# Wireless Sensor Networks (WSNs)

# Wireless Sensor Networks

- A distributed connection of nodes that coordinate to perform a common task.
- In many applications, the nodes are **battery powered** and it is often very difficult to recharge or change the batteries.
- Prolonging network lifetime is a critical issue.
- Sensors often have long period between transmissions (e.g., in seconds).
- Thus, a good WSN MAC protocol needs to be **energy efficient.**

# Open Experimental Platform

Commercial Off The Shelf Components (COTS)

Services

Networking

TinyOS

**WeC 99**
**"Smart Rock"**

Small microcontroller
8 kB code
512 B data

Simple, low-power radio
10 kbps ASK

EEPROM (32 KB)

Simple sensors

**Rene 11/00**

Designed for experimentation

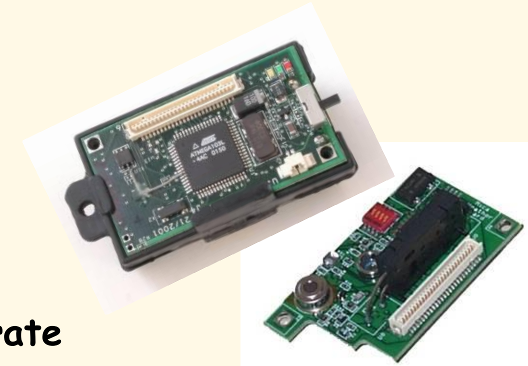
-sensor boards

-power boards

**Dot 9/01**

Demonstrate scale

**Mica 1/02**

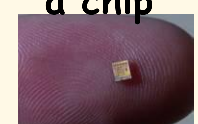


NEST open exp. Platform
128 kB code, 4 kB data
40kbps OOK/ASK radio
512 kB Flash

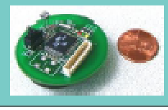
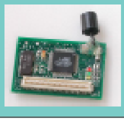
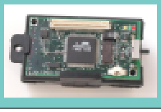
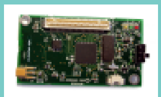
**Telos 4/04**
Robust
Low Power
250kbps
Easy to use

**Mica2 12/02**
38.4kbps radio
FSK

**Spec 6/03**
"Mote on a chip"



# Mote Evolution

| Mote Type<br>Year | *WeC*<br>1998 | *René*<br>1999 | *René 2*<br>2000 | *Dot*<br>2000 | *Mica*<br>2001 | *Mica2Dot*<br>2002 | *Mica 2*<br>2002 | *Telos*<br>2004 |
|---|---|---|---|---|---|---|---|---|
| |  |  | |  |  |  |  |  |
| Microcontroller | | | | | | | | |
| Type | AT90LS8535 | | ATmega163 | | ATmega128 | | | TI MSP430 |
| Program memory (KB) | 8 | | 16 | | 128 | | | 60 |
| RAM (KB) | 0.5 | | 1 | | 4 | | | 2 |
| Active Power (mW) | 15 | | 15 | | 8 | | 33 | 3 |
| Sleep Power ($\mu$W) | 45 | | 45 | | 75 | | 75 | 6 |
| Wakeup Time ($\mu$s) | 1000 | | 36 | | 180 | | 180 | 6 |
| Nonvolatile storage | | | | | | | | |
| Chip | 24LC256 | | | | AT45DB041B | | | ST M24M01S |
| Connection type | $I^2C$ | | | | SPI | | | $I^2C$ |
| Size (KB) | 32 | | | | 512 | | | 128 |
| Communication | | | | | | | | |
| Radio | TR1000 | | | | TR1000 | CC1000 | | CC2420 |
| Data rate (kbps) | 10 | | | | 40 | 38.4 | | 250 |
| Modulation type | OOK | | | | ASK | FSK | | O-QPSK |
| Receive Power (mW) | 9 | | | | 12 | 29 | | 38 |
| Transmit Power at 0dBm (mW) | 36 | | | | 36 | 42 | | 35 |
| Power Consumption | | | | | | | | |
| Minimum Operation (V) | 2.7 | | 2.7 | | 2.7 | | | 1.8 |
| Total Active Power (mW) | 24 | | | | 27 | 44 | 89 | 41 |
| Programming and Sensor Interface | | | | | | | | |
| Expansion | none | 51-pin | 51-pin | none | 51-pin | 19-pin | 51-pin | 10-pin |
| Communication | IEEE 1284 (programming) and RS232 (requires additional hardware) | | | | | | | USB |
| Integrated Sensors | no | no | no | yes | no | no | no | yes |

WPI

"The Mote Revolution: Low Power Wireless Sensor Network Devices"
Hot Chips 2004 : Aug 22-24, 2004 Polastre et al.

# Outline

- Introduction, Definition, Pictures
- Wireless Sensor Network (WSN) Applications
- WSN Details
- Types Wireless Sensor Networks (WSNs)
- Tiered Architectures
- Dynamic Cluster Formation
- Power-Aware MAC Protocols
  - SMAC, TMAC, WiseMAC, TRAMA, SCP-MAC, AS-MAC, Crankshaft

