EE542
Lecture 17: Internet of Things

Internet and Cloud Computing

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Final Project Discussion

- Requirements
  - Ten documents that support the validity and the value of your solution.
  - You must incorporate your custom xDot IIoT
  - You must incorporate AWS backend with Thingsboard IO
  - You must integrate AWS to analyze the data and respond (you may use simple analytics or ML)
- Final Project Proposal Slide Deck
  - Slide 1: Title and Team members
  - Slide 2: Summary of the real-world problem - why IoT is the best
  - Slide 3: How your hardware and software are going to be used
  - Slide 4: Schedule and Who is going to be doing what (as much detail)
  - Slide 5: List of References (at least 3, including websites and conference and journal papers – need a complete reference – summary of the evidence)

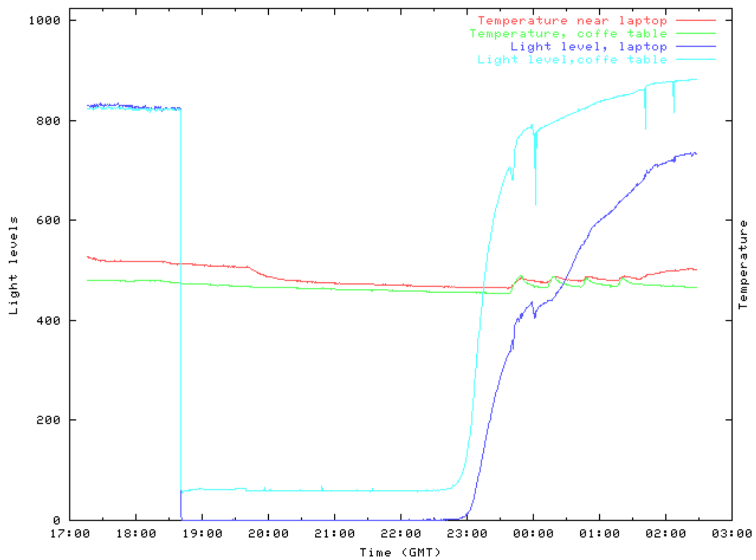
Course Schedule

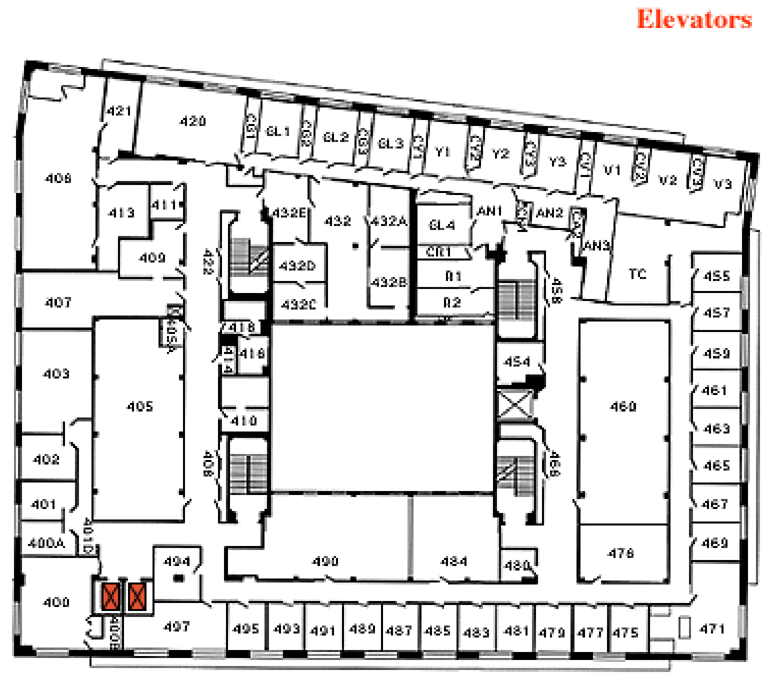
- Oct 18: Lecture IoT
- Oct 23: Lecture IIoT
- Oct 25: Machine Learning
- Oct 30: Large Language Model
- Nov 1: Power Estimation with ML
- Nov 8: Career Advice Lecture (Mandatory)
- Nov 17: Practice Final Presentation 1
- Nov 19: Practice Final Presentation 2
- Nov 22-26: Thanksgiving Break
- Nov 27: Final Project Progress Presentation 1
- Nov 29: Final Project Progress Presentation 2
- Dec 13: Final Project Demo Video

The Vision for Internet of Things

- Push out computers into the real world
- Billions of sensors and actuators
- Zero configuration
- Merging Cyberspace & Physical space

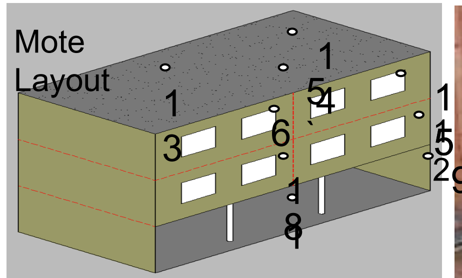
Energy Monitoring/Mgmt System



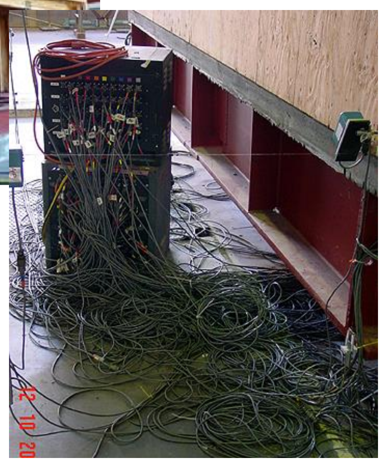


- 50 nodes on 4th floor
- 5 level ad hoc net
- 30 sec sampling
- 250K samples to database over 6 weeks

Structural performance due to multi-directional ground motions (Glaser & CalTech)

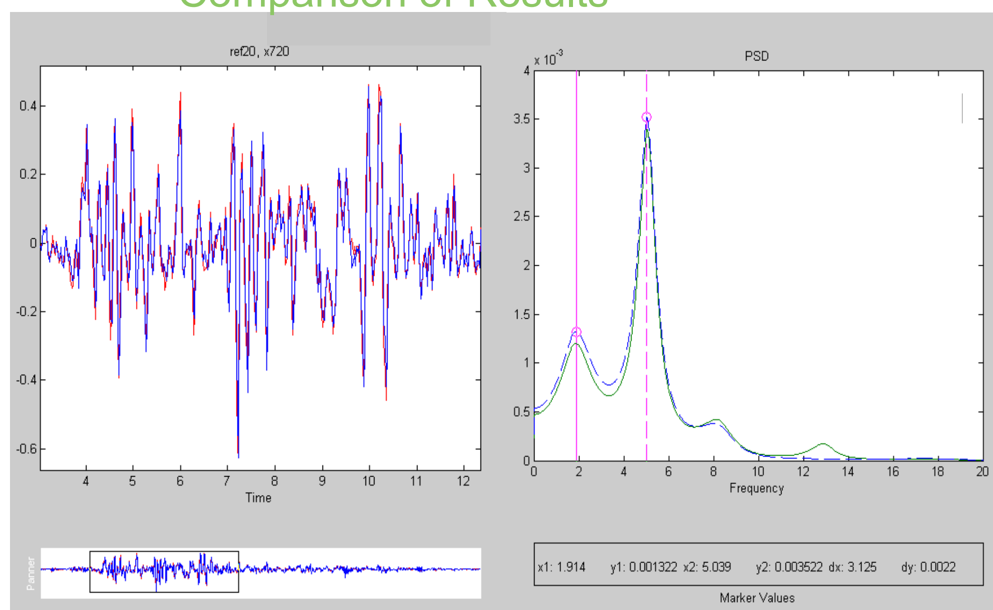


Mote infrastructure



Wiring for traditional
structural instrumentation
+ truckload of equipment

Comparison of Results



Network Algorithms

- Adaptive Routing
- Network Query Processing
- Distributed Data Aggregation
- Localization/Time Synchronization
- Power Management
- Compression
- Security

