CIS373 - Pervasive Computing
Wireless Sensor Networks

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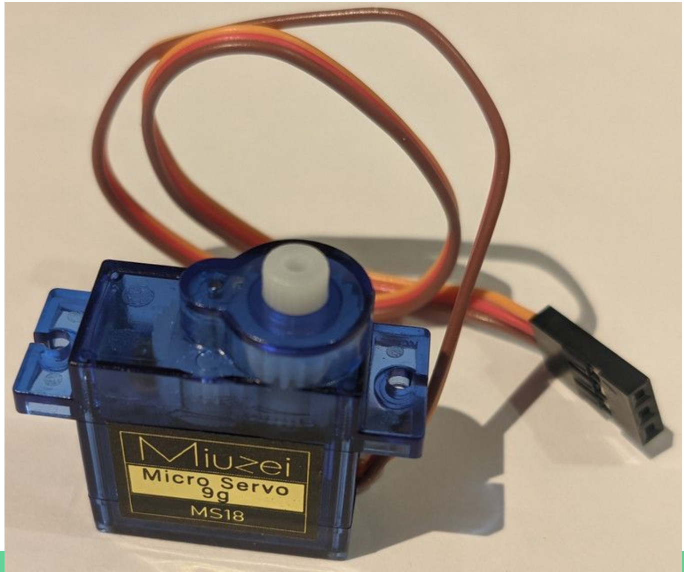
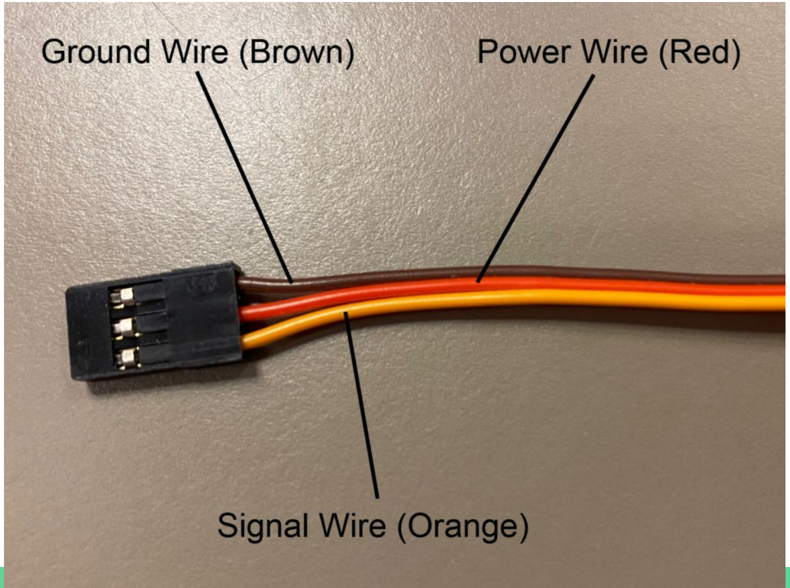
Adapted from materials provided by Xiang Cao

But first, a short demo

Some of you were interested in robotics...

https://learn.adafruit.com/adafruit-circuit-playground-express/circuitpython-servo

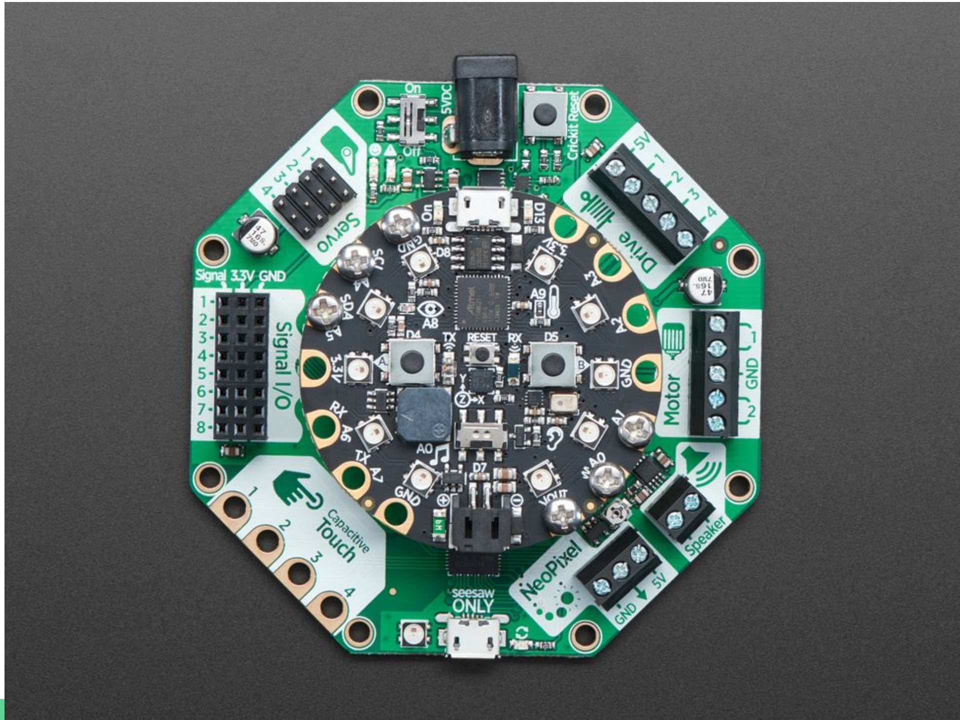




Crickit - expand capabilities of device

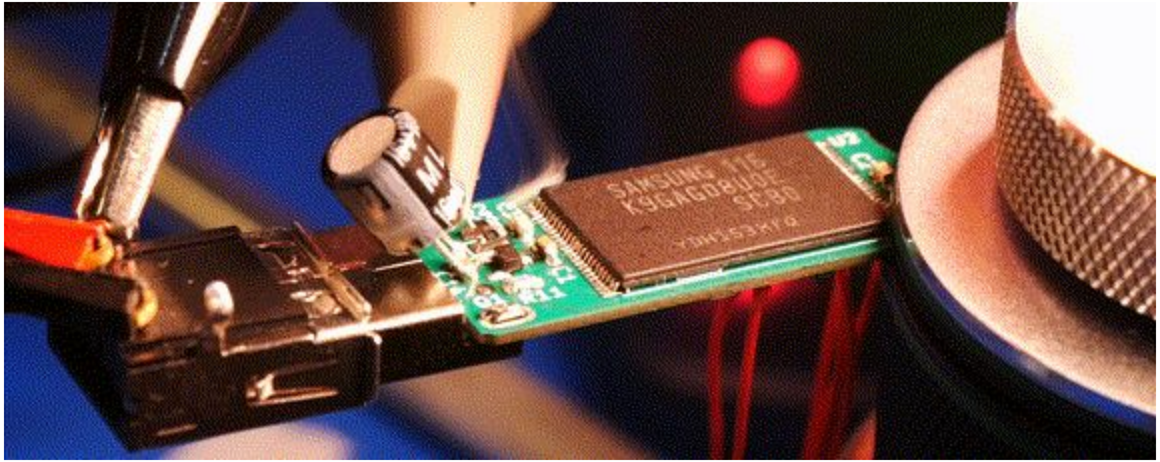
https://www.adafruit.com/product/3093

Currently ~$30



KEEP IN MIND

DISCONNECT POWER WHEN WIRING THIS KIND OF THING UP



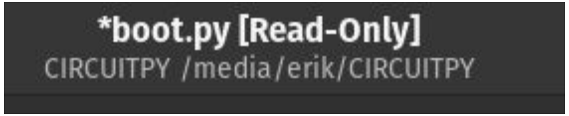
Also, I had to buy: male/male wires and the motors along with it

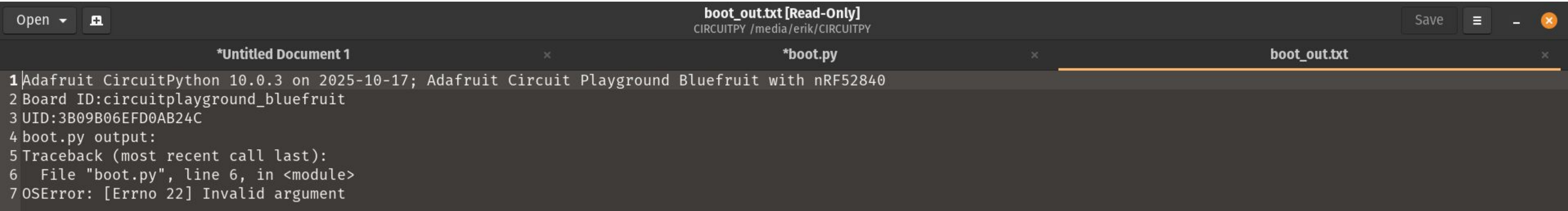
Another diversion, fixing corrupted device!