# Case Study in Crossbow Mote Deployment

# Water in the Vineyard

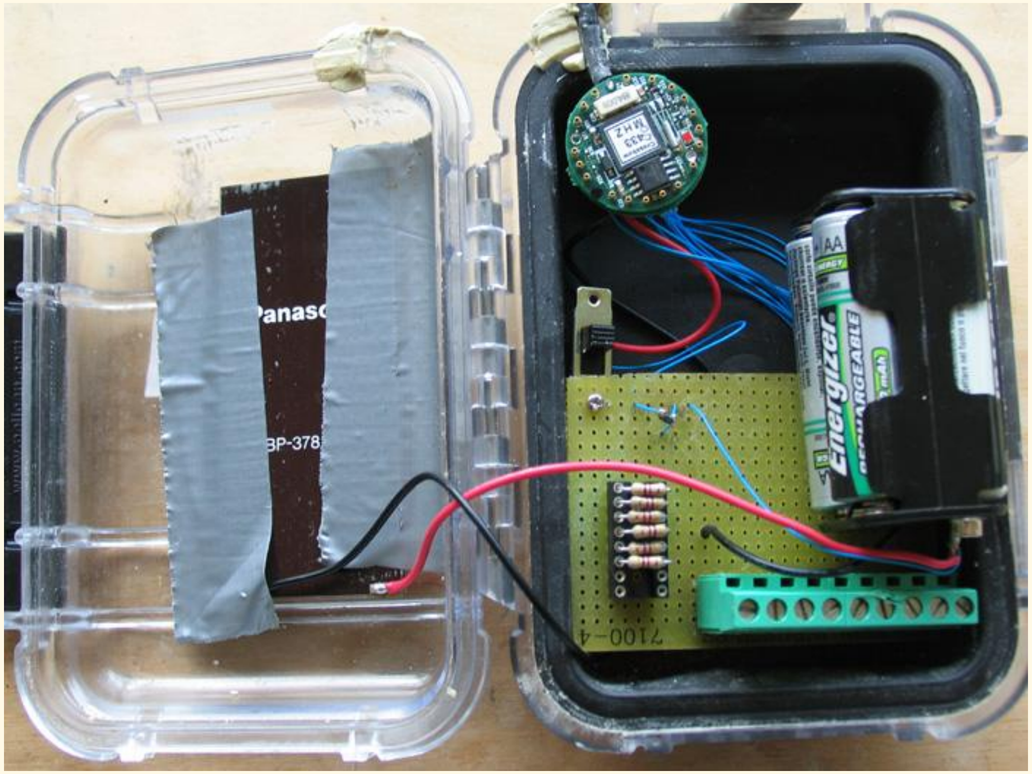
# Vineyard Installation

- At each Mote location:
  - 2 soil moisture sensors
  - 12” and 24” depth
  - 1 soil temp sensor to calibrate soil moisture sensors

# Power Supply

- 2 month max battery life now with 10 minute sampling interval
- Decided to use solar power, always there when doing irrigation. Solar cell $10 in small quantities and need a $.50 regulator.

