Application Report
SWRA616–October 2018

Designing Connected CPAP Machines With SimpleLink™ Wi-Fi® Wireless MCU

ABSTRACT

Continuous Positive Airway Pressure (CPAP) is the treatment of choice for obstructive sleep apnea. With the evolution of telehealth and telemedicine, CPAP devices with wireless connectivity are solving problems like lack of comfort and difficulties in usage that have been the most common reasons for poor CPAP adherence in the past. A connected CPAP device can use various wireless communication technologies like Wi-Fi, *Bluetooth*® Low Energy and cellular network to obtain internet connectivity.

This application report describes the Wi-Fi use case for a connected CPAP implementation. It also describes the development of Wi-Fi enabled CPAP machine using the SimpleLink Wi-Fi CC3220 Wireless MCU or CC3120 Wi-Fi Network Processor.

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1 Introduction

Obstructive sleep apnea syndrome (OSAS) is a sleep disorder in which breathing is briefly and repeatedly interrupted during sleep resulting in reduction of blood oxygen level. According to the National Sleep Foundation, millions of adults and children worldwide suffer from this sleep disorder. The prevalence of OSAS greatly increases the risk of cardiovascular and cerebrovascular diseases in such a large population, but this disorder can be treated. Continuous Positive Airway Pressure (CPAP) therapy is one of the most common treatment methods.

A CPAP machine applies gentle but constant positive pressure to the patient's respiratory system in order to keep the throat from collapsing and obstructing the airway. CPAP machines also record important usage data for the users and their physicians for therapy and compliance purposes. This usage data includes the duration of the CPAP usage, apnea events during the usage as well as other vital signs like pressure, humidity and respiration rates. Though CPAP machines have been around for decades, the lack of comfort and difficulties in usage have been some of the main reasons for the poor CPAP adherence among the OSAS patients. To mitigate these challenges, some of the newer CPAP devices are equipped with wireless connectivity options which allow the devices to transmit the usage data to the manufacturer's remote health platform service. This usage data is later used by the sleep physicians and patients to track the progress of the therapy. It can also be used by the physicians to track the patients' progress and adjust the prescription if needed. This capability allows the patients to use the devices at home rather than in a sleep lab, resulting in a much more comfortable environment for the CPAP therapy.

The connected CPAP machines can use various wireless technologies like Wi-Fi, Bluetooth Low Energy or cellular network to upload the usage data to the patients' cloud-based profiles. This document describes the Wi-Fi use case for the connected CPAP machines and the system level implementation using SimpleLink Wi-Fi Wireless MCU.

2 Connected CPAP Machine Use Cases and Features

Traditionally, CPAP devices use storage methods like SD card and USB drives to store the patient's usage data locally. This data would then be shared with the physician by mailing in the storage device to the sleep clinic. Connectivity to the internet can be used to replace the traditional data storage and delivery methods used in CPAP machines. Since you do not have to store the usage data in an SD card or USB drive, internet connectivity can help improve the user experience and in turn increase the CPAP adherence.

Figure 1 shows a diagram of various wireless links in the connected CPAP use cases. A connected CPAP machine can use Wi-Fi or cellular connectivity to upload the usage data to a cloud service after every use. Additionally, compact and portable CPAP devices designed for travel can use Bluetooth Low Energy to connect to a smartphone. The smartphone can then act as a data aggregator for the cloud service.

