EE 579: Wireless and Mobile Networks Design & Laboratory

Lecture 6

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USC, Spring 2014

Lecture notes and course design based upon prior semesters taught by Bhaskar Krishnamachari and Murali Annavaram.

Outline

- Administrative Stuff
- Summer Internship Announcement
- Wireless Sensor Networks Overview
- Contiki Operating System
- Hands-on with Tmote Sky (Hello World, Broadcast)

Summer Internship

- Startup looking for good students with expertise in application, middleware, and engineering solutions for mobile platforms

- Possibility of grant/funding to develop some engineering solutions, for example, connecting different health monitoring sensors to mobile platforms

- Contact: Professor Raghu Raghavendra (raghu@vsoe.usc.edu)

Summer Internship

- Profile I
  - Independently design and develop mobile applications for Android platforms
  - Integrate health monitoring sensors to mobile platforms
  - Implement complex and responsive user interfaces and utilizing native frameworks for animations

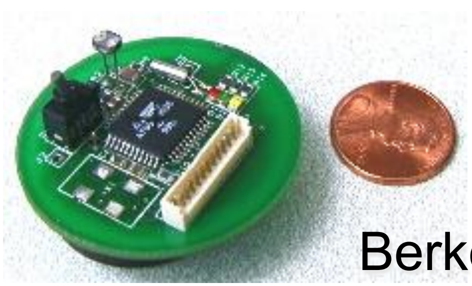
Summer Internship

- Profile II
  - Web-based software development experience
  - Experience with Java web framework such as Spring, Grails
  - Knowledge of front-end Web technologies
    - HTML, CSS, Javascript, AngularJS, Node.js, Backbone.js
  - Understanding of data modeling and database technologies (MySQL and Mongo DB)
  - Experience with REST design concepts
  - Familiarity with version control and configuration management
  - Ability to work independently with little guidance

- Profile III
  - Interest in doing engineering work to integrate various sensors for health monitoring to mobile platform

Sensor Networks: The Vision

- The "many - tiny" principle: wireless networks of thousands of inexpensive miniature devices capable of computation, communication and sensing
- For smart spaces, environmental monitoring, battlefield applications...

