ECEN 5823-001
Internet of Things Embedded Firmware

Lecture #1

28th August 2018

Be Boulder.

University of Colorado Boulder

Introductions (continued)

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Agenda

- Class Announcements
- Reading list
- Quiz #1 assigned
- Course Survey assigned
- ESE lab rules
- Course Goals and Expectations
- Project and Tool demo
- IoT and Covered Topics
- Where is the money in IoT?
- IIoT versus IoT

Class Announcements

- Quiz #1 is due at 11:59 on Sunday, September 2nd, 2018
- Course survey is due at 11:59 on Sunday, September 2nd, 2018

ESE lab, ECEE 1B24

Student Commitment as a Lab User

I understand that *

- [ ] No food or drinks are allowed in the lab at the computer stations. Water bottles may be brought in but left off of the computer stations. Food should be eaten before entering the lab.
- [ ] I have an obligation to help keep the labs, computers, and equipment in good working condition.
- [ ] My login and access card are for my personal use only. I will not disclose this information or give my access to another person.
- [ ] If I bring guests into the lab I am responsible for their behavior and they must leave the lab with me.
- [ ] I will not prop open any doors, or grant entry to any unknown person(s).
- [ ] I will act professionally in the lab, treating my teaching assistants and fellow students with respect, and I will adhere to the University of Colorado's Honor Code and Student Code of Ethics
- [ ] I am required to give priority use of lab stations to students who have scheduled class time.

Technical Resources Care

I agree that *

- [ ] I will treat all the hardware, software, computers and equipment as if I've paid for them, because, in part I have through my student fees.
- [ ] I am responsible for repair or replacement if I damage the equipment through improper use or handling.
- [ ] I am personally responsible if I check out or get access to specialized equipment, and I will replace the equipment if it is lost, stolen, or broken.
- [ ] I will report any broken or malfunctioning equipment, hardware, software, or computers to my Teaching Assistants and the department's laboratory administrators through ecehelp@colorado.edu
- [ ] I will not attempt to change the attachment of keyboards, mice, monitors, and network cables to their computers without first alerting ecehelp@colorado.edu
- [ ] If I violate this policy, I may, at the department's discretion, lose access to any or all ECEE labs.

- Must apply for card access via web form
  - http://bit.ly/ECEELabs

Reading List

Below is a list of required reading for this course. Questions from these readings will be on the weekly quiz.

- Silicon Labs' "Manage the IoT on an Energy Budget" https://www.silabs.com/Support%20Documents/TechnicalDocs/manage-the-iot-on-an-energy-budget.pdf
- Silicon Labs' Energy Optimization Application Note, AN0027 http://www.silabs.com/Support%20Documents/TechnicalDocs/AN0027.pdf
- Silicon Labs' Simplicity User Guide, AN0822 http://www.silabs.com/Support%20Documents/TechnicalDocs/AN0822-simplicity-studio-user-guide.pdf
- Designing Bluetooth Low Energy Smart Applications with Bluetooth Mesh - Part 1 https://www.digikey.com/en/articles/techzone/2018/mar/designing-bluetooth-low-energy-smart-applications-part-1?utm_medium=email&utm_source=tnl&utm_campaign=37650_TNL1808A&utm_content=article1learnmore_US&utm_cid=8792648&mkt_tok=eyJpIjoiTXpnd05UQmpOMk5rTW1SaiIsInQiOiJrWUNOZVhkbXNJR3VSaHZwTzlkYTM0NjVcL1wvand4VU1WZ0Q3bldaVGlFVjl2ckRtSFFVYVR5cGpNam81bWt1NlwvQTZ0cldFVGNcL1JDWlpVWDVqVk5kQkpkKzBNUnFGanBRcDBGa3RrNnJReHM4VFlYR0pQRkZ6Q2xxa3NOak9LSkUifQ%3D%3D

Rationale

- To meet the demands of the fast growing markets of mobile computing and Internet of Things, students graduating the ESE program will be able to make appropriate engineering decisions based on their product's ecosystem to design products that meet their solution's energy, product lifecycle, and communication requirements while taking into consideration the appropriate security requirements.
- Accenture estimates that the Industrial Internet of Things (IIoT) could contribute by 2030 $14.2 trillion US dollars in world output. For the US, it could contribute $6.1 to $7.1 trillion US dollars by 2030 which could result in the US GDP growing an additional 2.3% more than currently forecasted.
- The growth of IIoT solutions disrupt many markets as these markets transform from service economies to outcome economies.
  - Per the World Economic Forum, an Outcome Economy is a marketplace where businesses compete on their ability to deliver quantifiable results that matter to customers rather than just selling a product or service. The outcome could be measured energy savings, increased product yields, or increased uptime.
- As the IIoT transforms business, it will also transform the labor market as many lower skilled jobs are replaced by intelligent systems that require higher skilled workers to maintain and make creative decisions.

