Our Crossbow Sensor Equipment and Zigbee

Presentation by Philip Kuryloski
and Sameer Pai

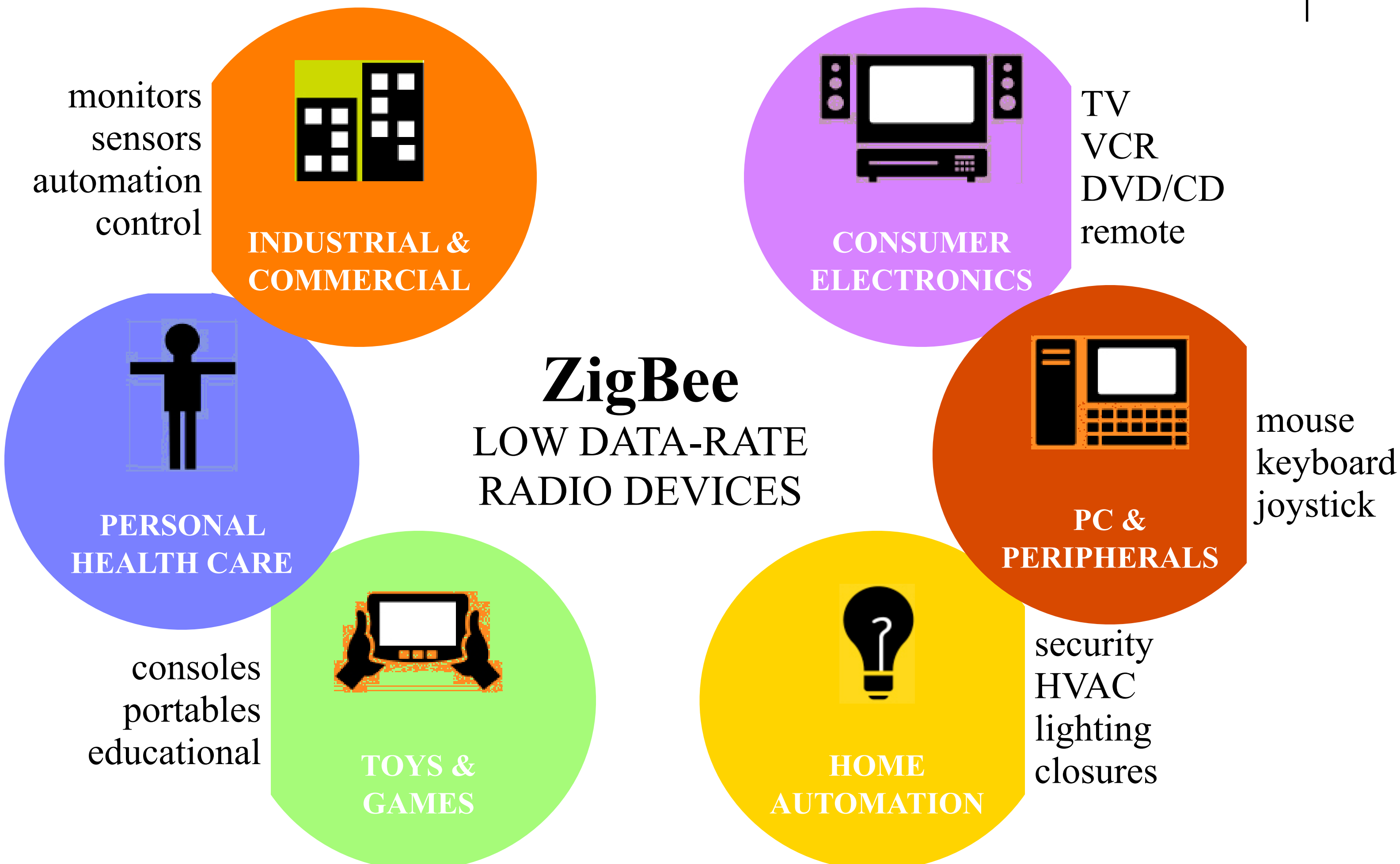
Presentation Outline

- Zigbee Overview
  - Overview of Zigbee and its uses
  - Zigbee Protocol Stack
    - 802.15.4 (Zigbee) Physical Layer
    - 802.15.4 (Zigbee) Medium Access Control Layer
    - Zigbee Network Layer
    - Zigbee Application Layer
- Overview of TinyOS
- Overview of Crossbow Equipment
- Demo
- Some Possible Projects

What is Zigbee?

