ZigBee RF4CE

- Radio Frequency for Consumer Electronics -

What is RF4CE

RF4CE

Radio Frequency for Consumer Electronics

ZigBee RF4CE Story

- Founding Members

The RF4CE industry consortium and the ZigBee Alliance are working together to jointly deliver a standardized specification for radio frequency-based remote controls.

Visit **www.zigbee.org/rf4ce** for more information on the RF4CE standard
Visit **www.ti.com/rf4ce** for more information on TI's RF4CE solution

What RF4CE would like to do

Faster, more reliable and provide more freedom to operate devices from greater distances by removing the line-of-sight barrier found in today's IR remotes. They also enable advanced features such as two-way communication between the device and the remote, creating a richer experience for consumers.

RF Remote Control Advantages

- **Non line-of-sight, control from any angle**
  - Control components behind cabinet or wall
- Control over extended ranges
  - Simultaneously update the scene in an entire room or throughout the house
- Enhanced features and functionality w/ RF
  - Interactive menus, pointing devices, locator
- Faster more reliable communication
  - Retransmit cmds until they are received
  - 20 times faster response time than IR
- Dynamic programming possible
  - In-system image upgrades possible
- **Two way data to/from remote control**
  - Send menus, song titles, etc. to display on RC
- Low power operation for extended life support
  - Power savings on RC and targeted component
- True interoperability, and much more…

TEXAS INSTRUMENTS

Features

- Bi-directional high speed communications
- Removes line-of-sight or field-of vision barriers
- Standardized commands
- Standards based
- Over the air upgrades and programmability
- Interference avoidance mechanisms
- Increased battery life

RF4CE Network Topology
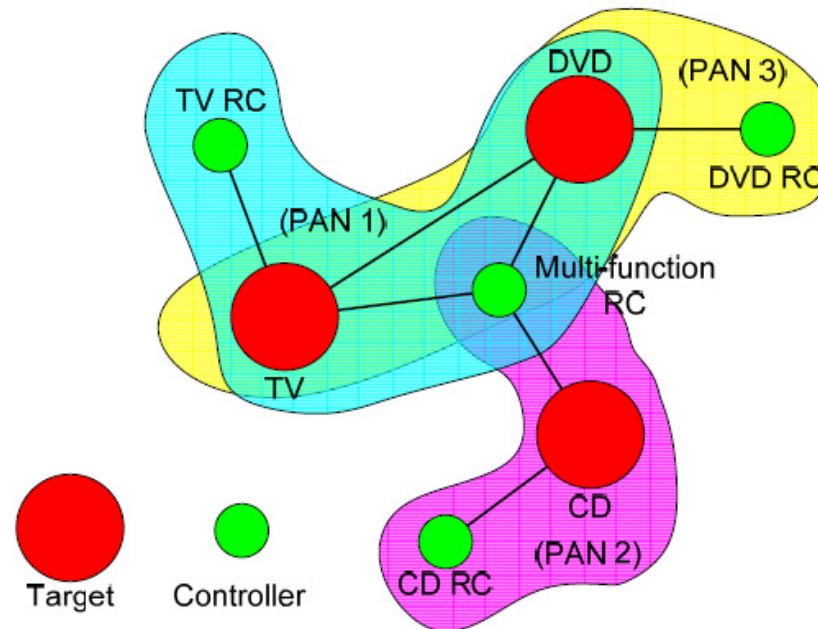
- Multiple Star Topology with inter-PAN communication

- TV, DVD and CD forms it's own RC PAN
  - TV RC paired with TV
  - DVD RC paired with DVD
  - CD RC paired with CD

- DVD paired with TV

- Multi-function RC paired with TV, DVD and CD

Device Types

A ZigBee RF4CE network is a fully peer-to-peer system with direction communication between devices. The are two logical device types:

- Target node
    - Initiator of a network (many networks can exist within the same space)
        - Starts a RC (Remote Controller) PAN network
        - Controls PAN and assigns network addresses
    - E.G. devices - TV, DVD, STB etc
    - Capable of low power operation
    - Can pair with other target nodes
        - DVD pairs with TV to control channel when playing DVD

- Controller node
    - RC - Remote Controller
    - Can pair with one or more target nodes (1 to many)
        - member of multiple RC PANs
    - Optimized for power consumption
        - Usually operates on batteries

SUPPORTED DEVICES

- Television
- Projector
- Player
- Recorder
- Video player/recorder (VCR, DVR, DVD, Blu-ray, portable)
- Audio player/recorder (CD, portable)
- Audio video recorder
- Set top box
- Home theater system
- Media center/PC
- Game console
- Satellite radio receiver
- IR extender
- Monitor
- …

Architecture
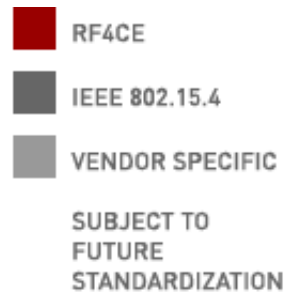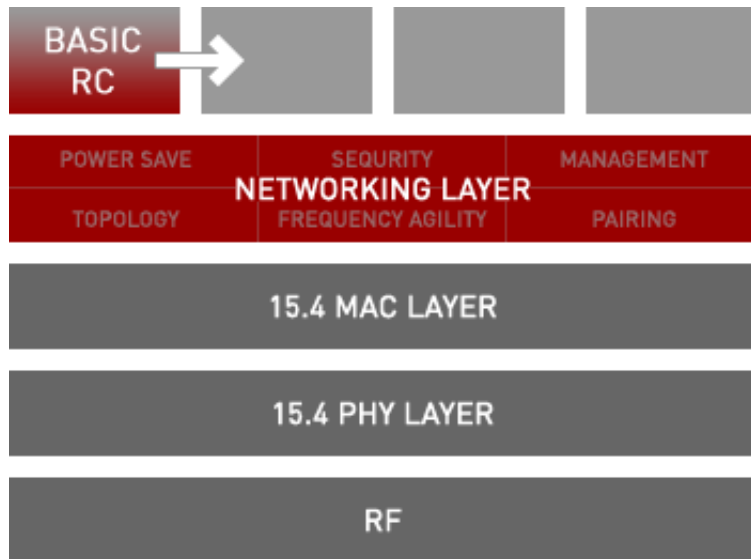
The RF4CE protocol:

- Based on IEEE 802.15.4

- Includes a thin NWK layer

- Command Set Interface

- Interoperable RC profile

The RF4CE Standard Includes:
- Frequency agility for multi-channel operation to avoid interference
- A mechanism for secure transactions
- A power save mechanism for power efficient implementations
- A simple and intuitive pairing mechanism

TEXAS INSTRUMENTS

Remote Control Profile

- Consumer Electronic Remote Control profile
  - First public profile defined on top of the RF4CE NWK layer
  - Provides push button discovery/pairing procedure
    - Utilizes auto discovery mechanism
  - Describes
    - Profile constants
    - Frame format
    - Command codes
    - Remote control (RC) command code fields (play, stop etc)
    - Specific configuration parameters to ensure interoperability

TI offering

RF Remotes – Why TI? Why Now?

