The Basics of Wireless Sensor Networking and its Applications

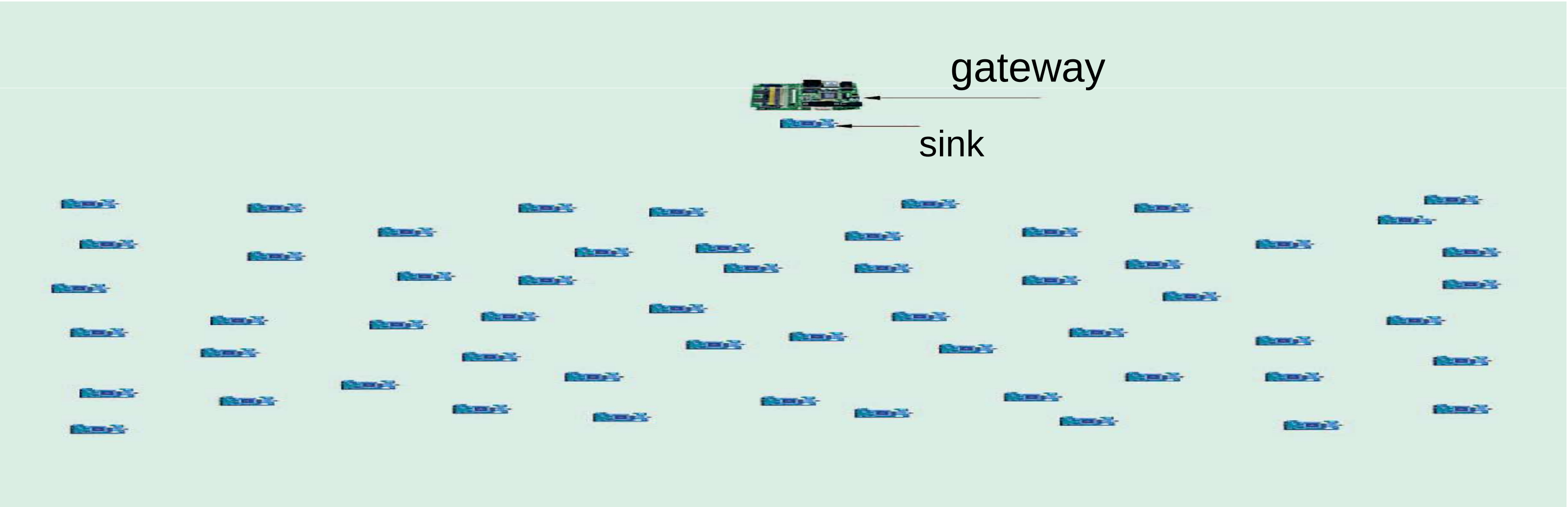
Daniele Puccinelli

daniele.puccinelli@supsi.ch

http://web.dti.supsi.ch/~puccinelli

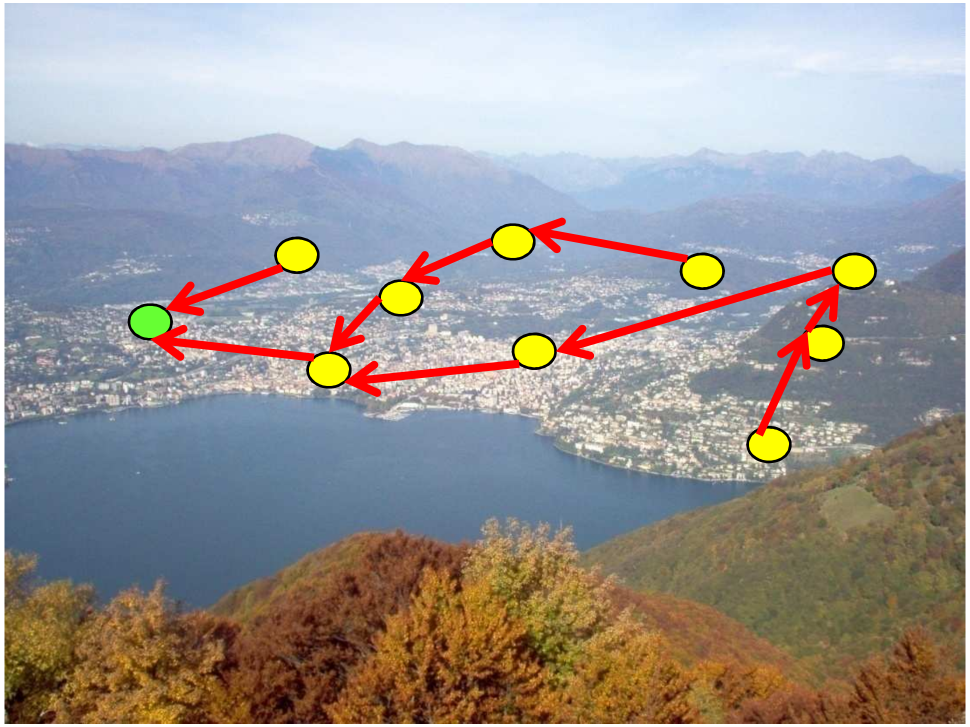
What is a Wireless Sensor Network?

- A collection of sensing devices that can communicate wirelessly
- Each device can sense, process, and talk to its peers
- Typically, centralized collection point (sink or base station)

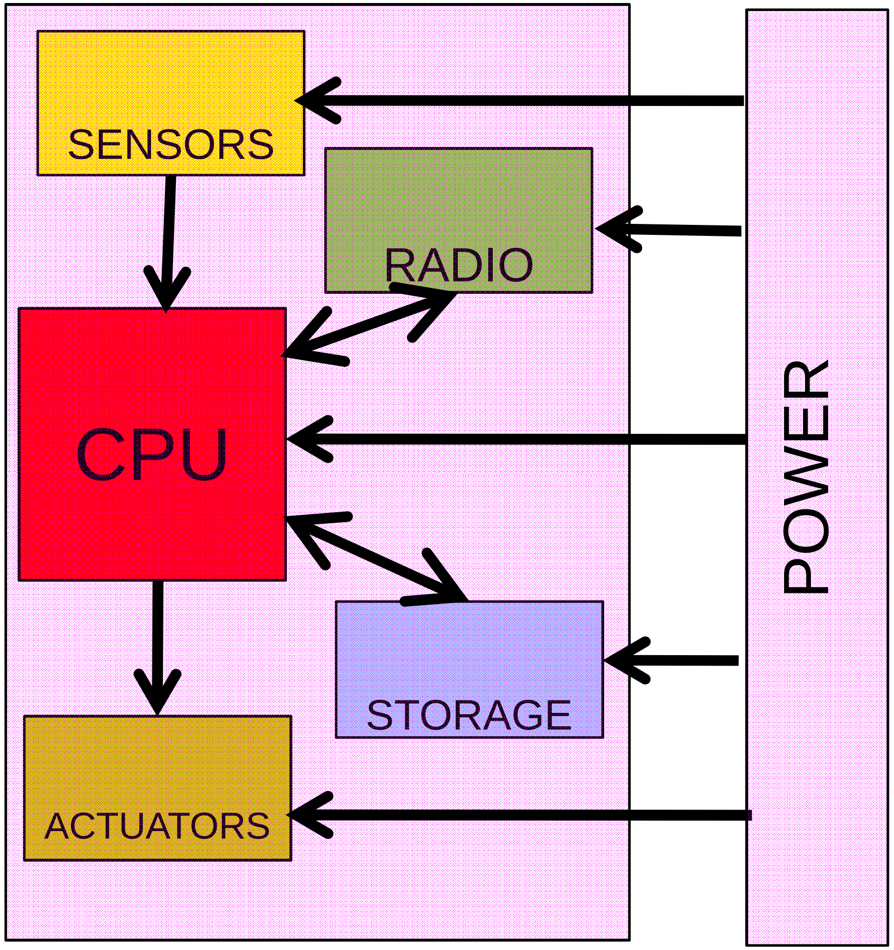


The Vision Behind Sensor Networks

- Embed numerous distributed sensor nodes into the physical world
- Exploit dense in situ sensing and actuation
- Network these devices so that they can coordinate to perform higher-level identification and tasks



What is a sensor node?



