Texas Instruments – Tech Day 2011

Bluetooth Low Energy CC2540

ANT+ CC2570 and CC2571

Agenda

- Overview
- Technology
- TI Solution
- Labs

Bluetooth Low Energy

Bluetooth standard

- Part of Bluetooth Spec 4.0, July 2010
- LE is not directly compatible with BR/EDR Bluetooth, but is evolution of BR/EDR.
- Devices which support only LE are single mode, and those which support BR/EDR&LE are dual mode.

Low Power

- Targeted for low power applications
- Coin cell operation

Bluetooth Device Types

LE Single Mode

Low Power, low data

Dual Mode

Gateway, Storage

Classic

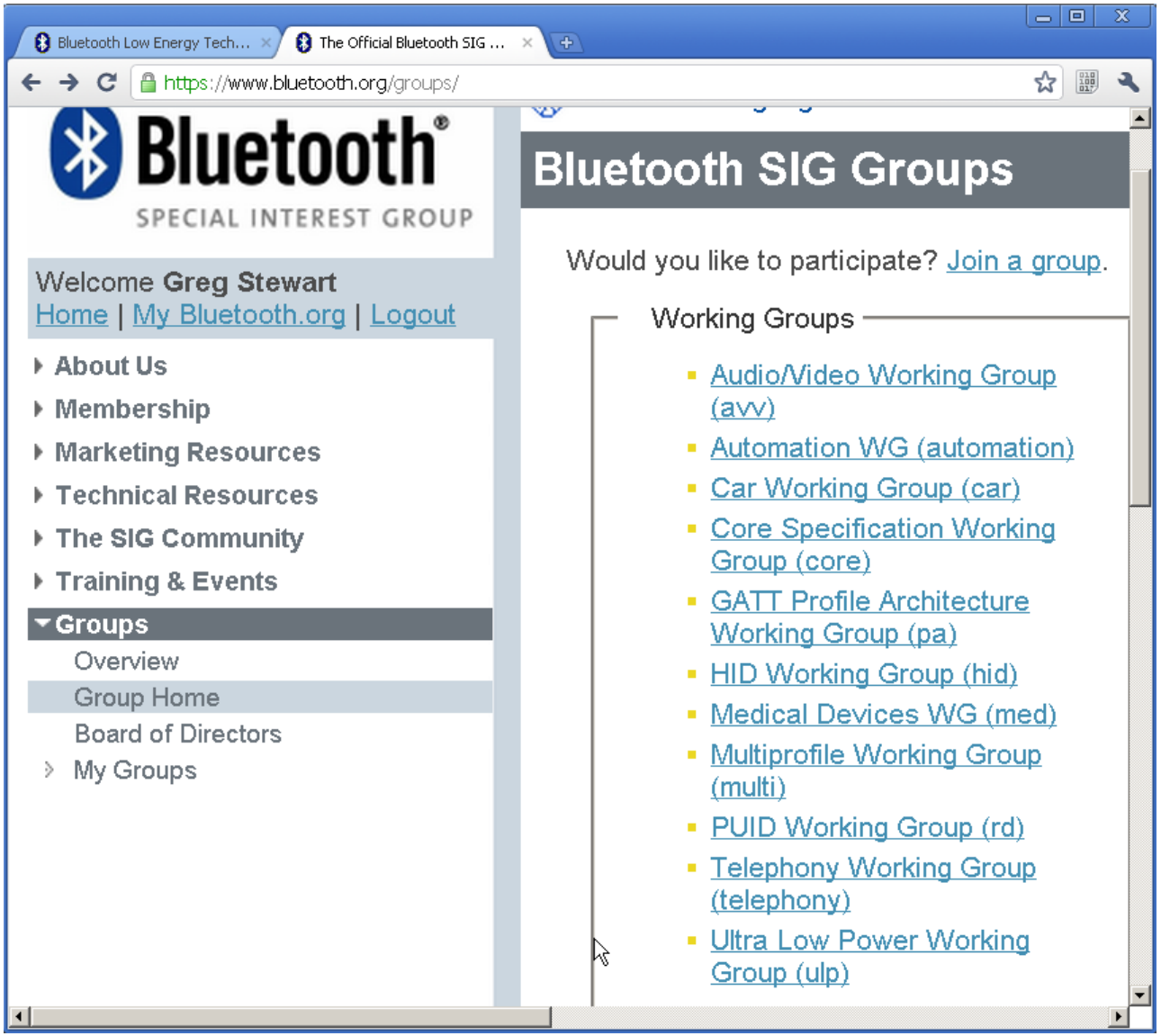
Steaming, file transfer

Marketing

As dual mode devices become the norm in cell phones and other classic BT devices, LE applications will open up whole new markets.

Bluetooth SIG Website

Groups in Bluetooth SIG



SIG Groups - Medical

Group Description Last Updated 12/14/2010

Medical Devices Working Group

Specifications/Features	MRD/FRD	0.5/DIPD	0.7/FIPD	0.9/CR	Prototyping Specification	IOP1	IOP2	Adopted V1.0
LE GATT-based Healh Thermometer Profile	2Q10	2Q10	N/A	3Q10	3Q10	UPF36	UPF37	4Q10
LE GATT-based Heart Rate Monitor Profile	1Q11	4Q10	N/A	1Q11	1Q11	UPF38	AHM	2Q11
LE GATT-based Blood Pressure Monitor Profile	1Q11	4Q10	N/A	1Q11	1Q11	UPF38	AHM	2Q11
LE GATT-based Weight Scale Profile	4Q10	4Q10	N/A	2Q11	2Q11	2Q11	UPF39	3Q11

Bluetooth SIG Website

Current status

- Bluetooth 4.0 adopted in July 2010
- First profiles around the corner

- First single-mode silicon now publicly available:
  CC2540 is certified and released – Sept 2010
  - HW, SW, kits available on www.ti.com/ble

- First phones with BLE expected mid-2011

Powered by TI - Bluetooth Innovation World Cup 2011

TI is the Title Sponsor of the *Bluetooth* Innovation World Cup 2011 and offers a 50% discount on the CC2540 *Bluetooth* low energy development kits to the developers who submit prototypes for the competition. Register at www.InnovationWorldcup.com

BLUETOOTH INNOVATION WORLD CUP 2011

Title Sponsor

Texas Instruments

Become the Innovator of the Year.
Win USD 5,000 and *Bluetooth* Qualification Program.
The Bluetooth SIG is looking for innovative ideas for new applications and products that use *Bluetooth* low energy technology in the categories of sports & fitness, health care & wellness, automotive, entertainment and more.

Who can participate?
Developers, distributors, partners, customers & students. You can submit an idea or a prototype.

Register to Win:
The database for submissions is open from
1 May – 15 September, 2011

Powered by TI - Bluetooth Innovation World Cup 2011

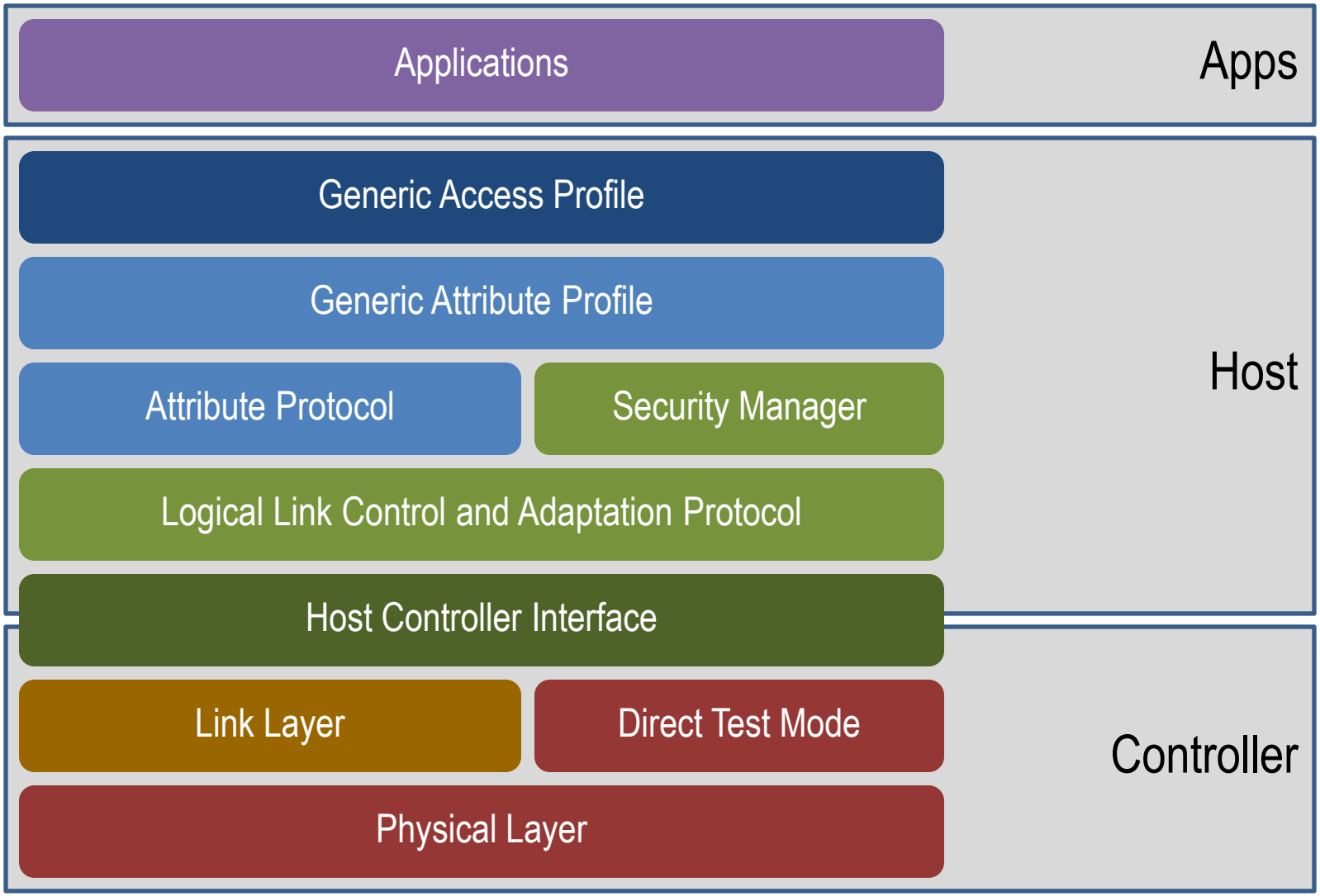
The winner of the Bluetooth Innovation World Cup 2010.

Are you the next winner?

BLUETOOTH INNOVATION WORLD CUP 2011
Title Sponsor
Texas Instruments

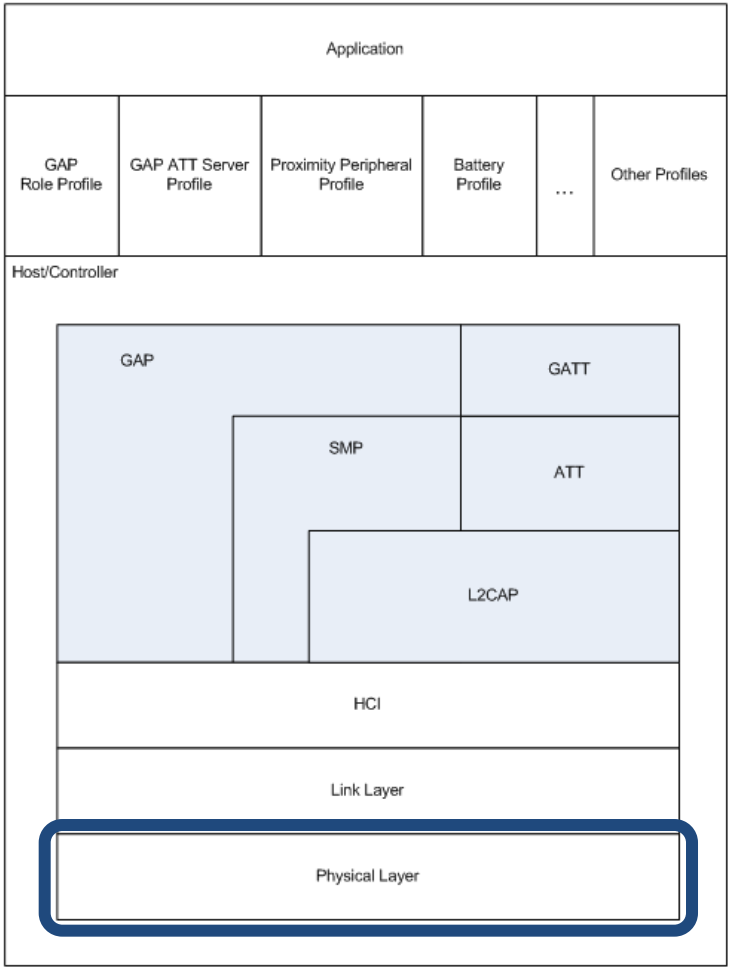
www.InnovationWorldcup.com

STACK ARCHITECTURE



Bluetooth Low Energy Protocol Stack: Physical Layer

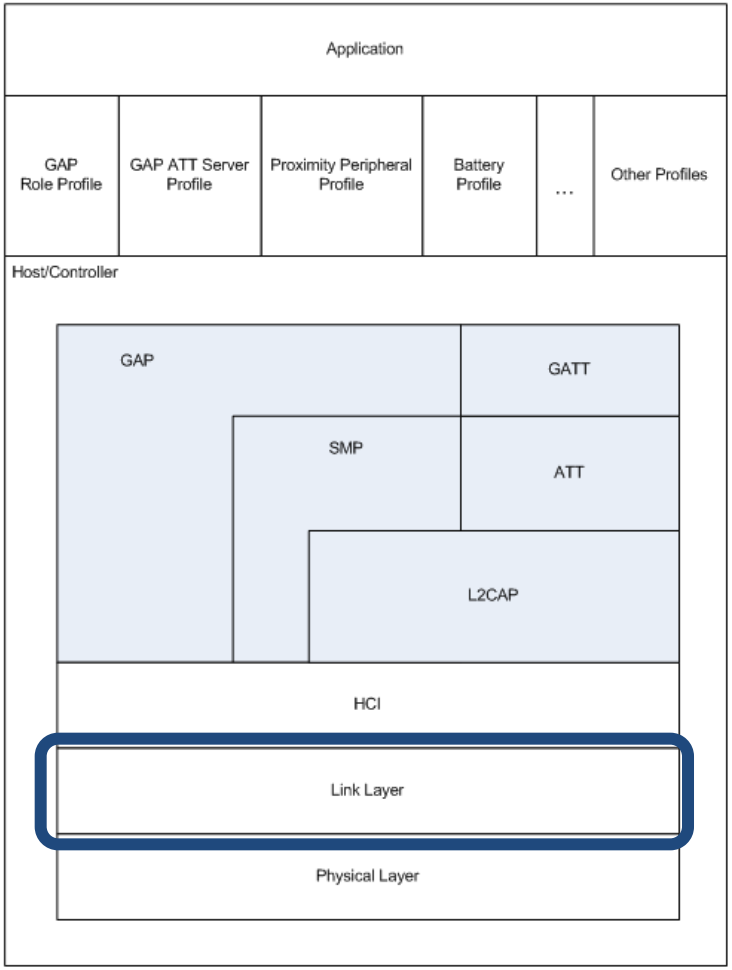
- RF Specifications
  - Operates in 2.4 GHz ISM band
  - GFSK modulation
  - 40 channels with 2 MHz spacing
    - 3 fixed advertisting channels for broadcasting, which avoid 802.11 interferance
    - 37 adaptively frequency hopped dynamic data channels
- Physical layer can be combined with standard Bluetooth RF in a dual-mode device
- 2 MHz spacing allows for better adjacent channel rejection



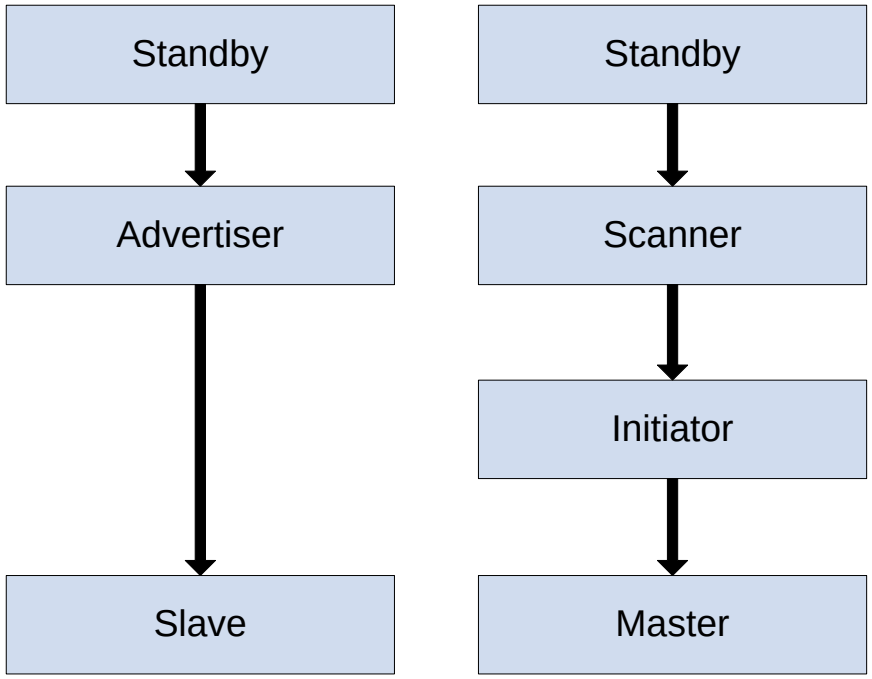
BLE Link Layer:
States and Network Topology

- There are six possible Link Layer states of a BLE device:
  - **Standby** - device is not transmitting or receiving any data, and is not connected to any other device
  - **Advertiser** - periodically broadcasting advertisements
  - **Scanner** - actively looking for advertisers
  - **Initiator** - actively trying to initiate a connection with another device
  - **Master** - connected to another device as a master
  - **Slave** - connected to another device as a slave

- BLE is a star topology network:
  - Master device “manages” the connection, and can be connected to multiple slaves
  - Slave device can only be connected to one master