- Remote controls in TV's and STB's moving from IR to RF – now!
- We have momentum with design-ins at key TV/STB manufacturers
- TI offer total solutions (HW, SW, kit, reference design, support)
- TI has a specialized RF4CE chip CC2533
- Robust SW designed by our ZigBee SW team
- Low system cost
- HID and 3D RF glasses will be supported
- Breadth of HW portfolio, including SoC, WNP and transceiver solutions
- Long standing involvement with ZigBee and have mature in-house solutions for hardware and software

TI RF4CE Advantages

- Third generation 802.15.4 devices

- Ability to provide worldwide support to Customers and partners

- High volume production capability to support large volume customers

- Range of 1 and 2 chip solutions optimized for RF4CE

TI Technical Advantages

- Higher output power and better sensitivity –> better range
  - Total link budget
    - CC253x   : 101.5 dB (104 with boost mode)
    - Competition   : 96 dB
      - 6 dB better link budget equals twice the range
- Better adjacent channel rejection -> interference robustness
  - CC253x   : 49 dB
  - Competition   : 30 dB
    - For every 6 dBs the CC253x can be twice as close to an interferer without losing sensitivity
- Very simple and low risk system integration
  - CC253x handles all the protocol and SW through RF4CE Network Processor
    - Simple Host Interface (SPI or UART)
- Serial and Over-the-Air Bootloader for SW updates
  - RF4CE standard upgrades
  - Upgrade of IR codes on RC
  - Upload of future features
- On chip support for capacitive sensing, touch button

TI's RF4CE Roadmap

TI RF4CE Solutions

Device in Development

Device in mass production

RF4CE SoC/WNP
- 64/128KB SoC
- Advanced process
- Software defined radio
- Low power – 10mA TX & RX.
- Software Defined radio – 802.15.4, BLE, proprietary
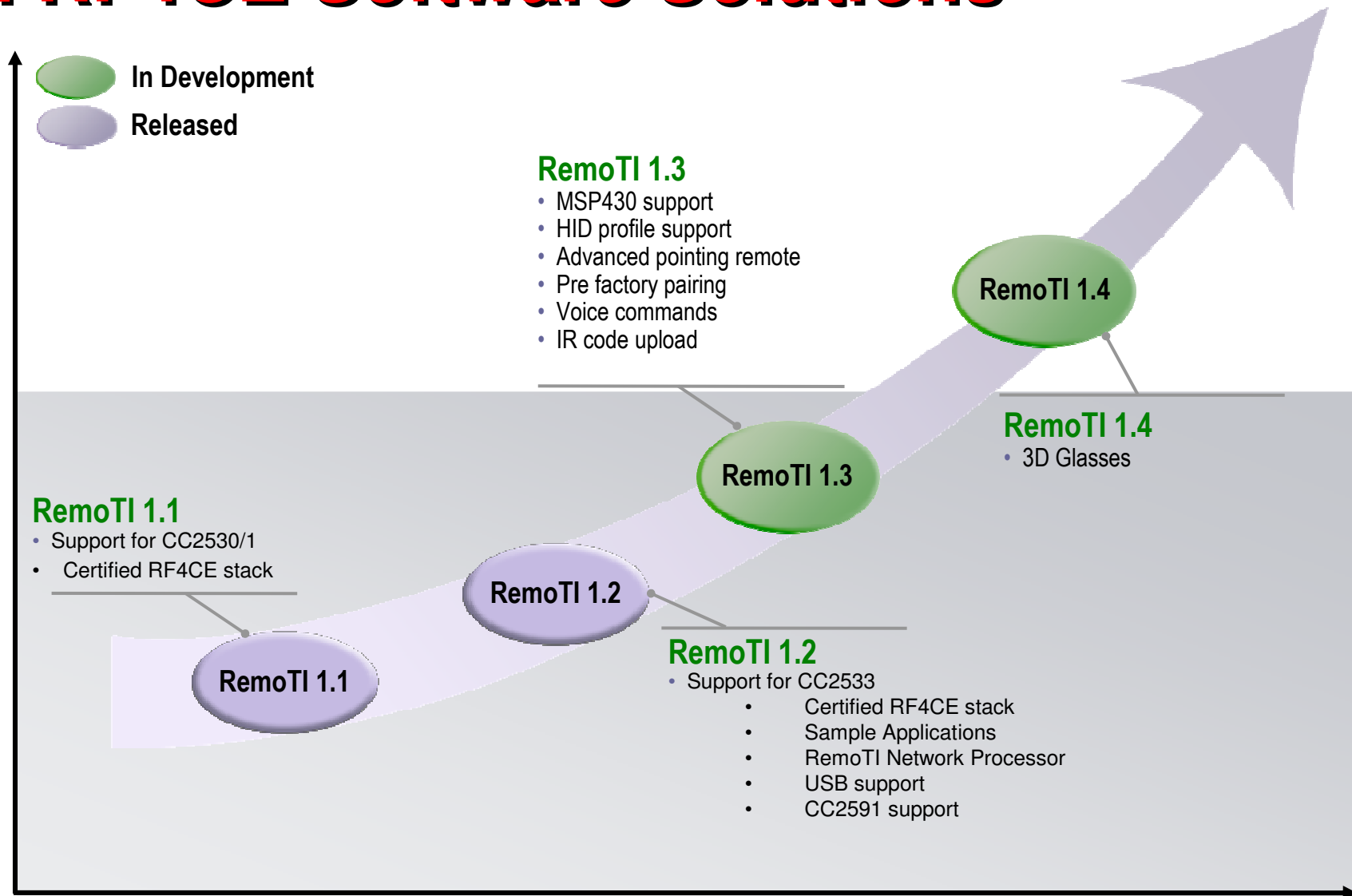- Interfaces – I2C, UART, SPI, I2S

