Abstract

Dozens of useful embedded-system products surround us every day; they are everywhere. But if you were asked to quickly name one that is not only very useful, but also is a ‘quality of life’ improver that enhances living comfort, saves energy, and is easy to use, flexible and relatively inexpensive, the list of candidates narrows considerably. Smart thermostats are particularly worthy of mention. They simplify our daily lives and make them more enjoyable. Warren Johnson invented electric thermostats in 1883 and, since then, these environment-control devices have progressed from the once ubiquitous round, hand-adjusted, mercury-based thermal-switch types to today’s popular all-electronic, programmable versions with touch screens. Some of the most-recent versions can connect wirelessly to PCs, smartphones and remotely located controllers and sensors. They are becoming sought-after products for home automation (HA) and building automation (BA) uses.

This white paper explains how economical microcontrollers (MCUs) and wireless modules can be applied to build smart thermostat products that offer Wi-Fi capabilities. For design perspective, it discusses wireless networking protocols and their suitability for smart thermostats, and then describes a reference solution that’s an excellent aid for analyzing and developing this type of application. It is built with a Renesas RL78/L13 MCU and a GainSpan Wi-Fi module.

I. Introduction

Smart thermostats that control heating and cooling systems offer multiple benefits. Especially, they save energy by adjusting the room temperature according to the time of day and the actual user profile of a home or business, among other factors. Microcontroller-based programmable thermostats also apply intelligent control algorithms and compressor protection features to lower the operating and maintenance costs of heating and cooling systems. Additionally, they eliminate the need for switching manually from the heating to cooling modes or vice versa when the environmental situation changes.

A smart thermostat that has a wireless connectivity capability can be controlled and monitored remotely. Often it costs very little or nothing to establish the digital link to a relatively close access point (AP) because wireless networks already exist in a huge number of businesses and homes. By connecting the smart thermostat to the network and hence to the Internet, it’s possible to manage
a heating and cooling system on a PC or even a smartphone wherever and whenever it's convenient or necessary to do so.

The capabilities thus achieved are encompassed by the ‘Internet of Things’. This important global application trend sees a growing span of devices with sensors (thermostats, security systems, etc.) communicating digitally to improve operational processes, boost overall system performance, save energy and cut costs. In turn, this technology shift is opening up new markets for embedded system products and enabling the creation of exciting new business models.

II. Wireless Networks

Designers of smart wireless thermostats can select from several different popular wireless protocols to implement communication with other wireless devices. This white paper covers the dominant Bluetooth, ZigBee and Wi-Fi protocols, first explaining their technologies and subsequently discussing their applicability for HVAC (Heating, Ventilation and Air Conditioning) applications.

**Bluetooth** is based on the IEEE 802.15.1 wireless standard. Designed to establish short-range communication links (up to ~10m), it is used primarily to replace cables for computer peripherals (mouse, keyboard, printer, etc.), as well as remote cellphone headsets. These applications establish wireless personal area networks (WPANs). Recently, Bluetooth technology has been the connectivity choice for remote transceivers for smartphones and in-car entertainment systems.

The initial Bluetooth standard has a maximum data rate of 1Mbps, but newer versions support up to 24Mbps. A master Bluetooth device can communicate with up to seven devices in a piconet, which is an ad-hoc computer network using Bluetooth technology. Bluetooth operates in the unlicensed Industrial, Scientific and Medical (ISM) band at 2.4GHz to 2.485GHz; it uses a spread-spectrum, frequency-hopping, full-duplex signal.

The Bluetooth Special Interest Group (SIG) maintains the technical standard. It also qualifies Bluetooth devices and issues licenses for the technology.

**ZigBee**® defines specifications for low-rate WPANs (LR-WPANs). It supports products that consume very little power and communicate over ranges from 10 to 100 meters. At the lower layers of its networking protocols, ZigBee is based on the IEEE 802.15.4 standard. This wireless communication technology provides reliable, self-organized, multi-hop mesh networking. It achieves a 250Kbps data rate and operates in the ISM bands: 868MHz in Europe, 915MHz in the USA and Australia, and 2.4GHz in most places, as well.

At the higher layers of this communication protocol, ZigBee defines various standard application profiles for interoperability. These include ZigBee Home Automation, ZigBee Smart Energy, ZigBee Health Care, and ZigBee Remote Control. A smart wireless thermostat might utilize the ZigBee Smart Energy profile.

Currently, the technical standards for this communication protocol are maintained and published by ZigBee Alliance, the group of companies promoting it. That organization has released several updates to the standard: ZigBee 2004, ZigBee 2006, ZigBee PRO, and the latest ZigBee IP. A company that wants to design, develop and market a device that uses ZigBee technology must become a member of the ZigBee Alliance.

