ECEN 5823-001
Internet of Things Embedded Firmware

Lecture #7

18 September 2018

Be Boulder.

University of Colorado Boulder

I2C assignment demo

Agenda

- Class Announcements
- Reading Assignment
- Managing Energy Modes Rubric
- Quiz 3 Review
- Bluetooth Classic

Class Announcements

- Quiz #4 is due at 11:59 on Sunday, September 23rd, 2018
- Homework #2: I2C Load Management Assignment is due on Saturday, September 22nd, at 11:59pm

Lessons Learnt

- "Meta Fixation"
  - A term I learned taking my freshman psychology class in 1981
  - The tendency to take a successful solution in the pass and apply it to a similar application sometime later
    - Tendency implies not take a look for possible alternative solutions
    - Similar implies not exact
- Example:
  - Utilize a solution developed for the Leopard Gecko on the Blue Gecko

Additional reading that can be helpful

ANALOG DEVICES

AN-686 APPLICATION NOTE

One Technology Way • P.O. Box 9106 • Norwood, MA 02062-9106 • Tel: 781/329-4700 • Fax: 781/326-8703 • www.analog.com

Implementing an I²C® Reset

By Jim Greene

The I²C bus is a high integrity, robust serial bus used for control purposes in many systems. The primary components that make up a system are at least one master and one slave. Under normal conditions, everything works fine; however, it is the abnormal conditions that generate problems. Two questions present themselves when a problem arises: Is the problem device or system related, or some combination of both? What, if anything, can be done about it?

state. It is the only method of ending a transmission after the reception of a byte.

Byte Width—all bytes are 8 bits wide, with no exceptions.

Message Length—technically there is no maximum length for a message; a minimum message consists of 2 bytes (an address and a data byte).

Wait State—this condition is rarely used, but is worth understanding. Once the SCL line is low, a device may