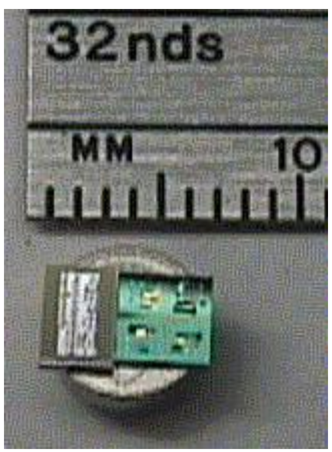


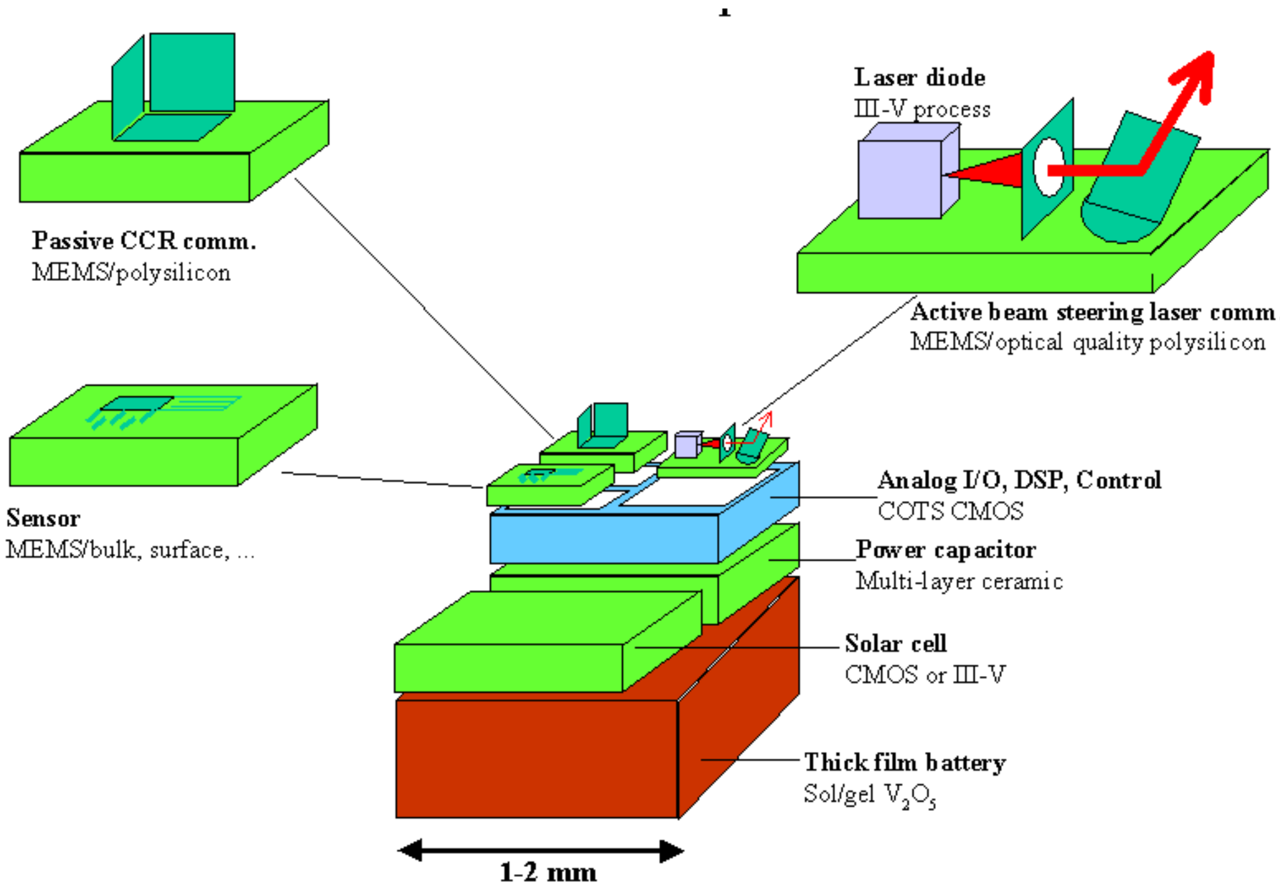
Berkeley Mote

PC104 Sensor

From Pister *et al.*, Berkeley Smart Dust Project

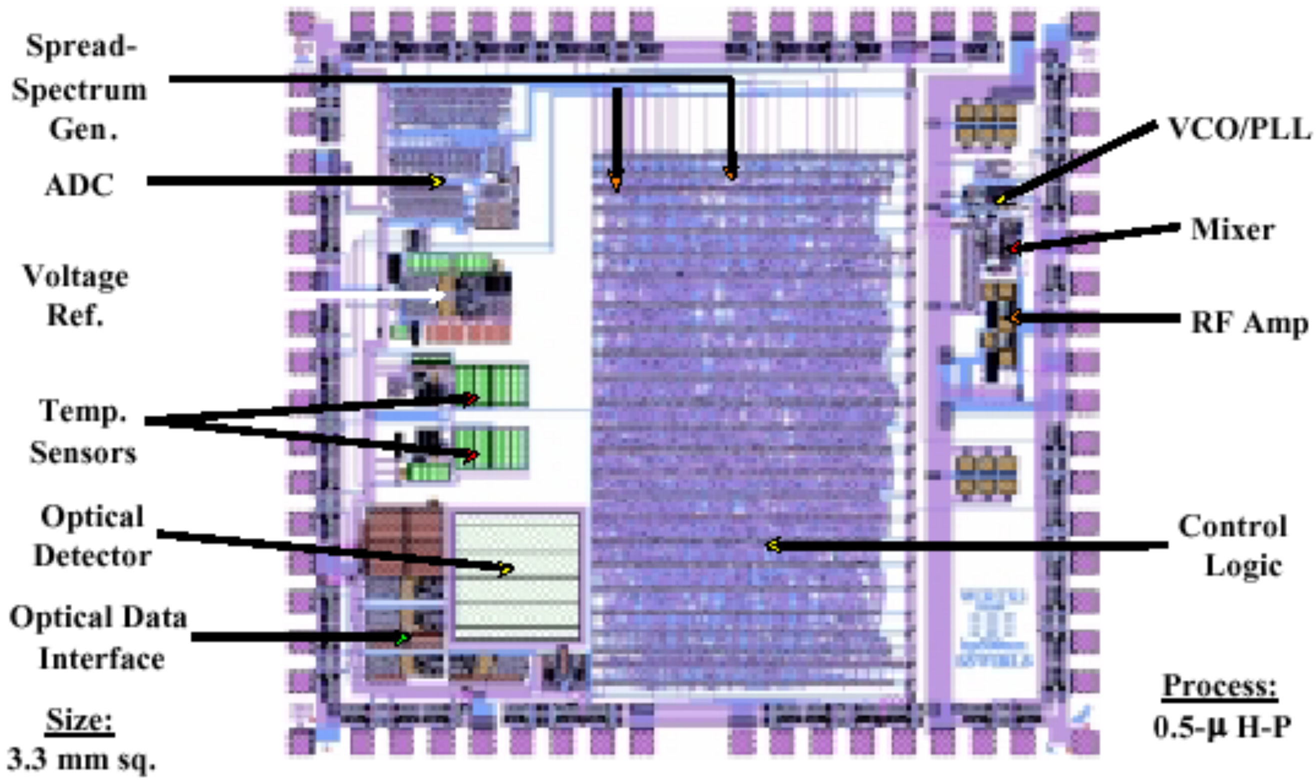
Tomorrow’s Devices





Berkeley Dust Mote

Tomorrow's Devices



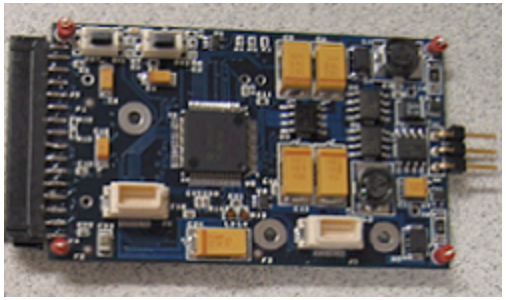
ORNL Telesensor Chip

From Manges *et al.*, *Oak Ridge National Laboratory, Instrumentation and Controls Division*

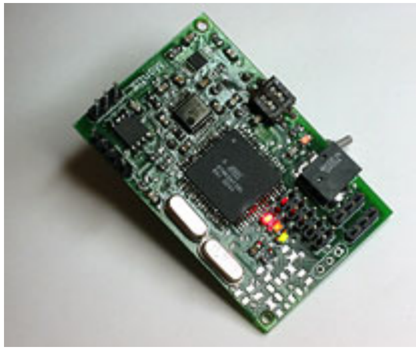
WSN Devices

WINS (Rockwell)

MICA 2 Mote (Berkeley)