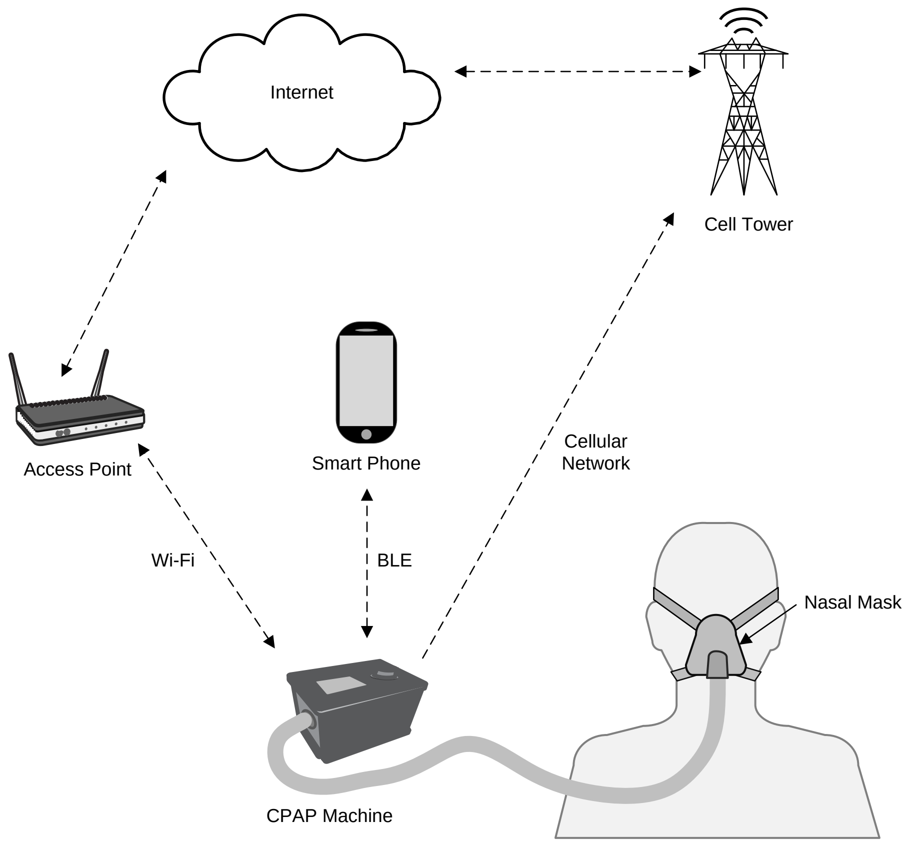

Figure 1. Connected CPAP Use Cases

2.1 Wi-Fi Use Case and Benefits

While cellular connection and Bluetooth Low Energy offer various benefits in specific scenarios, the Wi-Fi connectivity offers the following advantages that can increase the ease of use and the efficiency of a connected CPAP machine.

2.1.1 Wider Network Coverage

Even with a CPAP machine with cellular connectivity, the user may have to revert to the clunky local storage methods in areas with poor cellular reception. Wi-Fi can be used as an alternative to the cellular connection in this situation in order to provide internet connectivity to the CPAP machine.

2.1.2 Cost Effective compared to Cellular Network

Wi-Fi connectivity also offers significant cost savings to the CPAP manufacturer by eliminating the service provider's data charges associated with the cellular network.

Unlike cellular devices, Wi-Fi devices do not require roaming when traveling abroad. Thus, a Wi-Fi enabled CPAP machine can be used without additional cost both at home and while traveling.

2.1.3 Faster Data Transfer and Over-the-air (OTA) Update

Compared to the cellular connection or Bluetooth Low Energy, a Wi-Fi connection offers higher throughput resulting in faster uploads of the patients' CPAP usage data.

The higher throughput of Wi-Fi also allows the CPAP manufacturers to provide faster over-the-air software updates without causing longer interruptions in the transfer of the CPAP usage data.

2.1.4 Ease of Setup

There are varieties of Wi-Fi provisioning methods that can be used to simplify the initial Wi-Fi setup procedure of the connected CPAP device. Since Wi-Fi enables the CPAP device to directly connect to a home Access Point (AP), the CPAP device can easily maintain its internet connection after the initial setup, thus requiring minimal intervention from the user.

3 System Overview

A typical CPAP system consists of the following functional blocks:

- Motor subsystem
- Microcontroller unit (MCU)
- Sensors
- User interface
- Wireless connectivity
- Power management

Figure 2 shows a typical block diagram of a SimpleLink Wi-Fi enabled CPAP machine.

