Introduction to Bluetooth LE

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A little background…

- My professional background in Systems & Networking programming and administration
- Involved with Inveneo & ICTP in ICT-related work for 10 years
- Living & working in Silicon Valley since 1997
- Largely self-taught “Technology enthusiast” (Which is a polite way of saying I’m just a big GEEK)

Bluetooth LE

- AKA Bluetooth 4.0
- AKA “Bluetooth Low Energy”, BLE, BTLE
- As opposed to “Classic Bluetooth” or “Bluetooth 2.0” or “Bluetooth BDA*”

  *Battery’s Dead Again

Why ?

- Why do we need another set of wireless protocols, standards, widgets, etc. ?
- What’s wrong with Bluetooth 1.x/2.x ?
- Haven’t we been here before ?

Let’s take a little hike back in time…

Personal/Body-Area Networks

“The future is gonna be AWESOME!!”

Then reality intruded

- Bluetooth 1.x/2.x modules were expensive ($15-35/unit in quantity in 2001, never really got much cheaper)
- Market timing/application
  - Most vendors & manufacturers ended up trying to compete w/ WiFi.
  - Devices were power-hungry, Battery technologies not mature
- Competing & incomplete implementations of the Bluetooth spec
  - Pairing & security issues
  - Inteference w/ other wireless tech. like WiFi

“But wait,
there’s just one
more thing…”

Technology moves with time….

- Classic Bluetooth: 1994(spec) 1999(devices)
- BLE spec(2004), MiMOSA (2006)
- Battery Technology:
  - Li-Ion Sony 1991
  - LiPoly Bellcore 1996
- “Smart Dust” sensor motes (1998)

….but also with *money*

- First-gen iPhone sold ~5 million units in the first year(2007-2008)*
- iPhone 4s first to support BLE in 2011
- 4 million BLE-enabled phones sold in first 4 days**
- Simplified chipset made BT/BLE commercially viable for Apple to use in the 4s

*source: http://www.statista.com/statistics/263401/global-apple-iphone-sales-since-3rd-quarter-2007/

**http://en.wikipedia.org/wiki/IPhone_4S#Commercial_reception

so...

Bluetooth LE is as much about being in the right place & the right time in the market as it is about being a useful technology.

Bluetooth “Classic” Design

- “Cable replacement” technology
  - RFCOMM
    - Serial emulation & modem/Dialup profile
      - PPP-over-Bluetooth AKA wireless TCP/IP
- A2DP - Audio transmission (Headset/headphones)
- Wireless data-syncing
- All very much designed to solve 1990s era problems.
- Sensors?—-yeah, we’ll get to that…

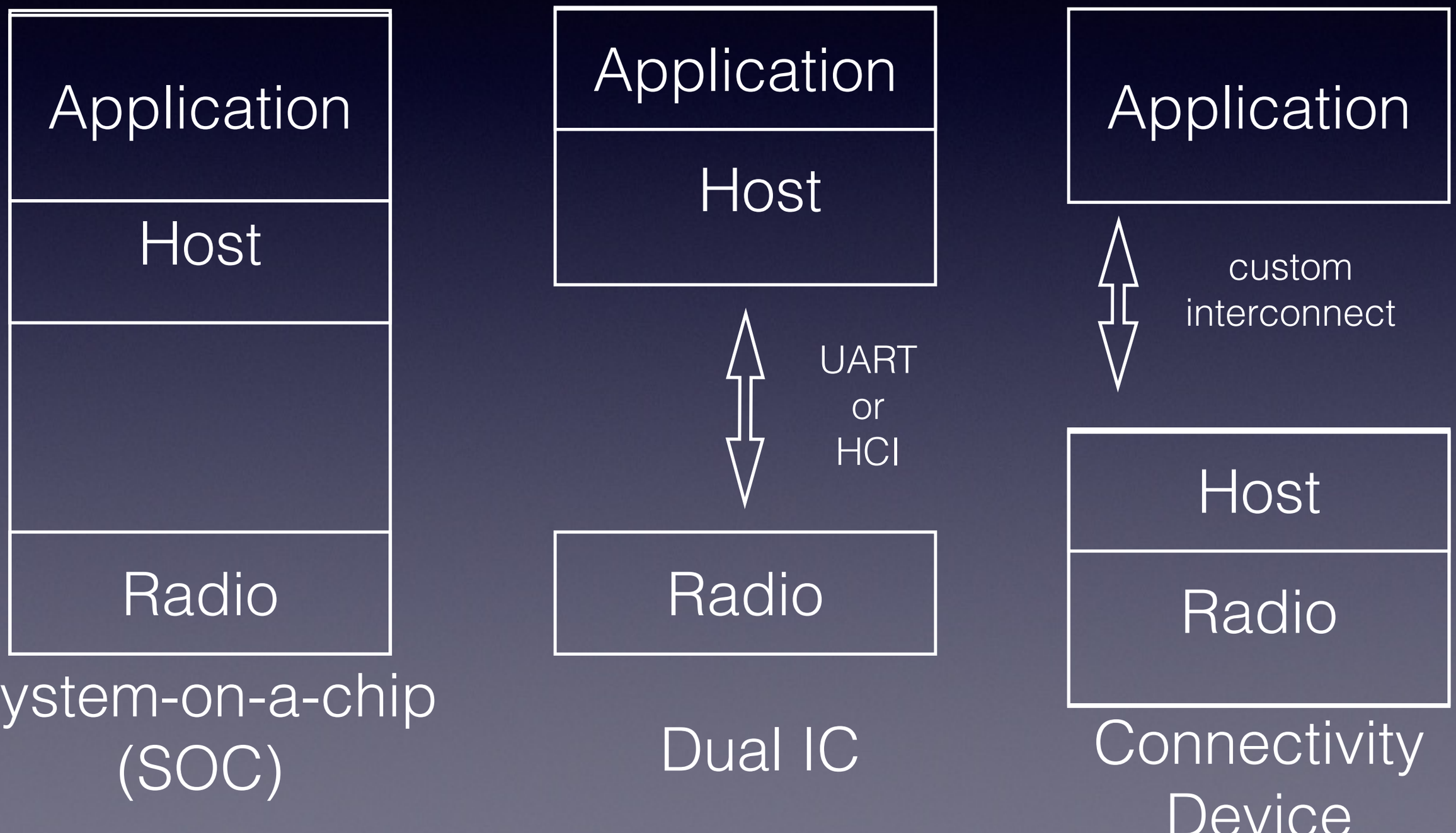
BLE Design

- Designed to be a low-power, low-bandwidth, wireless technology for sensors
- Spec was originally written separate of Bluetooth, then later rolled into Bluetooth 4.0
- Not meant to be another “data pipe”
- “Ask a specific question, get a specific answer”

BLE Design(cont'd)

- Specialization yields
  - A less complex protocol stack
    - Smaller packets
    - Asynchronous data transfer
    - Less energy spent running radio hardware, etc.