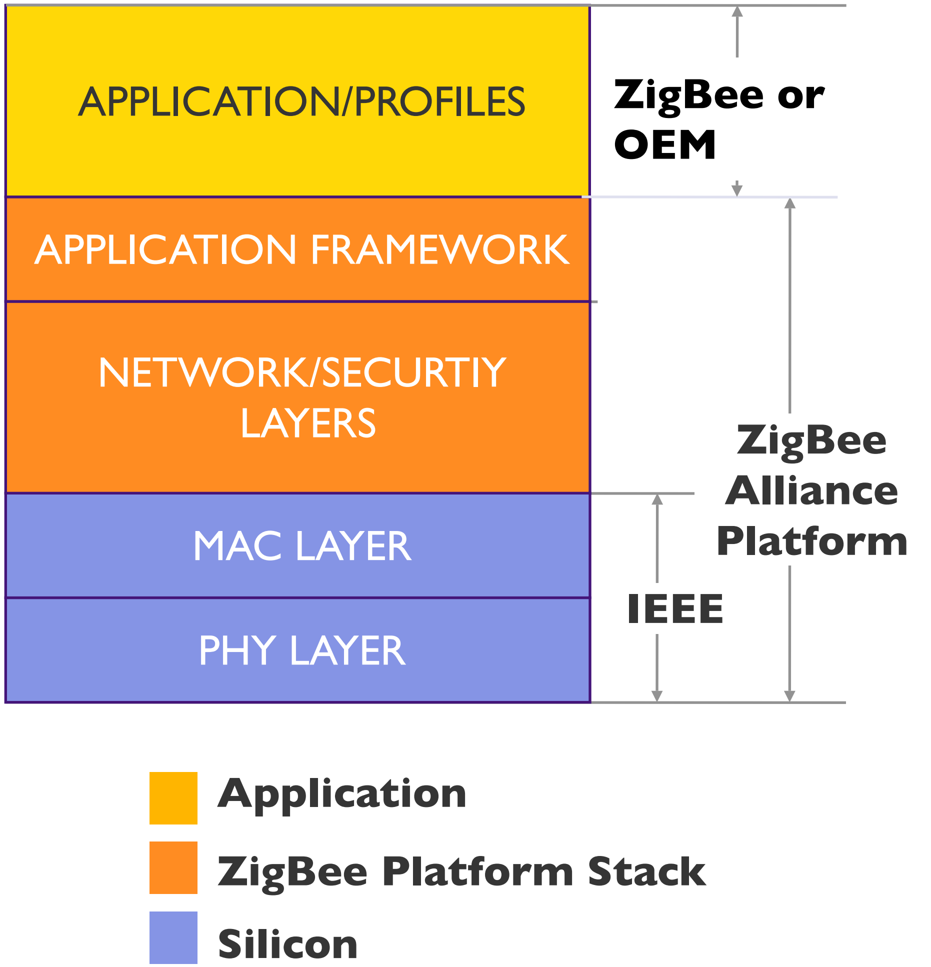
- Alliance of over 100 active member companies involved in development of wireless specification for sensors & control equipment
- IEEE 802.15.4 State-of-the-art PHY and MAC layer Standard
- Zigbee Protocol stack finalized in December of 2004
- Low data rate, low power, low cost solution

Uses for Zigbee



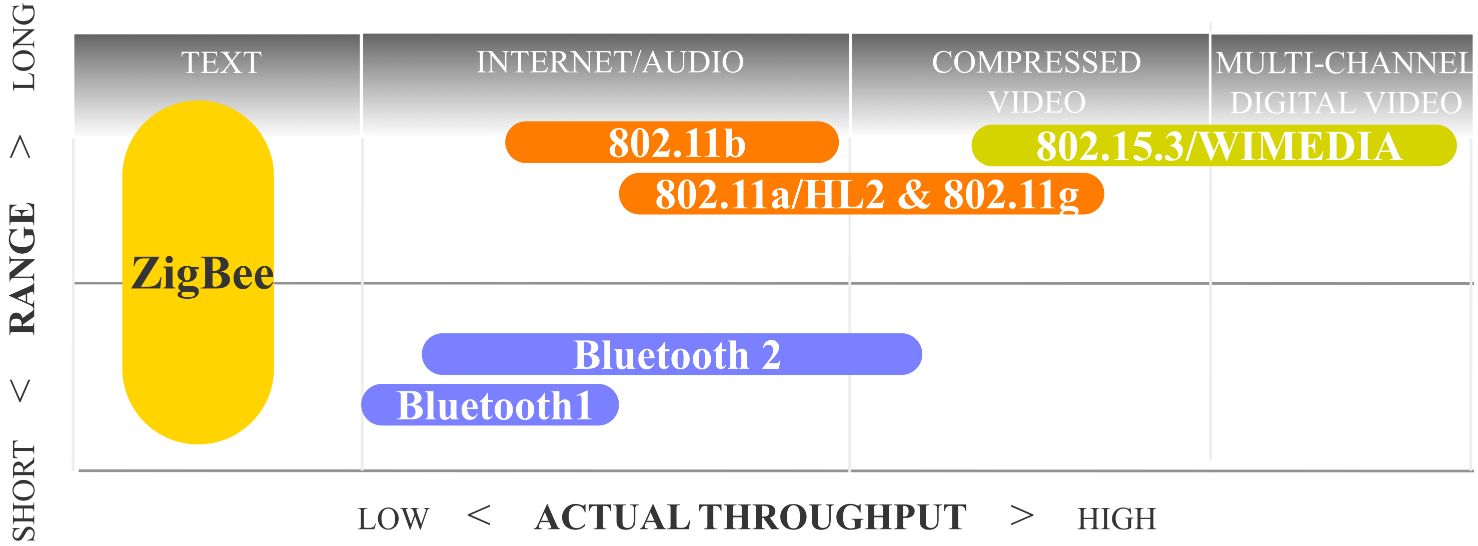
Zigbee® Protocol Stack

- 802.15.4 PHY and MAC based on the proposal sent by Zigbee Alliance to IEEE 802.15 task group 4
- Small Protocol Stack
  - Estimated to be ¼ the size of 802.11 stack (< 32k)
  - Simple and cost effective
- Only two states active (transmitting, receiving) or sleeping
- Low power cycle (~0.1%) allows batteries to last for years



Data Rate and Range

- Data Rates of 250kbps when operating at 2.4 GHz, 40 kbps when operating at 915 MHz, and 20kbps when operating at 868 MHz
- Range ~50m range (5-500m depending on environment)



802.15.4 Physical Layer Specs

- Operates in World ISM Bands
  - North America, Australia, etc. 915 MHz or 2.4GHz bands
  - Europe: 868 MHz or 2.4 GHz bands
- Our MicaZs operate in 2.4 GHz frequency band
  - Multiple channels available, some overlapping with 802.11 channels
  - 802.11 channel access considered as noise for our MicaZs
- Uses DSSS