- A sensing node has 3 basic components: a CPU, a radio transceiver, and a sensor array.
- Any kind of sensor, interfaced through an ADC.
- Nodes are normally battery-powered.
- On-board storage
- May have actuators, too

Hardware platforms

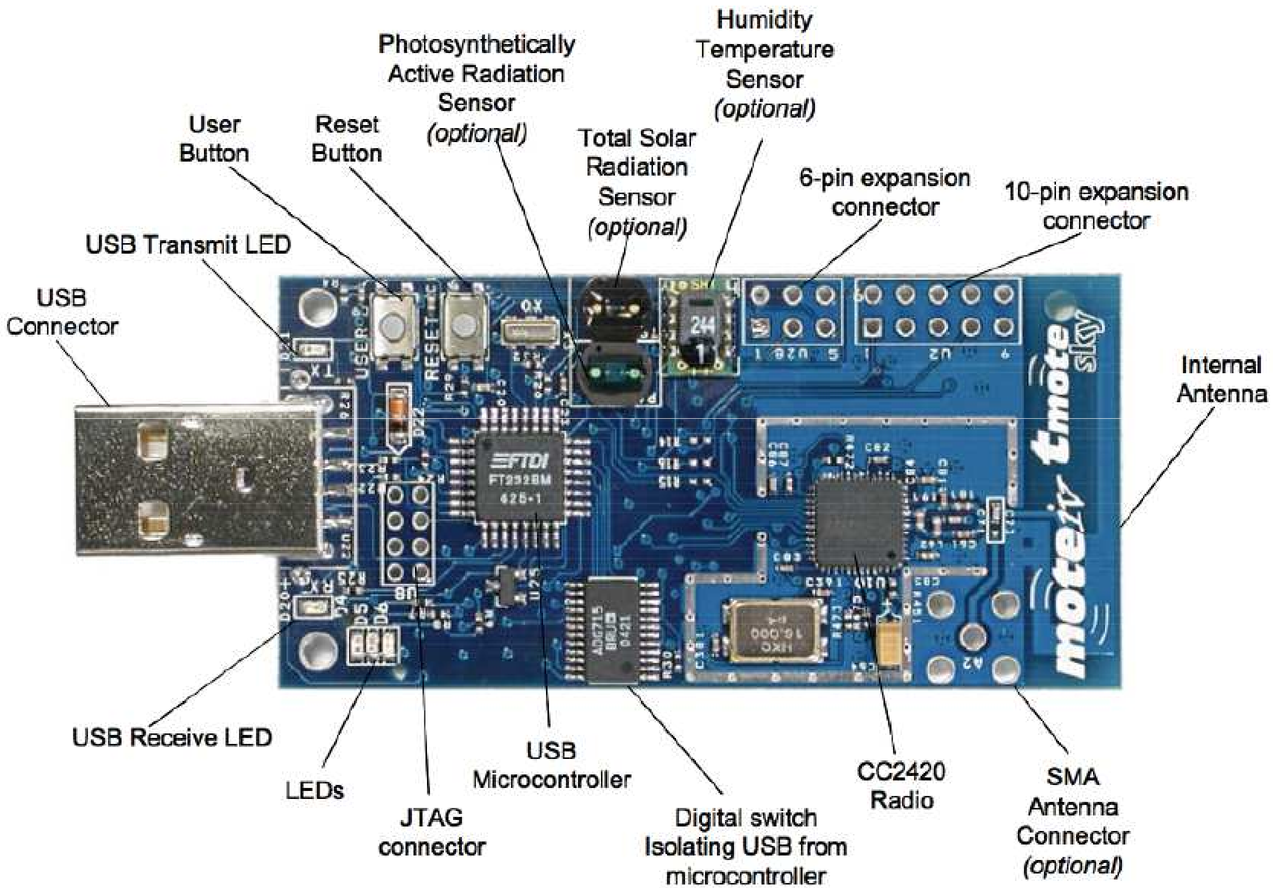
Low-end: mote-class device

•Sensing and basic processing
•Short-range, low-power radio

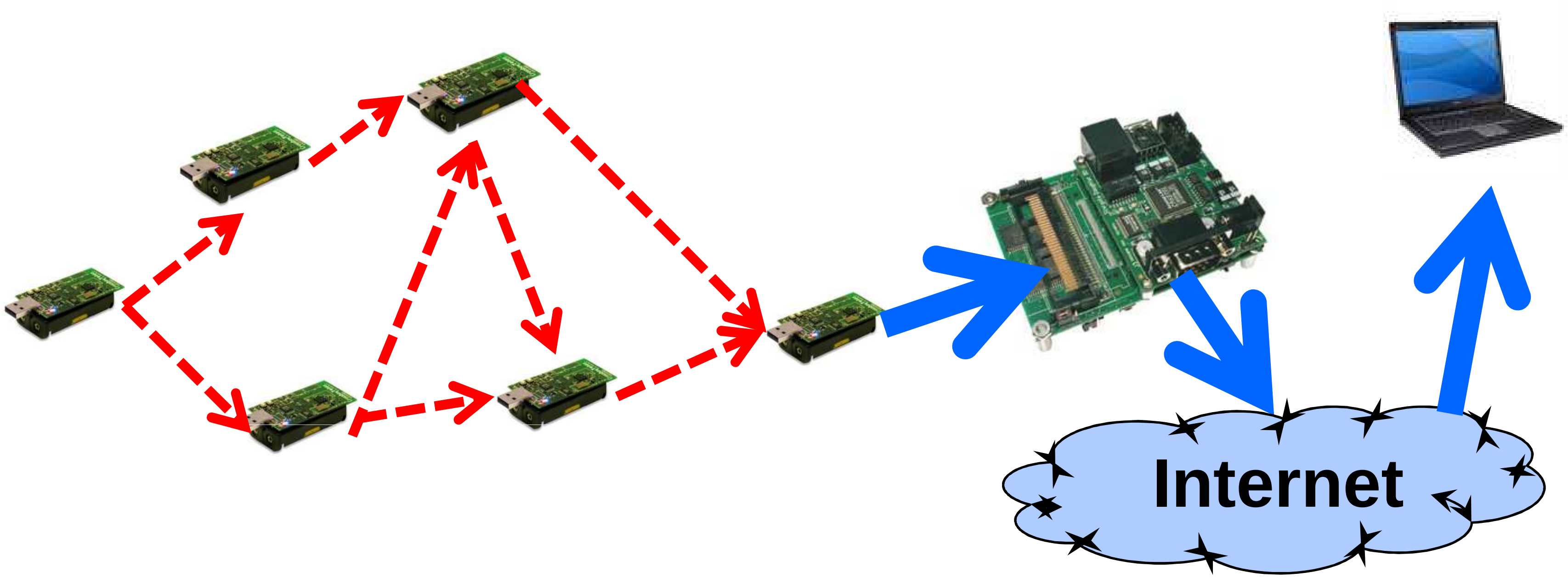
High-end: gateway

• Advanced processing
• Interface to the outside world

TelosB: Our Low-End Mote



Motes and gateways



- Motes can talk to each other wirelessly
- They get the data to a sink (one of their own)
- The sink is wired to a gateway
- The gateway provides out-of-network connectivity (e.g., Internet)

dB, dBW, dBm

- dBW (commonly called dB): 10*log10(ratio of measured power to 1W)
- Example: we measure 100W
- Ratio to 1W is 100
- We get 20dB