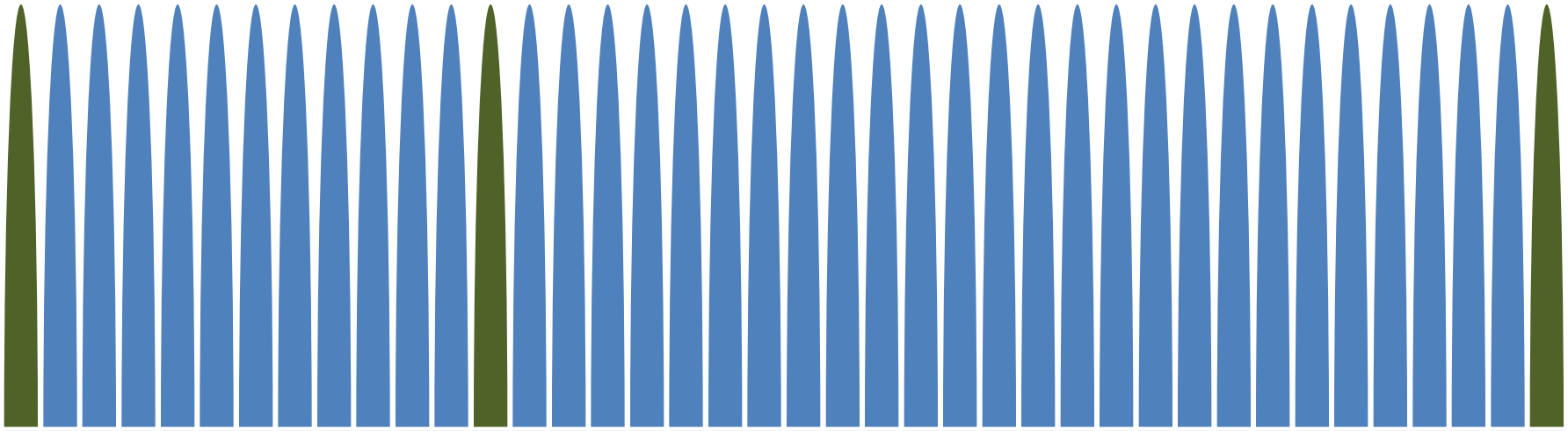


BLE Link Layer: States Flow Chart



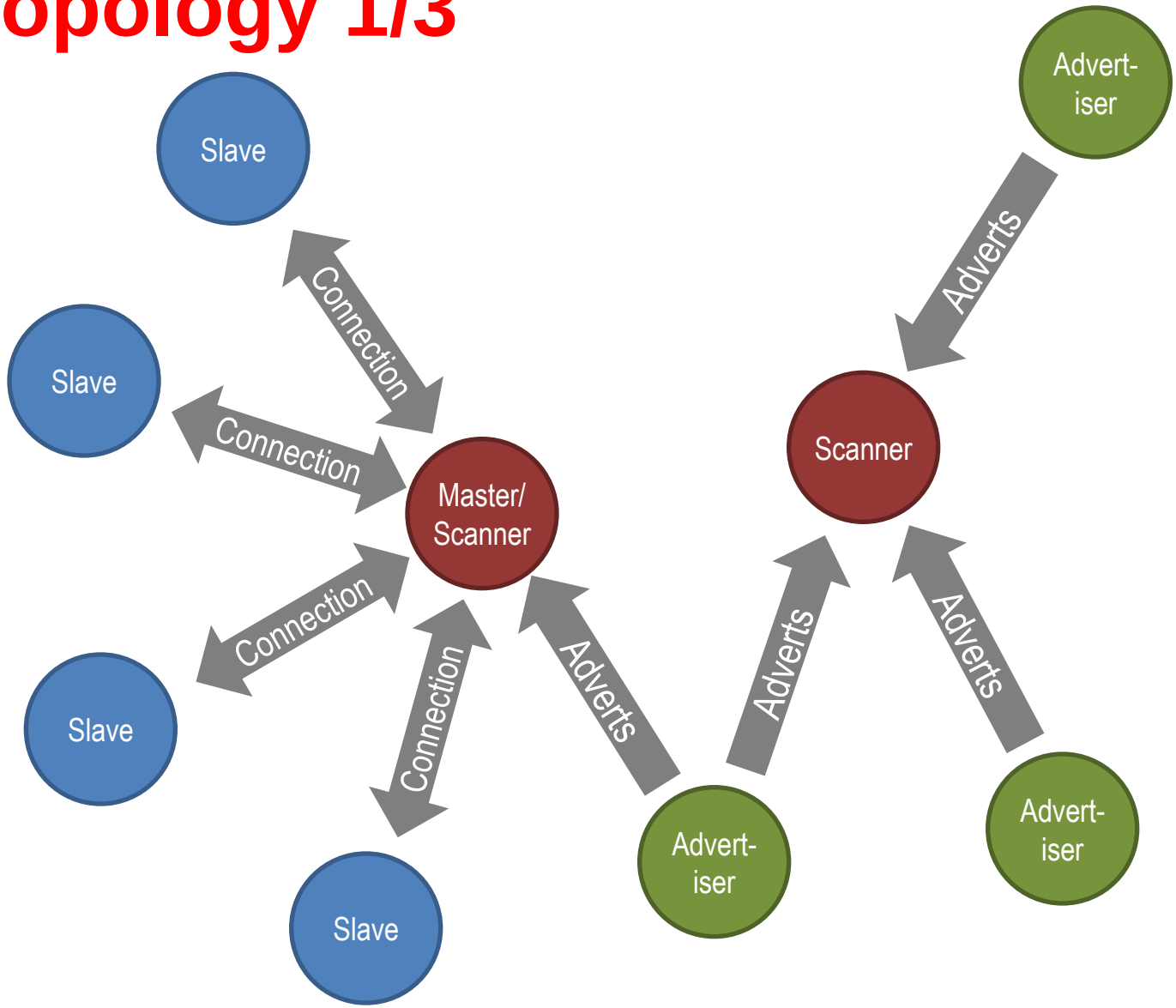
LINK LAYER CHANNELS

3 Advertising Channels and 37 Data Channels

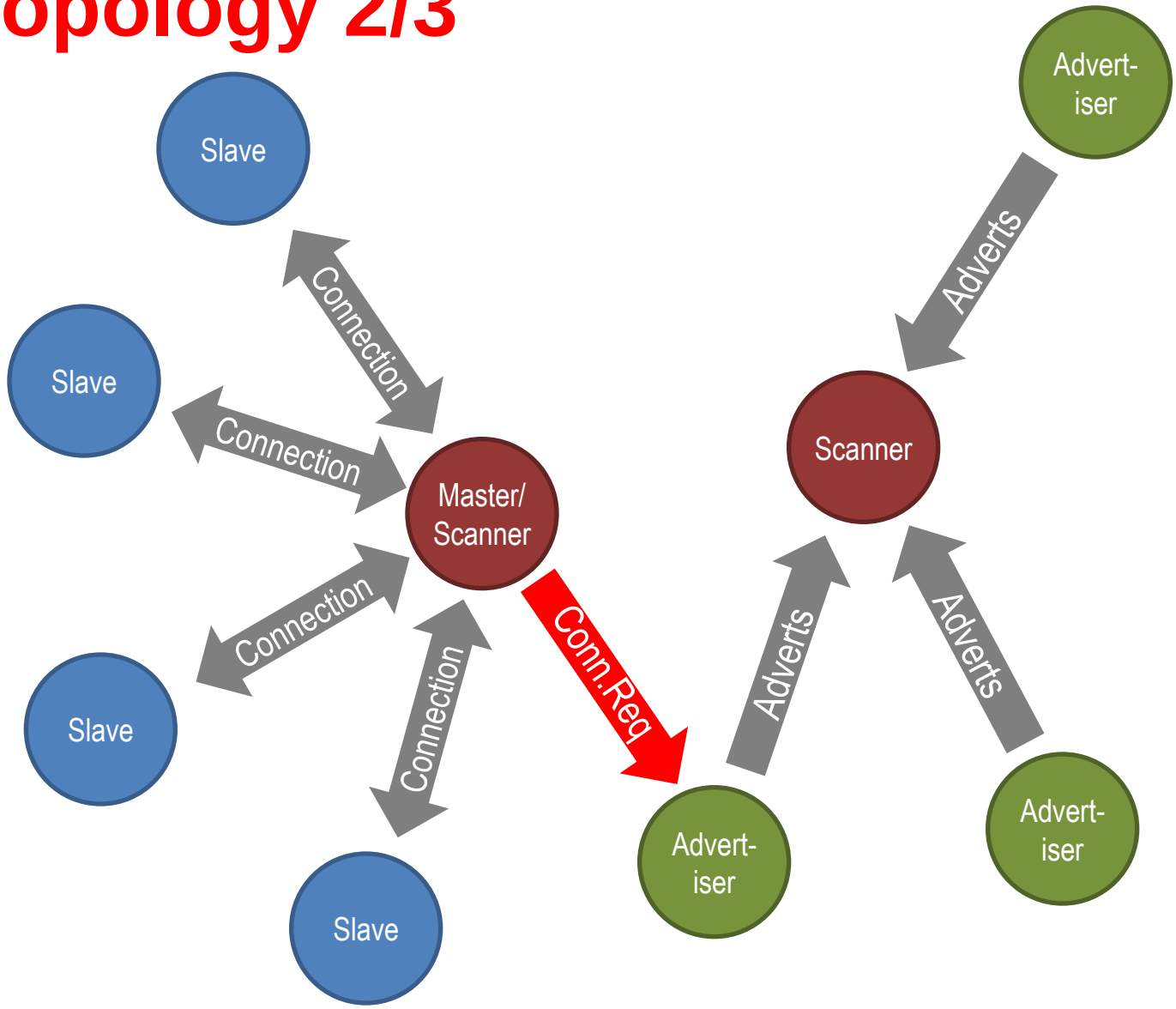


LL	Frequency
37	2402 MHz
0	2404 MHz
1	2406 MHz
2	2408 MHz
3	2410 MHz
4	2412 MHz
5	2414 MHz
6	2416 MHz
7	2418 MHz
8	2420 MHz
9	2422 MHz
10	2424 MHz
38	2426 MHz
11	2428 MHz
12	2430 MHz
13	2432 MHz
14	2434 MHz
15	2436 MHz
16	2438 MHz
17	2440 MHz
18	2442 MHz
19	2444 MHz
20	2446 MHz
21	2448 MHz
22	2450 MHz
23	2452 MHz
24	2454 MHz
25	2456 MHz
26	2458 MHz
27	2460 MHz
28	2462 MHz
29	2464 MHz
30	2466 MHz
31	2468 MHz
32	2470 MHz
33	2472 MHz
34	2474 MHz
35	2476 MHz
36	2478 MHz
39	2480 MHz

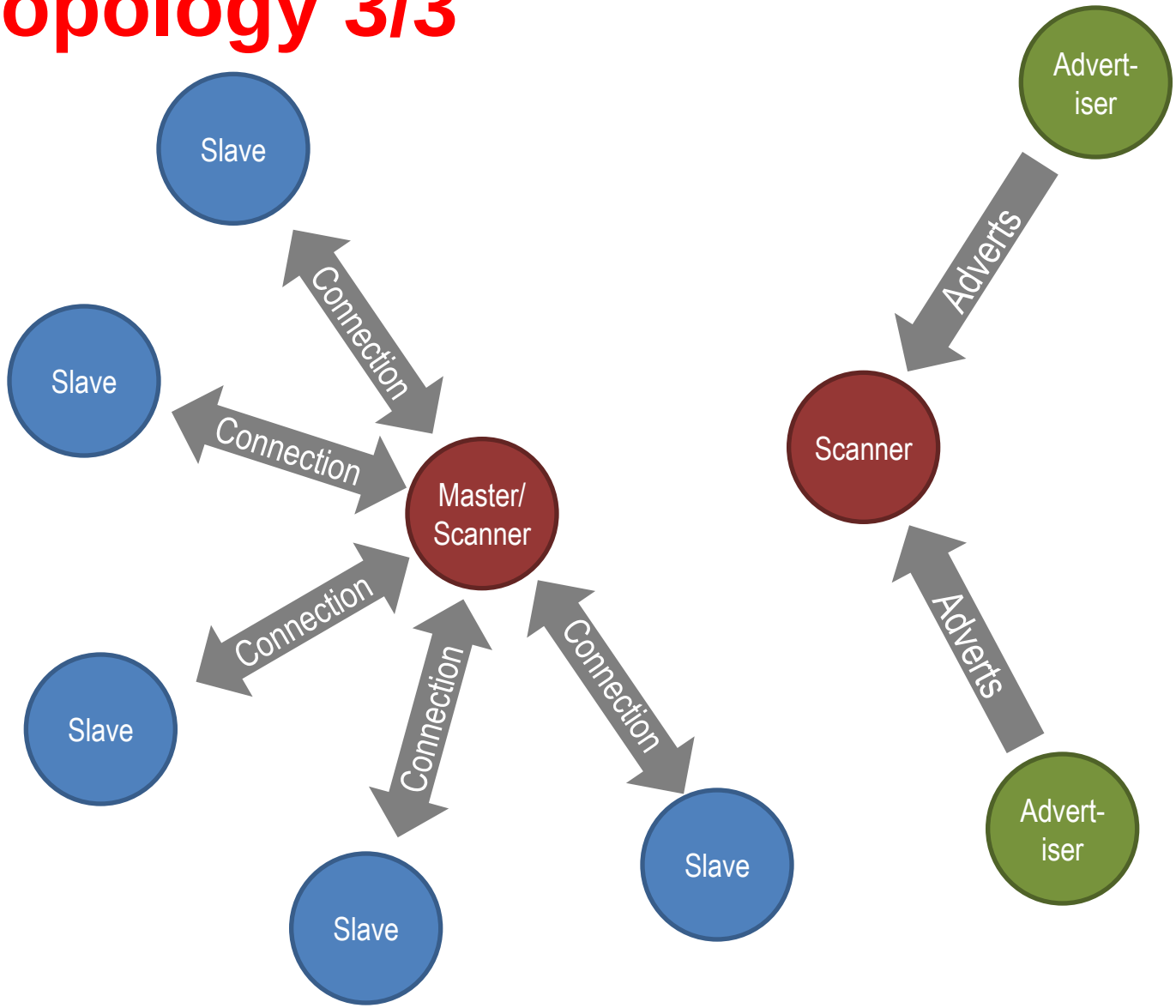
Star Topology 1/3



Star Topology 2/3



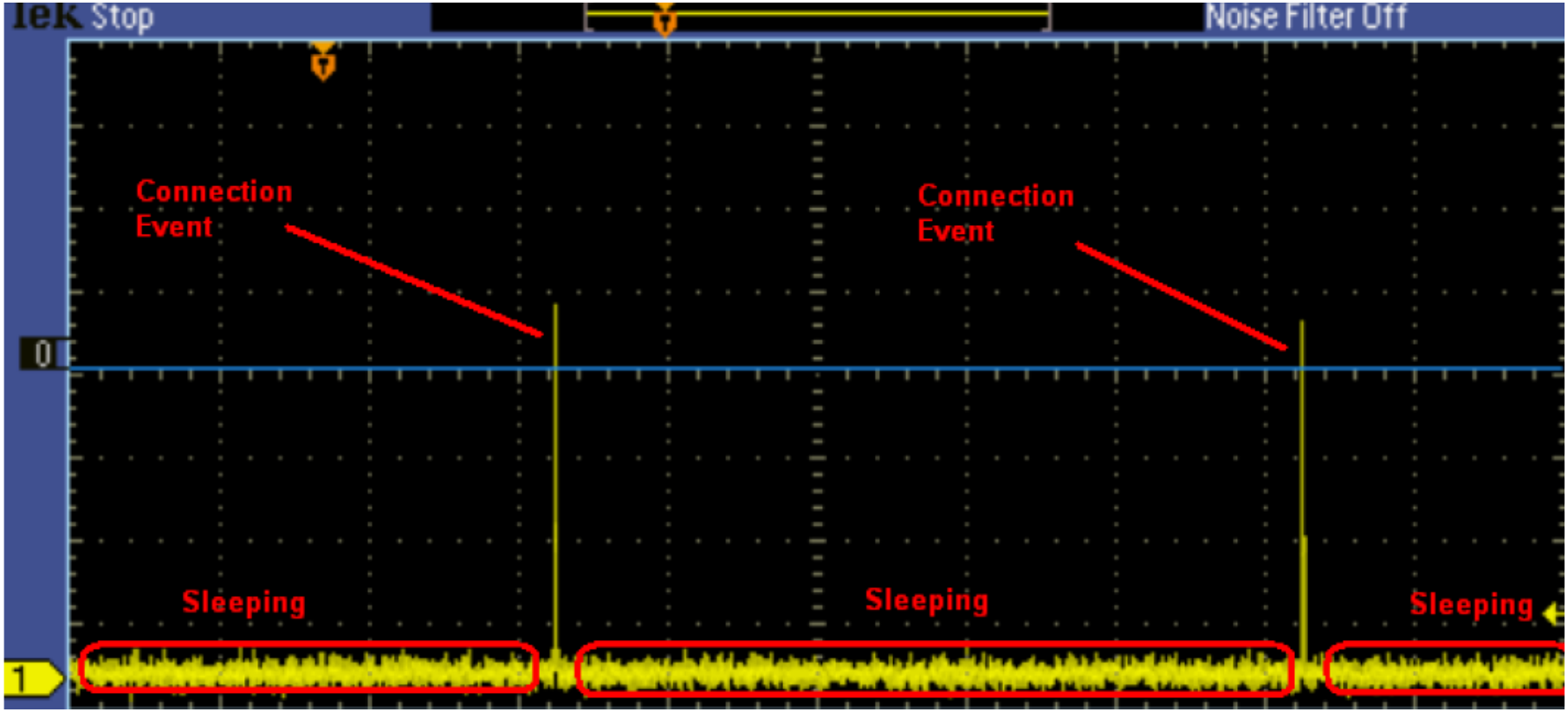
Star Topology 3/3



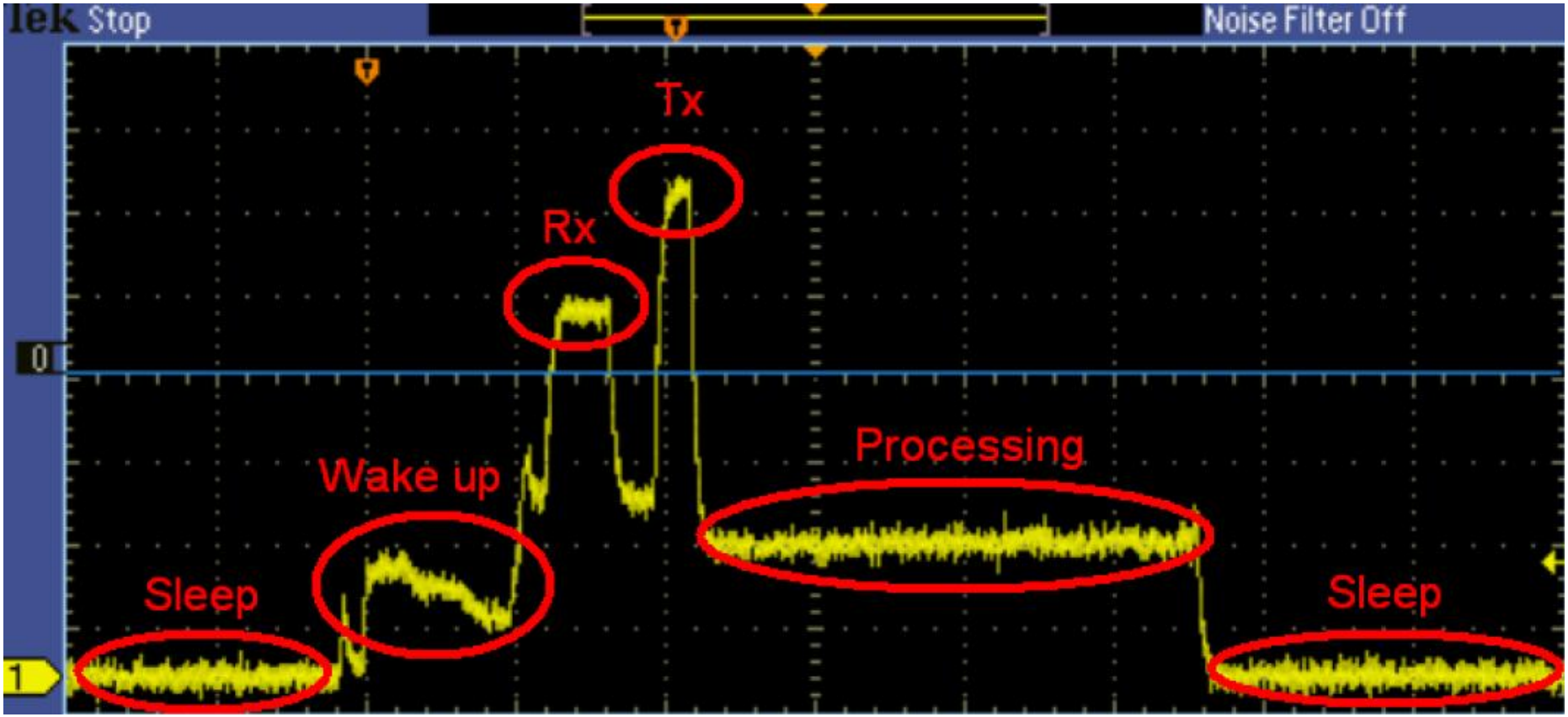
Bluetooth vs. Bluetooth LE

Feature	BR/EDR	LE	Notes
RF Channels	79	40	2 MHz spacing in LE
Range (typical)	30 meters	50 meters	
Ack Packet Len	126 µs	80 µs	63% shorter
8 octet Packet	214 µs	144 µs	67% shorter
Max Packet Size	2875 µs = 1021 octets	328 µs = 27 octets	LE very short
Max Data Rate	2178.1 kb/s	305 kb/s	EDR much faster
L2CAP overhead	4 to 12 octets	4 octets	LE basic headers only