Description and Content

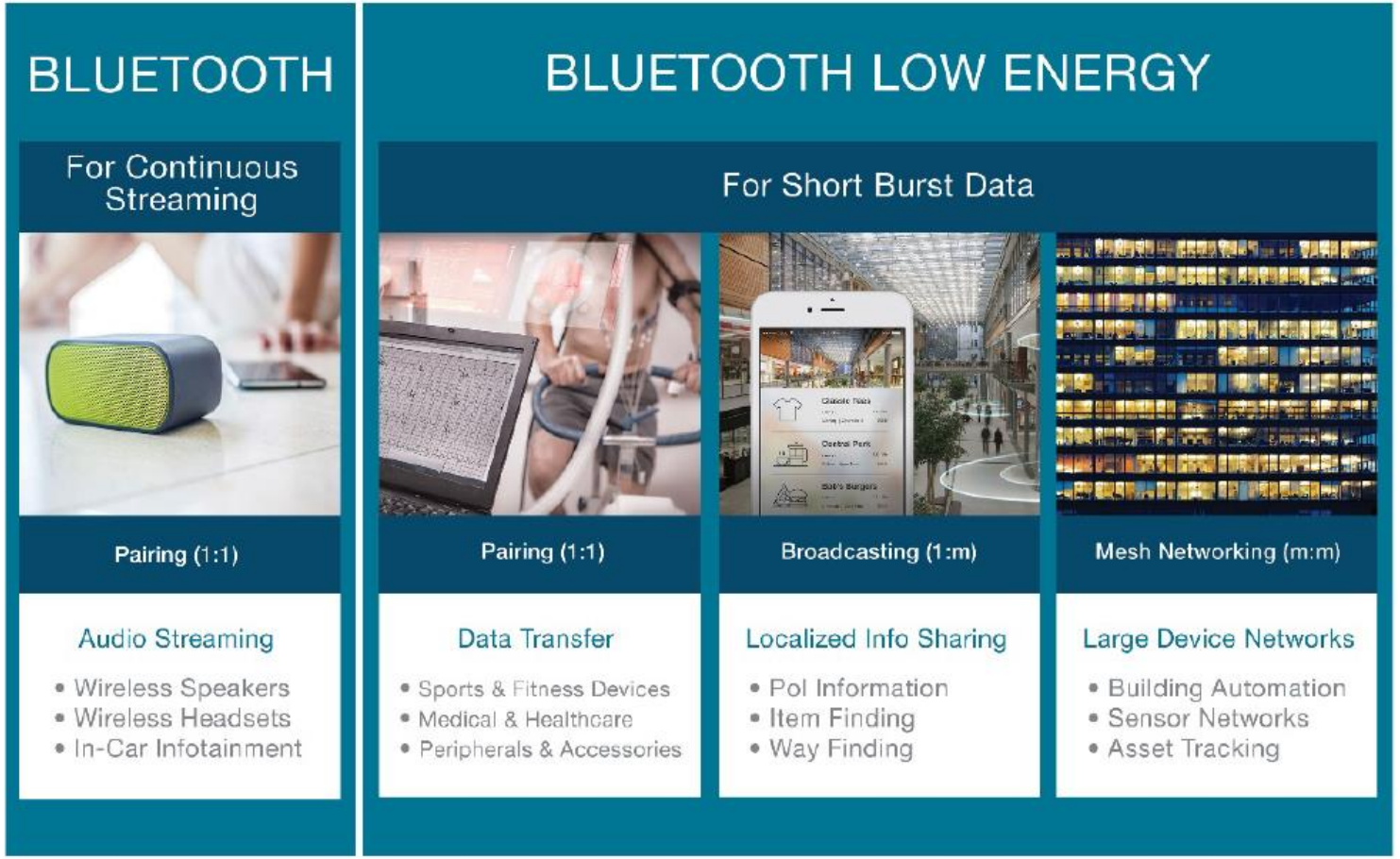
- The course material will convey both technical and industry requirements to enable proper engineering architectural decisions as well as implementation. The course will explore through weekly and course projects low energy firmware design concepts, extending FLASH memory data retention reliability, Bluetooth, and developing a secure manufacturing process of micro controller firmware and encryption keys. The programming assignments will be "coding to the metal" to control individual micro controller peripherals and utilizing them in the most energy efficient ways.
- What is "coding to the metal?"

Description and Content (continued)

- Topics covered:
  - Low Energy versus Low Power design
  - Wireless Computing tradeoffs: Available resources, application, infrastructure
  - Interrupt or event driven firmware
  - Wireless standards: applications and tradeoffs
  - Bluetooth Smart: protocols, profiles, and services
    - Client, Server
  - Bluetooth Mesh: Provisioning, and Client, Services, and Control Models
    - Relay, Proxy, Low-Power, Friend nodes
  - Designing for product lifecycle of 20+ years
  - Designing embedded systems with security in mind
  - Project that will incorporate Bluetooth communications, low power sensors, and low energy design concepts


1:02 / 1:26

Bluetooth Mesh



Development of Bluetooth standard from Bluetooth BR/EDR (left) to LE and Bluetooth mesh (right)

