ECEN 5823-001 / -001B

Internet of Things Embedded Firmware

Lecture #9

26 September 2017

Be Boulder.

University of Colorado Boulder

Agenda

- Class announcements
- SPI tap sensor assignment questions?
- Quiz 4 review
- Bluetooth Classic
- Bluetooth Smart

Class Announcements

- Quiz #5 is due at 11:59pm on Sunday, October 1st, 2017
- SPI tap sensor Assignment is due at 11:59pm on Wednesday, September 27th, 2017

Update on the SPI tap sensor assignment

7. BMA280 settings should be initialized to:
    a. Range +/- 4g
    b. Bandwidth 125Hz
    c. Tap quiet 30mS
    d. Tap samples 4
    e. Tap duration 200mS
    f. Tap shock 50mS
    g. Tap threshold 4g

SPI tap sensor assignment questions?

- Does anyone have questions on this assignment that I can address right now?

SPI tap sensor assignment questions?

- I have a question.
  - What size should I set in the SPI frame to?
- You set it to the minimum size of the unit of information
  - 8-bits for 1 byte of data

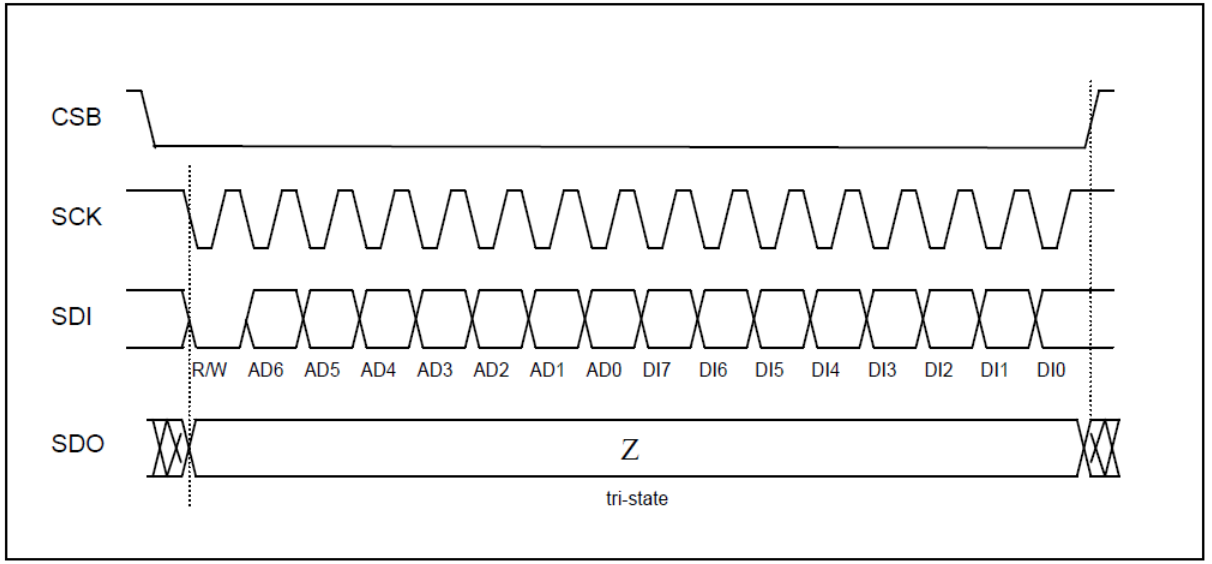


Figure 14: 4-wire basic SPI write sequence (mode ´11´)

SPI tap sensor assignment questions?

- I have another question.
  - If I have to transmit data even though I am doing a read, what is the best method
  - USART1->TXDOUBLE = read_request;
  - How do I read the data?
  - read_data = spi->RXDOUBLE;
  - read_data = read_data >> 8;

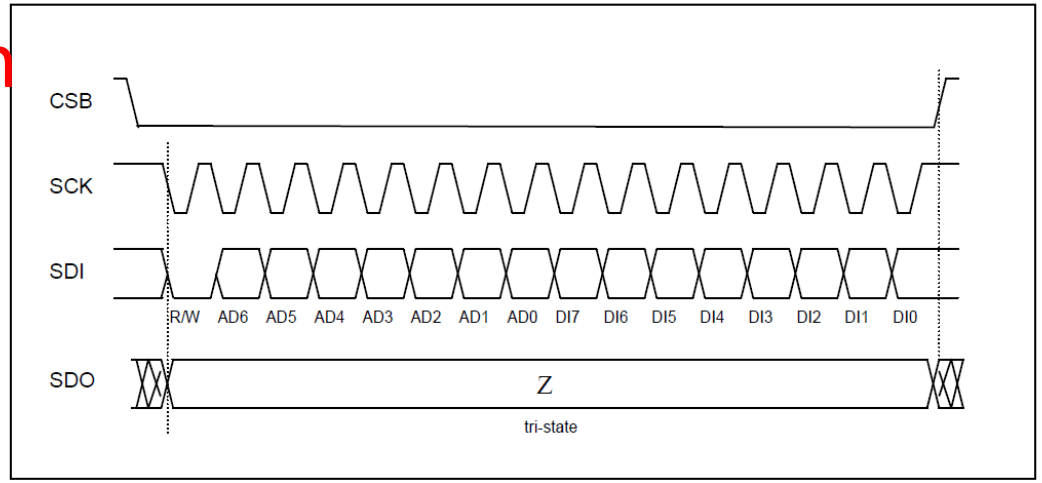


Figure 14: 4-wire basic SPI write sequence (mode ´11´)

Quiz 4 Review

All accelerometers are not affected by rotations around which axis?