BLE in hardware



How low can you go?

- BLE specification defines a connection duration of 7.25ms to 4 seconds.
- 10ms transmit window
- Data packets nominally 20 bytes, up to 39 bytes in payload.
- This results in an effective throughput of 10KB/s
- 0.01-0.5W peak power consumption
  < 15mA peak current

How low can you go ?

- Power consumption:
  - BLE Specification:
    0.01-0.5W peak power consumption
    < 15mA peak current
  - Studies by Microsoft Research* and Univ. Michigan** looked at power draw during sleep, scanning, connection negotiation, data transmission, etc.

* http://research.microsoft.com/pubs/192688/IWS%202013%20wireless%20power%20consumption.pdf

** http://www.eecs.umich.edu/courses/eecs589/papers/06215496.pdf

Comparing power consumption between BLE, ZigBee and ANT

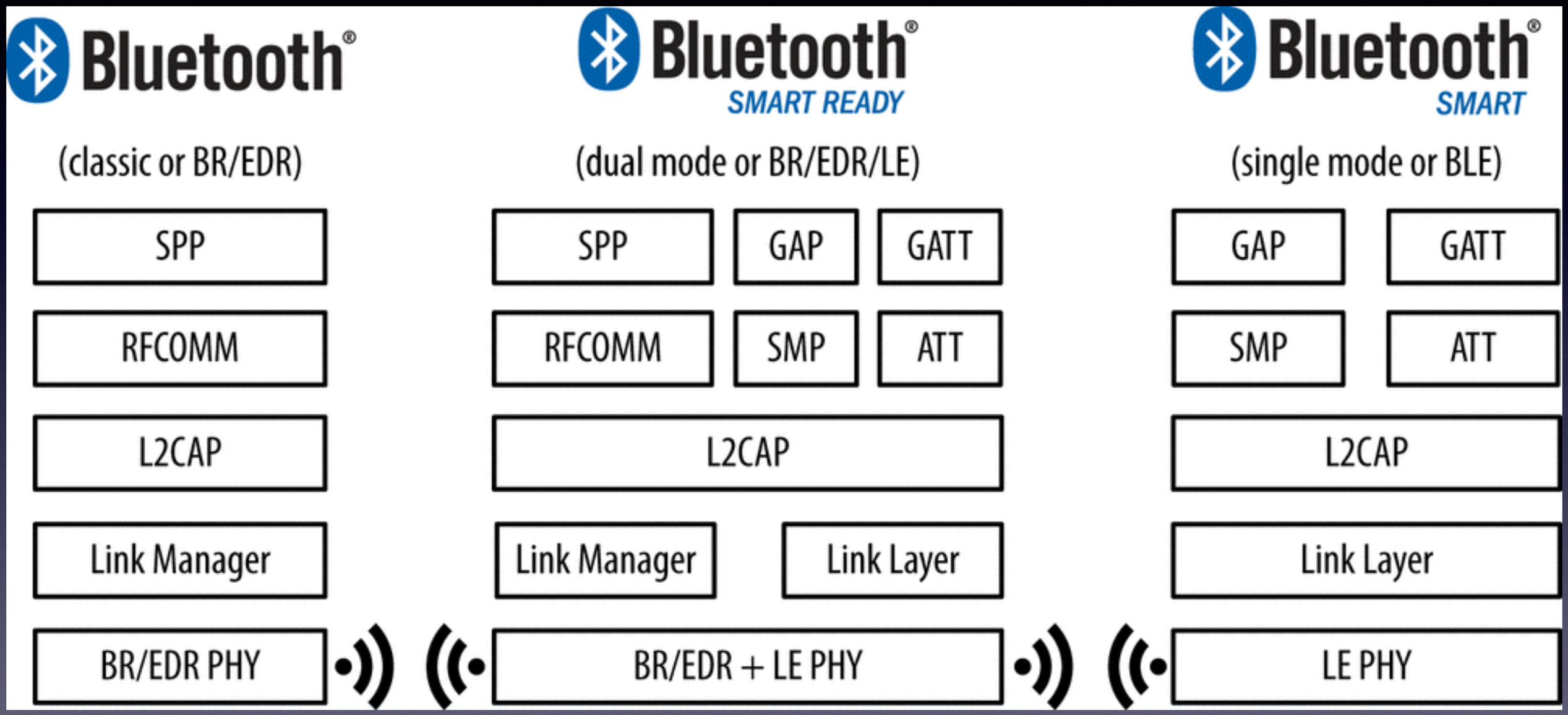
	BLE	ZigBee	ANT
Time of one connection ±SD*	1150 ms ±260 ms	250 ms ±9.1 ms	930 ms ±230 ms
Sleep current	0.78 uA	4.18 uA	3.1 uA
Awake current	4.5 mA	9.3 mA	2.9 mA
Min current (at 120 sec interval)	10.1 uA	15.7 uA	28.2 uA
Optimal sleep interval	10.0 s	14.3 s	15.3 s
*SD: standard deviation			

“Power Consumption Analysis of Bluetooth Low Energy,ZigBee and ANT” - Microsoft Research
http://research.microsoft.com/pubs/192688/IWS%202013%20wireless%20power%20consumption.pdf

BLE still inherits much from Classic Bluetooth

- Roles/Topologies:
  - Support for Role-switching between Central & Peripheral, multiple simultaneous connections
- Security
  - Pairing
  - Bonding
  - Similar Encryption Algorithms
    - ….similar bugs