Expected Outcome

You will be able to …

- Develop event based "code to the metal" firmware to extend the battery life of Internet of Things applications using a scheduler
- Debug low level / machine centric firmware
- Select the wireless protocol that best addresses the end application requirements
- Develop an interoperable Bluetooth Smart device/peripheral product
- Develop a Bluetooth Mesh proxy, relay, friend, and low power node
- Match the appropriate memory technology to the end application
- Extend flash data retention to 20+ years to meet the requirements of industrial applications

Class structure

- On average, each week the lectures will be covering both theory and concepts as well as implementing low energy design principles in hardware/firmware
- Tuesday will be focusing on theory and concepts while on Thursday the lecture will be split between theory and concepts with low energy design practices
- Most weeks, these low energy design principles will then have a weekly homework programming assignment
- These assignments will not require the purchase of lab equipment or the use of a lab, but will require access to a computer running Windows, Mac OS, or Linux OS

Class structure (continued)

- Quizzes
  - Will be published, put on Canvas, by the end of Sunday to Tuesday and will be due by the end of the following Sunday
  - Two attempts will be available for each quiz with best grade used for scoring and there will be 15 minutes to complete each attempt
  - There may be in-class quizzes where 1 attempt is given and administered via Canvas, paper, or some other media
  - No quiz will be dropped from the total
- Homework assignments
  - Will generally be assigned at Thursday's lecture and will be due the end of day the next Wednesday
  - No assignments will be dropped

Quizzes work different in Canvas

- For questions with Multiple Answers, it only an score the following:
  - + credit for all correct answers
  - - credit for all incorrect answers
  - 0 credit for all questions not answered
  - It may be best to leave a question blank instead of guessing
- For multi-fill in the blank, I will grade them as the following
  - + credit for all correct answers
  - 0 credit for all incorrect answers
  - It may be best to answer/guess the answer

Class structure (continued)

- Prerequisites
  - Knowledge of assembly and C programming, digital logic design, and embedded computer architecture
  - Students should have had at least one course in each of these subjects
  - ECEN 5813, Principles of Embedded Software, is a recommended prerequisite
  - Students should also have experience using a microcontroller Integrated Development Environment (IDE) and its associated tools including its debugger and register views
- Expectations
  - Lectures, Programming Assignments/Course Project, Readings, and Quizzes will require on average 10-14 hours per week of work
  - For on campus students, class attendance is expected. For distant learners, live video streaming and videos will be made available

Development boards provided for ECEN 5823

- Silicon Labs' Blue Gecko STK6101C starter kit. The description can be found at http://www.silabs.com/products/development-tools/wireless/bluetooth/bluegecko-bluetooth-smart-module-wireless-starter-kit

Note: These development boards will be provided to the students at no charge, but the boards will be required to be returned upon completion of the course project demo

Homework programming assignments

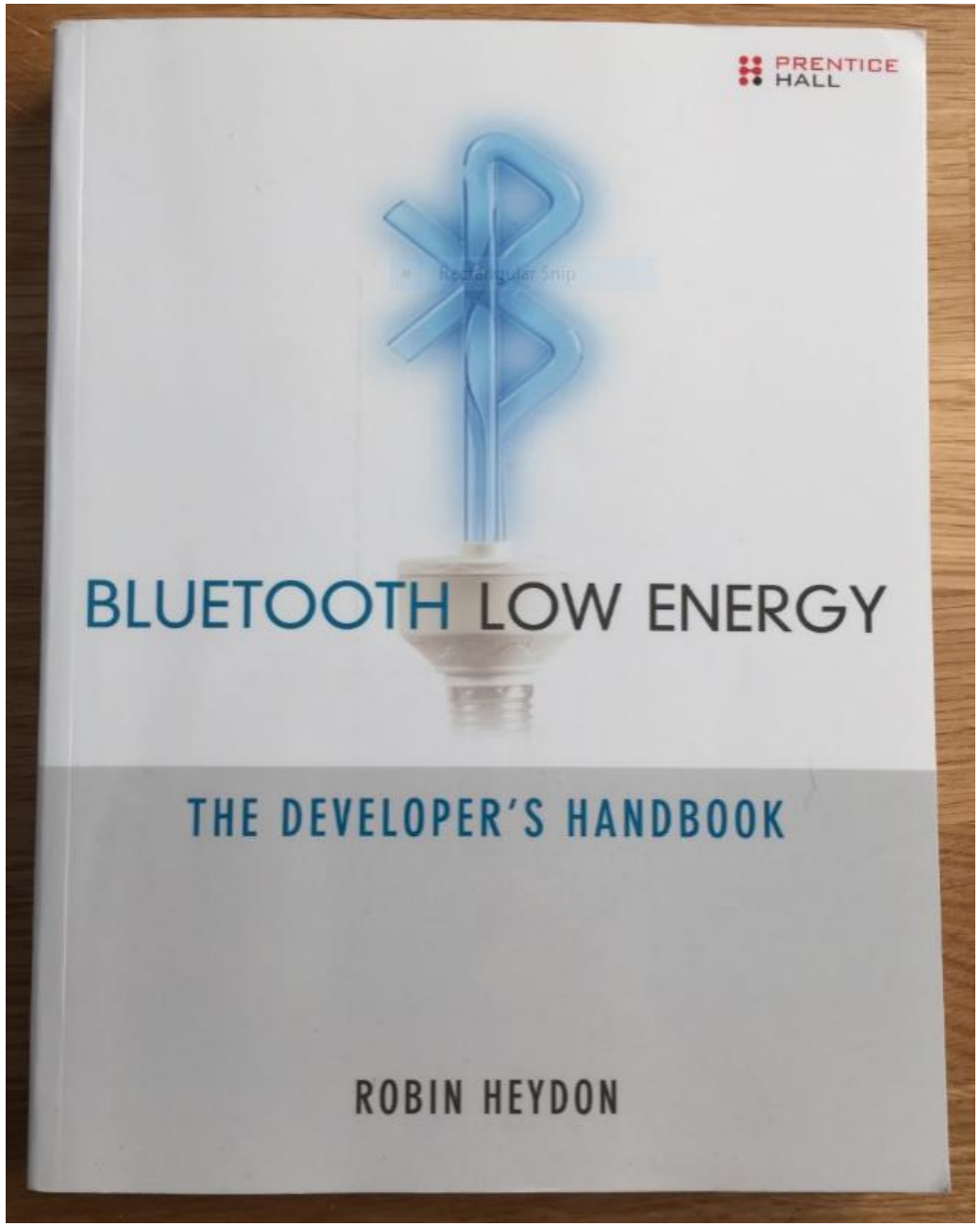
- The homework programming assignments will be designed to build upon previous assignments
- By the start of the course project, the students will already have experienced with event driven firmware as well as low energy firmware concepts (700 – 1000 lines of code)
- Homework assignments (subject to change):
  - Exercise: Introduction to the Simplicity development environment
  - #1: Interrupt based programming using LETIMER including developing a sleep() routine and comparing energy profiles across different energy modes
  - #2: Develop a low power routine using I2C and the Si7021 temp/humidity sensor including load power management