- x-axis
- y-axis
- z-axis

Quiz 4 Review

If the magnetometer is inverted, what orientation will the X-axis be at its maximum?

- South
- North 
- East
- West

Quiz 4 Review

After enabling the ADC in the Blue Gecko, what energy mode enumeration (EM0, EM1, EM2, EM3, or EM4) would be used to set the BlockSleepMode() routine in its lowest energy mode if using a synchronous clock source for ADC Clock?

(em1, EM1, BlockSleepMode(EM1), BlockSleepMode(EM1);)

Quiz 4 Review

After enabling the ADC in the Blue Gecko, what energy mode enumeration (EM0, EM1, EM2, EM3, or EM4) would be used to set the BlockSleepMode() routine in its lowest energy mode if using a asynchronous clock source for ADC Clock?

(em3, EM3, BlockSleepMode(EM3), BlockSleepMode(EM3);)

Bluetooth Classic – Bluetooth Channels

- A master can create two types of logical channel with a slave device:
  - Asynchronous Connection Less (ACL): Packet Switched System provides a reliable data connection with a best effort bandwidth; depends on radio performance and number of devices in the piconet.
  - Synchronous Connection Oriented (SCO): Circuit Switched System provides real time reliable connection with a guaranteed bandwidth; usually used for voice based applications.
  - Would ACL or SCO be best for wireless speakers?
- The Bluetooth connections are limited to 1Mbps across the air
  - Giving a theoretical maximum of ~723kbps of useable data
  - Why is the theoretical maximum not 1Mbps?

Bluetooth Classic – What Bluetooth Is Not?

- Bluetooth is not intended to compete with or replace 802.11b, they are complimentary technologies
- The data rates, usage scenarios and fundamental ethos behind them are all different!
- It is unlikely to be used in corporate wireless LAN's. It is not suitable for high data rate applications
  - High data rate is defined to be >600kbps this allows suitable margin for re-transmissions
  - Therefore, high quality video streaming is not possible.

Bluetooth Classic - The ISM Band

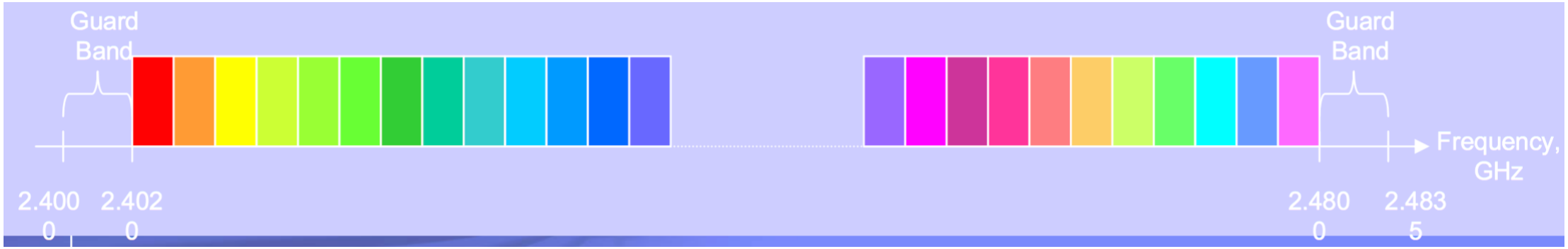
- Bluetooth uses the 2.4GHz ISM frequency band
- The Industrial, Scientific and Medical (ISM) band is an unlicensed band, I.e. any one can use it provided they don't exceed certain power constraints
- The 2.4GHz ISM band is unlicensed all over the world which makes Bluetooth the only completely world wide standard
- Bluetooth uses the frequency range 2.4000 - 2.4835GHz

Bluetooth Classic – Overcoming Interference

- Due to the unrestricted nature of the ISM band, Bluetooth must overcome interference from other systems and minimize its interference on other systems
- Bluetooth does this by using a Frequency Hopping Spread Spectrum (FHSS) technique
- This spreads the RF power across the spectrum which reduces interference and the spectral power density.