# Vineyard Mote Prototype

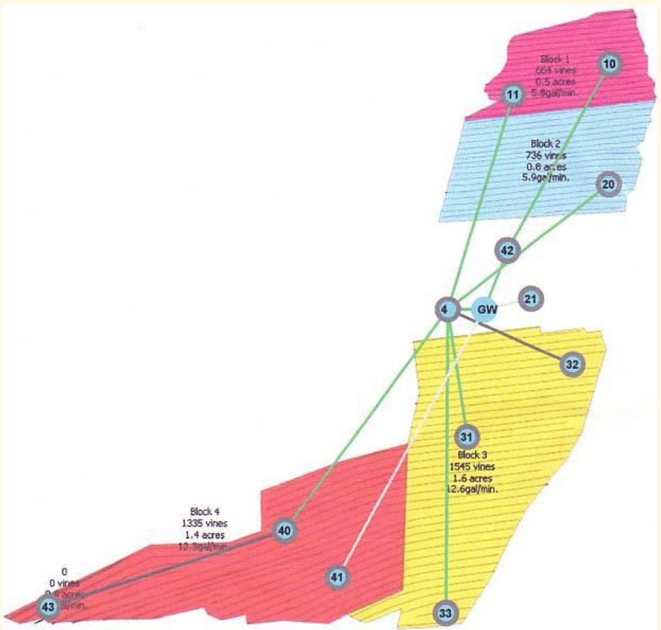


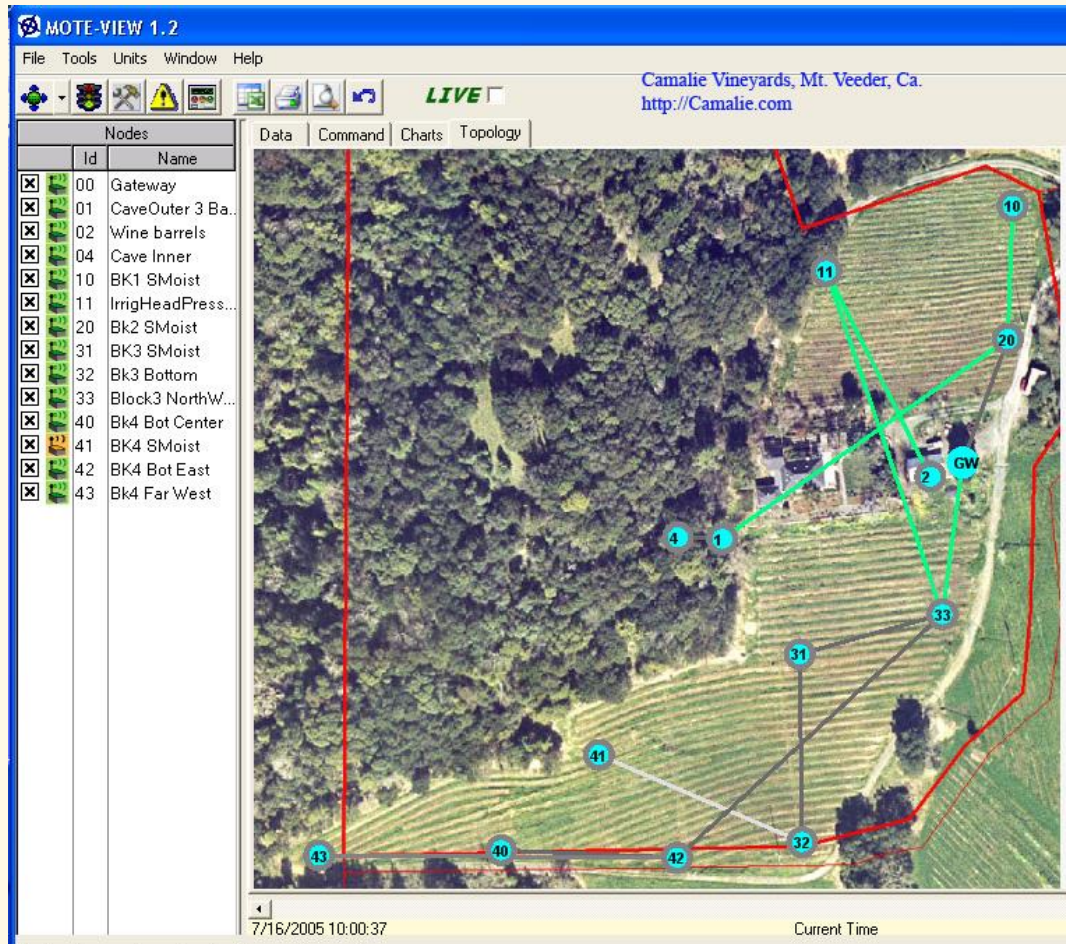
- 433MHz Mica2dot
- Solar power supply
- Up to 6 resistive sensor inputs

# Network Maps

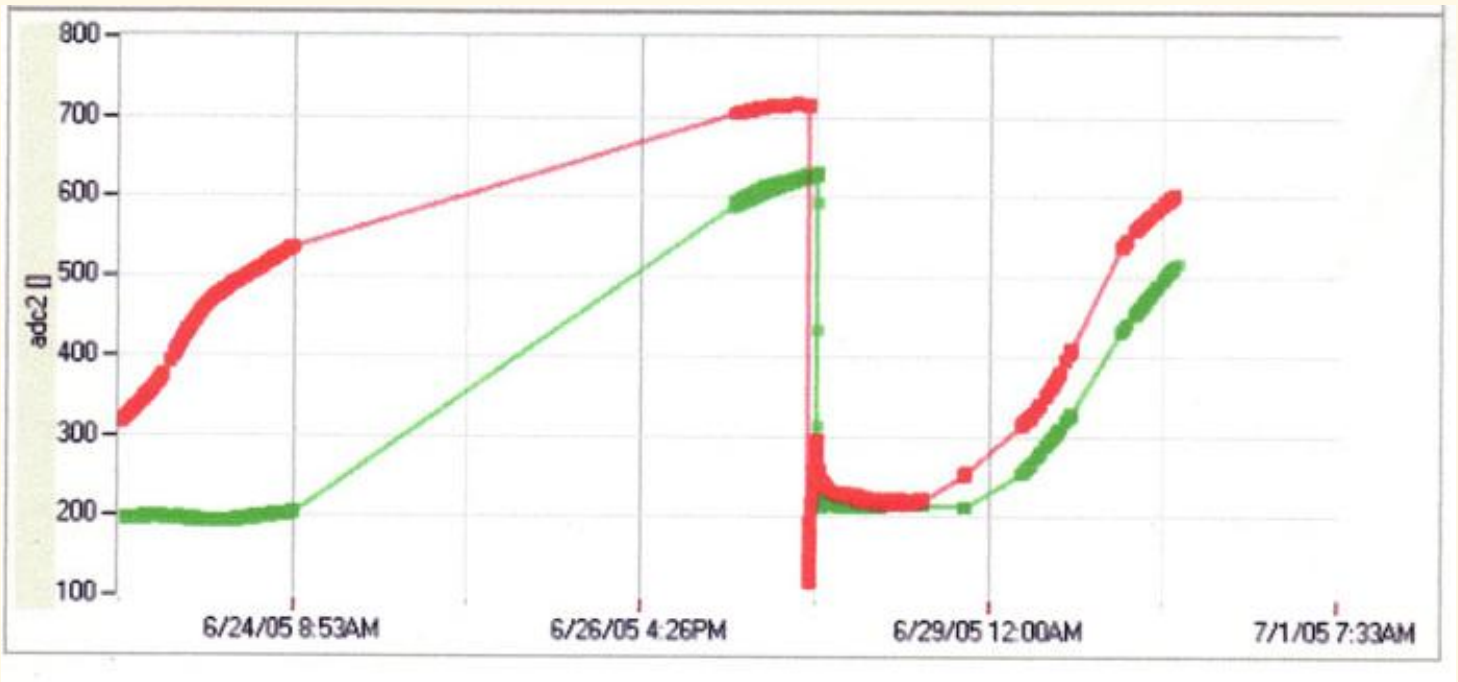
13 nodes late 2005,   18 nodes in 2006

Irrigation Block Map



# Soil Moisture Data




- Red = 12” depth soil moisture
- Green= 24” depth soil moisture
- Note delay deeper
- More frequent, shorter watering keeps water shallow