Homework programming assignments

- Homework assignments (continued):
  - #3: Using the Blue Gecko to transmit the Blue Gecko temperature to the Silicon Labs' Andriod/IoS demo application.
  - #4: Bluetooth Smart client (tentative)
  - Demo: Implement Bluetooth Mesh Lighting services
  - #5: Implement a Bluetooth Mesh Friend or Low Power node (tentative)

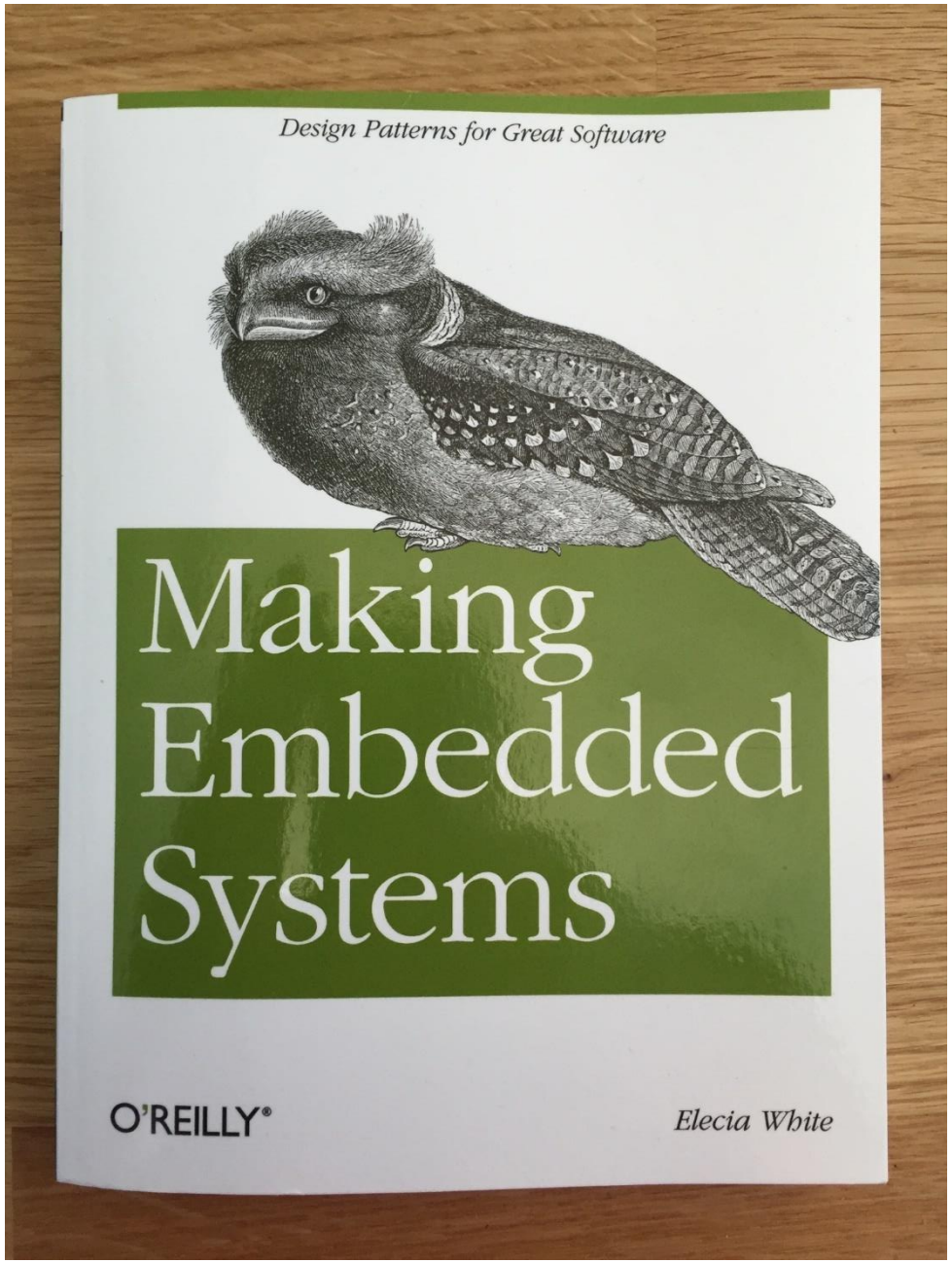
Bluetooth Mesh Lighting Model demo

Required book for Bluetooth portion of course



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

Recommend book for this course for students who would like an embedded C reference book



Course Project

- There will be one course project that will combine the low energy design principles and Bluetooth radio taught throughout the course utilizing the Silicon Labs' Blue Gecko development Kit. The course project will include developing a product proposal that will include a Bluetooth Smart or Bluetooth Mesh device in a cohesive application such as home security, retail, etc..
- This project will include developing code as a Bluetooth Smart or Bluetooth Mesh device providing the associated services for external sensors. The project/product will need to include Bluetooth Client Profile and Services implementing notifications, indications, as well as attribute writes/reads, and attribute commands or a Bluetooth Mesh network including a Proxy, Friend, and Low Power nodes supporting Publishing/Subscribing and unicast addressing.
- The course project will be further defined as updates to the Bluetooth Mesh stack becomes available.

General Attendance

Going forward, the following will be in effect for ESE program courses, as reported by ESE course instructors:

1) Students enrolled but not engaging in an ESE course for the first week will be moved to the end of any existing waitlist.

2) Students enrolled but not engaging in an ESE course for the first two weeks will be administratively dropped from the course.

Per the Registrar, administrative drops can occur for two reasons:

- nonattendance or
- missing required course prerequisites or corequisites.

Academic Integrity

- Any suspected violations of the Honor Code will be submitted to our Honor Code Office. **Students found responsible for any violation by our faculty and the Honor Code Office will earn an automatic F in the course.** We take these issues seriously and have a responsibility to all students who uphold the Honor Code, and to the highest industry standards for which we are preparing students.
