ZigBee RF4CE

- Radio Frequency for Consumer Electronics -

IEEE BU, Low Power Wireless

Texas Instruments

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ZigBee RF4CE Overview

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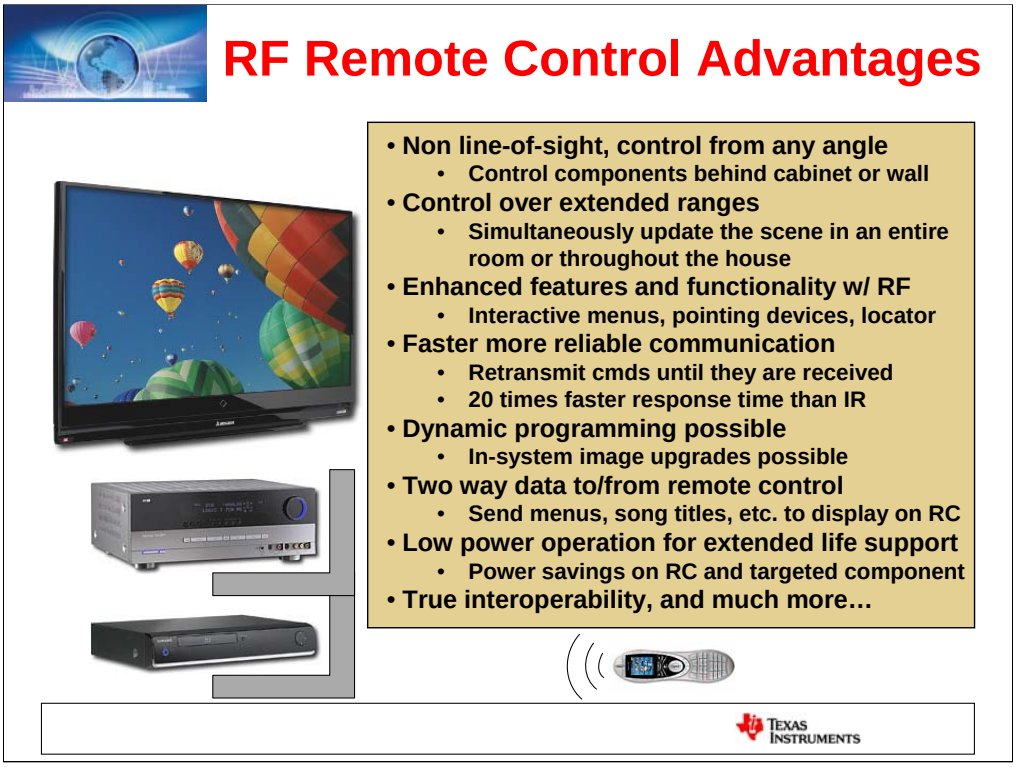
RF4CE consortium founded by Sony, Philips, Panasonic and Samsung, with invitation to TI, Freescale and OKI for technical contribution

RF4CE integrated into ZigBee Alliance early 2009. Specification released shortly thereafter, including single Remote Control profile.

"ZigBee" branding now represents a portfolio of technologies (that will grow) including ZigBee PRO, ZigBee RF4CE, and soon ZigBee IP. On top of these core protocol stacks application specific "profiles" exist to customize the technology to a market and ensure interoperability where desired.

Please visit the ZigBee Alliance website for more information including

- RF4CE page
- FAQ's
- White Papers
- Featured products



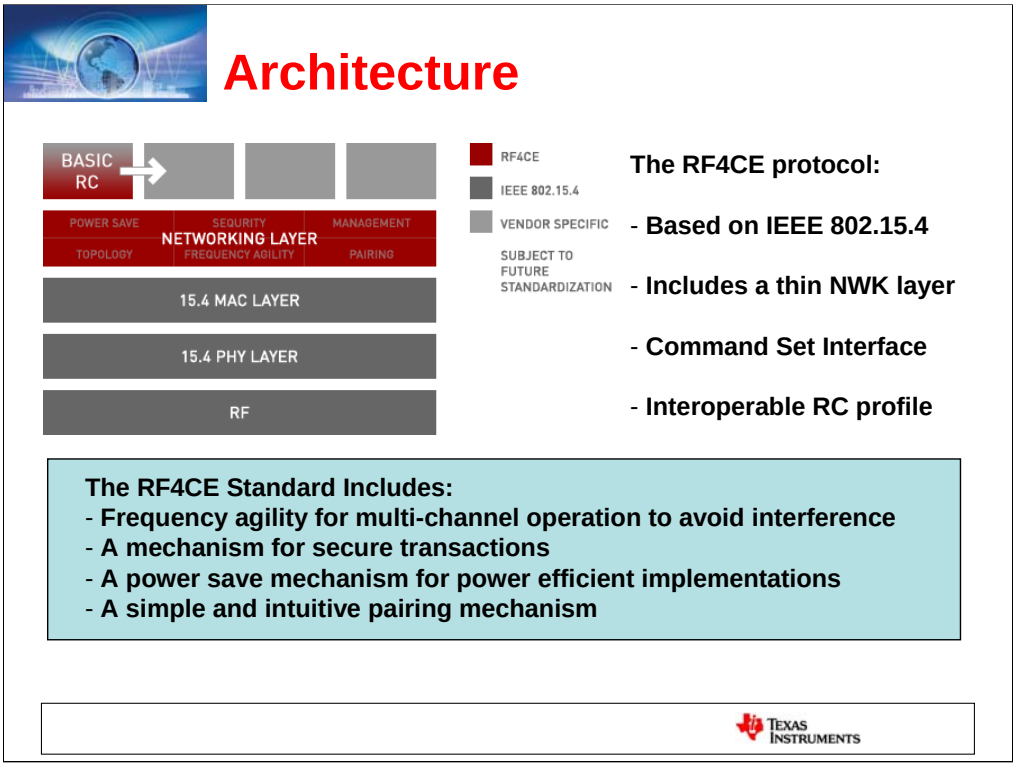
RF offers several advantages over IR that justify the small additional cost of this technology.