Node Requirements

- Low Power, Low Power, Low Power…
- Support Multi-hop Wireless Communication
- Self Configuring and Small Physical Size
- Programmable Processor
- Integrated Sensors
- Meets Research Goals
  - Operating system exploration
  - Enables exploration of algorithm space
  - Instrumentation
  - Network architecture exploration

System Architecture

- Node Architecture
  - Hardware architecture: how different hardware components interact with each other
  - Software architecture: how software pieces are put together for various functionalities
- Network architecture
  - How nodes interact through different topologies
  - How different protocols coordinate such interaction

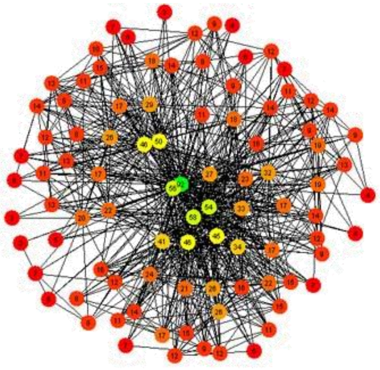
The Nodes

- Alternative Names
  - Wireless Sensor Network
  - Cyber-Physical Systems
  - Internet of Everything
- Sensing the Environment
  - Temperature, pressure, flow rate, et
  - Calibration

- Intelligent Data Processing
  - Data processing/forming
  - Detect problems locally or with neighbors
  - Proactively report exceptions
- Collaborative Networking
  - Does not require special infrastructure
  - Sensor nodes relay data for other nodes

Composition of Node

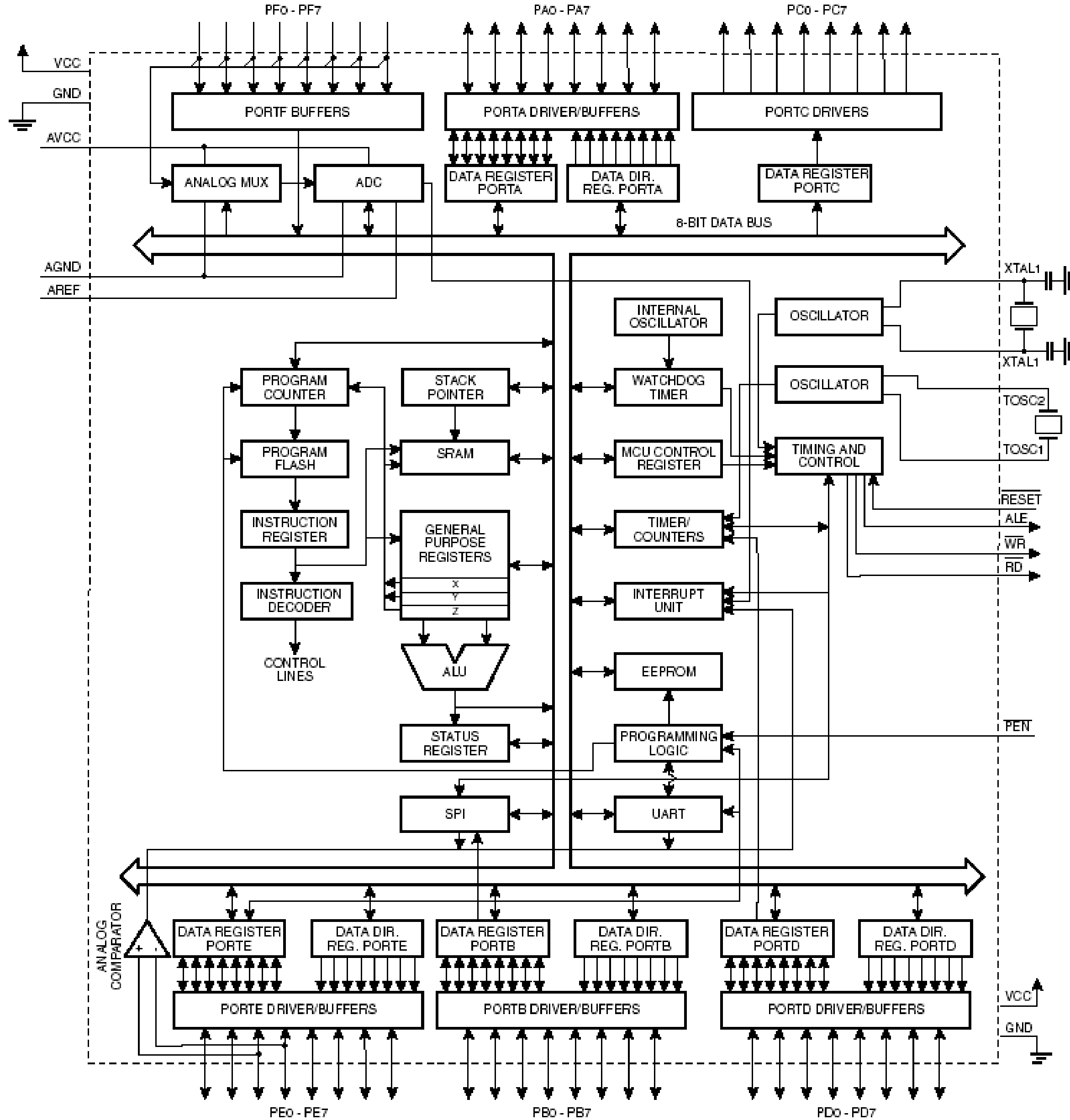
- Sensor
  - Detect/Measure Physical Phenomenon
  - Variety of Responses
  - Different Types of Sensors
- Network
  - Communications between the Nodes
  - Multiple Wired/Wireless Nodes
  - Data Distribution
- Intelligence
  - General Purpose Processor
  - Application Specific Logic
  - Software



The Processor

- Intelligence in the Node
- Important Questions
  - What's inside a microcontroller today?
  - What peripheral support?
  - How do you program one?
  - How much memory?
  - Programming platforms?

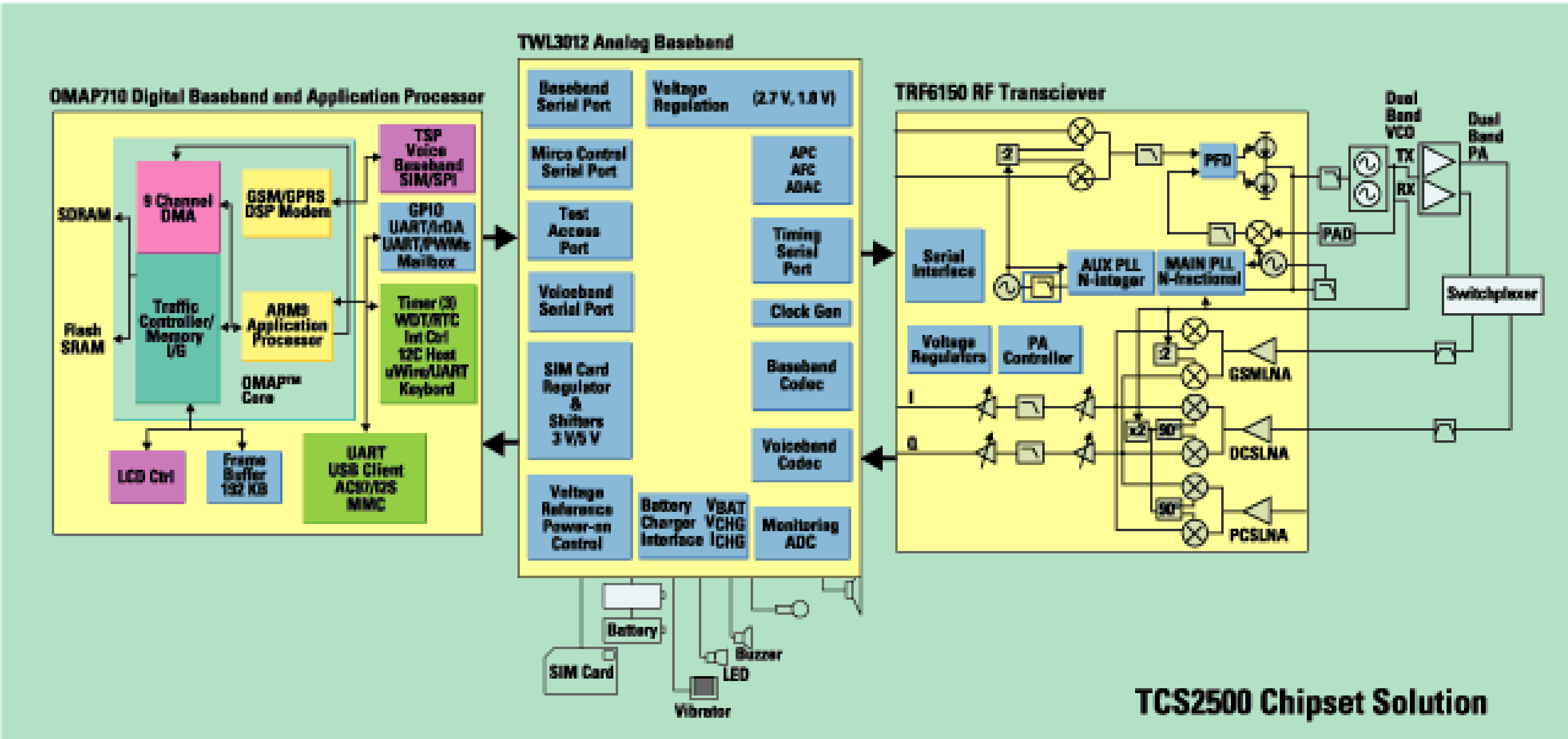
Figure 1. The ATmega103(L) Block Diagram