- Radio (transmit and receive) power is typically measured in dBm
- dBm: 10*log10(ratio of measured power to 1mW)

- 100W is 100000 times 1mW; the ratio is 100000
- To get the dB ratio to 1mW (dBm): 10*log10(100000)=50dBm

- Practical rule: dBm are more than dBW
- *x* dBm = (*x*-30) dBW

- The difference between two dBm values is expressed in dB

Example: IRIS mote

CPU

- Code memory (Flash): 128KB
- Measurement Flash: 512KB
- RAM: 8KB
- Active mode current draw: 8ma
- Sleep mode current draw: 8uA

TRANSCEIVER

- Theoretical data rate: 250kbps
- Maximum tx power: 3dBm
- Rx current draw: 16mA
- Tx current draw (@ -17dBm): 10mA
- Tx current draw (@ 3dBm): 17mA

Gateway-class devices

- Idle: 180mA
- Sleep: 60mA
- Active: 330mA
- Idle/Wi-Fi: 360mA
- Active/Wi-Fi: 530mA

Example: CrossBow Stargate

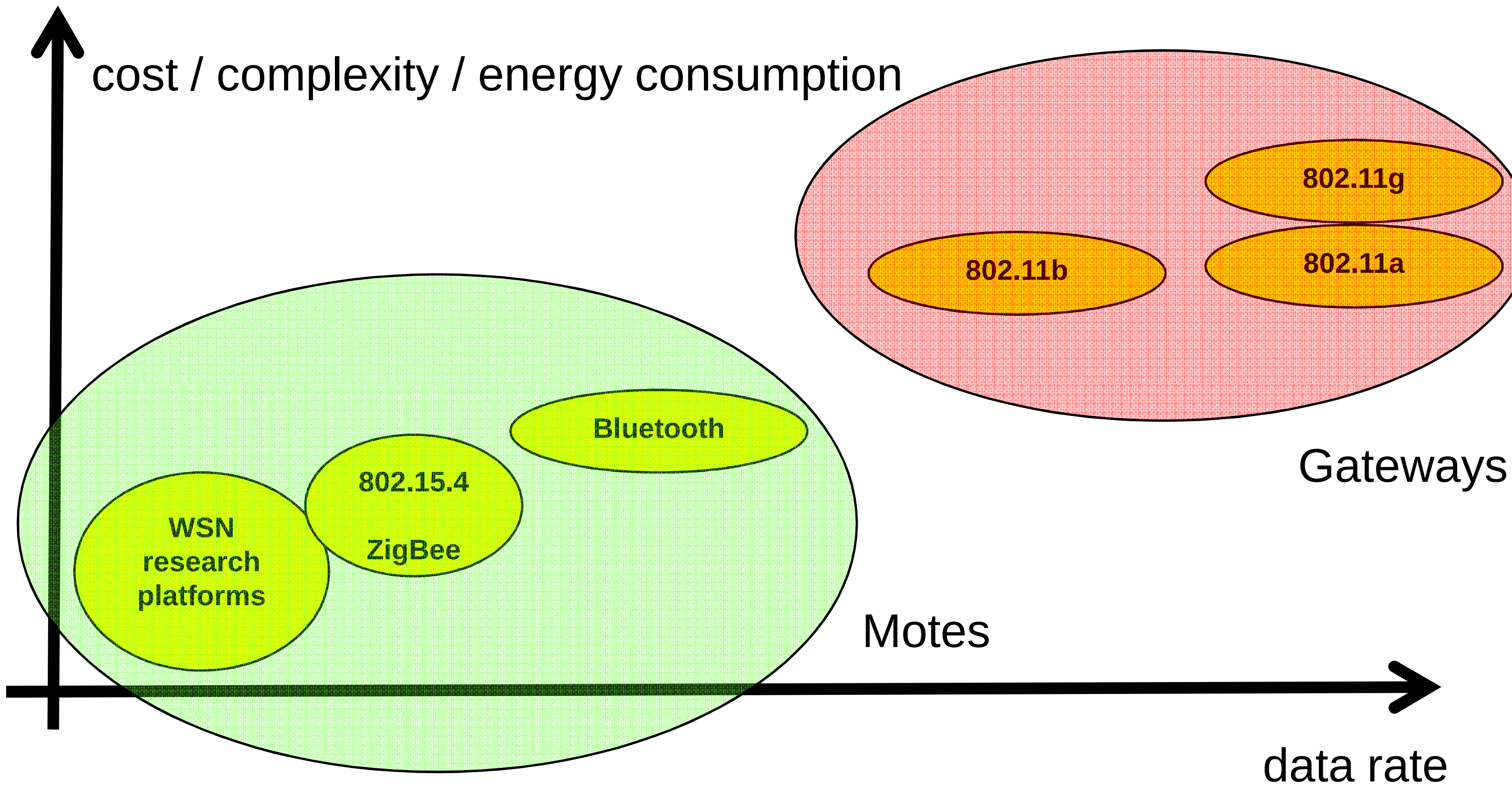
CPU

- Flash memory: 32MB (50x more than a mote)
- RAM: 64MB (>8000x more than a mote)