Mainly RF allows for non line-of-sight control over longer distances and at any angle.

RF provides two way communication which means the remote control can display additional information provided by the consumer electronics device, or can receive configuration or software updates while in operation.

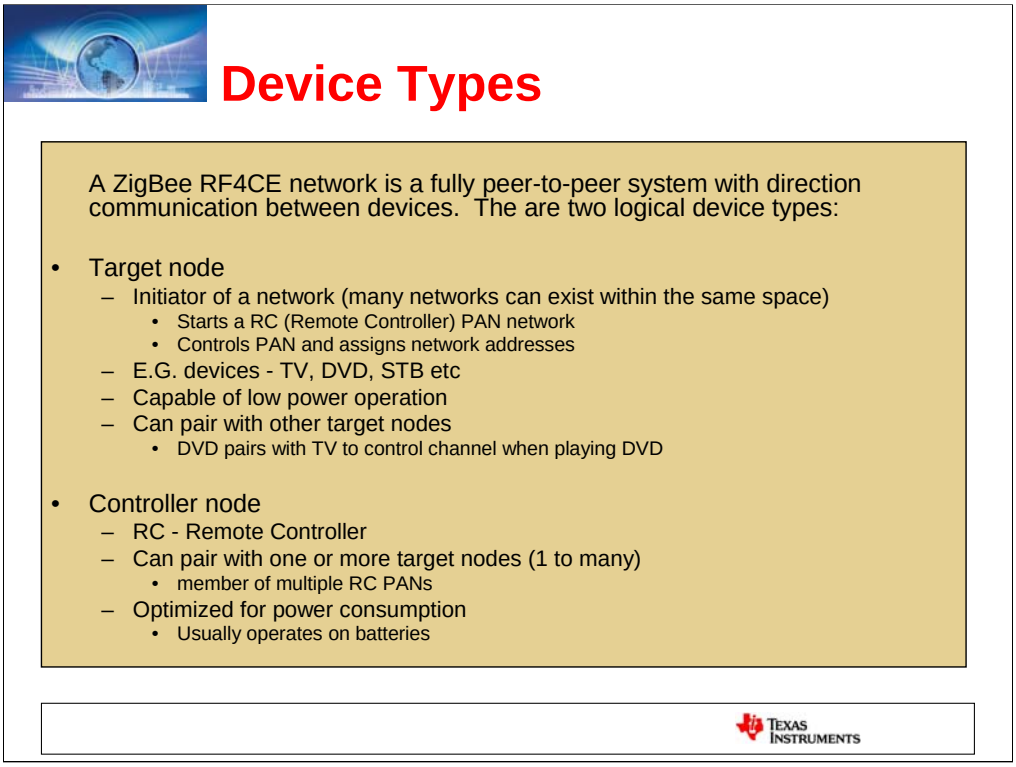
RF actually consumes significantly less power than its IR equivelent, both on the remote control and on the target side.

By specifically utilizing the RF4CE Remote Control profile, RF also ensures interoperability by adhering to a very specific command set.



The RF4CE protocol stack builds on top of the mature IEEE 802.15.4 PHY and MAC protocols, simply adding a very thin networking layer to establish and configure devices into a network, create pairings between control and target devices (or in some cases between two target devices), provide secure communication, optimize low power operation, and ensure robust communication by employing features such as frequency agility and nwk level retransmissions. On top of the networking protocol RF4CE also provides a simple Remote Control profile that defines the command set used for basic remote control operation.

When products are built using a certified compliant RF4CE protocol stack while adhering to the Remote Control profile, they are sure to be interoperable with other vendor devices.



RF4CE defines two device types, a target node and controller node. The target node is for the most part the device being controlled by the controller (aka remote control).

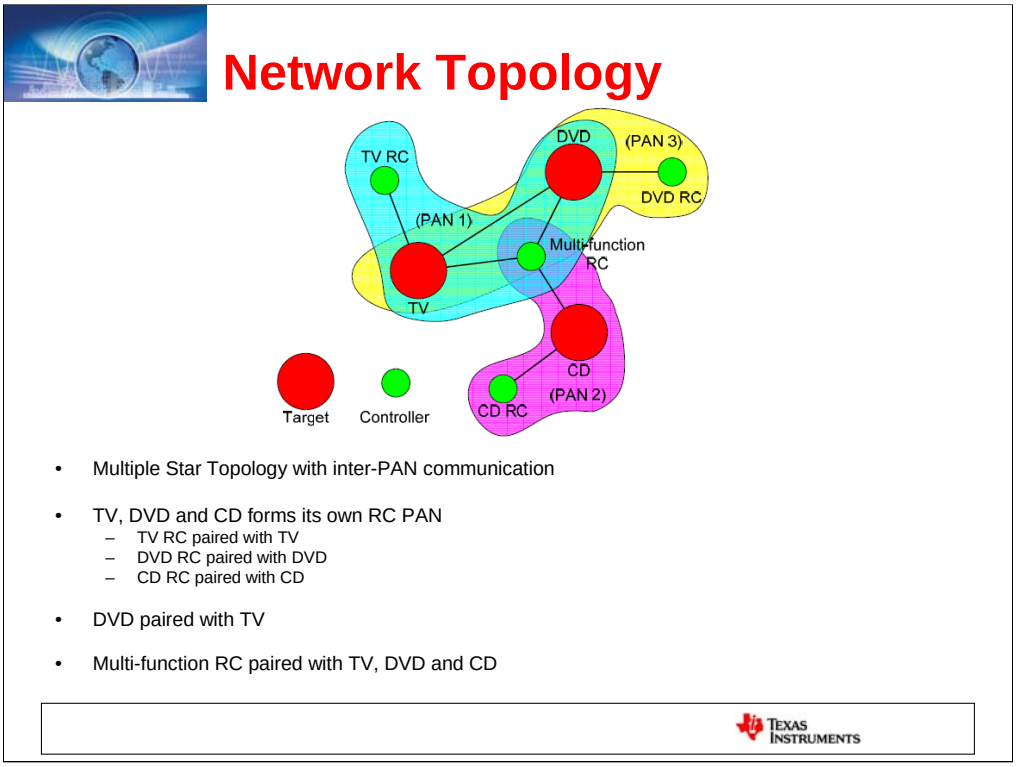
Each RF4CE target node essentially forms a PAN, or personal area network. By PAN we mean a network of locally collaborating devices in relatively close (10's meters or less) proximity.