- If you have any questions whatsoever regarding what collaboration is permissible in the course, consult your instructor directly before proceeding.
- By default, you are expected to turn in your own original work and cite any and all portions you did not create. All aspects of the Honor Code apply.

CU Honor Code violation example

- If on a quiz, you obtain the answer from screen shot or information from a previous semester. Is this a violation of the CU Honor Code?
  - Yes. You are not doing your own work.
- If on a quiz, you obtain the answer from a screen shot or information from another student willingly. Who is in violation of the CU Honor Code?
  - Both the student who copied and the student who willing provided you the answer.

CU Honor Code violation example

- Feedback from the ESE Industrial Advisory meeting
  - It will come out through the interview process that you do not know the material
    - Resulting in no job offer
- If discovered that you cheated on the job, the following could occur:
    - Will be fired immediately
    - Will be banned permanently from employment at all locations

Evaluation and Grading Procedures

- The course grade will be based on in-class participation, homework assignments, quizzes, course project, and 2 exams. The grade proportions are as follows:
  - Homework and Class Participation 20%
  - Course projects 25%
  - Quizzes 15%
  - Final and Mid-term Exam 40%
- Grading will be based on total points accumulated from each of these areas. Assignment of grades will be based on an absolute scale of:

A : 93+
A-: 90
B+: 87
B : 83
B-: 80
C+: 77
C : 73
C-: 70
D+: 67
D : 65
Fail: < 65

Evaluation and Grading Procedures

- Upon the professor's discretion, assignment of grades can be based on both absolute and relative standards if it would be helpful to the overall class. To receive an A grade in this assignment of grades option, a student must show mastery of the material and need to acquire more than 90% of the points possible. A student earning less than 50% of the points possible will be given a failing grade. In between these marks, grades will be assigned on a curve using a mean and standard deviation method.
- **Make-up Exam Policy:** No make-up exams are given except for medical or other similar hardships where advanced arrangements are made with the instructor; or in case of non-selective medical emergencies with physician's note or documentation. Otherwise, failure to take the exam at the scheduled time will result in a zero grade in the exam.