COMMUNICATION INTERFACES

- Wired ethernet
- Wi-Fi

WSNs in the Tech Space



Energy vs. Duty Cycling Efficiency

MICA Mote
CPU: ATMega12
Radio: CC1000

Stargate
CPU: PA255
Radio: 802.11b

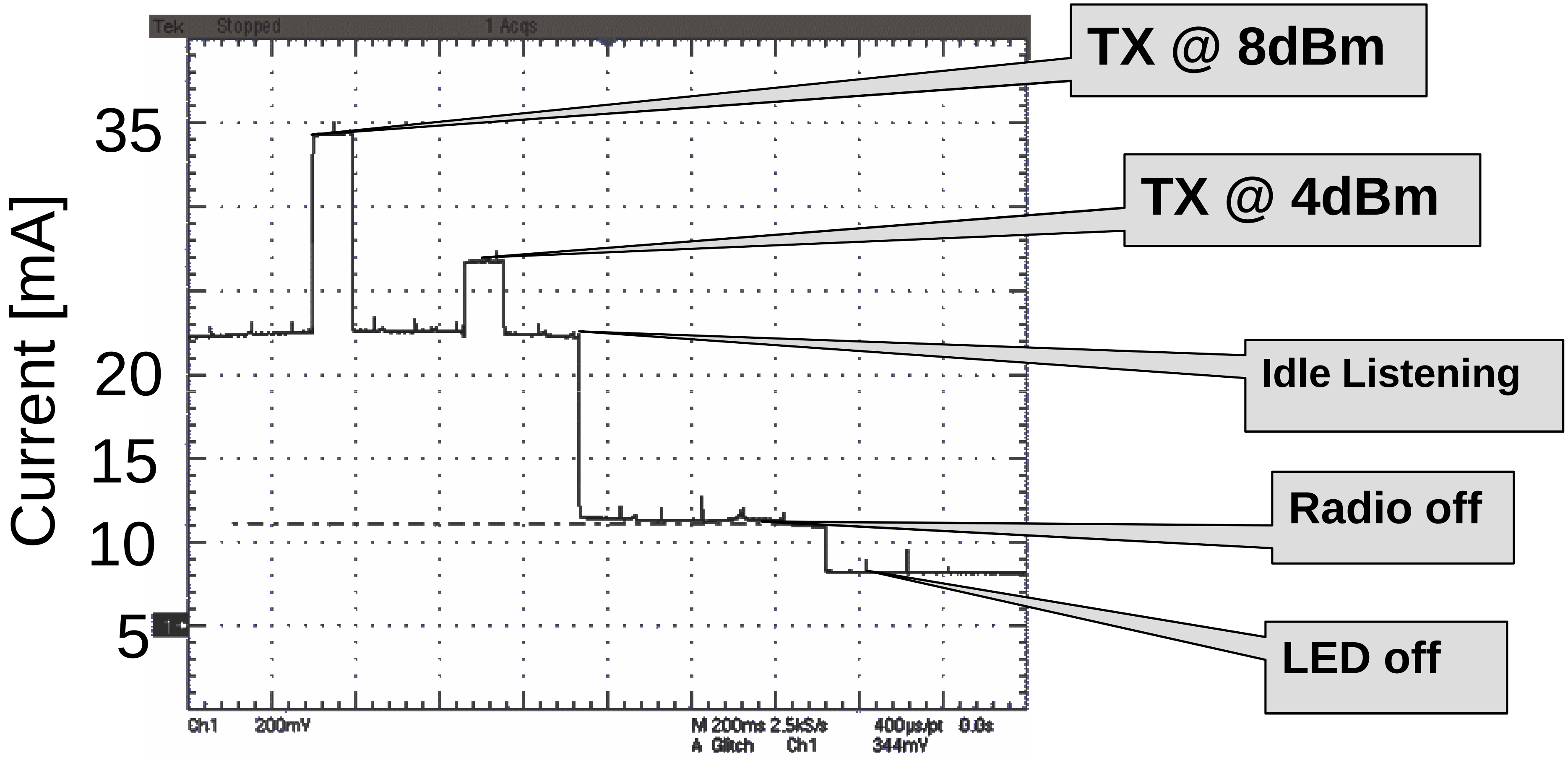
CPU			Radio		
Energy per computation	Sleep Power	Startup Cost	Energy per bit	Idle Power	Startup Cost
4 nJ/instr (8b)	30 uW	4 ms 7.2 uJ	430 nJ/b	7 mA	Low
1.1 nJ/instr (32b)	20 mW	10.6 ms 4.17 mJ	90 nJ/b	160 mA	High

Energy conservation

- Goal: unsupervised operation with no maintenance
- Nodes need to conserve energy
- Radio is power-hungry!

- WSN protocols leverage on radio sleep modes

Energy consumption



Power and Energy

Energy = the capacity of a system to perform work (how much work it can do)
Power = rate of energy consumption (how hard the system works)

1 Joule = work required to continuously produce 1W for 1s (1 Ws)

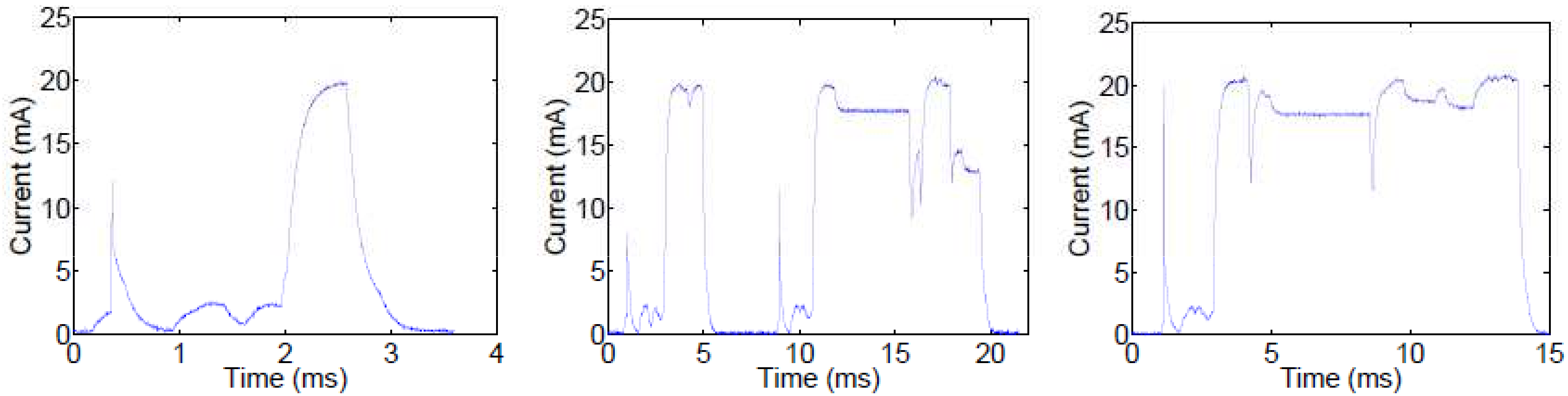
4 Watt-hours = if you use 1W continuously, it lasts you 4 hours
Ampere-hours = Watt-hours divided by the voltage used
Wh and Ah are used to measure the stored energy (Wh=V A h)

Analogy to driving:
distance [km] = energy [V A h]
speed [km/h] = power [V A]

More figures

Operation	Telos	Mica2	MicaZ
Minimum Voltage	1.8V	2.7V	2.7V
Module Standby	5.1 μA	19.0 μA	27.0 μA
MCU Idle	54.5 μA	3.2 mA	3.2 mA
MCU Active	1.8 mA	8.0 mA	8.0 mA
MCU + Radio RX	21.8 mA	15.1 mA	23.3 mA
MCU + Radio TX (0dBm)	19.5 mA	25.4 mA	21.0 mA
MCU + Flash Read	4.1 mA	9.4 mA	9.4 mA
MCU + Flash Write	15.1 mA	21.6 mA	21.6 mA
MCU Wakeup	6 μs	180 μs	180 μs
Radio Wakeup	580 μs	1800 μs	860 μs