Class Announcements

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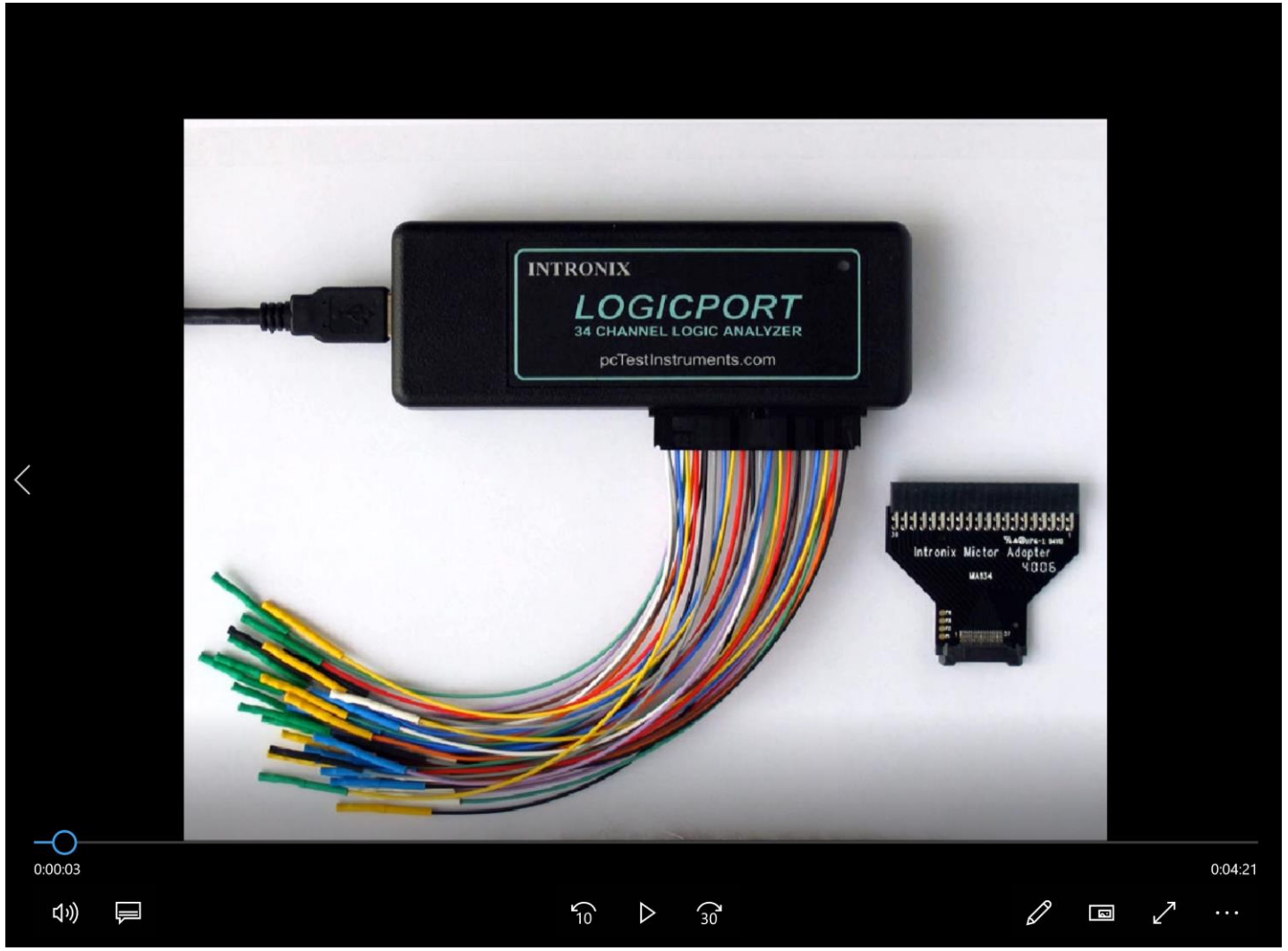
- I2C operation update:
  - The Blue Gecko reference manual specifies that even if the I2C peripheral is not busy, that an abort command is required!
  - 18.3.2 Enable and Reset
    - The I2C is enabled by setting the EN bit in the I2Cn_CTRL register. Whenever this bit is cleared, the internal state of the I2C is reset, terminating any ongoing transfers. Note: When enabling the I2C, the ABORT command or the Bus Idle Timeout feature must be applied prior to use even if the BUSY flag is not set.

Lessons Learnt

- A corollary to “Meta Fixation” lesson learnt:
  - The difficult parts of a design will most likely work and work well, but the more simpler circuits are the ones that will not.
- The difficult circuits most likely work because that is where you spend the vast majority of your focus, energy, and time to engineer to work
- To prevent this corollary from happening, it is important to have others review your design

Bus Analyzer tutorial on Canvas – Course Material



Reading Assignment

ECEN5823-001, -001B – Reading List
Internet of Things Embedded Firmware
Week 4

Below is a list of required reading for this course. Questions from these readings plus the lectures from January 16th onward can be on the weekly quiz.

1. Circuit Cellar: Electronic Compass: Tilt Compensation & Calibration
   http://cache.nxp.com/files/sensors/doc/reports_presentations/ARTICLE_REPRINT.pdf

2. AN607: Si70XX HUMIDITY AND TEMPERATURE SENSOR DESIGNER 'S GUIDE
   https://www.silabs.com/Support%20Documents/TechnicalDocs/AN607.pdf

3. AN580: Infrared Gesture Sensing
   https://www.silabs.com/Support%20Documents/TechnicalDocs/AN580.pdf

4. Bluetooth blog: An Intro to Bluetooth Mesh Part 1 by Martin Woolley
   http://blog.bluetooth.com/an-intro-to-bluetooth-mesh-part1

5. Bluetooth blog: An Intro to Bluetooth Mesh Part 2 by Martin Woolley
   http://blog.bluetooth.com/an-intro-to-bluetooth-mesh-part2

