INTELLIGENT SENSORS AND SENSOR NETWORKS

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DESIGN ISSUES

DESIGN CONSIDERATIONS

Fault tolerance – The failure of nodes should not severely degrade the overall performance of the network

Scalability – The mechanism employed should be able to adapt to a wide range of network sizes (number of nodes)

Cost – The cost of a single node should be kept very low

Power consumption – Should be kept to a minimum to extend the useful life of network.

Hardware and software constraints – Sensors, location finding system, antenna, power amplifier, modulation, coding, CPU, RAM, operating system

Topology maintenance – In particular to cope to expected high rate of node failure

Deployment – Pre-deployment mechanisms and plans for node replacement and/or maintenance

Environment – At home, in space, in the wild, on the roads, etc.

Transmission media – ISM bands, infrared, etc.

DESIGN THEMES

Long-lived systems that can be **untethered** and **unattended**

- Low-duty cycle operation with bounded latency
- Exploit redundancy and heterogeneous tiered systems

Leverage data processing inside the network

- Thousands or millions of operations per second can be done using energy of sending a bit over 10 or 100 meters (Pottie00)
- Exploit computation near data to reduce communication

Self-configuring systems that can be deployed **ad hoc**

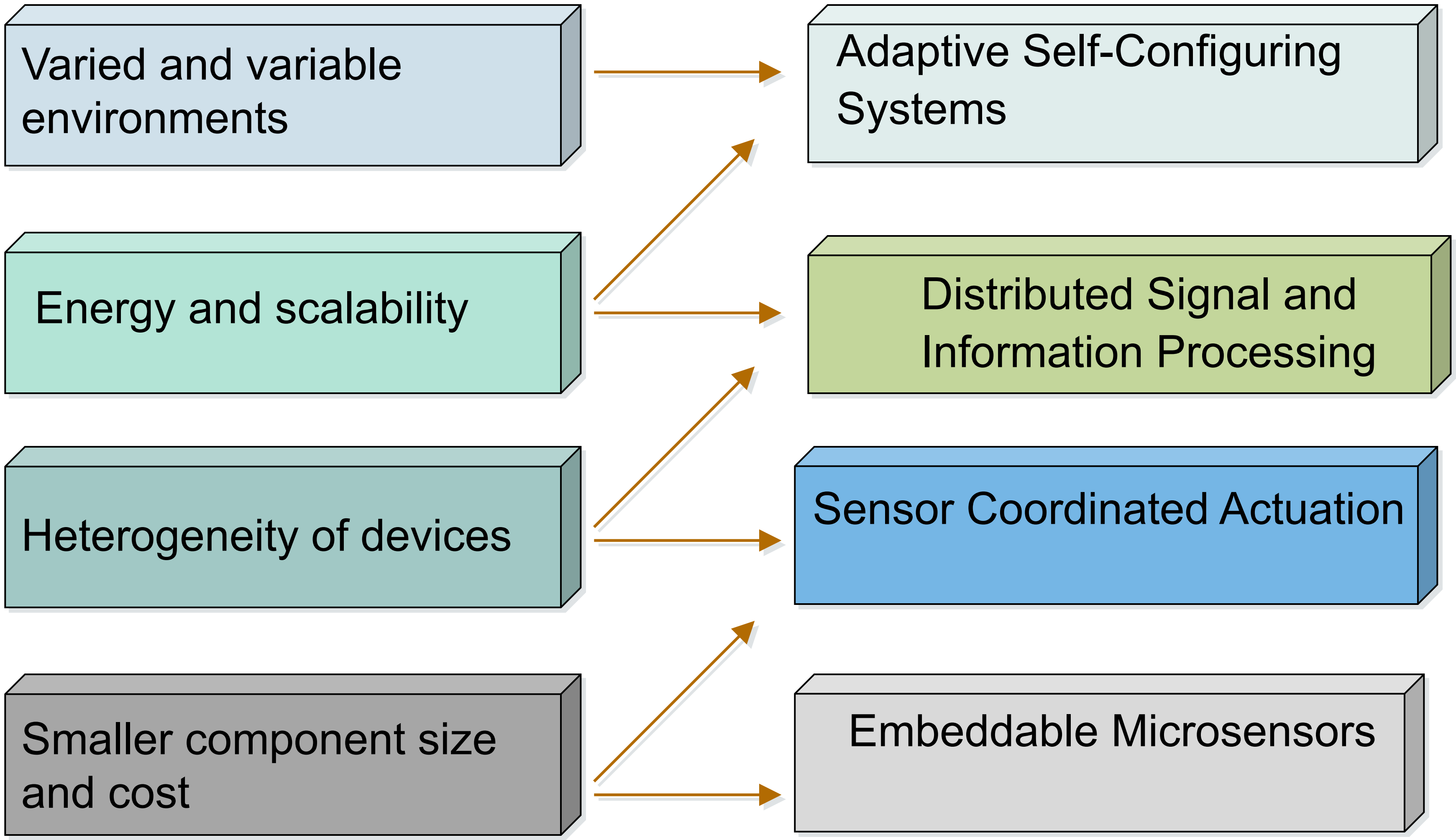
- Un-modeled physical world dynamics makes systems appear ad hoc
- Measure and adapt to unpredictable environment
- Exploit spatial diversity and density of sensor/actuator nodes