CC26xx

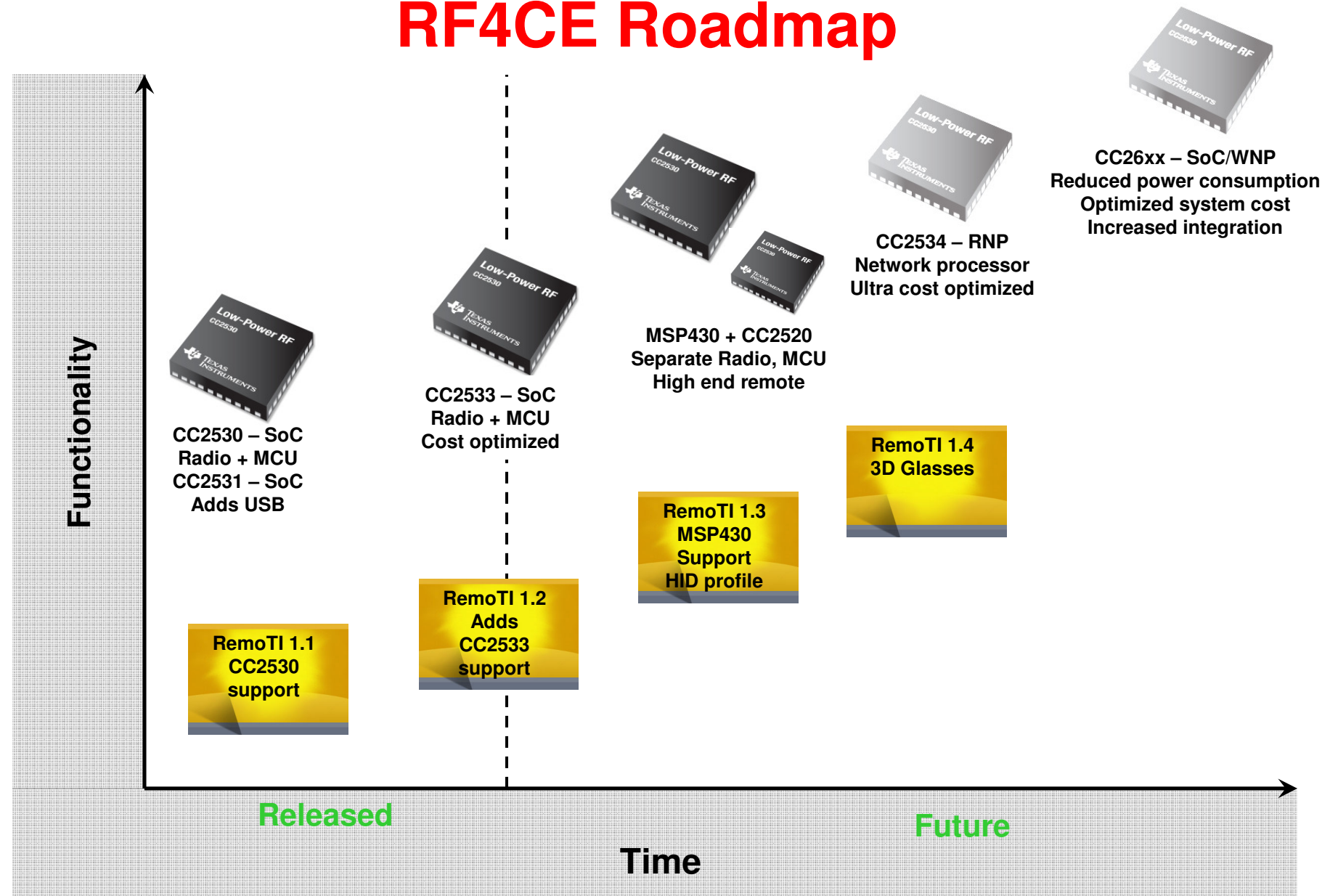## CC2534 WNP
- Cost down CC2533 WNP
- Pin, RF and SW compatible with CC2533 WNP
- Minimal SW development on Host MPU
- Low latency, real-time stack execution

CC2536

CC2533 SoC/WNP
- 64/96kB FLASH SoC
- CC2533F64 using RemoTI Network Processor (RNP)
- Wireless Network Processor
- 6x6 QFN
- Minimal SW development on Host MPU
- Low latency, real-time stack execution
- RemoTI 1.2
- Available Today!

CC2534

RF4CE ROM WNP
- Network Processor as CC2533
- 5x5 QFN
- Minimal SW development on Host MPU
- ROM based
- RF and SPI compatible with CC2533

CC2520

CC2520 transceiver
- 802.15.4 (RF4CE) compliant transceiver
- 5x5 QFN
- Best in class link budget (103 dB)
- Some SW development, RemoTI running on host MPU
- Available Today!

CC2533F64

Texas Instruments

TI RF4CE Software Solutions

- In Development
- Released

RemoTI 1.3
- MSP430 support
- HID profile support
- Advanced pointing remote
- Pre factory pairing
- Voice commands
- IR code upload

RemoTI 1.4

RemoTI 1.3

RemoTI 1.4
- 3D Glasses

RemoTI 1.1
- Support for CC2530/1
- Certified RF4CE stack

RemoTI 1.2

RemoTI 1.1

RemoTI 1.2
- Support for CC2533
  - Certified RF4CE stack
  - Sample Applications
  - RemoTI Network Processor
  - USB support
  - CC2591 support

TEXAS INSTRUMENTS

RF4CE Roadmap

Functionality

Time

Released

Future

CC2530 – SoC
Radio + MCU
CC2531 – SoC
Adds USB

CC2533 – SoC
Radio + MCU
Cost optimized

MSP430 + CC2520
Separate Radio, MCU
High end remote

CC2534 – RNP
Network processor
Ultra cost optimized

CC26xx – SoC/WNP
Reduced power consumption
Optimized system cost
Increased integration

RemoTI 1.1
CC2530
support

RemoTI 1.2
Adds
CC2533
support

RemoTI 1.3
MSP430
Support
HID profile

RemoTI 1.4
3D Glasses

TEXAS INSTRUMENTS

Devices – single chip solutions

CC2530 – Large applications

- 256/128 KB Flash
- 8 KB RAM
- 12-bit ADC
- Comparator
- OpAmp
- UART/SPI (soft I2C)
- IR generation hardware
- 21 GPIO
- 6x6mm QFN

CC2531

- CC2530 + USB

CC2533 – Cost optimized

- 96/64 KB Flash
- 6/4 KB RAM
- UART/SPI/I2C
- Low Battery monitor
- IR generation hardware
- 23 GPIO
- 7 dBm output power
- 6x6mm QFN

Devices – two chip solutions

MSP430 + CC2520 or CC2533 RNP
- 256 - 64 KB Flash
- 16 - 4 KB RAM
- 12/10-bit ADC
- Comparator
- Temp sensor
- DMA
- UART/SPI/I2C
- RTC, IRDA, USB
- Up to 87 GPIO