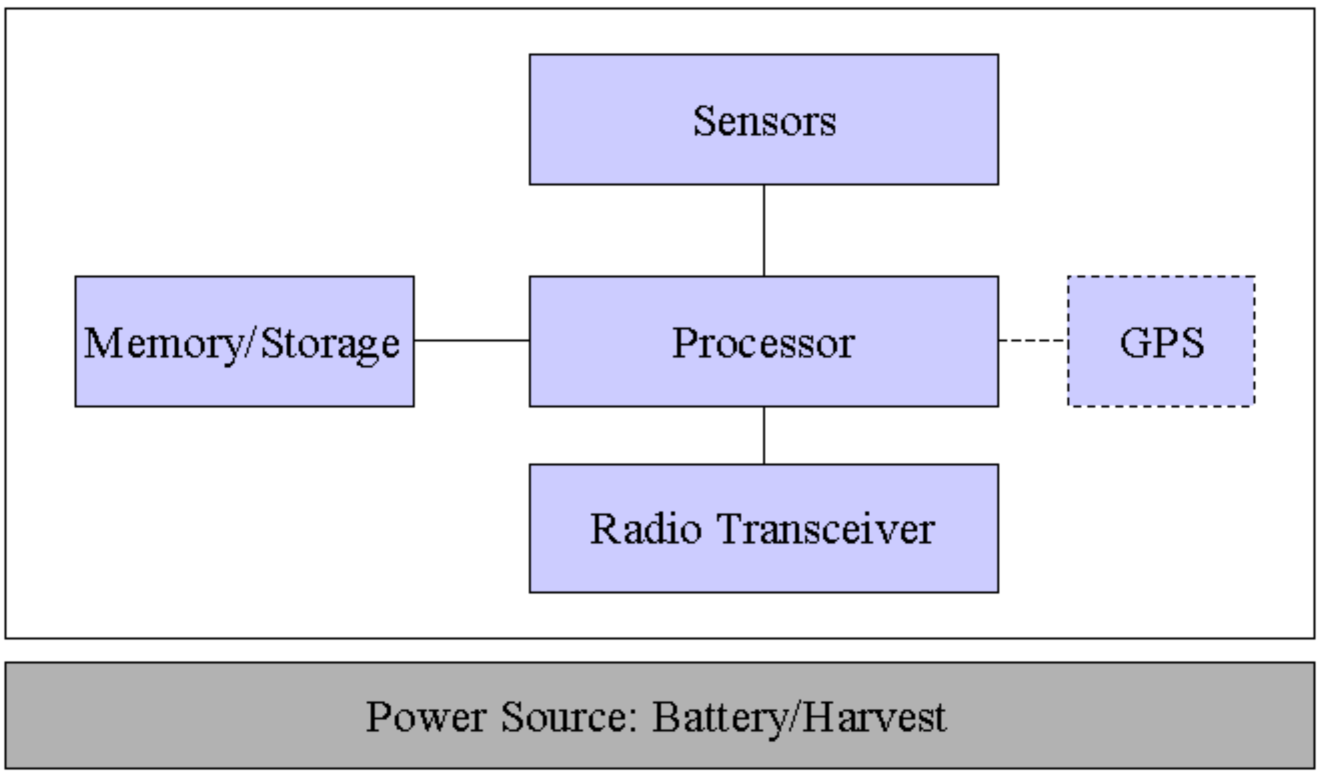


GNOMES (Rice)

