Energy Efficient Mobile Computing Building low power sensing devices with Bluetooth low energy

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Bluetooth low energy

- Short range radio technology and protocol suite designed for minimum power consumption
- Operates on the 2.4GHz band
- Specified as part of Bluetooth 4.0
- Many System-on-Chip (SoC) solutions available
- Supported on mobile devices since Android 4.3, iOS6 and Windows Phone 8.1

Bluetooth Smart and Smart Ready

Bluetooth SMART

Bluetooth SMART READY

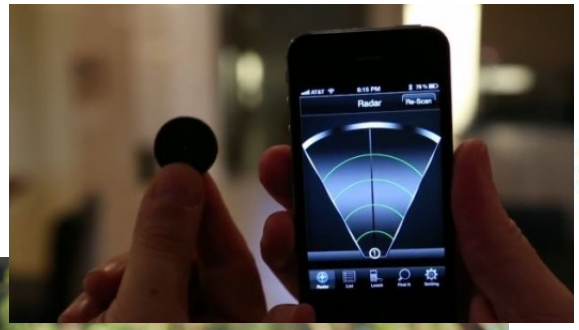
Bluetooth Smart devices connect to devices you carry

BLE ”appcessories”

1 Keyfobs and tracker devices

2 Sports and health equipment

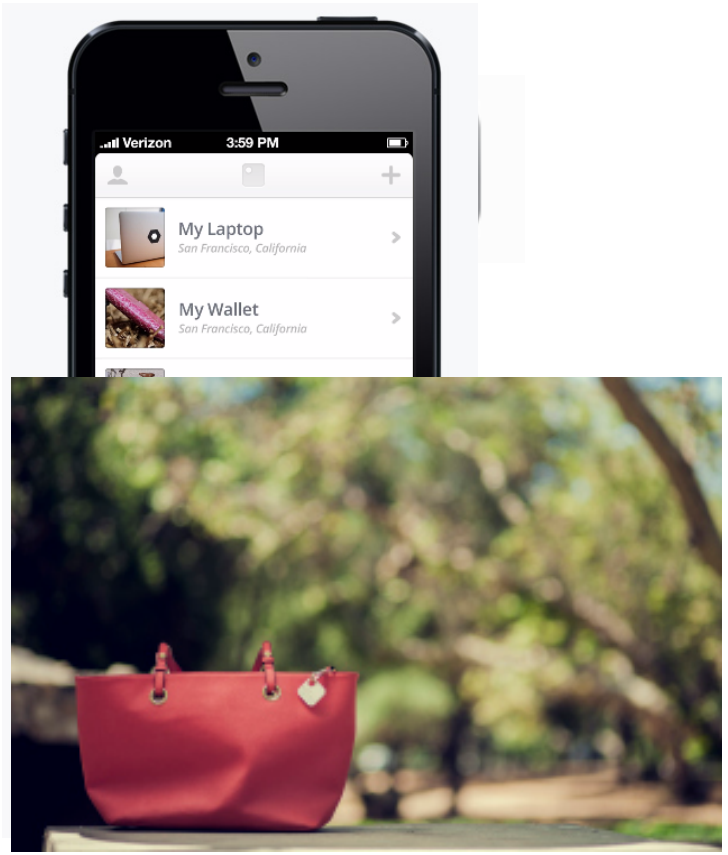
3 Home automation and surveillance



Keyfobs and trackers

Connectivity: Bluetooth 4.0 (Bluetooth Low Energy)
Range: Approximately 100 feet line of sight.
Battery: Lasts up to 1 year (based on 30min. a day use).
Battery Type: CR2016 watch battery (replaceable).

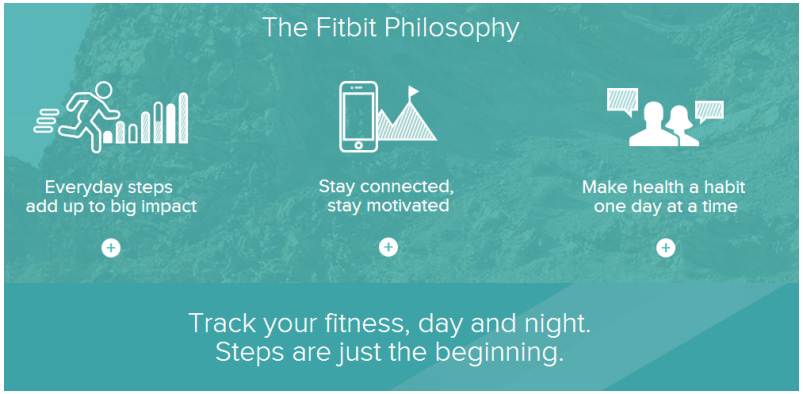
Connectivity: Bluetooth 4.0 (Bluetooth Low Energy)
Range: Approximately 100 feet line of sight.
Battery: Lasts up to 6 mo
Battery Type: CR2032 (replaceable).



Connectivity: Bluetooth 4.0 (Bluetooth Low Energy)
Range: Approximately 50-150 feet line of sight.
Battery: Lasts up to 1 yr
Battery Type: Not replaceable

Sports and fitness

Nike+ training app with Hyperdunk+ shoes can tell you number of jumps in a game, hang time of each jump, and when the highest and lowest jumps were made.



Fitbit wrist devices are pedometers with added functionality with associated app for smartphones