Let's say you corrupted your file system and you get a read-only error!

(Can't change files, delete, etc.)

(For me, a bad boot.py file to rename the device)





The fix:

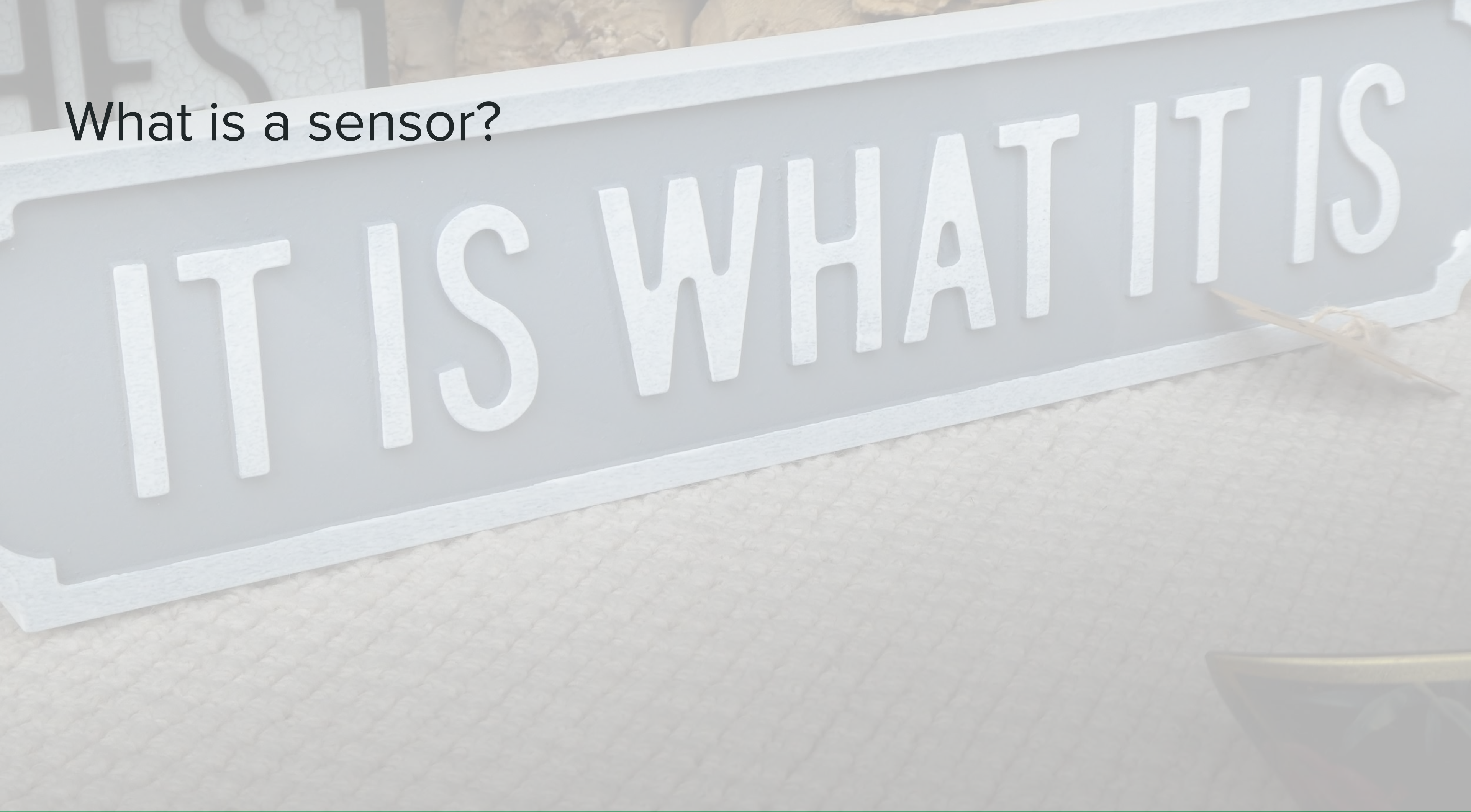
1) **BACKUP YOUR FILES (minus the one that broke things – most likely boot.py)**

2) Get into the REPL and delete the filesystem (THIS ERASES EVERYTHING)

```
>>> import storage
>>> storage.erase_filesystem()
```

3) Copy your files back, minus the bad file

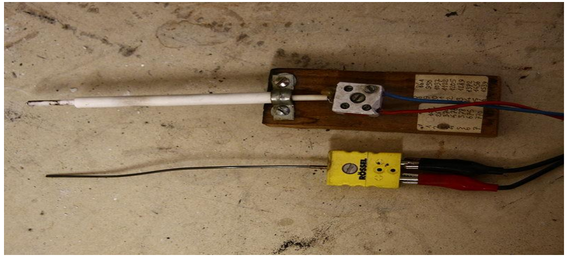
What is a sensor?



A sensor is a...

Device that measures:

- a **physical quantity** and **converts it into a signal** which can be read by an observer or by an instrument.

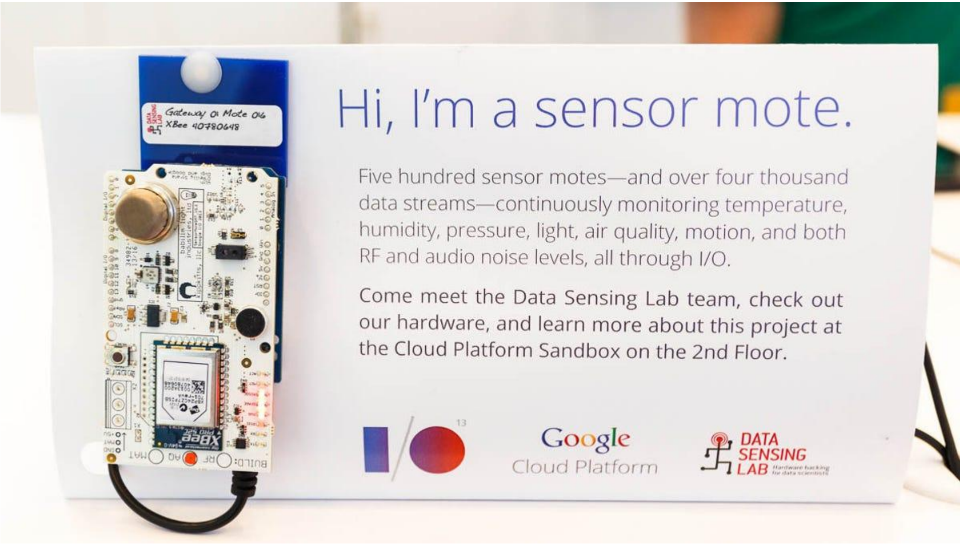


A sensor **node** is...

Node that is capable of:

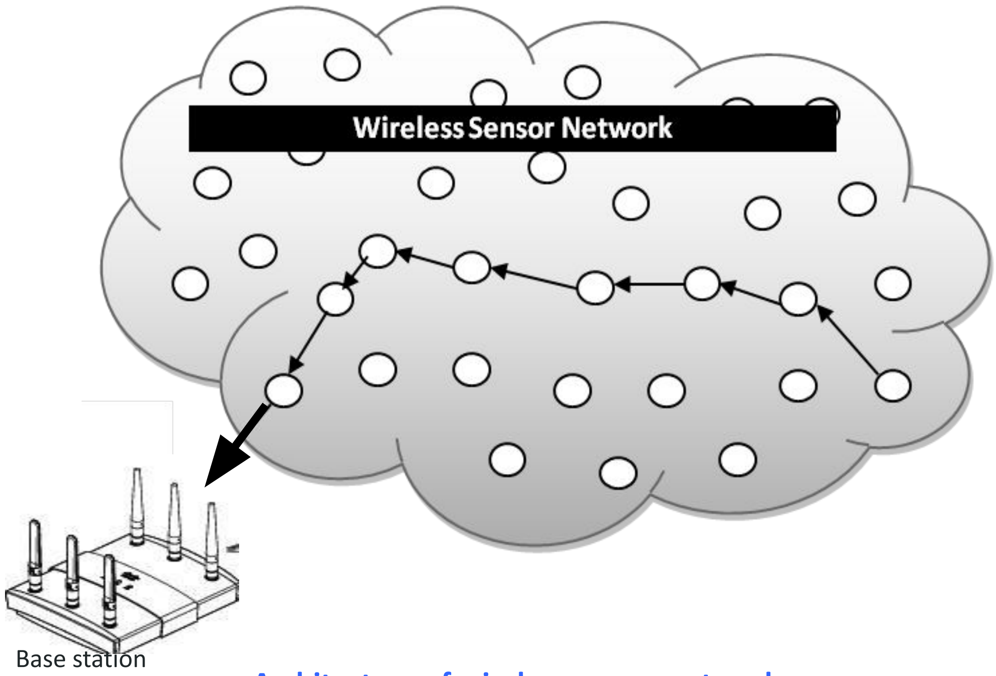
- Sensing Information
- Processing (on-board)
- Communicating to *nodes in the network*

MICA 2 MOTE



Wireless Sensor Networks (WSNs)

A sensor network is a **wireless network** that consists of **thousands** of very small nodes called sensors.