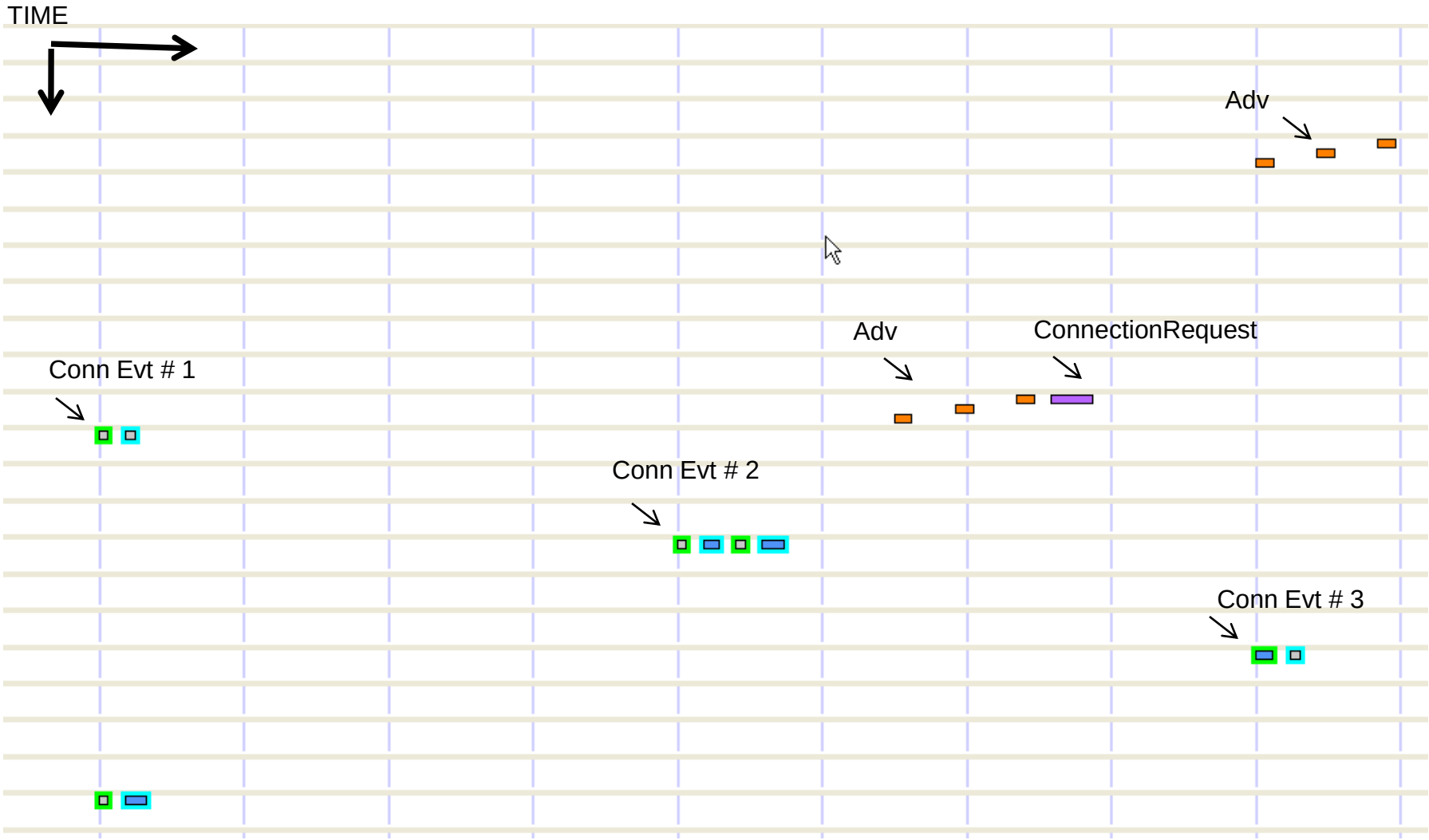
Connection Interval



Connection Interval Power



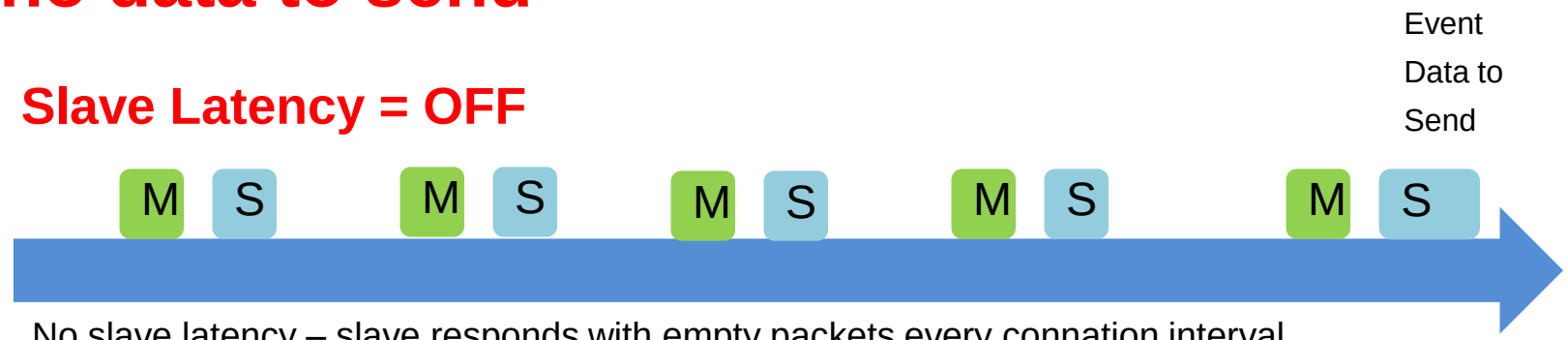
Sniffer Capture



Slave Latency

Slave device sleeps during connection interval if no data to send

Slave Latency = OFF

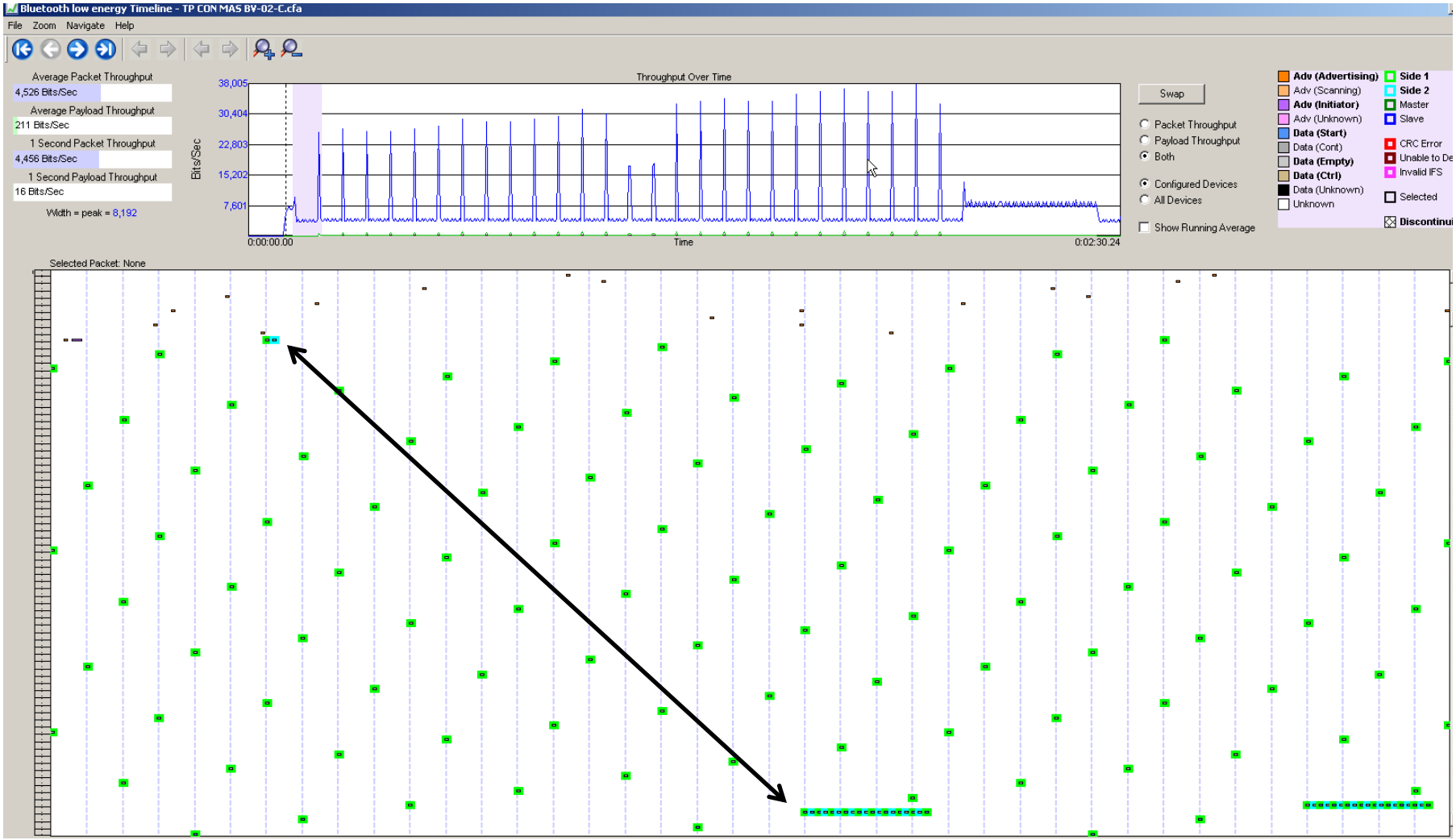


No slave latency – slave responds with empty packets every connation interval.

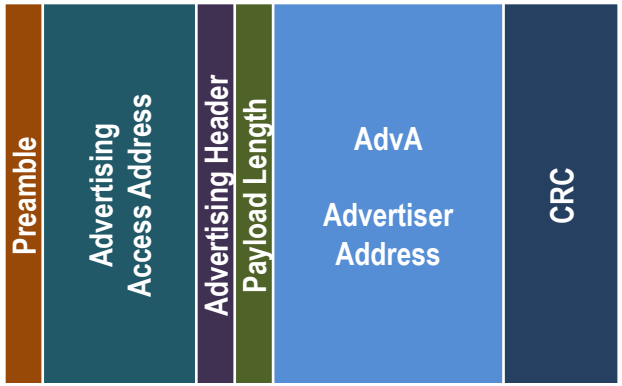
Slave Latency = ON

Slave latency on. Slave can skip n connection events. Only wake up if slave has data to send.

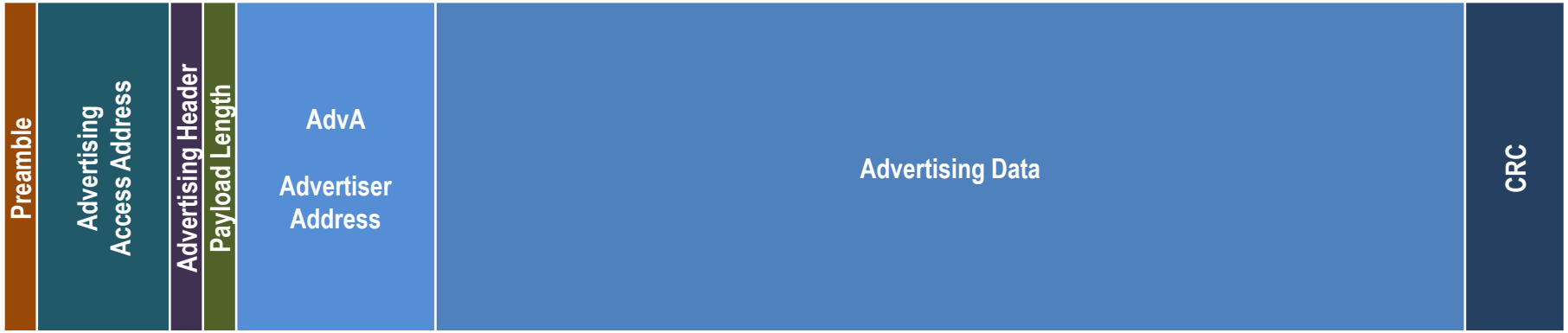
Slave latency on Frontline sniffer



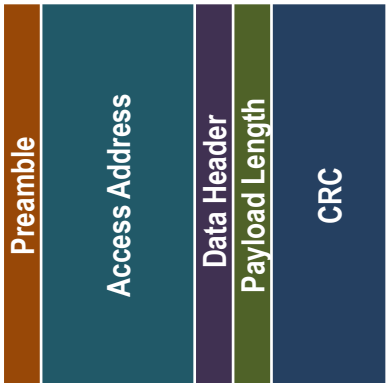
ADVERTISING PACKET



- 0 to 31 bytes of Advertising data

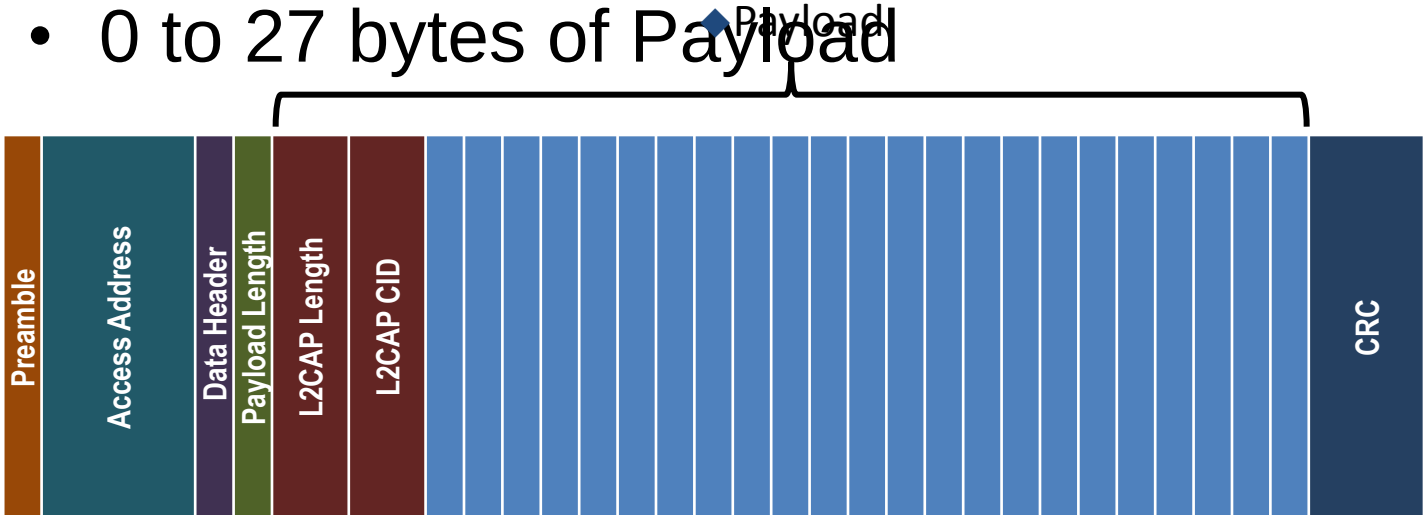


DATA PACKET



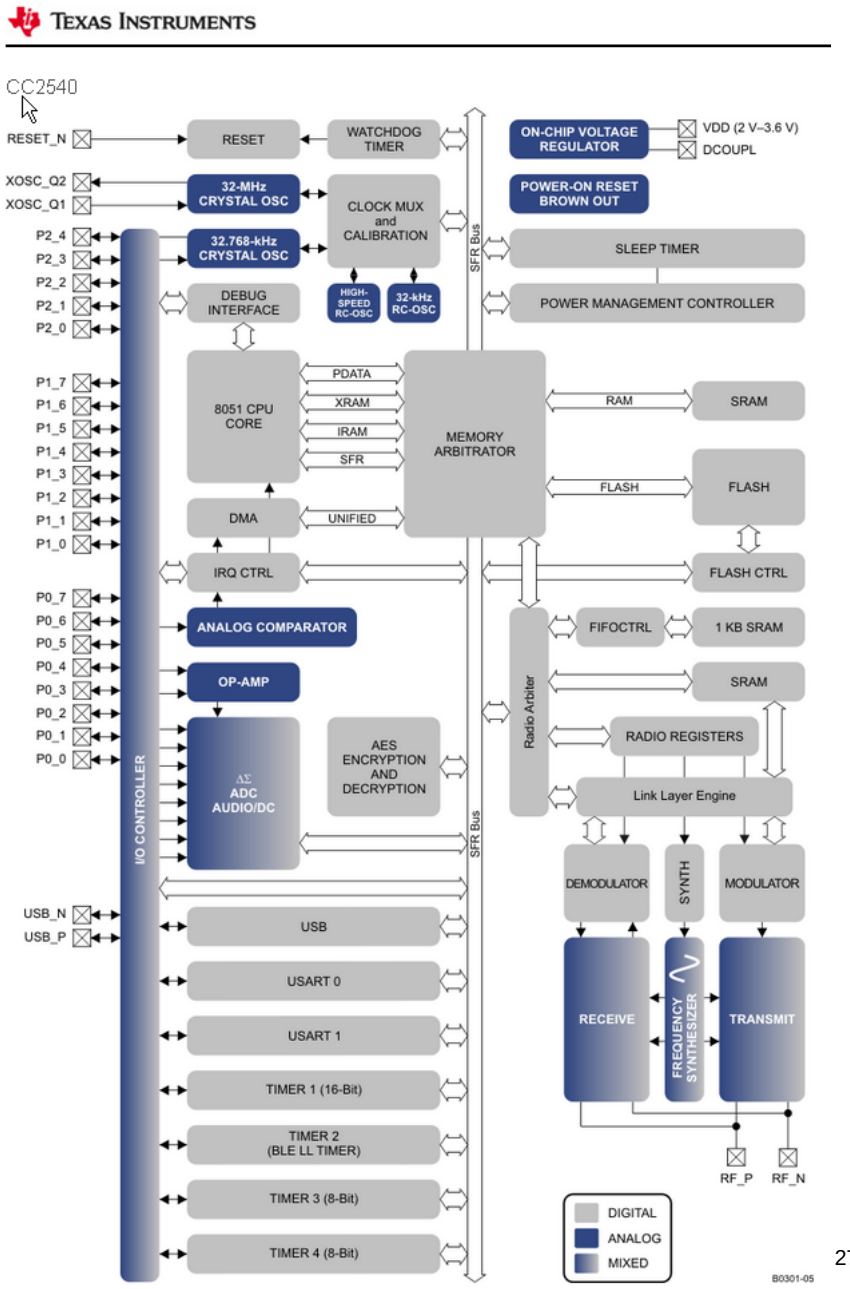
Empty Packet

- 0 to 27 bytes of Payload

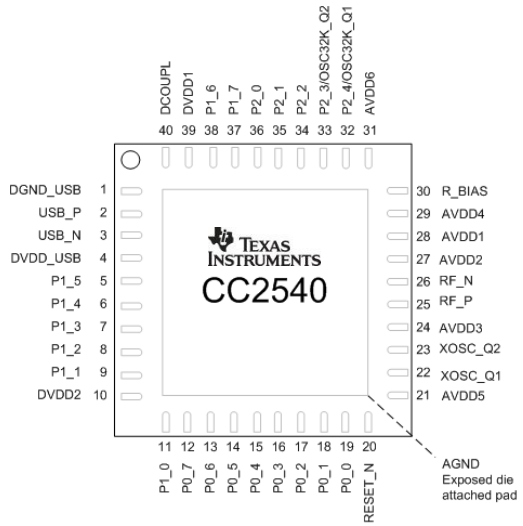


TI CC2540 Solution

- System on chip
- RF Transceiver + 8051MCU
- Master or Slave
- Programmable flash
- 8KB RAM
- Full SW stack – royalty free
- First to RTM & meet full qualification



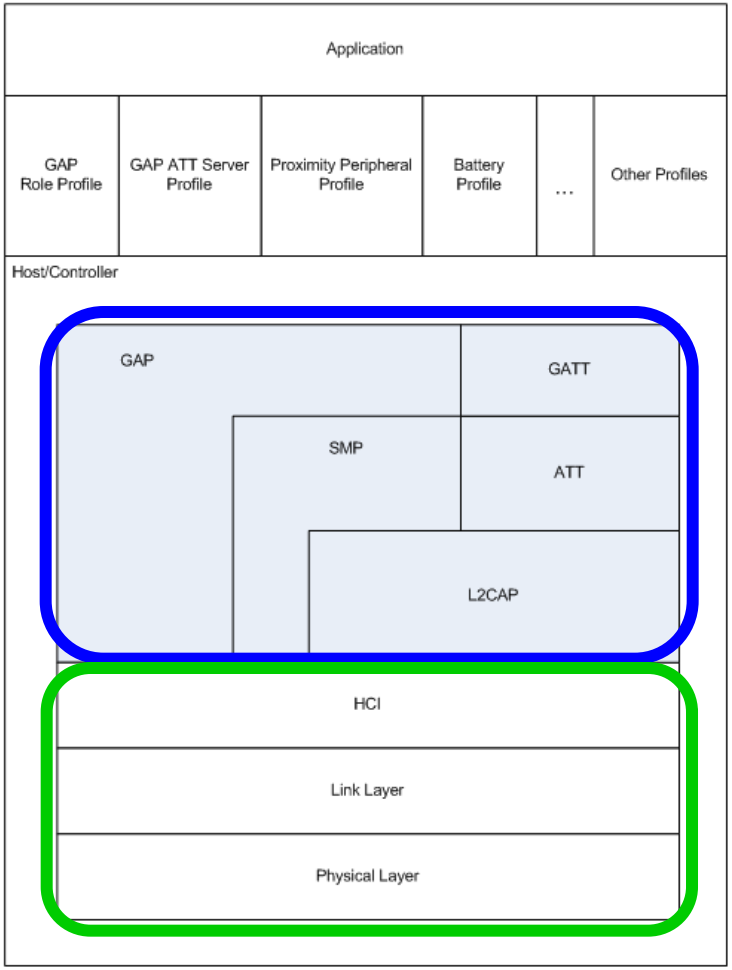
CC2540 System-on-a-chip (SoC)



- **8051 MCU - 128/256 kB in-system programmable Flash → 8 kB SRAM**
- **Programmable Radio Supports**
  - **Bluetooth Low Energy (1Mbps GFSK)**
- **Digital peripherals**
  - 21 GPIOs
  - 2 USART (UART or SPI)
  - Full Speed USB 2.0
  - 2x 16 bit, 2x 8-bit timers
  - Dedicated Link Layer timer for Bluetooth LE protocol timing
  - AES-128 encryption/decryption in HW
- **Advanced analog peripherals**
  - 8-channel 8-12 bit delta-sigma ADC
  - Ultra-low-power analog comparator
  - Integrated high-performance op-amp
- **All in a 40-pin 6x6x0.85mm QFN package**
- **Pin compatible with CC2530/33 and CC2541**

Bluetooth Low Energy Protocol Stack Architecture / Configurations

- Protocol stack consists of two main sections:
  - **Controller**
  - **Host**
- Profiles and Application sit on top of the GAP and GATT layers of the host
- In a “single-device solution” (or “single-chip solution”), the host, controller, profiles, and application are all implemented together on the same chip
- In a “dual-device solution”, the BLE controller is implemented on one device, while the host, application, and profiles are implemented seperately
- In a “network processor”, the host and controller are implemented together, but the application and profiles sit on another device (such as a PC or external microcontroller)
- CC2540 can support any of these configurations



TI CC2540DK-MINI Hardware

Debugger

- Works with keyfob and USB dongle
- Supports IAR and TI flash programmer

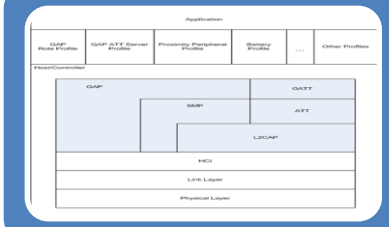
CC2540 Keyfob

- Powered by CR2032 coin cell battery
- LED, buttons, buzzer, accelerometer
- Usually acts as peripheral, application is on chip.