ECEN 5023-001, -001B

Fall 2018

Managing Energy Modes Rubric

Managing Energy Modes Rubric

1. Total points for this exercise is 10 points
    a. 5.0 pts for the questions
    b. 5.0 pts of the code

2. Question scoring. Max score is 5.0 pts.
    a. Question 1: EM0
        i. Period average current: 4.5 – 5.2mA (0.4 pts)
        ii. Current LED off: 4.4 – 5.1mA (0.4 pts)
        iii. Current LED on: current in (ii) plus 0.40 to 0.55mA (0.2pts)
    b. Question 2: EM1
        i. Period average current: 3.0 – 3.9mA (0.4 pts)
        ii. Current LED off: 3.2 – 3.8ma (0.4 pts)
        iii. Current LED on: current in (ii) plus 0.40 to 0.55mA (0.2 pts)

Quiz 3 Review

What are the valid communication standards between different Bluetooth devices? (select all that apply)

- [ ] Classic to Dual-Mode in Bluetooth Classic
- [ ] Dual-Mode to Dual-Mode in Bluetooth LE
- [ ] Single-Mode to Classic in Bluetooth LE
- [ ] Single-Mode to Single-Mode in Bluetooth LE

Quiz 3 Review

Using the Blue Gecko data sheet and reference manual, what would be the lowest sleep mode that the Blue Gecko could enter after enabling the I2C as an I2C master and perform I2C operations after a successful BlockSleepMode()?

(Use the enumerations EM0, EM1, EM2, EM3, or EM4)

Quiz 3 Review

Slaves on the I2C bus can pause communications to give them time to process information by _____ the SCL line.

Quiz 3 Review

To save energy, Bluetooth LE uses only 3 radio frequencies for discoverability out of the 40 radio channels.

- ○ True
- ○ False

Quiz 3 Review

If the maximum count of the LETIMER0 is 65,536, what would the minimum LETIMER0 LFXO prescaler need to be to enable the LETIMER0 to count to 12 seconds based on the LFXO set to the frequency of 32,768 to interrupt on the underflow condition only when 12 seconds have past.

What count would be required to be stored in the LETIMER0->CNT register to equal 12 seconds based on the above prescaler which is indicated upon an underflow event?

Quiz 3 Review

Which device is the primary power source in a BLE device while in sleep mode?

- The coin-cell battery
- The capacitance

Quiz 3 Review

At what temperature is a coin-cell battery capacitor assisted power source more important?

- 25C
- 70C
- 105C
- 0C

Quiz 3 Review

Which device is the primary power source in a BLE device while the radio is active?