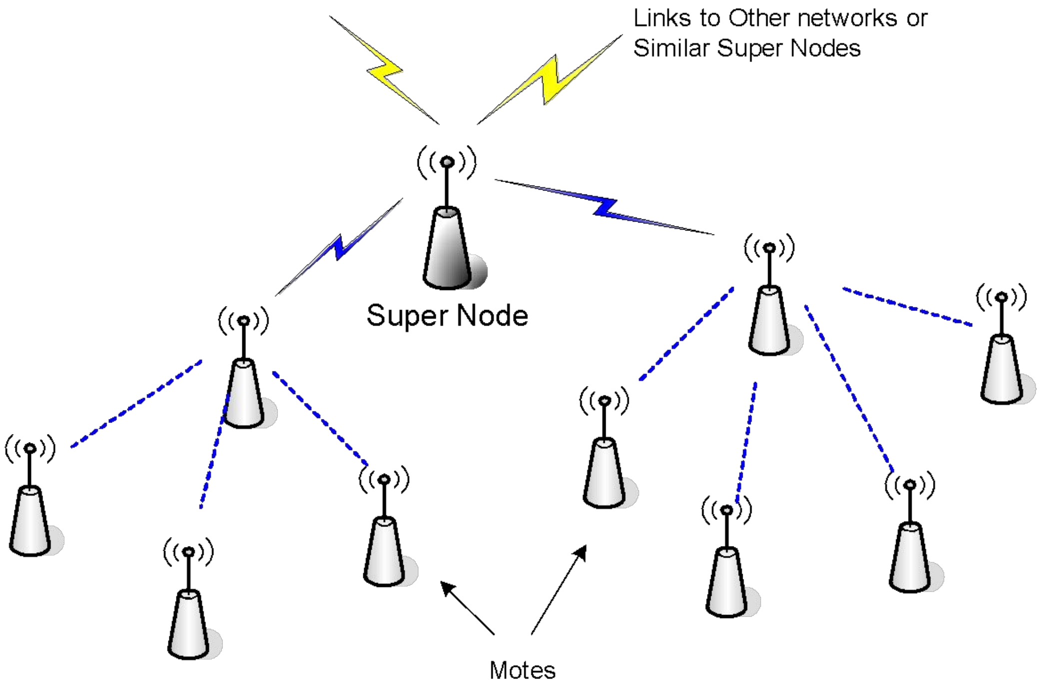


Architecture of wireless sensor networks

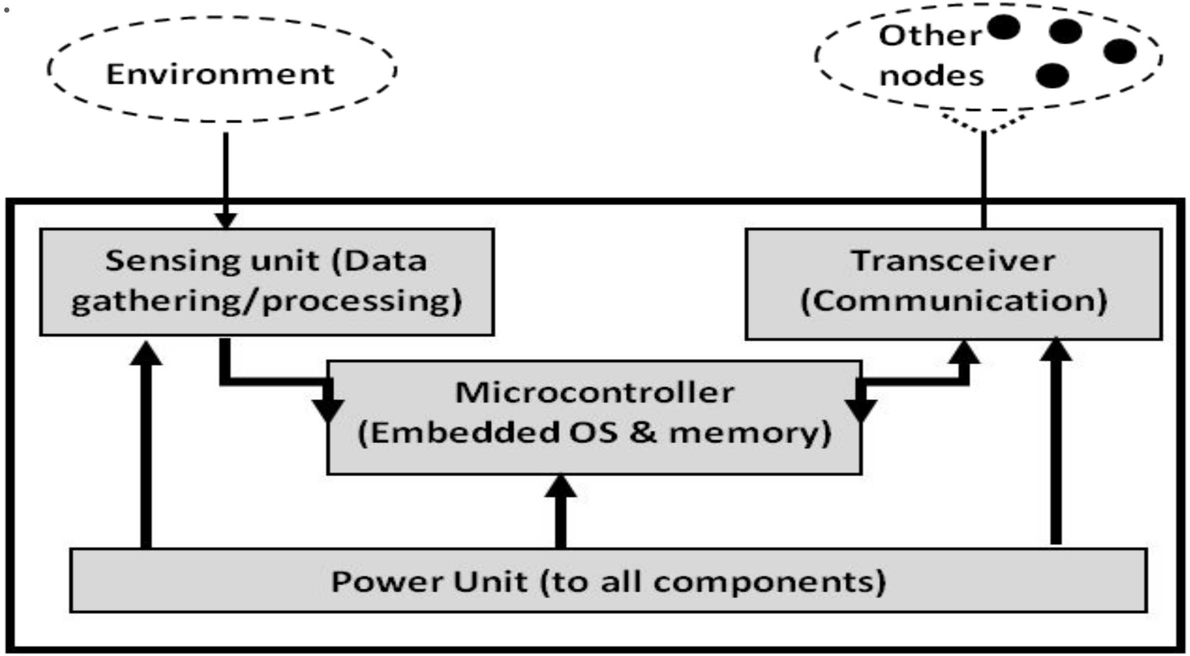
WSNs

Formed by hundreds or thousands of motes that communicate with each other and pass data along from one to another

These sensors work with each other to sense some physical phenomenon and then the information gathered is processed to get relevant results.



WSN sensors are equipped with sensing, limited computation, and wireless communication capabilities.



Typical hardware components of a sensor node in wireless sensor networks

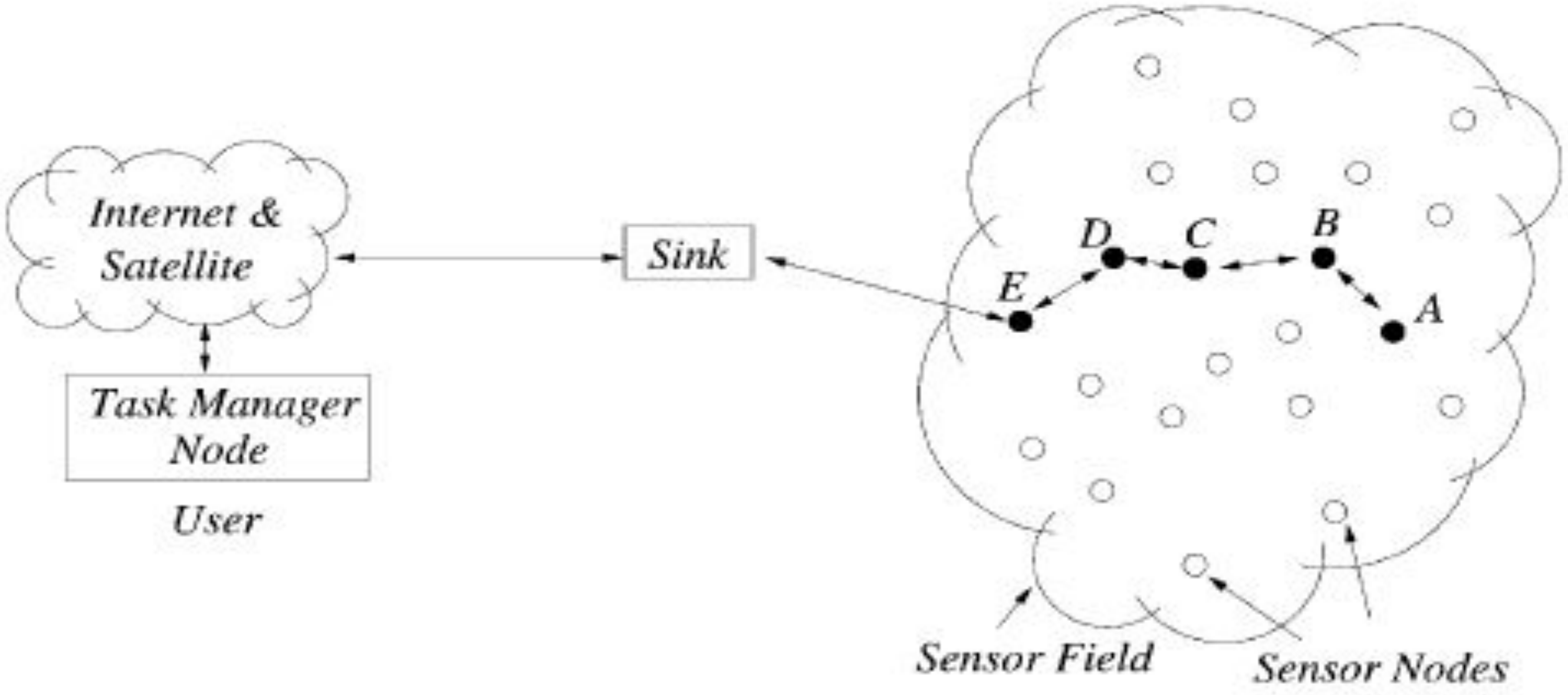
Couple o' examples

https://www.youtube.com/watch?v=GORdqCKsHMo

(mildly creepy...)