TelosB Power Draw

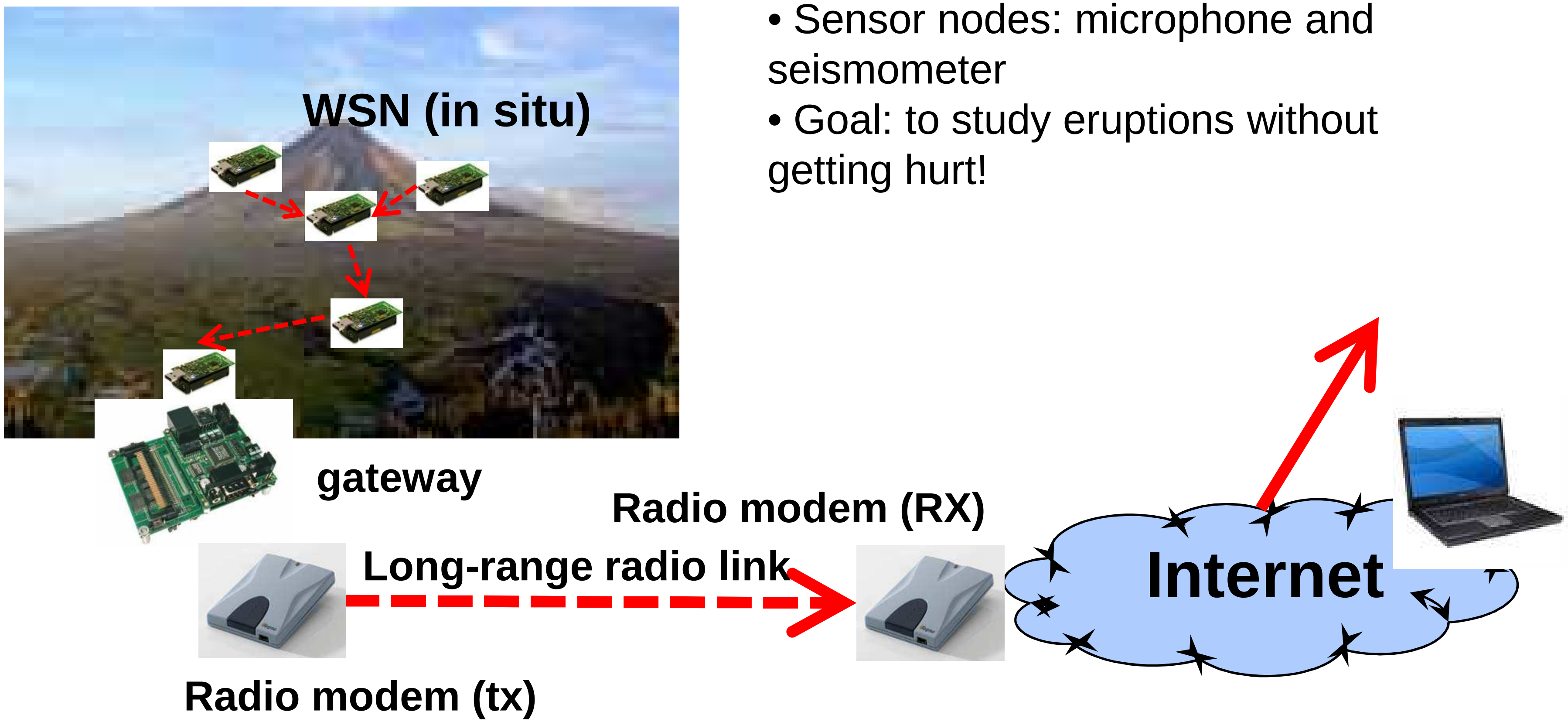


(a) Channel Sample (b) Receive Len=127B (c) Transmit Len=127B

Possible applications

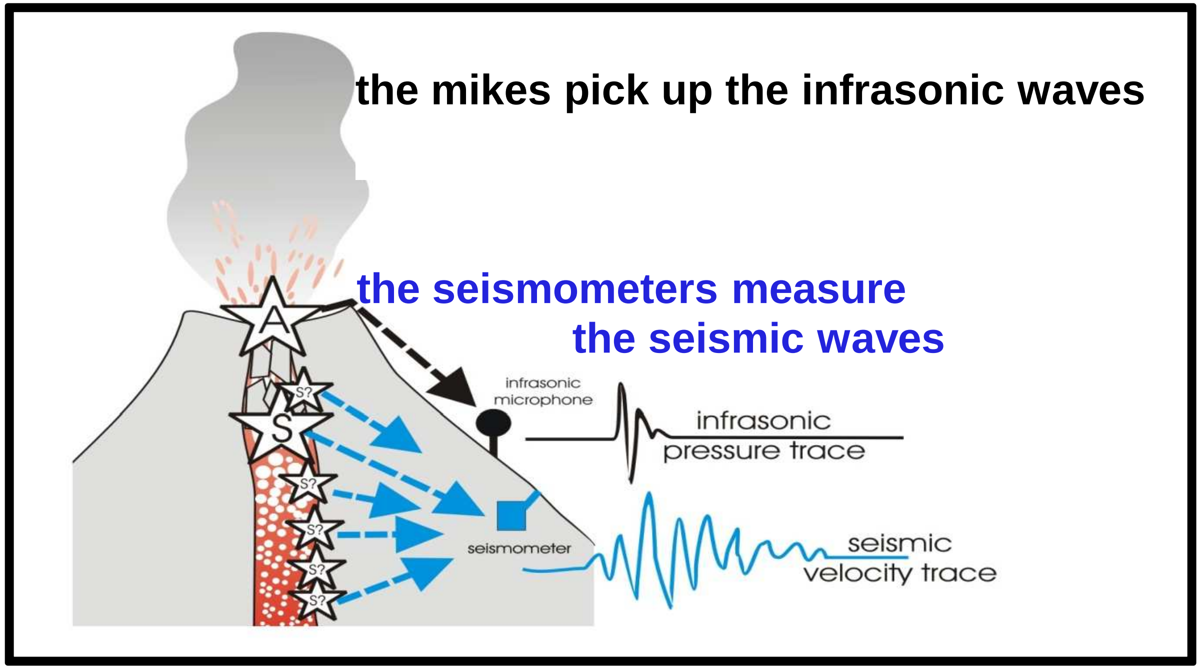
Anything that requires
- Distributed data collection
- Unobtrusive observation in remote/hard-to-get-to locations

- Environmental monitoring (earthquakes, animals, volcanoes, …)
- Agricultural monitoring
- Human behavior monitoring
- Healthcare
- Home automation and indoor energy conservation
- Civil engineering
- Warfare



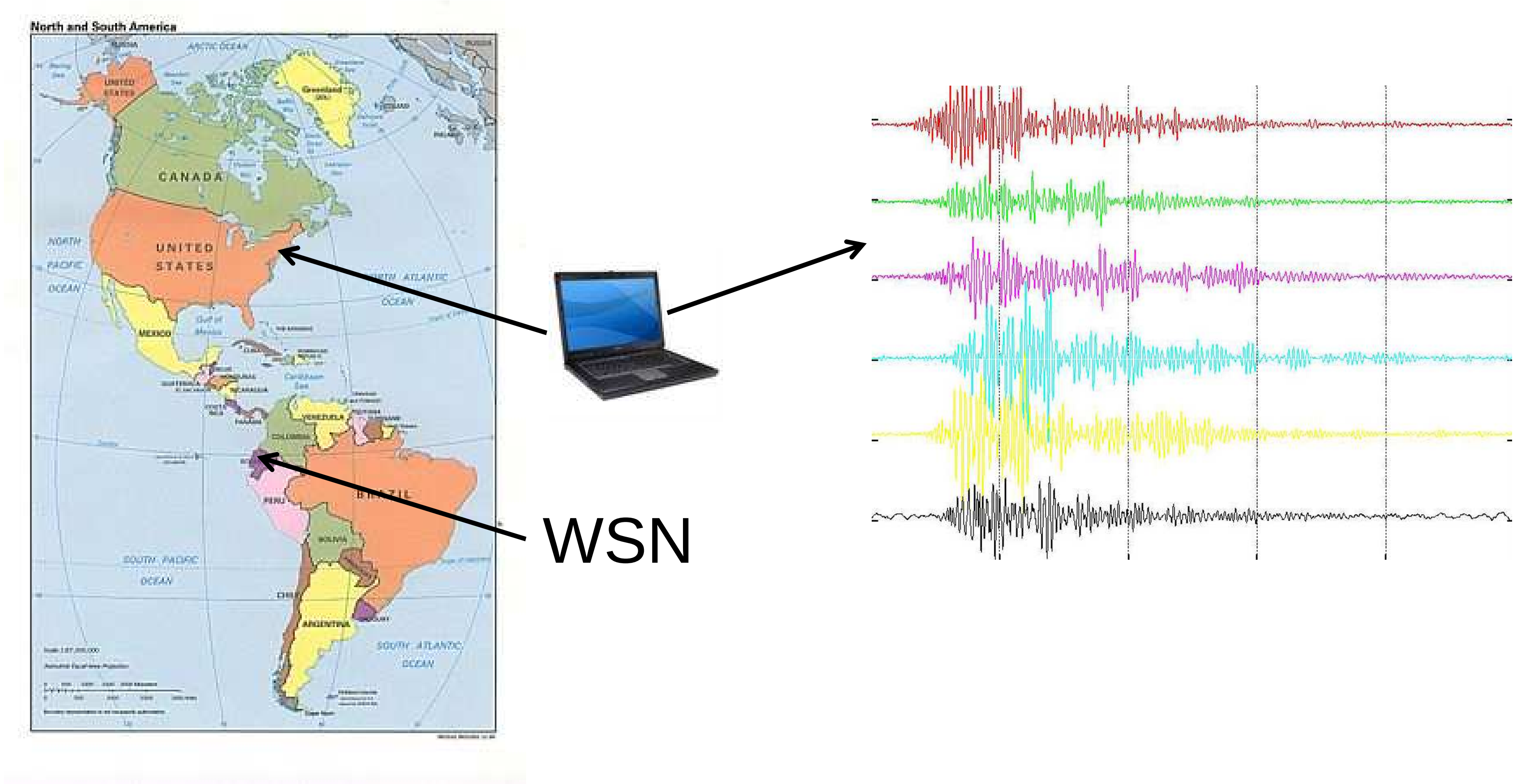
- Sensor nodes: microphone and seismometer
- Goal: to study eruptions without getting hurt!

