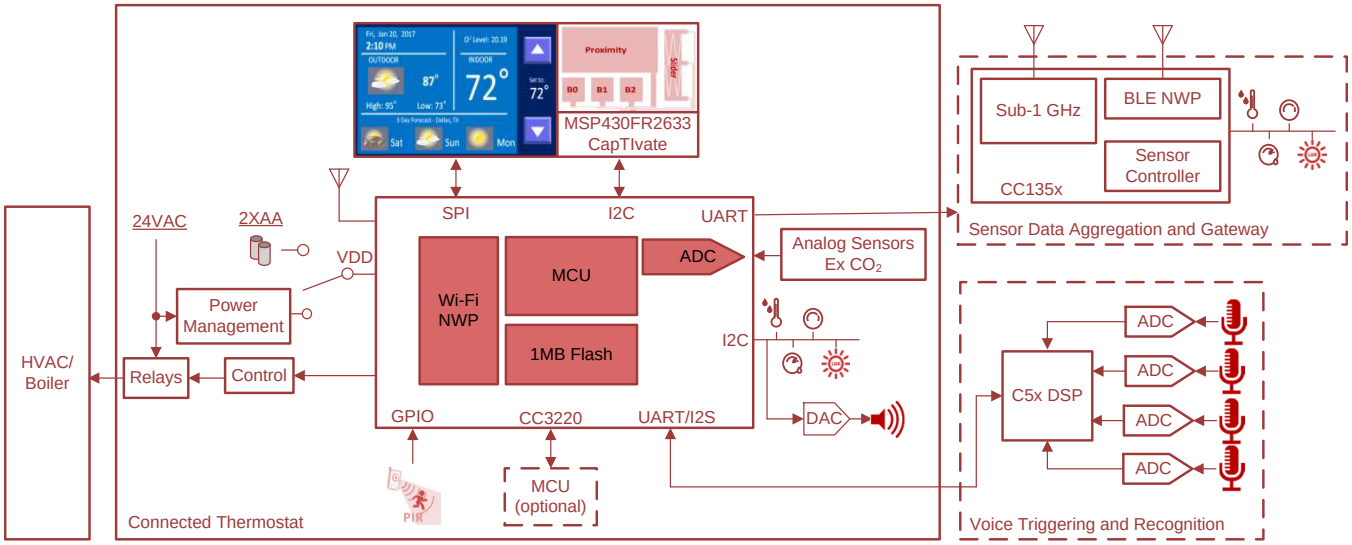

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Figure 2. Block Diagram of the Thermostat Design Based on CC3220 Wi-Fi and MCU SoC

The smart thermostat features can be addressed with the CC3220 device in the following ways:

- Ease of Setup and Control

  By using CC3220 device, connection to Wi-Fi is made easy with a variety of provisioning methods (SmartConfig™ technology, Access Point (AP) Mode, and Wi-Fi Protected Access 2 [WPA2]). These provisioning methods are explained in detail with both code examples and documentation (see the *CC3120, CC3220 SimpleLink™ Wi-Fi Internet-on-a chip™ Solution Device Provisioning* application report). The easy-to-use defined APIs provide both secure and nonsecure connection to the access point and to the internet.

  Additionally, the CC3220 device provides support for HomeKit, AWS, Azure, and IBM cloud servers, and a host of internet protocols (see Section 2.1) to connect to the other cloud and internet services. The SimpleLink SDK also includes code examples for cloud Over the Air (OTA) for end equipment manufactures to update the software on the thermostat after it is deployed to the field. The TI Resource Explorer has several examples to illustrate the complete OTA update mechanism, MQTT client and server.

- Security

  Security is an important consideration for all connected IoT devices. The SimpleLink CC3220 device is designed to provide security at several exposure points—internet network level security, local network level security, and protection against physical access and tampering.

  To provide additional security, the CC3220 device has two separate execution environments for application and network connectivity.