Bluetooth Classic - Frequency Hopping Spread Spectrum - FHSS

- Bluetooth splits the spectrum up into 79 1MHz wide channels with a small guard band at each end of the whole band
- The Bluetooth radio changes transmission frequency 1600 times a second
- The frequency hops follow a pseudo random sequence that meets the power density requirements for the FCC and other regulatory bodies



IBM Bluetooth Wireless Technology presentation @ 2003
http://www.ncsysadmin.org/meetings/0506/slides.pdf

Bluetooth Classic - Hop Selection and Synchronization

- One frequency hop lasts 625us, this increment is called a time slot
- Each Bluetooth device has a clock circuit that counts frequency hops
- The address of the master of the piconet is used to seed a frequency hop calculation algorithm
- The phase of the hop sequence is defined by the Bluetooth clock of the master
- Device address and clock phase information is exchanged during connection negotiation
- The slave synchronizes its own clock to the master's during connection so that both devices change frequency at the same time

Bluetooth Classic – Transmission Timing

- A slave can only send data to the master after it has received a valid packet from the master
- Masters transmit in even numbered slots and slaves respond in the next odd numbered slot
- Single slot packets are less then 366us long to allow the synthesizer to retune to the next frequency hop
- Multi-slot packets of 3-slot and 5-slot packets are possible for higher data rates.
  - During 3 and 5-slot transfers, the radio transmitters remain on the same frequency
- Why is there no 4-slot transfer?

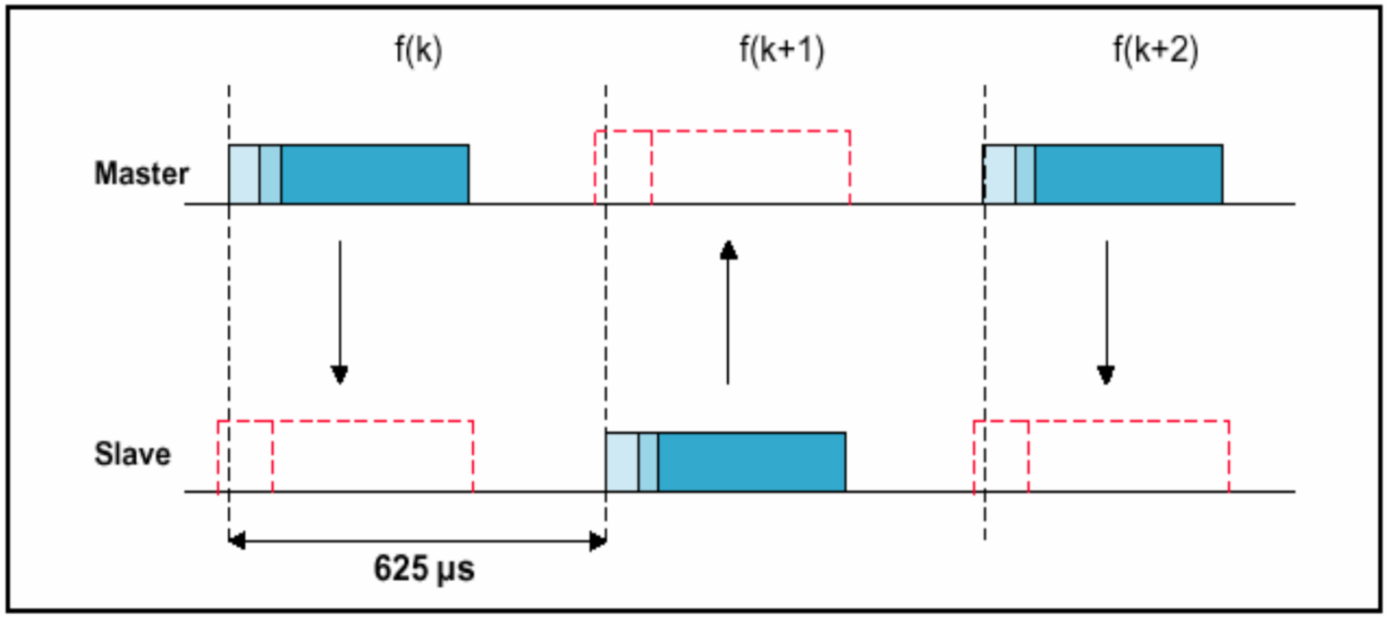


Figure 2.1: TDD and timing

IBM Bluetooth Wireless Technology presentation @ 2003
http://www.ncsysadmin.org/meetings/0506/slides.pdf
Mobile Communications: Second Edition by John Schiller

Bluetooth Classic – Power Classes

- Bluetooth defines 3 power classes for devices:
  - Class 1: 0dBm to +20dBm (1mW to 100mW)
  - Class 2: -6dBm to +4dBm (250uW to 2.5mW)
  - Class 3: <0dBm (<250uW)
- These power classes translate in to approximate distances often used when discussing Bluetooth:
  - Class 1: 100 Meters
  - Class 2: 10 Meters
  - Class 3: <10 Meters
- Which class would be most appropriate for a smart phone wireless headset? And, why?

