WHITE PAPER

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Wireless connectivity for the Internet of Things (IoT) with MSP430™ microcontrollers (MCUs)

Introduction

The early stage of the Internet of Things (IoT) has already started to change the way we live, do business and make decisions. As costs of controllers, processors, sensors and transmitters decrease, anything that can be given an electronic circuit and has reason to remotely communicate with other systems is a candidate to become "smart." This includes sensors, meters, thermostats, switches, medical monitors, motors, household appliances, vehicles, tools, even items of clothing and kitchen utensils. Whatever you name, it may soon become part of this fast-growing IoT.

As the IoT demands more connectivity in everyday products, MSP430™ microcontrollers (MCUs) are targeted to enable IoT applications through an ultra-low power architecture. This includes designing for the lowest standby power, active processing power, peripheral power, and memory read and writes. MSP430 MCUs offer the best power efficiency in any IoT application for developers that truly care about low power (and ultra-low power). MSP430 MCUs have a scalable platform to support consumer, industrial, and health and fitness applications today.

TI's ultra-low power MSP430 MCUs have been designed to serve in wireless-enabled applications with a variety of system architectures. The following paper presents four different IoT architectures and highlights how MSP430 MCUs can easily be designed with a wireless connectivity solution to kickstart an IoT design.

Wireless MCU solution

Ultra-low-power MSP430 MCUs are designed to serve in four different connectivity architectures. As shown in the diagram below, the first architecture is the wireless MCU solution that runs the network stack and the host application in one chip. TI's CC430 family is an example of a wireless MCU well suited for this architecture. This solution provides tight integration between the MCU core, peripherals, software, and a sub-1 GHz RF transceiver, creating a true wireless MCU solution that is easy to use. TI's CC2541 is another power-optimized wireless MCU example. It enables *Bluetooth*® low energy (BLE) and proprietary 2.4 GHz network nodes to be built with low total bill-of-material (BOM) costs. The CC2541 combines the performance of a leading RF transceiver with an 8051 MCU.

This configuration is ideal for small to medium RF protocol stacks where memory space can be evenly allocated for RF physical layer, RF protocol, and the top-layer application. Tight integration allows for highly optimized code and performance for transactions between physical and protocol layers.

On the hardware side, this configuration is an ideal fit for applications where physical layout size is a key priority. This configuration eliminates several external components that are now all integrated. In addition, the number of components required by both the MCU and the radio in two-chip solutions can be further reduced since the components can be shared in the wireless MCU configuration. Fewer components help simplify PCB routing and layout considerations, providing more freedom to optimize the RF layout and the placements of the components or sensors that actually matter in the applications, given the size constraint. Ultimately, these advantages all contribute to minimize the bill of materials (BOM) and physical board space to fit size-constrained and cost-optimized wireless applications.

One example of this architecture is the eZ430-Chronos™ smart watch, a highly integrated wireless development system that provides a complete reference design for developers creating wireless smart watch applications. Chronos is a reference platform for many applications, such as wireless watch systems, personal displays for personal area networks, wireless sensor nodes for remote data collection, and many other applications. The CC430 enables a high degree of integration, featuring a Sub-1 GHz radio front end, a 96 segment LCD display, a temperature sensor, a battery voltage monitor, an integrated pressure sensor and 3-axis accelerometer for motion sensitive control, all integrated into a small PCB that fits into a watch form factor. The Sub-1 GHz radio allows the Chronos to act as a central hub for nearby wireless sensors such as pedometers and heart rate monitors. On the software front, this application features SimpliciTI™, a thin and flexible RF protocol aimed for low-power wireless applications with star topology that can scale up to 255 nodes.

Architecture	MSP430 Example	Connectivity Example	IoT Applications
Wireless MCU – Network stack and host application both run on a single device **MSP430/RF** Appl Stack	**CC430** • Up to 20 MHz • 1.8V – 3.6V operation • Up to 32 KB Flash • Up to 4 KB RAM • Some devices include integrated LCD controllers • Integrates Sub-1 GHz RF transceiver	**SimpleLink Bluetooth low energy CC2541** • 2.4 GHz Bluetooth low energy compliant and proprietary RF wireless MCU • High-performance, low-power 8051 MCU core with code pre-fetch • In-system programmable Flash, 128 or 256 KB • 8 KB RAM with retention in all power modes	• Industrial/building automation • Asset tracking • Industrial monitoring and tamper detection • Alarm and security systems • Sports/body monitoring • Wireless sensor networks • Remote monitoring systems

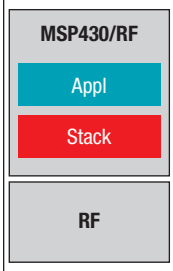
MCU runs stack and application

The second connectivity architecture has a powerful MCU, like the MSP430F5xx family, running both the host application and network stack, allowing wireless connectivity devices such as TI's SimpleLink Bluetooth CC2564 dual mode solution to provide best-in-class RF performance.