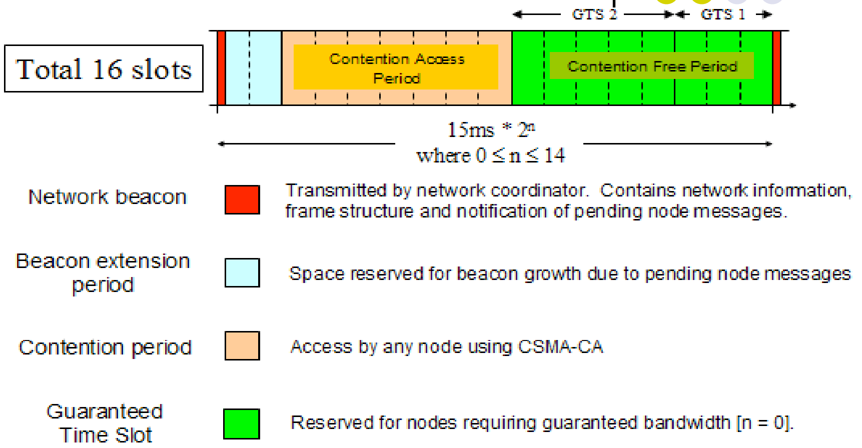
PHY	Frequency Band		Spreading Parameters		Data Parameters		
	Frequency	No. of channels	Chip Rate	Modulation	Bit Rate	Symbol Rate	Modulation
868/915 MHz PHY	868-868.6 MHz	1	300 kchips/s	BPSK	20 kbps	20 kbaud	BPSK
	902-928 MHz	10	600 kchips/2	BPSK	40 kbps	40 kbaud	BPSK
2.4 GHz PHY	2.4 - 2.4835 GHz	16	2.0 Mchips/s	O-QPSK (MSK)	250 kbps	62.5 kbaud	16-ary Orthogonal

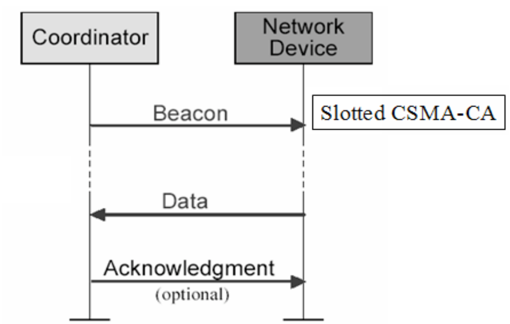
802.15.4 MAC Layer Specs

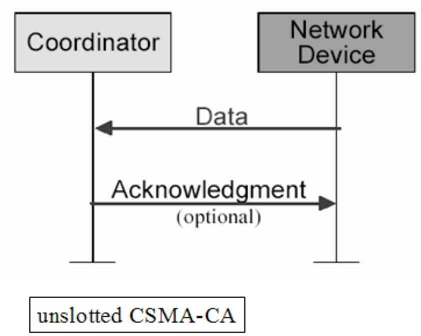
- CSMA-CA (like 802.11) channel access scheme
- Unlike 802.11 no RTS/CTS mechanism (due to relatively low data rate collisions are much less likely)
- Different Modes of Operation Depending on Nature of Traffic
  - Periodic Transmissions
    - Beacon Mode
  - Intermittent Transmissions
    - Disconnection Mode, node not attached to network when it doesn't need to communicate (energy savings!)
  - Low Latency Transmissions
    - Guaranteed Time Slot (GTS), allows for device to get an assigned time slot in super frame (a TDMA scheme)
- 16 bit short addressing scheme or 64bit long addressing scheme
- Four MAC frame types:
  - Beacon Frame
  - Data Frame
  - ACK Frame
  - MAC Command Frame

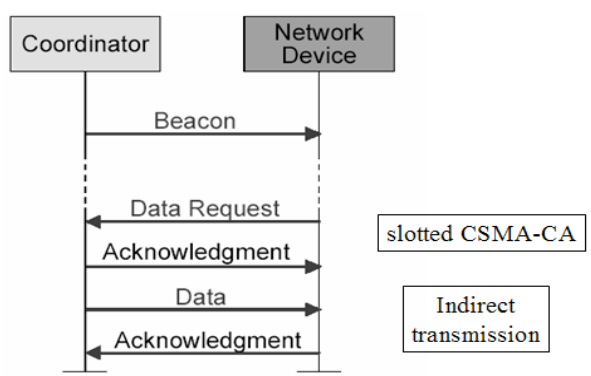
Beacon Mode and Non-Beacon Mode

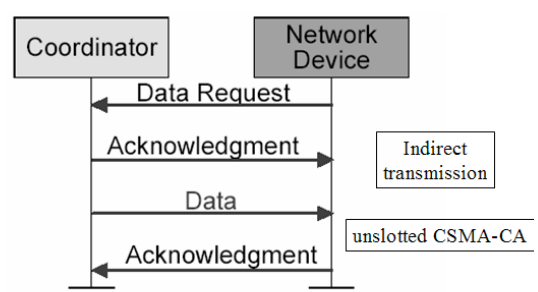
- 802.15.4 MAC using Slotted CSMA-CA (with beacons) and Guaranteed Time Slots











- Timing diagrams for information exchange at MAC layer using slotted CSMA-CA and unslotted CSMA-CA