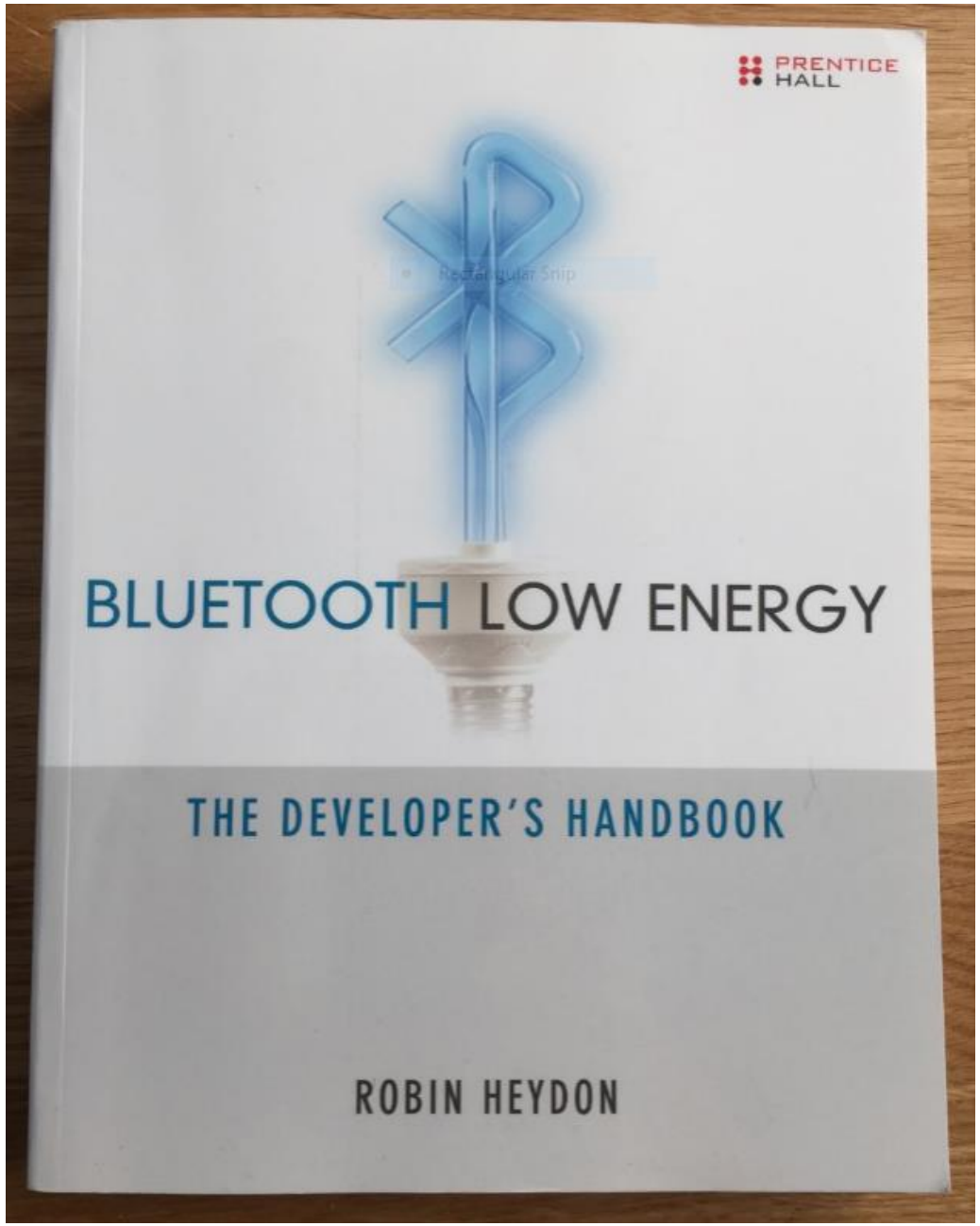
Bluetooth Classic - States

- Standby state: Each device which is currently not participating in a piconet (and not switched off) is in Standby mode.
  - This lower-power mode where only the device's native clock is running
- Inquiry state: A device wants to establish a Piconet or a device just wants to listen to see if something is going on.
  - Establishing a piconet – A device starts the inquiry procedure by sending an inquiry access code (IAC) that is common to all Bluetooth devices. The IAC is broadcast over 32 so-called wake-up carriers in turn.
    - A device in standby that listen periodically can wake up and respond to an IAC request by returning a packet address and timing information required by the master to initiate a connection. It is now a slave device. It receives an Active Member Address (AMA)
    - Note: There are 3-bits for Active Member Addresses which limit the Piconet to 8 total devices. There are 5-bits for Parked Member Addresses so there can be 64 parked devices associated with the piconet.