Achieve desired global behavior with **adaptive localized algorithms**

- Can’t afford to extract dynamic state information needed for centralized control

EMBEDDED NETWORK SENSORS ARCHITECTURE DRIVERS

Drivers



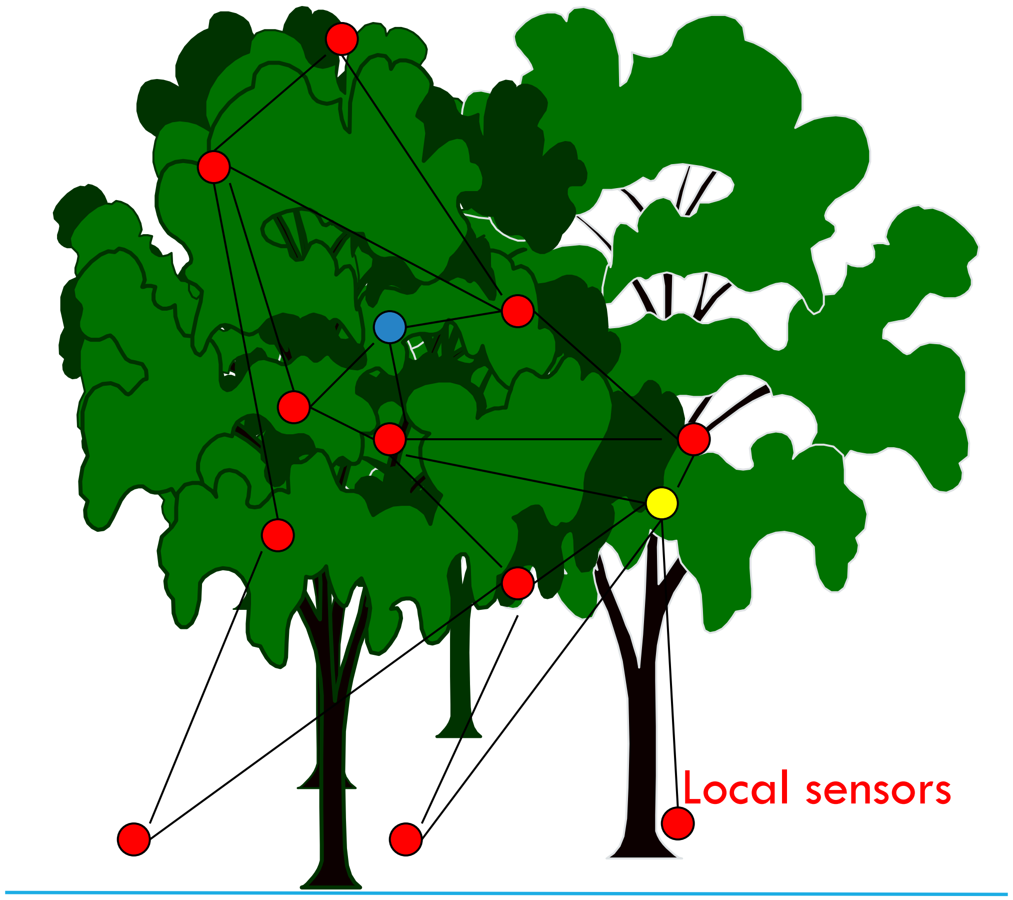
SELF-CONFIGURATION

- Each node assesses its connectivity and signals or actuates when it detects a depleted region.