  – At the internet security level, the CC3220 device provides:
    - Standard compliant secure sockets layer (SSL) [SSLv3] and transport layer security (TLS) [TLS1.0, TLS1.1, TLS1.2]
    - Domain name verification
    - Secure content delivery
    - Device-unique identifiers
    - Personal and enterprise Wi-Fi security to provide communication security at the network layer

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  - At the local network connectivity level, the Wi-Fi Alliance® has regulated security and compliance tests as part of its standard. The CC3220 device is a Wi-Fi CERTIFIED device that complies with the security requirements (for more details about the Wi-Fi certifications, see the *Transfer of TI's Wi-Fi® Alliance Certifications to CC3x00- and CC3x20-Based Products Using the WFA Derivative Certification Policy* application report).
  - At the device level or physical access level, the CC3220 device provides:
    - IP protection
    - File system security by means of encryption
    - File system integrity
    - Cloning protection

  For more details about the security options in the CC3220 device, see the *SimpleLink™ CC3120, CC3220 Wi-Fi® Internet-on-a chip™ Solution Built-In Security Features* application report.

- Low Power

  Low power is required for battery operated thermostats. Depending on the use cases, the system designers can choose to use *Intermittently* connected or *Always* connected modes of operation. Both the application MCU and network processor (NWP) can independently maintain separate power states. This feature allows each subsystem to independently handle low-power mode. For example: when the MCU and other peripherals are in sleep mode, the network connection can still be maintained.

  Additionally, TI's proprietary network learning algorithm can learn the AP behavior and further increase the sleep interval without dropping the connection. For more details about the power management schemes and recommendations for power savings, see *SimpleLink™ CC3120, CC3220 Wi-Fi® Internet-on-a chip™ Networking Subsystem Power Management*. The Network learning algorithm is tested with >210 access points, and this interoperability ensures high confidence on worldwide deployment.

- Environment Sensor Interfaces

  The CC3220 device provides both analog and digital sensor interfaces. The 4-channel ADC can be used for analog sensors, and I2C can be used for all digital sensor interfaces. The code example provided by SimpleLink™ Academy (Sample application to read temperature value from a TMP006 I2C temperature sensor) shows how to interface the temperature sensor over I2C. For details about the appropriate selection of the type of temperature sensor, see the What are you sensing? Pros and cons of four temperature sensor types blog.

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- Human Machine Interface (HMI)

  A key feature is providing the thermostat users with an HMI. The HMI display is used to indicate the following and more:

  – Current room temperature
  – Local weather
  – Local time
  – Mode (heating or cooling)
  – Fan speed
  – Wi-Fi connectivity indication
  – Humidity
  – Air quality

  Most thermostats on the market today have a minimal display along with buttons for programming. However, the trend is to replace the buttons with a touch screen. The touch and display can be developed using the Kentec QVGA Display BoosterPack™ (for more detailed information, see the technical documents for display booster pack). The on-chip SPI in the CC3220 device can be used to interface with the display. The touch-button functionality can be designed using the MSP CapTIvate™ MCU Development Kit. The number of buttons can be configured and customized as needed.

- Voice Triggering and Cloud-Based Voice Recognition

  One microphone can be connected to the ADC line of the CC3220 device to provide speaker-dependent voice recognition. In this solution, the user can program recognizable words and the application is designed to perform a specific action based on the words spoken by the user. In addition, the programmed word or words are used as trigger phrases. The voice commands following the trigger phrase are sent to the cloud for transcription, thus generating actions based on the transcription.

  In another demo, the same functionality is achieved with four microphones and a DSP (TMS320C5517 or TMS320C5545) to process the voice with beam forming and noise suppression. The implementation with the DSP is currently available as a demo (see the Voice Triggering and Processing with Cloud Connection to IBM Watson Reference Design).

- Additional Support for Bluetooth low energy and Sub-1 GHz

  To add remote sensor nodes for different rooms and zones, Bluetooth low energy or Sub-1 GHz technology can be added to the thermostat. TI's SimpleLink family of devices provides for both Bluetooth low energy and Sub-1 GHz (CC1350) technologies. For this use case, the thermostat functions as the gateway to interface with zone temperature sensors using Bluetooth low energy or Sub-1 GHz technologies. An example of using the CC3220 device as a gateway is explained in the Bluetooth Smart to Wi-Fi IoT Gateway Reference Design.