https://www.youtube.com/watch?v=W1aMmCZ25fw

WSN Communication Architecture



Classifications of WSNs

WSNs can be classified on the basis of their **mode of operation or functionality** and the **type of target applications**

Proactive networks

- The nodes in this network **periodically** switch on their sensors and transmitters
    - Sense the environment
    - Transmit the data of interest

- Provide a snapshot of the relevant parameters at regular intervals
- Well suited for applications requiring **periodic data monitoring**

Classifications of WSNs

Reactive networks:

- In this scheme, the nodes react immediately to sudden and drastic changes in the value of a sensed attribute
- Well suited for **time-critical applications**

Hybrid networks

- This is a combination of both proactive and reactive networks where sensor nodes not only send data periodically, but also respond to sudden changes in attribute values

Wireless Sensor Network Types

Time-driven

- Report data in the cycle time

Event-driven

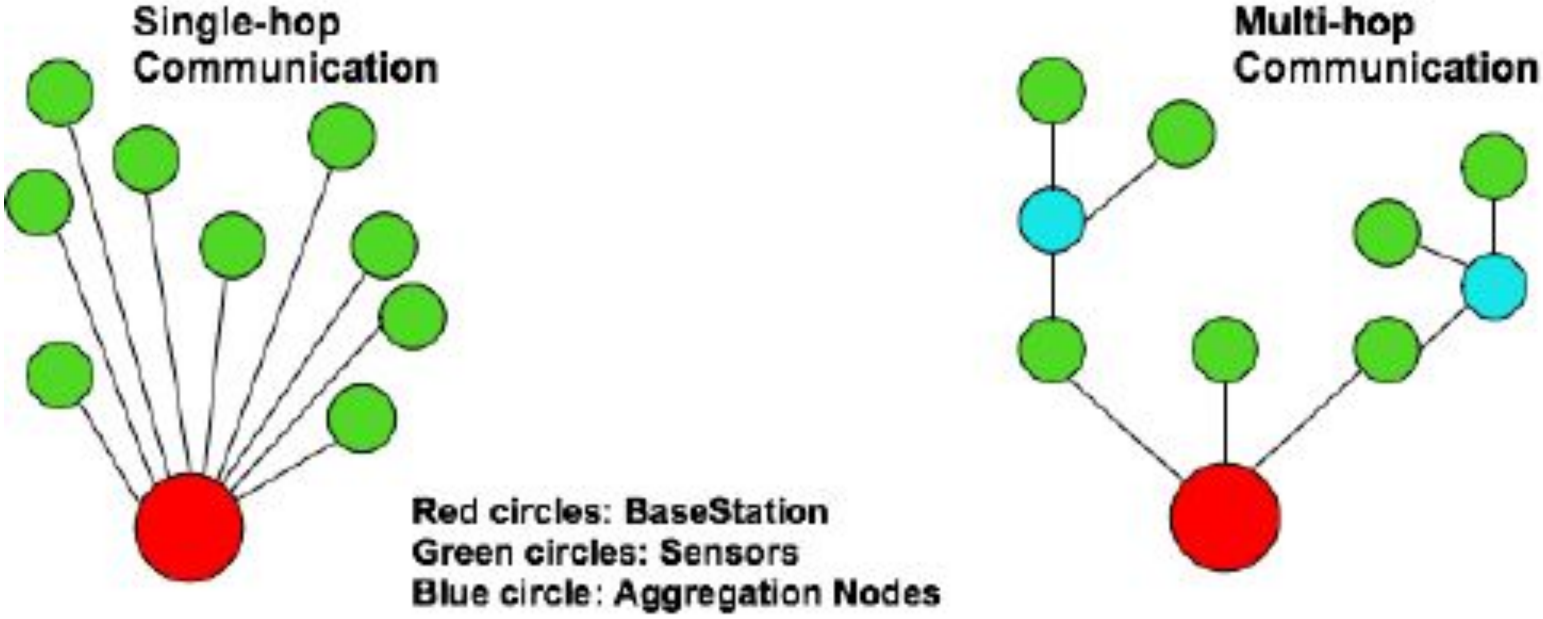
- Report data in the event

Single-hop

- Nodes communicate with each other directly

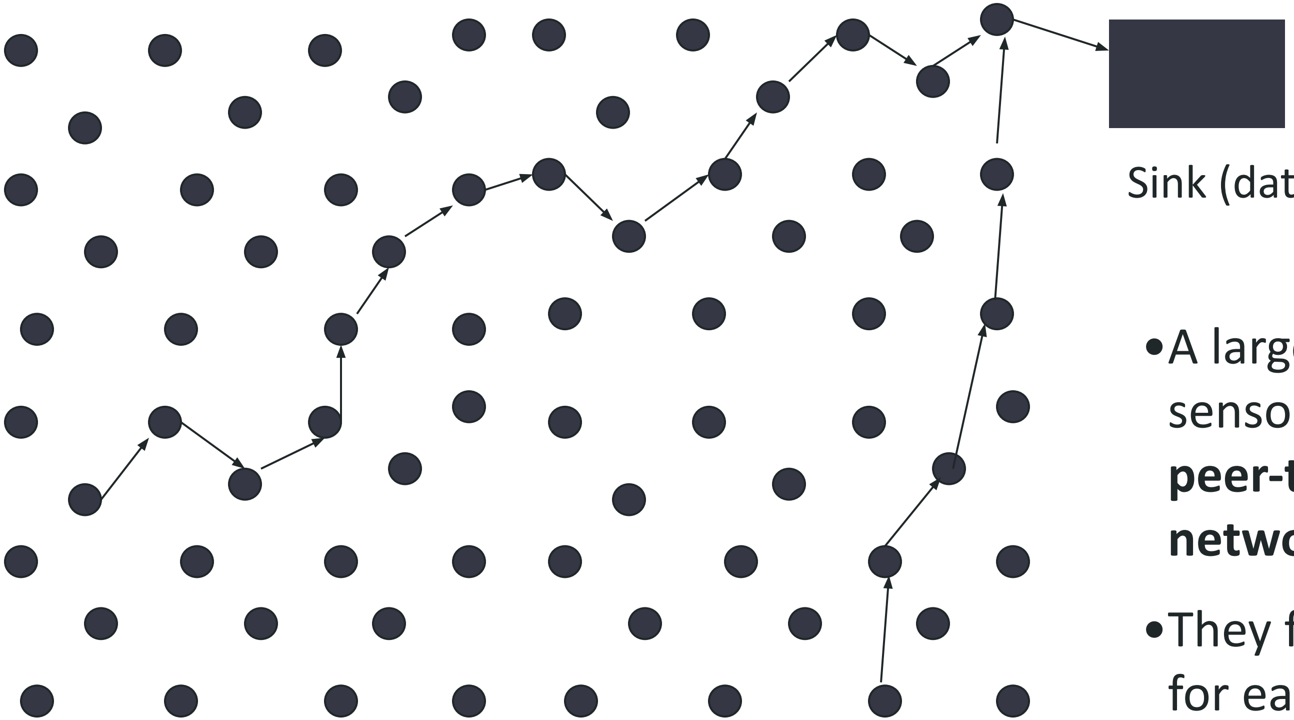
Multi-hop

- To communicate from a node to the other may need passing through another node



A case study of Internet of Things based on wireless sensor networks and smartphone. Tsitsigkos et al