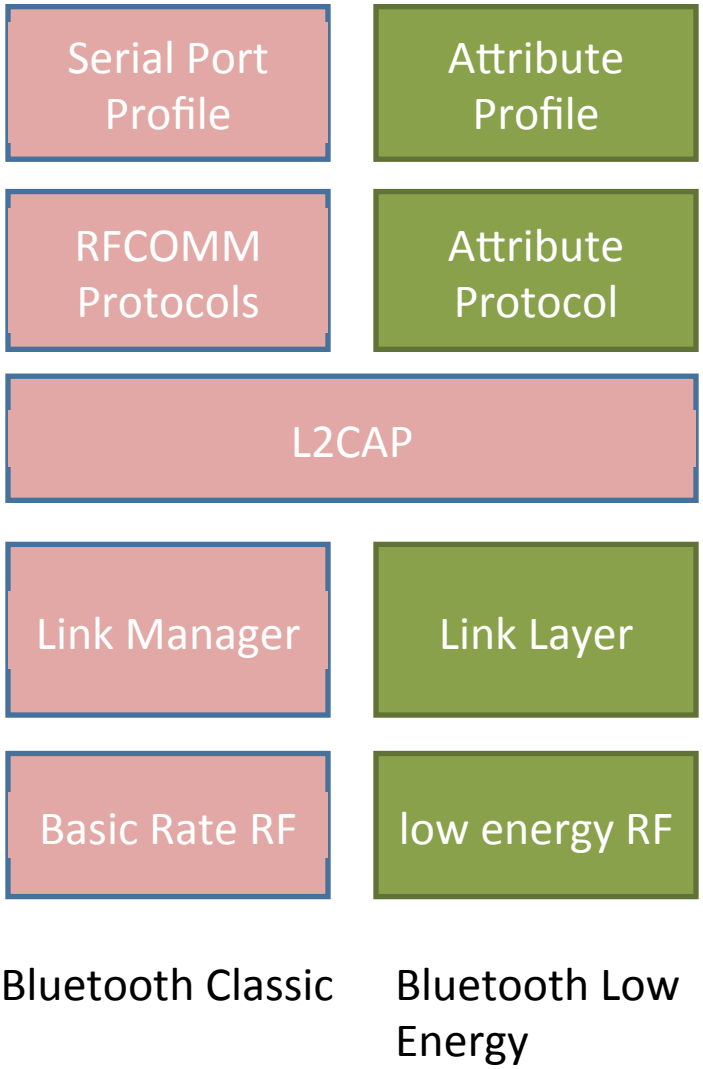
iBeacon

- Apple's enabler for building location services on Bluetooth Low energy
- What happens when two known devices meet?
- "Geofencing" with three different ranges: immediate, near and far

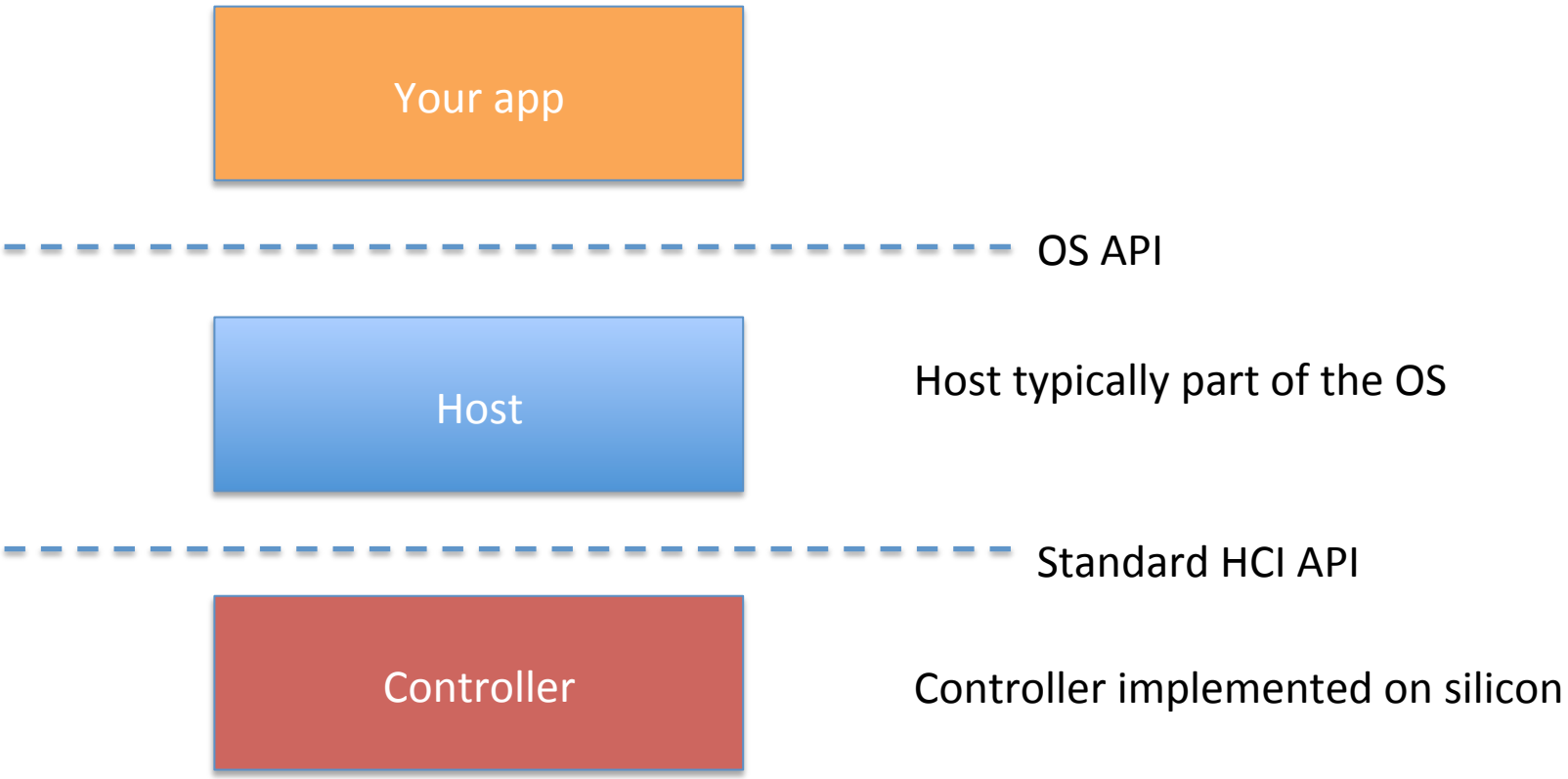
BLE design targets

- Everything optimized for power
- Operates 2 years off of a coin cell battery
- Simple and extendable protocol
- Limited use cases
- Cost to add BLE to Bluetooth classic devices is 0€ (in terms of hardware)