The Communication

- Major RF Devices
  - Cordless Phones Digital/Analog
    - Single Channel
  - Cellular Phones
    - Multi-channel, Base station controlled
  - 802.11
    - “wireless Ethernet”
  - Bluetooth
    - Emerging, low-power frequency hopping

Mobile Phone: An Ultimate IoT



Processor: ARM9, 120Mhz + DSP

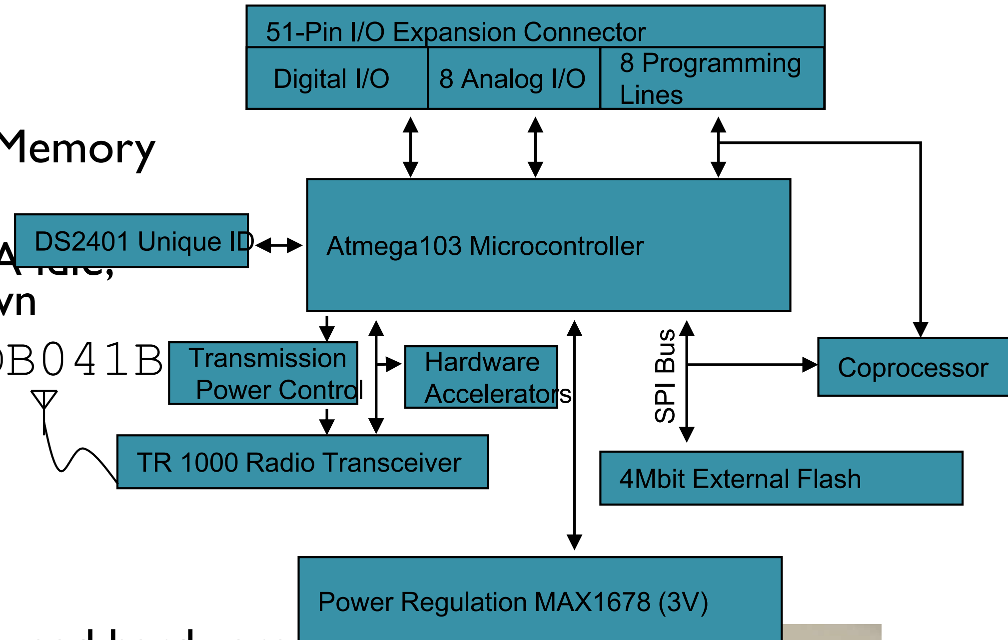
Communication: 270.833 kbps RF

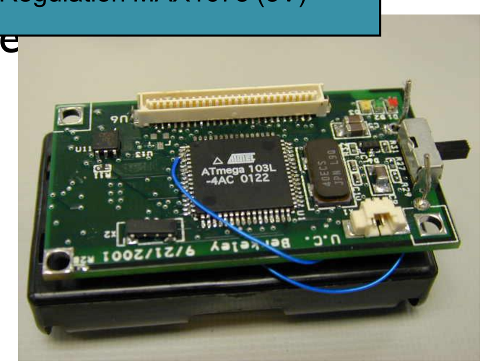
The Software

- TinyOS: Started the Academic Research Boom
- OS/Runtime model designed to manage the high levels of concurrency required
- Gives up IP, sockets, threads
- Uses state-machine based programming concepts to allow for fine grained concurrency
- Provides the primitive of low-level message delivery and dispatching as building block for all distributed algorithms

Early IoT: MICA

- Atmel ATMEGA103
  - 4 Mhz 8-bit CPU
  - 128KB Instruction Memory
  - 4KB RAM
  - 5.5mA active, 1.6mA idle, <1uA powered down
- 4 Mbit flash (`AT45DB041B`)
  - SPI interface
  - 1-4 uj/bit r/w
- RFM TR1000 radio
  - 50 kb/s – ASK
  - Communication focused hardware accele
- Network programmable
- 51-pin expansion connector
  - Analog compare + interrupts
- GCC based tool/programming chain





2xAA form factor Cost-effective power source

Constraints

- After Building Applications
  - System is highly memory constrained
  - Communication bandwidth is limited by CPU overhead at key times.
  - Communication has bursty phases.
- Where did the Energy/Time go?
  - 50% of CPU used when searching for packets
  - With 1 packet per second, >90% of energy goes to RX!

The Most Important Factor

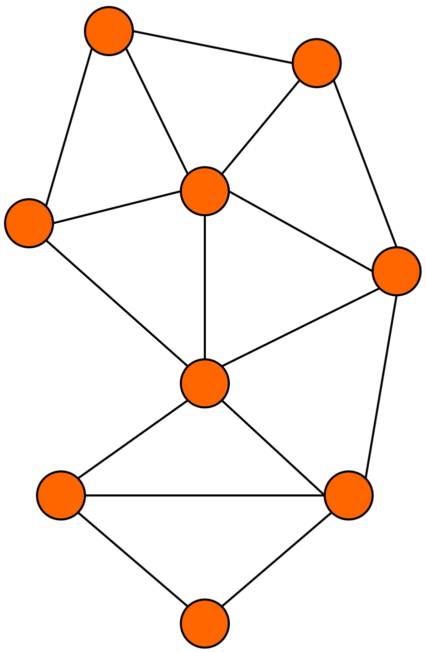
- POWER, POWER, POWER
- A Decade of Research: 90s-2000
  - Borrowed concepts from Distributed Systems
  - ALL with targeted focus on low power use
- Minimize Power for the Same Result?!?
  - Communication: the biggest power consumer
  - Then processor
  - Then peripherals/sensors