A target node creates a PAN by establishing a unique PAN_ID and determining which channel to operate on.

Controllers then join one or more PANs to establish a pairing with the target they will control. Once paired, controllers use unicast messages (optionally secured) to send commands or other data.

Once paired target nodes can communicate with a controller but must use broadcast communication to ensure that the controller will receive the message. This is in part due to the fact that a controller is likely to belong to multiple PANs and may have to communicate on several of the 3 available RF4CE channels. To allow target to controller communication in this manner while operating the controller in low power mode, the Controller application must explicitly enable RX.

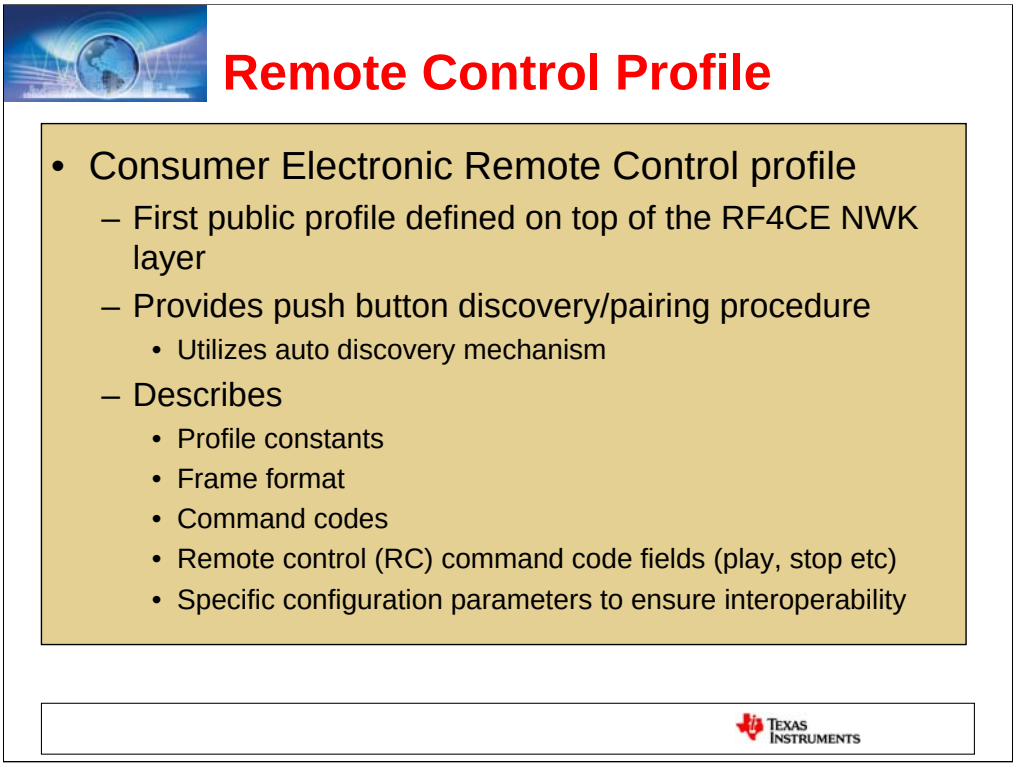
Details on various methods of achieving this, as well as more information on the device types, network configuration, supported methods of communication, and much more are discussed in the RF4CE developer's guide available on the RemoTI product folder page.



RF4CE keeps networks simple with a single network formed by every target device. Controllers are then introduced into one or more networks using a very simple discovery and pairing mechanism.

In addition to controller to target communication, target to target communication enables functionality like DVD->TV communication. This can be useful for media centers where it makes sense to have the powering on of a DVD player configure your TV and stereo for video and audio input from the appropriate source.

While the RF4CE specification itself does not limit the number of pairings, the existing RemoTI library supports 10 pairing entries for both the target and controller in order to effectively control RAM allocation on the CC2530.



The RF4CE protocol layer provides the core networking functionality while the Remote Control and other (future public) profiles built on top of the NWK layer define profile constants, frame formats, command codes, and other configurable parameters that define a common language for devices to ensure interoperability between products.

It is also possible to extend the Remote Control or other public profile with vendor specific commands that allow flexibility and differentiation.

It should be noted that it is not mandatory that you follow a public profile so long as you do not require interoperability with other vendors products. This could occur when you are building a product in a market that does not have a public profile (using RF4CE networking for a medical application) or you build a product that you specifically do NOT want to work with other vendor devices.

However please note that to utilize the RF4CE protocol a company must be a member of the ZigBee Alliance at the adopter level or higher.

TI offering

CC2530/CC2531

Second generation 2.4 GHz ZigBee®/IEEE 802.15.4 RF System-on-Chip

Features

- Up to 256 Kb Flash / 8Kb of RAM
- Excellent link budget (101dB)
- 49dB adjacent channel rejection (best in class)
- Four flexible power modes
- Extended temperature range: -40 to +125 degrees C
- AES-128 security module
- 21 GPIOs, 2 USARTs, and a rich peripheral set
- CC2531 supports USB 2.0 Full Speed device
- Fully compatible with the CC259x range extenders
- RoHS compliant 6x6mm QFN40
- Powerful IR generation circuitry

Benefits

- 2X FLASH over closest competitor
- Supports ZigBee PRO, ZigBee RF4CE, and more!
- 400m+ LOS range with CC2530EM dev boards
- 12dB better than closest competitor filters interference from a jammer over 4x closer
- Lowest current consumption power down mode for long battery life low duty-cycle applications
- Widest temperature range for superior robustness
- Efficient security takes up little FLASH or MCU cycles
- Reduced part list and lower BOM cost
- Ideal for Gateway or Bridge device
- Simple low-cost solution to 1000+ meter range
- Allows smaller PCB to help miniaturize product
- Provides legacy IR support with no added cost