Bluetooth Classic - States

- Page state: Once an inquiry is successful, the device enters the page state.
  - In page state, the master set up connections to each device.
- Connection state:
  - Comprises of all active and low power devices in the piconet
  - Active state: Slaves participate in the piconet by listening, transmitting, and receiving.
  - Low power states:
    - Sniff state: Highest power consuming low power state. The device listens to the piconet at a reduced rate. Not on every other slot as a active device.
    - Hold state: The device does not release its Active Member Address, but stops all ACL transmissions.
    - Park state: Lowest of the power saving states. The device releases its AMA and receives a Parked Member Address (PMA). The device is still a member of the Piconet, but gives room to another device to be an active member.

Required book for Bluetooth Smart / Bluetooth Low Energy portion of course

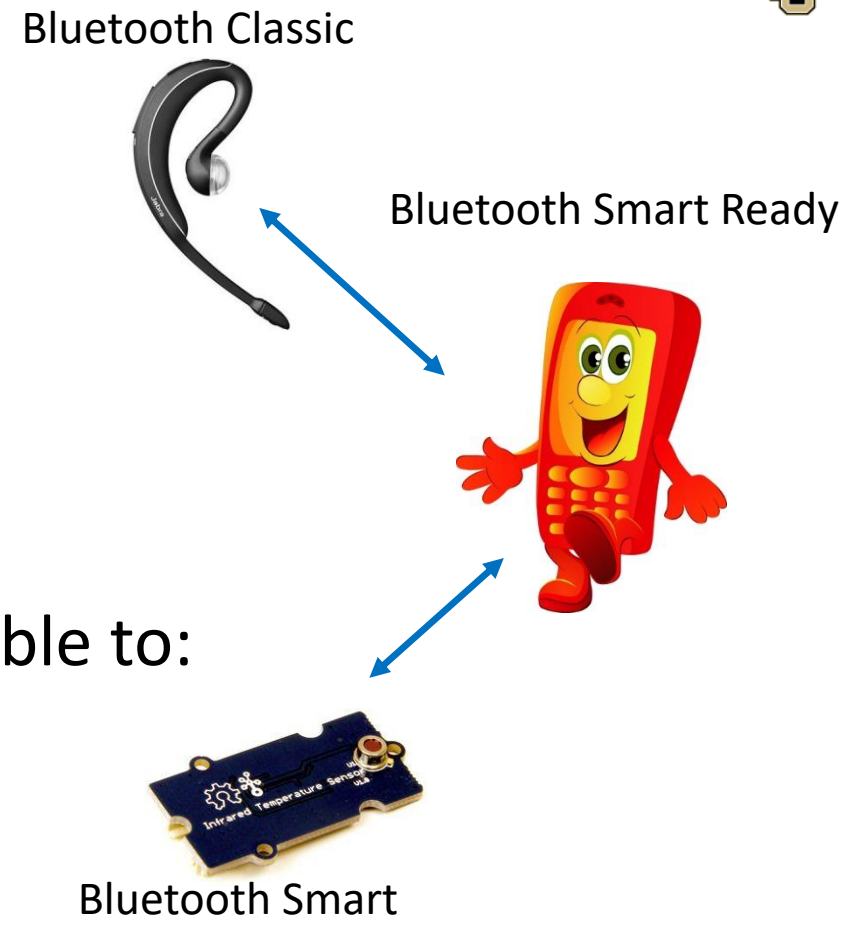


"Bluetooth Low Energy, The Developer's Handbook," by Robin Heydon
ISBN: 9780132888363

Bluetooth Low Energy / Smart

Bluetooth Low Energy = Bluetooth Smart

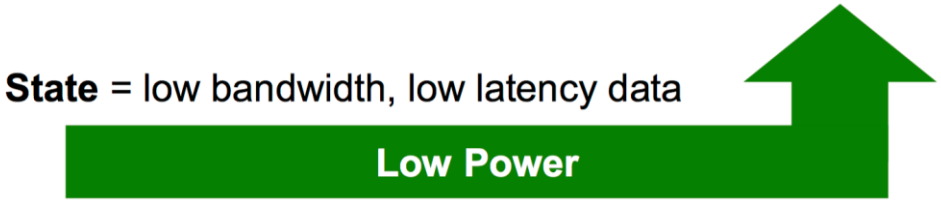
Key take aways from the video



- Bluetooth Low Energy = Bluetooth Smart
- Bluetooth Smart != Bluetooth Classic
  - They are not compatible
- Bluetooth Smart Ready (Dual-Mode) is compatible to:
  - Bluetooth Smart (Single-Mode)
  - And,
  - Bluetooth Classic
- Bluetooth Smart Ready is a gateway between Bluetooth Smart and Bluetooth Classic

Bluetooth Low Energy / Smart

	Voice	Data	Audio	Video	State
Bluetooth ACL / HS	x	Y	Y	x	x
Bluetooth SCO/eSCO	Y	x	x	x	x
Bluetooth low energy	x	x	x	x	Y
Wi-Fi	(VoIP)	Y	Y	Y	x
Wi-Fi Direct	Y	Y	Y	x	x
ZigBee	x	x	x	x	Y
ANT	x	x	x	x	Y