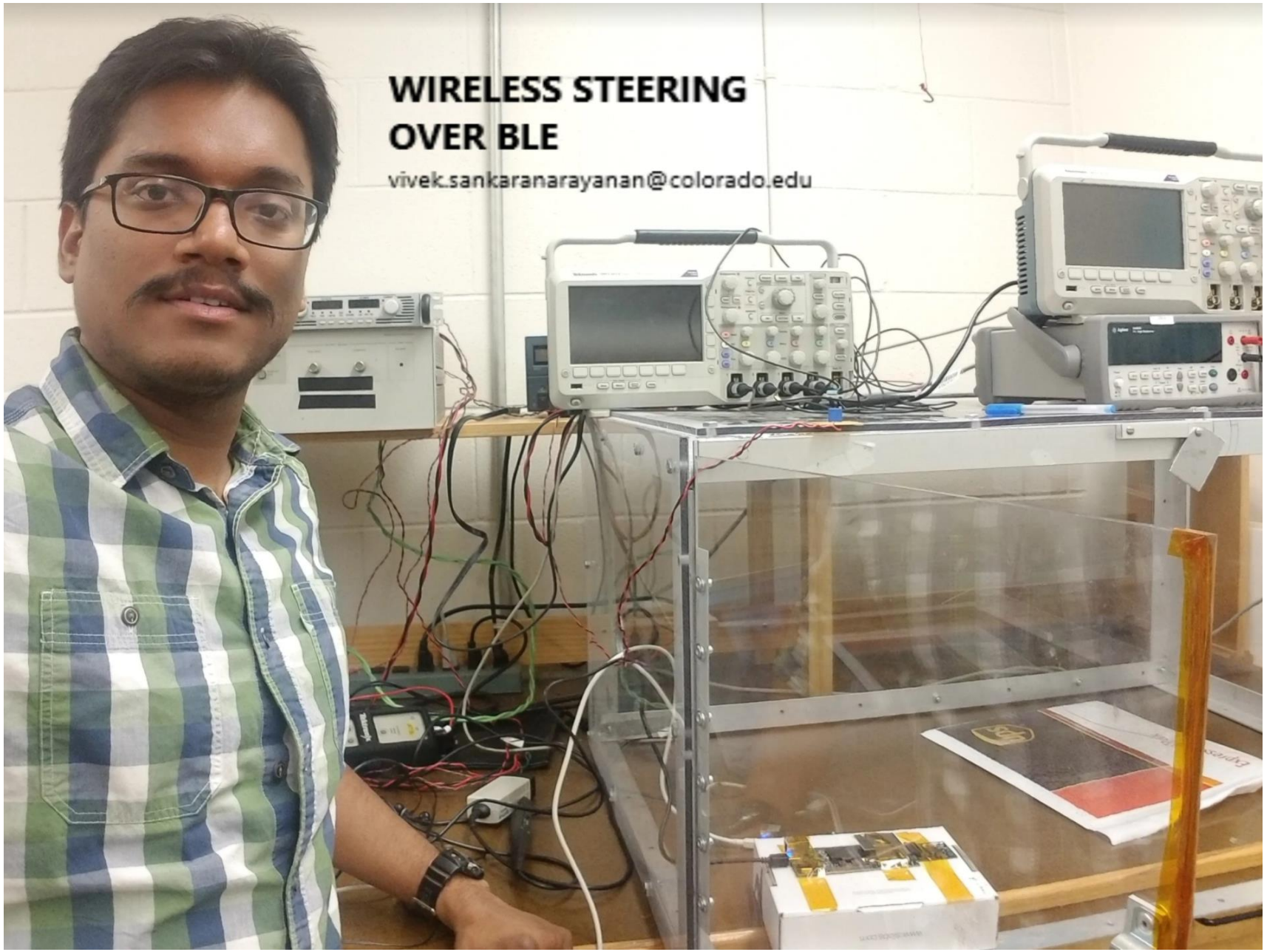
- The capacitance
- The coin-cell battery

Quiz 3 Review

Bluetooth Classic is architected for applications that need to transmit a few bytes of data every second.

- True
- False

Sample course project



Other Digital Serial Bus Considerations

- I2C
  - Advantage: Addressable address bus up to 128 devices
    - Supports multiple sensors without increasing GPIO pin utilization or additional MCU resources
- SPI
  - Disadvantage: Requires additional GPIO pin for Chip Select for each additional addressable device
- UART
  - Disadvantage: Requires additional UART resource and GPIO pins for each device

Bluetooth Classic

- Perceived User Scenarios
  - Connection to peripheral devices
    - Wireless means no cables, and most likely battery operated
    - Low power wireless a must
  - Ad-hoc Networking
  - Bridging of Networks
    - Bluetooth has targeted lower cost, lower bandwidth applications
    - WiFi/WLAN designed for higher bandwidth, longer range, and larger devices

Bluetooth Classic – Technology Summary

- Globally free spectrum
  - 2.45 GHz, ISM band
  - GFSK modulation
  - Frequency Hopping (1600 hops/sec)
- Range
  - 10m piconet (0dBm)
  - 100m optional (+20dBm)
- Data and voice capable (1Mbps)
  - Full duplex: 478kbps, Asymmetric 721kbps
- Secure
  - Authentication
  - 128 Encryption
  - Limited Signal range 0 – dBm
  - Pseudo Random hop sequence

Bluetooth Classic - What does Bluetooth provide?