Dual mode architecture



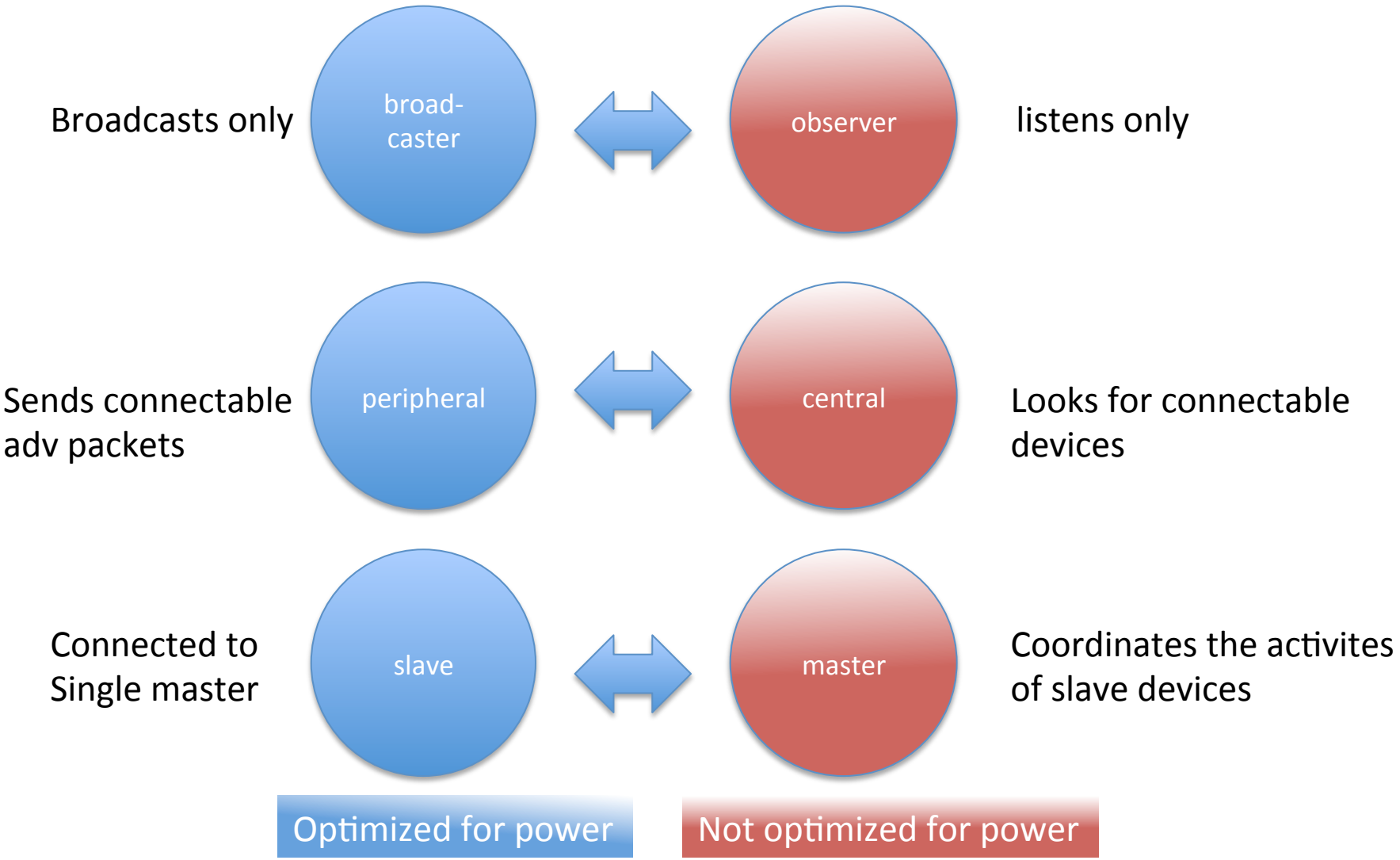
Host-Controller Interface



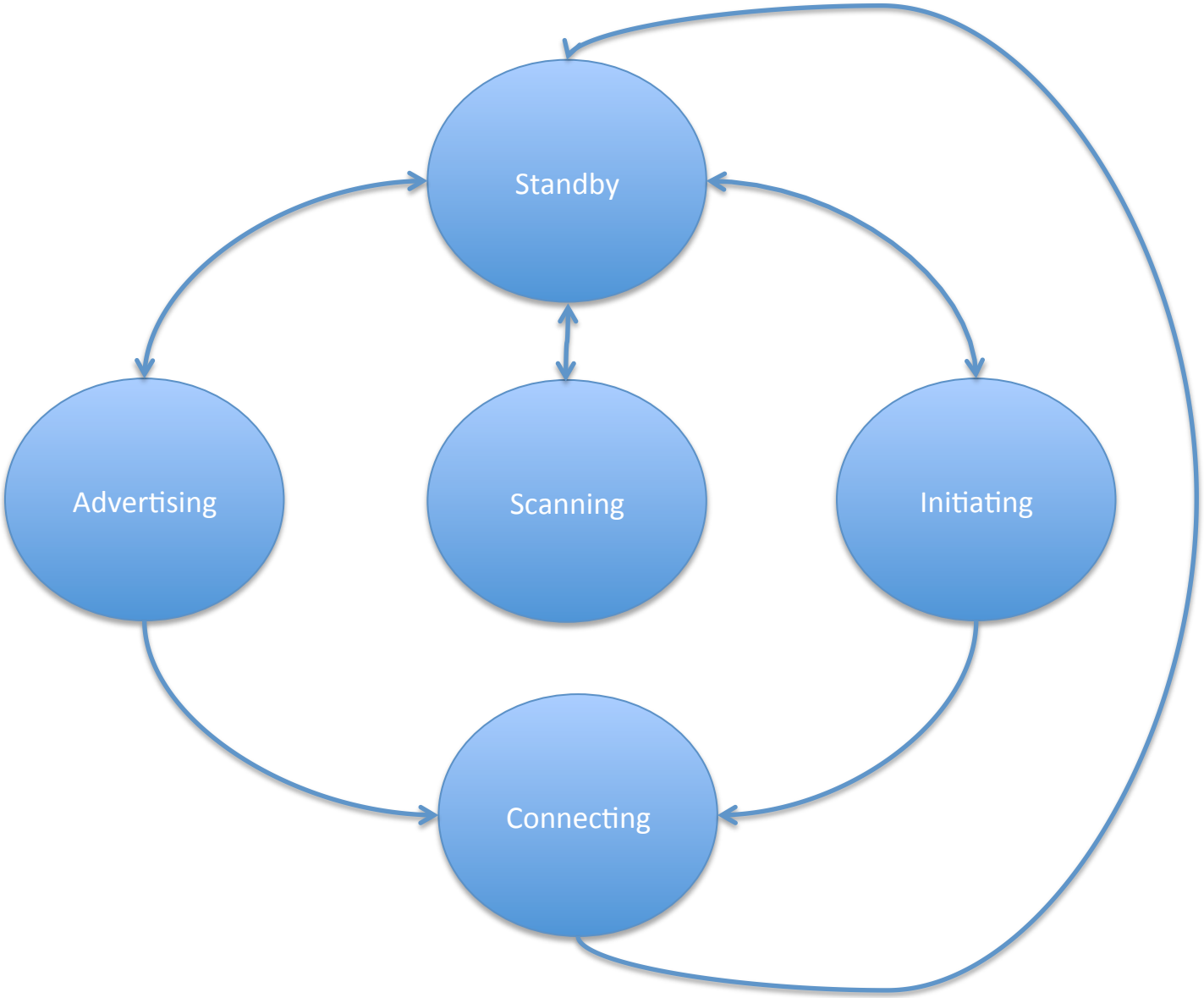
Physical layer summary

- 2.4 GHz ISM Band
- GSFK modulation
- 40 channels
  - 2 MHz channel spacing
  - 2402 MHz to 2480 MHz
- Range 30m to 100 m

BLE roles

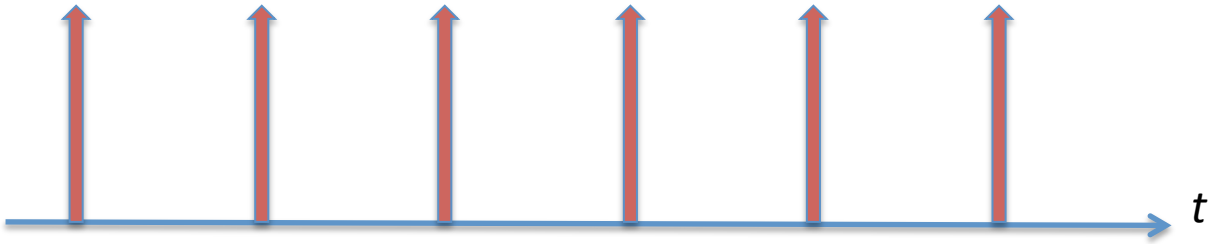

Broadcasts only
broad-caster
observer
listens only
