Wireless Sensor Networks

CMPSCI 677
Lecture 26

Wireless Sensor Networks

- What are building blocks of a WSN?
- What is a WSN used for?

Structure:

- Hardware platforms ("motes")
- Sensing applications
- Canonical problems
- Examples
- Operating systems

WSN Platforms

What are the differences between WSN platforms and typical computers?

- Battery power
  - Goal: maximum system lifetime with no recharge/replacement
- Low-power radios for communication
  - 10-200kbit/sec
- Small CPUs
  - E.g. 8bit, 4k RAM.
- Flash storage
- Sensors

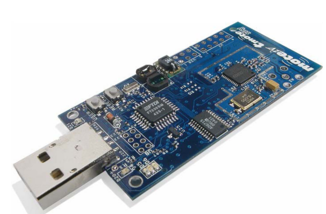
Battery Power

Example: Mica2 “mote”

- Total battery capacity: 2500mAH (2 AA cells)
- System consumption: 25 mA (CPU and radio on)
- Lifetime: 100 hours (4 days)

Alternatives:

- Bigger batteries
- Solar/wind/… (“energy harvesting”)
- **Duty cycling**

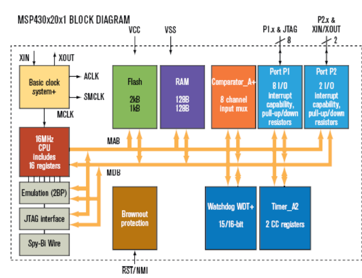


Low Power Radios

- ISM band – 430, 900, or 2400 MHz
- Varying modulation and protocol:
  - Custom (FSK?) – Mica2, 20 kbit/s
  - Bluetooth
  - Zigbee (802.15.4) - ~200kbit/sec
- Short range
  - Typically <100 meters
- Low power. E.g. Chipcon CC2420:
  - 9-17 mA transmit (depending on output level)
  - 19 mA receive
- Listening can take more energy than transmitting

Small CPUs

- Example: Atmel AVR
  - 8 bit
  - 4 KB RAM
  - 128 KB code flash
  - ~2 MIPS @ 8MHz
  - ~8 mA
- Example: TI MSP430
  - 16 bit (sort of)
  - 10 KB RAM
  - 48 KB code flash
  - 2 mA

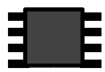


Higher-powered processors:

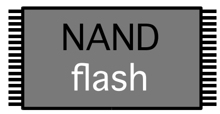
ARM7 (Yale XYZ platform)
32 bit, 50 MHz, >>1MB RAM

ARM9 (StarGate, others)
32 bit, 400 MHz, >>16MB RAM

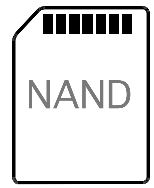
Flash Storage



Serial NOR flash



Removable flash media



Raw flash
- Small (serial NOR), very low power (NAND)
- Page-at-a-time write
- No overwrite without erasing
- Divided into pages and erase blocks
- Typical values: 512B pages, 32 pages in erase block
- Garbage collection needed to gather free pages for erasing

“Cooked” flash

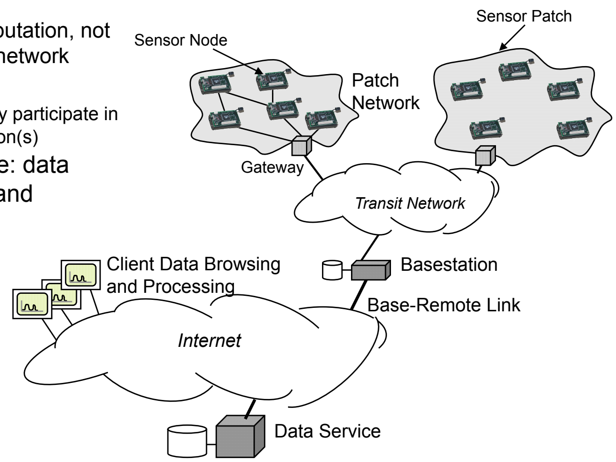
- Disk-like interface
- 512B re-writable blocks
- Very convenient
- Higher power consumption

Sensors

- Temperature
- Humidity
- Magnetometer
- Vibration
- Acoustic
- Light
- Motion (e.g. passive IR)
- Imaging (cameras)
- Ultrasonic ranging
- GPS
- Lots of others…

Sensor Applications

- Data driven
  - Distributed computation, not communication network
- Homogeneous
  - All sensors typically participate in the same application(s)
- Typical architecture: data collection, fusion, and transport



Canonical WSN Problems

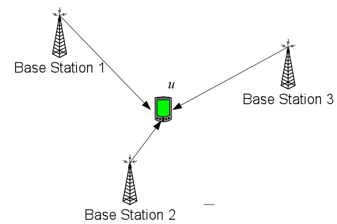
- Localization
- Time Synchronization
- Routing
- Duty cycled networking
- Data aggregation

Localization

Determining relative or absolute location of a sensor

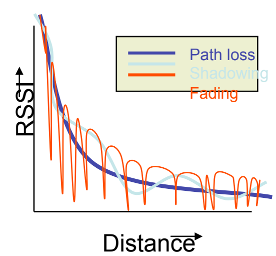
Solutions:

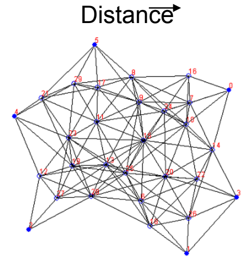
- GPS
- Ranging and triangulation
  - Radio strength (RSSI)
  - RF time-of-flight (interferometry)
  - Acoustic time-of-flight
- Directional triangulation
  - Acoustic – phase measurement