# WSNs for Assisted Living

Alarm-Net
University of Virginia

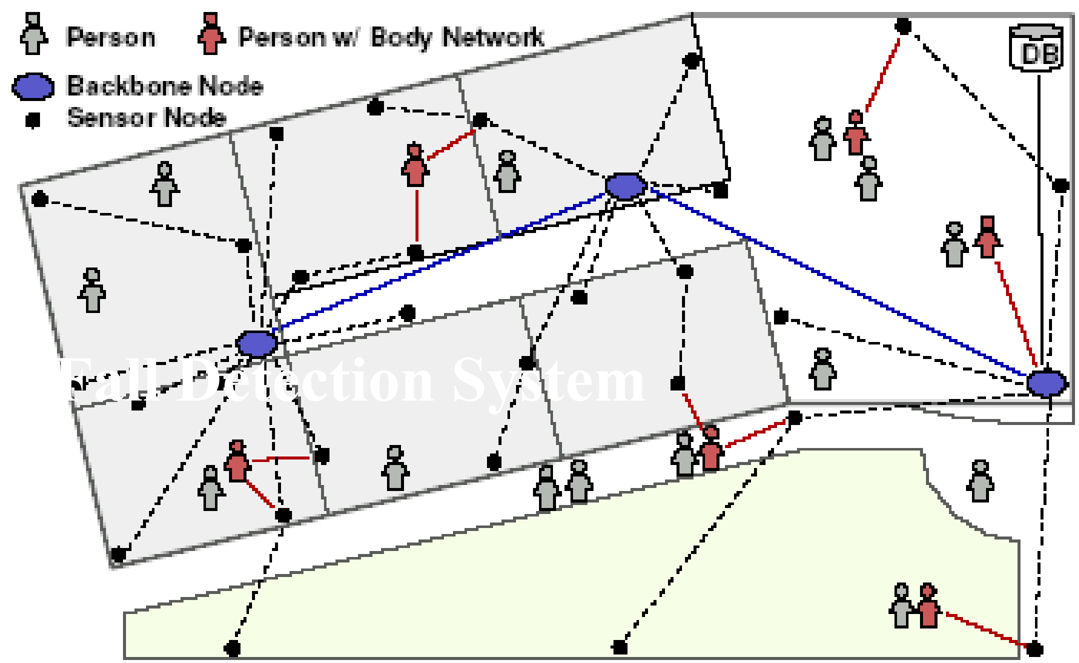



Figure 1. Assisted-living deployment example, showing connections among sensors, body networks, and backbone nodes.

# WSNs for Assisted Living

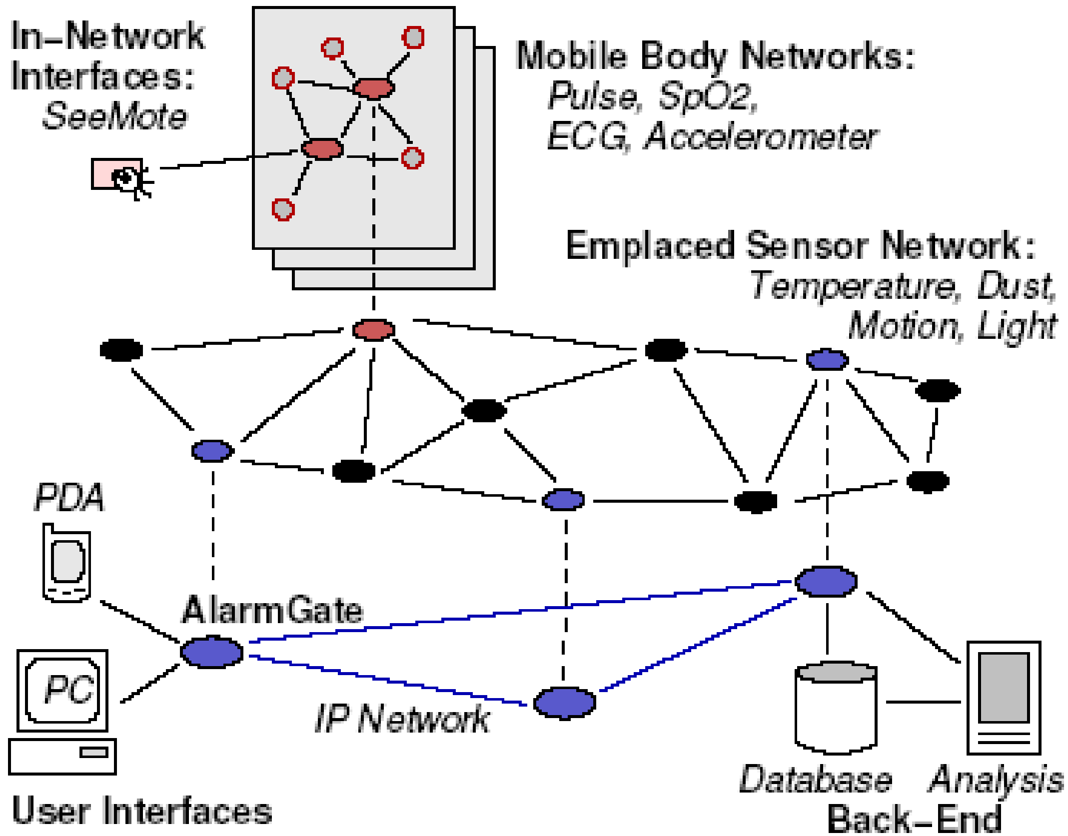



Figure 2. ALARM-NET architecture components and logical topology.