Volcano monitoring (2)

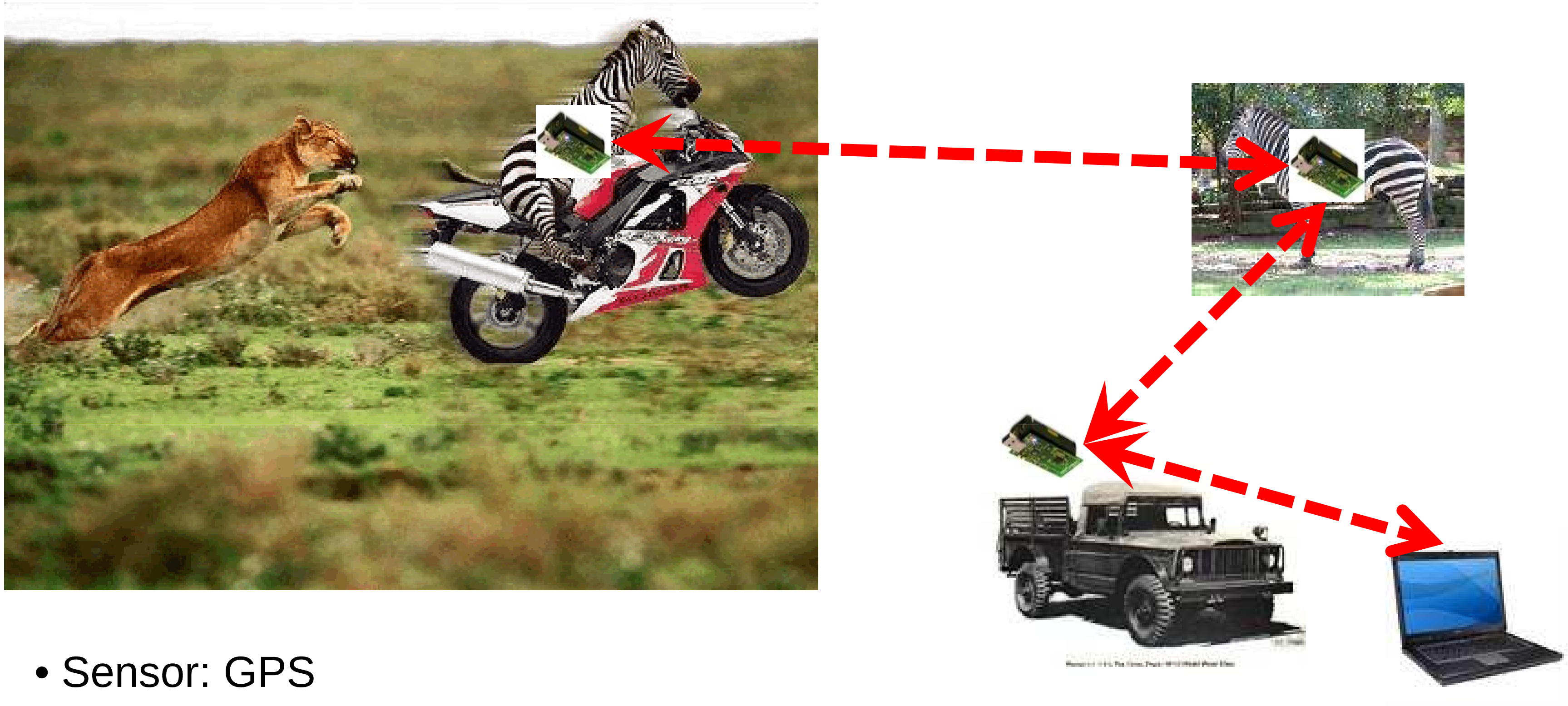


Adapted from Matt Welsh's Keynote at DCOSS'08

Volcano monitoring (3)



Tracking zebras



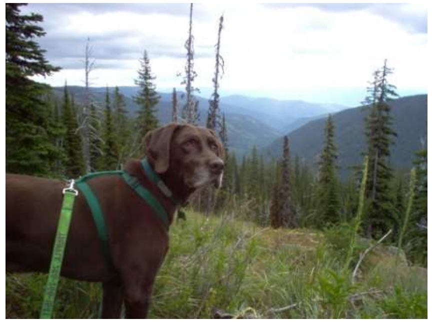
- Sensor: GPS
- Nodes on zebras, drive-by data collection