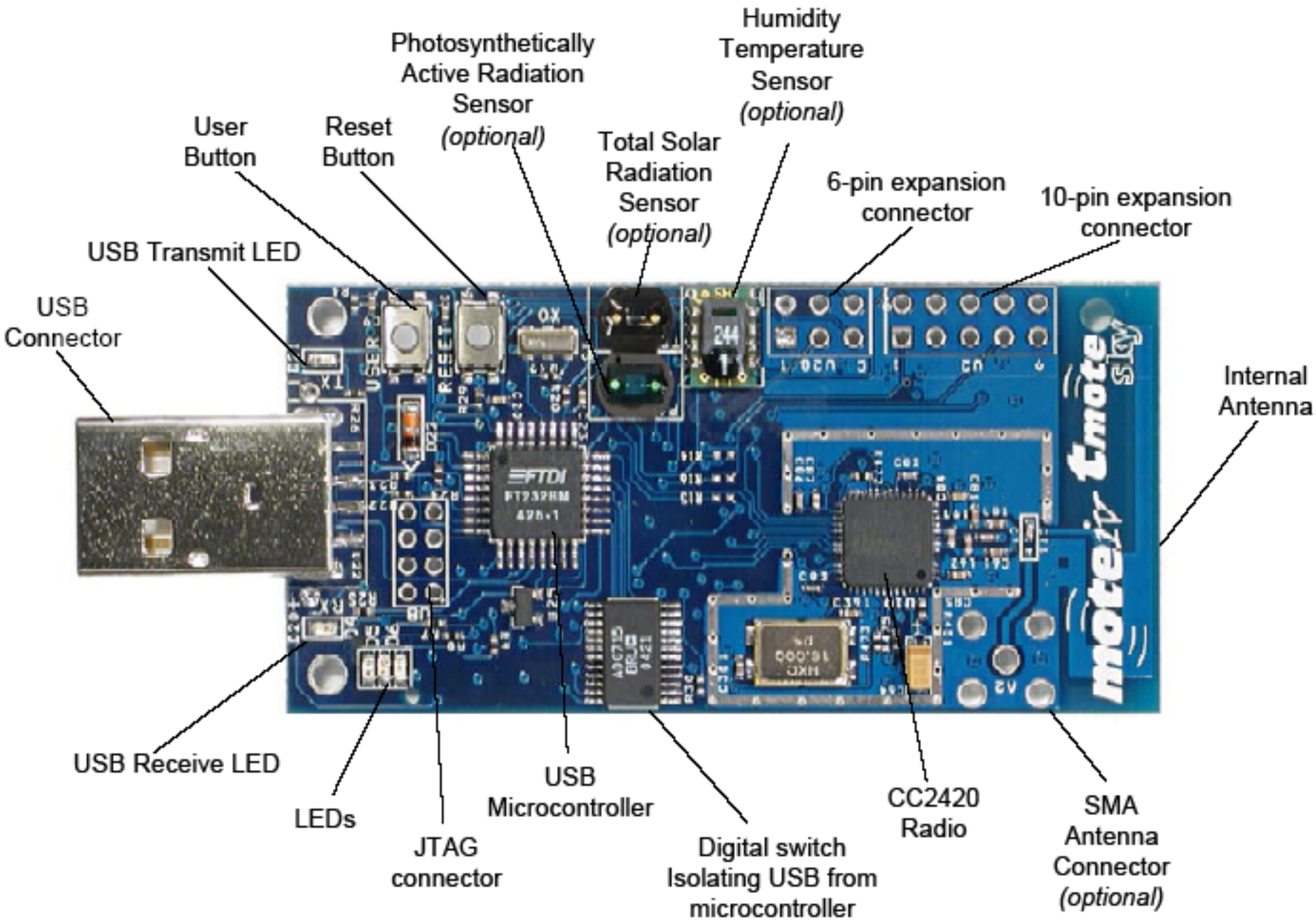


MANTIS Nymph (Colorado)

Basic WSN Hardware



Moteiv Tmote Sky



Tmote Sky Features

- 2.4 GHz, 250 Kbps IEEE 802.15.4 CC2420 radio, range: tens of meters
- MSP430 microcontroller, 10 KB RAM, 48 KB flash
- 1 MB external flash
- USB programming using NesC/TinyOS/Contiki
- On-board Humidity, Temperature, and Light Sensors
- Power consumption @ 3V: mcu + radio: ~20 mA, mcu alone: ~2 mA, standby: 20 μA

Applications of Interest

- Seismic Sensing and Actuation
- Structural Condition Monitoring

From CENS

Applications of Interest

- Monitoring ecosystems and species habitats

From Berkley Intel Lablet: Great Duck Island (greatduckisland.net)