CC2520
- IEEE 802.15.4 PHY
- Excellent link budget (101dB)
- 49dB adjacent channel rejection (best in class)
- AEC encryption

CC2533 RNP
- RNP contains complete stack and profile
- RPC over UART or SPI

Devices – future

CC2534

- Cost optimized
- RemoTI Network Processor version of CC2533
- MSP430 or any other MCU host
- QFN40 6x6 mm

CC2536

- Ultra cost optimized
- RemoTI Network Processor
- MSP430 or any other MCU host
- Minimal peripheral set
- 64KB ROM
- 1KB OTP
- QFN28 5x5 mm

Devices – future

CC26xx

ARM M3

65nm process

128/64KB Flash

8KB RAM

Output power up to 5dBm

Low power – 10mA TX & RX.
<1uA sleep, <2uA with RTC

Software Defined radio –
802.15.4, BLE, proprietary

Interfaces – I2C, UART, SPI, I2S

ADC 10-bit, 20ksps

QFN40 6x6 mm

TEXAS INSTRUMENTS

Configurations

- Target – Set-top box, TV, Receiver, Blu-ray
  - CC2530/2531/2533
  - RF4CE network processor + any host MCU
  - UART, SPI or USB communications with host

- Remote
  - CC2530 SoC – high end remote (large application code, IR tables etc)
  - CC2533 SoC – cost optimized single chip solution for basic remotes
  - MSP430 + CC2520 or CC2533 RNP – high end remote with touch pad, accelerometer etc

Software

- RemoTI 1.2
  - Certified RF4CE stack with Remote profile
  - Sample Applications
  - RemoTI Network Processor
  - USB support
  - CC2591 support
  - Supports CC2530/2531/2533

- Next release - RemoTI 1.3
  - Add support for MSP430 + CC2520 platform
  - HID profile
  - High end pointing remote
  - Pre-pairing,
  - RC finder, battery low,
  - IR code upload,
  - Voice commands

- RemoTI 1.4
  - 3D Glasses – being defined in the ZigBee Alliance
  - Other enhancements

Tools – Basic Remote Kit

- RemoTI-CC2530DK Kit
  - RF Remote Control
  - Target Module (Receiver Board) w/ CC2530EM
  - CC2531 USB Dongle
  - CC Debugger, cables, adapter board
- Software
  - RemoTI Installer
    - Stack + applications
    - PC Emulator Tool
    - OAD / Serial Bootloader Demo

- Also available
  - CC Packet Sniffer
  - Flash Programmer
  - Legacy IR support

Tools – Advanced Remote

- Pointing remote control with gyro and accelerometer

IR LED
(OPE5594)

IR Driver
(BC817-16)

PWM

Buzzer — PWM — CC2530F256

Debug
Connector

Buttons

Analog

I2C

Backlight

Gyroscope
(IXZ-500)

Accelerometer
(CMA3000-D01)
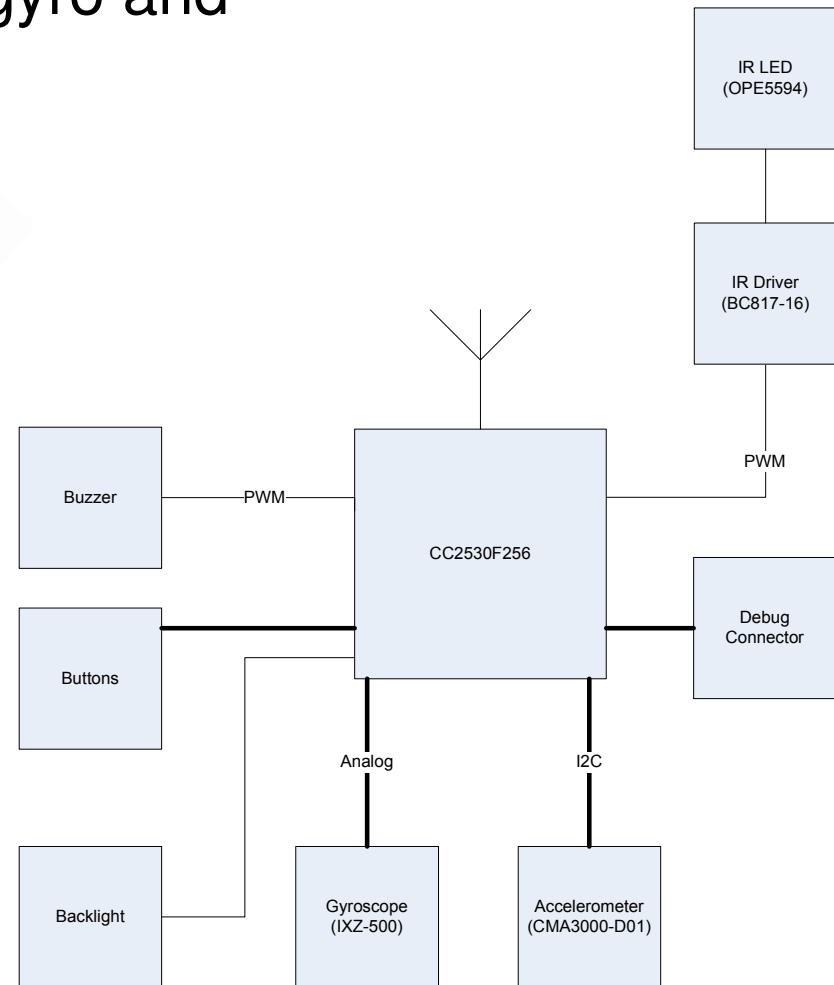
CC2530/CC2531

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

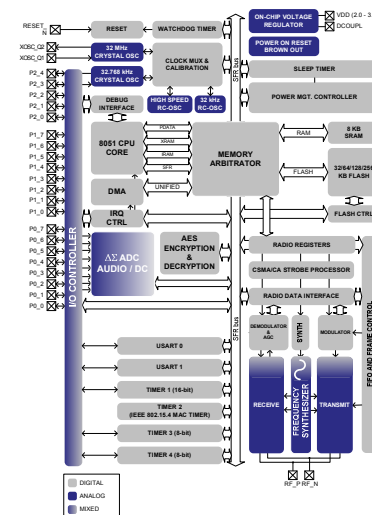### Applications

- 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

CC2533

2.4 GHz ZigBee®/IEEE 802.15.4 RF SoC for Remote Control

Features

- 32 MHz single-cycle low power MCU
- 96 or 64 KB Flash, 6 or 4 KB RAM
- ~1 uA power mode with sleep timer running
- Best-in-class co-existence and selectivity properties
- Powerful IR generation hardware
- AES-128 security module
- I2C, SPI and UART support
- Pin, RF and software compatible with CC2530