Important Services in IoT

- Localization
- Data Aggregation
- Time Synchronization

Sensor Network Localization

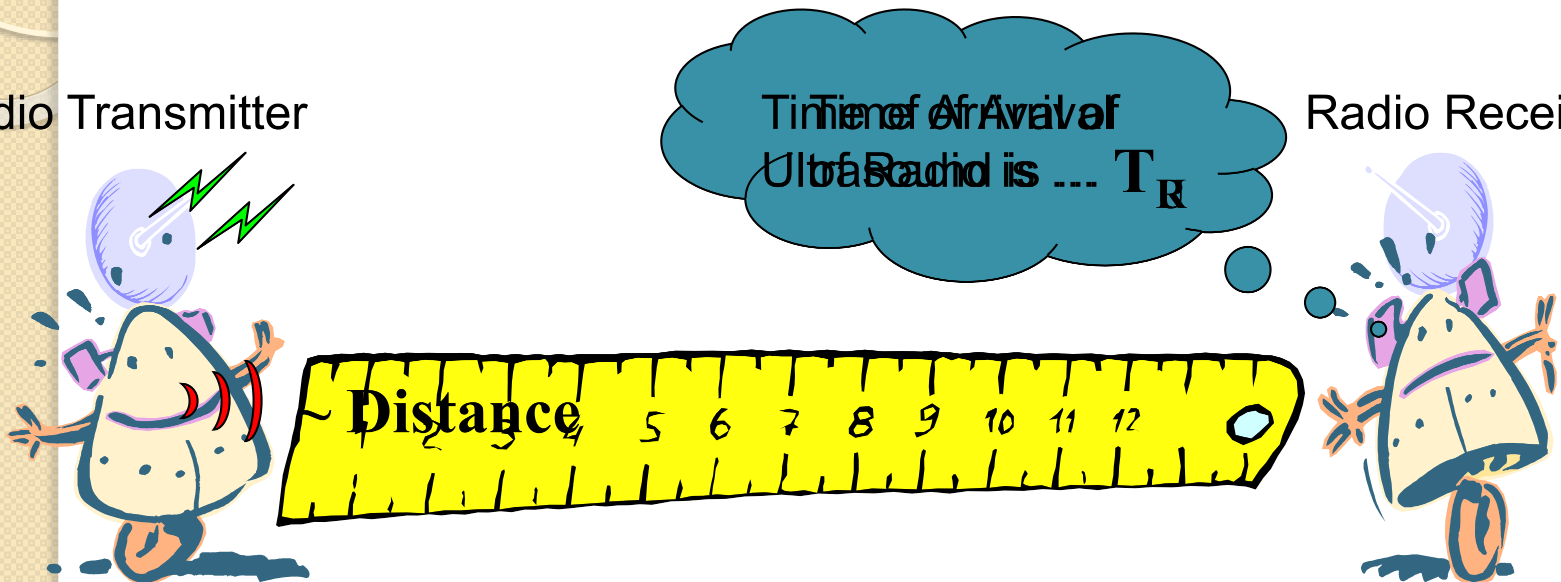
- GPS Localization
  - Use the GPS coordinates
    - Additional GPS units
    - High Cost in Area and Energy
    - Not always available
- GPS-less Localization
  - Find Relative Angle
    - Where the angular vectors meet
  - Find Distances and estimate coordinates
    - Use Radio and/or Ultrasound
    - Additional localization algorithm
    - Low Cost in Area and Energy
    - Available within range



TDoA: Distance Calculation

Radio Transmitter

Radio Receiver



Ultrasound Transmitter

Ultrasound Receiver

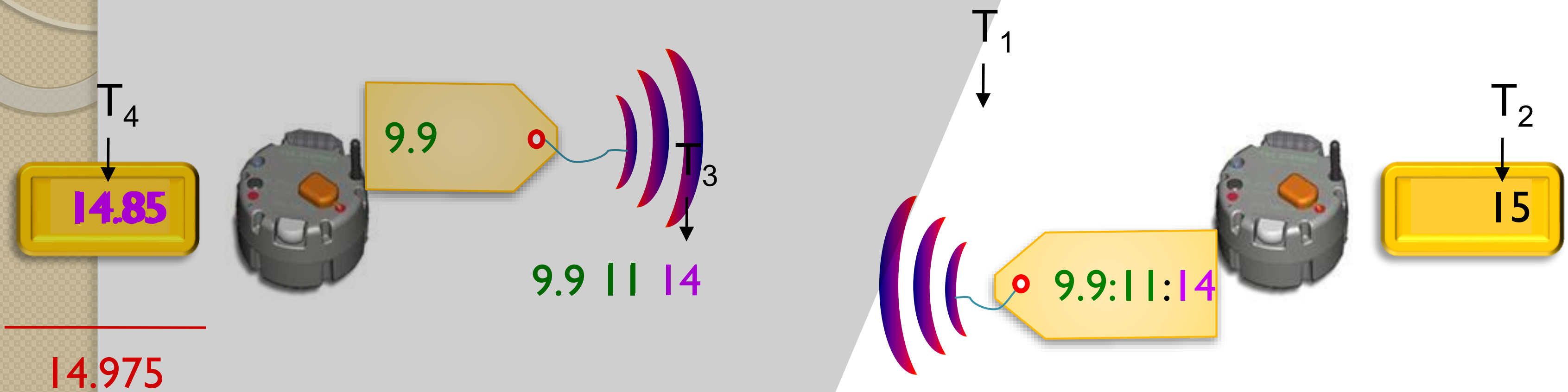
Speed of Sound

- **=** **Time Difference of Arrival**

Time Synchronization

Drift is highly dependent on the environment (i.e. Temp)
Difference in drift can accumulate over Time

Time Synchronization

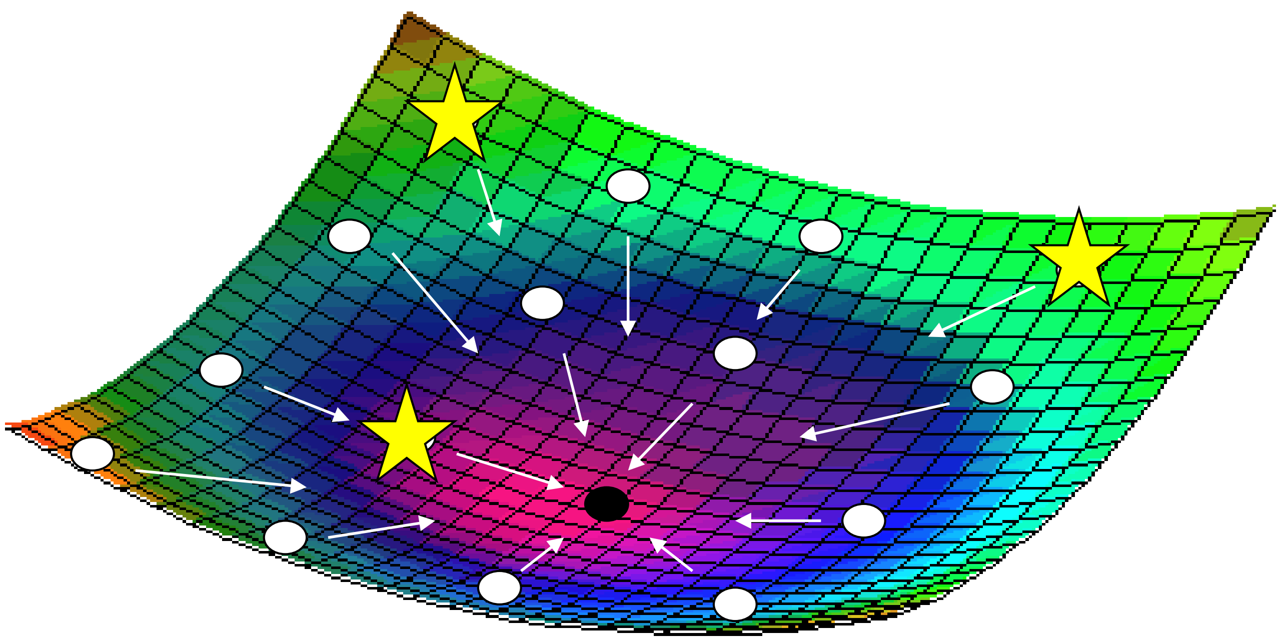


- $T_2 = T_1 + \text{Propagation Delay} + \text{Timer Offset}_1$
- $T_4 = T_3 + \text{Propagation Delay} - \text{Timer Offset}_2$
- Propagation Delay ≈ ((11 - 9.9) + (14.85 - 14)) / 2 = 0.975
- Timer Offset ≈ ((11 - 9.9) - (14.85 - 14)) 0.125 125

Not exactly equal due to frequency drift of the clocks during the flight times of messages
May solve the problem, BUT time synchronizations COST resources!!
For resource constrained systems like wireless sensor network, fewer time synch is better.