Applications

- 2.4 GHz IEEE 802.15.4 Systems
- ZigBee RF4CE Remote Controls
- Set-Top Boxes and RF controlled TVs
- ZigBee-Pro AMI systems
- Low-Power Wireless Sensor Networks
- Lighting and Home Controls

Suitable for systems targeting compliance
- ETSI EN 300 328 and EN 300 400 class 2 (Europe)
- FCC CFR47 Part 15 (US)
- ARIB STD-T66 (Japan)

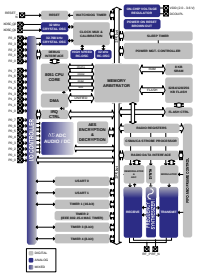
EVM

CC2530 DK

CC2530 ZDK

CC2530/1 EMK

RemoTI-CC2530DK



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The CC2530 is TI's second generation IEEE 802.15.4 compliant System on Chip. The CC2530 couples the 15.4 transceiver with an 8051 MCU core.

The CC2530 is capable of transmitting at up to +4.5 dBm, and when communicating with another CC2530 achieving -97 dBm receive sensitivity, the CC2530 can easily communicate 10s, and potentially can communicate 100's meters under the right conditions (environment, antenna, packaging, obstacles, etc…). Communication is further enhanced through the CC2530's excellent selectivity, all while consuming very little power thanks to several power down options and quick state transitions.

The CC2530 core has also been optimized for the 802.15.4-based low power RF market. Memory configurations run from 32 to 256K FLASH, and all devices support 8K of RAM to ensure support for any of the several standard or proprietary protocols available for this device. The CC2530 supports a diverse peripheral set and comes with IR generation capabilities to support RF remotes that must be backward compatible with legacy IR. A sister device of the CC2530, the CC2531, support full speed USB and will be available end Q3 2009.

The CC2530 can be designed into any product using one of several antenna reference designs available, or coupled with an RF front end such as the CC2590 or CC2591 to increase communication ranges.

There is much more to share about the CC2530, so please visit www.ti.com/CC2530 to download the datasheet and other documentation on this device.

RemoTI Software Stack

RemoTI is the leading RF4CE-compliant software architecture

- ZigBee RF4CE compliant Golden Unit
- Standard interoperable RC profile support (Remote)
- Simple remote control kit w/ target board and PC emulator
- Simple RemoTI API, or optional direct RF4CE interface
- Basic remote sample application code
- UART, SPI, keypad, LED, and other driver support
- IR generation and sample code
- Network processor support for fast and easy development
- Serial boot loader and over-air download sample code

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RemoTI is TI's golden unit protocol stack built fully compliant to the ZigBee RF4CE specification. In addition to supporting the RF4CE protocol and public Remote Control profile, RemoTI also offers the following:

-Sample application code including Remote Control profile examples

-Remote control form factor development kit

-Simple stack API and network processor form factor for easy development

-Comprehensive documentation, application notes, user guides, reference designs, etc…

-Driver support for UART, SPI, and future USB support for CC2531

-IR generation and sample code for legacy IR support

-Serial boot loader support and over the air download capabilities

Tools

- RemoTI-CC2530DK Kit
  - RF Remote Control
  - Target Module (Receiver Board) w/ CC2530EM
  - CC Debugger, cables, adapter board, etc…
- Software
  - RemoTI Installer
    - Stack Library
    - Sample Applications
    - PC Emulator Tool
    - Network Processor
    - OAD / Serial Bootloader Demo
- Also available
  - CC Packet Sniffer
  - Daintree Packet Sniffer
  - Flash Programmer
  - Legacy IR support

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For anyone looking to evaluate or get started with RF4CE we offer a remote control form factor kit that has everything needed to get started building an RF4CE compliant product. The kit includes a programmable remote control w/ sample code as well as a target module that interfaces to a PC over USB and connects to remote control emulation software running on the PC that can display incoming commands as well as manage the RF4CE network.

Aside from our kit, stack, software, sample application code, documentation, and tools, we also work with several third parties to support additional tools, modules, third party design services, and much more.

Please visit www.ti.com/remoti to learn more about our RemoTI-CC2530DK development kit, support documentation, tools, and other remote control or wireless sensor / actuator networking products.

Coexistence

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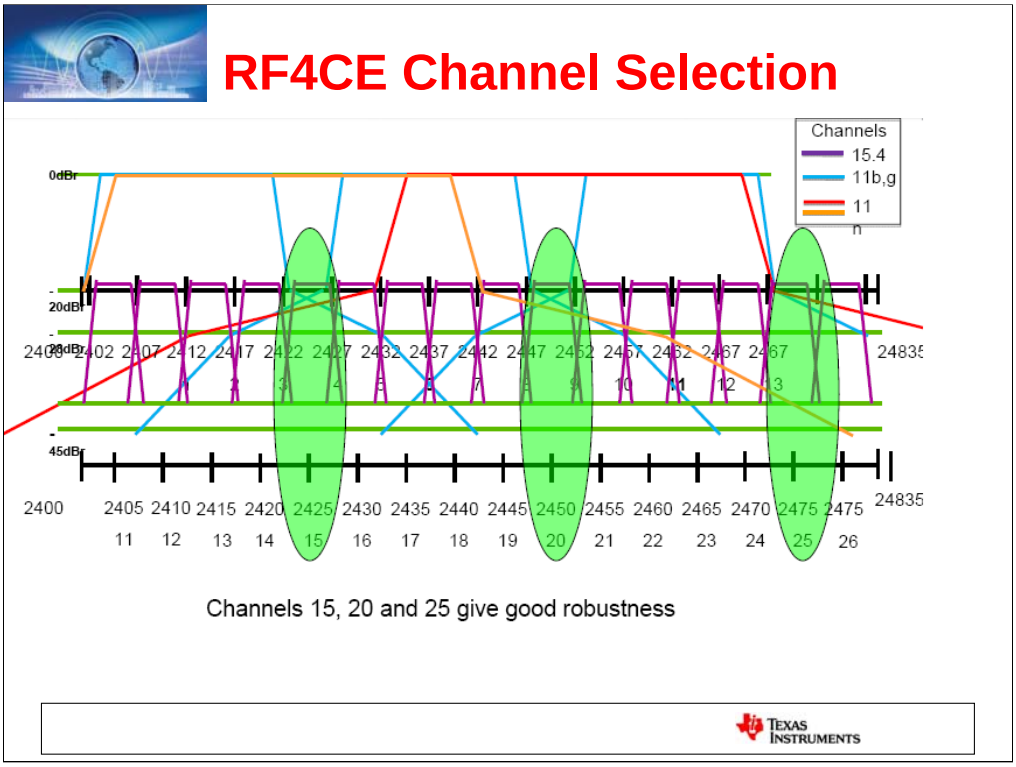
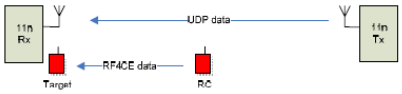