Canvas

- Syllabus and other course material will be inside the “Course file” folder
- Lectures, Homework and Reading assignments will be located in their weekly folder
- Quizzes will be administered through the Canvas course site
- Homework assignments will be delivered via “drop box” on Canvas

Slack

- A Mobile Computing and Internet of Things Security Slack team will be set up for this course
- The Slack channels/forums will be a valuable place to look for answers, ask questions, and to help others. As you work through problems, you may find documentation errors or lack of documentation that may have already been solved in the forum. The forum will be proctored by the instructor and course TAs. As in all engineering projects, collaboration and sharing knowledge of issues and solutions is very productive.
  - Please feel free to create new threads and help out others!


WE LEARN...
10% of what we read
20% of what we hear
30% of what we see
50% of what we see and hear
70% of what we discuss
80% of what we experience
95% of what we teach others
-William Glasser

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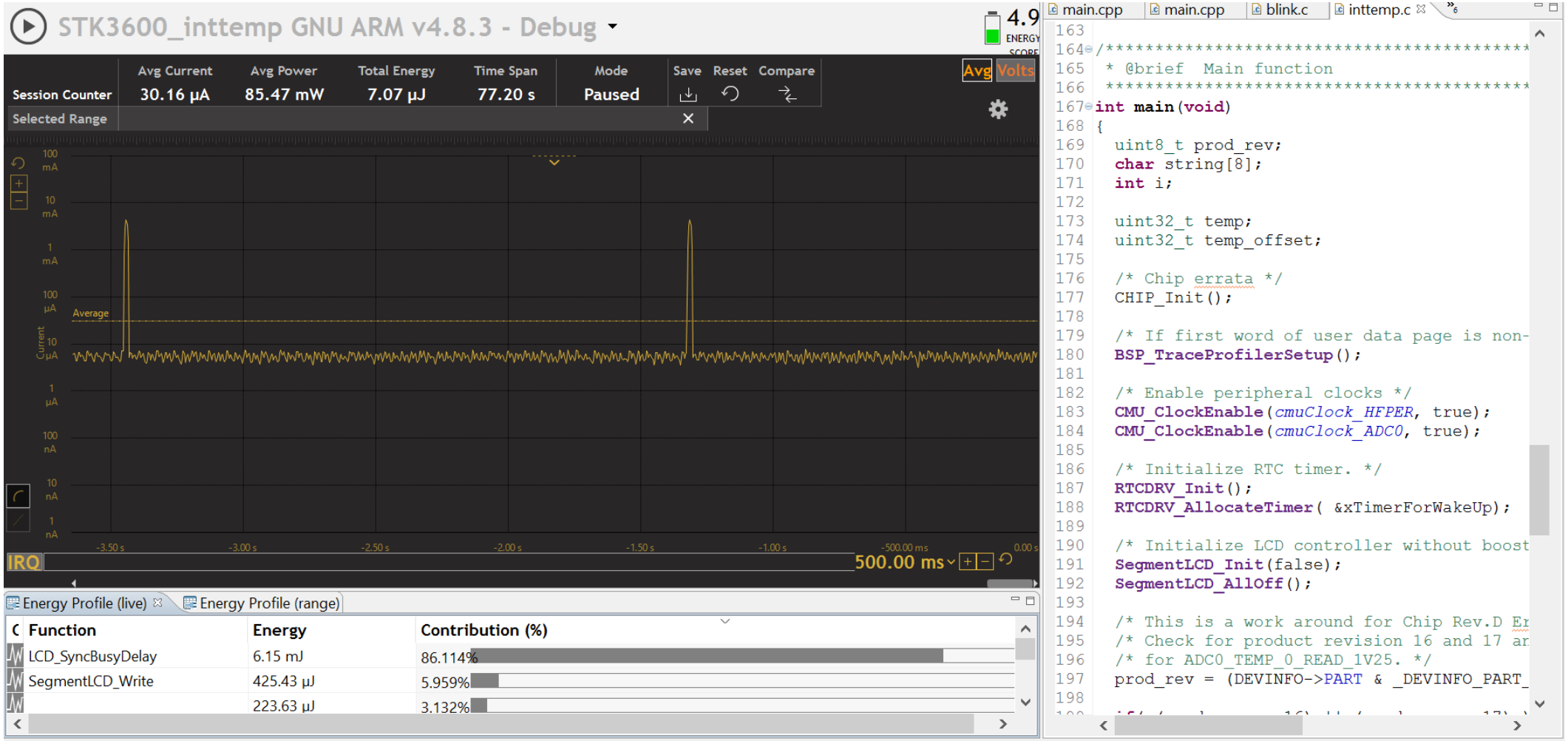
  - Please feel free to create new threads and help out others!
- In the coming week, everyone in the class will be invited to the course Slack team