Sends connectable adv packets
peripheral
central
Looks for connectable devices
Connected to Single master
slave
master
Coordinates the activites of slave devices
Optimized for power
Not optimized for power

Link layer states



Connection forming - advertising

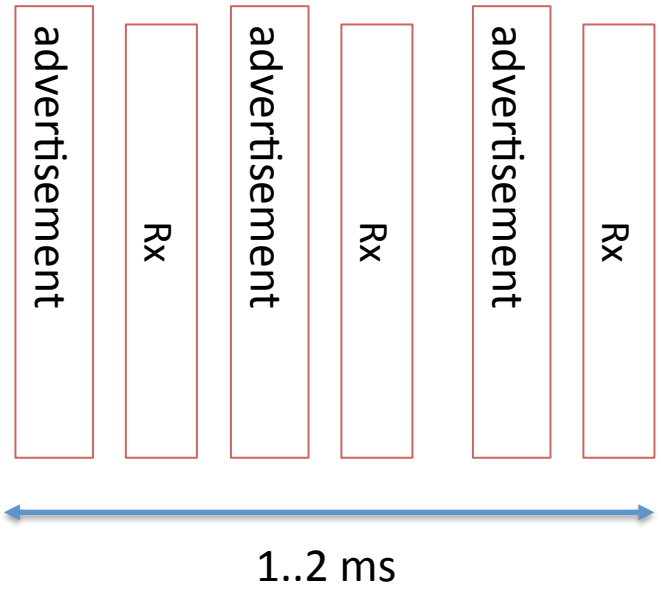
- Low power devices periodically advertise their presence
- Connectable or non-connectable