USB Dongle

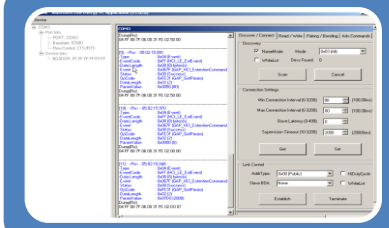
- Use Btool.exe to or custom app to send HCI commands.
- Usually acts as master (cell phone)

TI CC2540DK-MINI Software



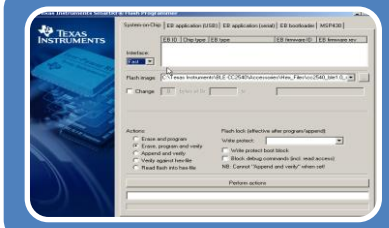
Stack Libraries

- Royalty free
- Full qualification
- Example Projects



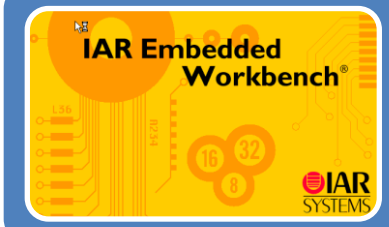
Btool Application

- Drives USB dongle with HCI commands
- Scan for devices, connect, authentication
- Log messages



SmartRF Flash Programmer

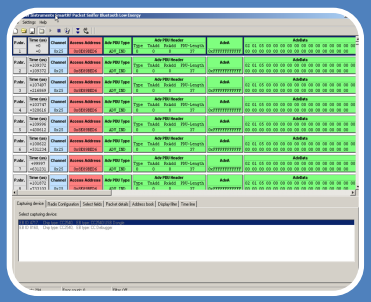
- Can flash CC2540
- Change address on device



IAR Compiler and IDE

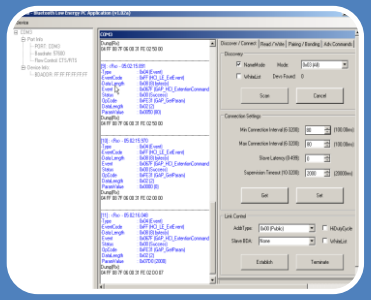
- Robust 8051 compiler with CC2540 support.
- 30 day free evaluation

TI CC2540DK-MINI Support



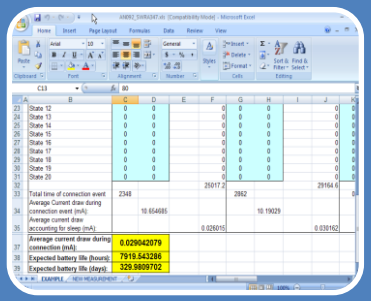
TI RF Sniffer

- Free
- Works with Mini Kit USB Dongle



Example Applications

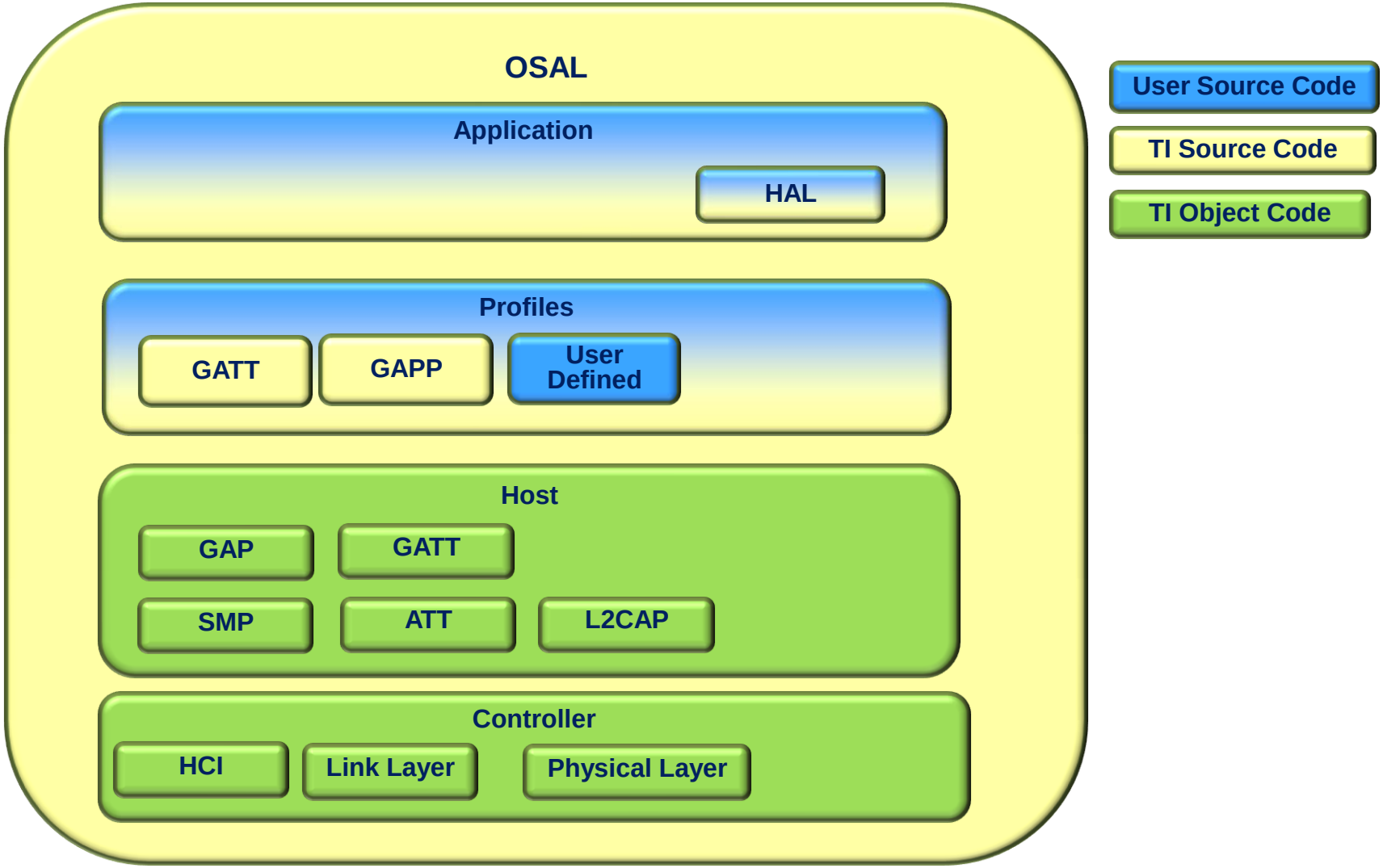
- SimplePeripheral – keypress, strings
- KeyFobDemo – Accelerometer, buzzer, beeper, proximity, battery level.
- Other SIG profile applications under development

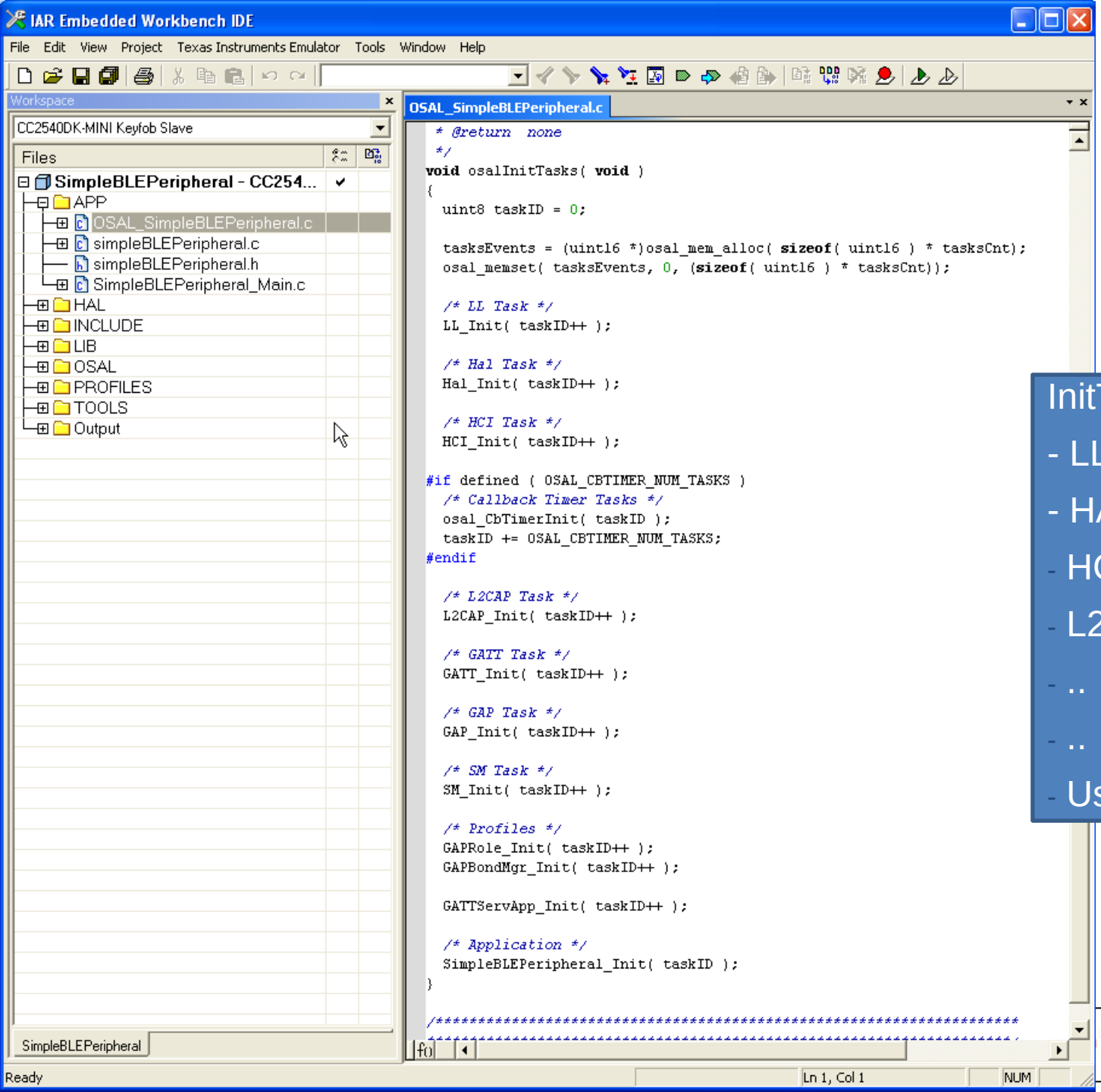


Power Calc Applications Note

- Excel sheet to help calculate battery life expectancy

Software Overview

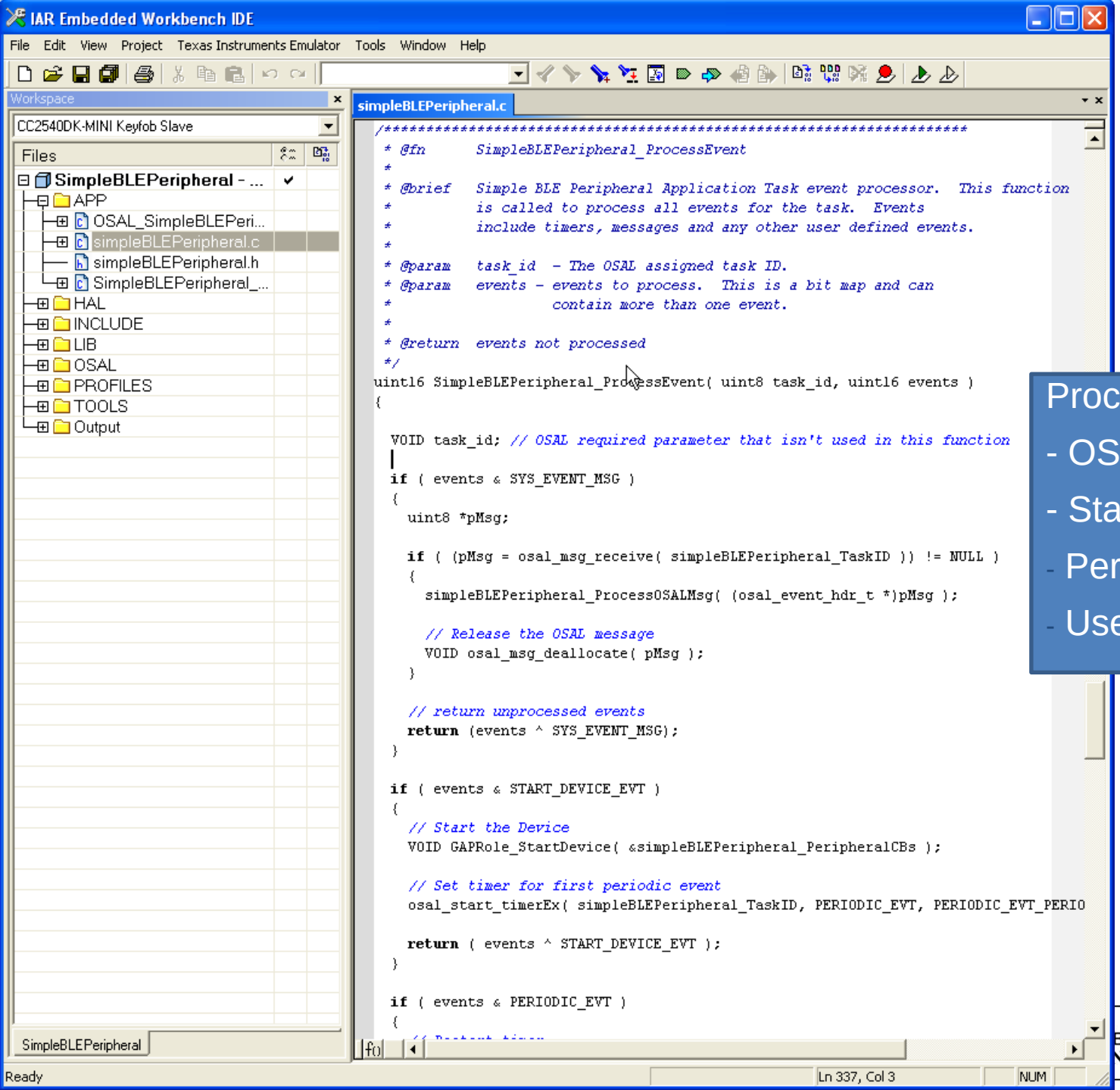




InitTask

- LL_Init
- HAL
- HCI
- L2CAP
- ..
- ..
- User Application

Texas Instruments



ProcessEvent

- OSAL Msg
- StartDevice
- Periodic Event
- UserDefined

KeyFobDemo Example

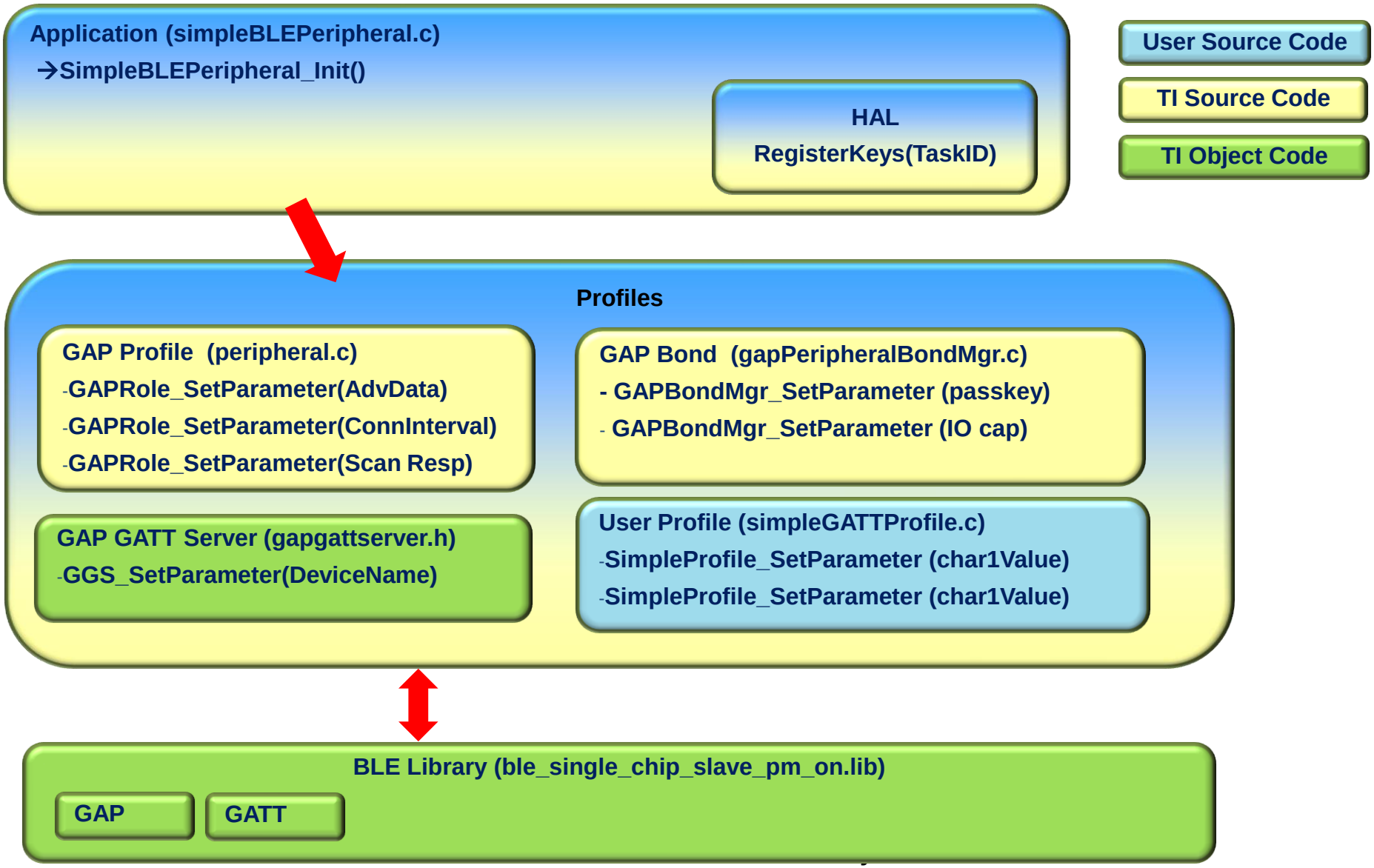
KeyFobDemo Application

- Key press notifications
- Buzzer (GPIO)
- Battery percentage measurement (ADC)
- Accelerometer data notification (SPI)

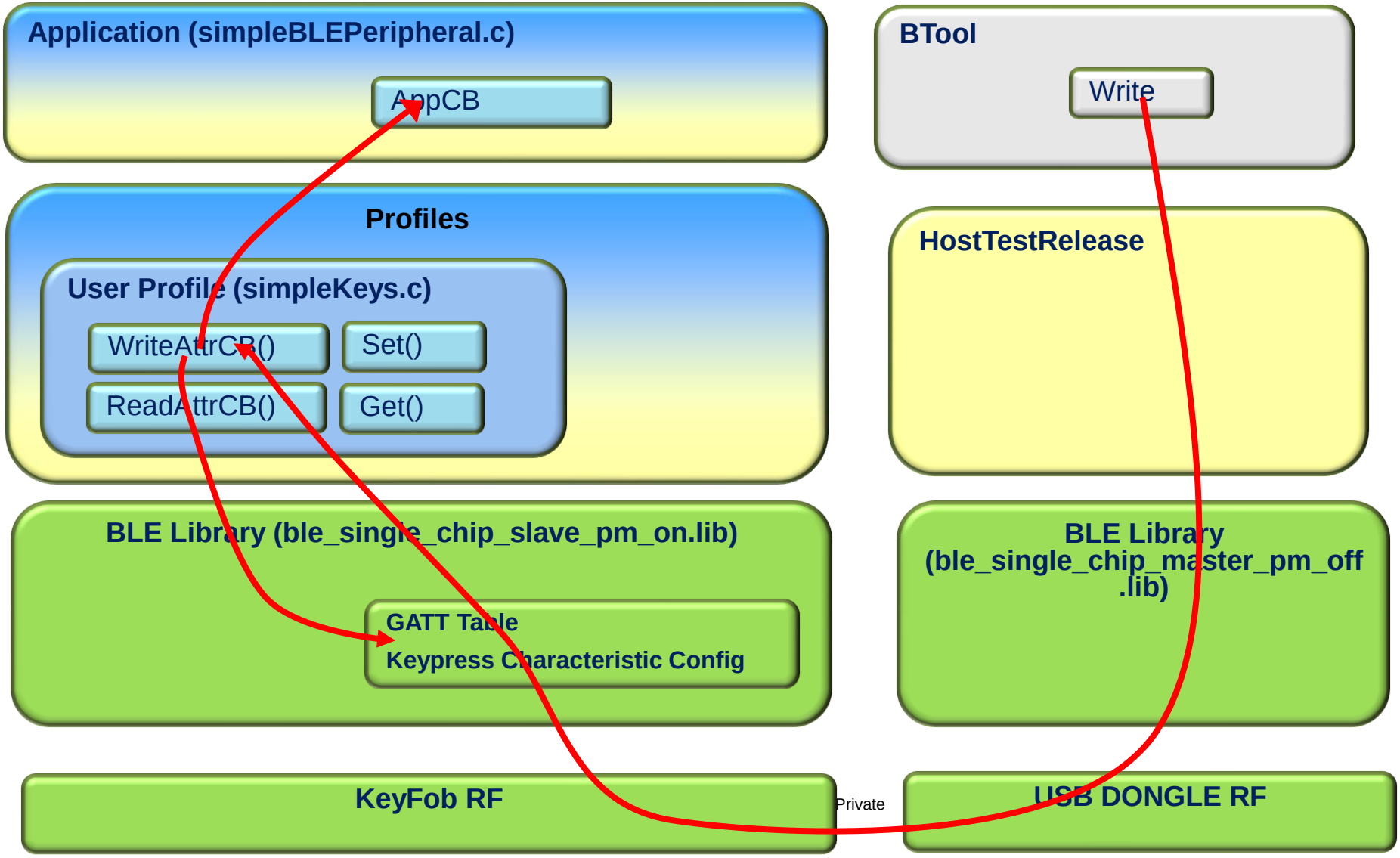
Source Code for KeyFob Demo available on TI Wiki

http://processors.wiki.ti.com/index.php/Category:KeyFobDemo

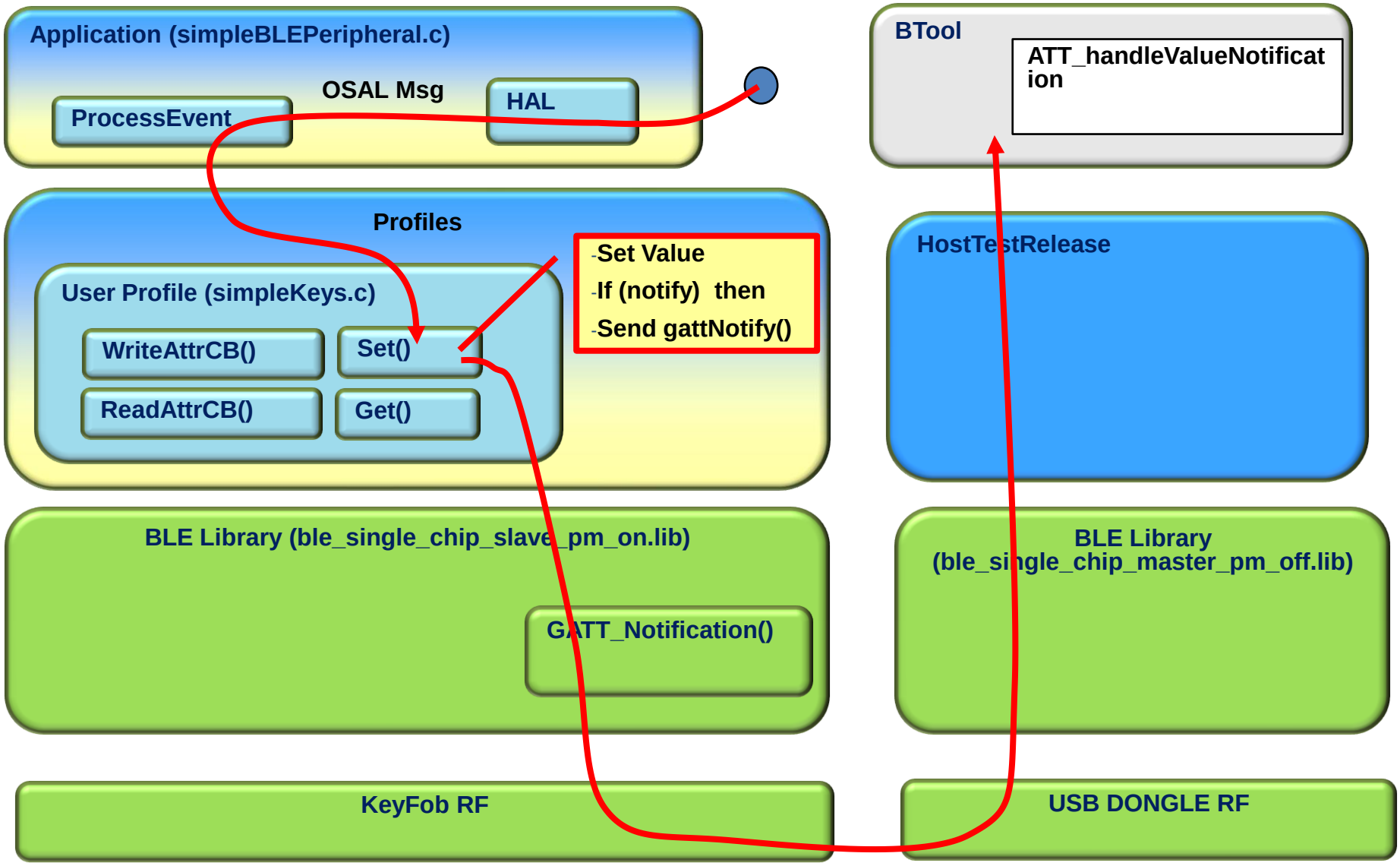
Application Startup (set values)