Wireless vineyards

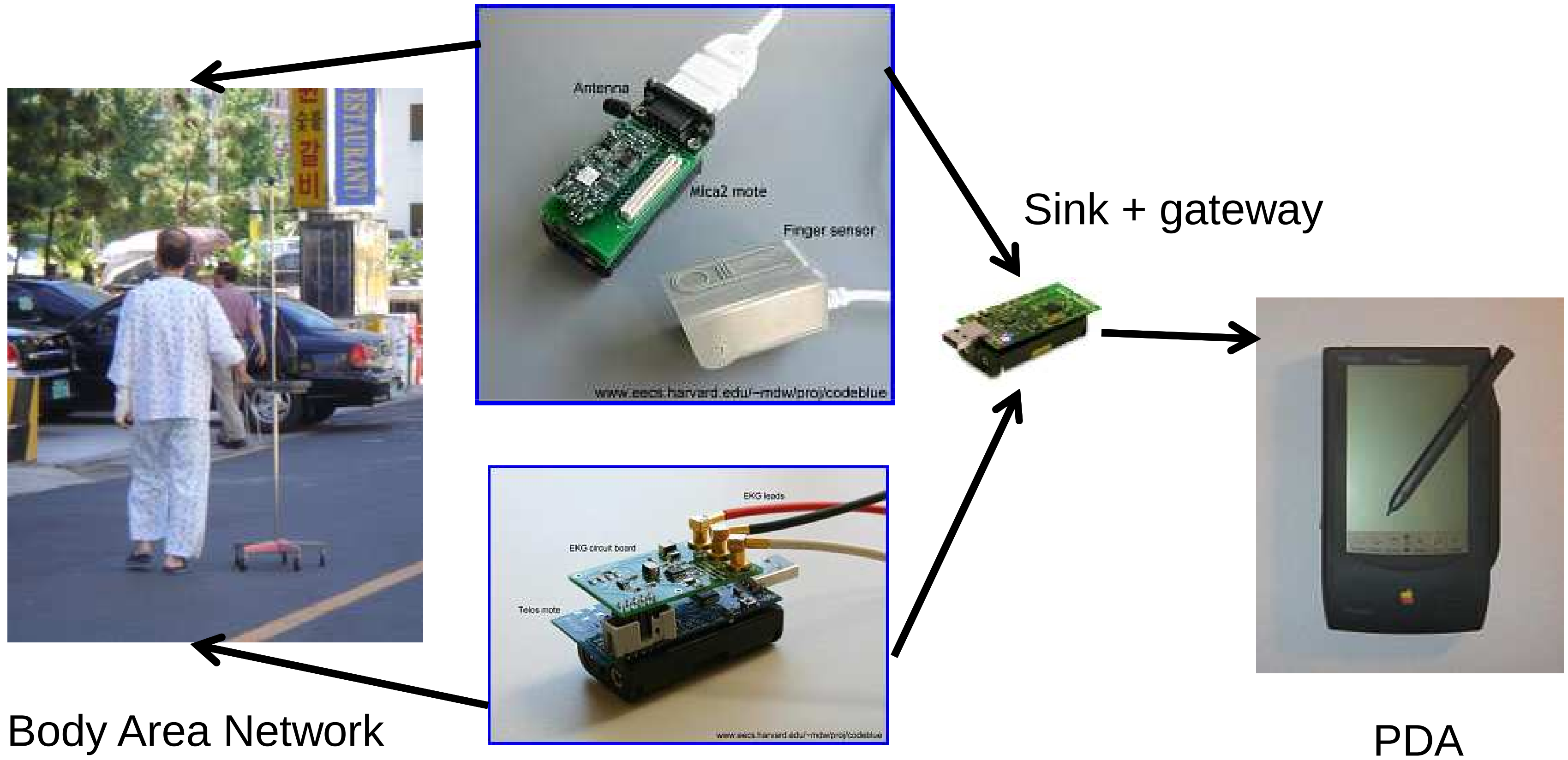
Sensors:
• soil moisture
• temperature
• biological

Goal: decision-making
• Should we irrigate area X now?
• Is there a parasite in area Y?

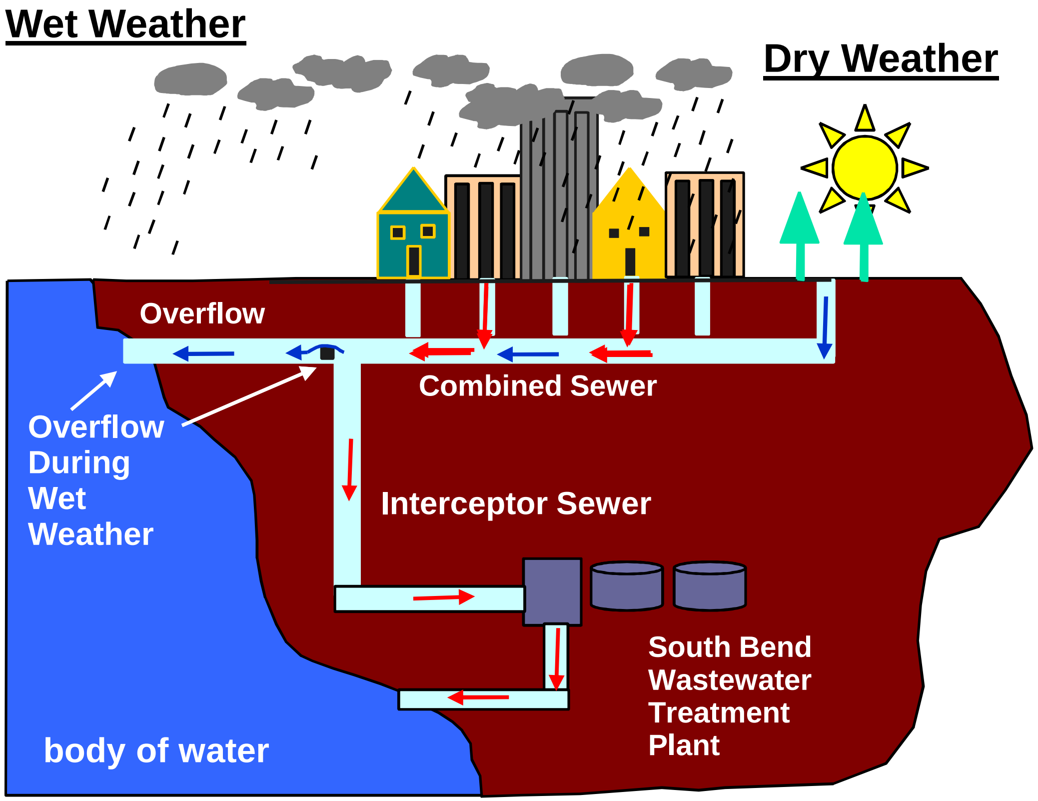
Data collection: mobile sink
People (or dogs) walking around