Benefits

- Reliable RF link with interference present
- Can implement single-chip remote control with legacy IR support
- Can implement target network processor with IR or I2C/SPI/UART
- Ultra low average power consumption in low duty-cycle systems like remote control
- RF4CE stack, CERC profile and network processor software provided free of charge
- Powerful development kit/reference design in remote control formfactor

TEXAS INSTRUMENTS
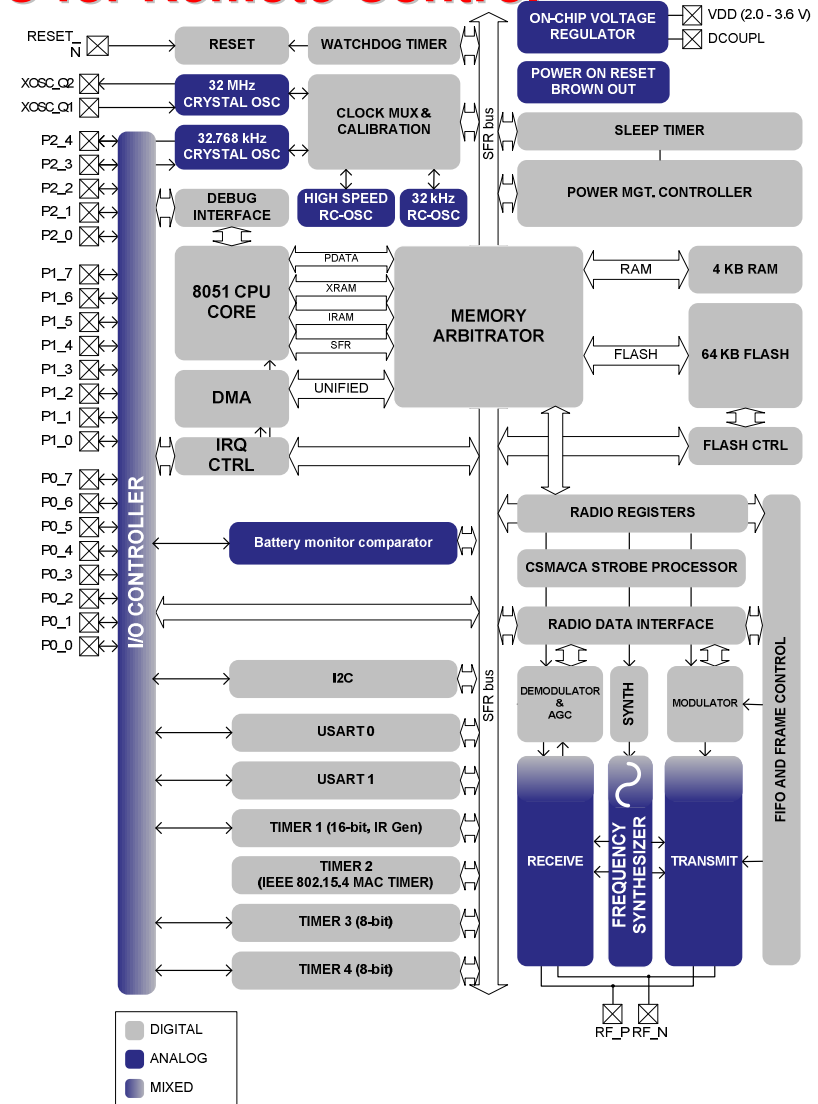
RemoTI Software Stack

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 application and USB HID / CDC interface support
- 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
- CC2591 support for long range applications

RemoTI Target Emulator

SmartRF Tools

Coexistence

RF4CE Channel Selection
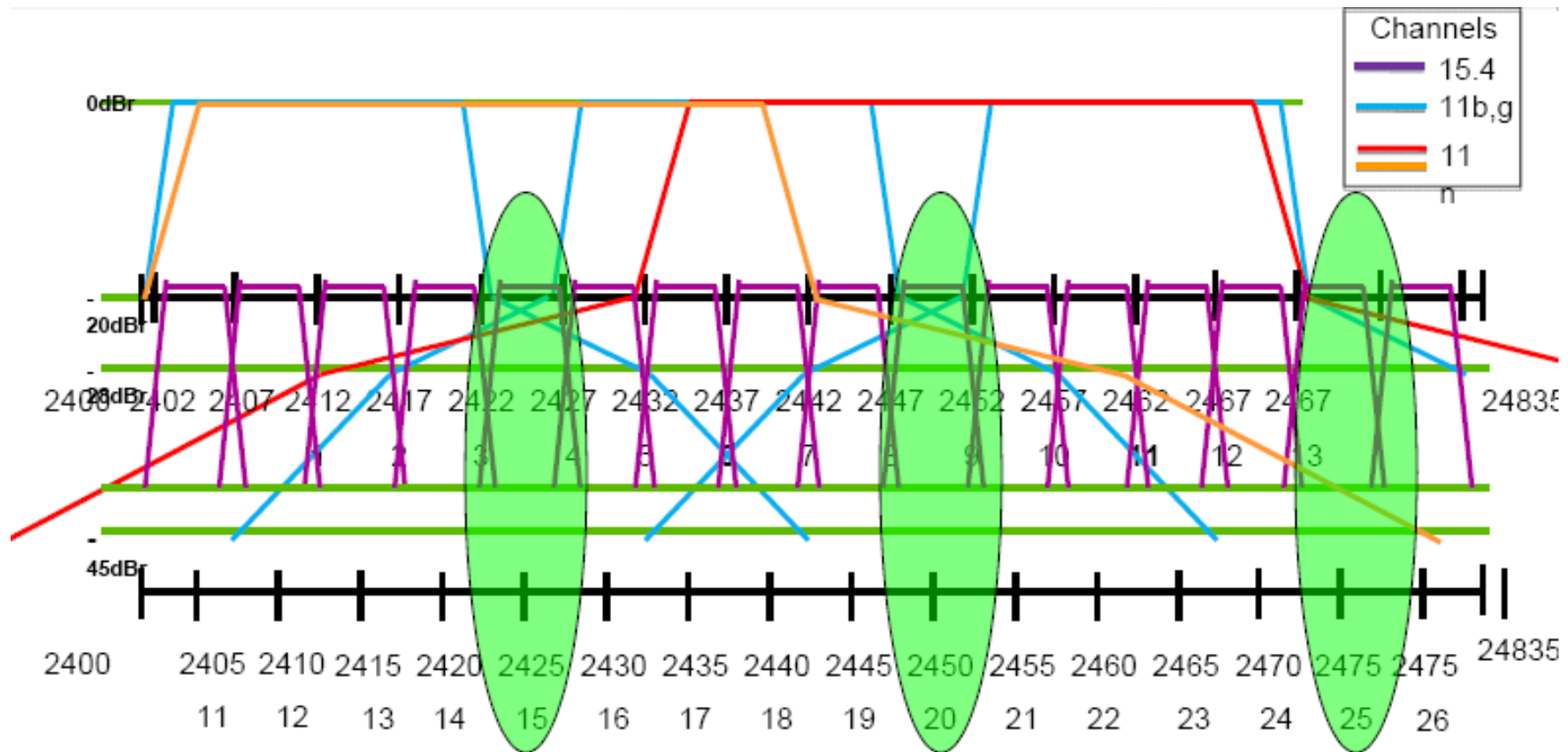
Channels 15, 20 and 25 give good robustness