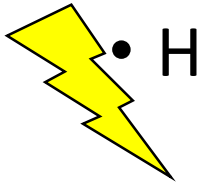
CSR: Bluetooth 4.0 Low Energy
http://chapters.comsoc.org/vancouver/BTLER3.pdf

Bluetooth Low Energy / Smart

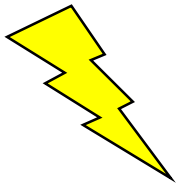
- What is traditional Bluetooth Classic used for?
  - Mobile phones, including ‘smart phones’
  - Wireless controllers for video games
  - Voice headsets and “Car kits”
  - Stereo speakers
  - PCs
  - M2M applications
    - credit card readers
    - industrial automation
- Bluetooth Classic is mainly or more commonly used for Human I/O applications!

Think of replacing wires

Bluetooth Low Energy / Smart



- How much energy does Bluetooth Classic use?
  - Bluetooth Classic is *connection oriented*
  - When a device is connected, a link, "pseudo wire," is maintained, even if there is no data flowing
  - Sniff modes allow devices to sleep, reducing power consumption to give months of battery life
  - Peak transmit current is typically around 25mA.

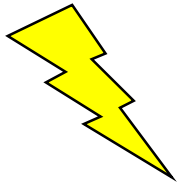


- Even though Bluetooth Classic has been independently shown to be lower power than other radio standards, it is still not low enough power for coin cells and energy harvesting applications

Bluetooth BLE - What is Bluetooth Low Energy?

- A new radio, new protocol stack, new profile architecture and a new qualification regime
- It's designed to run from coin cells
- It is a radio standard enabling the Internet of Things
- Features:
  - Mostly new PHY; some parts derived from the Basic Rate (BR) radio
  - New advertising mechanism, for ease of discovery & connection
  - Asynchronous connection-less MAC: used for low latency, fast transactions (e.g. 3ms from start to finish)
  - New Generic Attribute Profile to simplify devices and the software that uses them.
  - Asynchronous Client / Server architecture
- Designed to be LOWEST cost and EASY to implement

BLE - fact sheet



Range:	~ 150 meters open field
Output Power:	~ 10mW (10dBm)
Max Current:	~ 15mA
Latency:	3 ms
Topology:	Star
Connections:	> 2 billion
Modulation:	GFSK @ 2.4 GHz
Robustness:	Adaptive Frequency Hopping, 24 bit CRC
Security:	128bit AES CCM
Sleep current	~ 1µA
Modes:	Broadcast, Connection, Event Data Models Reads, Writes

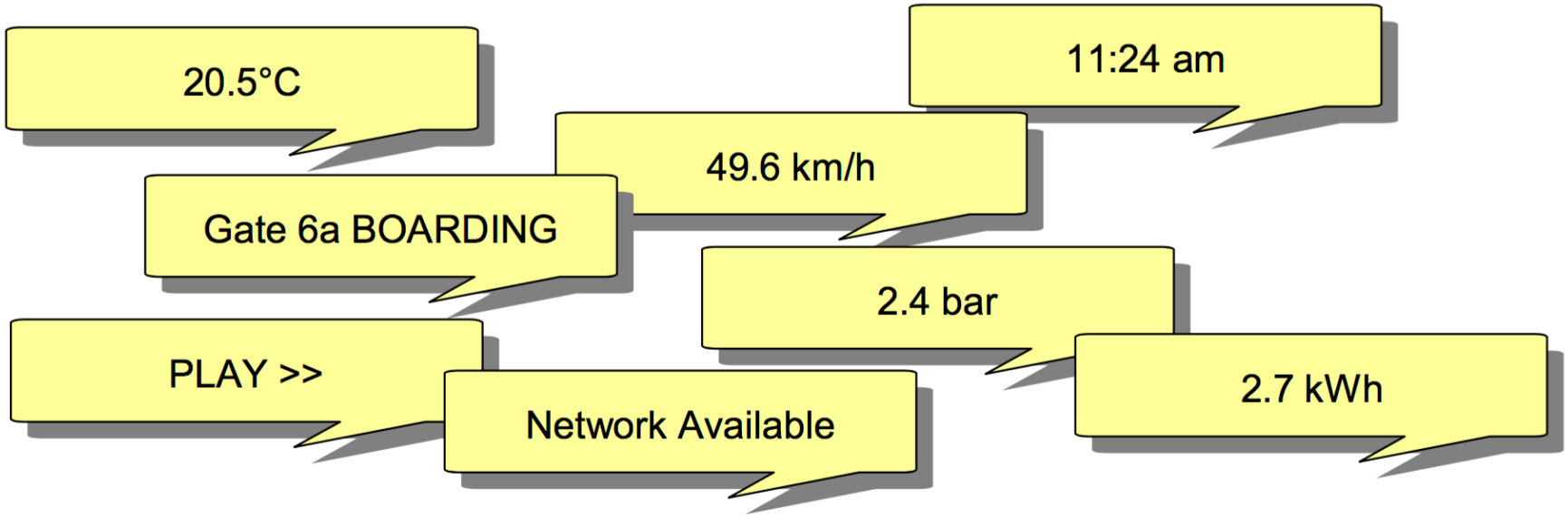
Specification

Implementation specific

BLE – fact sheet

- Data through put is missing
  - Data throughput is not a meaningful parameter for BLE
  - It does not support streaming
  - It has a data rate of 1Mbps, but is not optimized for file transfer.
- It is designed for sending small chunks of data (exposing state).