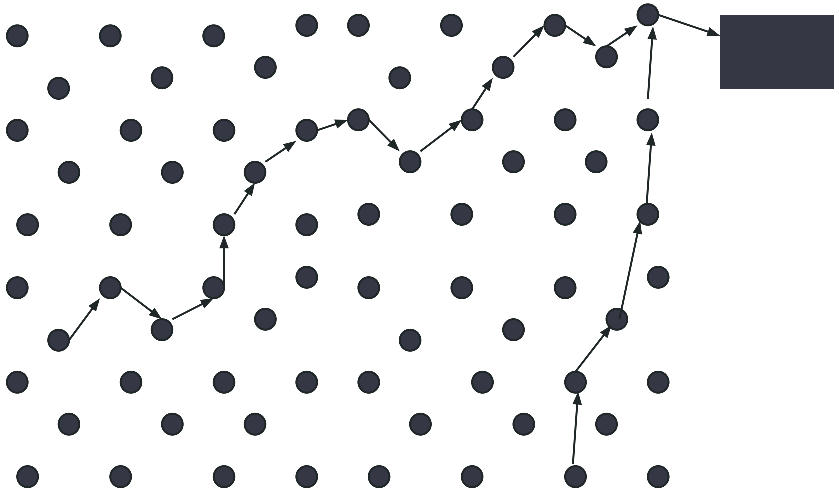
Network architectures – flat



Sink (data collector)

- A large number of sensor nodes form a **peer-to-peer ad hoc network**
- They forward message for each other

What kind of problems could be there? Any solutions to these problems?



What kind of problems could be there? Any solutions to these problems?

Imbalance of energy consumption among nodes

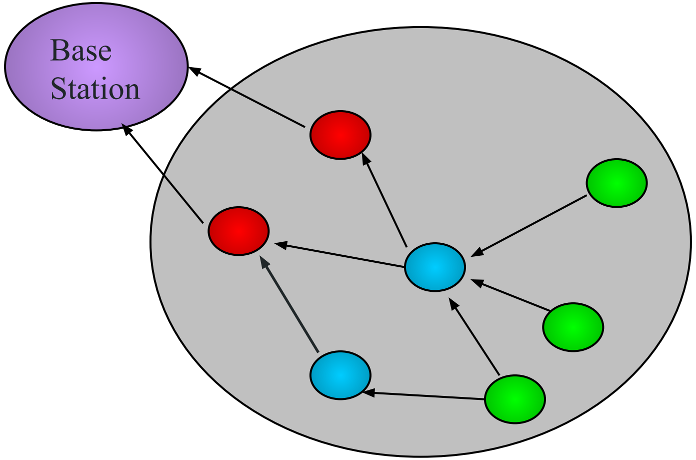
– change path from time to time

Not reliable. If one of them on the path is inactive, communication will be lost

– multiple paths from source to destination

Layer 3

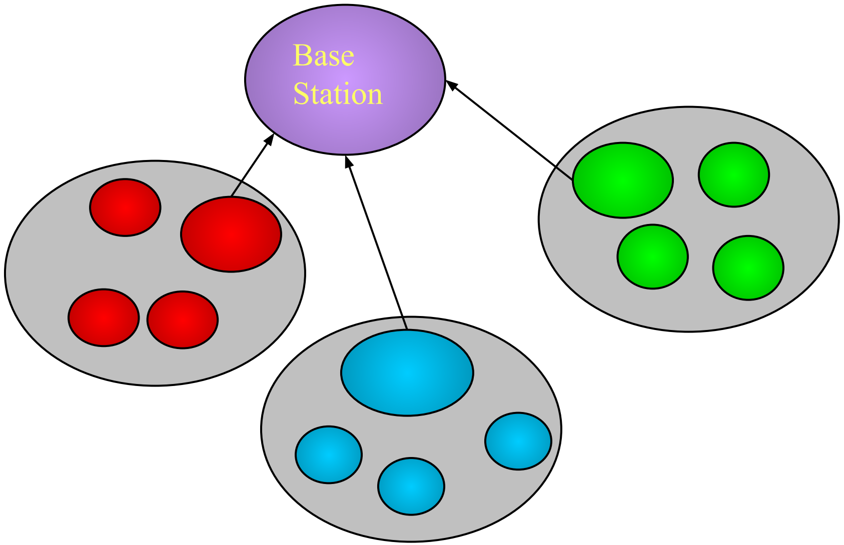
Network Architectures: Layered



Layered Architecture

Network architectures: Clustered

Clustered Architecture

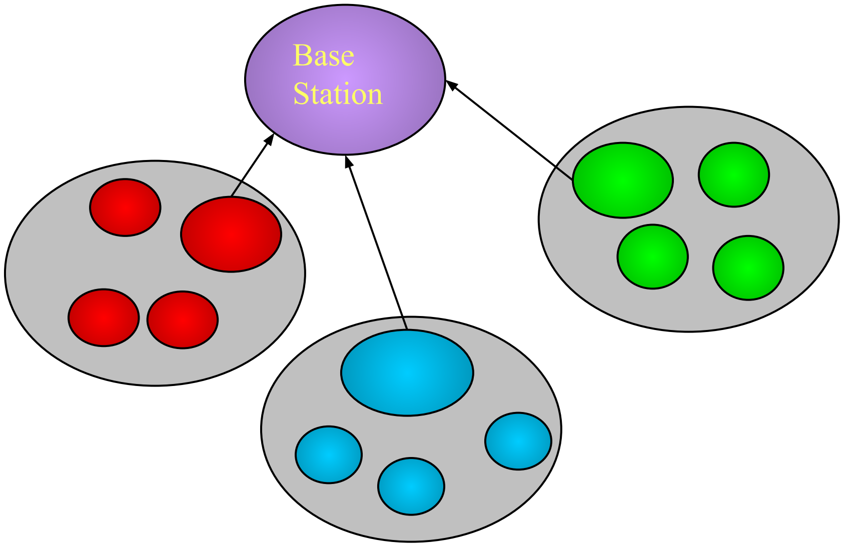


Larger Nodes denote Cluster Heads

What kind of problem could be there? Any solution to the problem?

Network architectures: Clustered

Clustered Architecture



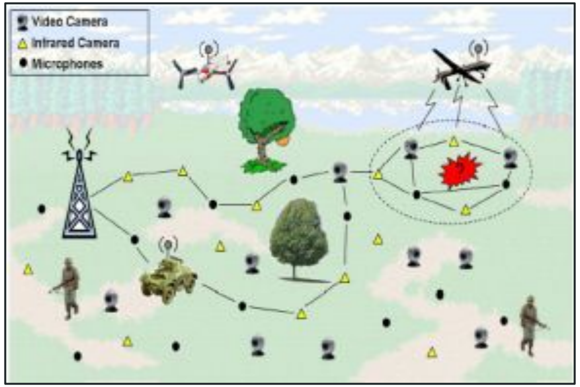
Larger Nodes denote Cluster Heads

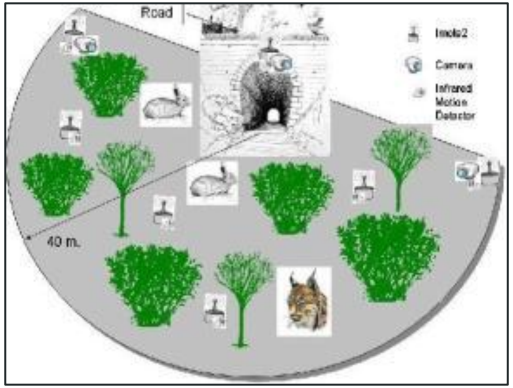
What kind of problem could be there? Any solution to the problem?