TEXAS INSTRUMENTS

Coexistence Testing

- 2.4GHz band is crowded: WiFi, microwave ovens, cordless phones, bluetooth etc

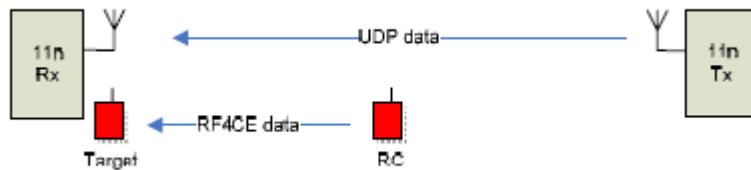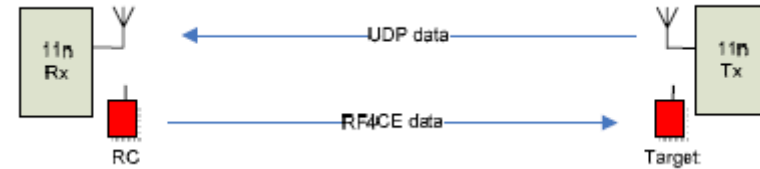- Co-existence testing shows very good results in presence of 802.11n 40MHz channel (see www.ti.com/lit/swra285 for details)

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

TEXAS INSTRUMENTS

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

TEXAS INSTRUMENTS

Compliance and Certification

- ZigBee Qualification Group (ZQG) is responsible for:
  - Establishing an independent test house program
  - Selecting test houses
    - National Technical Systems of Culver City, California
    - TÜV Rheinland of North America of Pleasanton, California
  - Write Protocol Implementation Conformance Statement (PICS)

- RF4CEFest
  - ZigBee RF4CE Alliance Interoperability testing events
  - Participating in a ZigBee RF4CE Alliance interoperability testing event is mandatory for compliancy

What can be tested?

- ZigBee RF4CE Compliant Platform
  - IEEE 802.15.4 PHY and MAC
  - RF4CE network, security and application layer functions
  - TI RemoTI development kits are based on ZigBee RF4CE Compliant Platforms

- ZigBee RF4CE Compliant Product
  - Product based on a ZigBee Compliant Platform
  - Can use the ZigBee RF4CE name and logo
  - Can co-exist with other ZigBee RF4CE systems
  - Interoperable with the CERC profile if used

Development cost for ZigBee RF4CE

- Development kit: e.g. RemoTI CC2530DK
  - Kit (RC + Target Board + RemoTI (TI RF4CE Stack) + Tools + Packet sniffer)
  - RF4CE stack updates
  - For price please see:
    http://www.ti-estore.com/
- Compiler from IAR ($2395/seat)
  - Volume prices available. Please contact IAR directly:
    http://www.iar.com/
- Regulatory certification (FCC, ETSI, ARIB etc.)
  - Price determined by the local test house
  - Same as for non-ZigBee products
- ZigBee RF4CE certification (TÜV or NTS)
  - Price decided by test houses (~$3k-10k/product)
- IEEE addresses
  - $1650 for all the addresses you will ever need (2^{40})
 - Provided by TI, CC2530 Information Page

Additional costs for ZigBee RF4CE

- ZigBee RF4CE Alliance membership
  - Adopter ($3500/year)
    - Additional $1000 for 1st product, $500 each additional product for **logo certification** to the Alliance

  - Participant ($9500/year)
    - Early access to specification
   - No additional cost for certification to the Alliance

RemoTI Configurations

- Basic Remote Controller
  - Contains keypad, LED(s) and possibly IR
  - No advanced UI functionality
  - Implemented on CC2530 SoC
  - Lowest cost solution
  - Lowest power consumption

- Network Processor
  - Enables RF4CE functionality by connecting host MCU via UART or SPI interface to CC2530 SoC
  - Flexibility to choose host MCU processor of choice
  - Enables target node functionality when connected to e.g. TV, DVD, STB main processor
  - Enables advanced remote controller functionality when connected to a host MCU for with UI features (e.g. LCD)
    - Additional cost due to two chip solution compared to basic remote controller
    - Additional power consumption due to two chip solution compared to basic remote controller
  - Network Processor provides same C programming interface as used in remote controller (SoC)