- Provides point-to-point connections.
- Provides ad-hoc networking capabilities.
- Bluetooth specification details how the technology works.
- Bluetooth Profiles detail how specific applications work to ensure interoperability.

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

Bluetooth Classic - Master /Slave Bluetooth Network Topology

- 1 master and up to 7 slaves
- Basic network structure – Star Network

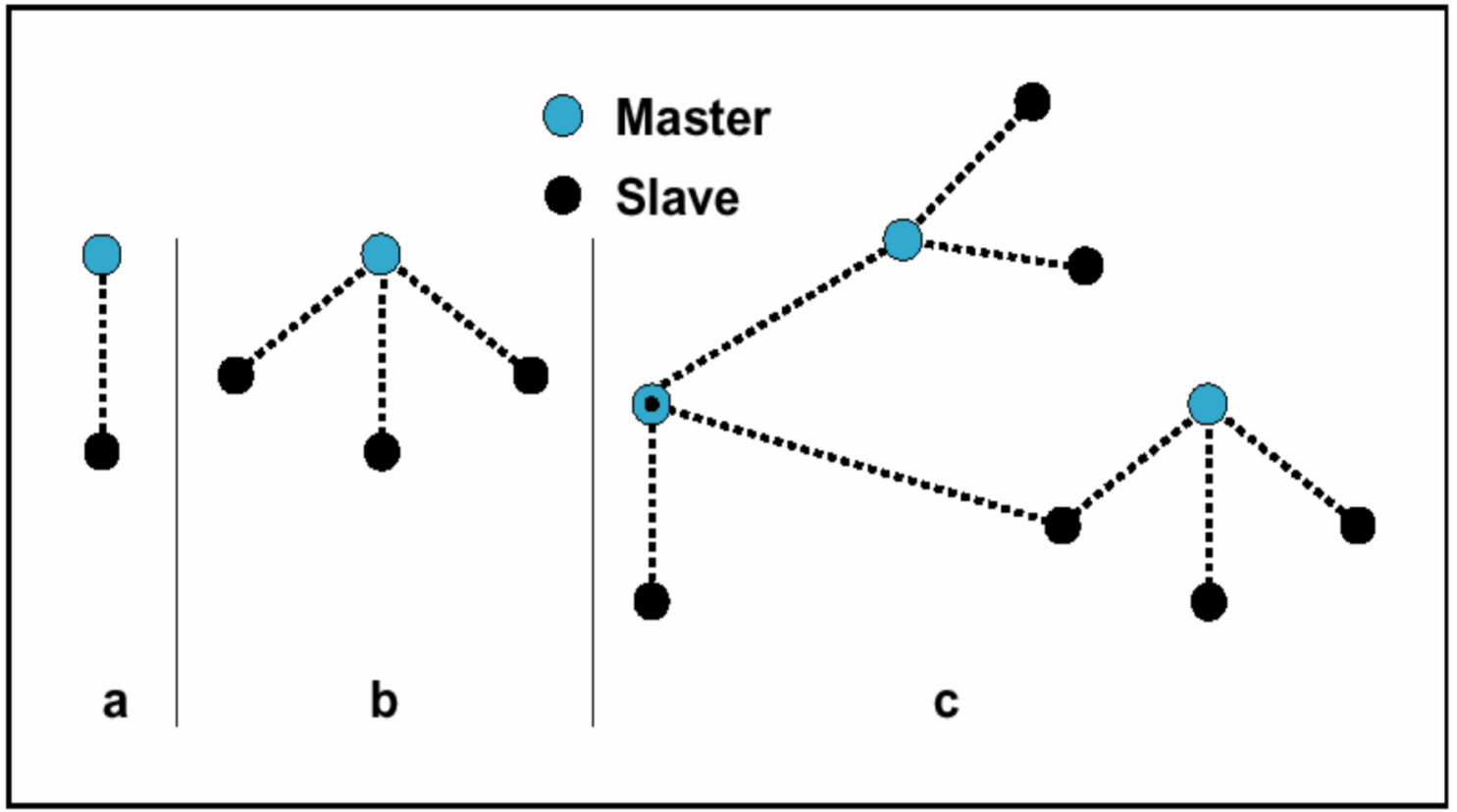
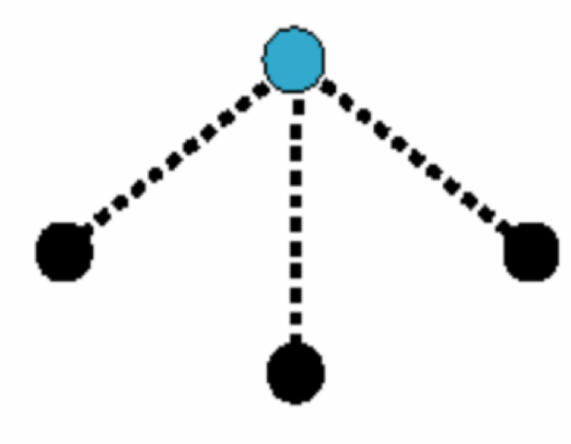