Application – Turn on Notifications

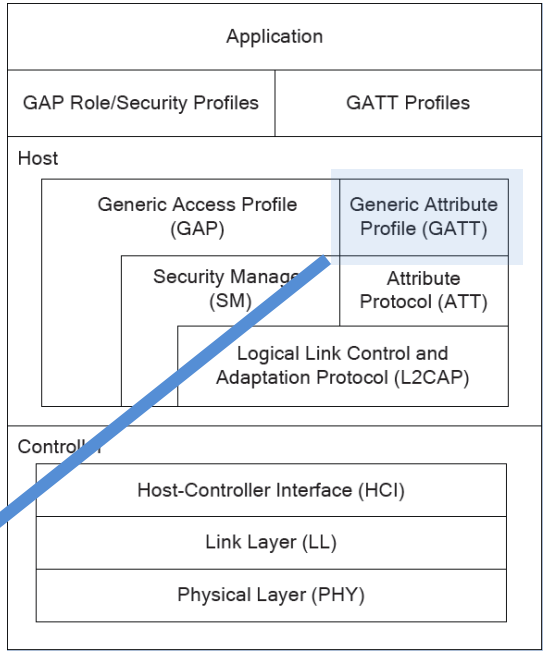


Application – Keypress Notification



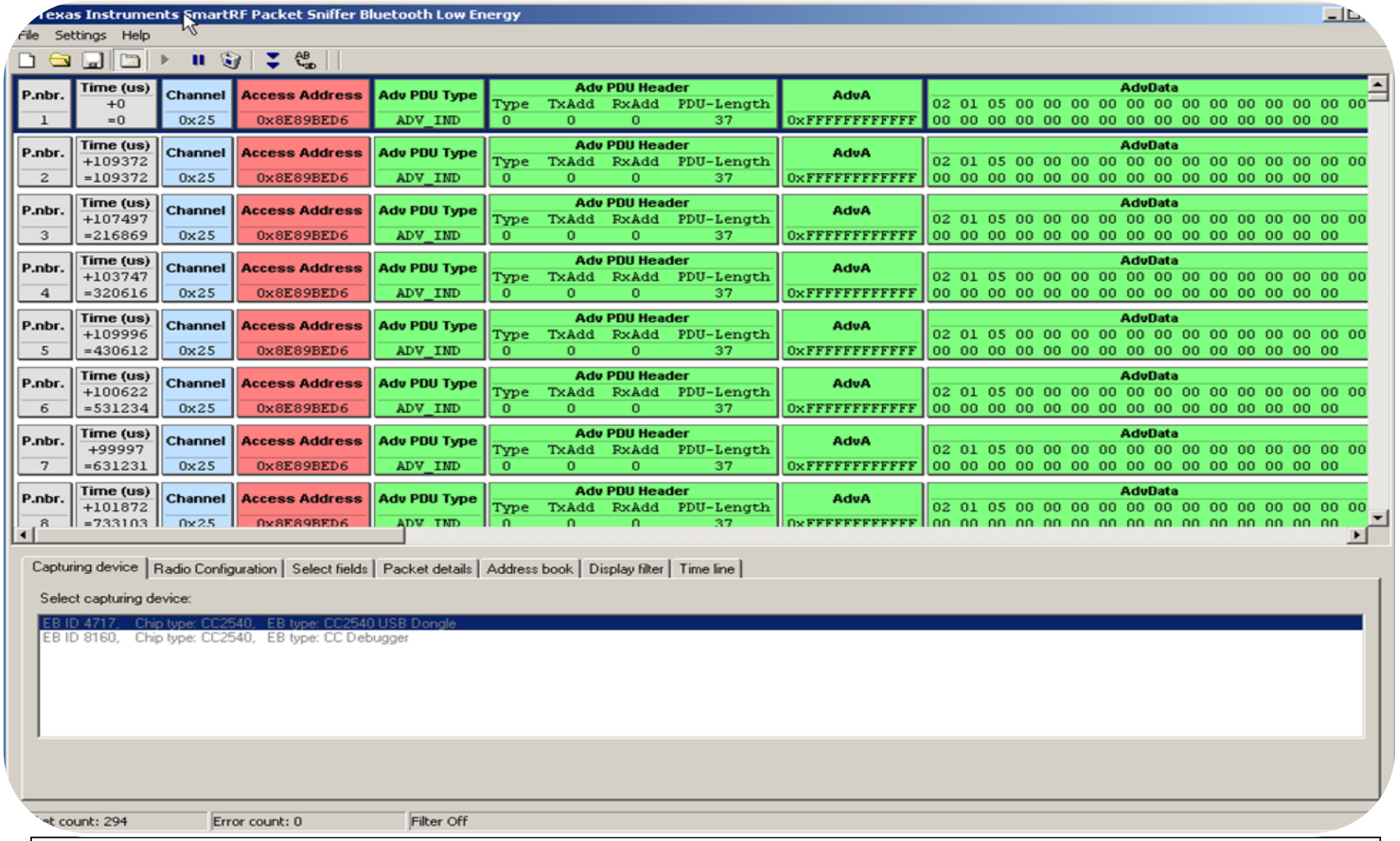
GATT Table

- Allows client to scan for services
- Contains groups of characteristics
  - Name
  - Permissions
  - Value
- SIG assigned numbers



Type (hex)	Type (#DEFINE)	Value (default)	Local Parameter Name	Application Permissions	GATT Server Permissions	Description
0x2800	GATT_PRIMARY_SERVICE_UUID	0xFFE0 (SK_SERVICE_UUID)			Read	Start of Service
0x2803	GATT_CHARACTER_UUID	10 (properties: notify only) 1F 00 (handle: 0x001F) E1 FF (UUID: 0xFFE1)			Read	Key Press State Characeristic Declaration
0xFFE1	SK_KEYPRESSED_UUID	0 (1 byte)	SK_KEY_ATTR	Read / Write	Notify	Key Press State Characteristic Value
0x2902	GATT_CLIENT_CHAR_CFG_UUID	00:00 (2 bytes)			Read	Key Press State Characteristic Value
0x2901	GATT_CHAR_USER_DESC_UUID	"Key Press State" (16 bytes)			Read	Key Press State Characteristic Configuration

TI BLE Sniffer

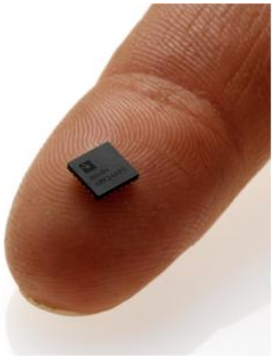


ANT

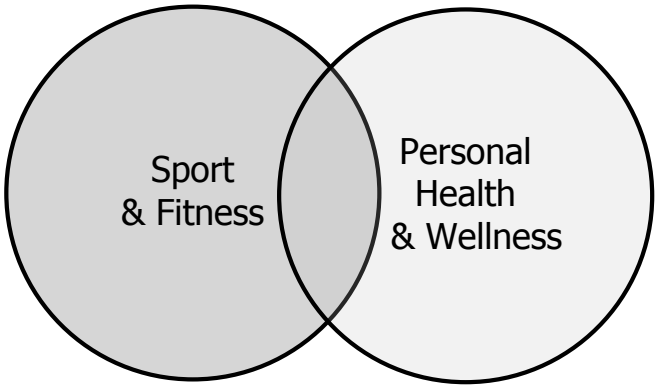
CC2570 – 1 Channel
CC2571 – 8 Channel

ANT: 2.4GHz WSN Protocol

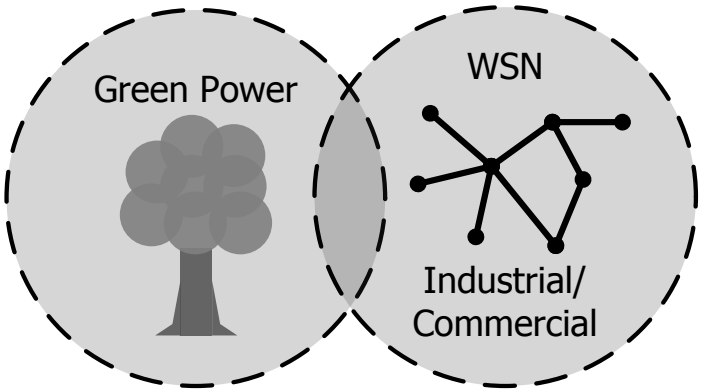
- Ultra Low Power on both master and slave
- Low development and system cost
- Mature, stable, third generation SW and HW
- Ease of integration allows fast time to market
- Simple to complex network topologies
- Sophisticated file transfer (ANT-FS)
- Established ANT+ interoperable ecosystem
- Proven installed base of 13M nodes to date (April 2011)



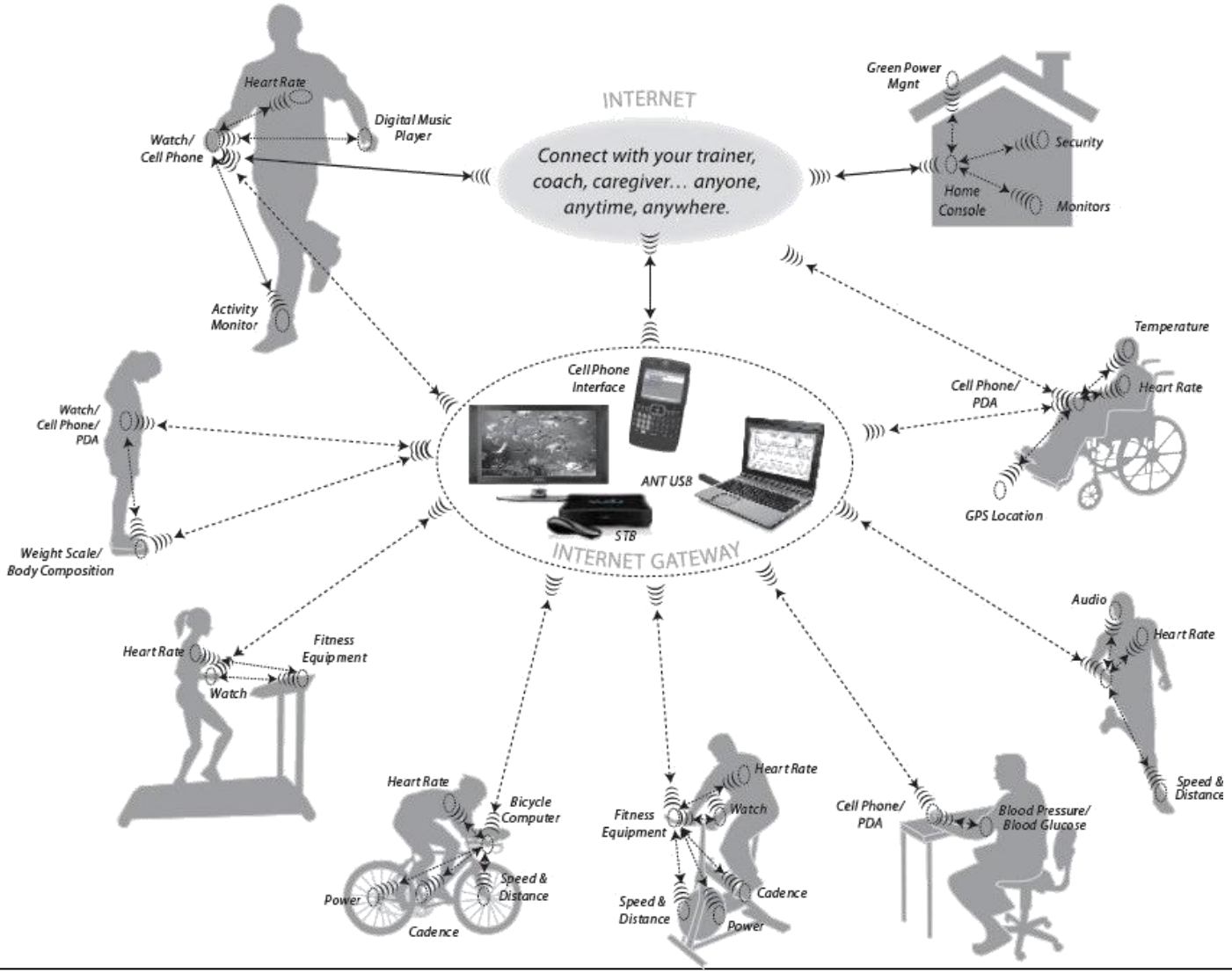
◆Proven



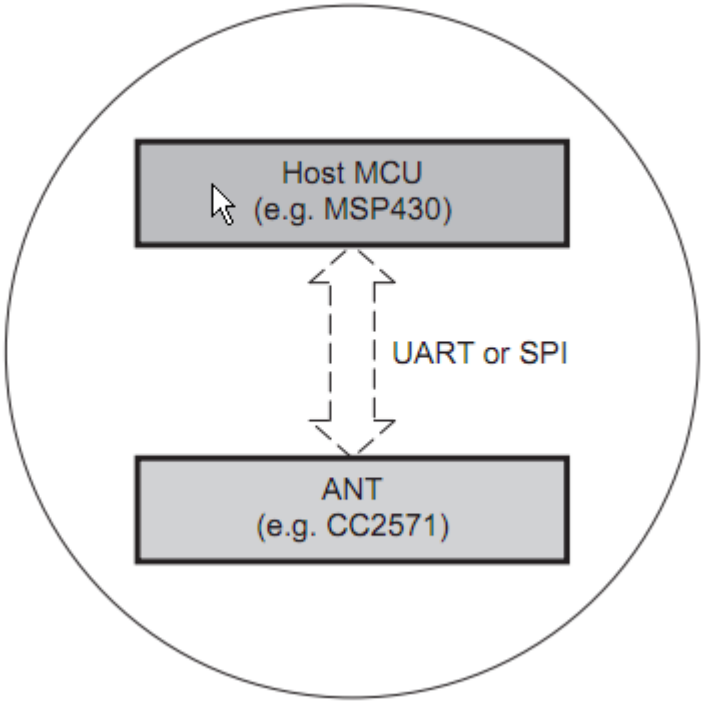
◆Opportunity



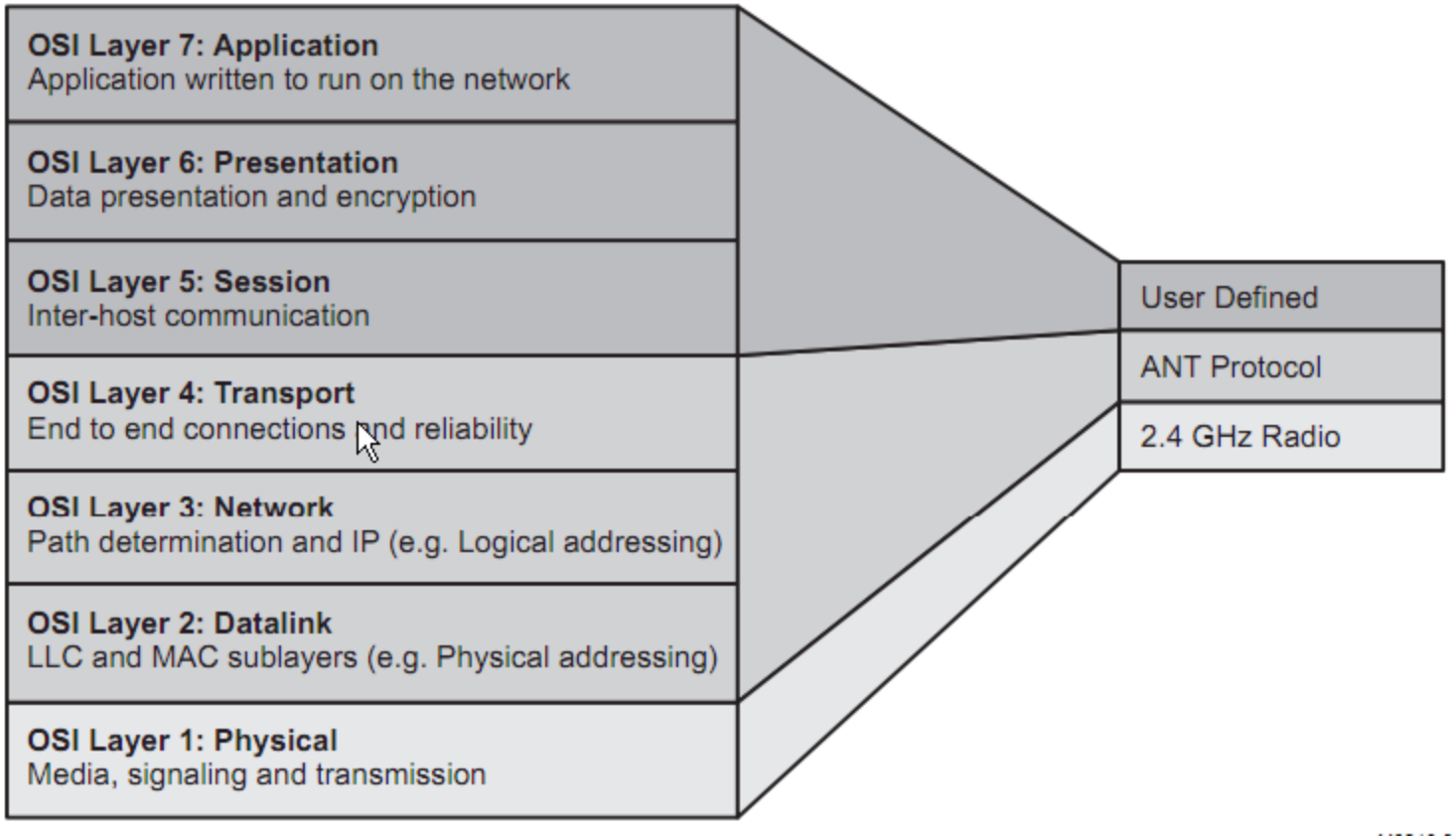
ANT+ Profiles



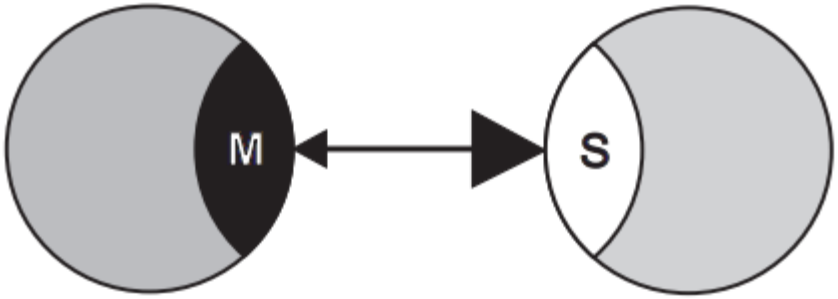
ANT – Network Processor

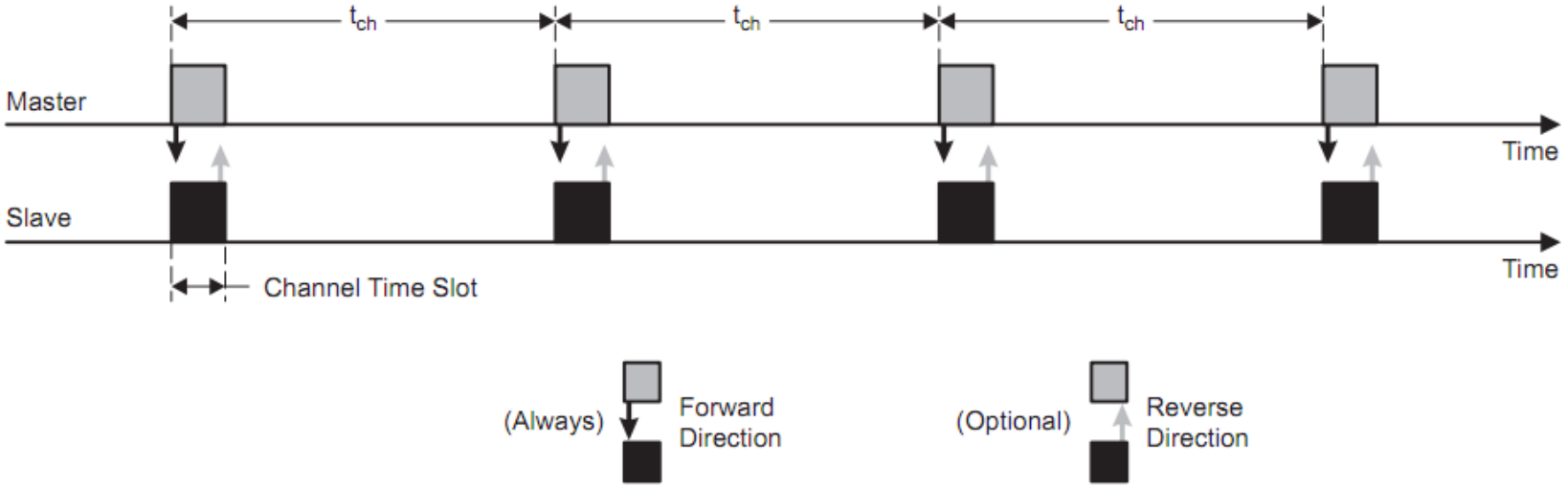


ANT OSI Model

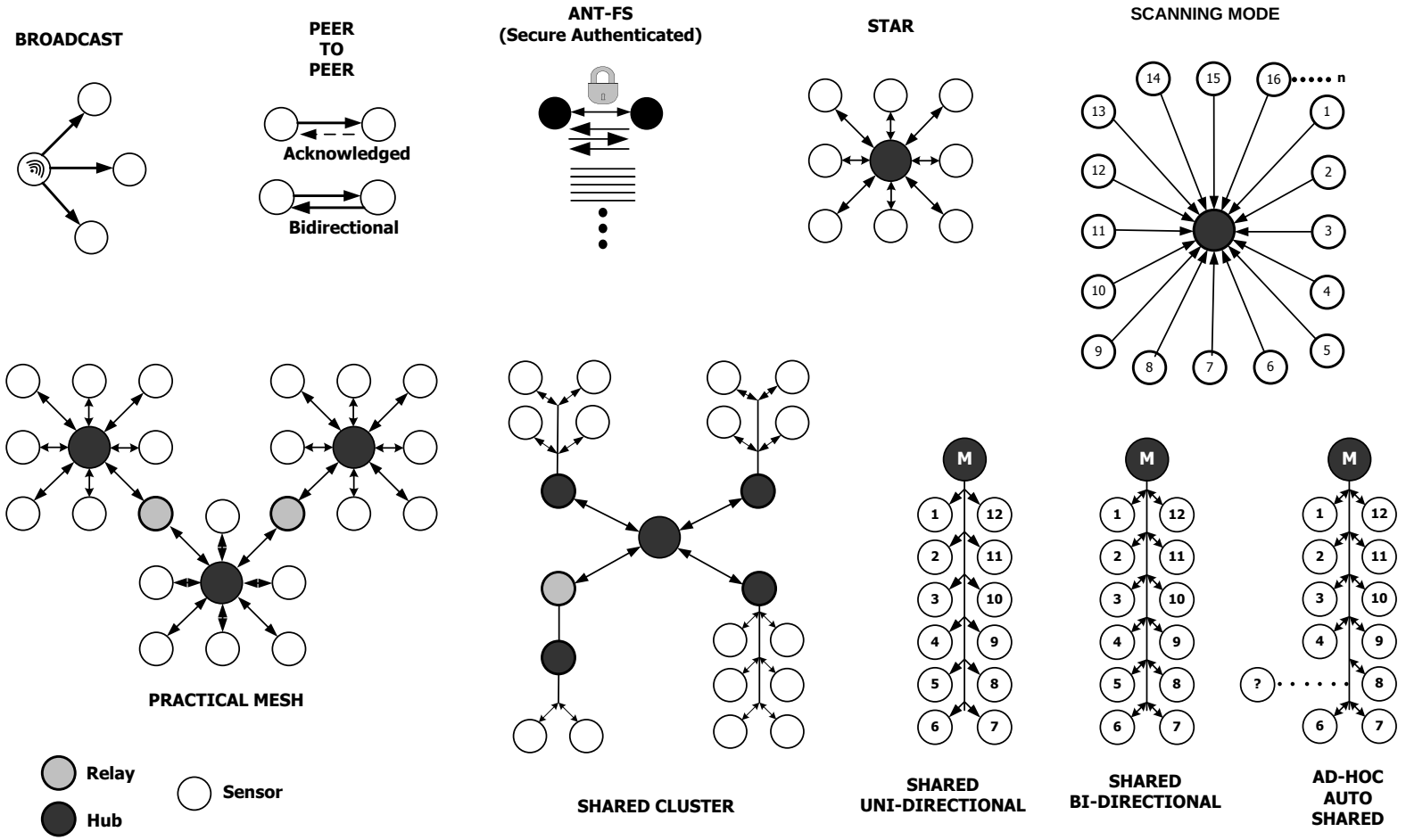


ANT – Overview





ANT – Network Topologies



ANT – FS and FIT

ANT-FS (Integrated into CC2570)