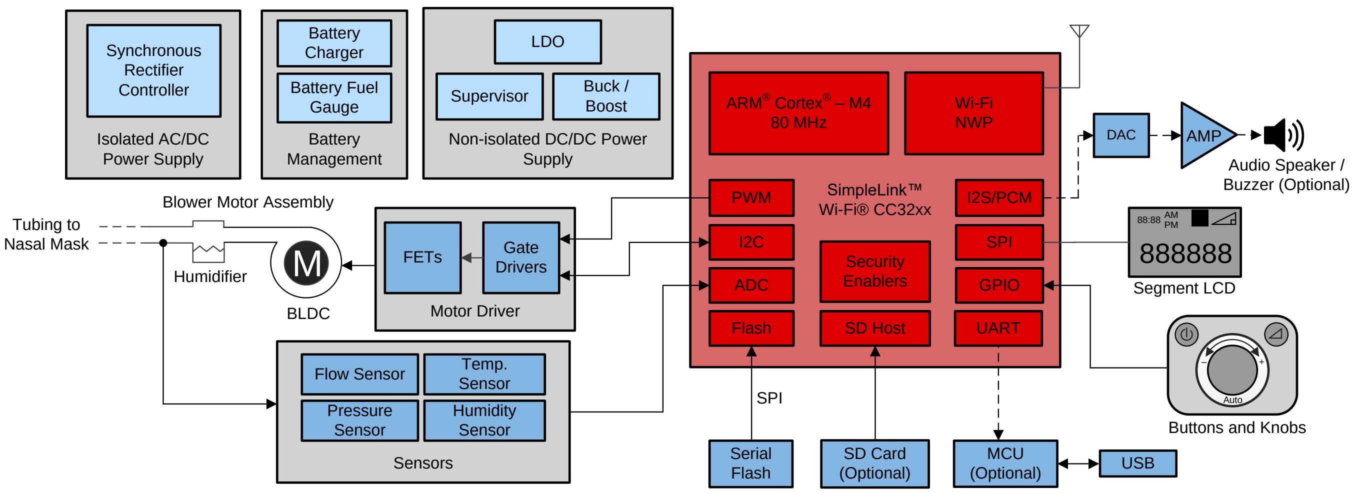

Figure 2. CPAP Machine Block Diagram Using the CC3220 SimpleLink Wi-Fi Wireless MCU

Motor subsystem— The Motor subsystem includes a motor blower assembly that is controlled by the MCU using a motor driver like the DRV10983. The blower assembly pushes air in the tubing that connects the blower assembly to the nasal mask. Most CPAP devices also use a humidifier. The humidifier increases the amount of vapor in the air to increase the patients' comfort.

Microcontroller unit (MCU)— A CPAP system maintains a constant pressure in the nasal mask by continuously monitoring the system pressure using pressure sensors and regulating the speed of motor blower accordingly. The MCU in the CPAP machine is responsible for receiving and processing the sensor data as well as controling the motor speed through the motor driver. Additionally, the MCU is also used to drive the user interface and wireless connectivity. Using the CC3220 wireless MCU, the MCU and Wi-Fi connectivity can be integrated into a single chip.

Sensors— In addition to the pressure sensor, CPAP devices also utilize several other sensors like temperature, humidity and flow sensors to measure these parameters in the nasal mask. An integrated humidity and temperature sensor like the HDC2010 can be used in the CPAP design to achieve high accuracy measurements with very low power consumption, while simplifying the MCU interface requirements . The MCU uses the input from these sensors to control the motor and humidifier assemblies.

User interface— The user interface typically consists of a small LCD (segment or color) screen for display and buttons and/or knobs for user input. Some CPAP systems may include a speaker or a buzzer for audio prompts. The CPAP device may also support SD card or USB interface for local storage of the usage data.

Wireless connectivity— Wireless connectivity such as Wi-Fi adds an additional data interface to the CPAP device. It can be used for various purposes including automatic secure transfer of the usage data to the cloud after each use. This data can then be accessed by physician to remotely track the patients progress in the therapy. The Wi-Fi capability can also be used to add features like allowing the patient's physician to remotely update the prescription (pressure level) based on the patient's usage data. Additionally, the Wi-Fi connectivity allows the CPAP manufacturers to perform faster OTA updates for system software.

Power management— CPAP devices are usually powered from the wall thorugh standard AC-DC power supply. However, some of the portable CPAP devices are designed to run on battery power while travelling. Depending on the use case, the system designers can choose to implement various power management schemes of CC3220 wireless MCU to power optimize the system for longer battery life. For more details, see *SimpleLink™ CC3120, CC3220 Wi-Fi® Internet-on-a chip™ Networking Subsystem Power Management*.

The SimpleLink CC3220 wireless MCU devices integrate multiple peripherals that support CPAP design, including a 12-bit analog-to-digital converter (ADC), general-purpose timers with a 16-bit pulse-width modulation (PWM) mode, and multiple serial interface standards. The SPI serial interface can be used to drive a segment LCD for user interface and the user input buttons can be implemented using the general-purpose input/output (GPIO) pins. The inter-integrated circuit (I2C) peripheral can be used to communicate with motor controller, digital sensors or configure audio codecs in the design. Transmission of digital audio to an audio codec or audio amplifier is possible using the multichannel audio serial port (McASP), which supports the inter-IC sound (I2S) bit stream format. Moreover, the SD Host capabilities of the CC3220 wireless MCU can be leveraged to add SD card as a local storage option for CPAP usage data. Alternatively, an external MCU (coprocessor) can be interfaced with the CC3220 wireless MCU over UART to meet additional GPIO and serial interface needs of the CPAP application.