Network Nodes

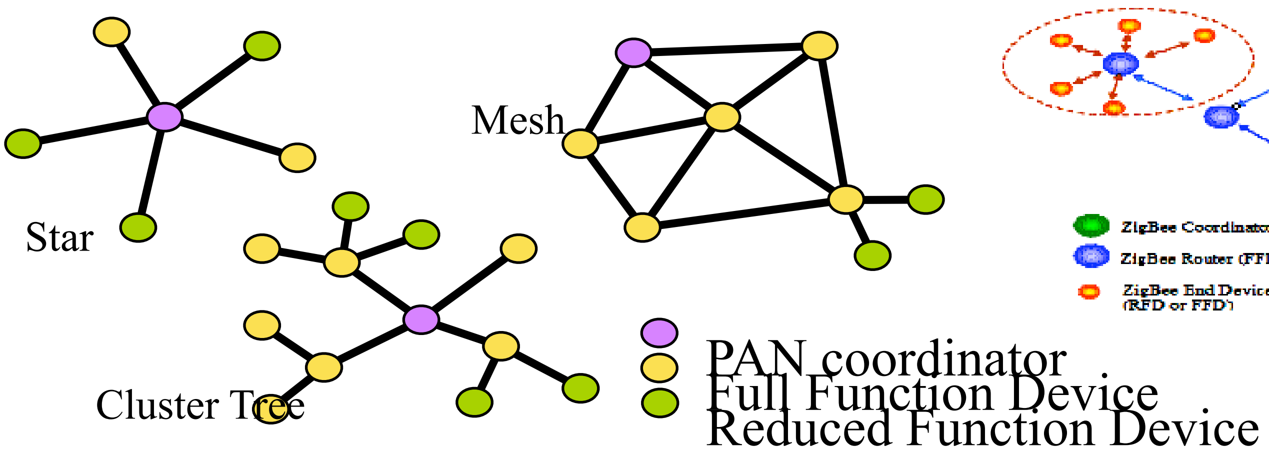
- Two different types of nodes available (reduces cost for large networks)
  - Full Function Device (FFD) – Capable of functioning in any topology, capable of acting as a coordinator, capable of talking to any other device in network
  - Reduced Function Device (RFD) – Capable of communicating in a star topology and only to a FFD, cannot be a coordinator
- Significant cost reduction for RFDs due to fewer requirements for hardware
- MICAz motes are all FFDs

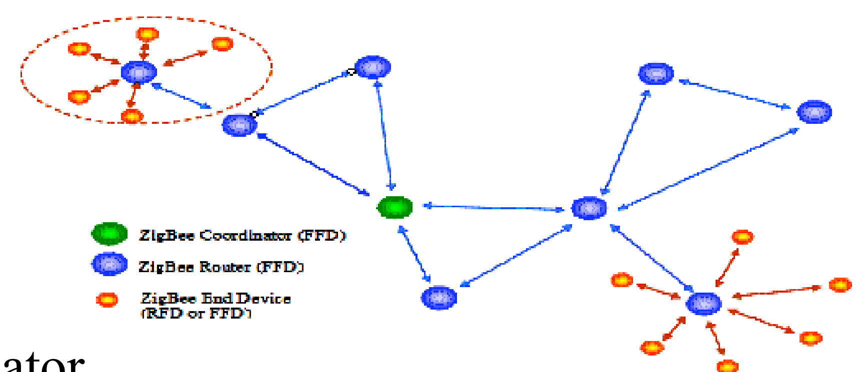
Network Layer Responsibilities

- **Starting a network** – able to establish a new network
- **Joining and Leaving Network** – nodes are able to become members of the network as well as quit being members
- **Configuration** – Ability of the node to configure its stack to operate in accordance with the network type
- **Addressing** – The ability of a ZigBee coordinator to assign addresses to devices joining the network
- **Synchronization** – ability of a node to synchronize with another node by listening for beacons or polling for data
- **Security** – ability to ensure end-to-end integrity of frames
- **Routing** – nodes can properly route frames to their destination

Network Layer and Network Topologies

- Self-Configuring (Network creation, Route Discovery, Data Forwarding) and Self-Healing Network (Data routed around broken routes)
- The network layer uses a form of Ad hoc On-demand Distance Vector routing (AODV)
- Uses Motorola’s clustering tree algorithm
  - Clusters added, Networks can be combined or split





Application Support Layer Responsibilities

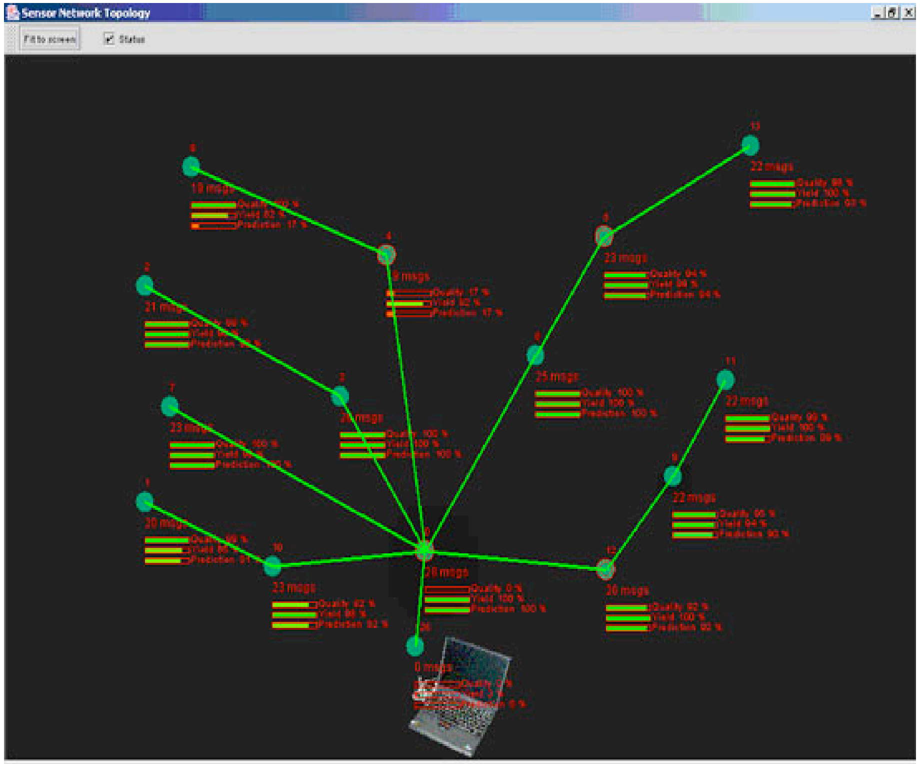
- Zigbee Device Object (ZDO) maintains what the device is capable of doing and makes binding requests based on these capabilities
- Discovery – Ability to determine which other devices are operating in the operating space of this device
- Binding – Ability to match two or more devices together based on their services and their needs and allow them to communicate