In this configuration, the MCU has complete control of the RF protocol and application layers, allowing the application to have more direct access and visibility into the RF and physical layers. This is the most traditional configuration for an MCU and RF transceiver. Pushing the intelligence into the MCU allows for a simple and robust radio doing what it does best: transmit and receive wireless data. Since the MCU usually has the most resources in terms of memory, processing power, as well as digital and analog integration, this configuration gives the MCU the most versatility, enabling it to leverage and optimize all of its resources to adapt and fit into various types of wireless protocols and applications.

For example, this architecture is often seen in ultra-low-power wireless sensor networks, such as the popular paring of the MSP430 MCU and the SimpleLink CC2500 2.4 GHz RF transceiver. Typically used in small to medium networks, the MSP430 MCU can run a relatively small and size-optimized wireless protocol with a small memory footprint supporting star and sometimes mesh topologies. The implementations in this type of architecture often build in features to optimize for power such as sleeping end nodes, time synchronization with access point beacons, packet store-and-forward, etc. These features are critical to enable ultra-low-power, energy harvesting, and battery-free applications.

This architecture is also seen in near field communication (NFC) applications. The TRF7970A NFC transceiver can be paired with the MSP430F5xx/6xx devices as they have multiple SPI ports, built-in USB and I²C interfaces. At the simplest level of pairing, this combination can add automation, control, and authentication to many existing MCU applications. For example, an NFC tag can replace a physical key for a door lock with the help of an MCU. The MCU contains the entire NFC stack, the security authentication software, as well as the application layer to control external peripherals including servos, motors, and LEDs. Taking a step further, this combination offers power savings and convenience in the connection handover applications, like an IoT gateway where users can benefit from a simple, one-touch set-up/configuration of a device on a Wi-Fi network.

Architecture	MSP430 Example	Connectivity Example	IoT Applications
MCU runs both network stack, and host application 	**MSP430F5xx** • Up to 25 MHz • 1.8V – 3.6V operation • Up to 256 KB Flash • Up to 18 KB RAM • Integrated USB connectivity • Unique USB developers' package to help you get started quickly **MSP430F6xx** All MSP430F5xx features + • Integrated LCD controller • Up to 512 KB Flash	**SimpleLink Bluetooth CC2564** • 2.4 GHz Bluetooth and Bluetooth low energy • BR/EDR features: Up to 7 active devices • LE features: supports up to six simultaneous connections • Class 1.5" TX power up to +12 dBm **TRF7970A** • Supports (NFC) standards NFCIP-1 (ISO/IEC 18092) and NFCIP 2 (ISO/IEC 21481) • Programmable output power: +20 dBm (100 mW), +23 dBm (200 mW) • Programmable I/O voltage levels from 1.8 VDC to 5.5 VDC • Programmable system clock frequency output (RF, RF/2, RF/4) from 13.56 or 27.12MHz crystal or oscillator	• Wireless audio solutions • Remote controls • Toys • Industrial control • Medical devices • Wireless sensor • Sports and fitness applications

MCU runs application

In the third architecture, the wireless connectivity solution contains the network stack like in the SimpleLink Wi-Fi® CC3000 module and a separate processor like the MSP430G2xx Value Line series MCU runs the host application. From the software standpoint, this configuration allows for minimal RF overhead on the MCU.

It is ideal for RF protocols that are well contained and do not change frequently. This is typically the case for the well-defined and fully matured RF technologies including Wi-Fi or GPS (and some Bluetooth). This scenario helps minimize field updating or re-programming of the RF stacks unless absolutely necessary. It also helps simplify the code development effort since developers can rely on the packaged RF stack and concentrate on the high-level application in the MCU. The isolation of the RF stack and the application layer allows the MCU to invest maximum hardware resources and bandwidth on the application.