**Wi-Fi** is the popular connectivity technology based on the IEEE 802.11 a/b/g/n standards for wireless local area networks (WLANs). Wi-Fi devices allow users to surf the Internet at high speeds when connected to an AP or when used in the ad hoc mode.

The IEEE 802.11 architecture consists of several components that interact to provide wireless LANs supporting communication mobility that aren’t dependent on the higher-layer applications. For that reason, Wi-Fi can be thought of as ‘cordless Ethernet’.
Wi-Fi has a range of about 50 to 100 meters and delivers data rates up to 54Mbps or more. It traditionally operates in the 2.4GHz ISM band. Due to the pervasiveness of Ethernet technology in home and business networks, Wi-Fi has become the top choice for wireless products. Its success has also been driven by an influx of smartphones that provide Wi-Fi connectivity.

A nonprofit organization, the Wi-Fi Alliance, enforces the standard interoperability and certification process.

Choosing between those three technologies for a wireless application first requires determining the design factors that must be considered. The engineering analysis must ascertain how important those factors are, research each protocol’s benefits and shortcomings in all areas of concern, and then make a design choice that takes into account tradeoffs between the alternatives.

Here, for example, are key technical issues pertinent to the design of a smart wireless thermostat:

- Bluetooth device designs can be more complicated than ones that apply ZigBee or Wi-Fi technology. Modular wireless solutions can lessen the complexity. However, some of the protocol’s higher layers may have to be implemented in the MCU, perhaps to the detriment of application performance. Bluetooth is most effective when it’s used to directly connect two devices that are in near proximity, but that’s not the case in a thermostat application.

- When ZigBee technology is used to provide wireless connectivity, the ZigBee PRO protocol and ZigBee Smart Energy profiles are usually implemented in the host MCU. Again, loading the MCU might degrade application performance.

- Wi-Fi technology requires more power, but achieves much higher data rates than Bluetooth and ZigBee while also delivering reliable communication over far greater distances. It’s the obvious choice if a product has to enable users to monitor and control system operations via the Internet. Of course, that is exactly the case for a wireless smart thermostat. The fact that a Wi-Fi enabled smartphone can also be used for remote control purposes is a huge bonus. By contrast, Bluetooth and ZigBee implementations require an Ethernet gateway to provide these capabilities, making the product more complex and expensive.

### III. Features of a Smart Wi-Fi Thermostat

In order to become a big seller in home markets, a smart Wi-Fi thermostat has to have a very simple set-up procedure. Manual operations must be intuitive, of course, and remote control and monitoring features have to be easy to use, too, preferably though a Web interface that is accessible over the Internet. Additionally, authentication and security features are essential for instilling confidence that the thermostat will function correctly when it’s being controlled remotely.

With those facts in mind, it’s instructive to examine how a smart Wi-Fi thermostat might be initially set up and put into use. When the thermostat is first powered up, the device might assume a limited Wi-Fi access-point role to allow the end user to connect to it and make it operational. The device could use its media access control (MAC) address to identify itself, for instance. (This procedure is basically similar to the one typically used to set up a newer wireless router, for example.)

After the user directly connects to the thermostat through a PC, smartphone or some other Wi-Fi enabled client, they could bring up a Web page on the client served by the thermostat and be prompted to search for and select the desired home or business network. Then they would be asked to enter the correct security keys for that Wi-Fi network to complete the local set-up process. After this process, the thermostat connects to the Wi-Fi network at the premise and gains access to the Internet.

The next step would be to configure the thermostat so that it could be accessed through the Internet. This might be accomplished by running a Web application usually called a portal. After creating an account and logging-in to the portal, the user, using the thermostat’s unique MAC address plus another key or a secure ID, registers the thermostat at the portal to complete the
remote set-up procedure. Thereafter, that key and secure ID would be used to authenticate the user and encrypt all messages to and from the thermostat. Just by accessing the Web application, the user would be able to securely control and monitor the thermostat over the Internet.

The Web portal might also be used to store the thermostat’s schedule and temperature settings. It could even trigger alarms if the thermostat senses that the environment it is controlling is getting too cold or hot. When the temperature exceeds preset thresholds, the device could send a warning message to the user’s PC and smartphone, hopefully prompting corrective action.

IV. A Reference Solution from Renesas

To give system engineers a head start for designing a smart Wi-Fi thermostat, Renesas application engineers have produced a valuable reference design for this application. This solution combines an RL78 MCU (microcontroller) and a GainSpan® Wi-Fi module (see block diagram, Figure 1).