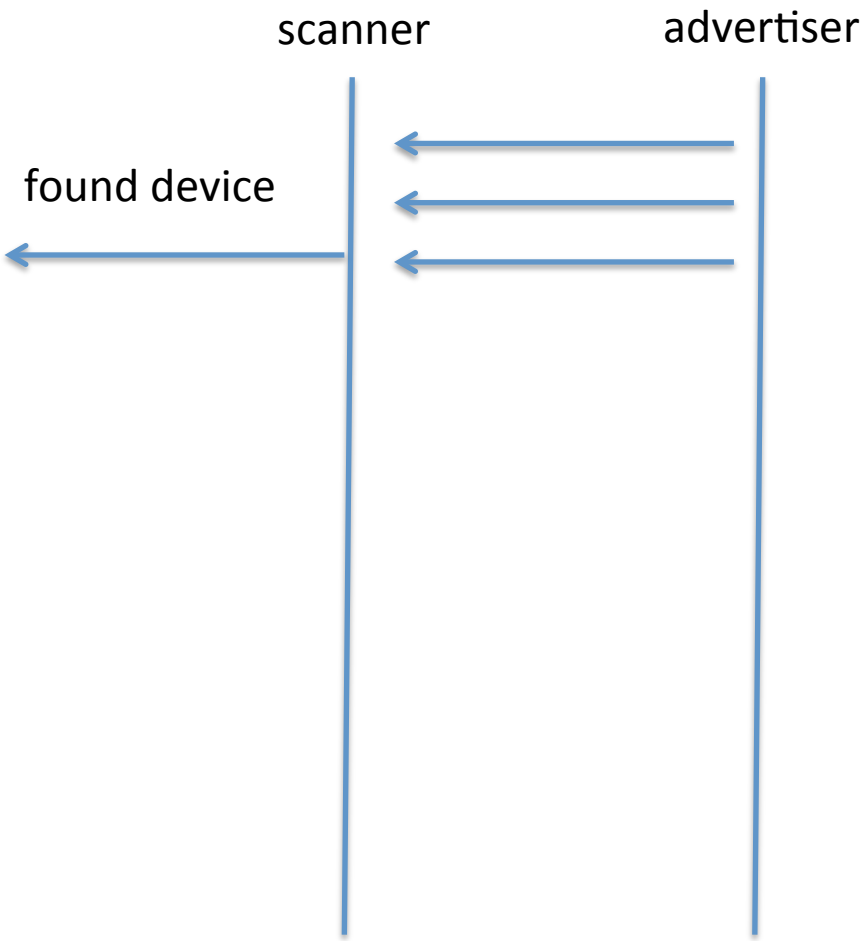
Advertising packets

Advertising packets

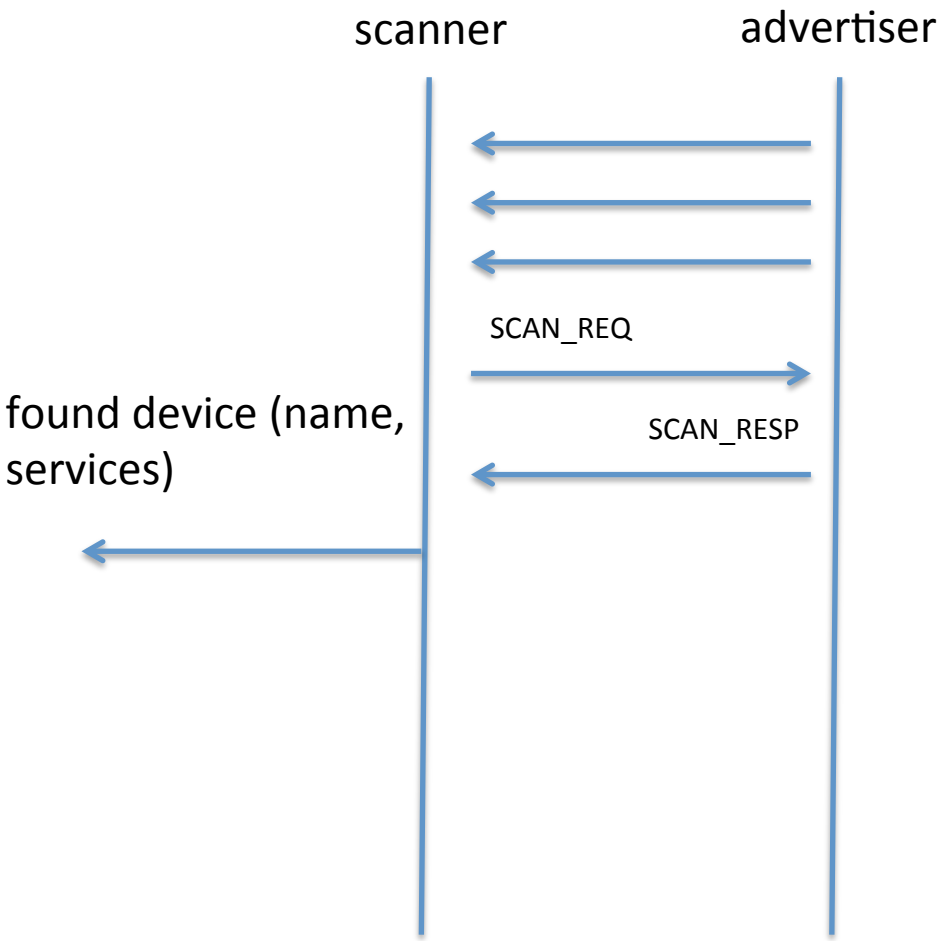
- Sent on three advertising channels
- Advertising burst (Tx) followed by Rx



Discovery – passive scanning

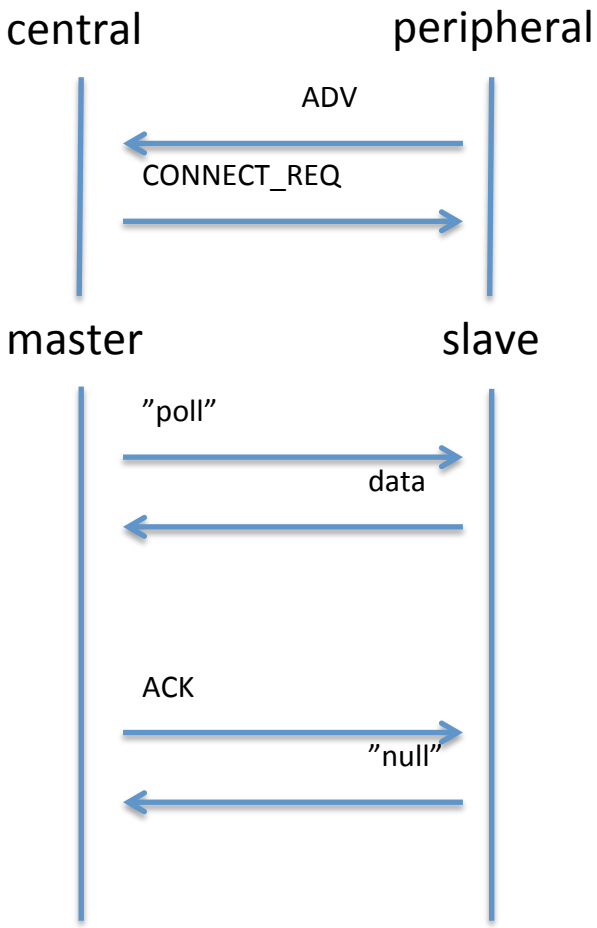


Discovery – active scanning



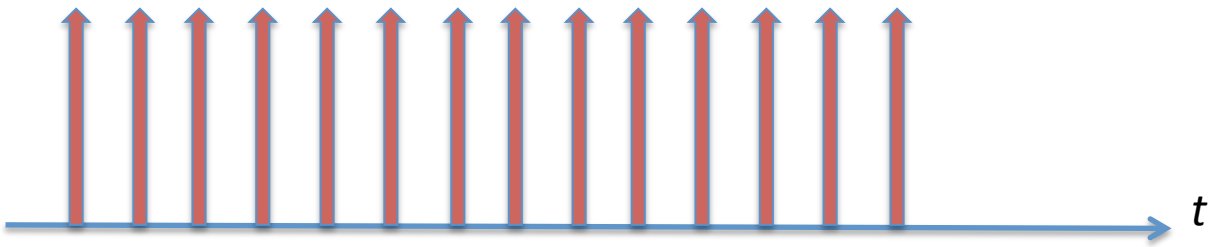
Active scanning typically used because advertising packet is very short (max 31 octets payload).