- File transfer protocol
- Protocol extension of ANT
- Authenticated/Seamless operation

FIT

- File format
- Extensible and scaleable
- Forward and backwards compatible
- End to end

Current status

- ANT Single Mode solutions (CC257x)
  - Samples + Datasheet + Development Kits – Available today
  - CC257x – Available today
  - Details on www.ti.com/ant and www.thisisant.com/ti/cc257x
- ANT Dual Mode solutions (CC2567, WL1271/81)
  - WL 1271/81 – Available today
  - CC2567 – Available today
  - Orderable on www.ti.com/ant
- ANT SW + Profiles – Certified and available

ANT – Eval Kit

Contents:

AT3 module X 2

AP2 module X 2

Battery board X 2

IO Board X 2

USB Stick X 2

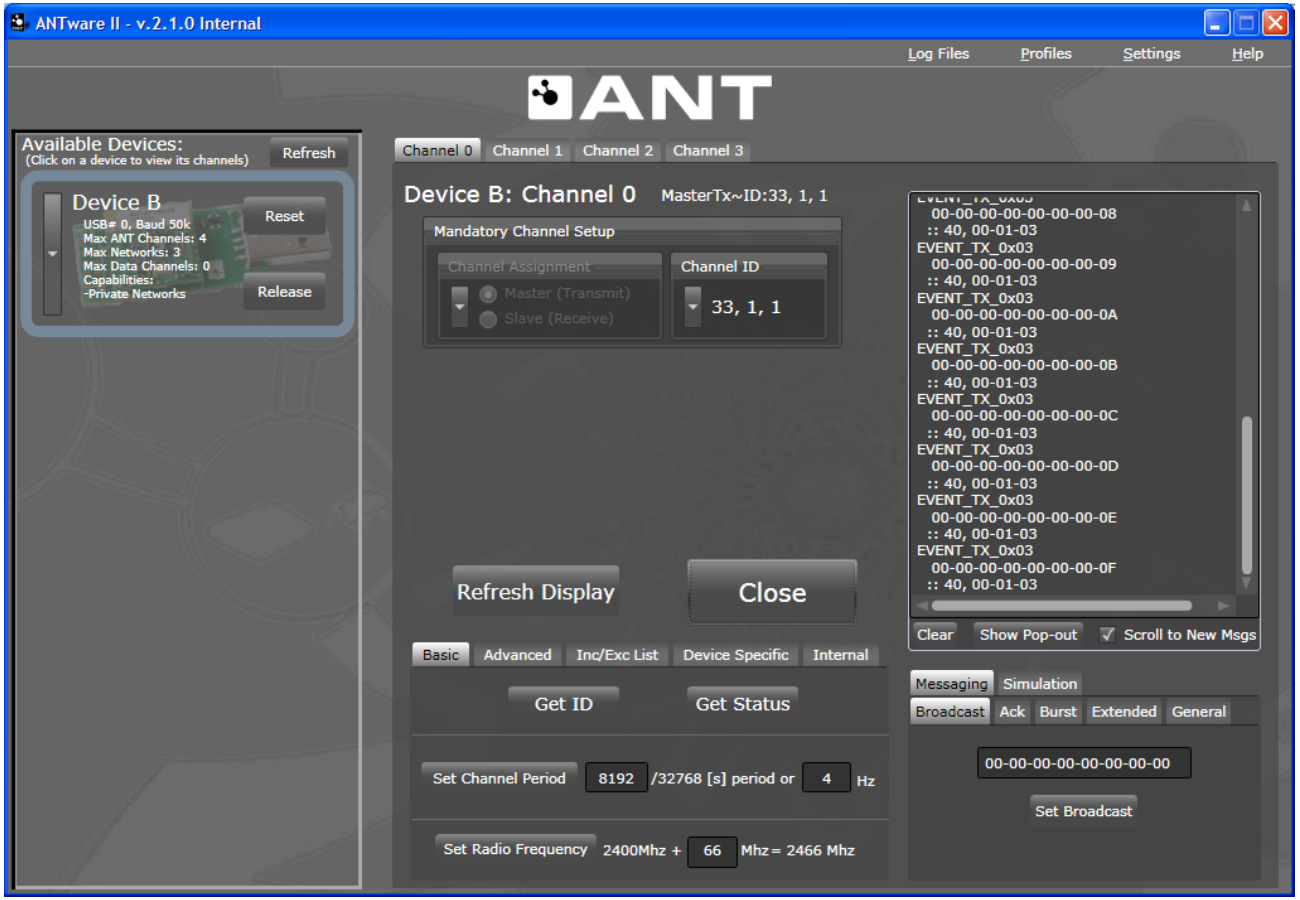
CR2032 battery X 2

CD-ROM (discontinued)

Quick Start Cards

ANT – Example Code

- C# .NET based
- Full source avail



ANT vs. BLE Comparison

ANT vs BLE

- Both ANT and BLE are point to multipoint standards
- BLE enjoys BT SIG support therefore may have wider deployment starting from 2012
- ANT provides immediate access to ~7 millions of ANT+ sensors already in the market (ANT+ infrastructure and ecosystem is well established). BLE has no install base yet.
- ANT is more focused on proximity and fitness
- ANT is Mature, stable (protocol and development tools)
- ANT is capable of complex network topologies

PHY Layer Comparison

	ANT	BLE
ISM bandwidth	2402-2480MHz	2402-2480 MHz
Frequencies	f=2402+k MHz, k=0,…,78	f=2402+kx2 MHz, k=0,…,39
Channel Spacing	1MHz	2MHz
Data rate	1 Mbps	1 Mbps
Range	5-10 m	5-10 m
Modulation	GFSK	GFSK (GMSK)
Mod. Index	0.32	0.5
Maximum Power	+10dbm	+10dbm
Sync Word	16 bits	32 bits
Power Control	YES	NO (left for future spec release)
Sensitivity (Device pin)	-95 dBm	- 98 dBm

- As output power is similar, BLE link margin is expected to be ~3dB better due to wider modulation index, although for the relevant use cases we do not expect noticeable user experience impact

MAC Layer Comparison

	ANT	BLE
Topology	Adhoc networking /Star /Mesh	Pure Star (no piconet)
Roles	Master / Slave / Multiple Master / Multiple Slave Roles defined per channel	Master / Slave Rolls defined per device
Device Discovery	Slave channel scans, master channel transmits data	Master scans, slave advertises, defined per device
Synchronization	Semi-Asynchronous Scheduled connection events	Semi-Asynchronous Scheduled connection events
MAC Addressing	Managed by ANT	48-bit IEEE Assigned or Private Address (secured)
Packet Formats	Data, Maximum 8 bytes	Data, Maximum 27 bytes
Error Protection	Header + Payload are protected by 16 bit CRC	Header + Payload are protected by 24 bit CRC
Hopping Algorithm	None, hop on interference, or profile defined	pseudo-random modulo algorithm (X mod N)
Broadcast Capability	YES	YES
Whitening	NO, not required for short transmission lengths ANT uses	YES
Link Layer Security	None (Future AES support)	AES-CCM (NIST approved)
Scheduling / BT Co-ex	Distributed: ANT and BT networks can not be synchronized, but can coexist	Joint scheduling (dual-mode synchronizes BLE and BT networks)

Host Stack, Use-Cases

	ANT	BLE
Host Interface	ANT message protocol / is supported over BT HCI vendor-specific commands	Standard BT HCI for commands Standard BT HCI (ACL) for data
Service Discovery	ANT+ Profiles	Attribute Protocol
Host Stack Footprint	< 16KBytes below profiles	Under analysis
Bonding	Broadcast: OOB, wild card, pairing flags, proximity Session (ANTFS): proximity, OOB, passkey, just works, support for new methods	OOB, Passkey, Just works Future versions will support SSP
Target Use-Cases	Sport sensors, medical, proximity, remote controls, active RFID, Home automation, environmental monitoring	Sport sensors, medical, proximity, remote controls, active RFID, Home automation, environmental monitoring, HID (future)
High Density Broadcast	Yes, active channel avoidance supports 100+ devices on a single frequency, scalable with added frequencies	No, relies on probability to avoid collisions
Low Power Search	Tradeoff between receive window and detection time, same for ANT and BLE	Tradeoff between receive window and detection time, same for ANT and BLE

BLE LABS

Labs

KeyPress

- Use TI flash programmer to assign address and flash images.
- Enable keypress notifications from keyfob to USB dongle.
- Use Btool to see logging

Sniffer

- Load sniffer image into USB Dongle
- Enable advertisements on keyfob and watch on sniffer.

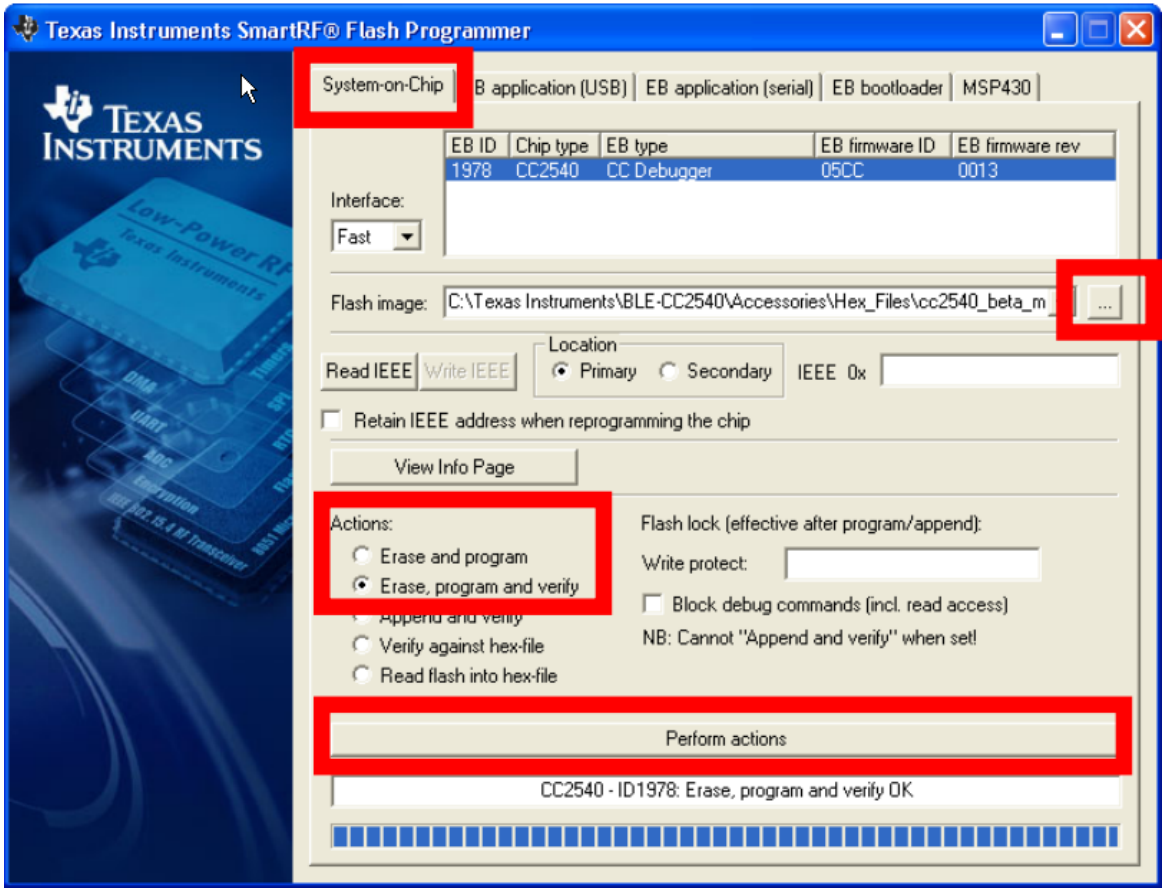
Accelerometer

- Load keyfobdemo application
- Enable accelerometer notifications

Lab #1.1

1. Connect USB Dongle and CC Debugger as shown
2. CC debugger light should be green and USB dongle LED should be green.

Lab #1.2

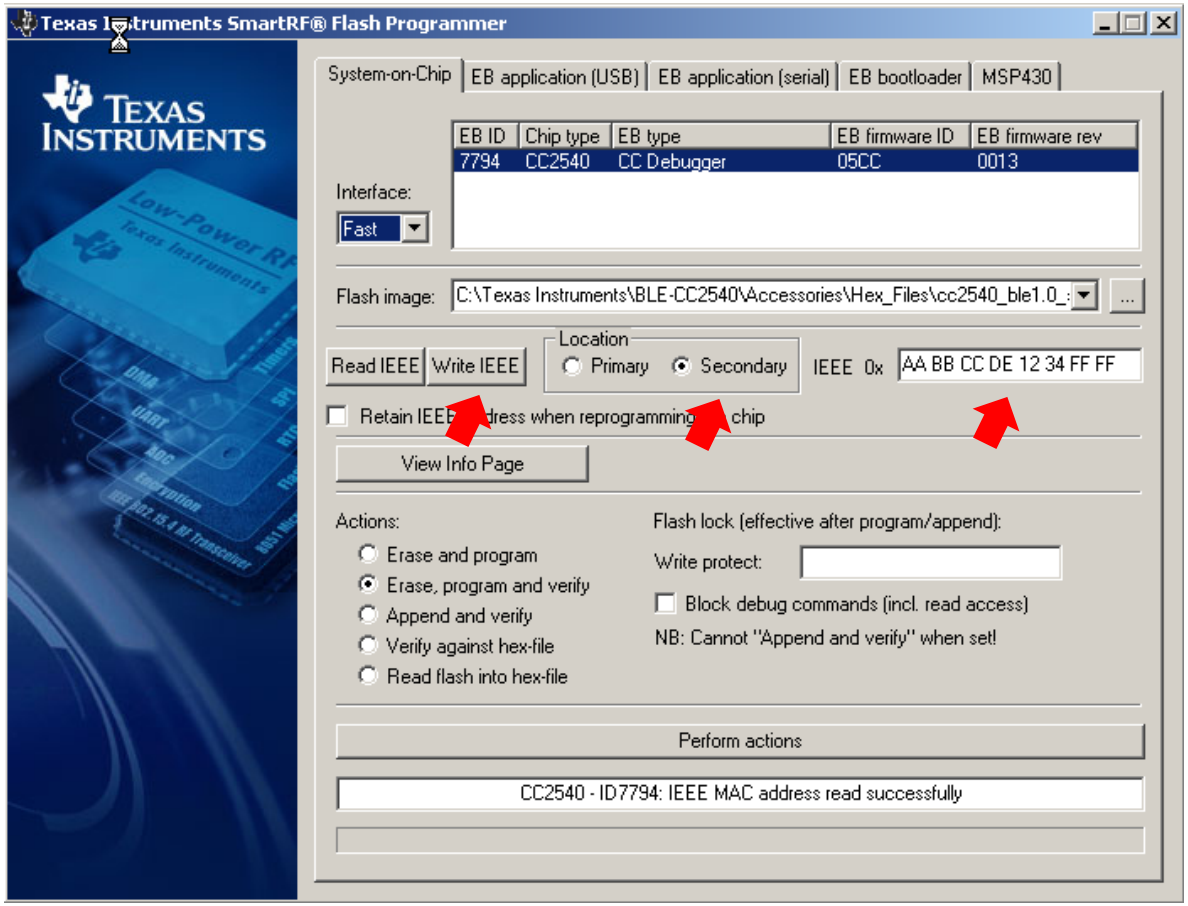


1. Use SmartRF flash programmer to download .hex file

C:\Texas Instruments\BLE-CC2540\Accessories\Hex_Files\cc2540_ble1.0_master_usb_dongle.hex

* USB Dongle LED should turn red

Lab #1.2b

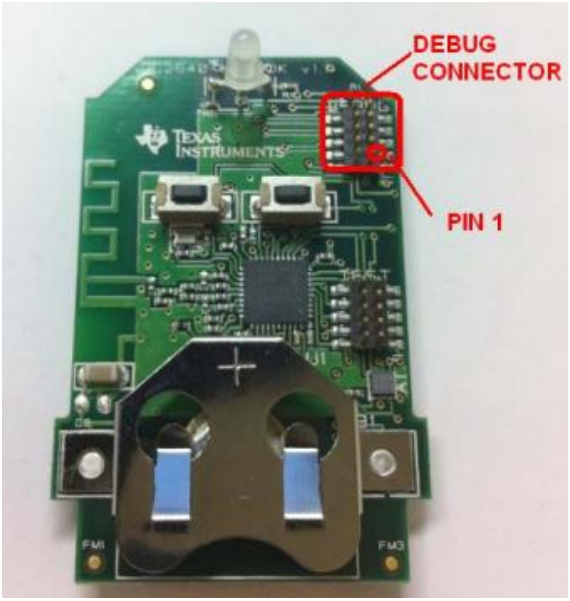


1. Use SmartRF flash programmer change address

- Click secondary radio button
- Enter in new address – left six bytes
- Click Write IEEE
- Read back to verify

Lab #1.3

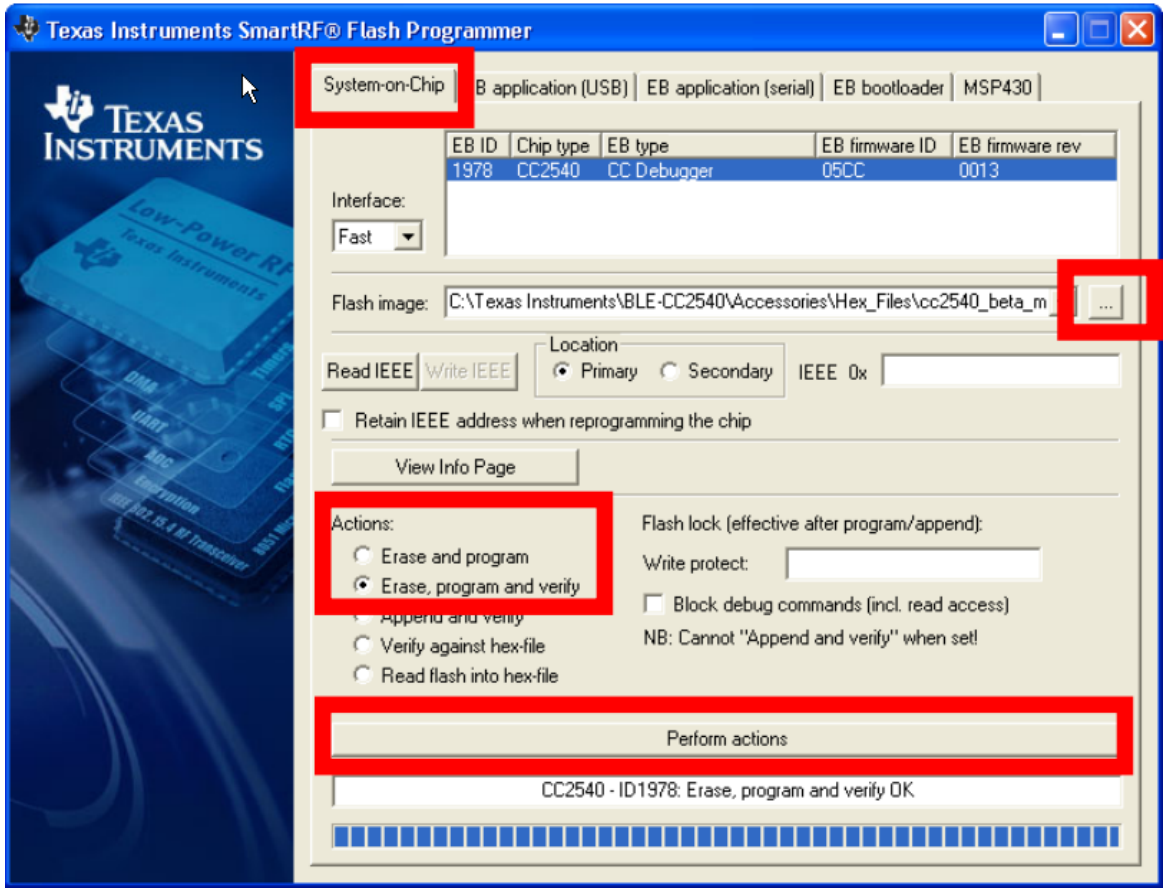
1. Connect keyfob and CC Debugger as shown
2. Insert battery
3. Press button to stop buzzer
4. CC debugger light should be green. (may need to detach and attach USB cable)