Data Aggregation

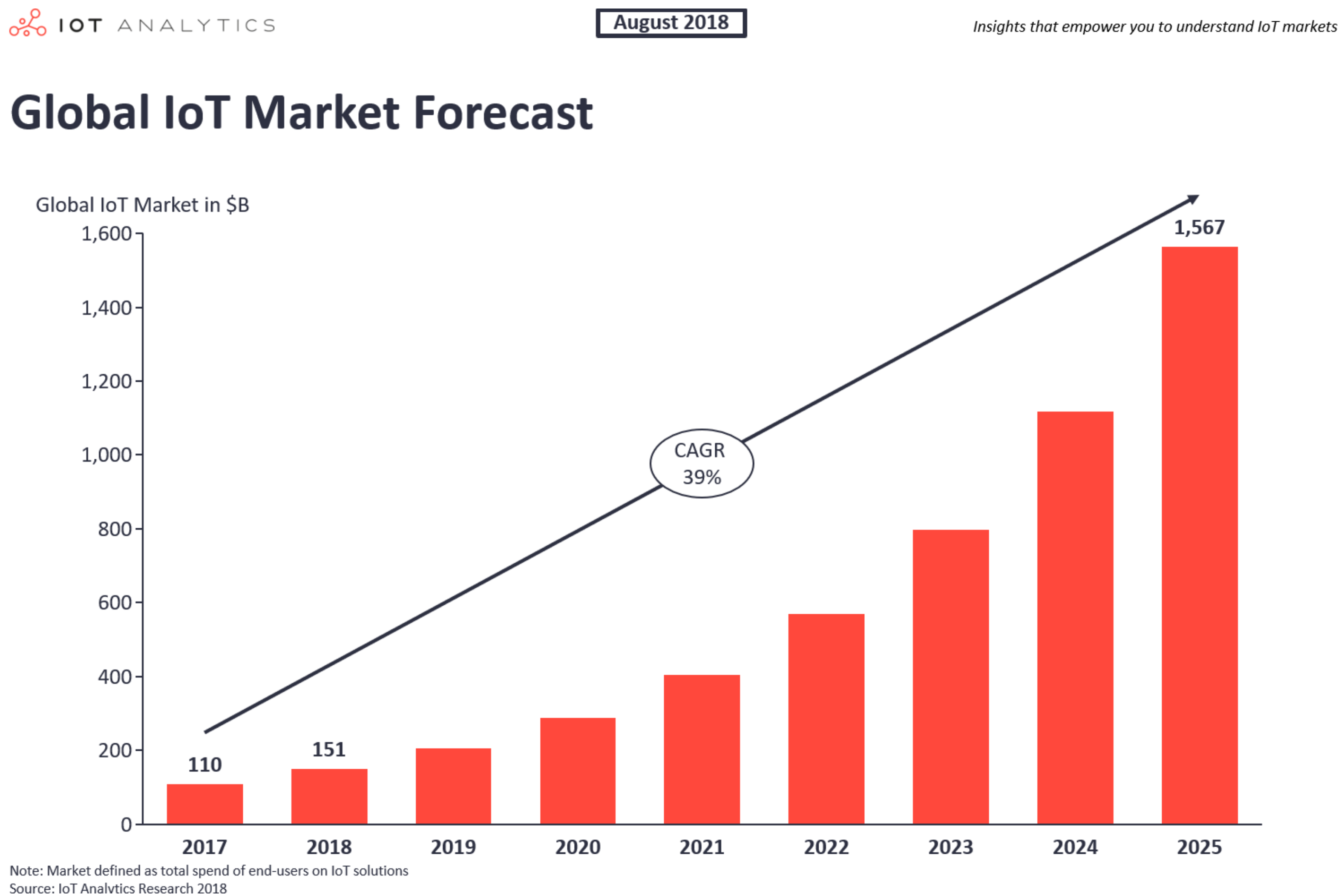
- Example: Virtual Gradient based
  - Flow of water from mountain to valley
  - Gradient is setup from network to Sink



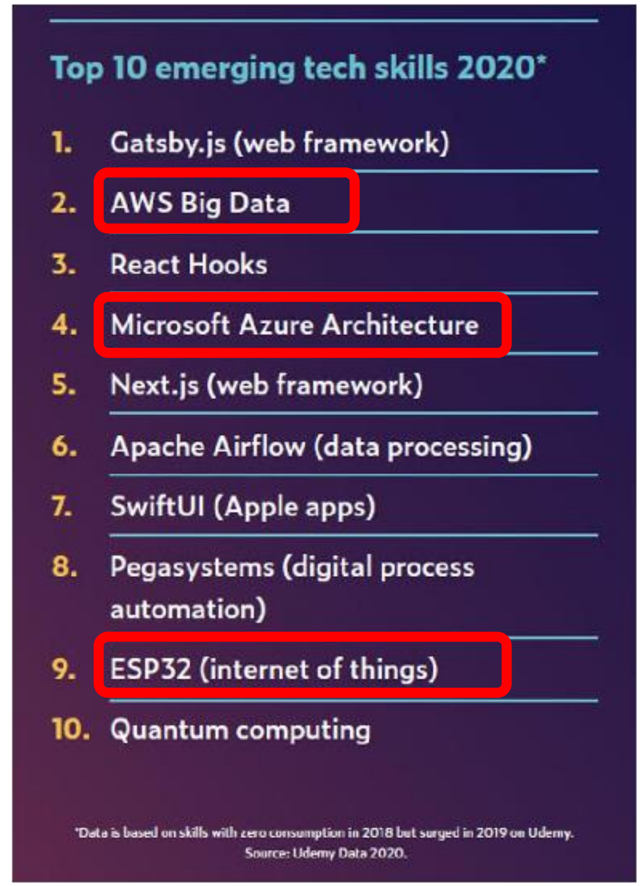
Summary

- Key Components
  - Processor
  - Communication
  - Software
- The Main Constraint
  - Low Power Consumption
  - Comm then Processor then Peripheral/Sensor
- Important Services
  - Localization
  - Time Synchronization
  - Data Aggregation

IoT Growth Forecast



Job Skills 2020



Top Tech Skills: Web development, quantum computing, and Internet of Things IoT

A Lot of Jobs - No Skills

- In-Demand Internet of Things (IoT) Skills

"The Internet of things (IoT) is in the midst of an explosion, as more connected devices proliferate. But there's a problem: not enough talent with the right skills to manage and execute on IoT project. So while IoT is poised to be the next great IT jobs boom, insufficient staffing and lack of expertise is the top-cited barrier for organiz currently looking to implement and benefit from IoT, according to research from Gartner."