Connection establishment



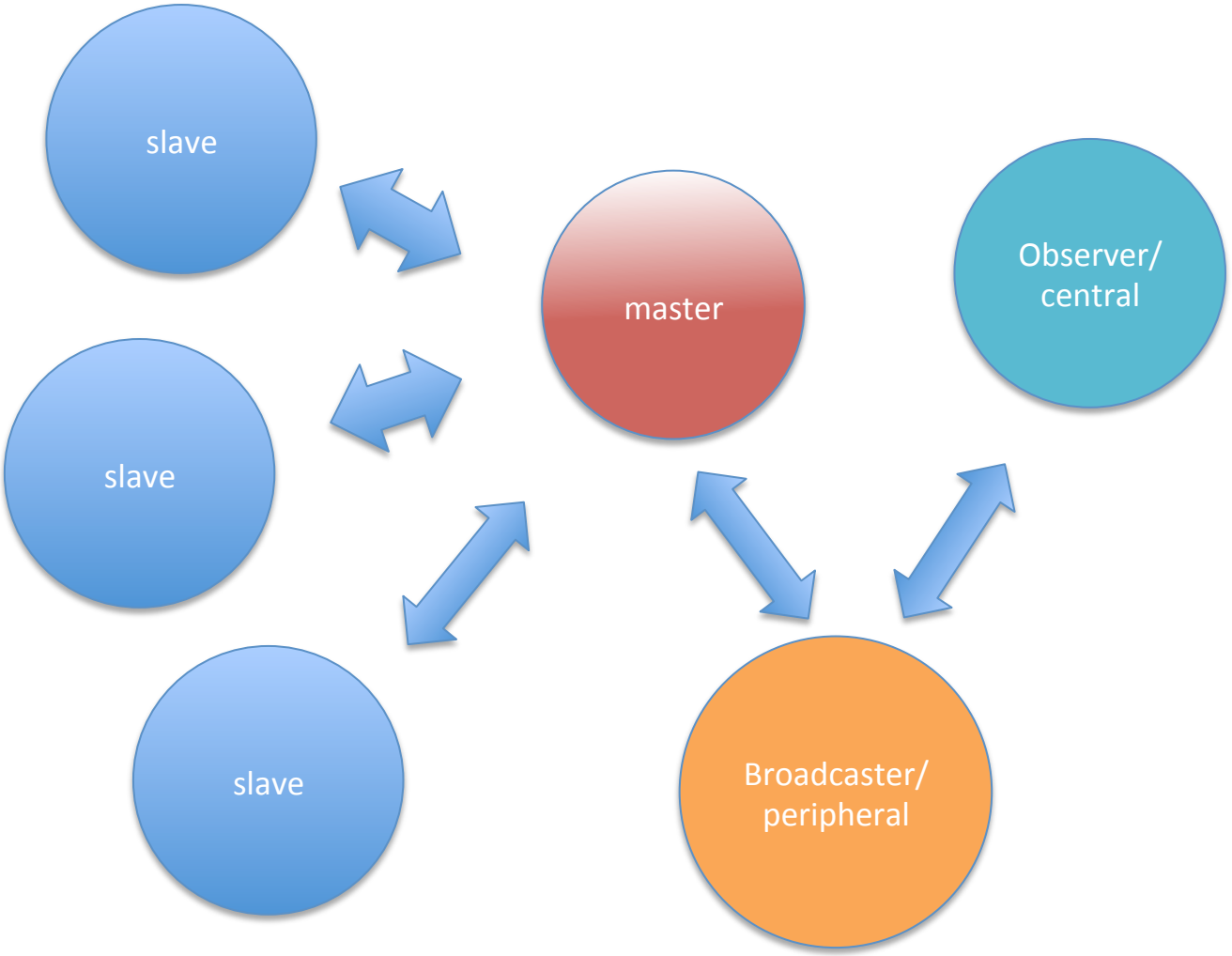
Connection intervals

- Once connected, data is exchanged at connection events
- Event interval is negotiated during connection establishment, and depends on application requirements



Connection events

Topology


slave
slave
slave
master
Observer/
central
Broadcaster/
peripheral

L2CAP

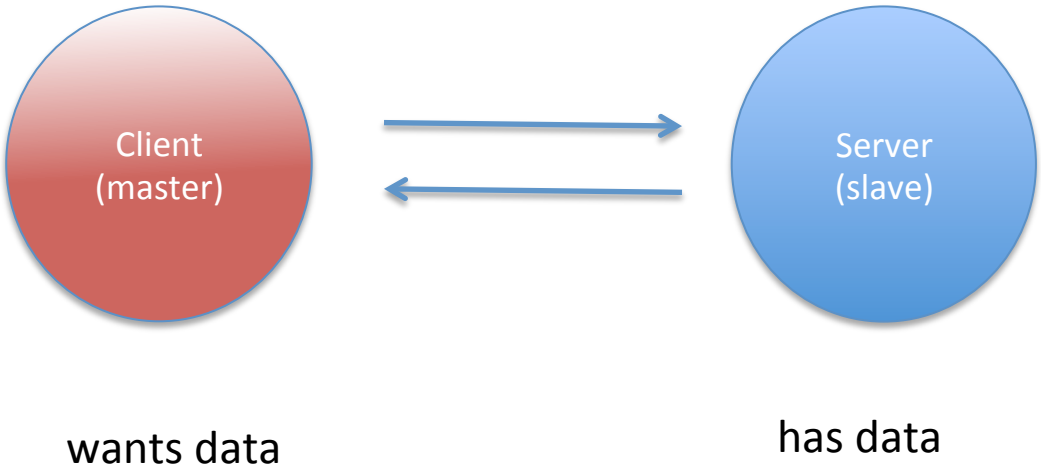
- Simple encapsulation scheme
- Fixed CID for all low energy applications
- Default MTU is 23 octets

CID	Description	Notes
0x0001	L2CAP BR Signaling	Fixed channel to create / manager connection oriented channels
0x0002	Unicast Connectionless	Fixed channel for unicast connectionless data (not used in profiles today)
0x0003	AMP Manager Signaling	Fixed channel used to negotiate AMP
0x0004	Attribute Protocol	Fixed channel for accessing device attributes
0x0005	L2CAP LE Signaling	Fixed channel to manage Low Energy devices
0x0006	Security Manager Protocol	Fixed channel to enable security protocols