BLE in the Bluetooth 4.0 stack



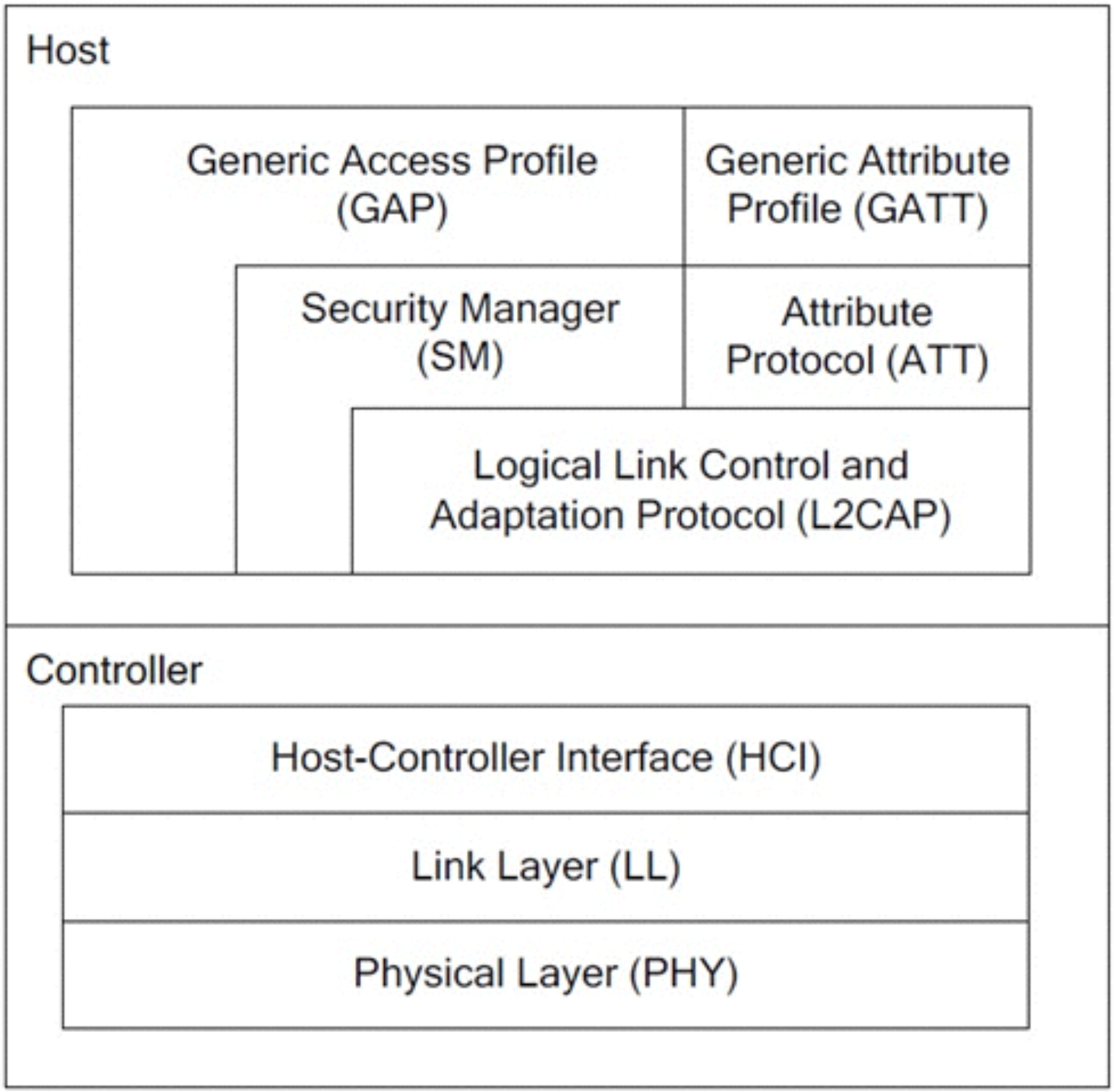


Image Courtesy: Texas Instruments (http://www.ti.com/lit/ug/swru271f/swru271f.pdf)

Some BLE chipsets & vendors*

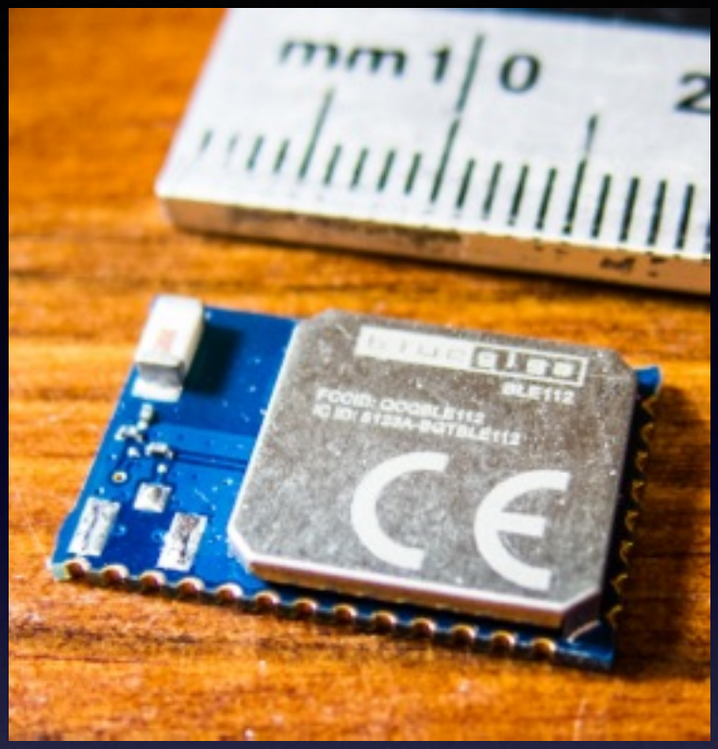
	CC2540/CC2541	CC256x	nRF51822	DA14580	PSoC 4 BLE / PRoC BLE
Vendor	Texas Instruments	Texas Instruments	Nordic Semiconductor	Dialog Semiconductor	Cypress Semiconductor
Mode	Single Mode v4.0	Dual Mode Classic + BLE/ANT	Single Mode v4.1 / ANT	Single Mode BLE v4.1	Single Mode BLE v4.1
Integrated Processor	8051	No - External	Cortex-M0	Cortex-M0	Cortex-M0
Flash	128kB/256kB	None	128kB / 256kB	32kB OTP	128kB
RAM	8kB	None	16kB / 32kB	42kB + 8kB	16kB
Current Consumption (RX/TX)	17.9mA / 18.2mA to 14.7mA / 14.3mA	-	9.7mA / 8mA	4.9mA / 4.9mA	15.6mA / 16.4mA
Chip Size	6mmx6mm QFN-40	8mmx8mm QFN	6x6mm QFN 3.5mmx3.8mm WLCSP	2.5mmx2.5mm CSP 6mmx6mm QFN48	7mmx7mm QFN 3.9mmx3.5mm WLCSP

http://www.argenox.com/bluetooth-low-energy-ble-v4-0-development/library/a-guide-to-selecting-a-bluetooth-chipset/*