Energy Profiler demo

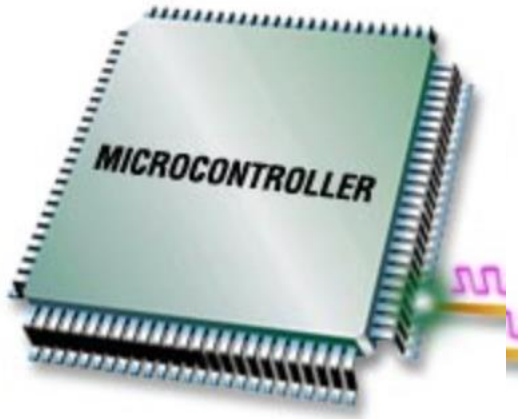


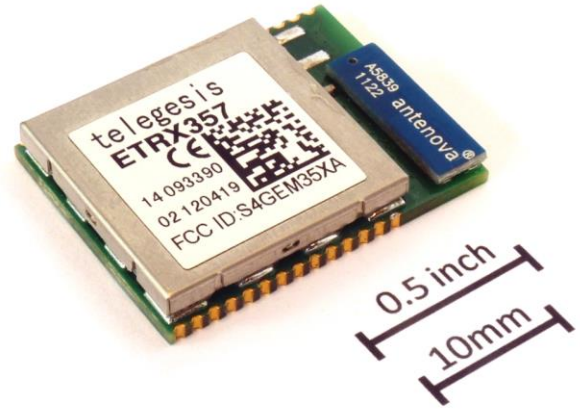
IoT computing for ECEN 5823

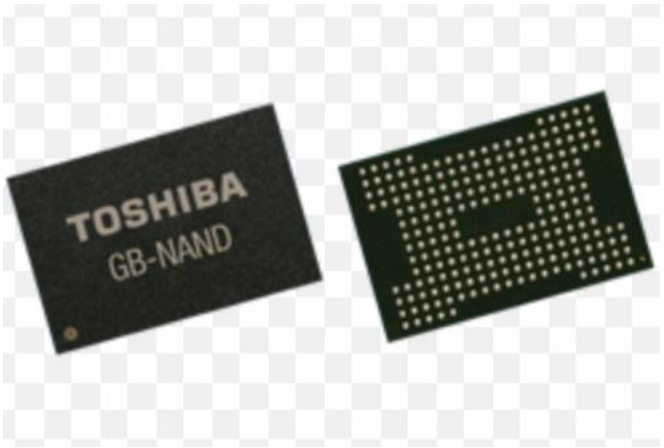
What are key factors in designing for IoT?

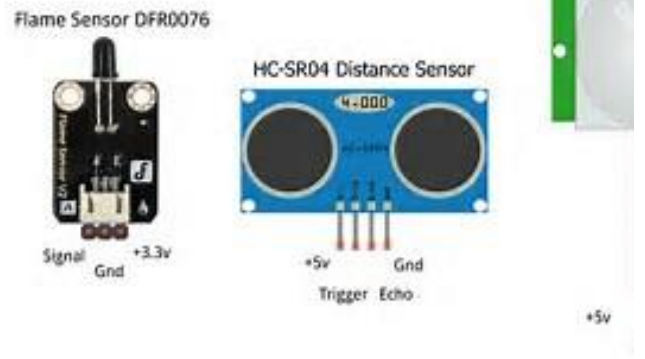
- Battery Life
  - Everyone would like their smart phone or watch to last longer.
- Communications (Radios)
  - Different standards for different industries
- Operating Temperature
  - Benign or harsh
- Physical Durability
  - Survive the accidental drop
- Warranty
  - Needs to match the market segment sold into
- Security
  - As these devices are becoming more prevalent, security needs are growing

What components will this class focus on?