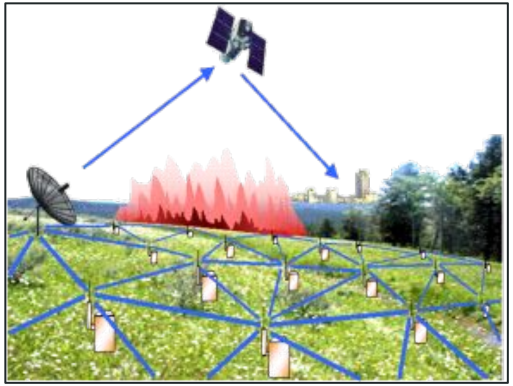
Cluster head consumes energy more rapidly

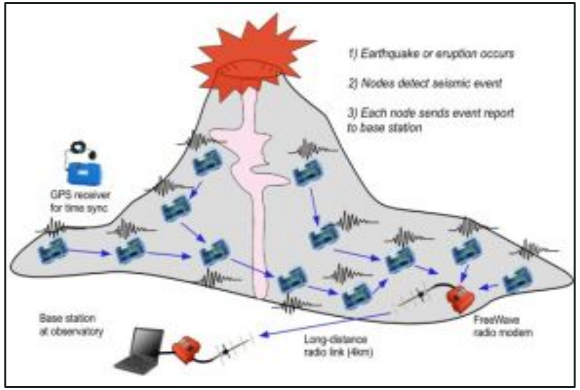
– Take turns to be the cluster head

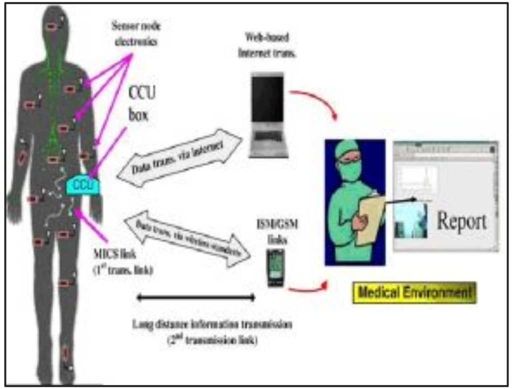
WSNs Applications

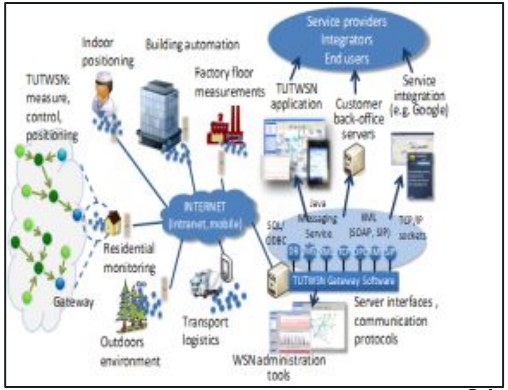




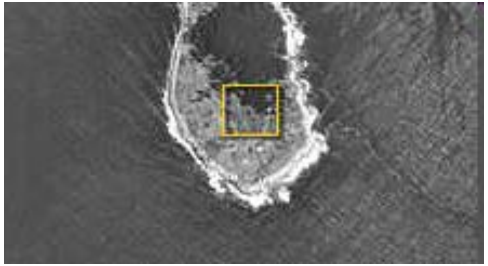








Habitat Monitoring: Great Duck Island



- Intel Research Laboratory at Berkeley initiated a collaboration with the College of the Atlantic in Bar Harbor and the University of California at Berkeley to deploy wireless sensor networks on Great Duck Island, Maine (in 2002)
- 150 sensing nodes deployed throughout the island relay data temperature, pressure, and humidity to a central device.
- Data was made available on the Internet through a satellite link.
- Goal : habitat monitoring kit for researchers worldwide

Environment monitoring

Zebranet: a WSN to study the behavior of zebras

Special GPS-equipped collars were attached to zebras

- Data exchanged with peer-to-peer info swaps
- Coming across a few zebras gives access to the data

Medical application

- Vital sign monitoring
- Accident recognition
- Monitoring the elderly

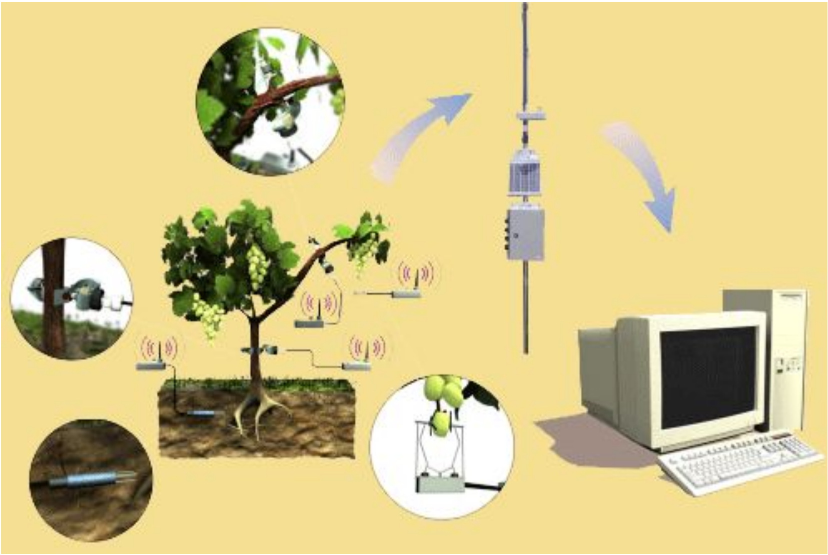
- Intel deployed a 130-node network to monitor the activity of residents in an elder care facility.

- Patient data is acquired with wearable sensing nodes (the “watch”)

Precision Agriculture

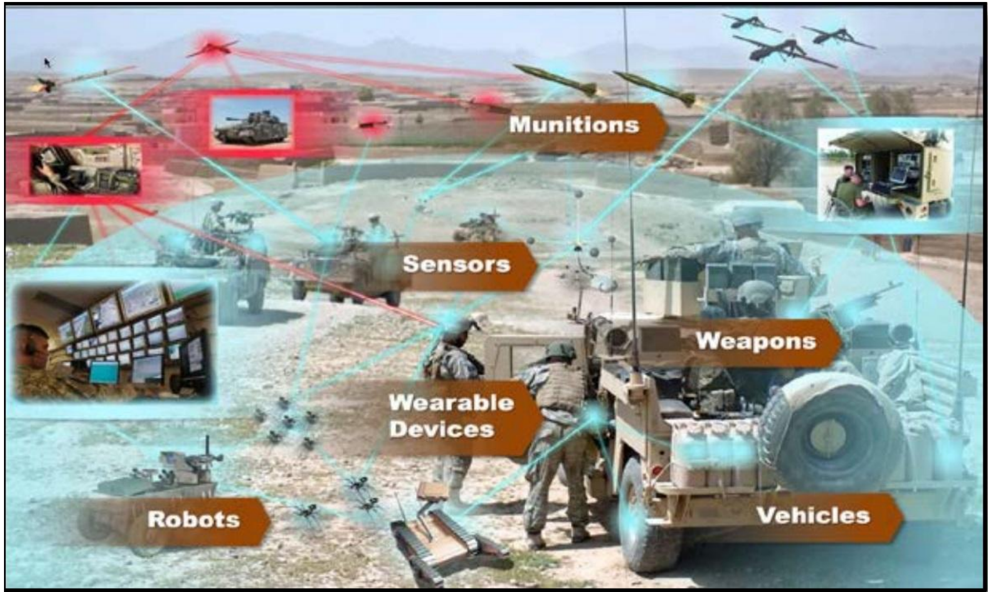
Precision agriculture aims at making cultural operations more efficient, while reducing environmental impact.

The information collected from sensors is used to evaluate optimum sowing density, estimate fertilizers and other inputs needs, and to more accurately predict crop yields.



Military

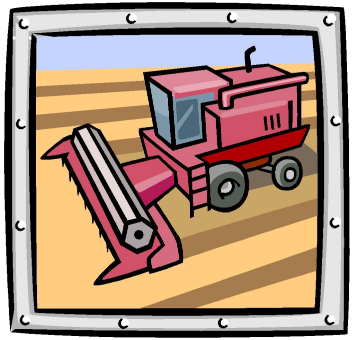
Remote deployment of sensors for tactical monitoring of enemy troop movements.



Industrial & Commercial

Numerous industrial and commercial applications:

- Agricultural Crop Conditions
- Inventory Tracking
- In-Process Parts Tracking
- Automated Problem Reporting
- Theft Deterrent and Customer Tracing
- Plant Equipment Maintenance Monitoring



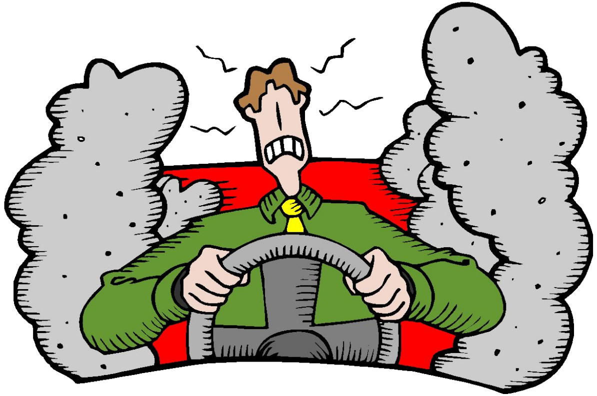
Traffic Management & Monitoring

Future cars could use wireless sensors to:

- Handle Accidents
- Handle Thefts

✔ Sensors embedded in the roads to:

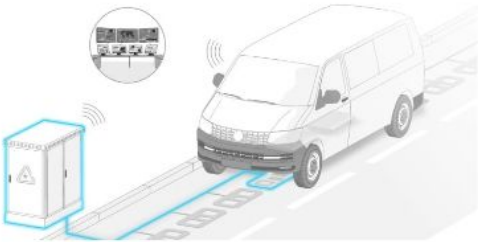
- Monitor traffic flows
- Provide real-time route updates



Wireless Charging Roadway

https://www.michigan.gov/mdot/travel/mobility/initiatives/wireless-charging-roadway

How Wireless Charging Works

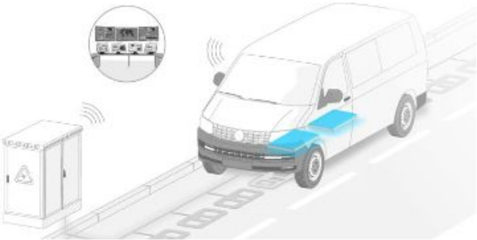


Connects

The system connects energy provided by the unit to the in-road wireless charging coil segments when an authorized vehicle is directly above the segment.