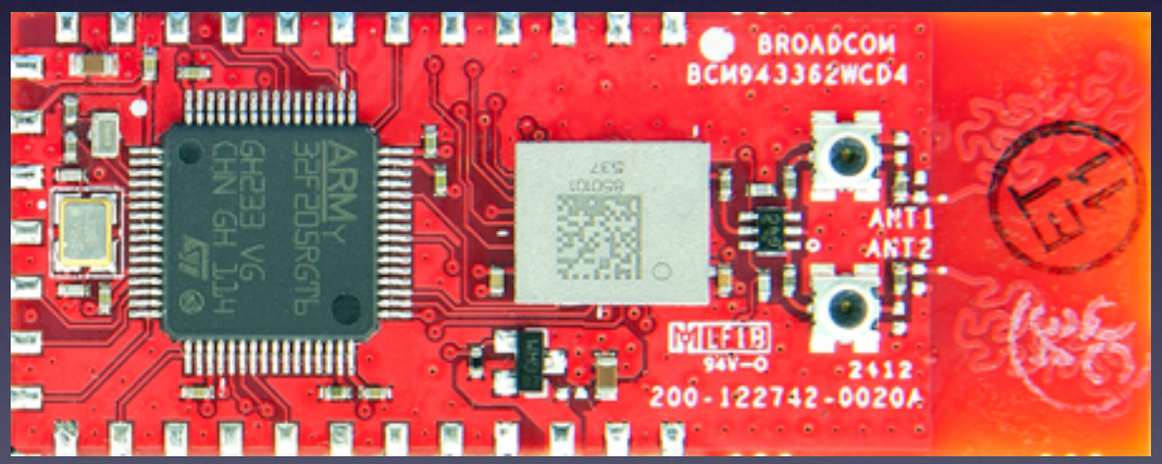
BLE Chipsets

Nordic nRF 51882

PAN 1721



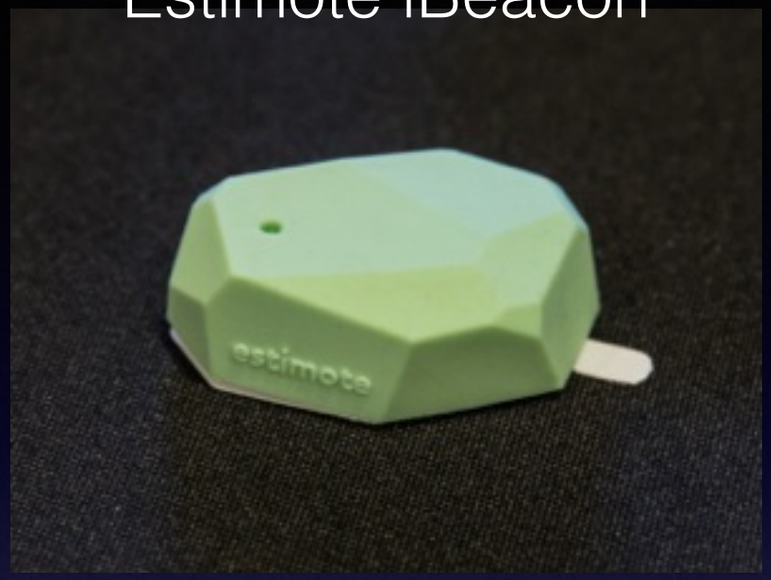
BlueGIGA 112



Broadcom WICed Dev Board

Platforms and Devices

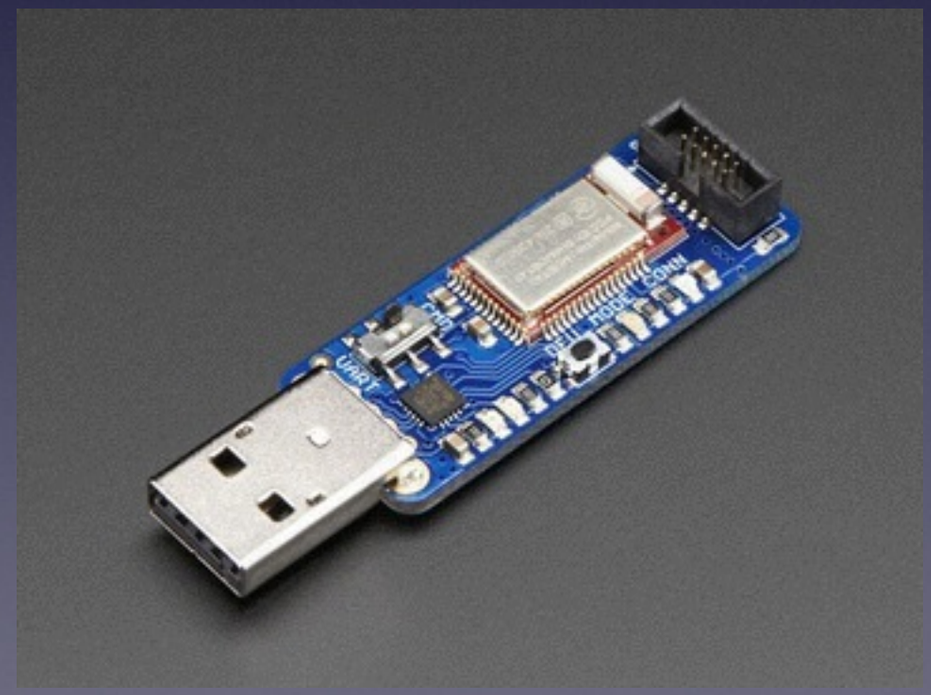
Estimote iBeacon



TI CC2540

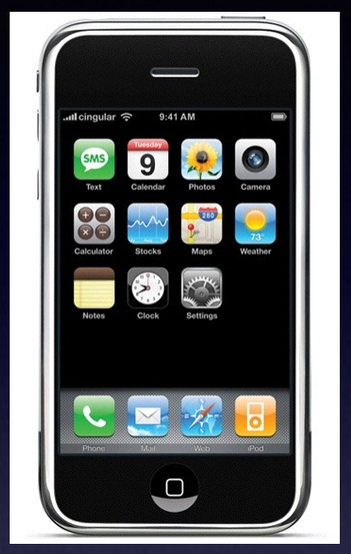
Seeduino BLE Shield

Nordic nRF Developer Kit



Adafruit “BLE Friend”

How does this work ?



scan

advertisement

conn req.

conn. response

GAP req.

GATT Service: “health thermometer”

ATT req:

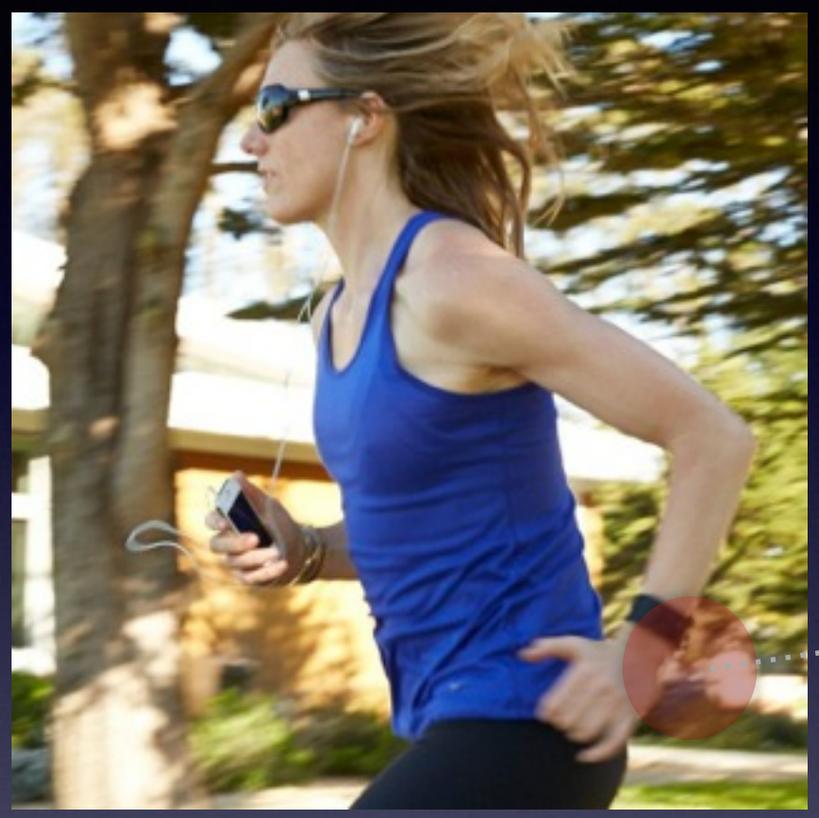
“read:temperature(sublingual)”