This workload distribution scenario is also an ideal fit to exploit a new and unique type of memory in the MCU industry, Ferro-electric Random Access Memory (FRAM). FRAM offers both non-volatile attributes (like Flash) and ultra-low power high-speed read, write and erase accesses (like SRAM). It has virtually unlimited read/write cycles and bit-level addressability offers embedded developers complete freedom to allocate and map out their MSP430 MCU memory for code, memory, and data logging without restrictions or power consequences. Flexible memory configuration accommodates stringent wireless protocol requirements, enabling various wireless stacks on the same memory footprint. Universal memory offers freedom to innovate. The mostly static and unchanged RF code can reside in the traditional Flash memory on the radio, while application code of a more dynamic nature (data logging, versatile allocation of code and data memory, etc.) can use the universal memory on MSP430 FRAM MCUs.

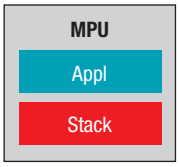
Architecture	MSP430 Example	Connectivity Example	IoT Applications
RF solution contains network stack, and a separate MCU runs host application **MSP430** Appl **RF** Stack	**Value Line – MSP430G2xx** • Up to 16 MHz • 1.8V – 3.6V operation • Up to 56 KB Flash • Up to 512 B RAM • MSP430G2xx2 and G2xx3 provide unique capacitive touch sense IO ports **FRAM – MSP430FR5xxx** • Up to 24 MHz • 1.8V – 3.6V operation • Up to 64 KB FRAM • Up to 1 KB RAM	**SimpleLink Wi-Fi CC3000** • IEEE 802.11 b/g Wi-Fi • Embedded IPv4 TCP/IP stack • Operating temperature: –20°C to 70°C • Small form factor: 16.3 mm × 13.5 mm × 2 mm **SimpleLink GPS CC4000** • Fully integrated GPS driver and firmware • NMEA 0183 interface protocol communication • NMEA messages supported: GGA, GLL, GSA, GSV, VTG,RMC • GPS tracking sensitivity: –162 dBm • Host interface: UART	• Home automation • Smart appliances • Smart energy • Portable medical • Sensor networks • M2M communications

MCU runs low-power task

In the last connectivity architecture, a wireless connectivity solution, such as TI's WiLink™ 8 combo connectivity solutions, connects to a microprocessor (MPU) like TI's Sitara™ AM335x processor, which runs the host application, Wi-Fi and Bluetooth network stacks. A separate MCU runs a specific low-power task (e.g. sensor hub).

In this combination, MSP430 MCUs functions as an "always-on" processor monitoring user stimuli to determine when to enable wireless communication, like when an accelerometer records movement and some data needs to be transmitted. The application processor and RF transceiver can go into sleep mode while the MSP430 MCU periodically monitors the accelerometer and wakes up the MPU and RF only when necessary. The battery life can be greatly extended due to the lower active and standby power consumption of MSP430 MCUs.

MSP430 MCUs can wake up to touch and proximity, sensor activation, or hook to push buttons or other sensors via GPIOs. MSP430 MCUs can also be used as a system controller for battery management, temperature sensing and general system management functions. In this architecture, MSP430F552x, F522x and F525x devices have 1.8V IOs that allow interface to the applications processor without any level shifters (thereby saving costs and PCB size).

Architecture	MSP430 Example	Connectivity Example	IoT Applications
MCU runs low-power task and a separate MPU runs both network stack and host application  *MPU: Sitara AM335x processor*	**MSP430F5xx** • Up to 25 MHz • 1.8V – 3.6V operation • Up to 256 KB Flash • Up to 18 KB RAM • Integrated USB connectivity • Unique USB developers' package to help you get started quickly	**WiLink 8 platform** • Wi-Fi, Bluetooth, Bluetooth low energy and ANT on a single chip • Attaches to MPUs (i.e. Sitara AM335x processor) • Based on 45nm CMOS technology • Shared HCI transport for BT/BLE/ ANT over UART and SDIO for Wi-Fi	• Smart appliances • Automotive • Portable consumers and enterprise • Smart home • Smart energy

Conclusion

Products that we're accustomed to seeing with wires are now increasingly becoming wireless. Increasing a product's capability and accessibility are among the many benefits to adding wireless connectivity. There are several things developers should consider when evaluating wireless options because different application architectures have their own strengths; but also pose challenges that must be solved before becoming wirelessly enabled. By first determining which architecture fits best in a given application, whether it be a wireless MCU; an MCU running the stack and application; an MCU running the application; or an MCU running low-power tasks, developers can select the key components that make wireless designs simpler and smarter. If power consumption is a consideration, TI's ultra-low power MSP430 MCUs are a great foundation for your IoT projects. TI offers the broadest portfolio of wireless and MCU solutions designed to enable any IoT application.

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