MicaZ,TinyOS, and Zigbee

- Our MicaZ motes do use the 802.15.4 standard defined in 2003
- Our MicaZ motes do not use the network and application layers defined by the Zigbee Alliance's network and application layers
  - Zigbee upper layers had not been finalized in time for Crossbow
- Our MicaZ motes are using TinyOS 1.1.7 and Crossbow's mesh networking stack

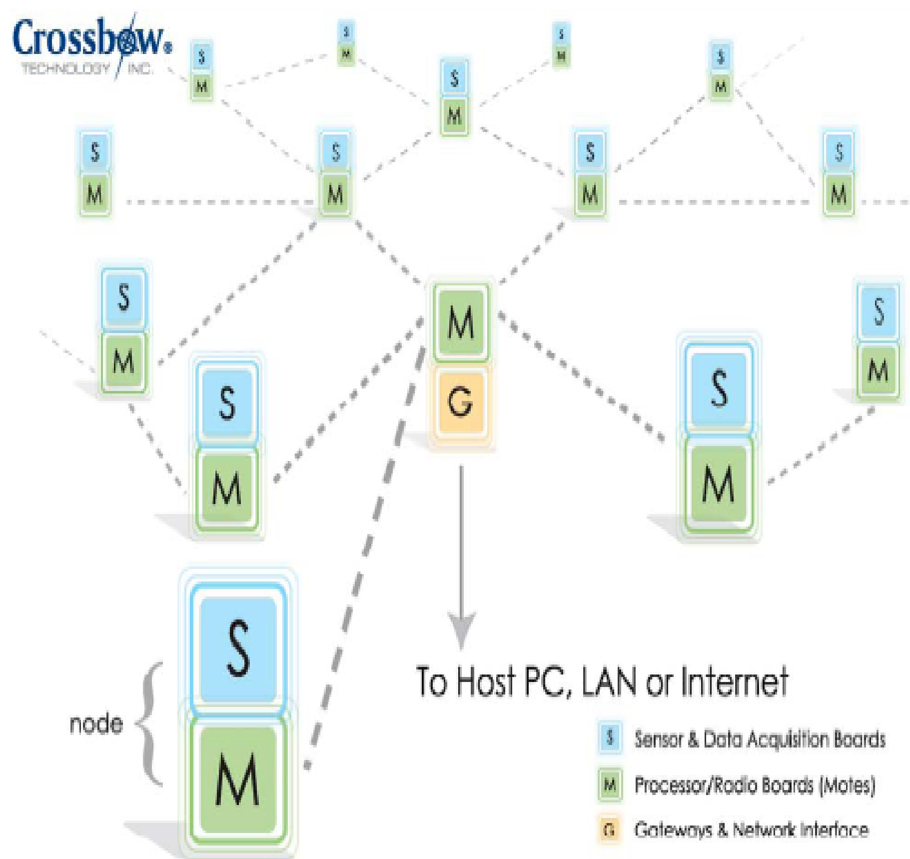
Crossbow Network & Application Layers

- Network Layer:
  - Any Network Layer/ Routing Algorithm can be implemented in TinyOS
    - Many available already
- Application Layer: open-source TinyOS supported
  - Applications can be developed for use with TinyOS



More 802.15.4 Specs

- MicaZ Power Consumption
  - 30 μW during sleep
  - 33 mW while active
- MicaZ Lifetime
  - ~ 1 year (Zigbee specifies up to 2 years)
- MicaZ Range
  - 75 – 100 m (outdoors)
  - 20 – 30 m (indoors)
    - Indoor range tested in Rhodes Hall



Equipment

- 8 MICAz processor/radio boards (TinyOS & Surge software preloaded)
- 18 MICAz (no software loaded)
- 4 light/temp/acoustic/seismic/magnetometer sensor boards
- 21 light/temp/acoustic boards
- A data acq. Board with temp/humidity sensor
- 1 ethernet gateway/programming board
- 1 serial gateway/programming board
- 5 Stargate Boards & Daughter Cards

MICAz MOTE

- IEEE 802.15.4
- 250 kbps radio
- 128KB program flash memory
- 512KB measurement log memory (xbow estimates > 100000 samples)
- 10 bit Analog to Digital Converter
- Red, Green, & Yellow LEDs

Stargate Gateway

- 400MHz RISC Processor
- 64MB RAM, 32MB flash
- Embedded Linux (10MB on flash)
- AC powered, optional battery
- Can be connected to MICAz
- Ethernet, USB, RS-232, PCMCIA, Compact Flash