“write:C or F”

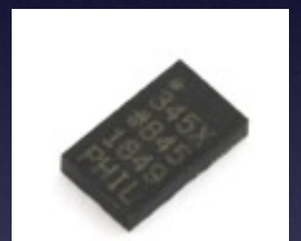
Char. req: “current temp in C”

“38.3 C”

How does this work ? (cont'd)

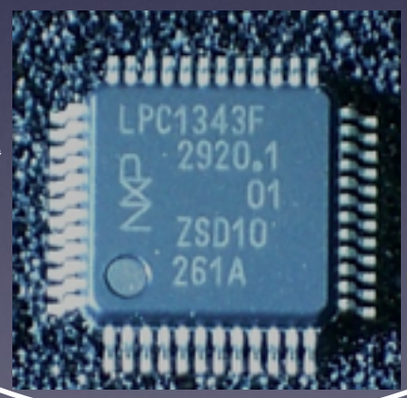


Wireless Comm.



Sensors

(optional) Co-processor



Mind the GAP (and GATT)

- GAP - General Access Profile
  - Defines Roles, Protocols, etc. for discovery, connection & security between BLE devices
- GATT Generic ATTribute Profile
  - Defines Roles, Attributes, Permissions,etc. for the actual exchange of data between connected devices

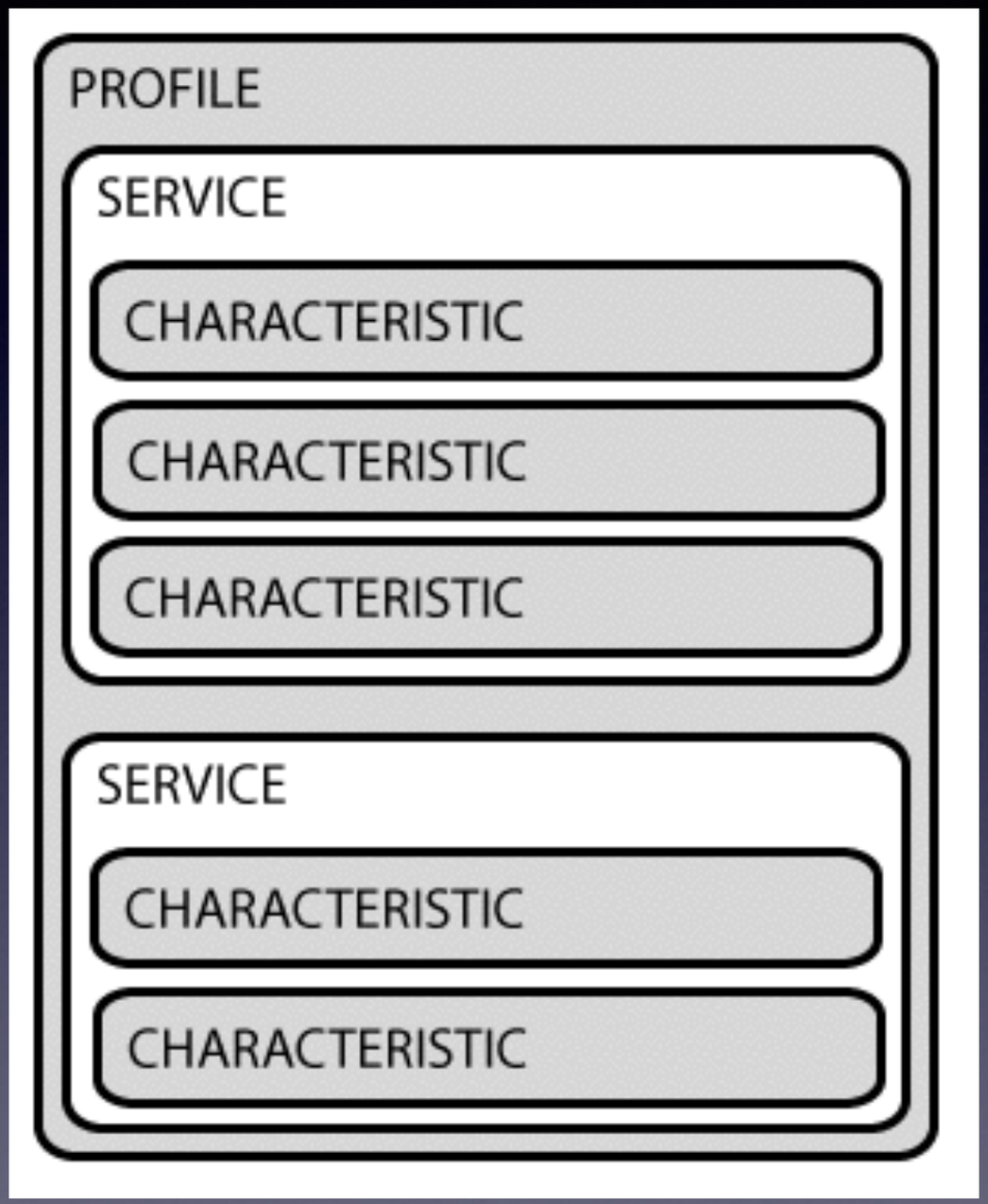
GAP Device Roles

- Broadcast - Beacons, sends all data in beacon frame.
- Central - Master/Coordinator nodes
- Observer - Passive link-layer receiver
- Peripheral - Link-layer slave device, beacons for Central nodes and connectivity

GATT Profiles

- Defines/Controls data transfer between connected devices
- Applicable after discovery/connection has been established.
- Describes Services and Characteristics available on connectable devices with UUIDs

GATT Profiles



GATT Example

Blood Glucose Measurement

UUID 0x1808
org.bluetooth.service.glucose

UUID 0x2A08
org.bluetooth.characteristic.glucose_measurement

Measurement Timestamp - org.bluetooth.characteristic.date_time
Glucose Concentration - units of kg/L 16-bit SFLOAT
Glucose Concentration - units of mol 16-bit SFLOAT
Sample Location - bitfield (0-finger, 1-earlobe, 2- internal/IV….)