1. Use SmartRF flash programmer to download .hex file

C:\Texas Instruments\BLE-CC2540\Accessories\Hex_Files\cc2540_ble1.0_slave_keyfob.hex

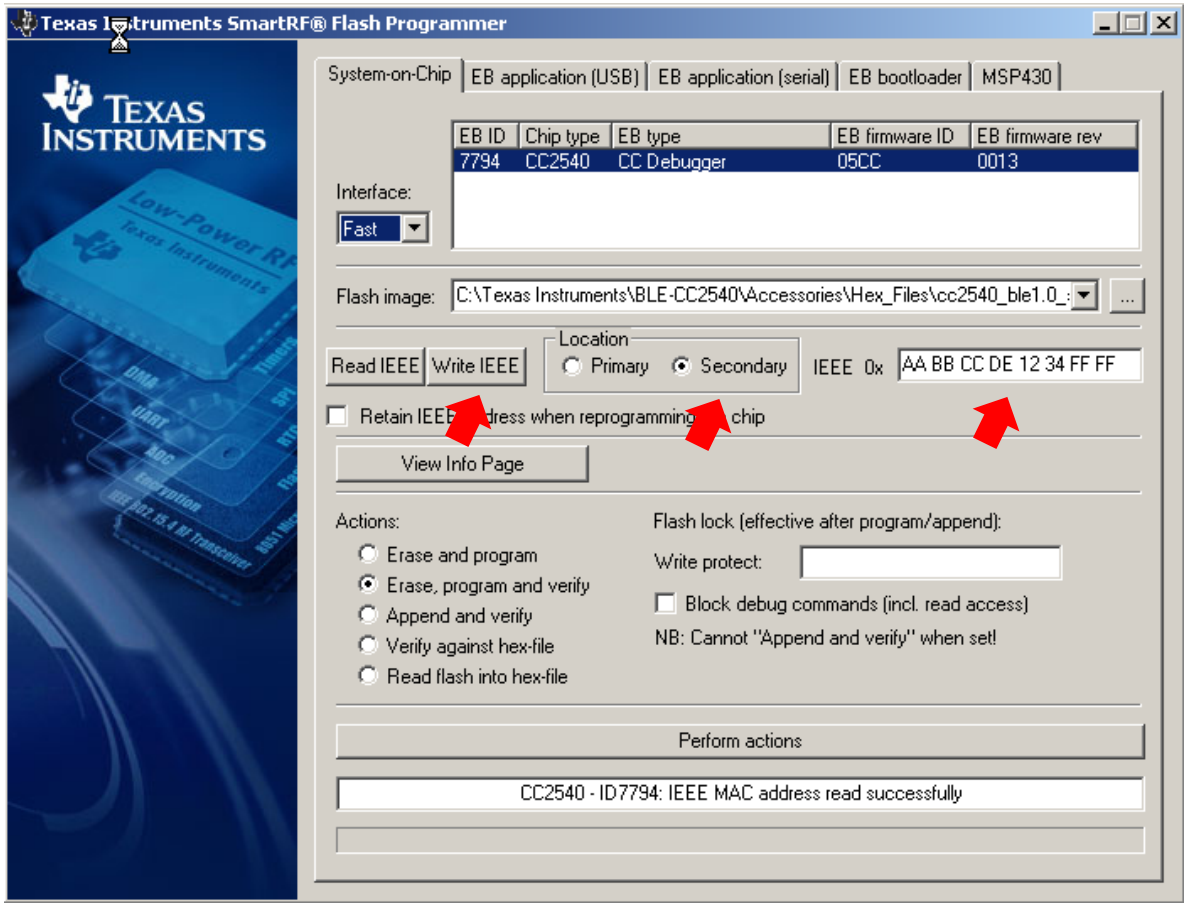
Lab #1.4



1. Use SmartRF flash programmer to download .hex file

C:\Texas Instruments\BLE-CC2540\Accessories\Hex_Files\cc2540_ble1.0_slave_keyfob.hex

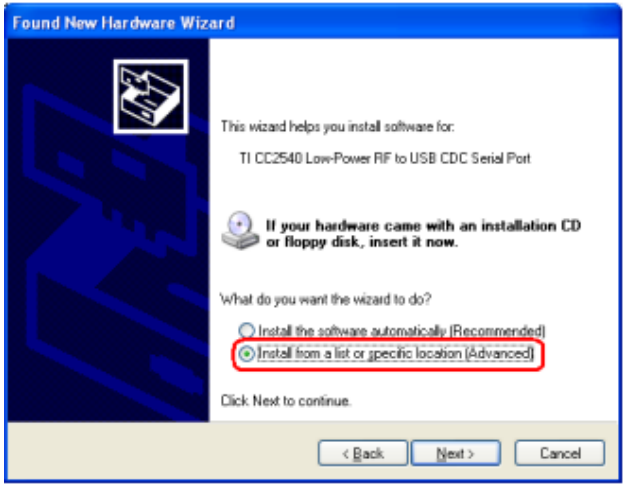
Lab #1.4b



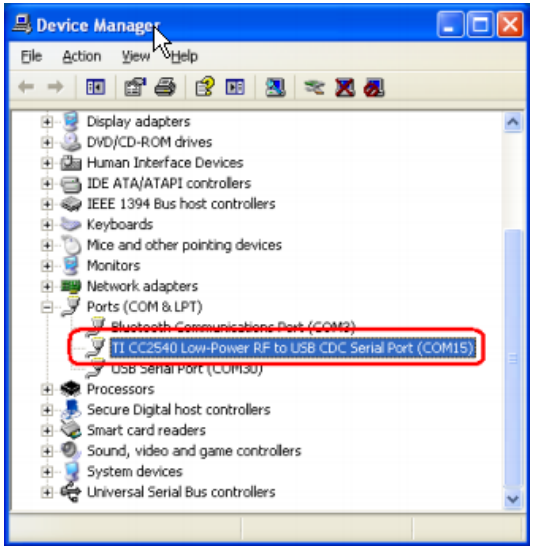
1. Use SmartRF flash programmer change address

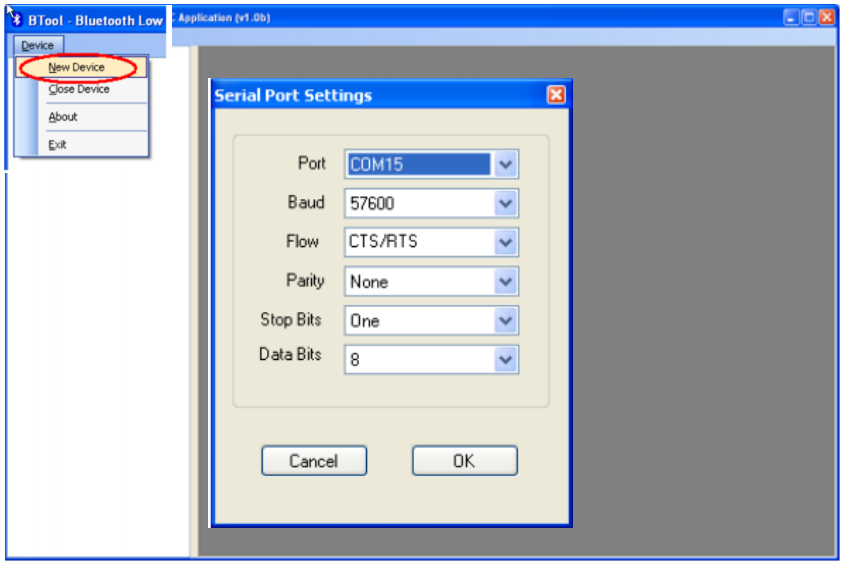
- Click secondary radio button
- Enter in new address – left six bytes
- Click Write IEEE
- Read back to verify

Lab #1.5

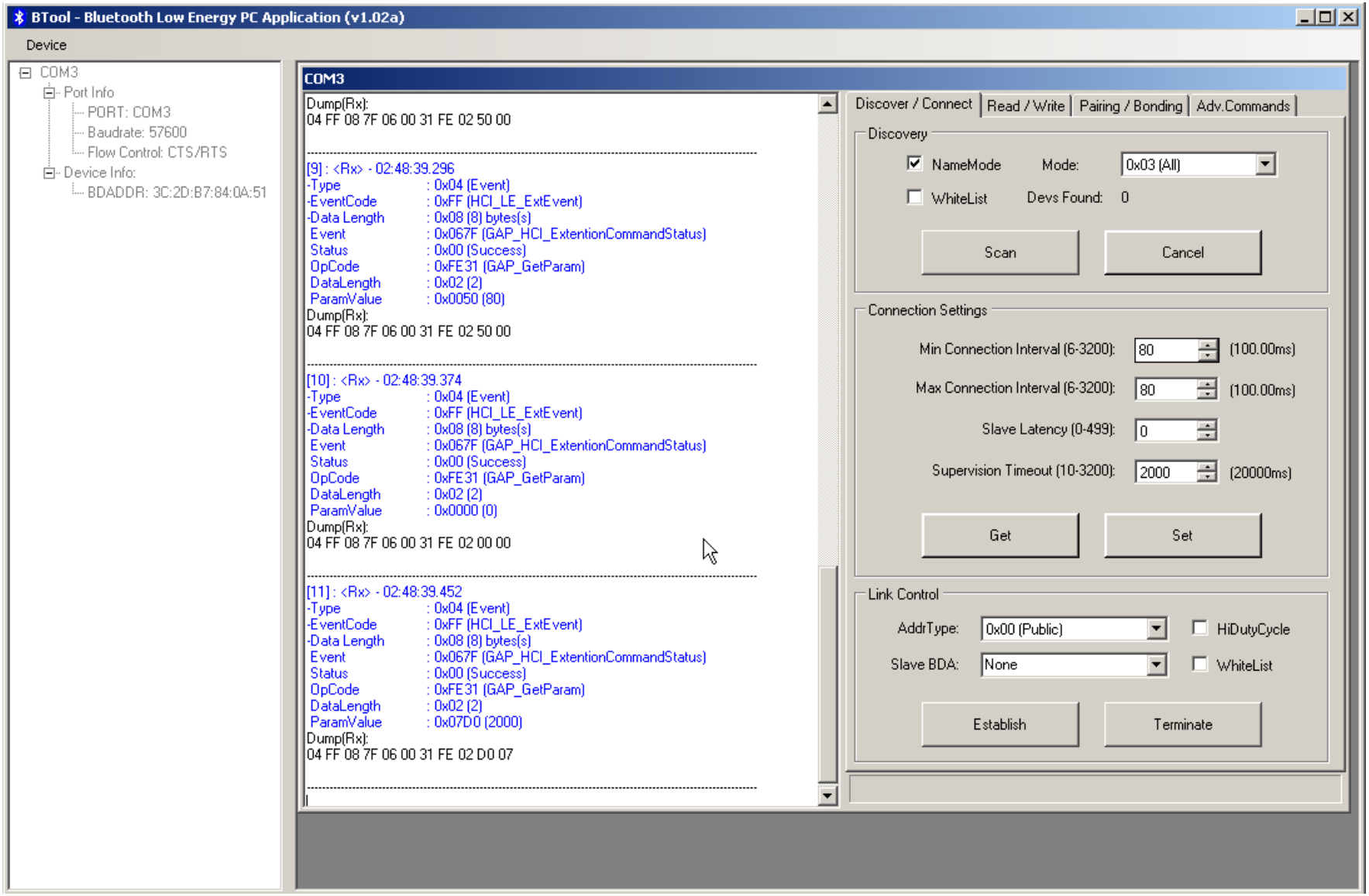


1. Plug in USB Dongle, install driver from - C:\Texas Instruments\BLE-CC2540\Accessories\Drivers
2. Use Device Manager to determine COM used for USB Dongle.
3. Start Btool.exe (C:\Texas Instruments\BLE-CC2540\Projects\Btool)
4. Open Device (this is COM port which USB Dongle shows up as)



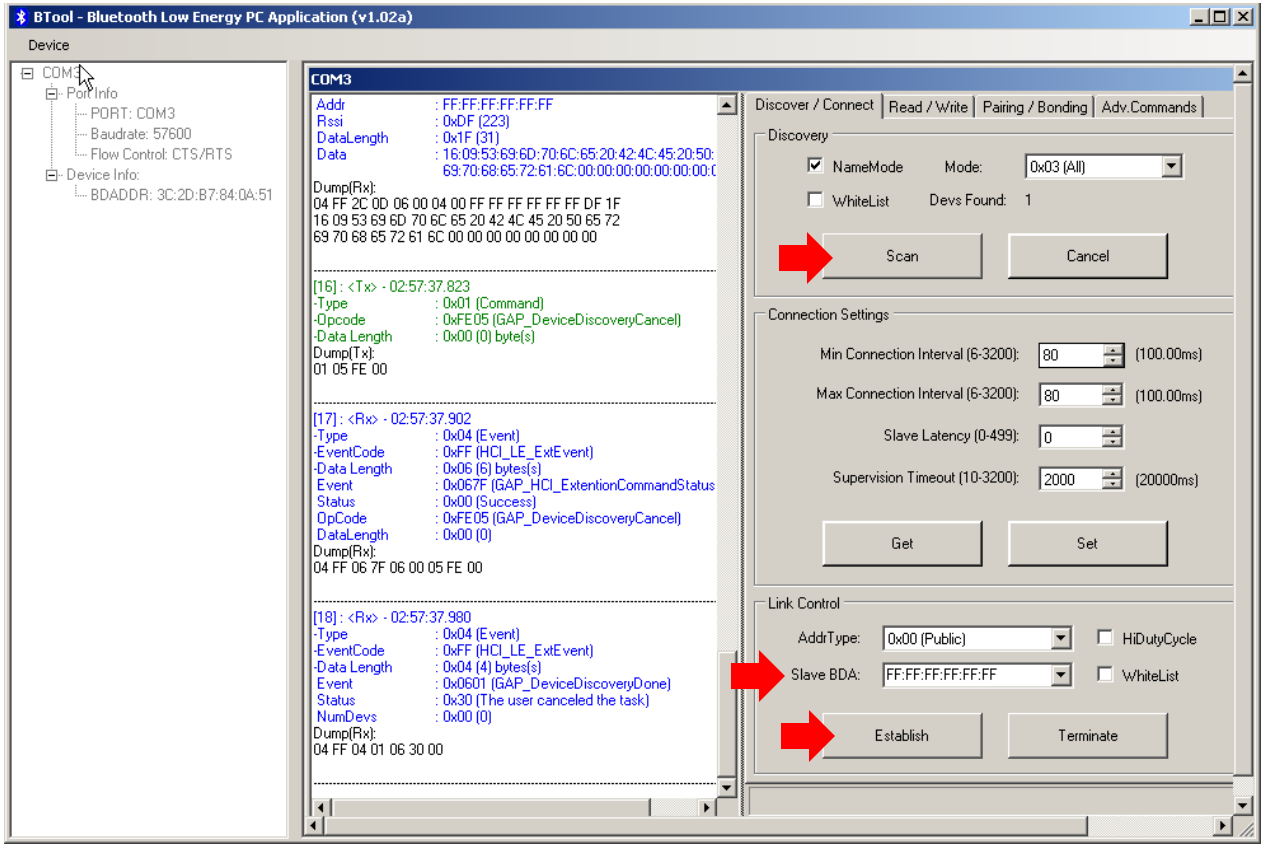


Lab #1.6


BTool - Bluetooth Low Energy PC Application (v1.02a)
Device
COM3
Port Info
PORT: COM3
Baudrate: 57600
Flow Control: CTS/RTS
Device Info:
BDADDR: 3C:2D:B7:84:0A:51
COM3
Dump(Rx):
04 FF 08 7F 06 00 31 FE 02 50 00
[9] : <Rx> - 02:48:39.296
-Type : 0x04 (Event)
-EventCode : 0xFF (HCI_LE_ExtEvent)
-Data Length : 0x08 (8) bytes(s)
Event : 0x067F (GAP_HCI_ExtentionCommandStatus)
Status : 0x00 (Success)
OpCode : 0xFE31 (GAP_GetParam)
DataLength : 0x02 (2)
ParamValue : 0x0050 (80)
Dump(Rx):
04 FF 08 7F 06 00 31 FE 02 50 00
[10] : <Rx> - 02:48:39.374
-Type : 0x04 (Event)
-EventCode : 0xFF (HCI_LE_ExtEvent)
-Data Length : 0x08 (8) bytes(s)
Event : 0x067F (GAP_HCI_ExtentionCommandStatus)
Status : 0x00 (Success)
OpCode : 0xFE31 (GAP_GetParam)
DataLength : 0x02 (2)
ParamValue : 0x0000 (0)
Dump(Rx):
04 FF 08 7F 06 00 31 FE 02 00 00
[11] : <Rx> - 02:48:39.452
-Type : 0x04 (Event)
-EventCode : 0xFF (HCI_LE_ExtEvent)
-Data Length : 0x08 (8) bytes(s)
Event : 0x067F (GAP_HCI_ExtentionCommandStatus)
Status : 0x00 (Success)
OpCode : 0xFE31 (GAP_GetParam)
DataLength : 0x02 (2)
ParamValue : 0x07D0 (2000)
Dump(Rx):
04 FF 08 7F 06 00 31 FE 02 D0 07
Discover / Connect
Read / Write
Pairing / Bonding
Adv.Commands
Discovery
NameMode
Mode:
0x03 (All)
WhiteList
Devs Found: 0
Scan
Cancel
Connection Settings
Min Connection Interval (6-3200):
80
(100.00ms)
Max Connection Interval (6-3200):
80
(100.00ms)
Slave Latency (0-499):
0
Supervision Timeout (10-3200):
2000
(20000ms)
Get
Set
Link Control
AddrType:
0x00 (Public)
HiDutyCycle
Slave BDA:
None
WhiteList
Establish
Terminate

Lab #1.7

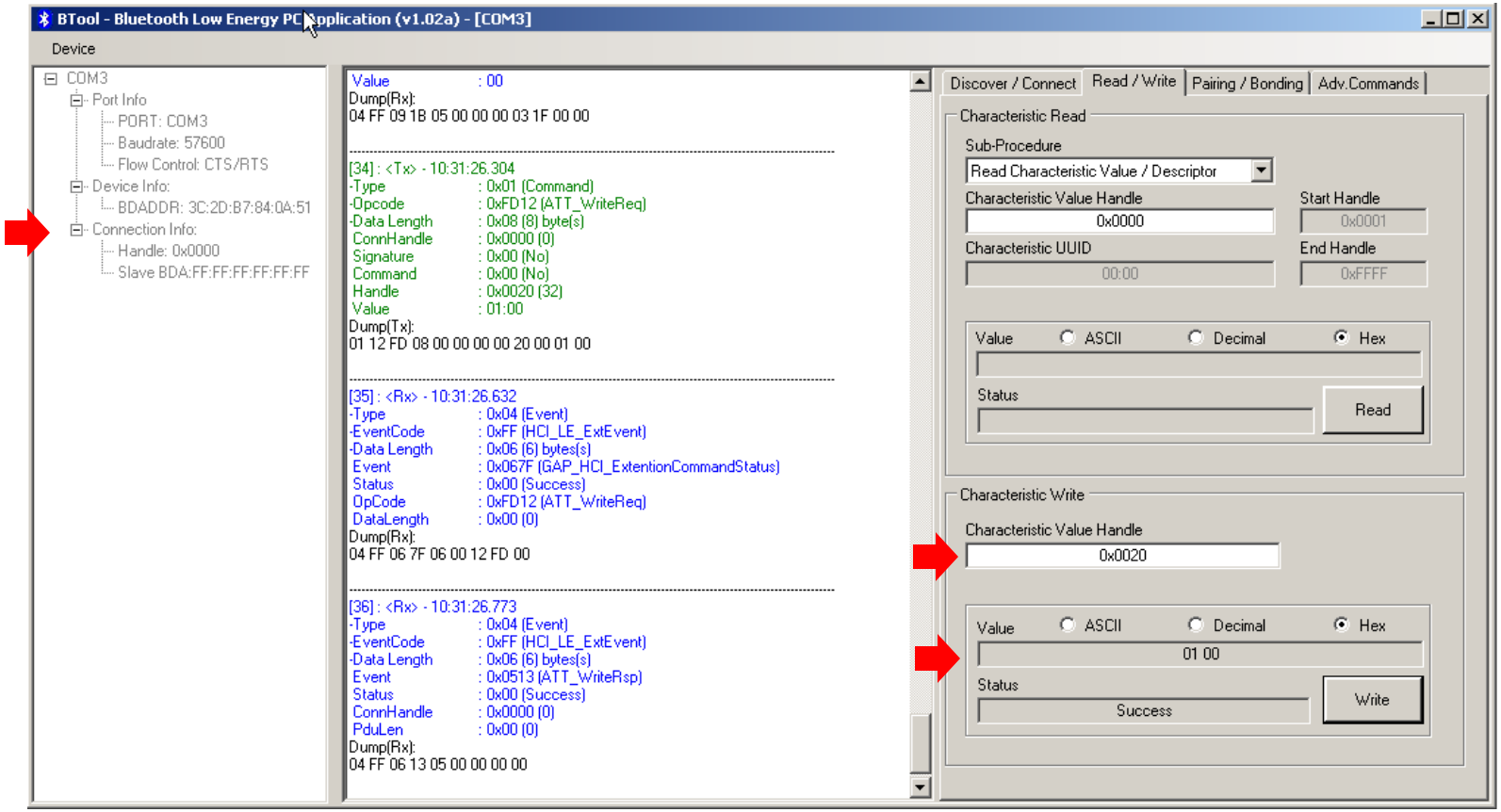
1. Press button on keyfob to begin advertising for 20 sec
2. Scan, select you keyfob address, and establish