TinyOS

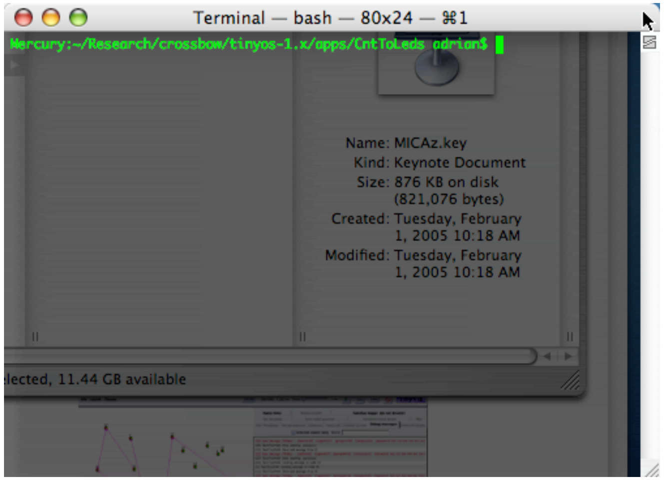
- Open Source Operating System designed for MOTEs
- Programs written in an extension of C called nesC
  - TinyOS is event driven
  - nesC - wire together *components* that handle *events*/fire *commands* through *interfaces* to build an application (highly modular)
- Preinstalled (8 motes) Surge ad-hoc multi-hop (Destination-Sequenced Distance Vector routing) software (xbow) written in nesC

Software -> MOTES

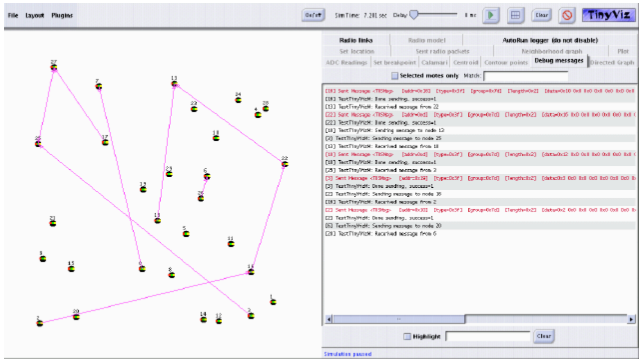
- RS-232 serial connection gateway & programming/flashing board
- Ethernet gateway & programming/flashing board
- Wireless mote programming via deluge TinyOS software

Simulation Tools

- TOSSIM - TinyOS simulator
  - simulates application code more so than a network simulation like ns2, Opnet



- TinyViz - graphical interface for TOSSIM
  - can be extended with plug-ins



Possible Applications

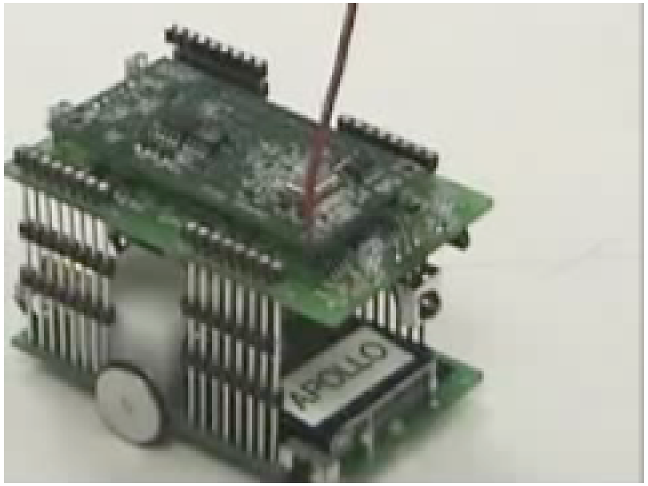
- Routing Algorithm Implementation
- In network data processing
  - e.g. Query a single node for network mean temp. & temp. range, average calculated by nodes rather than gateway
- Lifetime Extension scheme implementation
- Trust based Routing

Other Projects using TinyOS: FireBug

- GPS & thermal sensors on mote for monitoring forest fires
- motes route using *mh6* protocol used in surge demo program
  - DSDV (Destination Sequence Distance Vector) table based routing
  - Separate data & route packets
  - route packets used for calculating link efficiency
  - motes forward data only to ‘parent’ node with highest link efficiency
- MySQL & PHP Web-based monitoring program

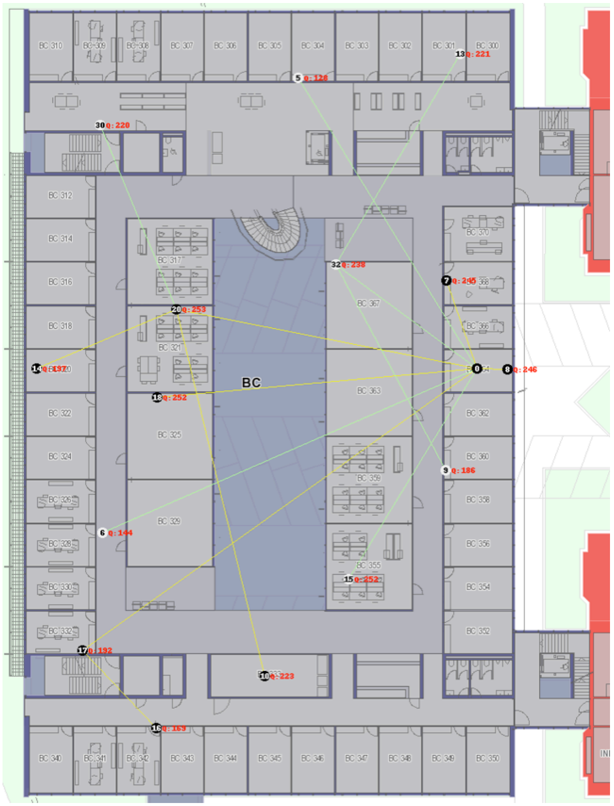
Robomote

- Custom mobile mote
- Atmel processor similar to MICAz.
- TinyOS software
  - Bacterium inspired movement -> biased random walk
  - biased random walk towards light source
- 20-30 min. running time
  - actuation (motors) highest drain @ .72 W
  - simultaneous RX/TX @ .588 W



Sensor Scope

- Testbed deployed at the EPFL campus
- 20 mica2 and micadot motes
- Reports sensor data in real time on the internet, also allows sending of commands to motes with password authentication.