Figure 1.2: Piconets with a single slave operation (a), a multi-slave operation (b) and a scatternet operation (c).

Bluetooth Classic – Point-to-Point (Piconet)

- Two devices locate each other
- Form a connection and transfer data
- “Wireless cable replacement” scenario
- The device that initiates the connection is called the Master
- Any other devices the Master is connected to are referred to as Slaves.

Bluetooth Classic – Point-to-Multi-Point (The Piconet)



- Two devices create a point-to-point connection
- A third device comes into range
- The new device is discovered
- It is added to the piconet and data can be transferred
- Up to seven slaves can be connected to one master
- Slaves cannot pass data to other slaves without sending through the master
- The master defines the timing for the piconet
  - Each Piconet has a unique hopping pattern
- Piconets can collide if their unique hopping sequences overlap in a frequency band
  - Due to Ad-Hoc networking and not an infrastructure network!

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

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 WiFi, 802.11x, 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

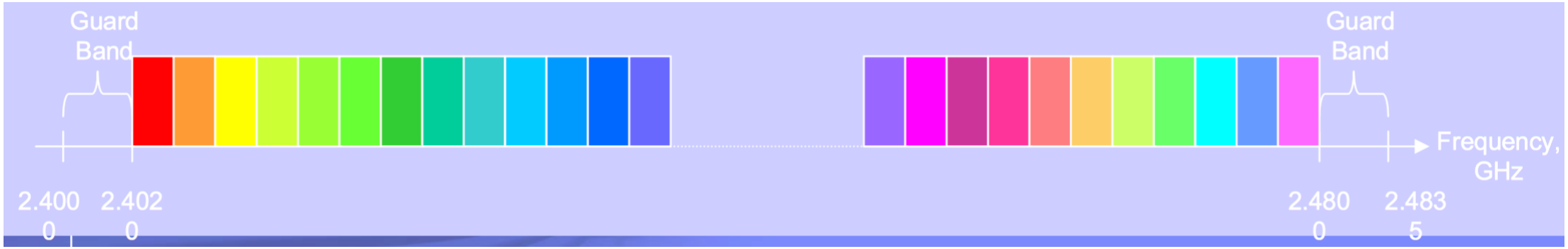
- Bluetooth uses the 2.4GHz ISM frequency band
- The Industrial, Scientific and Medical (ISM) band is an unlicensed band, I.e. any one can use it provided they don't exceed certain power constraints
- The 2.4GHz ISM band is unlicensed all over the world which makes Bluetooth the only completely world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



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?