- Proximity and Occupancy Sensing

  Proximity sensing enables the display to turn on from sleep mode when a user is nearby the thermostat. The Smart Backlight Control by White LED Driver, Ambient Light, and Proximity Sensor Reference Design explains the same using the MSP430FR5969 device. This example can be ported to the CC3220 platform.

  Also, following TI Design Thermopile-Based Occupancy Detector for People Counting Applications Reference Design provides a people-counting example using IR sensors.

- Power Supply and HVAC Interface

  Thermostats using 24-V AC as the power source must convert the voltage to make it suitable for the power requirements of the CC3220 device. This is provided as TI Design 24-V AC Power Stage With Wide V_{in} Converter and Battery Gauge Reference Design for Smart Thermostats. Another TI Design covers the section for relay interface to HVAC system.

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4 Summary

The SimpleLink CC3220 wireless MCU device provides a System-on-Chip functionality for embedded IoT end equipment design and applications. With complete Wi-Fi Networking capability embedded in the Network Processor and an ample amount of memory (1MB integrated flash and 256KB RAM), the feature-rich CC3220 device makes the perfect platform to realize the smart thermostat. With a host of design examples and documentation, it is easy for developers to bring down the development time and cost.

5 References and Related Collateral

The resources available with the CC3220 device are as follows:

Product Pages

- SimpleLink™ Wi-Fi® main page
- SimpleLink™ CC3220 Wireless MCU main page
- TI E2E™™ Support Community
- SimpleLink™ MCU Platform

Development Hardware and BoosterPack™

- SimpleLink™ Wi-Fi® CC3220SF Wireless Microcontroller LaunchPad™ Development Kit
- Kentec QVGA Display BoosterPack™
- Sensors BoosterPack™ Plug-In Module
- Audio Signal Processing BoosterPack™ Plug-In Module
- CC2650EM-7ID Reference Design

Software

- SimpleLink™ SDK
- SimpleLink™ SDK Resource Explorer
- Code Examples – Provisioning
- Code Examples – Cloud OTA
- Code Examples – Mqtt Client Server
- Code Examples – Sensor Interface

Companion Products

- CC1350 SimpleLink™ Ultra-Low Power Dual Band Wireless Microcontroller
- TMS320C5517 Fixed-Point Digital Signal Processor

TI Designs

- Bluetooth® Smart to Wi-Fi® IoT Gateway – LaunchPad™/BoosterPack™ Approach
- MSP CapTIvate™ MCU Development Kit
- Thermopile-Based Occupancy Detector for People Counting Applications Reference Design
- Smart Backlight Control by White LED Driver, Ambient Light, and Proximity Sensor Reference Design
- 24-V AC Power Stage With Wide Vin Converter and Battery Gauge Reference Design for Smart Thermostat
- Isolated Self-Powered AC Solid State Relay With MOSFETs Reference Design

Blogs

- MCUs can recognize what you say
- What are you sensing? Pros and cons of four temperature sensor types
- CC3220 Security Blog: Strengthening Wi-Fi security at the hardware level

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Application Notes

- *CC3120, CC3220 SimpleLink™ Wi-Fi Internet-on-a chip™ Solution Device Provisioning*
- *SimpleLink™ CC3120, CC3220 Wi-Fi® Internet-on-a chip™ Solution Built-In Security Features*
- *SimpleLink™ CC3120, CC3220 Wi-Fi® Internet-on-a chip™ Networking Subsystem Power Management*

Videos

- SimpleLink™ Wi-Fi® integrated security features
- SimpleLink™ Wi-Fi® CC3220 and CC3120 Product Overview
- Introducing the SimpleLink™ MCU platform
- 100 percent code reuse with SimpleLink™ MCU platform SDK
- Other videos are also available at the bottom of the SimpleLink™ Wi-Fi® family Wireless MCUs and Network Processors overview page.

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