MANTIS

- MANTIS operating system running on Mica2 & MicaZ motes
- Multi-threaded OS in place of TinyOS with more C-like API
- Projects dealing with security, sensor user interfaces, time synchronization, routing protocols, low power operation
- Used to teach a WSN class which implemented above topics as well as a flash file system.

MANTIS
TRAVELER
University of Colorado, Boulder

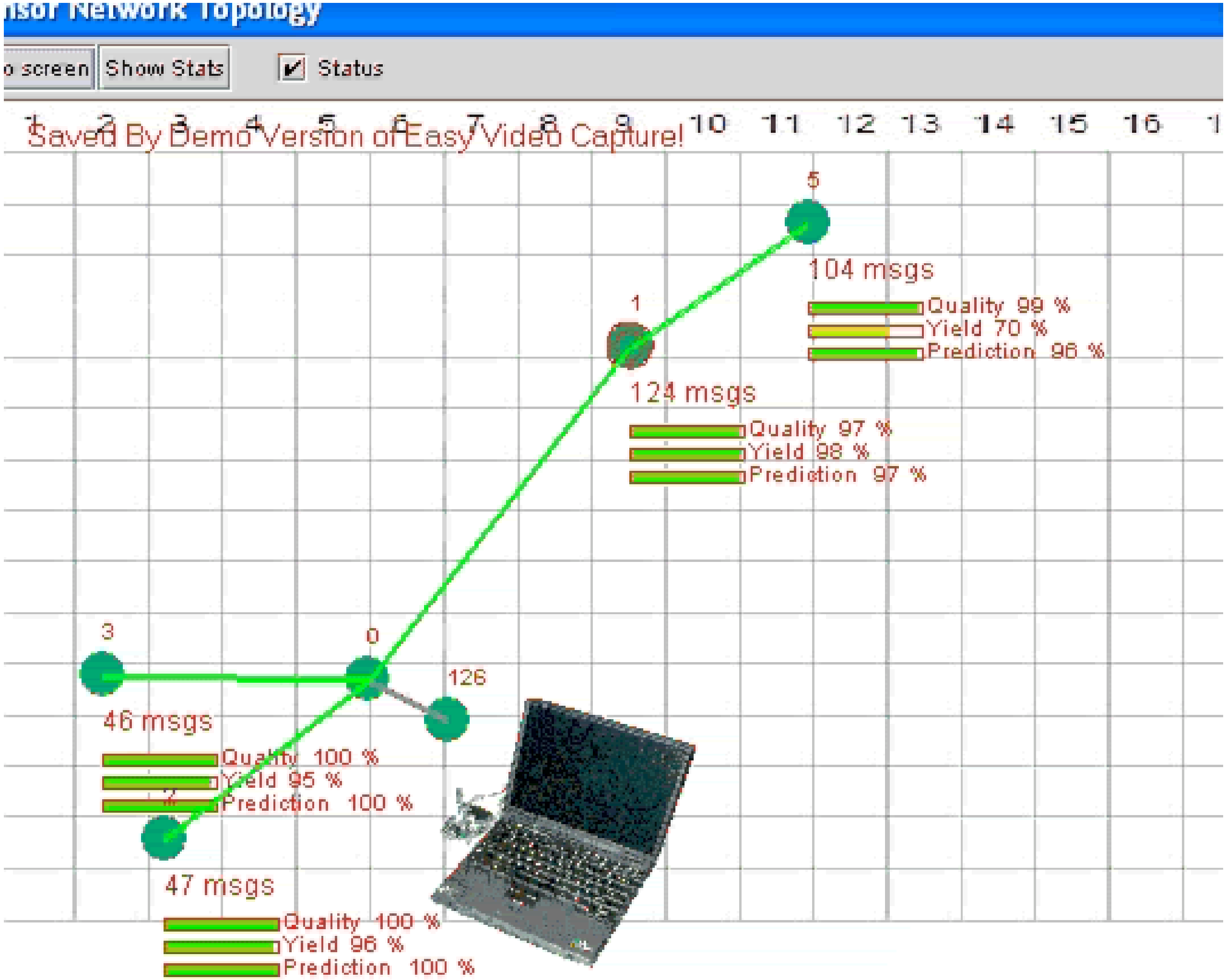
Open Questions

- What happens to temporal accuracy if we sense and store before broadcasting?
  - energy savings from a sensing only state
- What battery life will we typically see, how does TX power affect this?
  - we have several transmitting powers to choose from
- How accurate are our sensors?
  - various types of sensors on mote
- Complexity of code possible on a MicaZ?