BLE – Exposing state

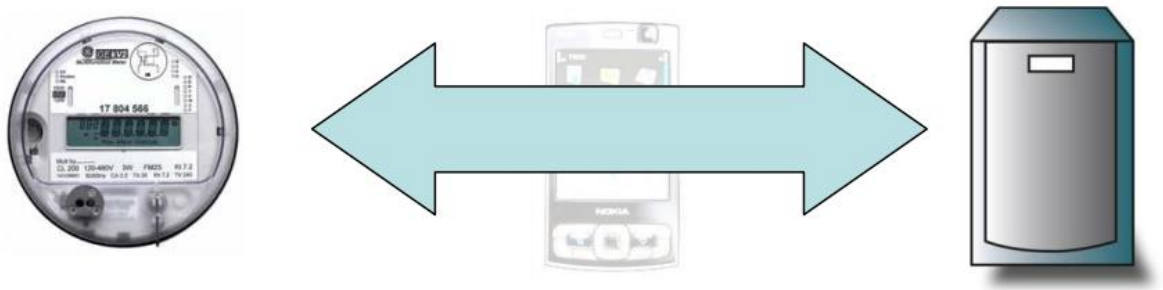


- It's good at small, discrete data transfers
- Data can be triggered by local events
- Data can be read at any time by a client
- Interface model is very simple (GATT)
- Not targeted for Human I/O

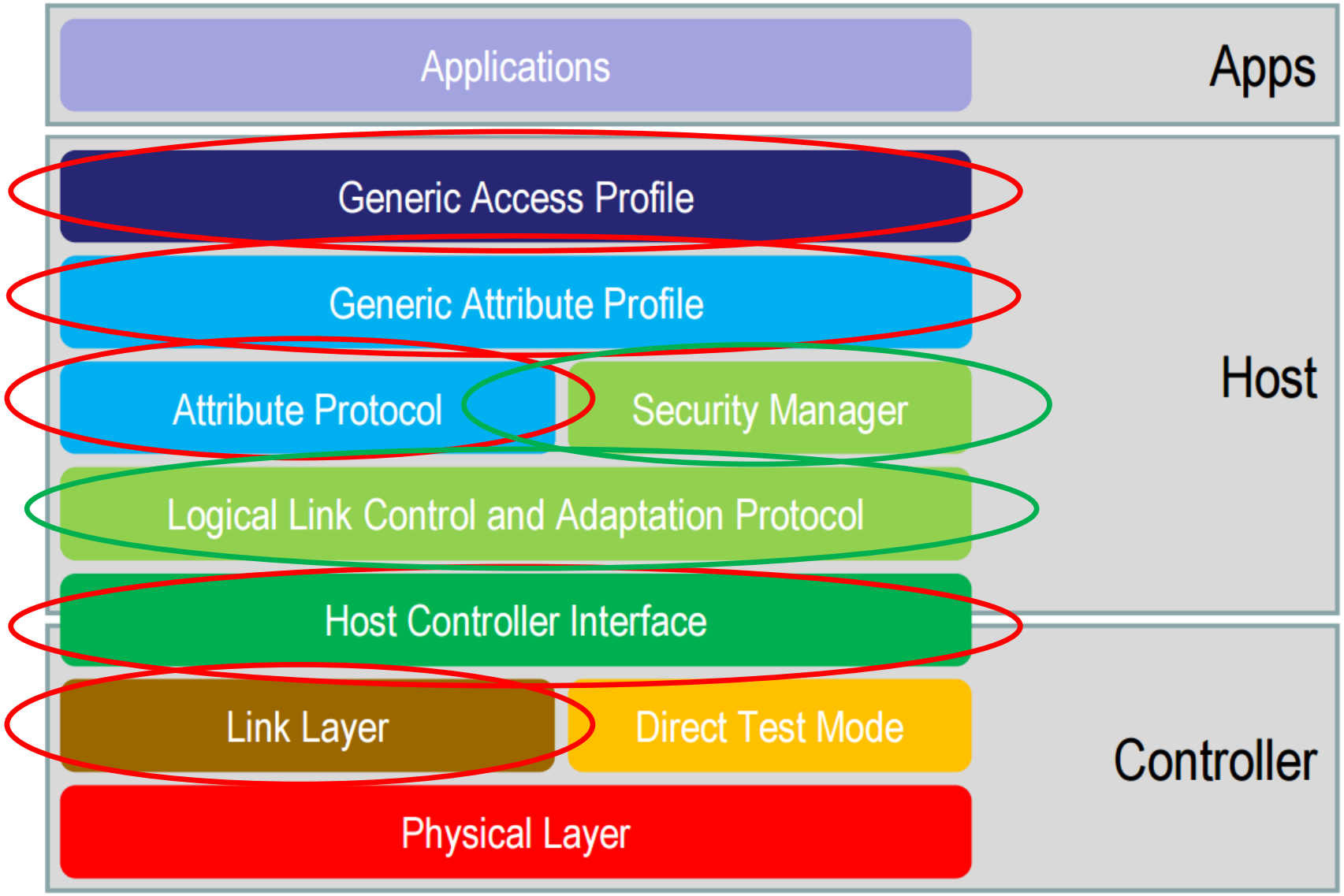
Bluetooth Low Energy is about ~~generic~~ gateways