UUIDs

- “Universally Unique ID”
    - 128-bit(16-byte) value used to represent a (very likely) unique identifier for Services and Characteristics
    - Originating from ITU-T Rec. X.667(ISO/IEC 9834-8:2005)
    - Used in BLE to identify: Devices, Services and Profiles

“If generated according to one of the mechanisms defined in Rec. ITU-T X.667 | ISO/IEC 9834-8, a UUID is either guaranteed to be different from all other UUIDs generated before 3603 A.D ….The UUID generation algorithm specified in this standard supports very high allocation rates: 10 million per second per machine if necessary, so UUIDs can also be used as transaction IDs…”

–ITU UUID Website
http://www.itu.int/en/ITU-T/asn1/Pages/UUID/uuids.aspx

Defining Custom UUIDs

- Check again to make sure that there isn't an existing UUID set that defines what you want.
- Visit the ITU UUID Generator site: http://www.itu.int/en/ITU-T/asn1/Pages/UUID/uuids.aspx
- include in the libraries/headers of your application source code.

```java
/**
 * This class includes a small subset of standard GATT attributes for demonstration purposes.
 */
public class SampleGattAttributes {
    private static HashMap<String, String> attributes = new HashMap();
    public static String HEART_RATE_MEASUREMENT = "00002a37-0000-1000-8000-00805f9b34fb";
    public static String CLIENT_CHARACTERISTIC_CONFIG = "00002902-0000-1000-8000-00805f9b34fb";
    public static String TINY_BLE_SENSOR_MEASUREMENT = "195ae58a-437a-489b-b0cd-b7c9c394bae4";
    public static String TINY_BLE_SENSOR_READ_CHARACTERISTIC = "21819ab0-c937-4188-b0db-b9621e1696cd";
    public static String TINY_BLE_SENSOR_WRITE_CHARACTERISTIC = "5fc569a0-74a9-4fa4-b8b7-8354c86e45a4";

    static {
        // Sample Services.
        attributes.put("0000180d-0000-1000-8000-00805f9b34fb", "Heart Rate Service");
        attributes.put("0000180a-0000-1000-8000-00805f9b34fb", "Device Information Service");

        // Sample Characteristics.
        attributes.put(HEART_RATE_MEASUREMENT, "Heart Rate Measurement");
        attributes.put("00002a29-0000-1000-8000-00805f9b34fb", "Manufacturer Name String");

    }

    static {
        attributes.put(TINY_BLE_SENSOR_MEASUREMENT ,"tinyBLE Sensor Service");
        // Sample Characteristics.
        attributes.put(TINY_BLE_SENSOR_READ_CHARACTERISTIC, "tinyBLE Sensor Read Characteristic");
        attributes.put(TINY_BLE_SENSOR_WRITE_CHARACTERISTIC,"tinyBLE Sensor Write Characteristic");
        attributes.put("00002a29-0000-1000-8000-00805f9b34fb", "Manufacturer Name String");
    }
```

```
/*********************************************************************
 * INCLUDES
 */
#include "st_util.h"

/*********************************************************************
 * CONSTANTS
 */

// Service UUID
#define BAROMETER_SERV_UUID             0xAA40  // F000AA40-0451-4000-B000-000000000-0000
#define BAROMETER_DATA_UUID             0xAA41
#define BAROMETER_CONF_UUID             0xAA42
#define BAROMETER_CALI_UUID             0xAA43
#define BAROMETER_PERI_UUID             0xAA44

// Sensor Profile Services bit fields
#define BAROMETER_SERVICE               0x00000010

// Length of sensor data in bytes
#define BAROMETER_DATA_LEN              4
#define BAROMETER_CALI_LEN              16

/*********************************************************************
```

BLE and the IOT

- Not immediately IOT-ready
- Some research has been done to run IPV6 over BLE *
- Generally, BLE Central Role device with Internet connectivity is required.
    - Laptop, Raspberry Pi, Beaglebone, Mobile Phone, etc.

*Wang, H.; Xi, M.; Liu, J.; Chen, C. “Transmitting IPv6 Packets over Bluetooth Low Energy Based on BlueZ.” In Proceedings of 15th International Conference on Advanced Communication Technology (ICACT’13),

Platform Support

- Platform/OS
  - iOS5 and up (iPhone 4s or later)
  - Android 4.3 and up(Galaxy S4, etc.)
  - Apple OS X 10.6+
  - Windows 8
  - GNU/Linux BlueZ 4.93+
  - Arduino: Various shields & peripherals

Developer Support for BLE chipsets

- Mostly closed-source, depends on chipset & vendor
  - TI CC2540 : OSAL via Keil/IAR compilers
  - iBeacons: Obj. C using Apple Xcode
  - BlueGIGA:BGScript on Linux and Windows
  - Nordic nrf51822: C/C++ w/ GCC
  - Arduino IDE
  - Android:Android Studio (Eclipse support limited)