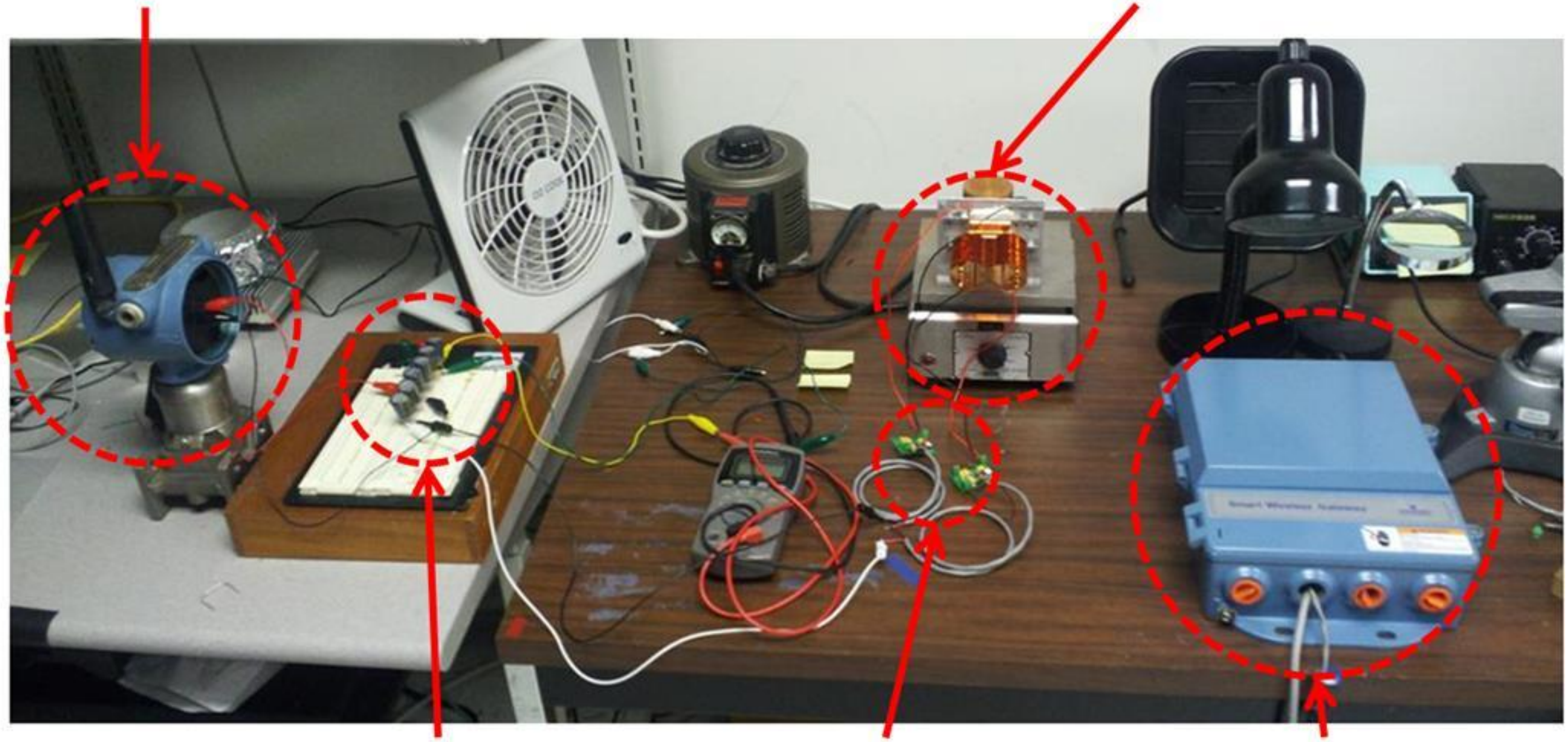
Powering Industrial Sensing Equipment

- Specific Field Device
  - Rosemount Wireless Transceivers
  - Continuous Monitoring of Oil Pipes
  - Uses Lithium Battery (10 years self-life)
  - Short Life in Practice (1-2 years typical)
- Our Research Goal
  - Remove the Batteries
  - Increase the System Life