RF4CE has defined usage of 3 of the 16 available IEEE 802.15.4 channels. Three channels were chosen to reduce the amount of time spent searching when discovery and frequency agility take place. The three selected channels, 15, 20 and 25, were chosen specifically to ensure that operation is as far outside of the WiFi bands as possible.

Coexistence Testing

- 2.4GHz band is crowded: WiFi, microwave ovens, cordless phones, bluetooth etc
- Co-existence testing shows very good results in presence of 802.11n 40MHz channel (see www.ti.com/lit/swra285 for details)



Latency (ms)	Packets received	
	6mbps	*15mbps*
0 – 10	87.2	78.9
10 – 20	99.8	94.3
20 – 30	100.0	97.9
30 – 40	100.0	98.9
40 – 50	100.0	99.6
50 – 60	100.0	99.8
60 – 70	100.0	99.9
70 – 80	100.0	100.0
80 - 90	100.0	100.0
90 – 100	100.0	100.0

Latency (ms)	Packets received	
	6mbps	*15mbps*
0 – 10	83.7	55.2
10 – 20	99.3	79.4
20 – 30	99.8	90.0
30 – 40	99.9	94.0
40 – 50	100.0	96.3
50 – 60	100.0	97.9
60 – 70	100.0	98.8
70 – 80	100.0	99.4
80 - 90	100.0	99.6
90 – 100	100.0	99.8
100 – 150	100.0	100.0

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From basic WiFi co-existance testings we are able to show virtually 100% data throughput within a very small latency window.

Under normal remote control operation this latency is well within the noticeable range of human perception (estimated at 2-300 ms).

For pointing devices, gaming controllers, and other advanced RC devices latency could become more of an issue although it is not likely when there is a physical separation between WiFi and the RF4CE devices.

Please take a look at the RemoTI Co-existance application note for more information and a more in depth discussion.

Power Consumption

Example RC Usage Model

RC Usage Model

SWRA263, AN073

System	Number of units	Standby mode key presses	Active mode key presses	Standby mode current consumption	Active mode current consumption
TV	1	2	50	9080	18679
Receiver	1	2	100	9080	37359
DVD/Bluray	1	1	20	4540	7472
Cable/Satellite	1	0	100	0	37359
Active current				22700	100869
Avtive Total					123569
Sleep Total					34560
Total Power consumption in a day					**158129**

Average RF Current consumption (mA)	**0.0018**	mA
LED	**0.0000**	mA
Display	**0.0000**	mA
Avergage System Current Consumption (mA)	**0.0018**	mA
Battery life (years)	**187.12**	years
Total packets sent in a day	**1092**	

Inputs

Number of CERC packets per button press	3	
Battery capacity (AA=3000mAh, AAA=1200mAh)	3000	mAh
Active Period (Target node)	16.8	ms
Duty Cycle (Target node)	330	ms

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The chart above provides an example use case model of remote controls in the consumer electronics market.

Our analysis concludes that the power consumption from RF is a nominal portion of total power consumption on a remote control, especially in the case where a RC has a display, LEDs, etc…

Please reference the application note RemoTI Power Consumption for additional information and a more in depth power budget analysis.

Resources

Resources

- ZigBee RF4CE: www.zigbee.org/rf4ce
- CC2530: www.ti.com/cc2530
- RemoTI: www.ti.com/rf4ce or www.ti.com/remoti
- Application notes:
  - Coexistence: www.ti.com/lit/swra285
  - Simple Application: www.ti.com/lit/swra286
  - Power consumption: www.ti.com/lit/swra263
  - Host proc porting guide: www.ti.com/lit/swra259
- FAQ: www.ti.com/lit/swra281
- Support:
  - E2E community: community.ti.com
  - Factory email: lpwsupport@ti.com