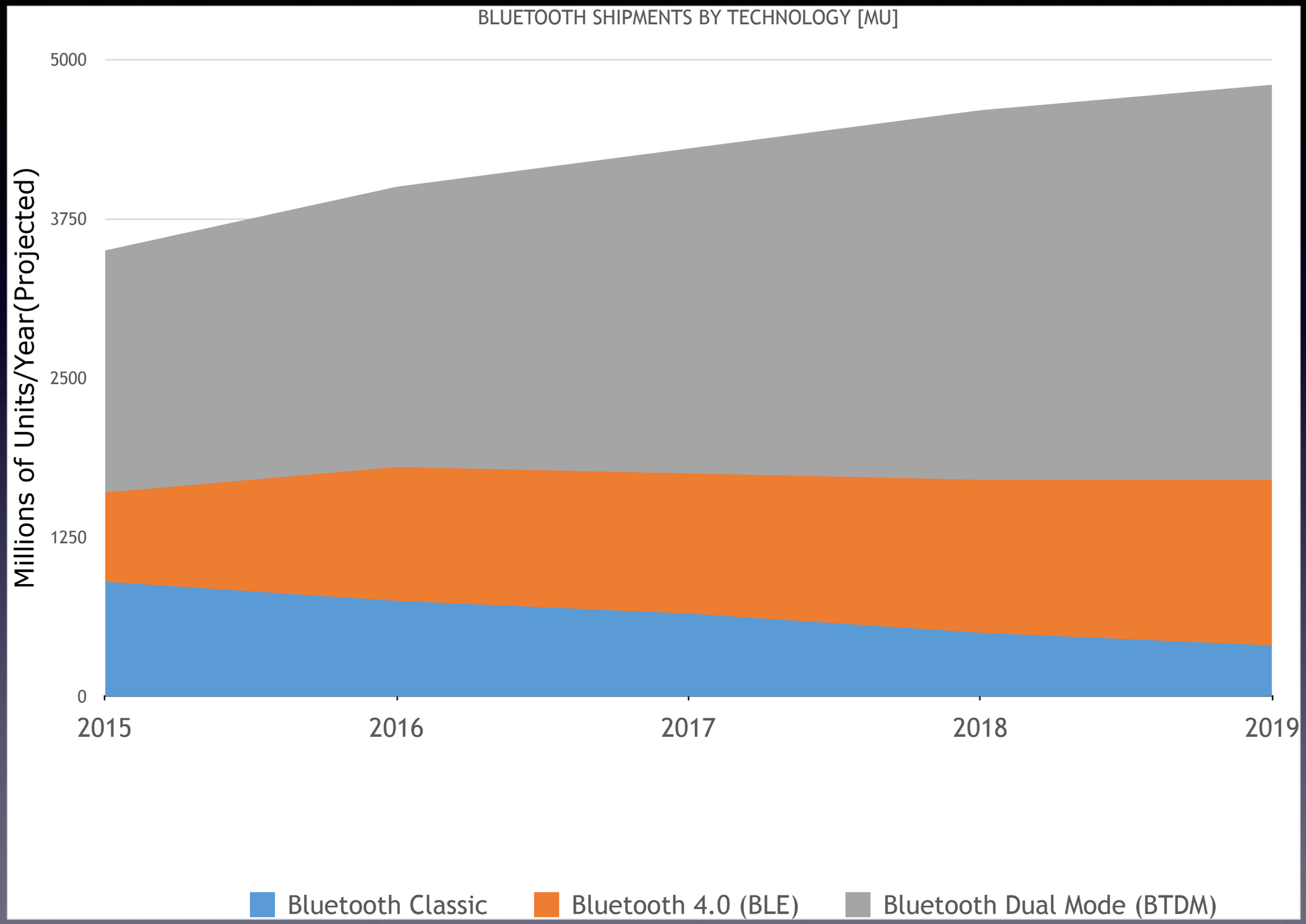
Looking forward…

Projected sales of Bluetooth devices 2015-2018

millions of units shipped

	2015	2016	2017	2018
BLUETOOTH UNITS IN PHONES & OTHERS				
Bluetooth Technology Total	3,500	4000	4300	4600
Bluetooth Technology In Mobile Phones	1,800	1925	2025	2100
Bluetooth Technology In Other Applicati	1,700	2,075	2,275	2,500
BLUETOOTH UNITS BY VERSION				
Bluetooth Classic	900	750	650	500
Bluetooth 4.0 (BLE)	700	1050	1100	1200
Bluetooth Dual Mode (BTDM)	1900	2200	2550	2900
BTLE+BTDM	2600	3250	3650	4100
PERCENTAGE SHARES				
Classic Percentage	26%	19%	15%	11%
BTLE Percentage	20%	26%	26%	26%
BTDM Percentage	54%	55%	59%	63%
BTLE+BTDM Percentage	74%	81%	85%	89%

Market data provided courtesy of Cratus Technology, Inc. www.cratustech.com



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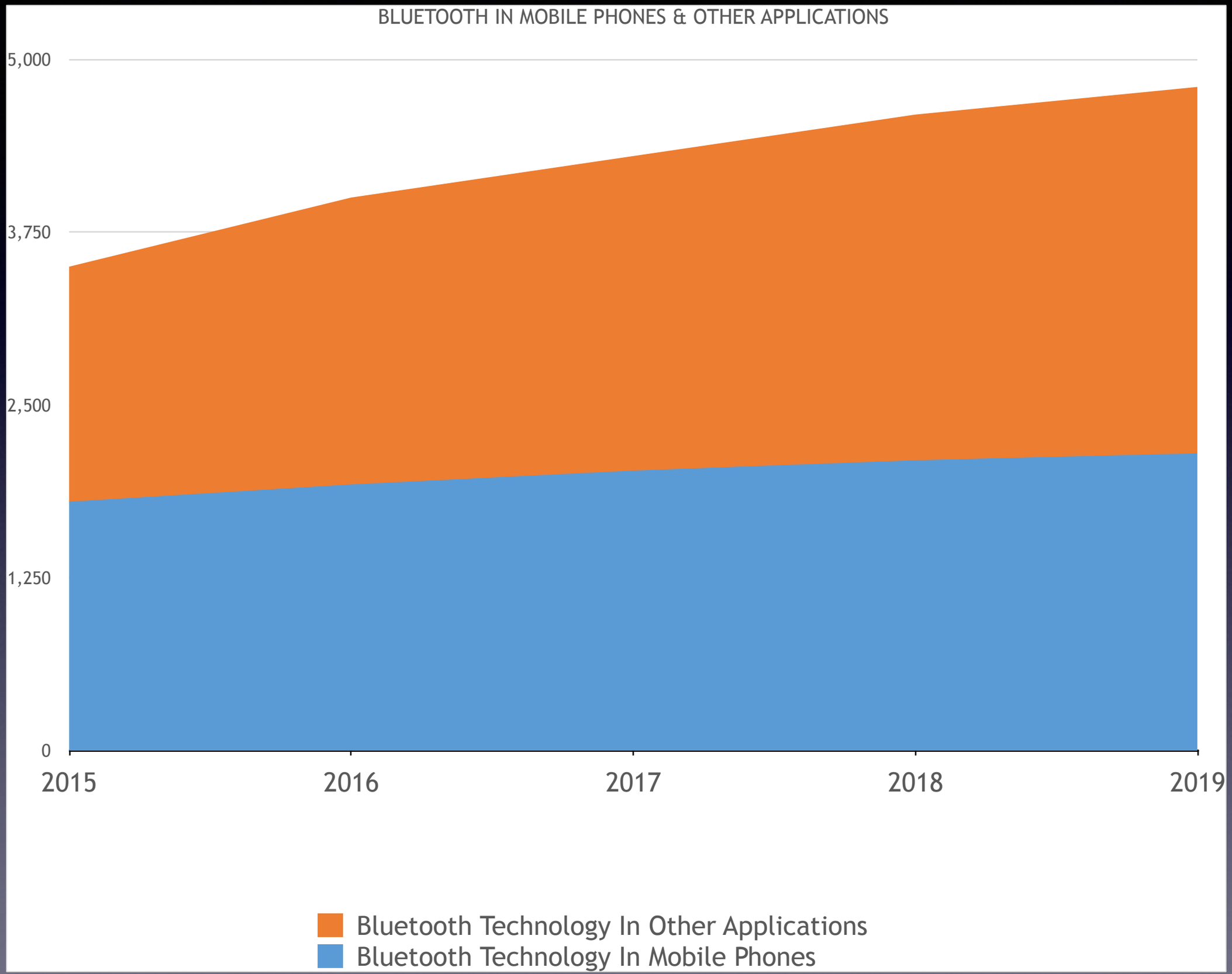