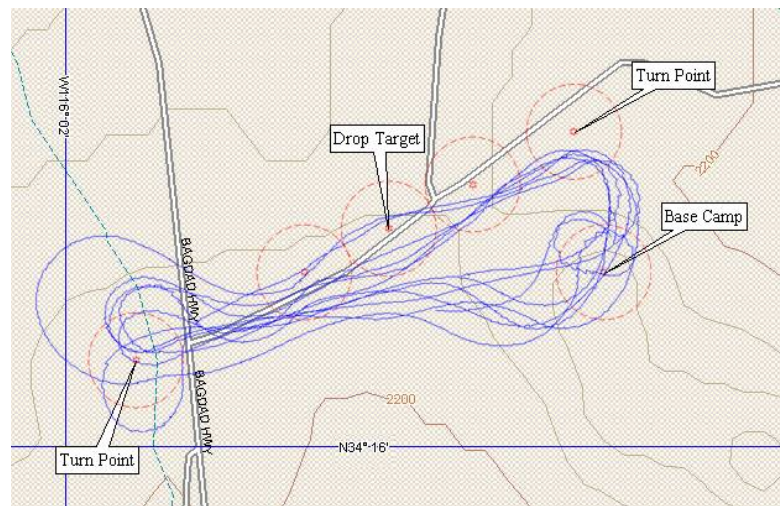
Applications of Interest

- Contaminant Flow
- Chemical Leaks
- Forest Fires
- Emergency Response

Images from Google

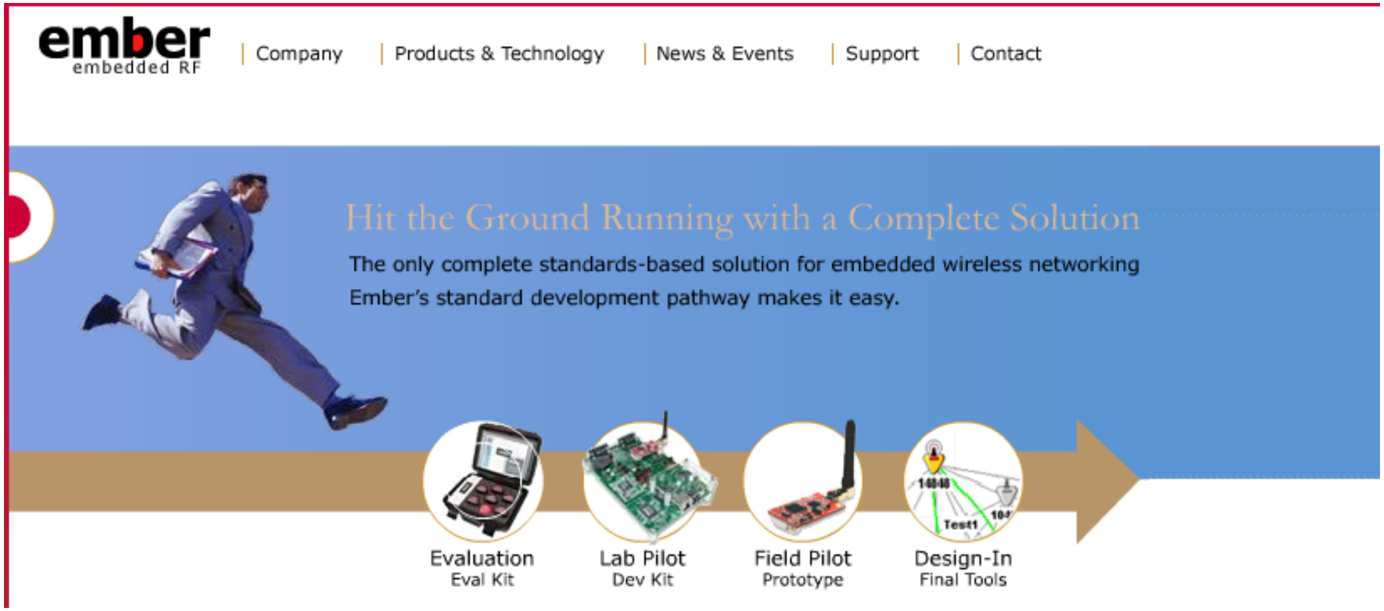
Applications of Interest

- Target Tracking



From 29 Palms Demo, UC Berkley and others

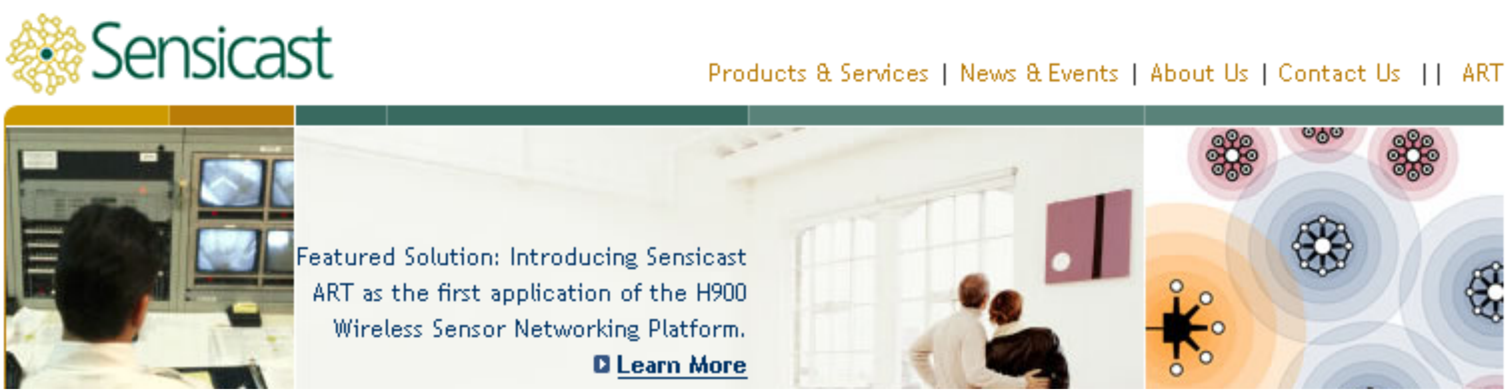
WSN Companies



USC Viterbi School of Engineering

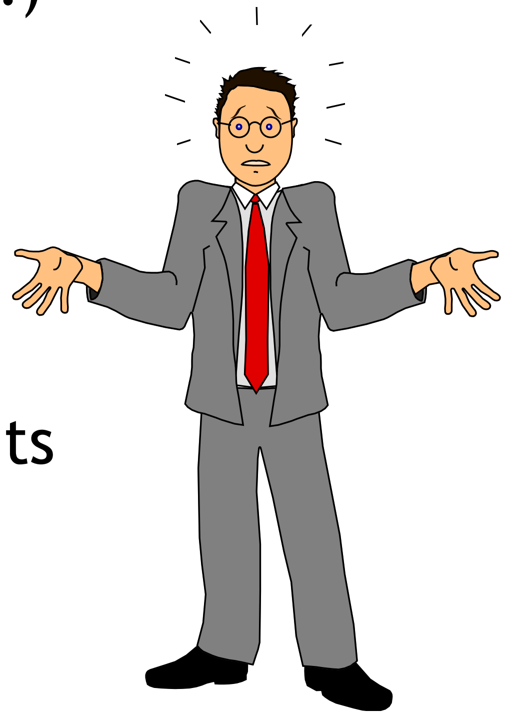
WSN Companies

WSN Companies



Challenges

- Unattended, ad-hoc deployment
- Energy scarcity
  - Radio communication is 100 to 10000 times more expensive than computational processing
- Large Scale: thousands of nodes (millions?!)
- Distributed data
- Heterogeneous capabilities
- Faulty/failed nodes, noisy measurements
- Dynamic, uncertain environment
- Potentially demanding real-time constraints