Laboratory Tests

Rosemount Wireless Transmitter

Hot Plate with TEGs and Heatsink

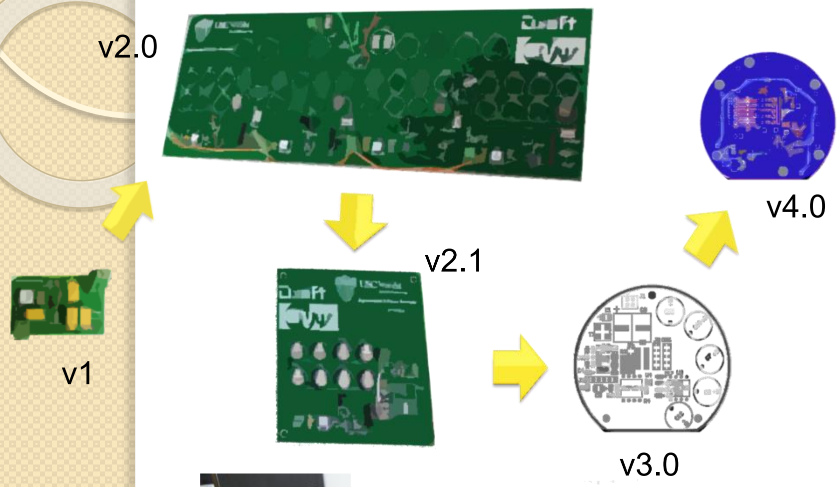


Array of Capacitors

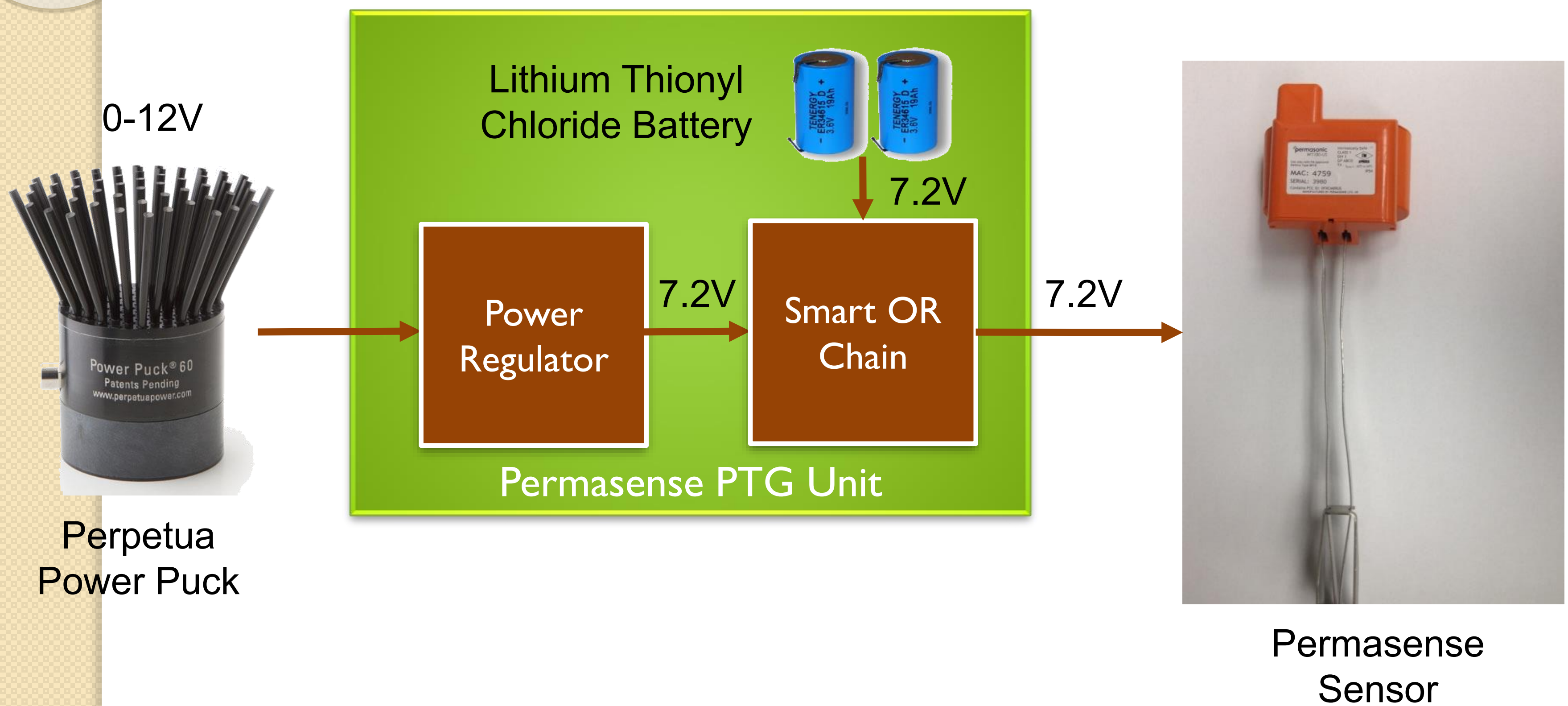
Stacked Prototype Boards

Rosemount Wireless Gateway

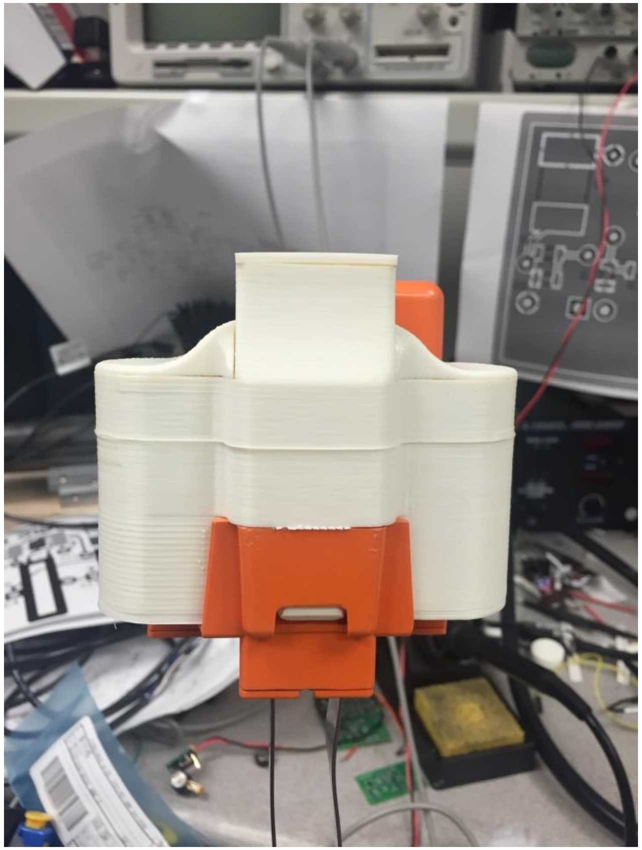
Pervasive Thermoelectric Generation

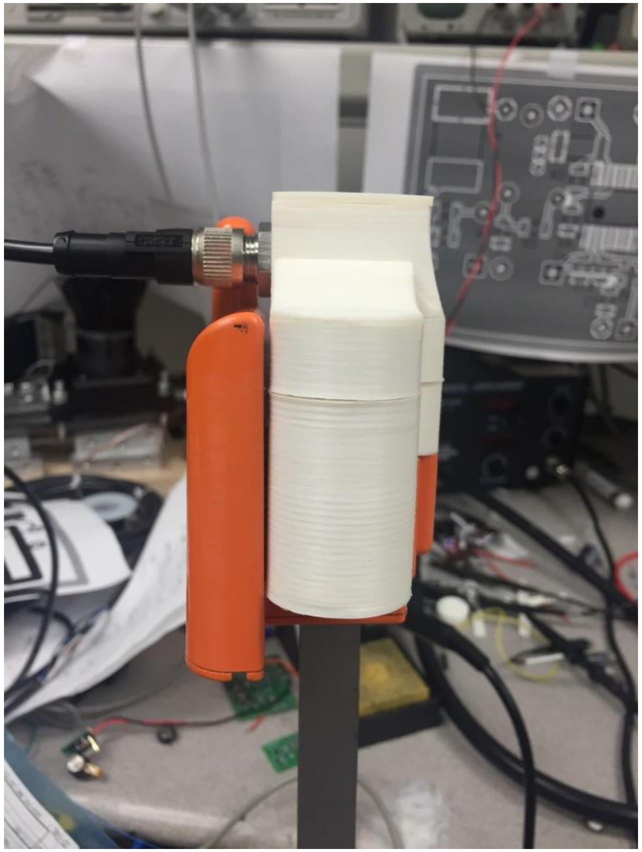


Fully Integrated Battery Unit



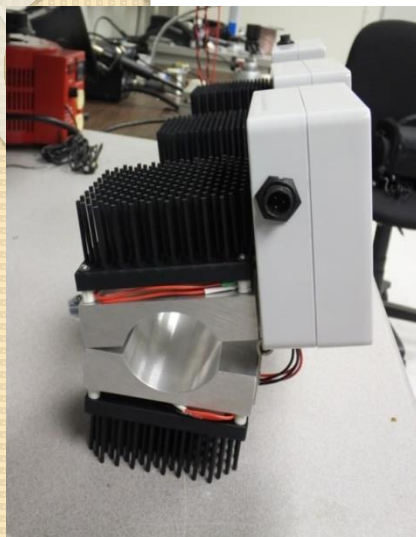
Functional Energy Harvesting Battery





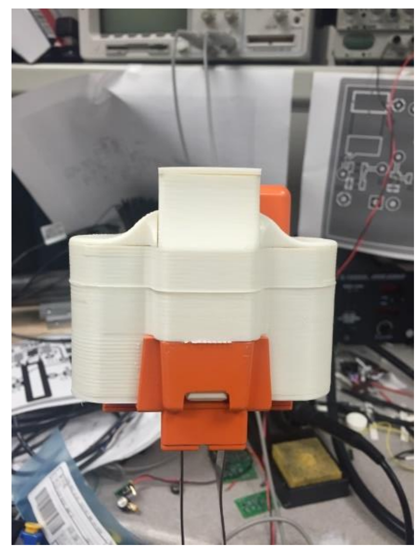
VIDEO: https://drive.google.com/file/d/0ByObcu8z9BbJdDBmLUZqMFI0YWM/view?usp=sharing

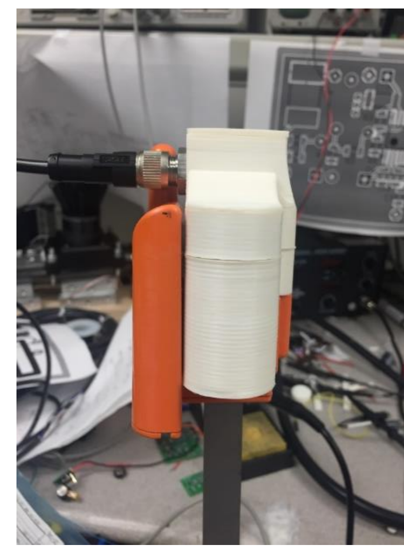
Pervasive Thermoelectric Generation (PTG)



<u>PTG for Permasense Transceivers</u>

Successfully Tested in the Laboratory
Higher Efficiency Conditioner Design
Integrated Perpetua PowerPuck
Integrated Dual Polarity





<u>PTG for Rosemount Transceivers</u>

Successful Field Trials
1+ Years Without Failure
With or Without Batteries
Integrated our TEG design
Integrated Dual Polarity
Integrated Module Chaining

VIDEO: https://drive.google.com/file/d/0ByObcu8z9BbJdDBmLUZqMFI0YWM/view?usp=sharing

PTG Summary

- Powers Industrial Standard Wireless Sensor Nodes
  - 6+ Months of Successful Operation in the Field
  - Conditions with Temperature Greater than 115 deg F
- Deployed under Temperature Diff of less than 10 deg F
  - Tested working at 8 deg F
  - Skin in the mid 90's and room at 75 degrees F
  - Possible to power wireless computers with sensors
- Low Cost - Pervasive Use
  - Less Than $100 per Unit with Estimated Overhead
  - As Compared to $200 Battery
- Other Applications?