When adding Wi-Fi capabilities to an existing MCU (host) based CPAP solution, the SimpleLink CC3120 Network Processor (NWP) can also be used to interface with the host MCU. A host MCU can communicate with the CC3120 device over either UART or SPI.

Figure 3 shows a typical block diagram for adding SimpleLink Wi-Fi NWP to an MCU based CPAP system.

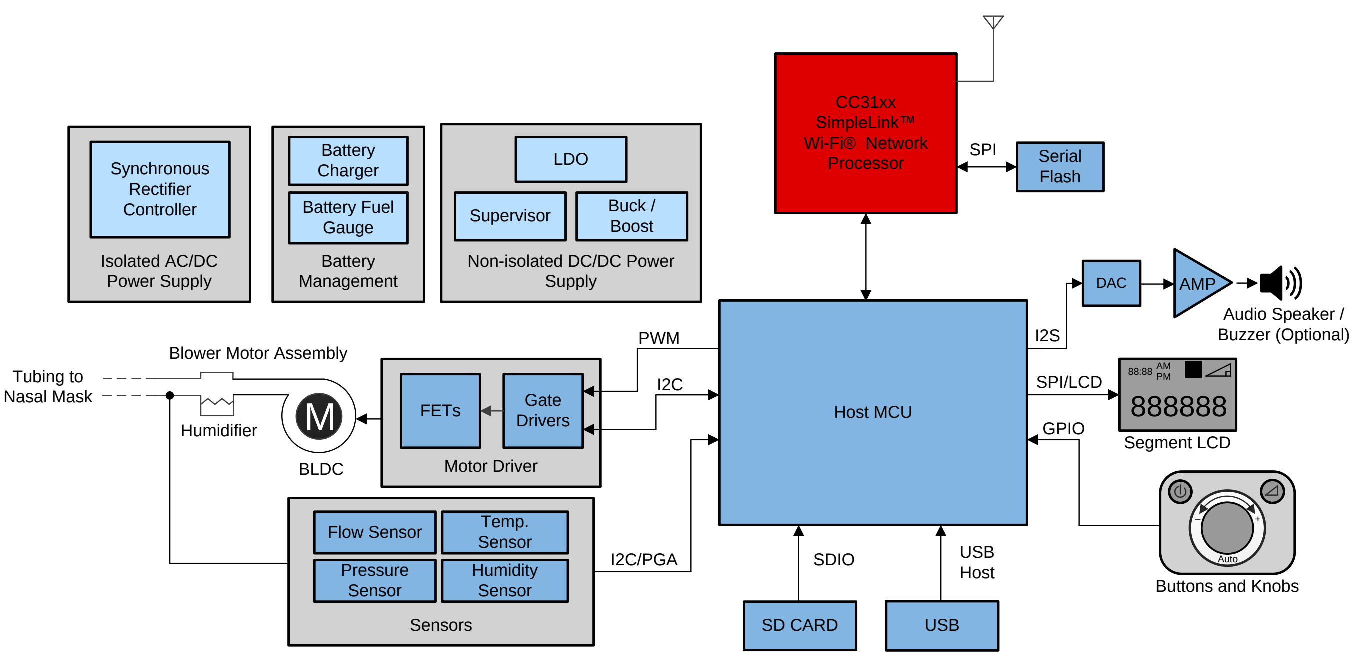

Figure 3. CPAP Machine Block Diagram Using the CC3120 SimpleLink Wi-Fi NWP

3.1 SimpleLink Wi-Fi Wireless MCU Key Features for Connected CPAP Implementation

3.1.1 Separate Execution Environments

The CC3220 device architecture is based on separate execution environments for the application MCU and the network processor. Figure 4 shows a simplified diagram of the CC3220 device architecture.