TEXAS INSTRUMENTS

Basic Remote Controller Architecture
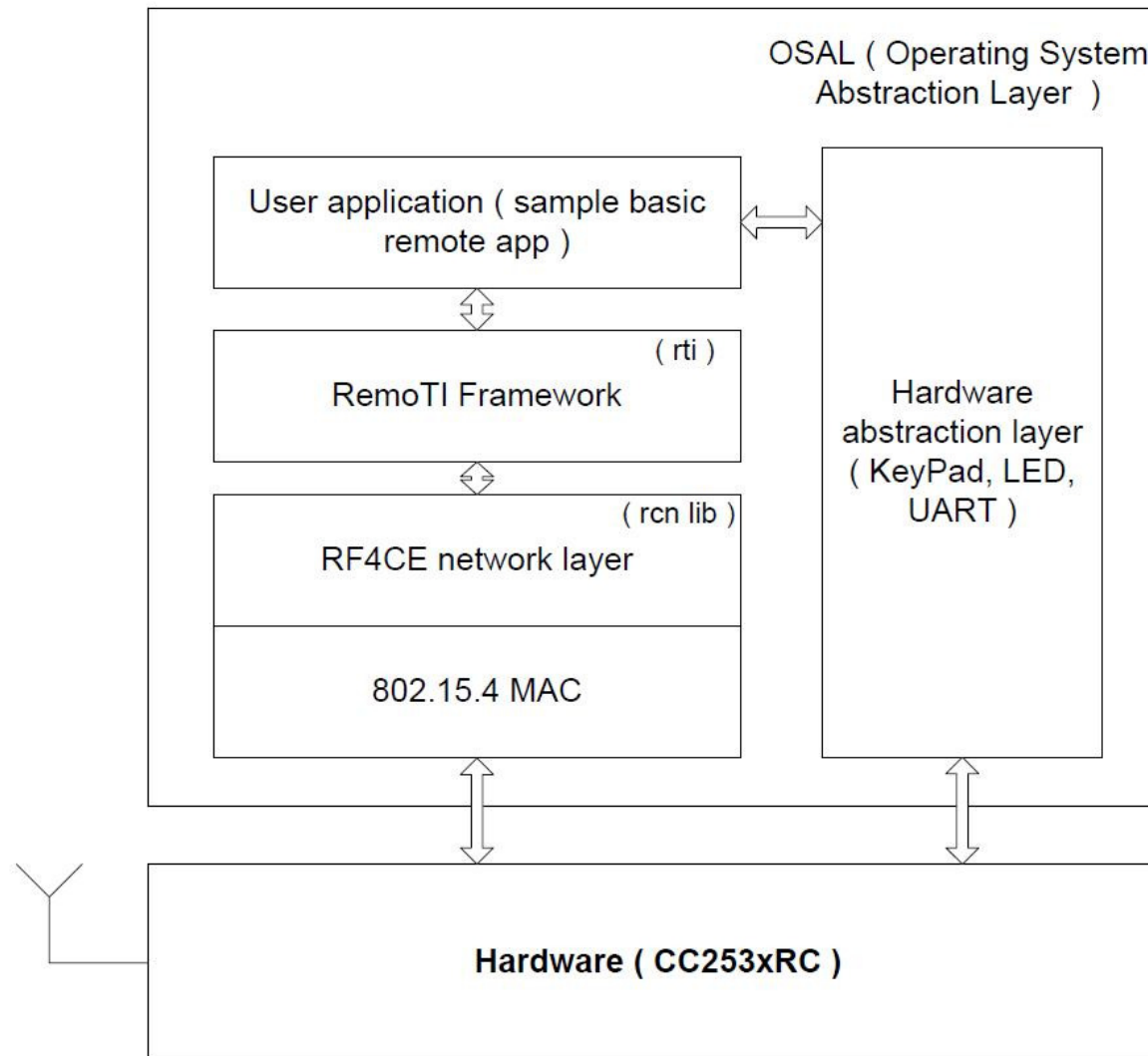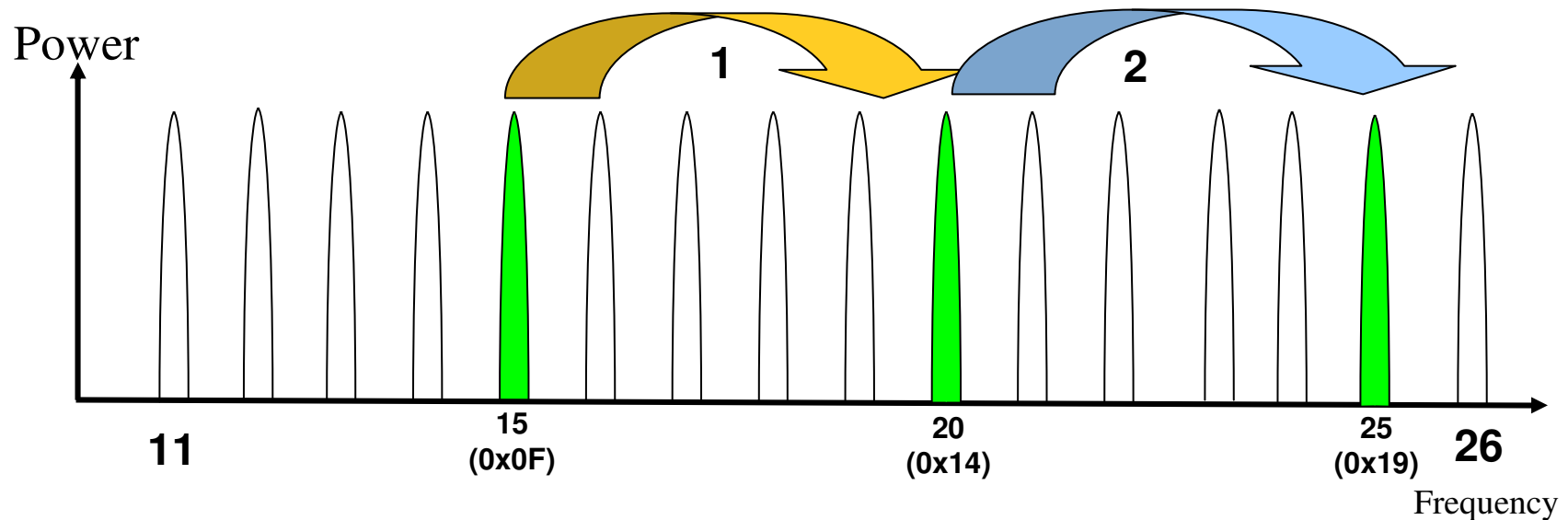
Network Processor Architecture
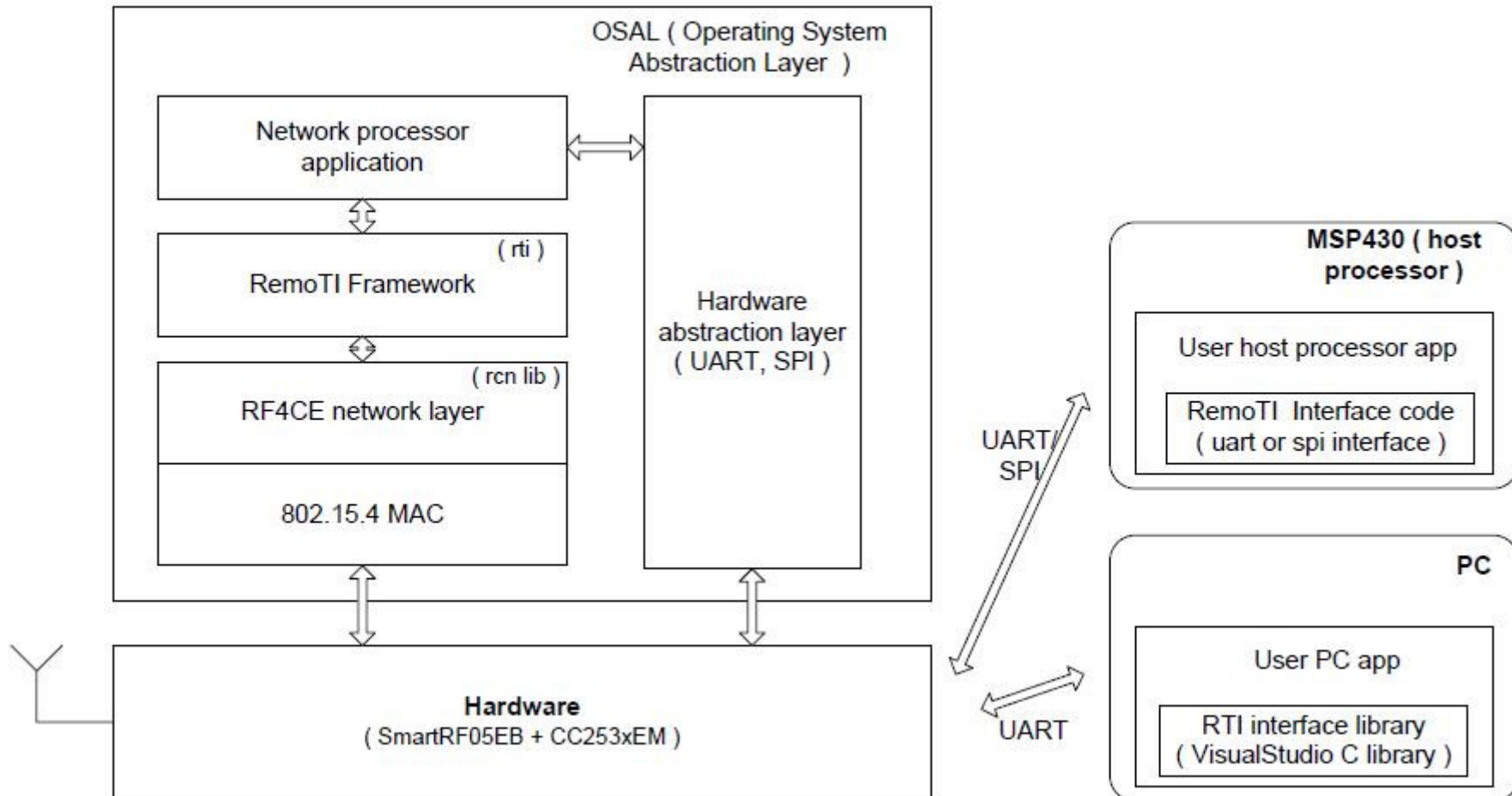
Frequency Usage