Phone based WSN

Continuous Audio Recording

Audio Upload using 3G

Efficient power optimization

Remote Access

Robust

Solar Powered

Cost: ~$250

Audio Processing

- Smartphone – Various Sensors
- Flash Ubuntu Touch OS
- Reconfigure to use only the essential parts

Self-Sufficient Wireless Sensors

Power Management

Efficient power optimization

- Display is always off
- Battery monitored every half an hour
- Data turned on only when uploading and remote access
- Goes into critical state when battery falls below 10%

Solar Powered and Robust

- Charges up during day
- Battery big enough to last 7 days without sun
- Sturdy case – Withstands high temperatures and water-proof

```
Wed Aug 24 14:45:03 PDT 2016 Battery capacity is 93 %
Wed Aug 24 14:45:03 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 15:15:02 PDT 2016 Battery capacity is 95 %
Wed Aug 24 15:15:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 15:45:04 PDT 2016 Battery capacity is 100 %
Wed Aug 24 15:45:04 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 16:15:02 PDT 2016 Battery capacity is 77 %
Wed Aug 24 16:15:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 16:45:03 PDT 2016 Battery capacity is 75 %
Wed Aug 24 16:45:03 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 17:15:02 PDT 2016 Battery capacity is 75 %
Wed Aug 24 17:15:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 17:45:02 PDT 2016 Battery capacity is 72 %
Wed Aug 24 17:45:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 18:15:02 PDT 2016 Battery capacity is 70 %
Wed Aug 24 18:15:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 18:45:02 PDT 2016 Battery capacity is 70 %
Wed Aug 24 18:45:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 19:15:02 PDT 2016 Battery capacity is 70 %
Wed Aug 24 19:15:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 19:45:02 PDT 2016 Battery capacity is 69 %
Wed Aug 24 19:45:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 20:15:02 PDT 2016 Battery capacity is 76 %
Wed Aug 24 20:15:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 20:45:01 PDT 2016 Battery capacity is 86 %
Wed Aug 24 20:45:01 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 21:15:01 PDT 2016 Battery capacity is 95 %
Wed Aug 24 21:15:01 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 21:45:02 PDT 2016 Battery capacity is 95 %
```

Cloud Servers for Data Storage

Continuous Audio Recording

- 44.1KHz sampling rate
- 24 hours/7 days
- Audio samples of configurable length using Vorbis tools

Audio Upload to Server

- Accessible via web page
- Every 6 hours
- Power efficient

Index of /test/audio_files/node_alpha

Name	Last modified	Size	Description
Parent Directory		-	
160914-130720-291376521.ogg	2016-09-14 18:01	158K	
160914-130740-846616714.ogg	2016-09-14 18:01	158K	
160914-130801-472994867.ogg	2016-09-14 18:01	157K	
160914-130822-162122069.ogg	2016-09-14 18:01	157K	
160914-130903-364209356.ogg	2016-09-14 18:01	158K	
160914-130923-932902311.ogg	2016-09-14 18:02	158K	
160914-130944-564130780.ogg	2016-09-14 18:02	158K	
160914-131005-062082341.ogg	2016-09-14 18:02	158K	
160914-131025-591576206.ogg	2016-09-14 18:02	158K	
160914-131046-250930403.ogg	2016-09-14 18:02	158K	
160914-131106-793694000.ogg	2016-09-14 18:02	158K	
160914-131127-441578268.ogg	2016-09-14 18:03	158K	
160914-131147-956338156.ogg	2016-09-14 18:03	158K	
160914-131208-502243779.ogg	2016-09-14 18:03	157K	
160914-131229-572654582.ogg	2016-09-14 18:03	158K	
160914-131251-104058886.ogg	2016-09-14 18:03	158K	
160914-131312-082039148.ogg	2016-09-14 18:03	158K	
160914-131332-602900063.ogg	2016-09-14 18:03	158K	
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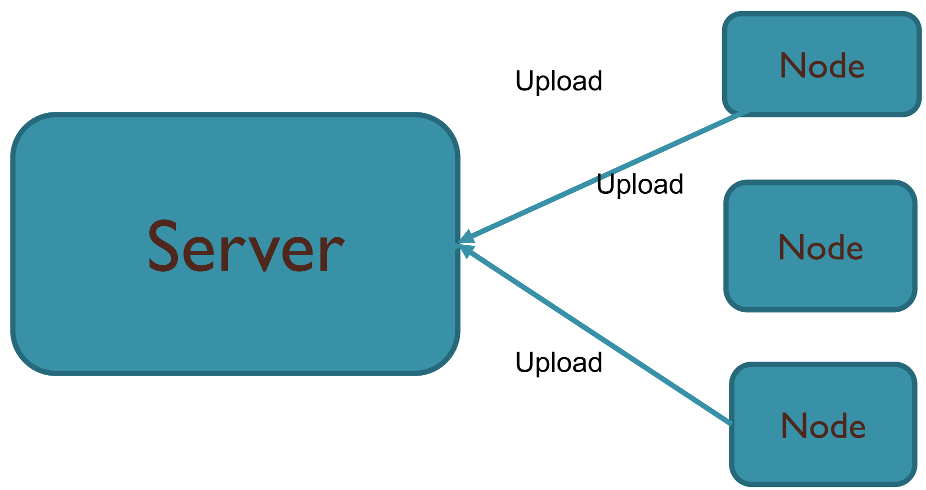
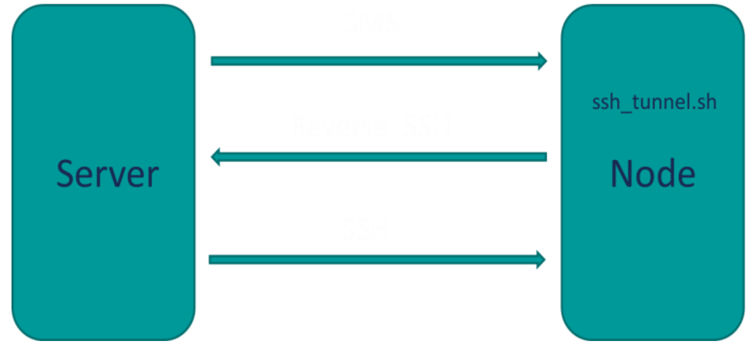
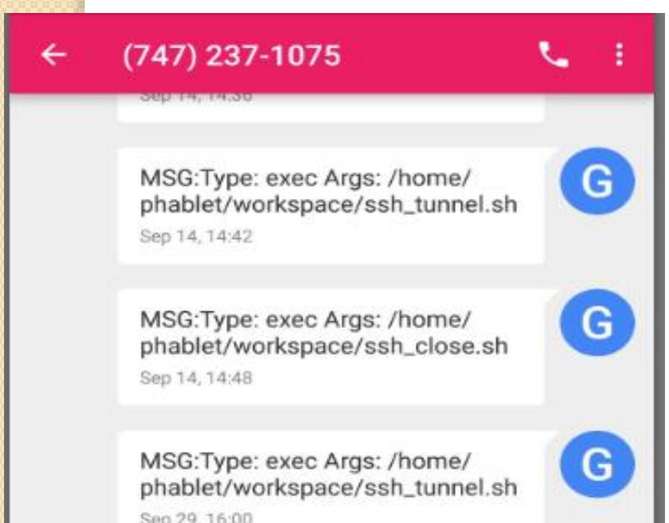
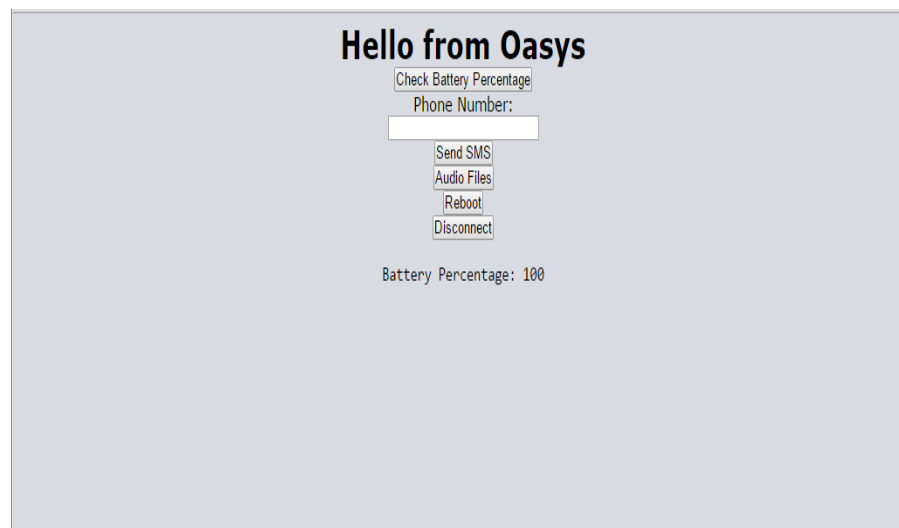


Remote Access

- Three step process
  - SMS to initialize reverse SSH from node
  - Node SSH to the server
  - Server can access node through local port
- SMS used as a side channel







Field Deployment