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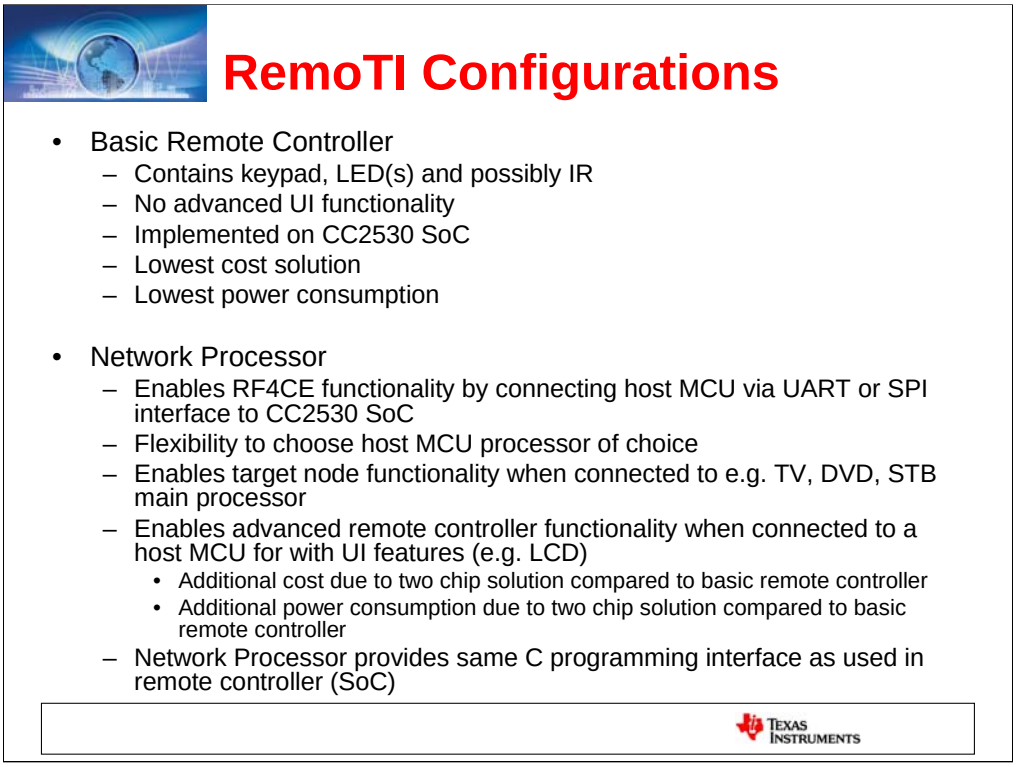
Technology in more details



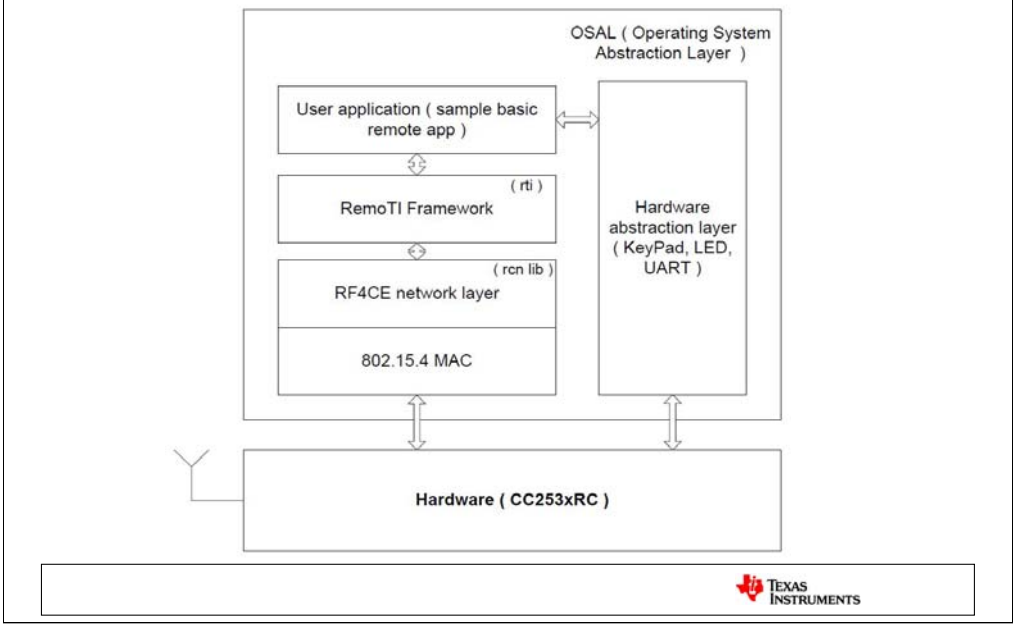
The Basic Remote Control sample application we provide with our kit showcases how a remote application can co-exist with the RF4CE protocol stack on our CC2530 System On Chip to produce the cheapest RF4CE solution. The basic remote controller does not have some of the bells and whistles that could be desired for an RF remote, but does provide everything needed (including legacy IR support) for building a simple RF remote control to replace existing IR RC's today.

For more advanced remote controls that require a secondary, possibly more powerful micro to implement advanced functionality, or for the target side module where a processor already exists in the TV, STB, or other device, a Network Processor configuration allows for easy integration utilizing the SPI or UART with a very simple messaging interface.

A network processor will require a second application micro-controller and may not be the most cost effective solution for simple remote controls. However using a network processor configuration creates a clean separation and abstracts the RF portion of the product, often simplifying design and reducing NRE costs.

Please see the RemoTI Network Processor User Guide for more information, available on the RemoTI product folder.