Attribute protocol (ATT)

- The only application protocol in BLE
- All data is exposed as attributes
- Attribute has
  - permissions
  - security requirements
- Attribute consists of
  - value: the value itself
  - UUID: what does this value mean
  - handle: how to address it
- Designed for maximum power efficiency

ATT is a Client-Server protocol



ATT procedures

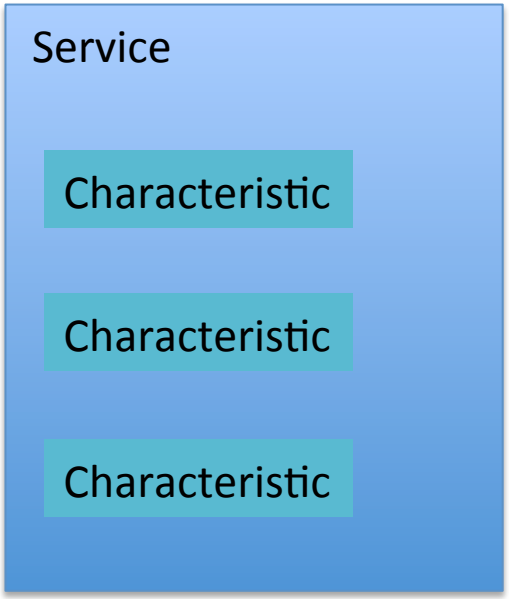
- Various types of read and write operations
  - Read by type, handle, or UUID
  - Authenticated write
- Client polls data
- Server may also send indications when data changes

Generic Attribute Profile (GATT)

- Used together with ATT
  - May be referred to as GATT/ATT
- Defines concepts of:
  - Service Group
  - Characteristic Group
  - Declarations
  - Descriptors

GATT procedures

- Same client/server architecture as in ATT
- Data is encapsulated in Services and exposed as Characteristics



Service and Characteristics

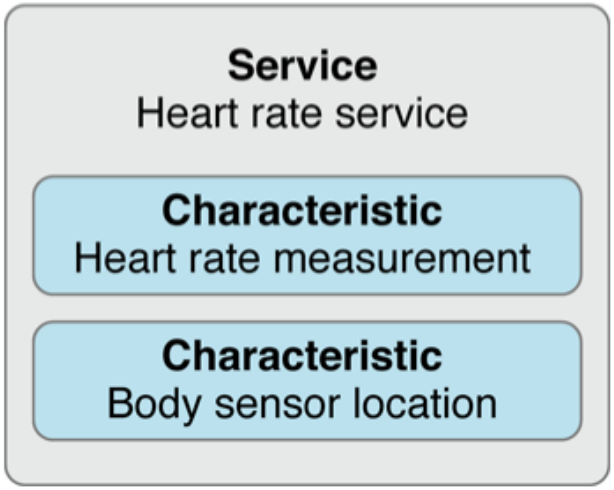
Handle	Type	Value	Permissions
0x0001	«Primary Service»	«GAP»	R
0x0002	«Characteristic»	{r, 0x0003, «Device Name»}	R
0x0003	«Device Name»	“Temperature Sensor”	R
0x0004	«Characteristic»	{r, 0x0006, «Appearance»}	R
0x0006	«Appearance»	«Thermometer»	R
0x000F	«Primary Service»	«GATT»	R
0x0010	«Characteristic»	{r, 0x0012, «Attribute Opcodes Supported»}	R
0x0012	«Attribute Opcodes Supported»	0x00003FDF	R
0x0020	«Primary Service»	«Temperature»	R
0x0021	«Characteristic»	{r, 0x0022, «Temperature Celsius»}	R
0x0022	«Temperature Celsius»	0x0802	R*

GATT in practice

As an example, in IOS7 (as Central device)

- Start up a central manager object
- Discover and connect to peripheral devices that are advertising
- Explore the data on a peripheral device after you've connected to it
- Send read and write requests to a characteristic value of a peripheral's service
- Subscribe to a characteristic's value to be notified when it is updated

Android BLE framework is similar.