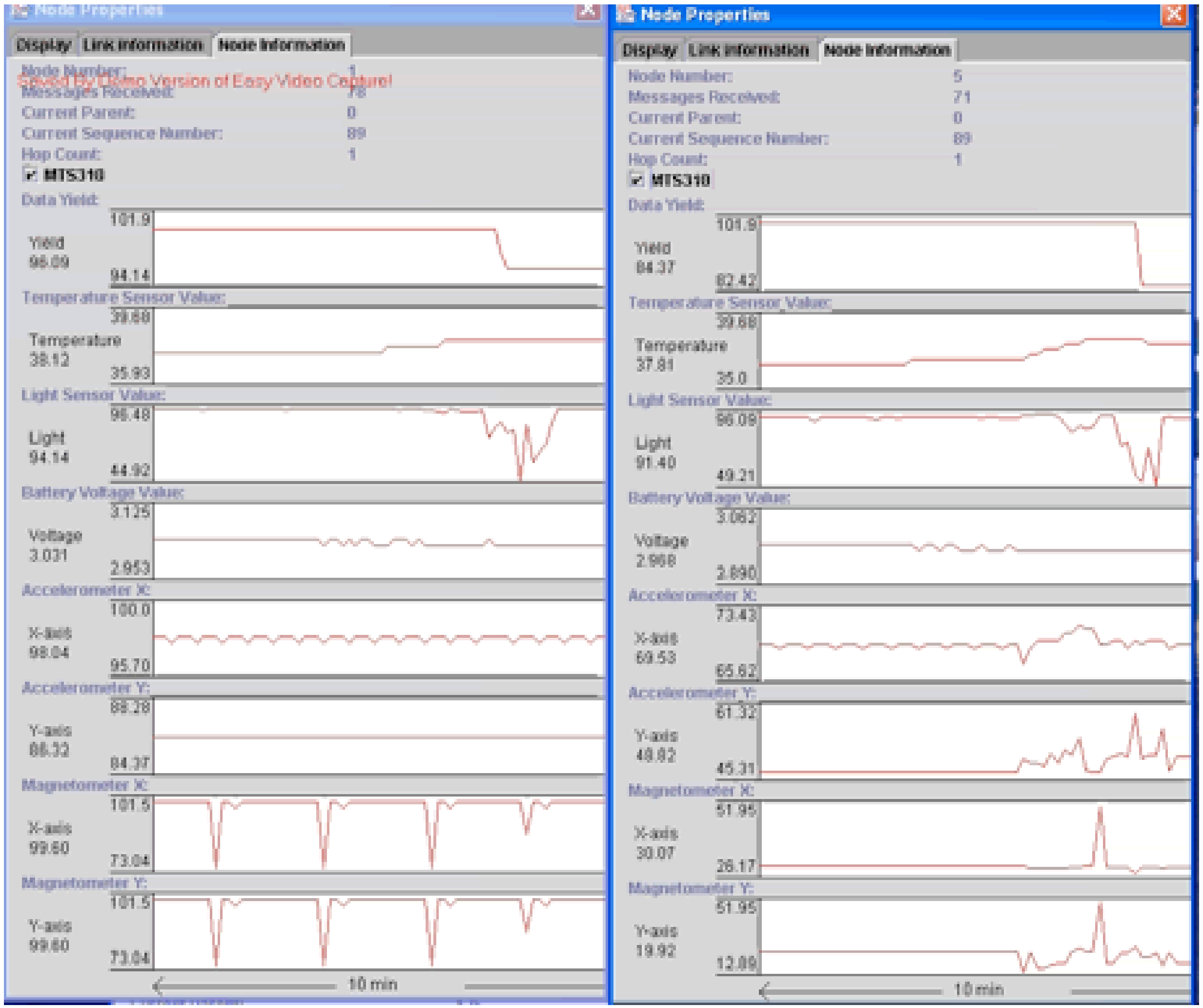
Demonstration of Equipment

- Surge & Surge Network Viewer
  - xbow existing multi-hop software
- Blink
  - LED's on motes blink independently
- CntToLeds
  - LED's used as 3 digit binary display

Surge Network Viewer



Surge-Viewer Data



Questions

- A survey was conducted mid-2002 on the characteristics of a wireless sensor network most important to its users
- In order of importance, these characteristics are
  - 1. Data Reliability
  - 2. Battery Life
  - 3. Cost
  - 4. Transmission Range
  - 5. Data Rate
  - 6. Data Latency
  - 7. Physical Size
  - 8. Data Security

References

- Crossbow Website, www.xbow.com
- Website of Zigbee Alliance, www.zigbee.org
- IEEE Standard for Information technology-Telecommunications and information exchange between systems-Local and metropolitan area networks-Specific requirements. Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs), (October 2003).
- Patrick Kinney, Chair of IEEE 802.15.4 TG, “ZigBee Technology: Wireless Control that Simply Works,” White Paper (October 2003)
- William C. Craig, “Zigbee: ‘Wireless Control That Simply Works’,” White Paper (2004)
- Bob Heile, ZigBee Alliance Chairman
- Taekyoung Kwon, “IEEE 802.15.4,” Presentation http://mmlab.snu.ac.kr/~tk/802_15_4.ppt#34
- Samir Goel and Tomasz Imielinski, “Etiquette protocol for Ultra Low Power Operation in Sensor Networks,” Presentation http://www.winlab.rutgers.edu/pub/docs/iab/2004Fall/14%20Goel.pdf
- Robomote: Enabling Mobility In Sensor Networks KARTHIK DANTU MOHAMMAD RAHIMI HARDIK SHAH SANDEEP BABEL AMIT DHARIWAL and GAURAV SUKHATME Dept of Computer Science University of Southern California

References (cont.)

- nesC Website, nescc.sourceforge.net
- Robomote Home Page, http://www-robotics.usc.edu/~robomote/
- FireBug Home Page, http://firebug.sourceforge.net/index.php
- TinyOS Tutorial, www.tinyos.net/tinyos-1.x/doc/tutorial/lesson5.html
- Joseph Polastre, Robert Szewczyk, Cory Sharp, David Culler, "The Mote Revolution: Low Power Wireless Sensor Network Devices," Presentation http://webs.cs.berkeley.edu/papers/hotchips-2004-motes.ppt#2
- MANTIS Project Home Page, http://mantis.cs.colorado.edu/tikiwiki/
- SensorScope Home Page, http://sensorscope.epfl.ch/index.php