Basic Remote Controller Architecture

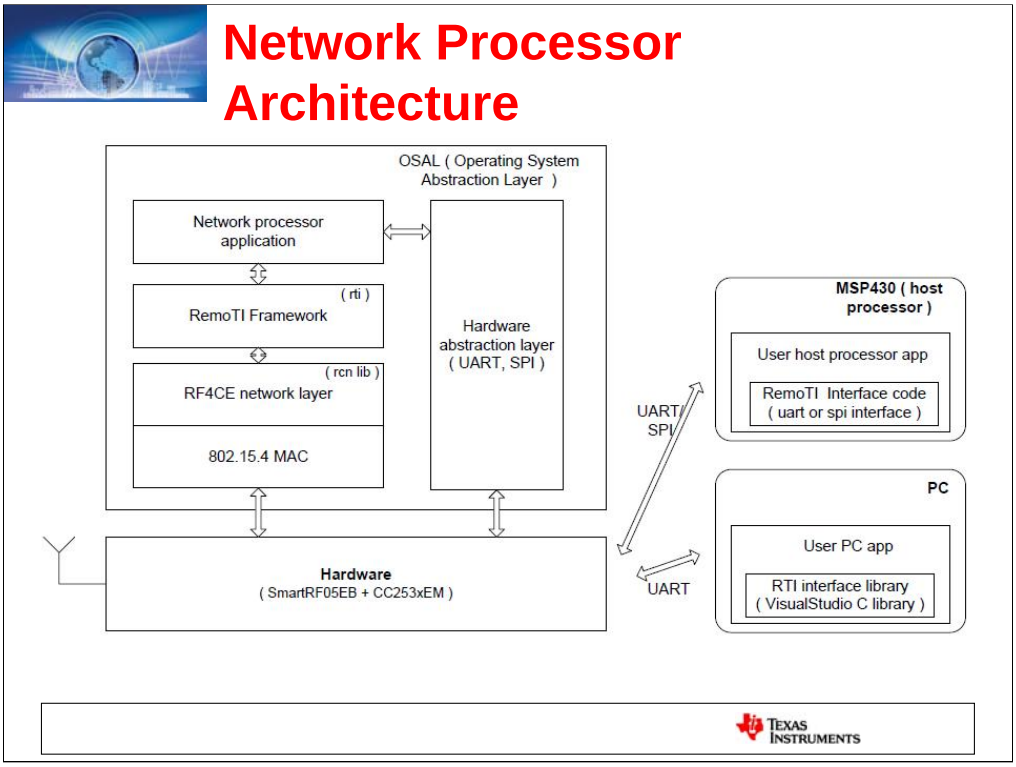


When utilizing RemoTI to build a basic RF4CE compliant remote control, the basic remote control architecture is comprised of the 802.15.4 compliant RF physical hardware running the RemoTI stack including various protocol layers, and the basic remote control application all on the single CC253x System on Chip.

The RemoTI framework provides the necessary interface to implement basic remote control functionality using the standard Remote Control profile defined by the ZigBee Alliance. Sample application code is provided with the RemoTI projects to show a simple remote control implementation that can be modified as needed.

Altogether the 802.15.4 MAC, RF4CE network layer, RemoTI framework, hardware abstraction layer and simple remote control user application fit nicely within the 64K FLASH, 8K RAM CC2530 device.

Network Processor Architecture



RemoTI includes support for the network processor application which allows a host processor to drive the CC2530 w/ RemoTI NP over UART or SPI for a simple interface that isolates the application from the networking / RF piece.

The RemoTI network processor application is fully compliant with ZigBee RF4CE network layer specification, either as a controller node or as a target node, and is dynamically configurable to either.

The RemoTI network processor application includes full network layer security, 115K baud rate UART (alternate 9.6k, 19.2k, 38.4k, or 57.6k baud supported). Alternately it supports configurable SPI connectivity.

The network processor code supports wakeup via UART

The network processor application code supports optional serial boot loader downloading (requires 128K or higher memory version of CC253x device)

Frequency Usage

- RF4CE operates in the 2.4GHz band as specified by the IEEE 802.15.4 specification
- To add robustness due to crowded 2.4GHz band, RF4CE operates on three channel; 15, 20 and 25
  - Target node chooses channel at startup (cold-boot).
  - Target node can change channel if conditions on current channel becomes compromised
    - RF4CE does not specify when to switch to another channel, this is implementation specific
- Controller node keeps record of current RC PAN channel
  - This is recorded in the pairing table after pairing with the target
  - Controller node will always start communication on the recorded RC PAN channel
  - In the event of no response from target due to channel change (for Unicast, Multi-channel, ACKed TX option)
    - Multiple (configurable, default is 4) attempts are made on current channel
    - Then 1 attempt is made on the next two channels successively
    - If still no communication with target, 1 attempt is made on all three channels in a round-robin fashion for a total of 1 sec
  - When the controller node reacquires communication on the new channel, the new channel is recorded in the pairing table for next communication attempt

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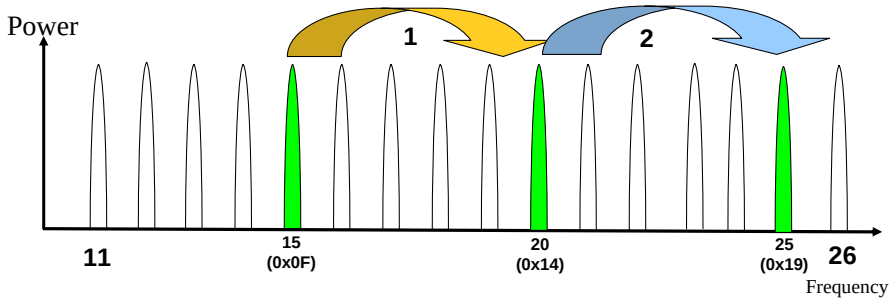
Frequency Agility

- All nodes support frequency agility
- Target specifies PAN base frequency
- Target can switch frequency on adverse channel conditions
- Controller node keeps record of current RC PAN channel
- Other nodes know where the target was and attempt to transmit
- If target not found, nodes re-acquire by trying each frequency



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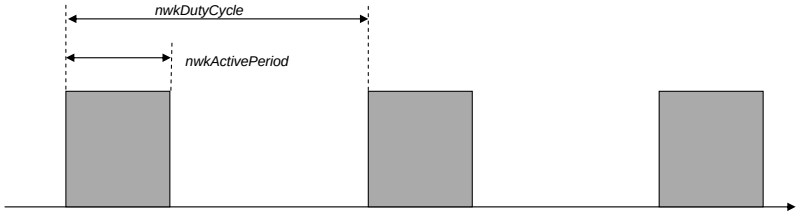
The standard specifies that the target can change channel at it's own discretion. It does not describe under what conditions frequency agility will take place. As a result the remote controller is designed to, upon communication failure and depending on the transmit options, to handle the possibility that the targets it is paired with could change channels at any given time.

For more detail on frequency agility please look at the RemoTI Developer's Guide.