![Figure 1 – Block diagram of the reference solution for a smart Wi-Fi thermostat.](image)

The reference solution is a powerful R&D tool that can be used to analyze and test a proven smart wireless thermostat design. It can also shorten the development cycle of a new product, serving as a solid starting point for further refinement and enhancement. It comes with complete schematic diagrams, layout files, a populated circuit board, and includes basic application software that runs on the RL78 chip. Android- and IOS-based smartphone code is also available. For more information on these development aids, please contact your Renesas sales representative.

The main component of the reference design is the Renesas RL78/L13 MCU — a 16-bit, 24MHz device in the RL78 family that incorporates an advanced LCD controller. The controller supports displays with up to 51 segments with 4 common signals, or types that have up to 47 segments with 8 common signals. The MCU’s ability to drive many segments with flexible configurations enables the creation of attractive, informative messages and graphics on the inexpensive, higher-resolution LCD devices now available.
Figure 2 shows the reference solution driving a custom LCD. The display's red ambient color indicates that the HVAC system is operating in its Heat mode. When the system is in Cool mode, the screen changes to a blue ambient color. In the photo, at 2:00 PM the temperature in the controlled area is 70° F and the humidity is 52 percent.

Because the RL78/L13 chip is a high-performance MCU with low power consumption, this reference solution includes a rechargeable battery. Normally, the smart thermostat is powered from the standard 24VAC typically available in HVAC systems, and the battery is charged from that source. However, the thermostat automatically switches to battery operation whenever the AC power is disrupted. The MCU can be put into many low-power modes, running on the subsystem clock or a low-speed on-chip oscillator, and those features make the chip ideal for battery-powered applications.

The RL78/L13 MCU provides up to 128KB of flash memory, 8KB of RAM and 4KB of data flash storage. The large flash can store not only the program code, but also the Web pages used during the thermostat’s initial set-up process. The reference solution, for example, uses only about 34KB of flash memory for those purposes. Heating and cooling set-points along with other user programming information can be stored in the data flash array.

The populated printed circuit board of the reference solution is shown in Figure 3. The five relays on the left control the power to the fan and the air conditioner or the furnace. The four push buttons on the left-hand edge of the PCB select different menu items available to the user to program and run the thermostat locally. The RL78/L13 MCU has many GPIO ports for controlling discrete logic or mechanical devices.

The GainSpan GS1011MEP Wi-Fi module on the right connects to the MCU (center) via a serial peripheral interface (SPI). That module supports IEEE 802.11b lower-layer protocols and also higher-layer networking stacks, including TCP/IP, HTTP, DHCP and SSL. It has been tested and certified by the Wi-Fi Alliance, an advantage that reduces system development time and cost.
In the reference solution, the RL78/L13 chip interfaces with a temperature sensor via an inter-integrated circuit (I²C) link. A humidity sensor connects to the microcontroller’s A/D input. Having many on-chip functions (real-time clock, etc.) and multiple interface options gives the RL78/L13 MCU great design versatility that system engineers can exploit here and in other applications.

The thermostat’s reference solution lets a user manipulate its functions and operation via a smartphone or a PC. Figure 4, for instance, shows the device’s control panel displayed on a Wi-Fi enabled smartphone. In this reference solution, the user directly connects to the thermostat using an IOS application.

The remote control function can be easily expanded to allow a user to monitor and control the thermostat over the Internet via a portal application. From that portal, many other possible functions could be implemented, including periodic monitoring of the HVAC system’s operations and generating and sending alarm notifications if abnormal situations are detected.

![Figure 4 – User interface for a smart Wi-Fi thermostat controlled from a smartphone.](image)

### V. Conclusion:

Smart programmable thermostats save energy and enable more comfortable environments in homes and businesses. Such thermostats can now be controlled and monitored remotely via wireless communication links to achieve additional cost savings and provide greater peace of mind.

Renesas supplies high-performance, low-power MCUs — especially the devices in the RL78 LCD family — for advanced home-automation and building-automation applications. Those versatile chips can also be used in blood glucose meters, security panels, home audio systems, smart home appliances, and other embedded system products. The reference solution for smart Wi-Fi thermostats showcases how friendly, flexible and informative human-machine interfaces can add value and make the advanced HVAC controllers easy to operate, manually or remotely, as well as more capable.

Renesas continues to partner with leading companies like GainSpan to extend the capabilities and market potential of the products customers produce for diverse global applications. We do so, for instance, by facilitating the design of the innovative devices with wireless connectivity features that now are rapidly establishing the ‘Internet of Things’. 