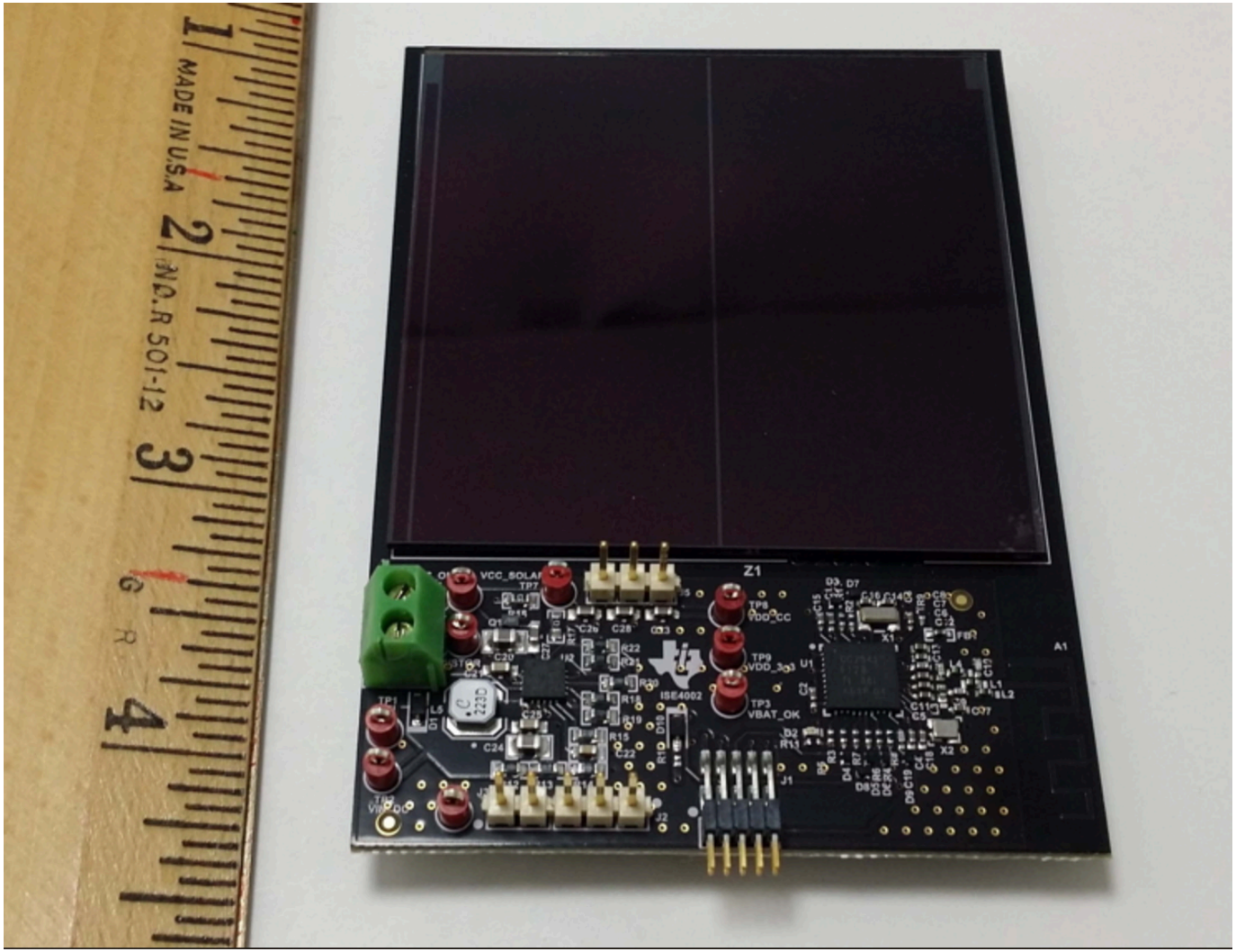


https://developer.apple.com/library/ios/documentation/NetworkingInternetWeb/Conceptual/CoreBluetooth_concepts/CoreBluetooth_concepts.pdf

Designing for low power

- Select a chip to be used in peripheral
  - TI, STM, Bluegiga, CSR, Nordic, Dialog
- Design your application
  - Broadcast only or connected mode
  - Number of simultaneous connections is limited in practice (3…8)
  - Select advertising and connection event intervals
  - Be conservative in the number of bytes needed to be sent
- Batteryless SoCs running on harvested energy

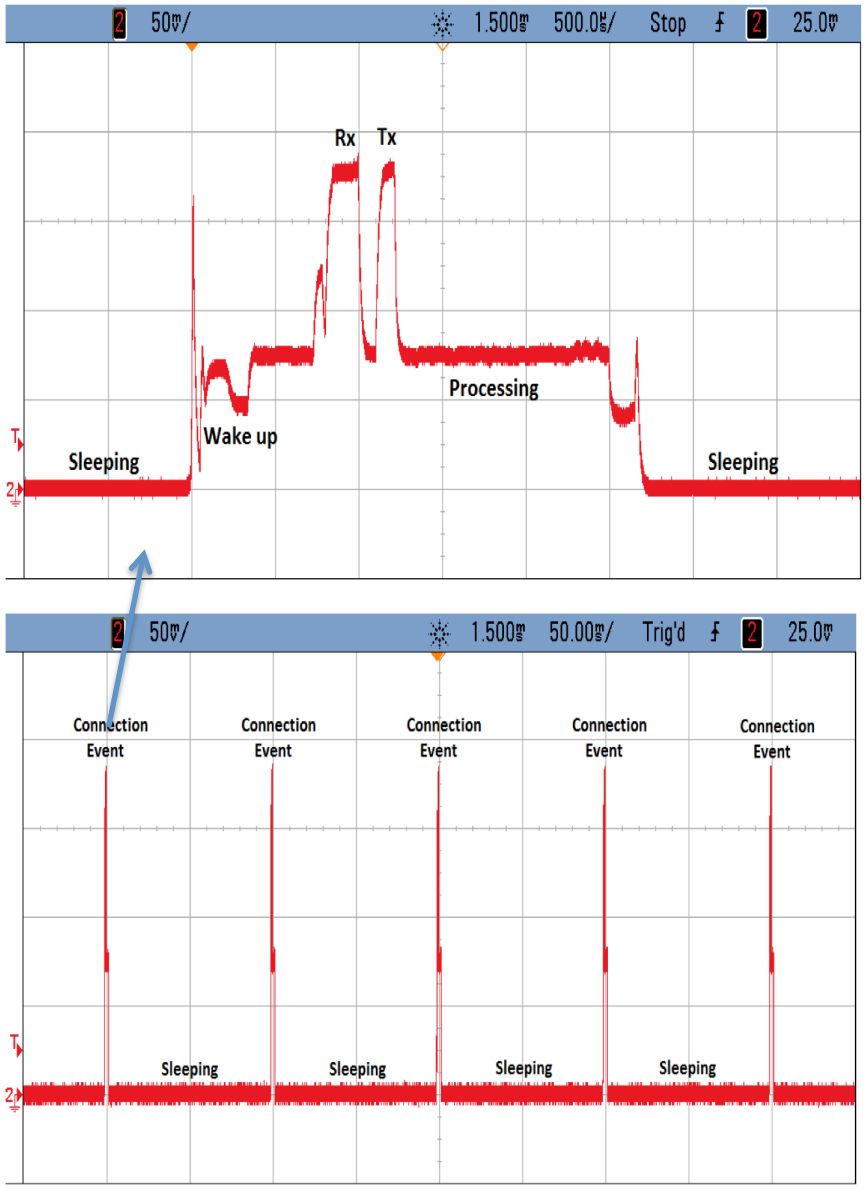
TI reference design with solar cell



http://www.ti.com/tool/tida-00100

Designing for low power

- With large connection/ advertisement intervals, leak currents of 1μA begin to dominate
- If you are using iOS or Android as the master, you will have to stick with the provided API



www.ti.com/lit/ml/swru347/swru347.pdf

Discussion

- So why not ZigBee?
  - ZigBee has a lot of support for embedded devices. If you want to communicate with a mobile device, BLE is your choice
- What about Internet of Things?
  - BLE can play an essential part in IoT
  - Work in progress for IP over BLE, IP over ZigBee done
  - Application protocols like CoAP