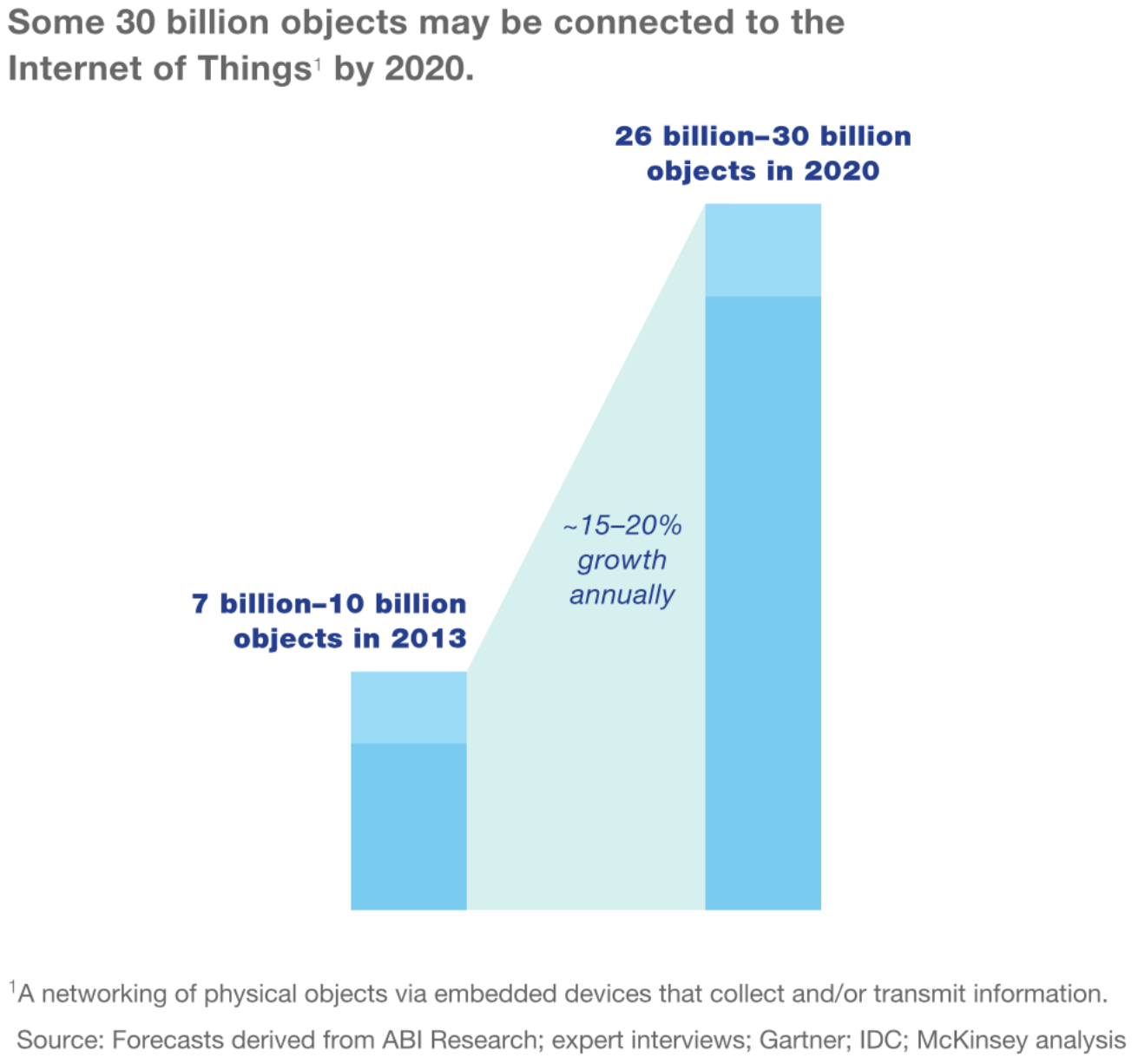


What is an IoT device?

- The **Internet of Things** (**IoT**) is the network of physical objects or "things" embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data.[1] The Internet of Things allows objects to be sensed and controlled remotely across existing network infrastructure,[2] creating opportunities for more direct integration between the physical world and computer-based systems, and resulting in improved efficiency, accuracy and economic benefit.[3][4][5][6][7][8] Each thing is uniquely identifiable through its embedded computing system but is able to interoperate within the existing Internet infrastructure. Experts estimate that the IoT will consist of almost 50 billion objects by 2020.[9]

Growth will generate new problems and create new opportunities

- What will be some of the issues as the number of connected devices grows to 30+ billion and beyond?
  - Capacity?
    - Bandwidth
    - IOPs
  - Security



Where is the money in (consumer) IoT?

- Selling an IoT device?
  - Fitbit, Garmin Running watches, Bluetooth door locks, ….
  - A recent InfoWorld article proclaims "The Internet of Things is not paying the rent." In it, Adobe's VP of Mobile Matt Asay cites data from Vision Mobile and McKinsey & Co. to point out that "less than 10 percent of IoT developers are making enough to support a reasonably sized team," and that "developers need to get real about what they're selling and to whom," which "probably involves a 'dull' enterprise-facing business." This begs the question, how do you make money in the IoT?

Where is the money in (consumer) IoT?

- IoT-as-a-Service?
  - Home/Security Automation, Smart Sprinkler Systems, ….
  - Internet of Things companies could potentially transition away from one-off IoT platform sales and into business models that allow for accretive growth by means of data and feature monetization. In this cloud-based approach, companies could establish service plans or provide additional features to end users similar to how your cell phone or cable company operate, generating recurring streams of income that continue to flow after the initial platform sale (or perhaps, giveaway) to help offset ongoing maintenance, service, and support costs.

Industrial Internet of Things (IIoT)

- The Industrial Internet of Things will combine the reach of the Internet with a new ability to directly control the physical world, including machines, factories, and infrastructure.
- Growth of “digital labour” in the form of smart sensors, intelligent assistants, and robots will transform not just the ability to manage and operate their assets, but also transform the skills and mix of the workforce.
- New jobs will be created in the form of IIoT device and robot designers, internet optimization, and software engineering to create the ecosystem or fabric for these IIoT devices to operate.

Outcome Economy

- Manufacturing economy: A marketplace based on producing and selling products
- Service economy: A marketplace based on providing services rather than manufacturing or producing goods. (Cambridge dictionary)
- Outcome economy: A marketplace where businesses compete on their ability to deliver quantifiable results that matter to customers rather than just selling products or services, e.g. energy saved, crop yield or machine uptime. Delivering customer outcomes requires sellers to take on greater risks. Managing such risks requires automated quantification capabilities made possible by the Industrial Internet. (World Economic Forum)

Industry Internet of Things – Reliability example!

- Stupid phone tricks
  - https://www.youtube.com/watch?v=9tiVxTU3olg