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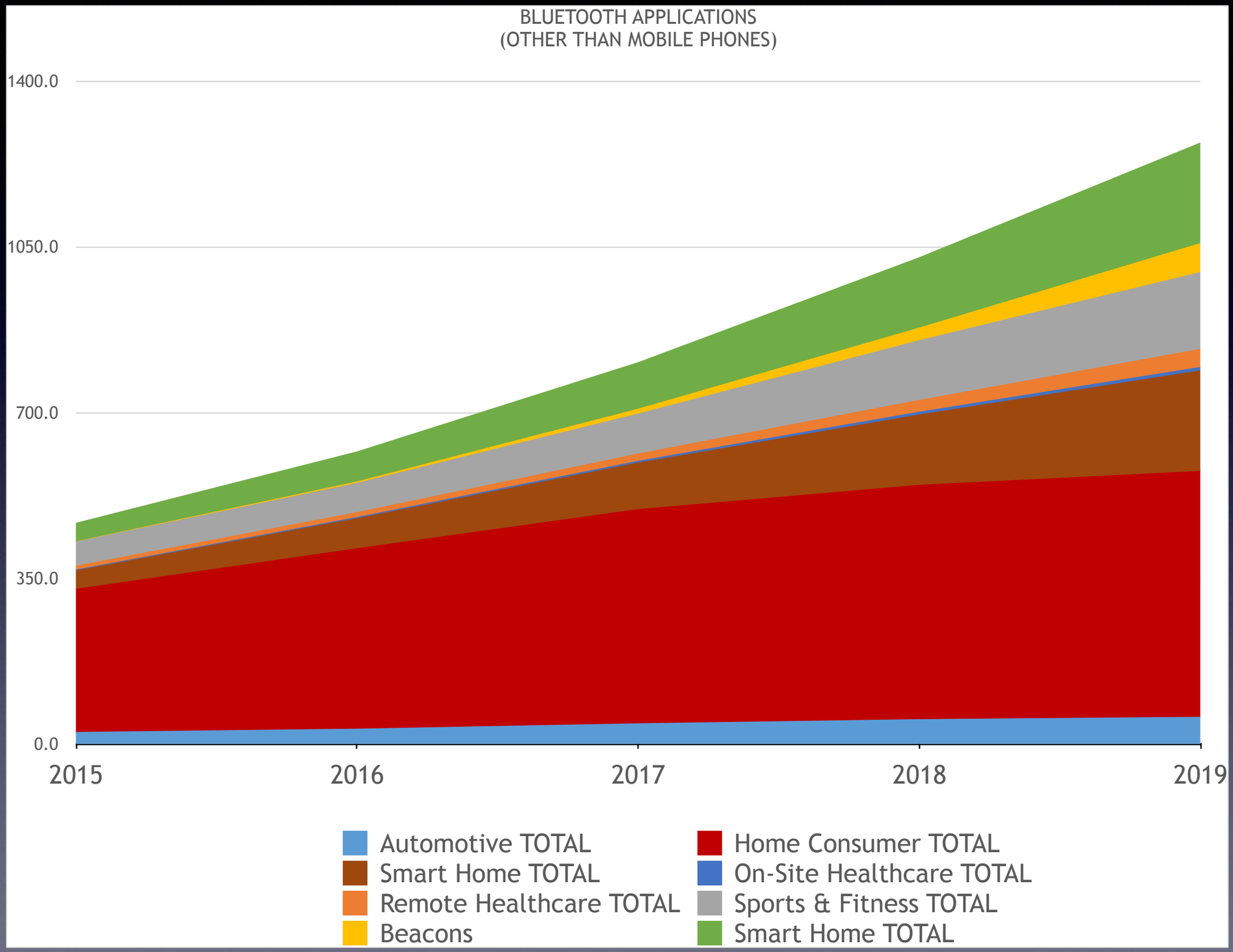

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Links/Resources

- Documentation
  - Bluetooth SIG BLE Site: https://developer.bluetooth.org/TechnologyOverview/Pages/BLE.aspx

- O'Reilly & Associates
  "Getting Started with Bluetooth Low Energy" (Book)

- Adafruit Learning Center - Intro to BLE: https://learn.adafruit.com/introduction-to-bluetooth-low-energy/introduction

BLE Starter kits

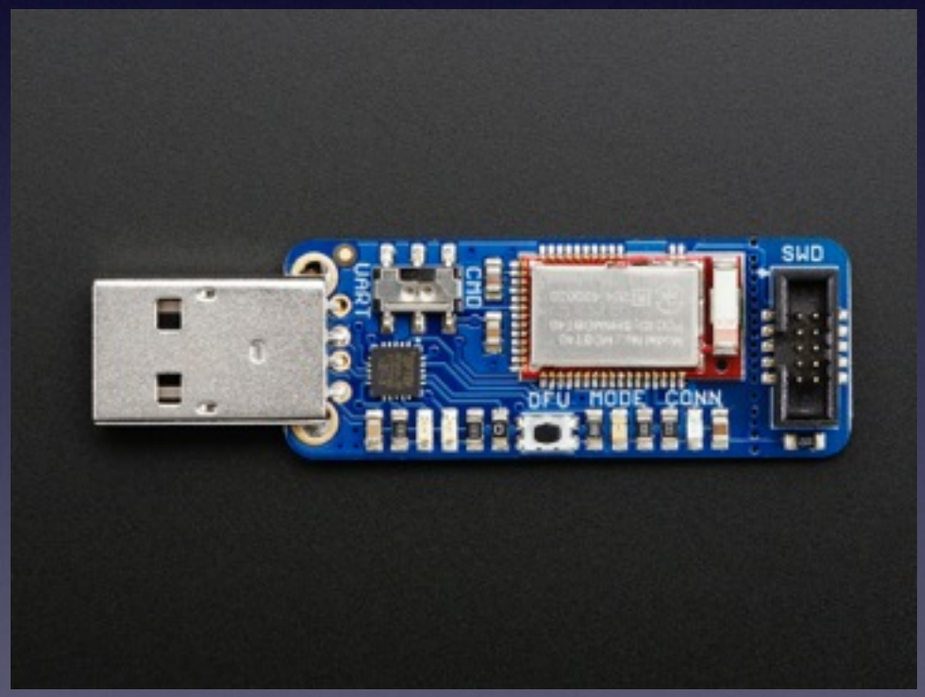
- TI CC2540 Sensor Tag $40
  http://www.ti.com/product/CC2541

BLE Starter kits

- SeeedStudio BLE kits & modules

BLE Diagnostic tools

Adafruit Bluefruit
Dedicated BLE Sniffer



Nordic 51822
chipset

Ubertooth One
BT/BLE/802.15.4 sniffer

TI CC259x
2.4Ghz chipset

Questions ?

Contact me

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- espressobot@gmail.com