Monitors

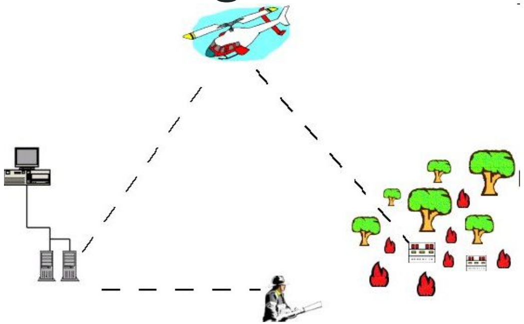
MDOT and our traffic service centers will monitor and gather insights in real-time with cloud-based software.

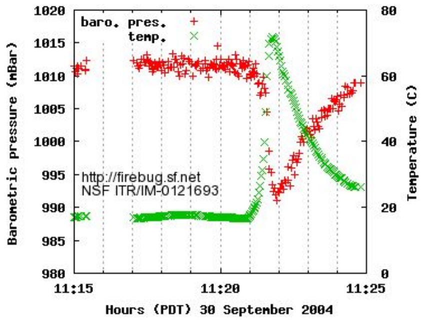


Receives

A vehicle kit receives the wireless energy from the wireless charging coils to transfer to the car battery.

FireBug





Wildfire Instrumentation System Using Networked Sensors

- Allows predictive analysis of evolving fire behavior
- Firebugs: GPS-enabled, wireless thermal sensor motes based on TinyOS that self-organize into networks for collecting real time data in **wildfire** environments
- Software architecture: Several interacting layers (Sensors, Processing of sensor data, Command center)
- A project by University of California, Berkeley CA.

Preventive Maintenance on an Oil Tanker in the North Sea: The BP Experiment

- Collaboration of Intel & BP
- Use of sensor networks to support preventive maintenance on board an oil tanker in the North Sea.
- A sensor network deployment onboard the ship
- System gathered data reliably and recovered from errors when they occurred.
- The project was recognized by InfoWorld as one of the top 100 IT projects in 2004

http://cricket.csail.mit.edu/

“Cricket” Mote

Basically, a location-aware mote.

- Includes an **ultrasound** transmitter and receiver.
- Uses the combination of RF and Ultrasound technologies to establish differential time of arrival and hence linear range estimates
- Based on Cricket Indoor Location System developed by a MIT researcher Nissanka Bodhi Priyantha

Single-hop vs. multi-hop WSNs [GROUPWORK]

What is single-hop vs. multi-hop again?

What types of WSN applications should be single-hop?

What types of WSN applications should be multi-hop?

Advantages vs. Challenges (2 for each group)

WSNs advantages

WSNs have many advantages, and may be applied for some applications that have the following requirements

- **Small size:**
  - Easy to be attached or embedded
- **Ease of deployment:**
  - Can be dropped from a plane or placed in a factory, without any prior organization, thus reducing the installation cost and time, and increasing the flexibility of deployment
- **Extended range:**
  - One huge wired sensor (macro-sensor) can be replaced by many smaller wireless sensors for the same cost, but larger coverage area

WSNs advantages

- **Fault tolerant:**
  - With wireless sensors, failure of one node does not affect the network operation
- **Ease of operation:**
  - Some applications do not need involvement of human.
- **Unfriendly working environment:**
  - WSNs can work in some environment that human beings cannot.
- **Low cost:**
  - Relative cheap hardware cost

WSNs challenges

There are many challenges, such as:

Networking

- Wireless connection: interference with others
- Wireless links are fragile, possibly asymmetric
- High error rate

Routing

- What is the path from source to destination with multi-hop wireless communication?
    - i.e., how do we get from a node to a laptop?
- Dynamic topology change (nodes drop out, etc.)

Challenges of WSNs

Power consumption

- Small size: limited power supply
- Replace or recharge is difficult

Fault tolerance

- Even if a few nodes fail, the whole network remain working
- How to bypass a few nodes which failed.

WSNs challenges

Scalability

- Algorithms should work well in large scale (1000s)

Low processing power

- CPU, memory, storage, bandwidth are limited

Heterogeneity of sensors

- Power consumptions are different among sensors
- Different hardware configuration
- Different protocols

WSNs challenges

Ad hoc and distributed

- Self-organized without human being
- Self-configure and be robust to topology changes (e.g., death of a node)
- Difficult to change the algorithm or software once being deployed

Sensors work in distributed mode

- The sensors need to coordinate with each other to produce required results.

Security and authenticity should be guaranteed

Real Time Computation

- The computation should be done quickly as new data is always being generated.

Issues

Coverage, connectivity and deployment

Power management

Routing

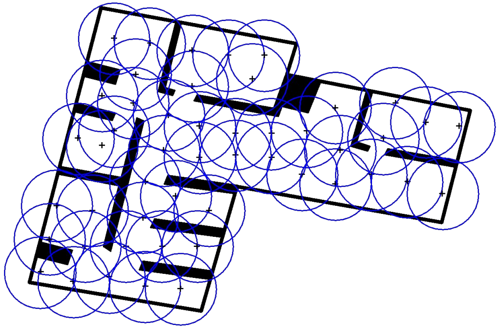
Localization

Coverage, connectivity and deployment

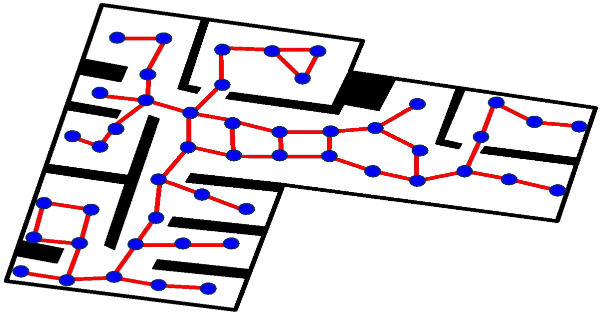
Coverage // Connectivity

Sensor deployment is a critical issue because it affects the **cost** and **detection capability** of a wireless sensor network

A good sensor deployment should consider both **coverage** and **connectivity**



Coverage



Connectivity

Node deployment

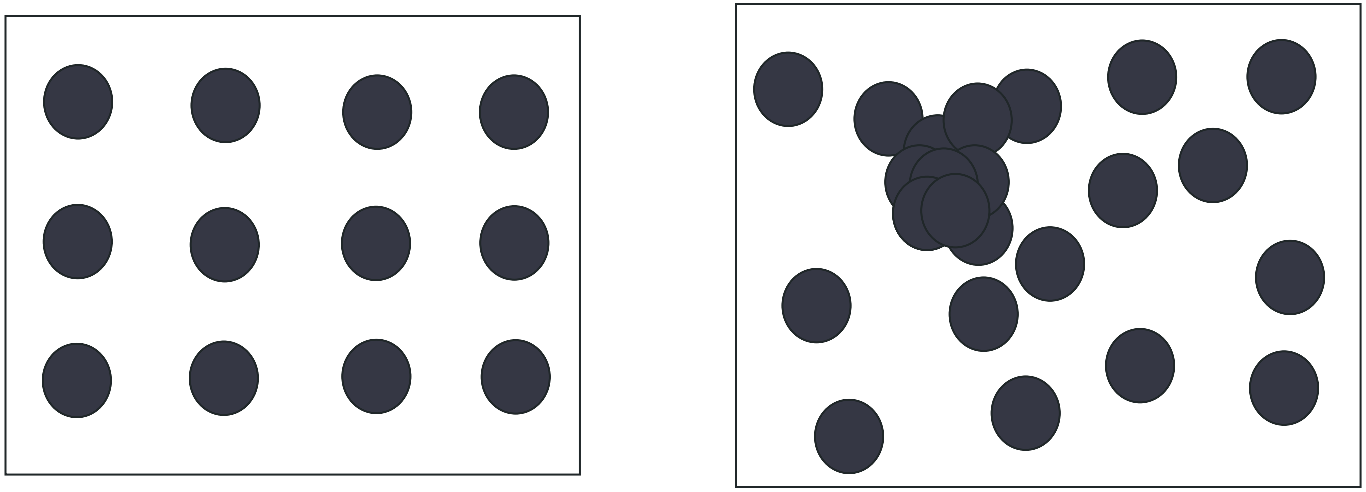
Node deployment in WSNs is **application dependent** and affects the performance of the routing protocol

The deployment can be either deterministic or randomized

- In **deterministic deployment**, the sensors are manually placed and data is routed through pre-determined paths.
  - How can we place the least number of sensors in a field to achieve desired coverage and connectivity properties?