- 'Healing' is collaborative self-organized deployment of nodes
  - Activate more/fewer nodes
  - Mobilize more/fewer nodes
  - Adjust duty cycle/power level of existing nodes…
- Assumptions:
  - No centralized processing; all nodes act based on locally available information.
  - A very large solution space; not seeking unique optimal solution.
  - Some links have high packet loss..

LONG-LIVED, SELF-CONFIGURING SYSTEMS

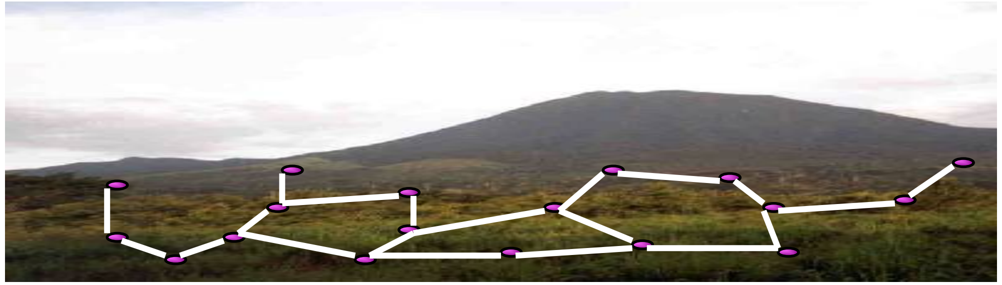
- Irregular configurations
- Network topology changes over time
- Hand configuration will fail -- scale, and variability



- Solution: local adaptation and redundancy

- Challenges:
  - Localization
  - Time Synchronization
  - Calibration
  - Information aggregation and storage
  - Event detection
  - Programming model!

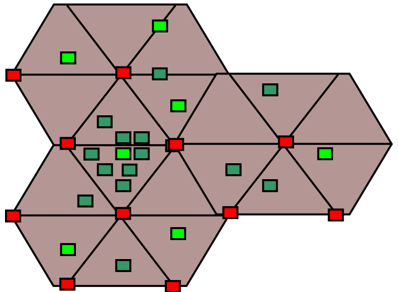
EXPLOITING REDUNDANCY EXAMPLE



- Efficient, multi-hop topology formation goal: exploit redundancy provided by high density to extend system lifetime while providing communication and sensing coverage.
  - If too **many** sensors active at the same time, increase energy consumption and competition for communication resources.
  - If too **few** nodes active, then lack of communication and/or sensing coverage.
  - **Central control/configuration** requires too much communication
  - Nodes should **self-configure** to find the right trade-off
  - Ultimately should adapt based on desired “fidelity”

Robustness and Scalability through Adaptation

- Adaptive mechanisms increase complexity but enable self-configuration for robustness and scalability
    - Self calibration to adapt to variations in sensor response and placement
    - Adjust duty cycle and transmit range as a function of node density and measured range (adaptive fidelity)
        - Balance increased system life-time with increased resolution
- Challenge: develop and evaluate localized adaptive algorithms
- We hope adaptive functions will go beyond "connectivity"



TECHNOLOGY CHALLENGES

Low computational power

- Current mote processors run at < 10 MIPS
- Not enough horsepower to do real signal processing
- *DSP integration may be possible*
- 4 KB of memory not enough to store significant data

Poor communication bandwidth

- Current radios achieve about 10 Kbps per mote
- Note that raw channel capacity is much greater
- *Overhead due to CSMA backoff, noise floor detection, start symbol, etc.*
- 802.15.4 (Zigbee) radios now available at 250 Kbps
- *But with small packets one node can only transmit around 25 kbps*