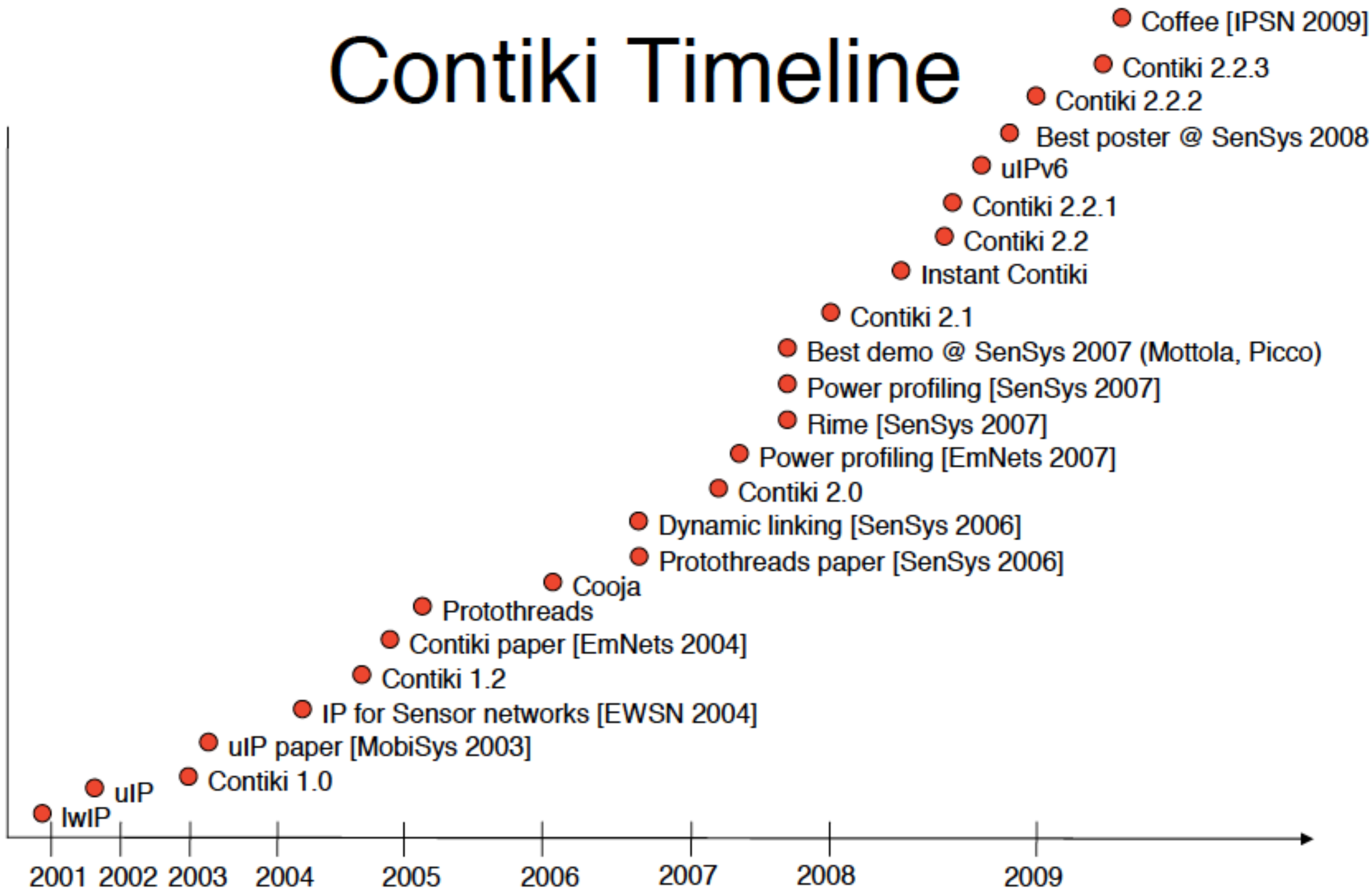
Contiki OS

- Open source - BSD license
  - Multitasking using C programming language
- Developed by Adam Dunkels at the Swedish Institute of Computer Science
  - Version 1.0 released in March 2003
  - Version 2.7 released November 15, 2013
- Highly portable
  - Tmote Sky, JCreate, TelosB, Atmel Raven, MicaZ, …
  - Simulators: Cooja, MSPsim, AvoraZ, netsim
  - Native platform
- Actively developed
  - 17 developers from SICS, SAP, Cisco, NewAE, TU

Contiki as a Research Theme

- Exploring successful computer science abstractions and mechanisms for sensor networks
  - Dynamic module loading and linking [ACM SenSys 2006]
  - File System [IEEE/ACM IPSN 2009]
  - Multi-threaded programming [EmNets 2004]
  - Java, scripting, … [ACM SenSys 2006, …]
  - Interactive network shell
  - IP networking for low-power embedded systems [ACM/Usenix MobiSys 2003, ACM SenSys 2007, ACM SenSys 2008]
- Pursuing new abstractions
  - Protothreads [ACM SenSys 2006]
  - Low-power radio networking [ACM SenSys 2007]
  - Power profiling [EmNets 2007]
  - Novel communication primitives

Contiki Timeline



Features

- Multitasking kernel
- Preemptive scheduling
- Managed memory allocator
- Protothreads
- TCP/IP networking, including IPv6

Coffee File System [IPSN 2009]

- Flash-based file system
- open(), read(), seek(), write(), close()
- Constant memory complexity
- Very lightweight
  - 5 Kb ROM
  - < 0.5 Kb RAM
- Very fast
  - More than 92% of raw flash throughput

Interactive Shell

- Network debugging, performance tuning
- Leverage UNIX-style pipelines
- Network commands
- Direct serial connection, or over Telnet/TCP
- A generic interface for higher level applications
  - Automated interaction, scripting

Power Profiling [EmNets 2007]