# WSNs for Assisted Living

Two-Tiered WSN Architecture

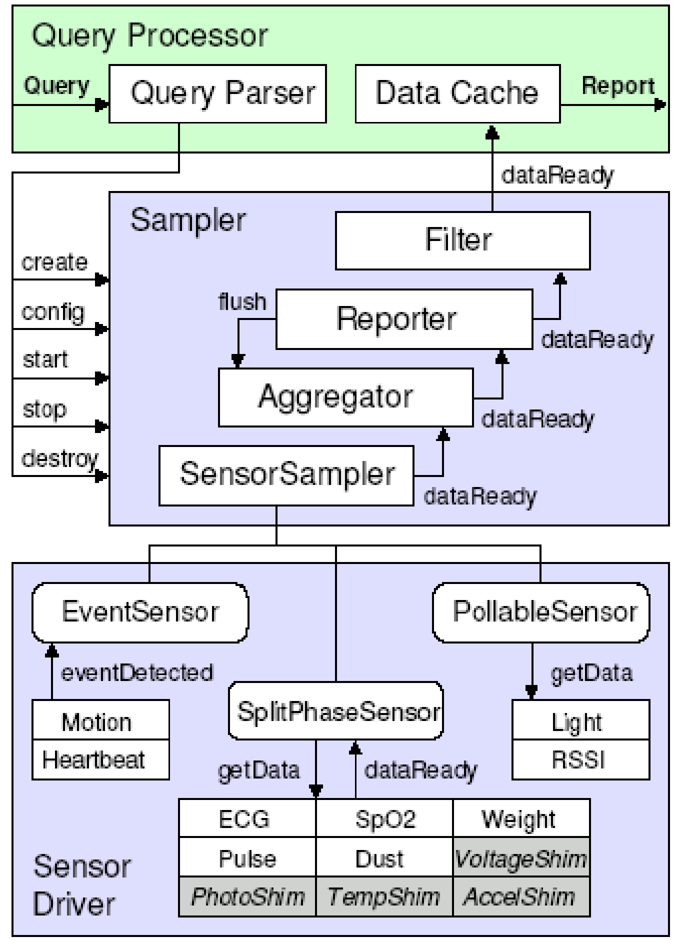



Figure 3. Query processing stack on sensor devices. The Query Processor parses queries, and starts the Sampler, which reads data from the sensor drivers on schedule, generating data that flows up the processing chain toward the Query Processor for reporting.

# Berkeley Fall Detection System

USING SMART SENSORS AND A CAMERA PHONE TO DETECT AND VERIFY THE FALL OF ELDERLY PERSONS

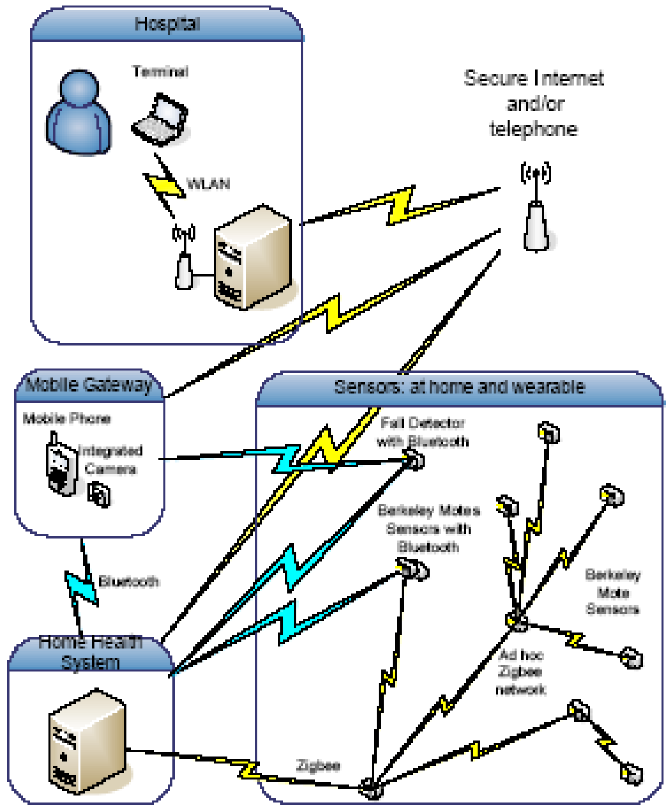



Figure 1: The Information Technology for Assisted Living at Home (ITALH) system overview