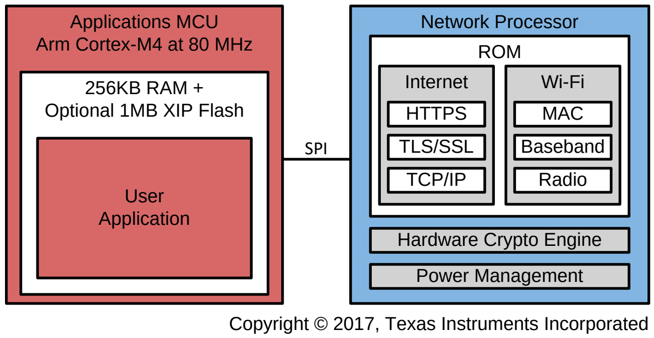

Figure 4. Separate Execution Environments

Separating the application and networking execution environments can be advantageous because this separation allows the network processor to offload the host MCU. The application can continue to run time-critical tasks while the network processor runs the networking stack and performs computationally intensive work, such as handling cryptographic algorithms.

3.1.2 Embedded Security Enablers

A network-connected device like a CPAP machine is commonly connected to a cloud server. An interaction with a cloud server typically requires uploading or downloading sensitive information to or from the cloud. An example of data sent to the cloud might be the patients' usage data, private information used to register for cloud services and more. Moreover, the application code running on the device and any data related to it can be the target of malicious activities aiming at stealing proprietary information or cloning the device. All of this sensitive data can be considered an “asset” and should be protected throughout its life cycle, when the data is in storage, in run-time or in transfer over the Wi-Fi medium. The comprehensive embedded security enablers in the CC3220S and CC3220SF devices can offer end-to-end secured data transfer between a CPAP device and the cloud. Moreover, the built in IP protection (cloning protection) can help secure the CPAP manufacturer's intellectual property.

For more details on all the security features of the CC3220 wireless MCU, see the *Understanding security features for SimpleLink™ Wi-Fi® CC3x20 MCUs*.

3.1.3 Provisioning

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*). The easy-to-use defined APIs provision both secure and nonsecure connection to the access point and to the internet. Because the provisioning logic is fully integrated inside the SimpleLink Wi-Fi device, developers can easily use it in their embedded wireless applications without any prior provisioning knowledge

3.1.4 Cloud Integration

Additionally, the CC3220 device provides support for HomeKit, AWS, Azure, and IBM cloud servers, and a host of internet protocols 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 CPAP 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.

3.1.5 Interoperability

When designing a Wi-Fi enabled CPAP, it is necessary to choose a Wi-Fi solution that is interoperable with a wide range of APs. Interoperability includes establishing and maintaining a connection with an AP, and also delivering consistent low-power operation without compromising the robustness of the solution.

SimpleLink Wi-Fi is tested against over 200 APs to ensure quality of the solution, enabling designs to be deployed in regions across the world. Texas Instruments™ has also obtained Wi-Fi Alliance certification for the CC3120 and CC3220 devices and modules.

The high level of interoperability provided by the SimpleLink Wi-Fi solution ensures that SimpleLink Wi-Fi enabled CPAP machines have consistent performance in various deployment scenarios; including different types of homes and buildings. To learn more about the WLAN radio performance of the SimpleLink CC3220 device, see *CC3220 SimpleLink™ Wi-Fi® Wireless and Internet-of-Things Solution, a Single-Chip Wireless MCU*.

4 Summary

CPAP devices with wireless connectivity help improve the user experience for patients resulting in better CPAP adherence. At the same time, the connected CPAP devices allow physicians to access patients usage data from anywhere. Wi-Fi connectivity provides key benefits over other RF technologies used in the CPAP devices by offering more coverage and simplified user experience for patients as well as cost savings for the CPAP manufacturers. Wi-Fi connectivity also enables CPAP manufacturers to add features like fast OTA updates to further enhance their user experience.

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 connected CPAP device. 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™
- Building Automation Sensors BoosterPack™ Module
- Sensors BoosterPack™ Plug-In Module
- 24V, 100W/30W Dual Sensorless Brushless DC Motor Driver 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

- CC3120MOD SimpleLink™ Wi-Fi® Network Processor IoT Module Solution for MCU Applications
- DRV10983 40W, 24V 3-phase sensorless BLDC motor driver
- HDC2010 Low Power Digital Humidity and Temperature Sensor

Blogs

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

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*

User's Guide

- *SimpleLink™ Wi-Fi® CC3120 and CC3220 Provisioning for Mobile Applications*
- *CC3120, CC3220 SimpleLink™ Wi-Fi® and Internet-of-Things Network Processor Programmer's Guide*

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.