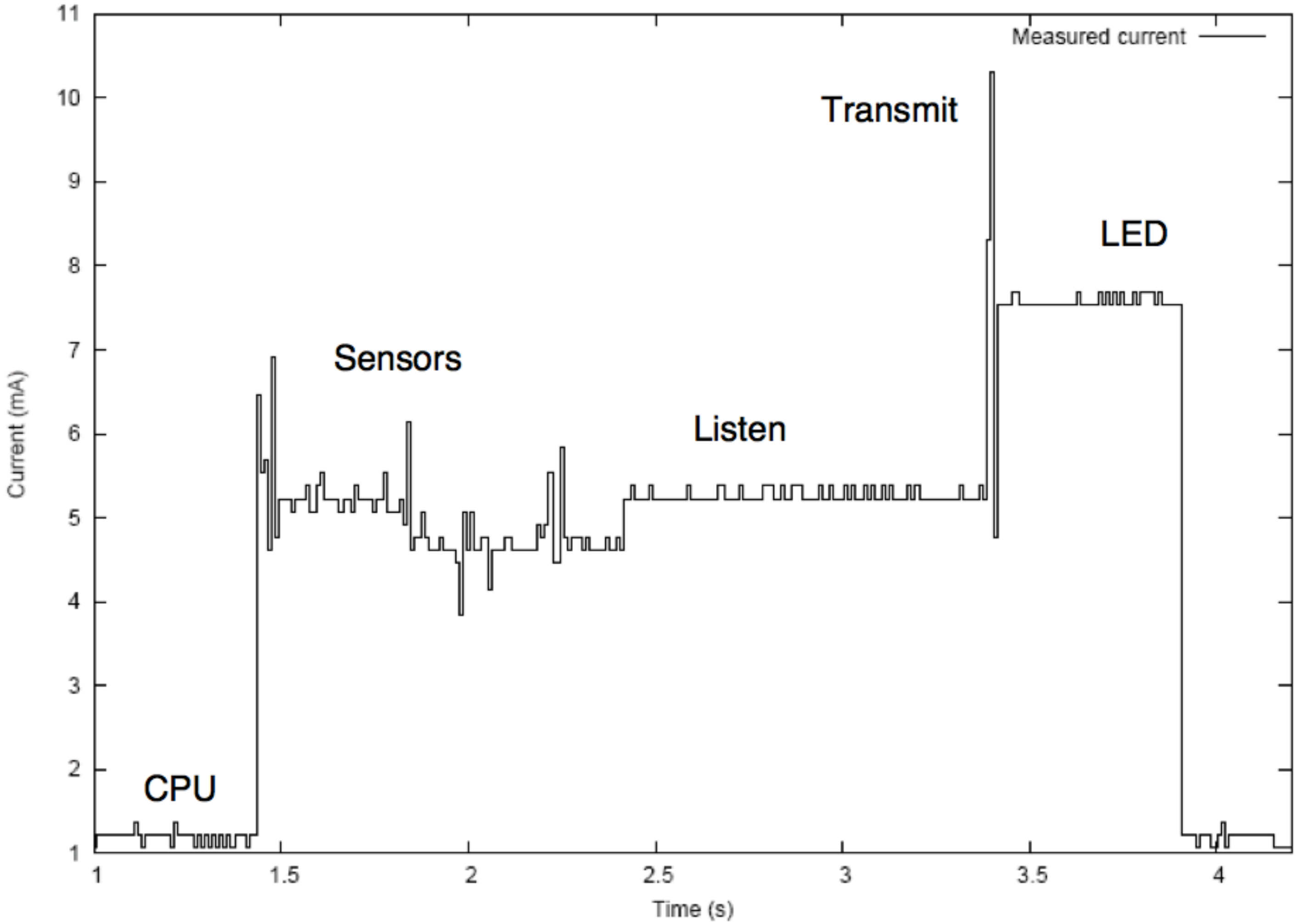
- Software-based
  - Zero-cost hardware
  - Zero-effort deployment