- In **random node deployment**, the sensor nodes are scattered randomly creating an infrastructure in an ad hoc manner.
  - Assuming nodes are mobilized, how can we move the sensors to achieve coverage and connectivity?

deterministic vs. random

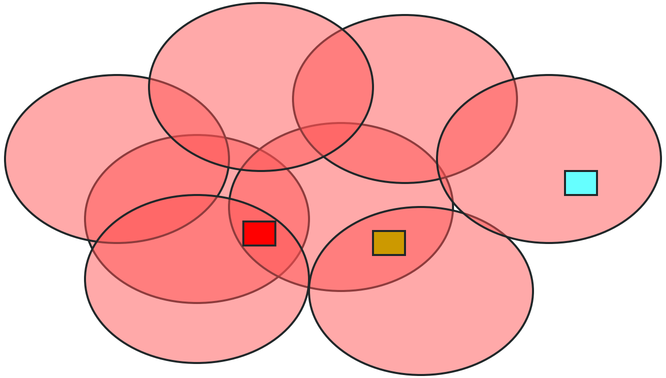


Coverage

Every point is covered by 1 - K sensors

- 1-covered, K-covered

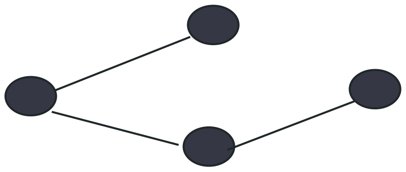
  - 1-covered
  - 2-covered
  - 3-covered



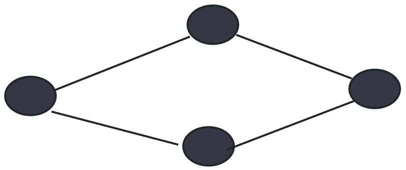
Connectivity

The sensor network is connected as: 1-connected, K-connected

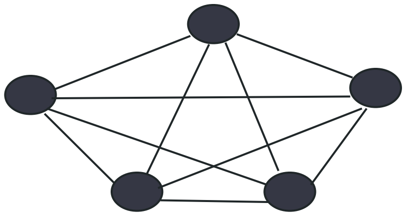
- For fault tolerance, k-connectivity is desirable!
- k-connected graph:
  - K paths between every two nodes
  - with k-1 nodes removed, graph is still connected



1-connected



2-connected



3-connected

QUESTIONS!

Which *network/sensing* issue is mostly related to K-coverage/K-connectivity?

Can you propose a solution to improve the reliability of the network without changing the number of sensors?

Tradeoffs

Better (redundant) coverage and connectivity:

➜ more nodes ➜ higher cost

Tradeoff: reliability vs. cost

—

Better (redundant) coverage and connectivity:

➜ larger transmission/sensing ranges ➜ more energy consumption

Tradeoff: reliability vs. energy consumption

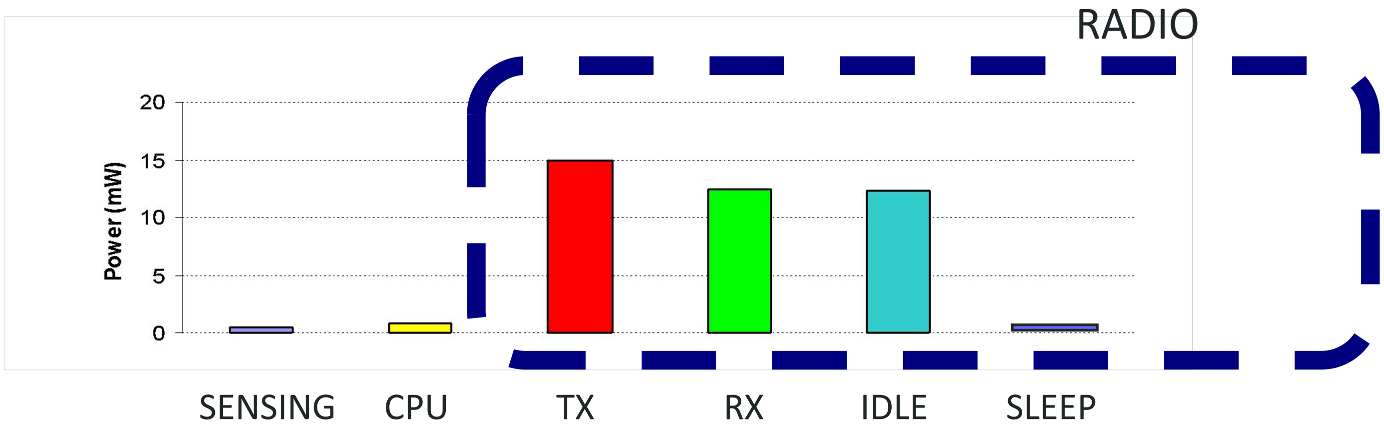
Power Management

Power consumption

Communication sub-system consumes more energy than computation sub-system

Radio component requires a lot of energy for reception, transmission and idle states

Sensing sub-system might also require some amount of energy based on the type of sensor node.



Overview

Lifetime

- Nodes are battery-powered
- It is difficult to change the batteries. So, each operation brings the node closer to death.

Discussion:

- What kinds of energy saving strategies can you think of?

Main techniques

Duty-cycling

Data-driven approaches

Mobility

Others

Duty-cycling

Sleep/Wake protocols

- On-demand or based on a frequency

Low duty-cycle

- Sensors take turns to be active for monitoring and sensing, while still trying to cover the area
- Related to K-coverage/K-connectivity
- Redundancy is necessary

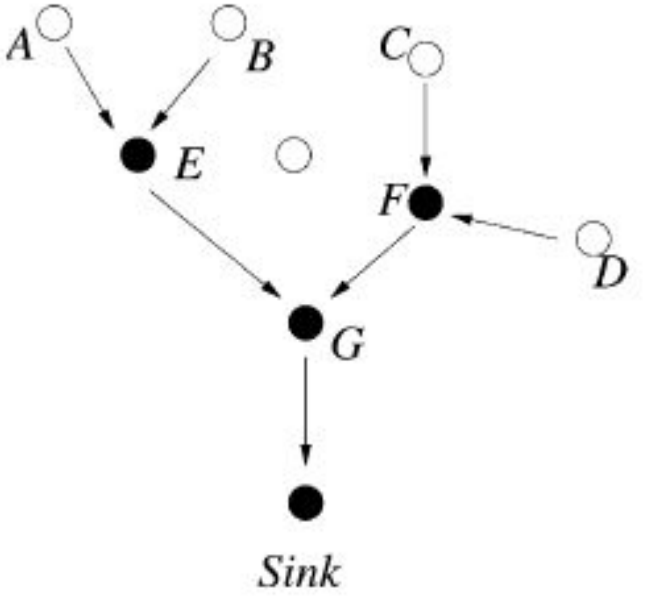
Data-driven approaches

Data reduction

- Data **compression**
    - What could be the disadvantage for this?
- Data **aggregation**
    - Clustering
    - Send data to cluster head, instead of sending to sink

Data coming from multiple sensor nodes are aggregated if they are about the same attribute of the phenomenon when they reach the same routing node on the way back to the sink

Can you list a few applications for data aggregation?



Mobility-based approaches???

Migrate the nodes near the event

- Other nodes can keep in sleep state

Itinerary design can further improve the lifetime of sensor network

Need to handle:

- Mobile-sink
- Mobile-relay

Others!

Turn off the transceiver when not required

Multiple paths could be derived and used to reach the destination

- Increase the network lifetime.

Data should be transmitted by the source node only when the destination node is ready

- Data could be reached without error at first place.

Avoid network collisions between nodes