# Berkeley Fall Detection System

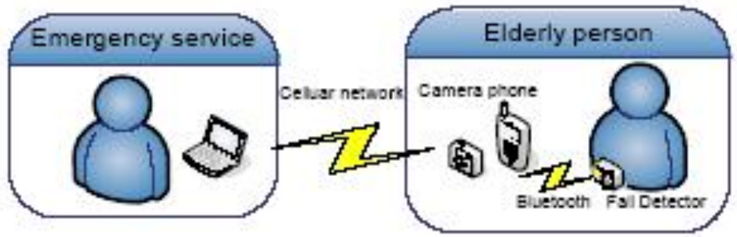



Figure 2: Fall detector system setup

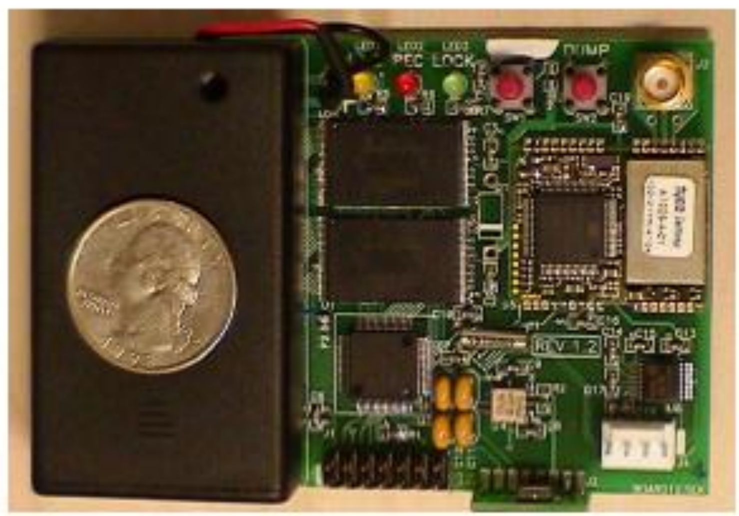


Figure 3: The Berkeley GPSADXL fall sensor

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# Wireless Sensor Networks

- Another attribute is **scalability and adaptability** to change in network size, node density and topology.
  - In general, nodes can die, join later or be mobile.
- Often high bandwidth is **not important**.
- Nodes can take advantage of short-range, mulit-hop communication to conserve energy.

# Wireless Sensor Networks

- Sources of energy waste:
  - Idle listening, collisions, overhearing and control overhead and overmitting.
  - Idle listening dominates (measurements show idle listening consumes between 50-100% of the energy required for receiving.)

Idle listening:: listen to receive possible traffic that is not sent.

Overmitting:: transmission of message when receiver is not ready.

# Power Measurements

| Symbol | Meaning | CC1000 | CC2420 |
|---|---|---|---|
| $P_{tx}$ | Power in transmitting | 31.2mW | 52.2mW |
| $P_{rx}$ | Power in receiving | 22.2mW | 56.4mW |
| $P_{listen}$ | Power in listening | 22.2mW | 56.4mW |
| $P_{sleep}$ | Power in sleeping | 3$\mu$W | 3$\mu$W |
| $P_{poll}$ | Power in channel polling | 7.4mW | 12.3mW |
| $t_{p1}$ | Avg. time to poll channel | 3ms | 2.5ms |
| $t_{cs1}$ | Avg. carrier sense time | 7ms | 2ms |
| $t_B$ | Time to Tx/Rx a byte | 416$\mu$s | 32$\mu$s |
| $T_p$ | Channel polling period | Varying | Varying |
| $T_{data}$ | Data packet period | Varying | Varying |
| $r_{data}$ | Data packet rate ($1/T_{data}$) | Varying | Varying |
| $L_{data}$ | Data packet length | 50B | 50B |
| $n$ | Number of neighbors | 10 | 10 |

**Table 1. Symbols used in radio energy analysis, and typical values for the Mica2 radio (CC1000) and an 802.15.4 radio (CC2420)**

# WSN Communication Patterns

- **Broadcast::** e.g., Base station transmits to all sensor nodes in WSN.
- **Multicast::** sensor transmit to a subset of sensors (e.g. cluster hear to cluster nodes)
- **Convergecast::** when a group of sensors communicate to one sensor (BS, cluster head, or data fusion center).
- **Local Gossip::** sensor sends message to neighbor sensors.

# Wireless Sensor Networks

- **Duty cycle:: ratio between listen time and the full listen-sleep cycle.**
- **central approach – lower the duty cycle by turning the radio off part of the time.**
- Three techniques to reduce the duty cycle:
  - TDMA
  - Schedule contention periods
  - LPL (Low Power Listening)

# Techniques to Reduce Idle Listening

- **TDMA** requires cluster-based or centralized control.
- **Scheduling** – ensures short listen period when transmitters and listeners can rendezvous and other periods where nodes sleep (turn off their radios).
- **LPL** – nodes wake up briefly to check for channel activity without receiving data.
  - If channel is idle, node goes back to sleep.
  - If channel is busy, node stays awake to receive data.
  - A long preamble (longer than poll period) is used to assure than preamble intersects with polls.

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# Tiered WSN Architectures

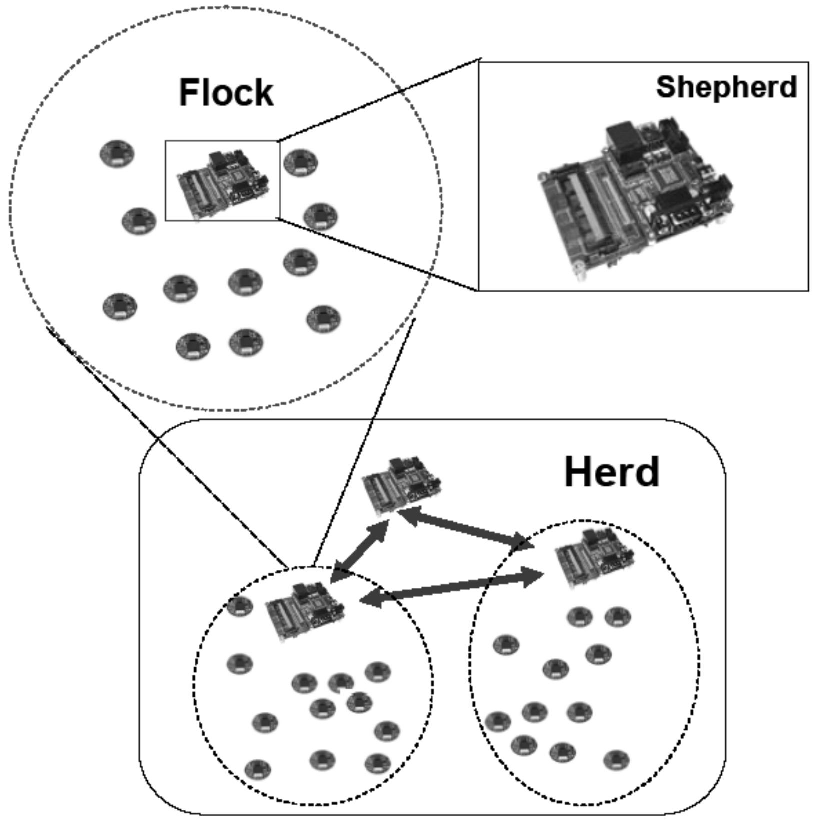



Figure 1: The Mote Herding architecture and its components, the *flock*, the *shepherd* and the *herd*