- 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

TEXAS INSTRUMENTS

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

Power

1

2

11   15
           (0x0F)   20
                          (0x14)   25
                                         (0x19)   26

Frequency

TEXAS INSTRUMENTS

Data Transmission Options

- Multiple transmission options supported
  - Single channel
    - Unicast
      - With acknowledgement (ACK)
        - » *4 TX on current channel with 4 CSMA backoffs*
      - Without acknowledgement (non-ACKed)
        - » *1 TX on current channel with 4 CSMA backoffs*
    - Broadcast
      - Without acknowledgement (non-ACKed)
        - » *1 TX on current channel with 4 CSMA backoffs*

  - Multiple channel
    - Unicast
      - With acknowledgement (ACK)
        - » *4 TX on current channel with 4 CSMA backoffs, then 1 TX on every channel in round robin fashion for 1 sec without backoffs*
      - Without acknowledgement (non-ACKed)
        - » *1 TX on all channels with 4 CSMA backoffs, starting with current channel*
    - Broadcast
      - Without acknowledgement (non-ACKed)
        - » *1 TX on all channels with 4 CSMA backoffs*

- Transmission option is specified by bitmap for each transmission

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

Over-The-Air Download

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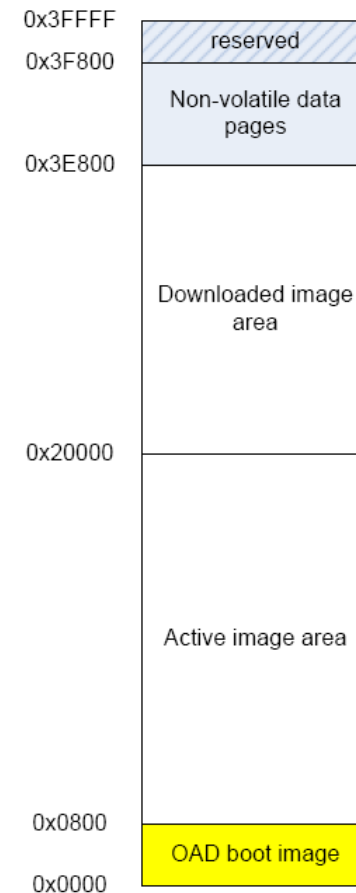
- Bootloader consumes 2K bytes

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

Address	Region
0x3FFFF	reserved
0x3F800	Non-volatile data pages
0x3E800	Downloaded image area
0x20000	Active image area
0x0800	OAD boot image
0x0000	

Serial Bootloader

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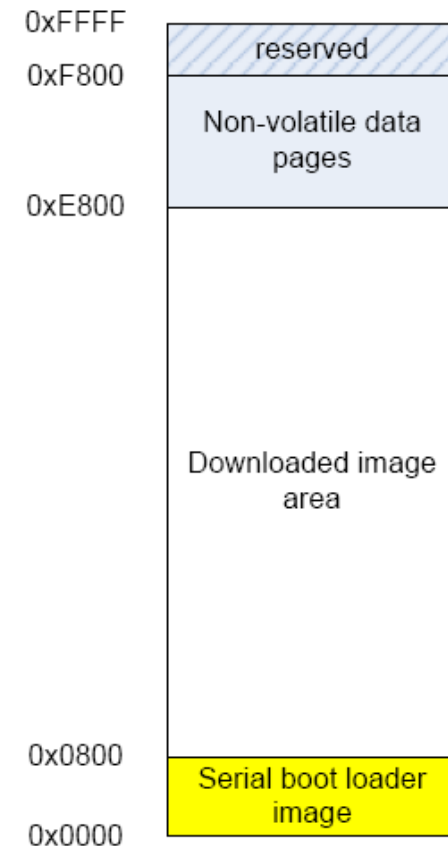
- Bootloader consumes 2K bytes

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

Address	Region
0xFFFF	reserved
0xF800	
	Non-volatile data pages
0xE800	
	Downloaded image area
0x0800	
	Serial boot loader image
0x0000	

TEXAS INSTRUMENTS

Q&A