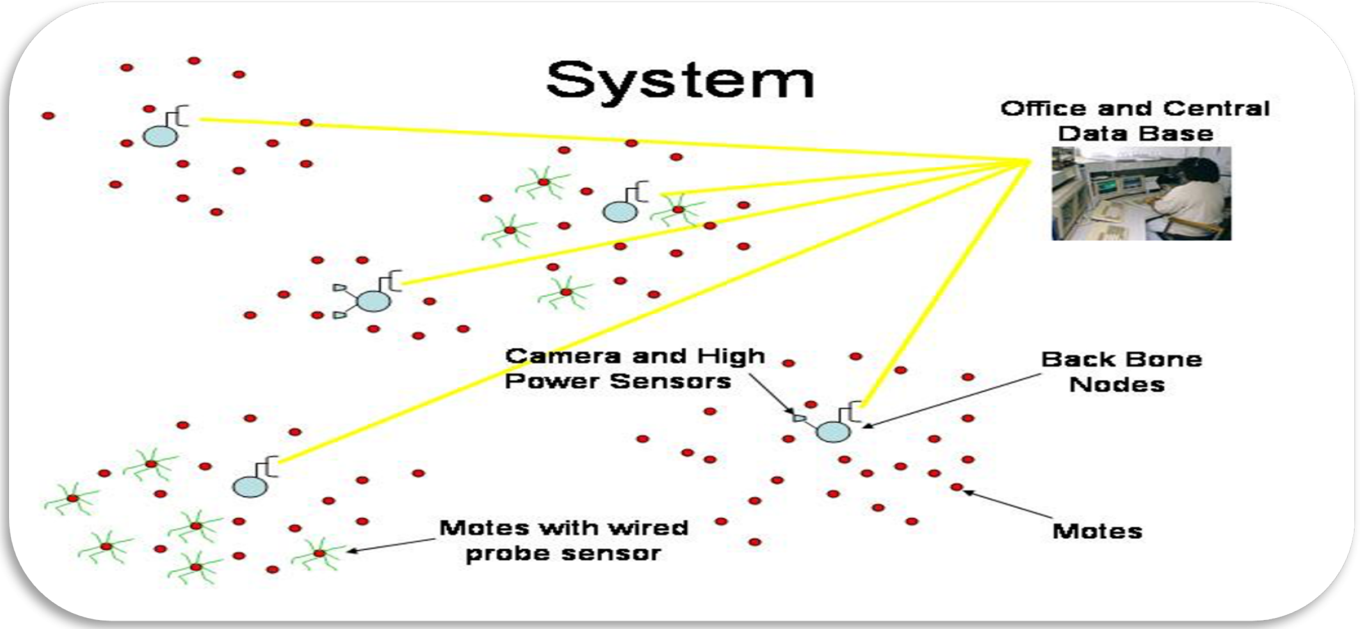
...... CHALLENGES

Limited energy budget

- 2 AA motes provide about 2850 mAh
- Coin-cell Li-Ion batteries provide around 800 mAh
- Solar cells can generate around 5 mA/cm2 in direct sunlight
- Must use low duty cycle operation to extend lifetime beyond a few days

- Nodes do not have a global ID such as an IP number
- The security, both physical and at the communication level, is more limited than conventional wireless networks

PROGRAMMING CHALLENGES



How do we task a 1000+ node dynamic sensor network to conduct complex, long-lived tasks ??

- Identify Spatio-temporal, multi-modal, events
- Scalability
- Energy constrained…Communication constrained

SENSOR NETWORKS VS AD HOC NETWORKS

Items for Comparison	Sensor Network	Ad-hoc Network
Number of Nodes	100 ~ 1000	10 ~ 100
Deployment	Densely	Relatively sparsely
Failure	Prone to Failure	Not Prone to Failure
Communication	broadcast	Point-to-point
Topology Change	Very frequent	Almost steady
Power	Limited	Rechargeable
Resource	Limited	Relatively high
ID	Local ID	Global ID(IP Address)

STANDARDS

- Standards (de jure)
  - IEEE 802.11a/b/g together with ancillary security protocols
  - IEEE 802.15.1 PAN/Bluetooth
  - IEEE 802.15.3 ultrawideband (UWB)
  - IEEE 802.15.4/ZigBee (IEEE 802.15.4 is the physical radio, and ZigBee is the logical network and application software)
  - IEEE 802.16 WiMax
  - IEEE 1451.5 (Wireless Sensor Working Group)
  - Mobile IP

STANDARDS

- Standards (de facto)
  - Tiny OS (TinyOS is being developed by the University of California–Berkeley as an open-source software platform; the work is funded by DARPA and is undertaken in the context of the Network Embedded Systems Technology Research Project at UC–Berkeley in collaboration with the University of Virginia, Palo Alto Research Center, Ohio State University, and approximately 100 other organizations)
  - Tiny DB (a query-processing system for extracting information from a network of TinyOS sensors)

IOT: TECHNOLOGY, SYSTEM AND NETWORK

WORKING PRINCIPLE