Power Saving

- Controller node
  - Only on when processing/sending data or instructed by the application to stay in RX mode (in anticipation of data from a target node)
- Target node
  - Always in RX mode if *nwkInPowerSave* = FALSE
  - In standby mode if *nwkInPowerSave* = TRUE
    - Power saving dependent on *nwkDutyCycle* and *nwkActivePeriod*
      - *nwkDutyCycle < (nwkcMaxDutyCycle = 1s)*
      - *nwkActivePeriod > (nwkcMinActivePeriod = 16.8ms)*



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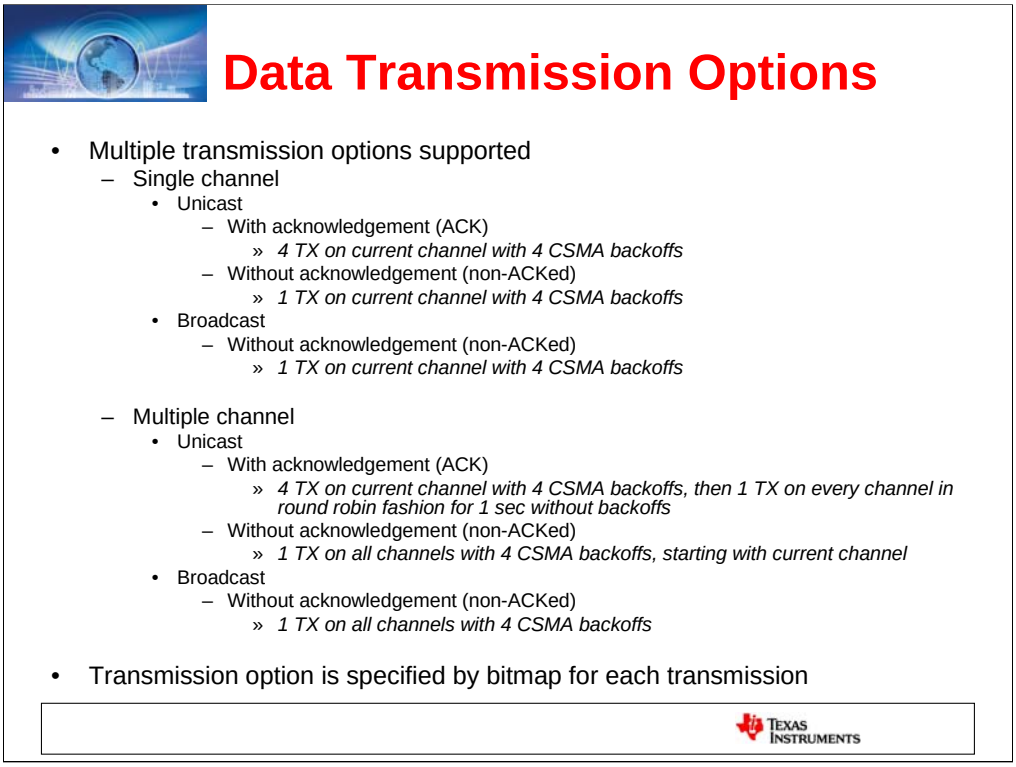
For a controller node that needs to receive commands from a target device the controller nodes application must control switching the transceiver into and out of receive mode. For periodic polling this must therefore be handled at the application layer.

For power savings on the target node the Active period was carefully selected to ensure that the RC could send a message on all 3 channels which would then be received by the target node at some point within the network duty cycle.



Various transmission options exist when using RF4CE and RemoTI.

Ack/NoAck

This option determines whether the source node should request an acknowledgement (802.15.4

MAC-level acknowledgement) from the destination node upon receipt of the original packet.

Unicast/Broadcast

This option determines if the packet is transmitted to a specific destination node (unicast) or if it is

broadcast to all nodes that are in radio range of the source node.

MultiChannel or SingleChannel

This option determines if the packet is transmitted on a single channel or on all three **RF4CE** operational channels.

This slide summarizes these options. More information is available in the RemoTI Developer's Guide to show how configuration options can be utilized for various forms of communication between target and controller.

Security

- Utilizes the AES-128 core
- Security features
  - Data confidentiality (via payload encryption)
  - Data authentication (via Message Integrity Code)
  - Replay protection (via frame counter)
- Nodes use 128-bit link keys
  - Keys are generated automatically, if security is supported
  - Keys are stored in the pairing table
- Application can decide which transmissions require the use of security

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Secure communication is managed between paired devices, not across a PAN.

Secured links are optional and key establishment is setup during pairing.

Confidentiality is when AES encryption is used with a private key.

The message integrity code ensures that a packet was decrypted with the appropriate key.

The frame counter ensures no two encrypted packets are identical to protect replay attacks.

Over-The-Air Download

- Enables field upgrade of the RC node image
- Bootloader consumes 2K bytes

Initial image programming
- Program bootloader
- Program active image

Upgrade in the field
- Download new image Over-The-Air
- When downloaded image is verified, copy into active image area
- Reset and boot new image

Note! Require additional flash to hold two images

TEXAS INSTRUMENTS

Over the air download is a TI supported feature, and is NOT part of the core RF4CE specification.

This is a clear differentiator as TI has a patent for over the air download.

OAD utilizes TI vendor specific extensions to the CERC profile to download a new stack (network and application) which then replaces the existing stack using the bootloader. Because you have to save the new image in memory you need additional FLASH available to store the new image.

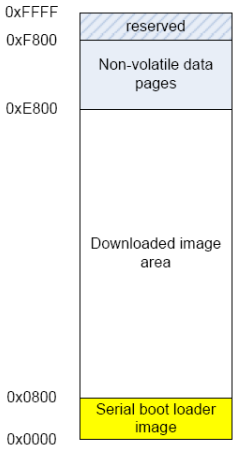
Serial Bootloader

- Enables field upgrade of the target node image
- Bootloader consumes 2K bytes

Initial image programming
- Program bootloader
- Program active image

Upgrade in the field
- Download new image over serial link (UART)
- When downloaded image is verified, reset and start new image

Note! Does NOT require additional flash to hold two images



When a device is connected via SPI or UART to another microcontroller the serial bootloader allows a new image to be uploaded without maintaing the existing image in parallel. This means that you will not require additional memory space on the device.

Many customers find this functionality critical as it ensures you can upload the software to fix application bugs or add enhanced features, extending the lifetime fo the product.

Q&A