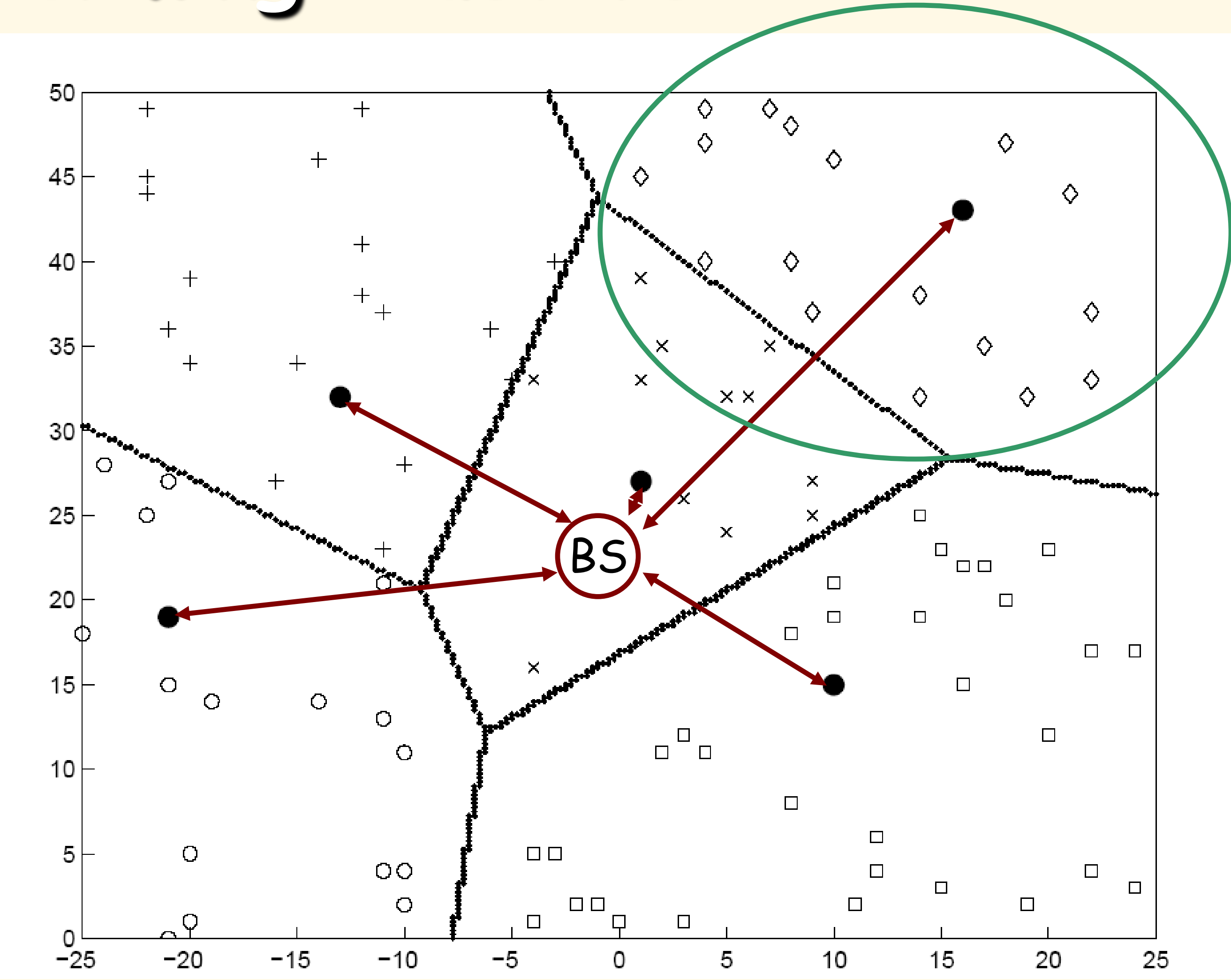
[ Stathopoulos]