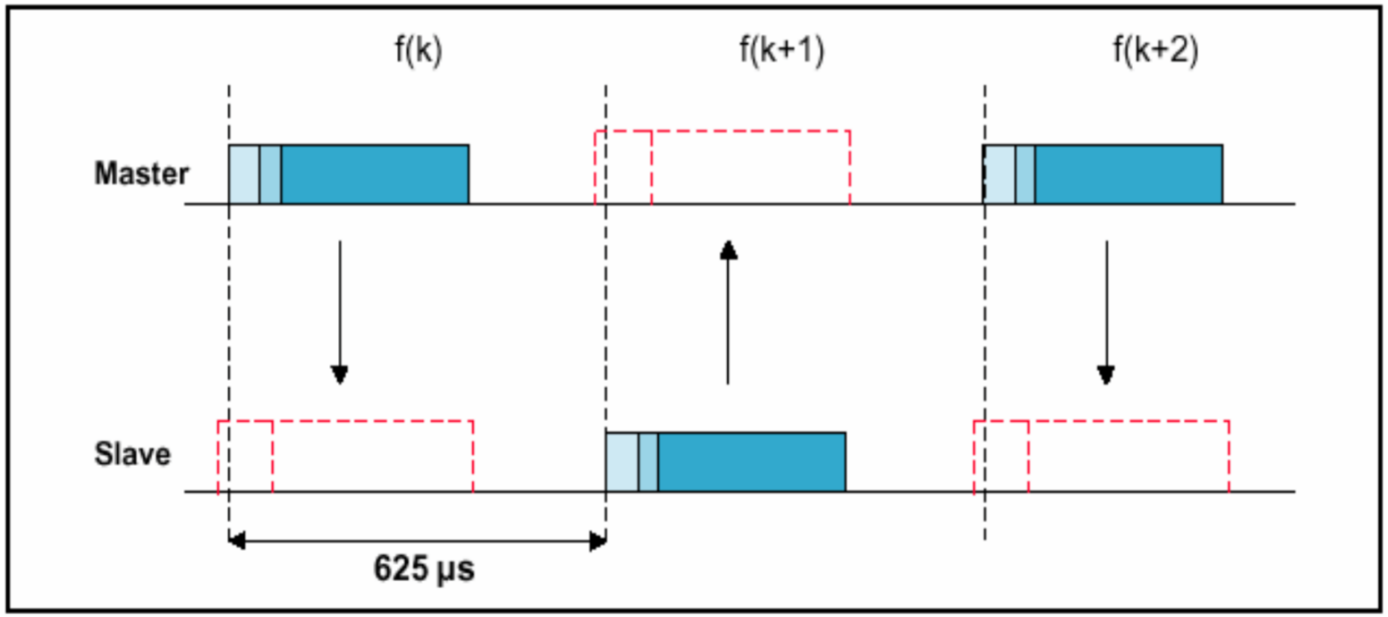


Figure 2.1: TDD and timing

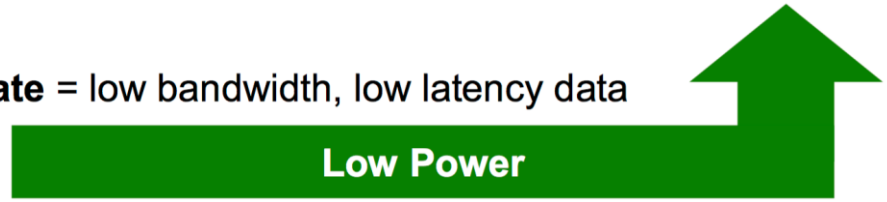
IBM Bluetooth Wireless Technology presentation @ 2003
http://www.ncsysadmin.org/meetings/0506/slides.pdf
Mobile Communications: Second Edition by John Schiller

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 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