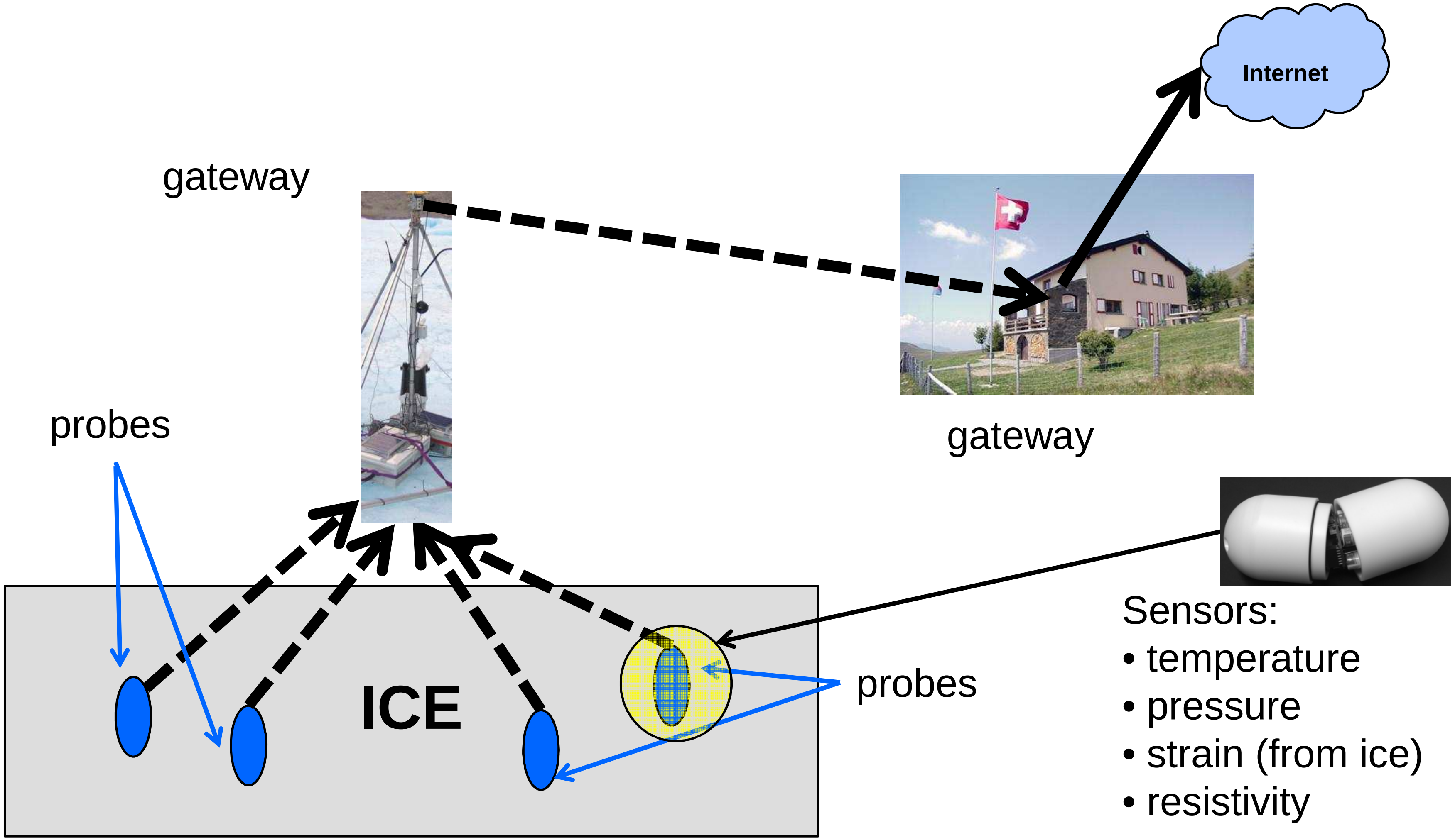
Medical applications



Sewer Overflow

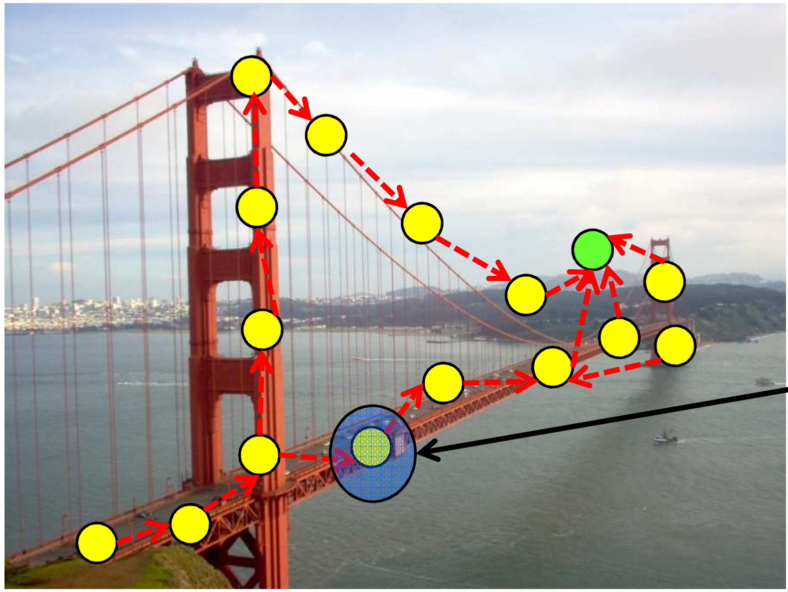


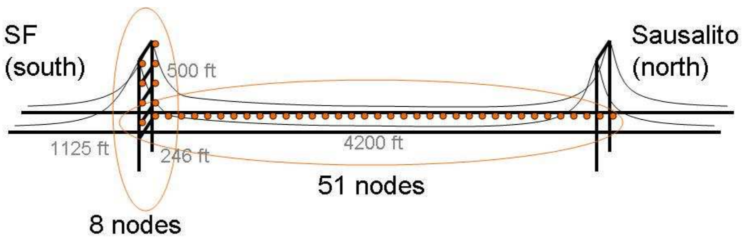
- Heavy rains cause sewers to overflow
- Sewage water gets dumped into rivers
- Sensor: water flow through a pipe
- Actuators to divert water flow
- Goal: in-line water storage in areas that are less affected by current storm

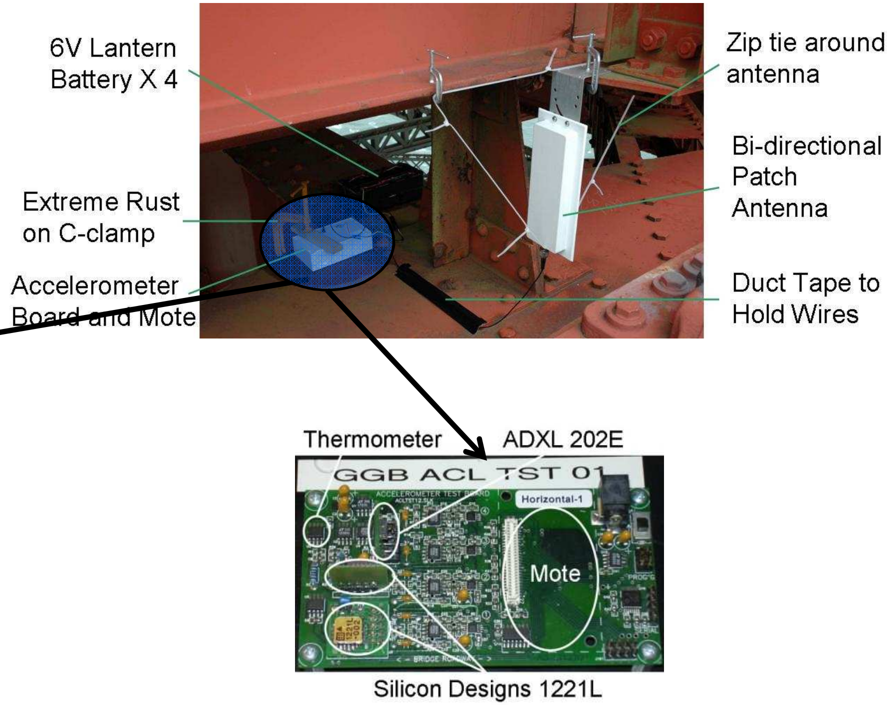


Internet
gateway
gateway
probes
ICE
probes
Sensors:
• temperature
• pressure
• strain (from ice)
• resistivity

Bridge monitoring







WSNs vs MANETs

WSNs share some MANET features

- No infrastructure
- Self-organization (dynamic topology)

But are rather different!

- Many more nodes
- Simpler, cheaper nodes
- Limited computing power
- Limited storage
- Limited energy
- Typically, static nodes

Key features of WSNs

Sensor network hardware should be

- energy-efficient, to maximize lifetime
- small, for ease of deployment
- inexpensive, so that many nodes can be deployed
- reliable, to minimize maintenance

Ultimate goal:

Long-lasting, flexible, and reliable operation

Theory-Reality Gap

There are some notoriously optimistic assumptions...

...that are hardly ever true in practice

The Theory

- Nodes are deployed randomly (e.g., thrown out of airplanes)

The Reality

- Time-consuming deployments

Theory-Reality Gap

There are some notoriously optimistic assumptions...

...that are hardly ever true in practice

The Theory

- Nodes are small and cheap

The Reality

- Same hardware platform for the past 6 years
- Still more than $100 for a mote

Theory-Reality Gap

There are some notoriously optimistic assumptions...

...that are hardly ever true in practice

The Theory

- Nodes have a fixed radio range and a fixed sensing range

The Reality

- No circular radios
- No circular sensors

Reading List

1. D. Puccinelli and M. Haenggi, “Wireless Sensor Networks-Applications and Challenges of Ubiquitous Sensing,” IEEE Circuits and Systems Magazine, Aug. 2005

2. G. Tolle et al., "A Macroscope in the Redwoods", SenSys’05

3. G. Werner-Allen et al., "Monitoring Volcanic Eruptions with a Wireless Sensor Network", EWSN'05