# Dynamic
# Cluster Formation

# Choosing Cluster Heads/ Forming Clusters

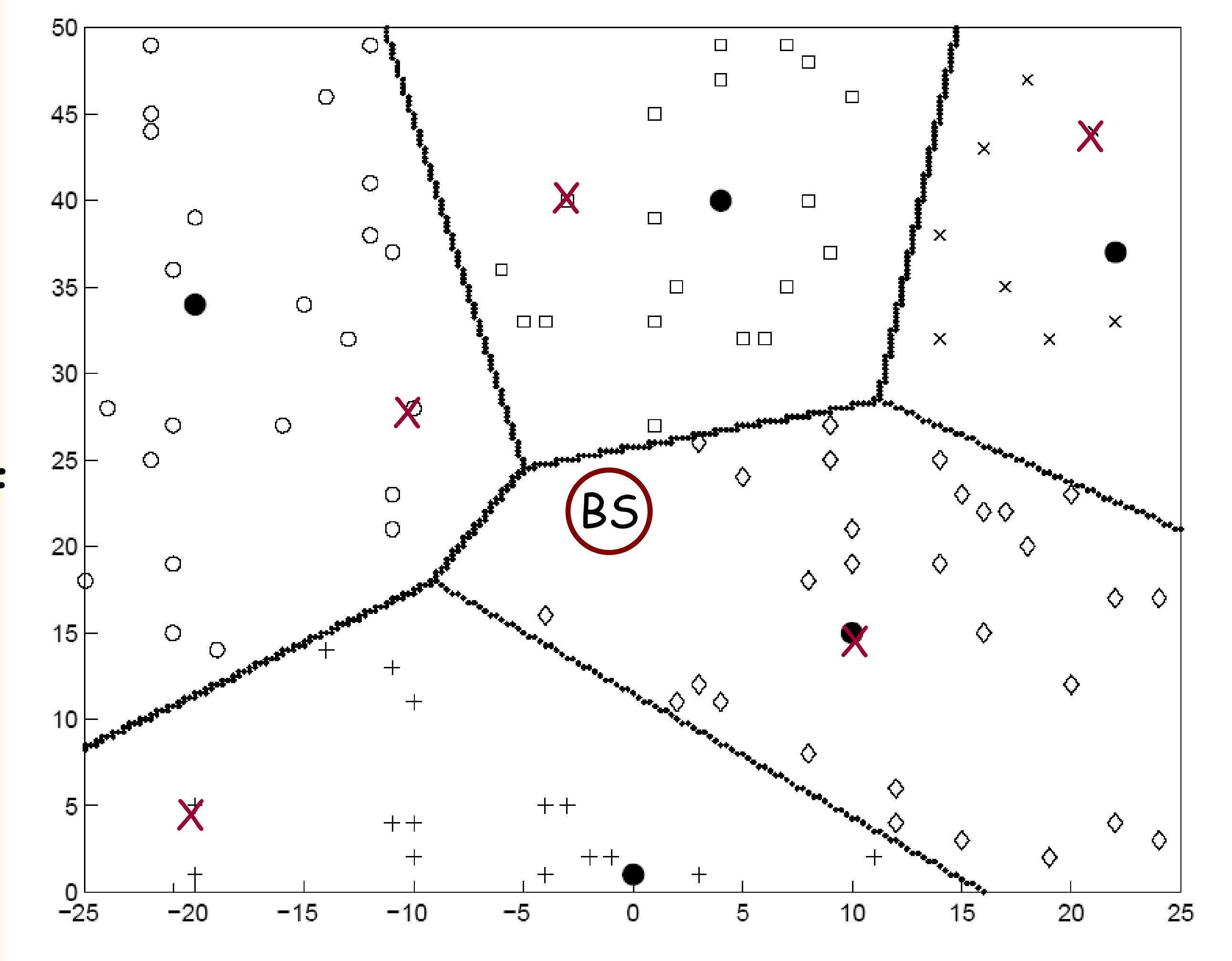
Two-tier scheme:

- A fixed number of cluster heads that communicate with BS (base station).
- Nodes in cluster communicate with head (normally TDMA).
- TDMA allows fixed schedule of slots for sensor to send to cluster head and receive head transmissions.



# Choosing Cluster Heads/ Forming Clusters

- Periodically select new cluster heads to minimize power consumption and maximize WSN lifetime.
- More complex problem when size of cluster changes dynamically.
- As time goes by, some sensor nodes die!
- Not worried about coverage issues!



# Dynamic Cluster Formation

- TDMA cluster algorithms:
  - LEACH, Bluetooth, …
- Rick Skowyra's MS thesis:

'Energy Efficient Dynamic Reclustering Strategy for WSNs'

  - 'Leach-like' with a fitness function and periodic reclustering.
  - He designed a distributed genetic algorithm to speed the recluster time.

# Power-Aware MAC Protocols

# Power Aware MAC Protocols

| | | | | | |
|---|---|---|---|---|---|
| 1997 | | | | | |
| 1998 | PAMAS | | | | |
| 1999 | | | | | |
| 2000 | | | | | |
| 2001 | SMAC | | | | |
| 2002 | LPL | NPSM | | | |
| 2003 | TMAC | TinyOS | EMACs | TRAMA | Sift |
| 2004 | BMAC | DMAC | DSMAC | LMAC | WiseMAC |
| 2005 | PMAC | ZMAC | SP | | |
| 2006 | SCP-MAC | | | | |
| 2007 | Crankshaft | | | | |
| 2008 | AS-MAC | | | | |

# Power Aware MAC Protocols

Three approaches to saving power:

1. **TDMA**: **TRAMA**, EMACs, LMAC

2. **Schedule**: PAMAS, SMAC, TMAC, DMAC, PMAC, **SCP-MAC** , Crankshaft, **AS-MAC**

3. **Low Power Listening**: LPL, BMAC, WiseMAC

**Cross-Layering**: SP, BSD

# Table I from WSN Survey Paper

TABLE I. COMPARISON OF MAC PROTOCOLS

| | *Time Synch. Needed* | *Comm. Pattern Support* | *Type* | *Adaptivity to Changes* |
|---|---|---|---|---|
| *S-MAC / T-MAC / DSMAC* | No | All | CSMA | Good |
| *WiseMAC* | No | All | np-CSMA | Good |
| *TRAMA* | Yes | All | TDMA / CSMA | Good |
| *SIFT* | No | All | CSMA/CA | Good |
| *DMAC* | Yes | Convergecast | TDMA / Slotted Aloha | Weak |