Lab #1.8

1. Verify connection in left pane
2. Write “01 00” to address 0x0020
3. Press button on keyfob to see notifications

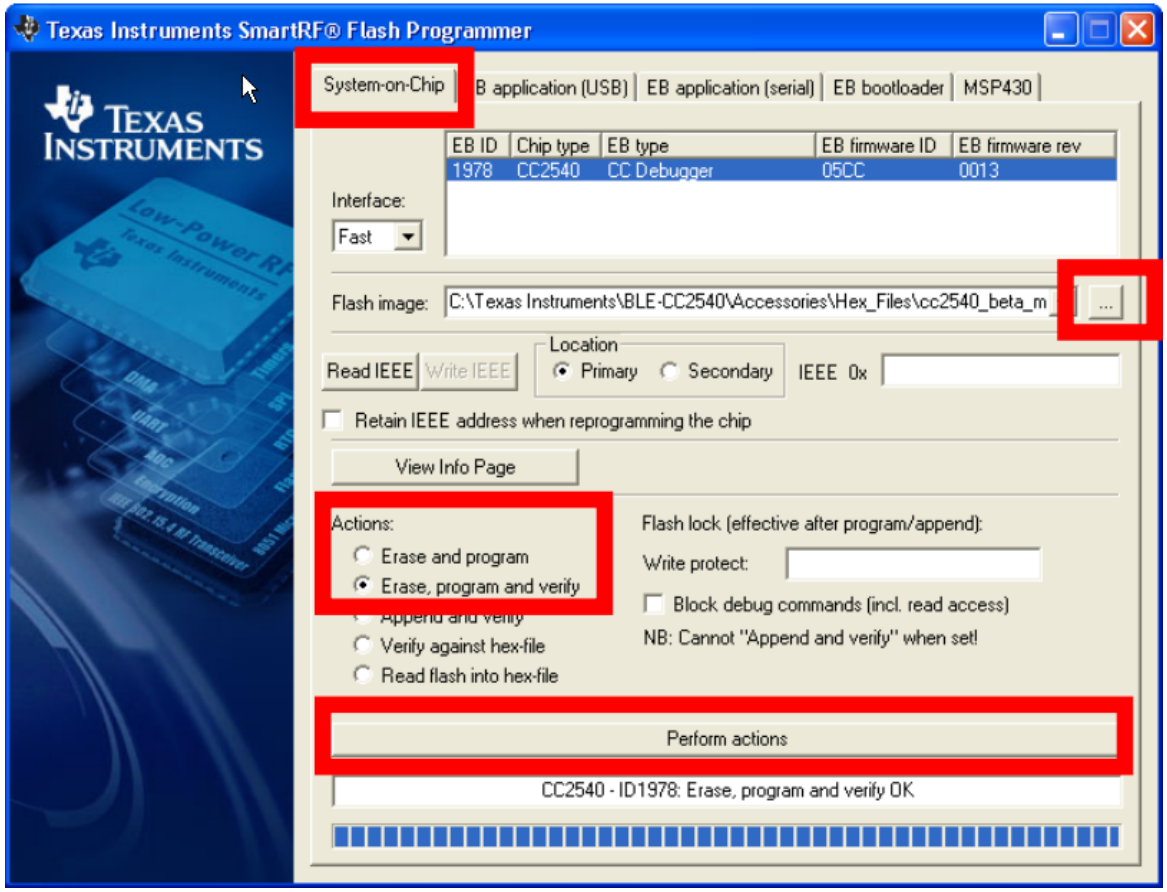
0x1D	29	0x2800	GATT_PRIMARY_SERVICE_UUID	0xFFE0 (SK_SERVICE_UUID)	GATT_PERMIT_READ	Start of Simple Keys Service
0x1E	30	0x2803	GATT_CHARACTER_UUID	10 (properties: notify only) 1F 00 (handle: 0x001F) E1 FF (UUID: 0xFFE1)	GATT_PERMIT_READ	Key Press State characteristic declaration
0x1F	31	0xFFE1	SK_KEYPRESSED_UUID	0 (1 byte)	(none)	Key Press State characteristic value
0x20	32	0x2902	GATT_CLIENT_CHAR_CFG_UUID	00:00 (2 bytes)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Key Press State characteristic configuration
0x21	33	0x2901	GATT_CHAR_USER_DESC_UUID	"Key Press State" (16 bytes)	GATT_PERMIT_READ	Key Press State characteristic user description



Lab #2.1

1. Connect USB Dongle and CC Debugger as shown
2. CC debugger light should be green.

Lab #2.2



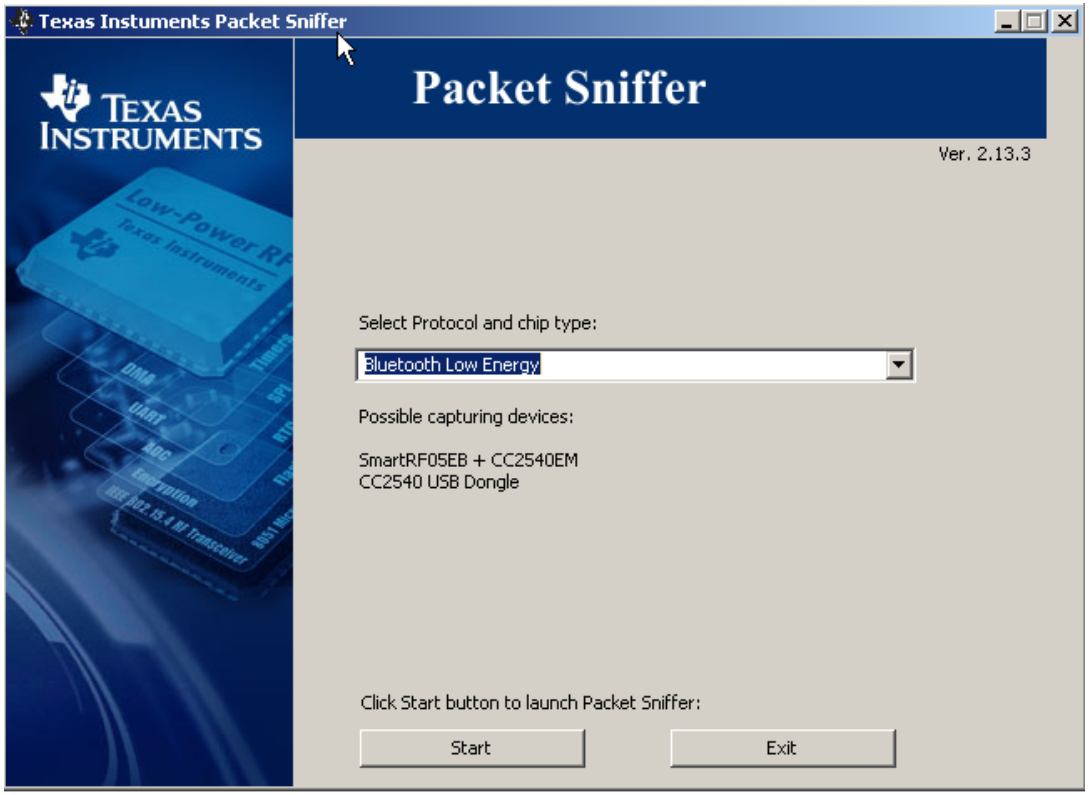
1. Use SmartRF flash programmer to download .hex file

C:\Program Files\Texas Instruments\Packet Sniffer\General\Firmware\sniffer_fw_cc2540_usb.hex

* USB Dongle LED should turn green

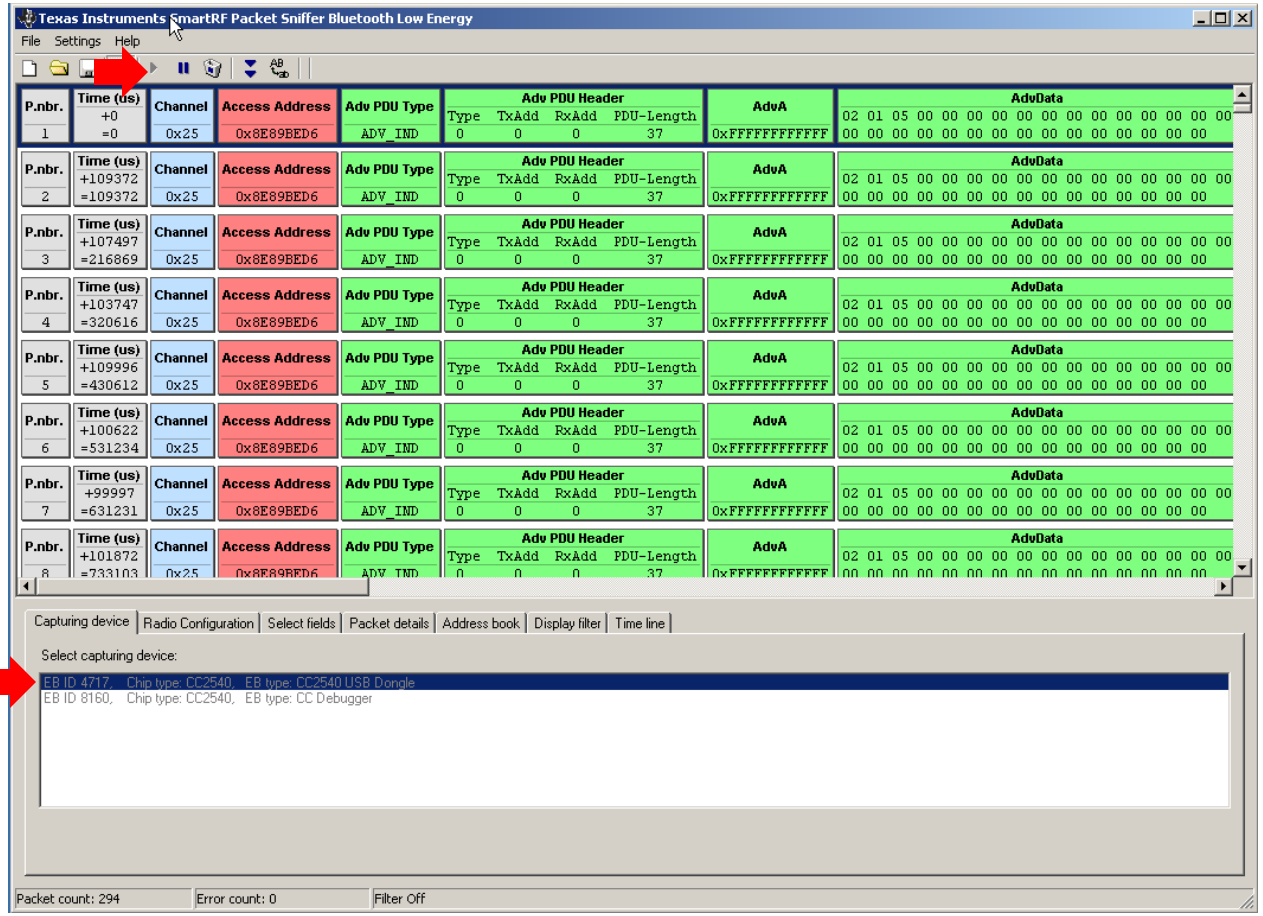
Lab #2.3

1. Start Packet Sniffer application
2. Select Bluetooth Low Energy



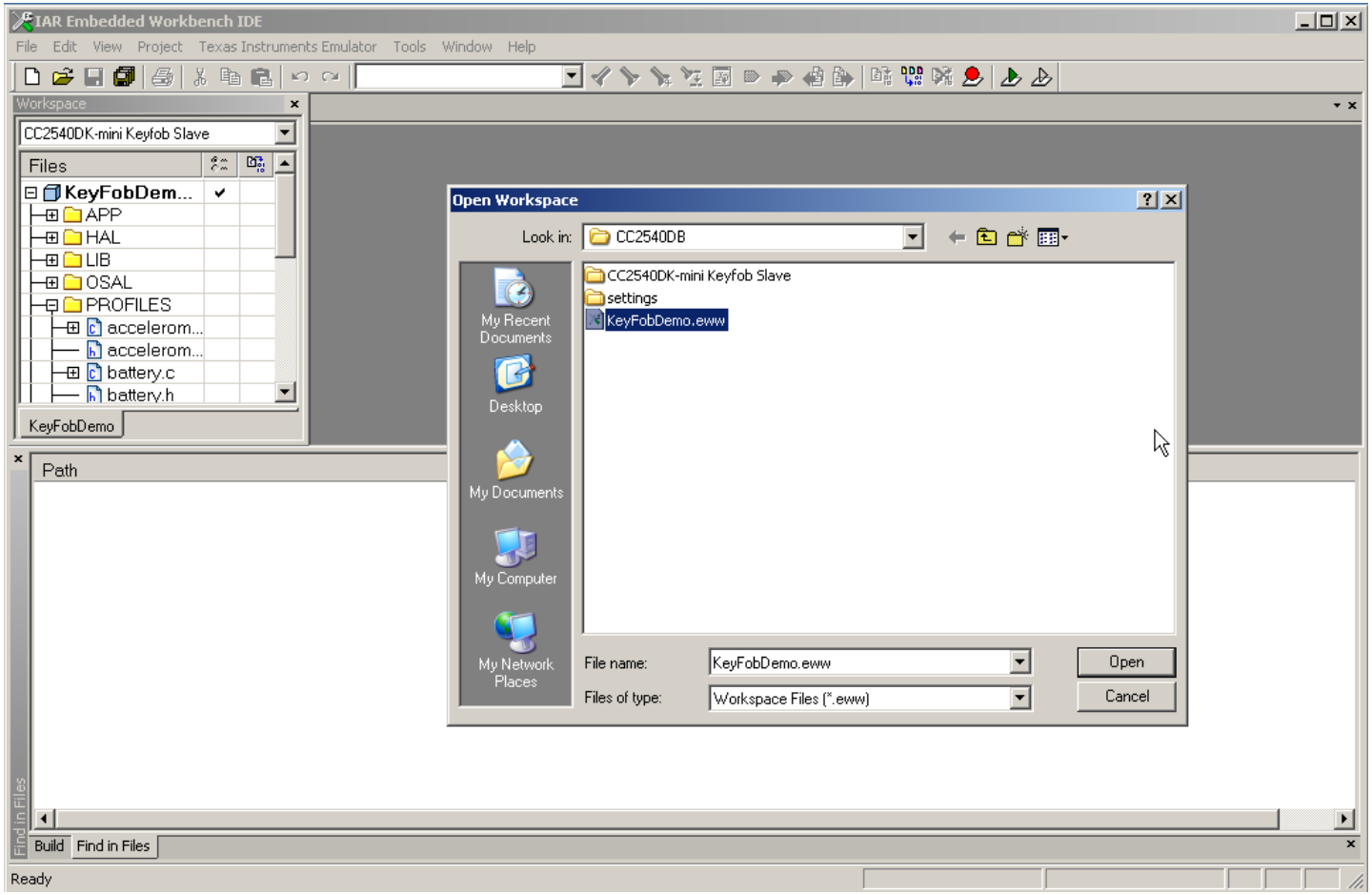
Lab #2.4

1. Select CC2540USB Dongle
2. Press play
3. Press button on keyfob to start advertising



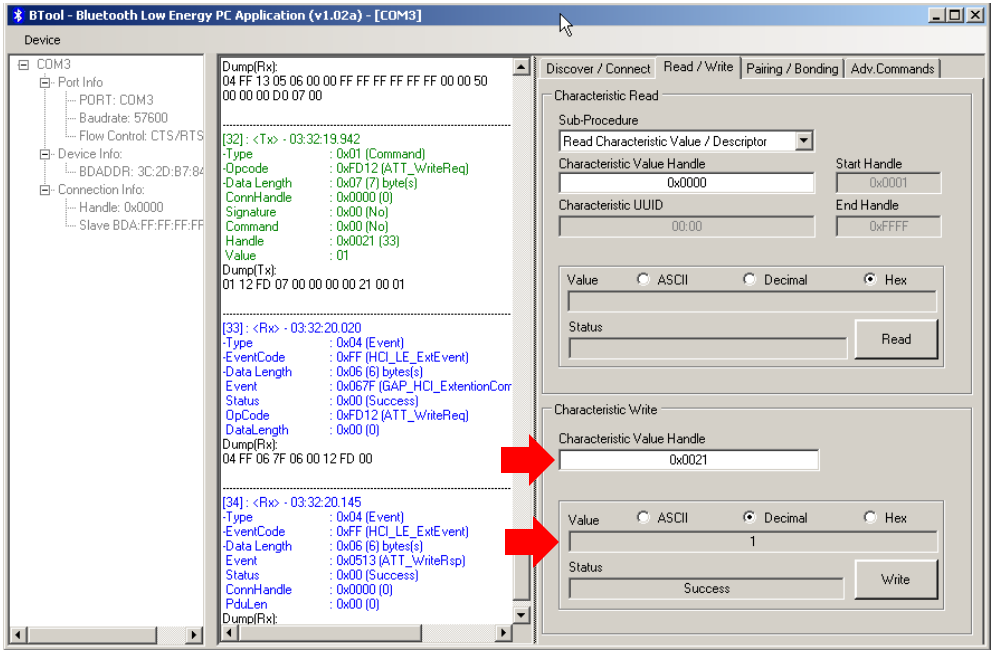
Lab #3.1 – Accelerometer and IAR

1. Download and unzip project from - http://processors.wiki.ti.com/images/e/ec/Keyfobdemo.zip
2. Extract to C:\Texas Instruments\BLE-CC2540
3. Open workspace C:\Texas Instruments\BLE-CC2540\Projects\ble\KeyFob\CC2540DB\KeyFobDemo.eww
4. Press play button to download and debug
5. Press Go button



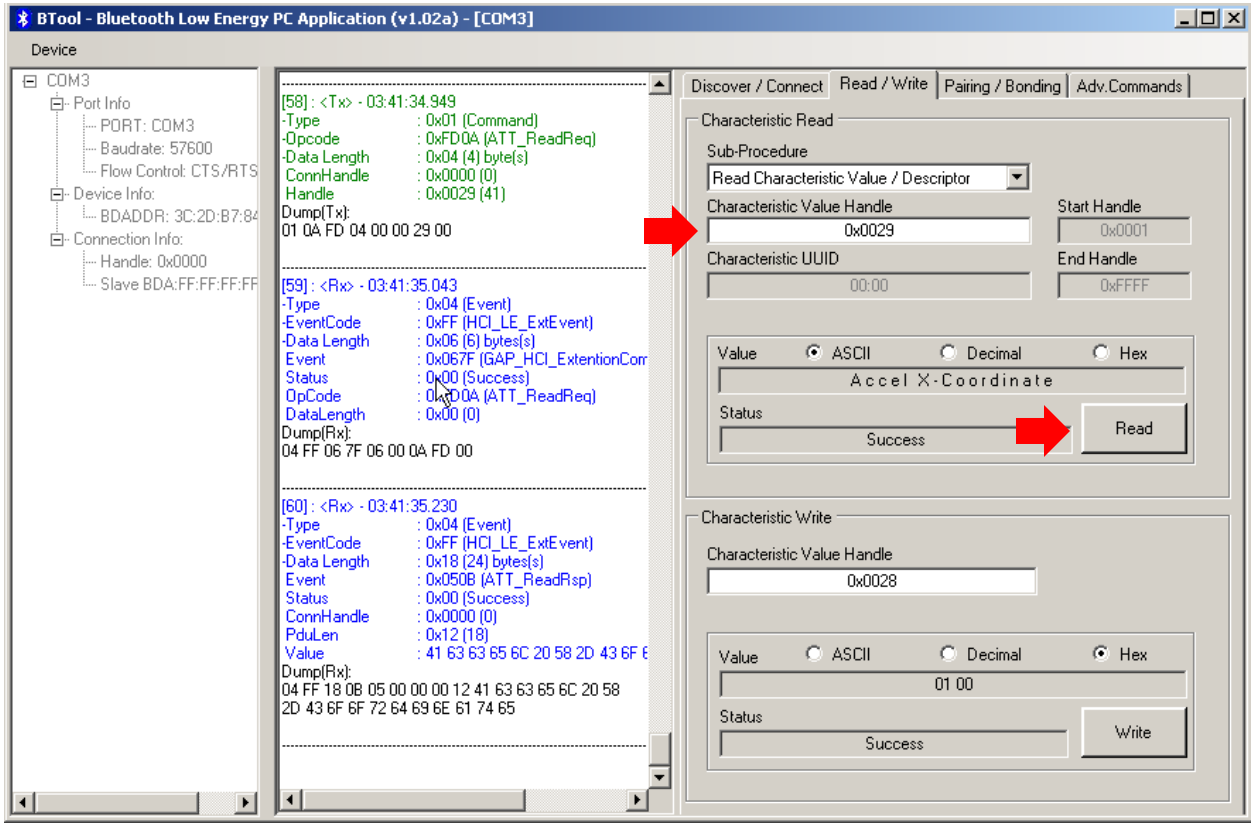
Lab #3.2 – Accelerometer and IAR

1. Start Btool
2. Scan and Connect
3. Write a “1” to 0x0021 to enable the accelerometer
4. Write a “01 00”to 0x0028 to enable the X axis notifications
5. Move the keyfob to generate notifications.



Lab #3.2 – Accelerometer and IAR

1. Enter 0X0029 in handle field
2. Click Read and change to ASCII
3. You should see Accel X-Coordinate
4. Change this in code with IAR.



Links BLE

Description	Link
CC2540 Mini Kit Order and Info	http://focus.ti.com/docs/toolsw/folders/print/cc2540dk-mini.html
TI Bluetooth, overview, link to Dual mode, data sheets	www.ti.com/bluetoothlowenergy
BLE Stack and tools	www.ti.com/blestack
CC2540 Datasheets, application notes	www.ti.com/cc2540
Hardware sharepoint	http://srvoswod34.norway.design.ti.com/wiki/CC2540_Project
LPRF Wiki Page – Keyfobdemo source	http://processors.wiki.ti.com/index.php/Category:LPRF
SmartRF Flash Programmer	http://focus.ti.com/docs/toolsw/folders/print/flash-programmer.html
Bluetooth SIG	http://www.bluetooth.com/English/Products/Pages/low_energy.aspx

Documents

Description	Link
Quick Start Guide	http://focus.ti.com/lit/ml/swru272/swru272.pdf
Mini Kit User Guide	http://focus.ti.com/lit/ug/swru270a/swru270a.pdf
Software Development Guide	http://www.ti.com/litv/pdf/swru271
CC2540 User Guide	http://focus.ti.com/lit/ug/swru191b/swru191b.pdf

Links ANT

Description	Link
CC257x ANT	http://focus.ti.com/docs/prod/folders/print/cc2570.html
ANT technology, SW examples	http://www.thisisant.com/