Currently, hardware or vendor specific

- Devices that support Bluetooth low energy Gateway functionality provide a transparent pipe from a device to an IP address
- Middleware at the IP address can access the device directly as if it were a collector talking to it locally
- The Gateway device plays no part other than in acting as a pipe

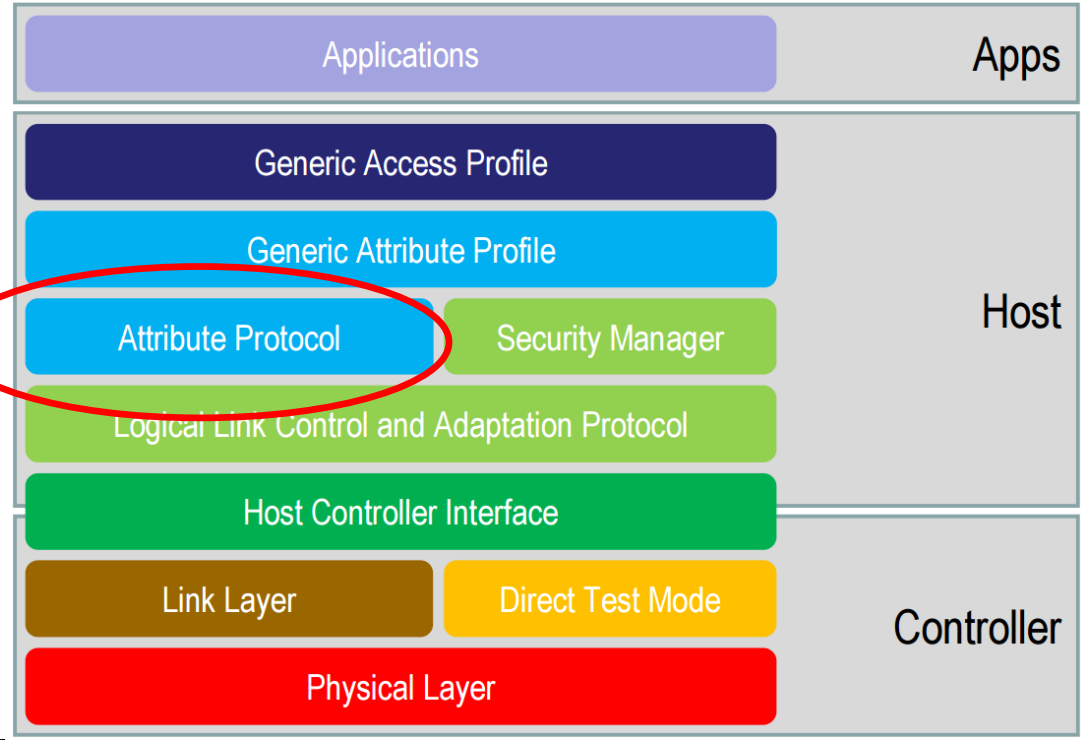


BLE: Stack


Applications
Apps
Generic Access Profile
Generic Attribute Profile
Attribute Protocol
Security Manager
Logical Link Control and Adaptation Protocol
Host Controller Interface
Host
Link Layer
Direct Test Mode
Physical Layer
Controller

BLE: Attribute Protocol

- Only one protocol which is used for name discovery, service discovery, and for reading and writing information required to implement a given use case
- Defines a set of rules for accessing data on a peer device
  - The data is stored on an attribute server in "attributes" that an attribute client can read and write
  - The client sends requests to the server, and the server responds with response messages



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Bluetooth Low Energy: The Developer's Handbook By Robin Heydon

BLE: The Attribute Protocol

- Defines six types of messages:
  - Requests sent from client to the server
  - Responses sent from the server to the client in reply to request
  - Commands sent from the client to the server that have no response
  - Notifications sent from the server to the client that have no confirmation
  - Indications sent from the server to the client
  - Confirmations sent from the client to the server in reply to an indication
- Communications can be initiated by both the client and the server