- Good accuracy, low overhead

- Enables network-scale energy profiling

- Enables energy-aware mechanisms

Linear Current Draw

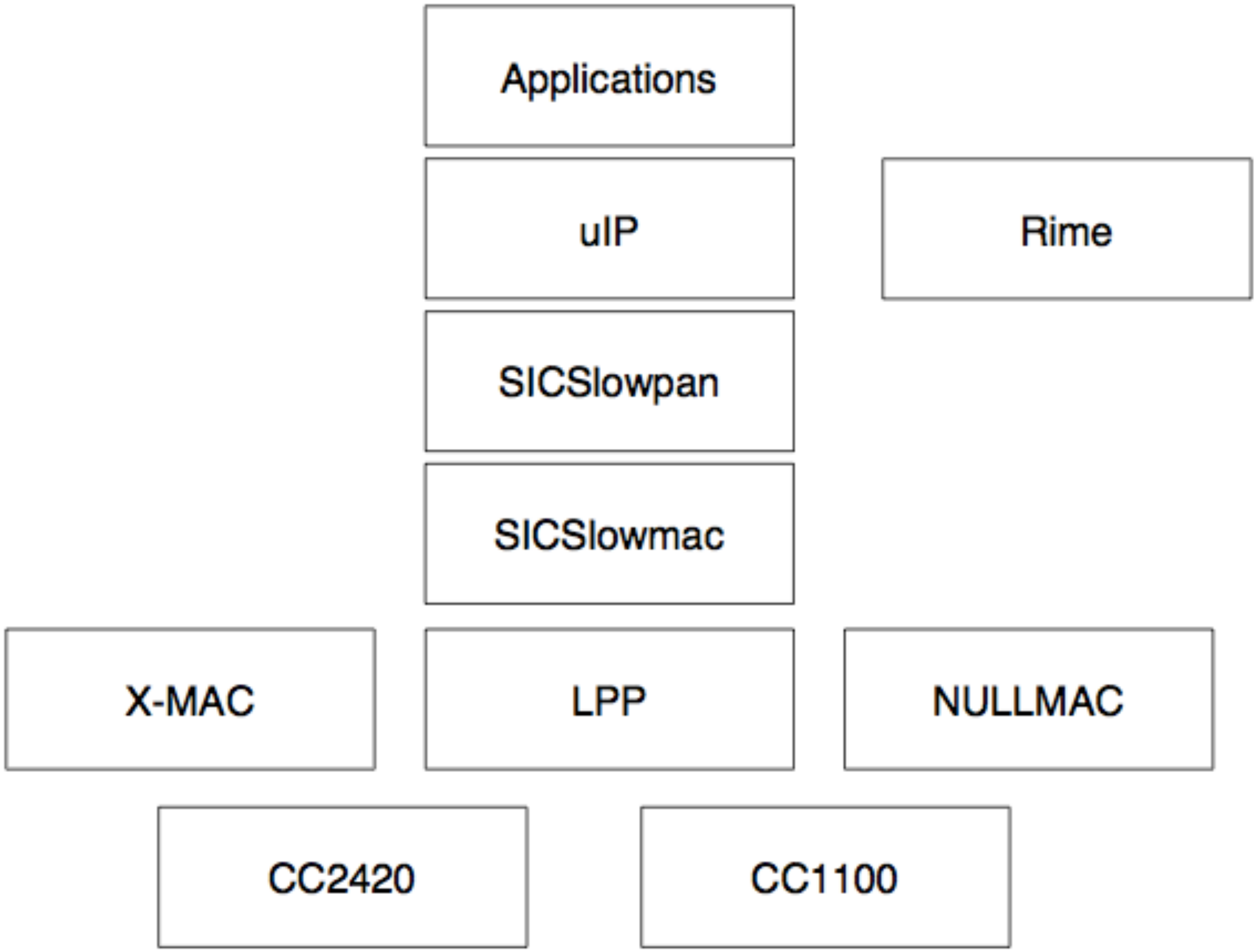


Rime: Communication Primitives

- Makes implementation of sensor network mechanisms easier

- A set of protocols
  - Data collection
  - Data dissemination
  - Unicast multi-hop routing
  - Single-hop bulk transfer
  - …

Contiki IP Architecture



Run Contiki on Hardware

- Contiki has a build system that is intended to make it easy to run Contiki directly on hardware

- Build system is same across different hardware platforms, so that the build commands are familiar when switching hardware

- Comprises a set of makefiles
  - Base makefile: `contiki/Makefile.include`
  - Platform makefiles in
    - `contiki/platform/*/Makefile.platform`
    - `contiki/cpu/*/Makefile.cpu`

Getting Started

- Step 1: Download Instant Contiki
  - Contiki development environment – single-file download
  - Ubuntu Linux virtual machine with all development tools, compilers, and simulators installed
  - www.contiki-os.org/start.html
- Step 2: Download VMWarePlayer
  - www.vmware.com/go/downloadplayer
- Step3: Start Instant Contiki
  - Open the Instant Contiki folder and execute
  - `instantContiki2.6.vmx`
  - Wait for the virtual Ubuntu Linux to boot up

Getting Started

- Step 4: Log in to Instant Contiki
  - Username: `user`
  - Password: `user`

- Step 5: Compile and run "Hello World" on native platform
  - `cd contiki-2.x`
  - `cd examples/hello-world`
  - `make TARGET=native`
  - `./hello-world.native`
  - Should print "Hello, world" on your screen and continue to hang – hit ctrl+c to quit

Run Contiki on Hardware

- Step 1: Open a terminal, go to the code directory
  - `cd contiki/examples/hello-world`
- Step 2: Compile Contiki and the application
  - Compile Hello World for our hardware platform
  - Also compiles the entire Contiki system (take some time)
  - `make TARGET=sky hello-world`
- Step 3: Upload Contiki to the hardware
  - Done with the special %.upload maketarget
  - `make hello-world.upload`
- Step 4: Check the serial port
  - `make login`

Contiki Mote Shell

- An interactive on-mote shell that provides a set of commands for interacting with the system

- Can be accessed over a serial USB connection, or over a network using Telnet

- Run over a USB serial connection
  - Compile and upload the shell
  - `cd contiki-2.x/examples/sky-shell`
  - `make sky-shell.upload`

- To connect over the USB port
  - `make login`
  - Next, we will try a few shell commands

Contiki Mote Shell

- To get a list of available commands
  - `help`

- Try other commands
  - `sense | senseconv`
  - `power | powerconv`
  - `ls`
  - `format`
  - `echo test | write file`
  - `ls`
  - `read file`
  - `nodeid`
  - `blink 10`
  - `reboot`

The Power Command

- Prints the current power profile from Contiki's software-based power profiler

- For decimal digit output
  - `power | binprint`
  - Example output

```
12   236 0 37421   0   4   0   380   0   0   0 380   0
```

- Output of power command can be used to compute an estimate of the mote's power consumption by multiplying the time with pre-measured current draw metrics

Run Contiki in Cooja Simulator

- Cooja – a network simulator

- Nodes can be either of three classes
  - Emulated nodes – entire hardware of each node is emulated (slower but allows precise inspection of the system behavior)
  - Cooja nodes – contiki code for the node is compiled and executed on the simulation host
  - Java nodes – behavior of the node must be re-implemented as a Java class

- A single Cooja simulation may contain a mixture of nodes from any class

Run Contiki in Cooja Simulator

- Open a terminal window and go to the Cooja directory
  - `cd contiki/tools/cooja`
  - `ant run`
  - Wait for Cooja to start

- When Cooja first starts, it will first compile itself (takes some time)

Comparison

Tiny OS

- Event-driven OS with multitasking
- Completely non-blocking
- Programs are built out of software components
- Tasks are non-preemptive and run in FIFO order
- Static linking
- Written in NesC (Networked Embedded Systems C)

Contiki OS

- Event-driven OS with multitasking
- Optional preemptive multitasking
- Dynamic linking
- Written in C