Problems in Localization

- GPS is expensive, sometimes difficult to use, and power-hungry
  - Requires line-of-sight to 3 or 4 satellites overhead
  - 80mA for 1-5 minutes to acquire fix
- Radio ranging is not accurate
- Acoustic ranging is limited
  - Range
  - Applications
- Sensitivity to errors
  - Robust triangulation is hard





Time Synchronization

- Applications:
- Event detection by arrival time
  - E.g. gunshot triangulation
- Duty cycling synchronization

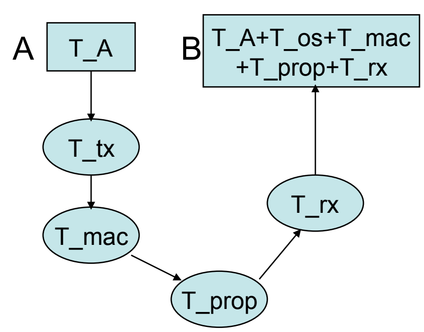
- External reference
  - GPS, WWV
- Autonomous synchronization
  - Receiver-receiver
  - Sender-receiver
  - Drift estimation

Autonomous Synchronization

Idea:
- Sample time at A
- Transmit to B

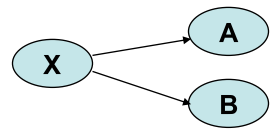
Issues:
- B receives T_A at T_A+Δ
- Software delays (T_tx, T_rx)
- Channel acquisition (T_mac)
- Propagation delay (T_prop)

Clock drift
- Quartz crystal:
  50 ppm = 50μS/s = 180ms/hr
- Varies with e.g. temperature



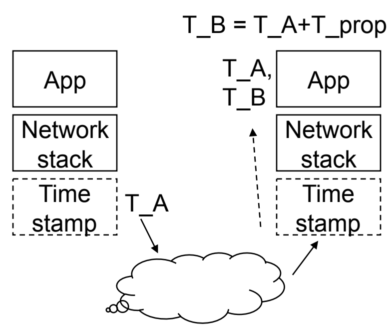
Synchronization methods

- Receiver-receiver
  - Eliminate transmit uncertainty



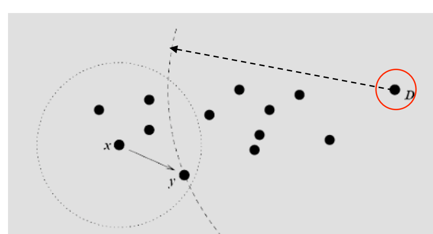
T_A = T_B ± T_rx

- Sender-receiver
  - Reduce transmit uncertainty
- Drift estimation
  - Estimate and correct



Routing

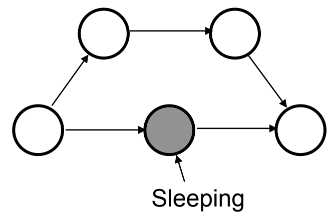
- What addresses make sense in a sensor network?
  - Location
  - Data
- Geographic routing
  - GPSR
  - Beacon routing
- Flooding, tree construction
  - Data collection architectures



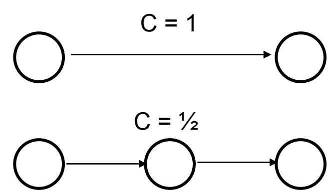
GPSR – forward to node physically closest to destination

More Routing

- How to handle duty cycling?
  - Sleep or go around?

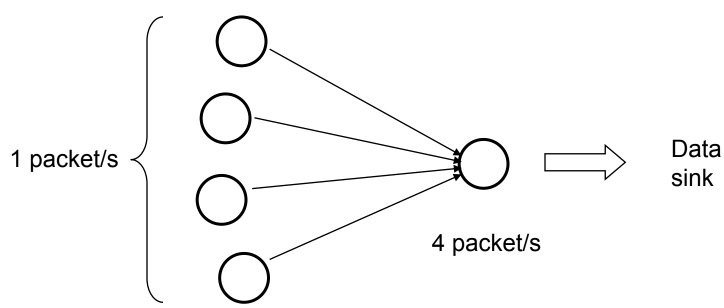


- Wireless vs. wired



More Routing

- Network lifetime
  - More packets = more battery drain

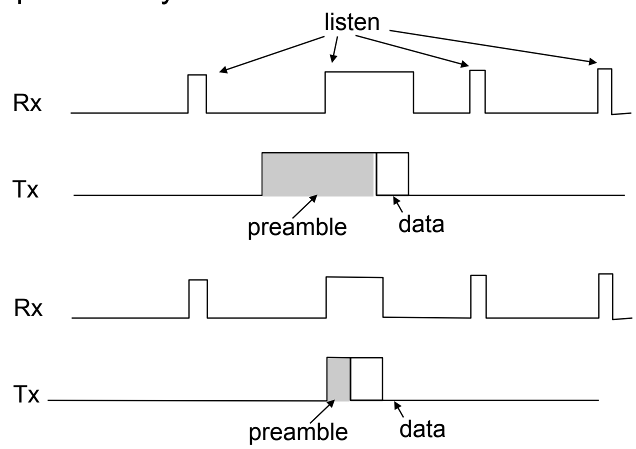


Duty Cycled Networking

Problem: continuous listening is too expensive
Solution: listen periodically

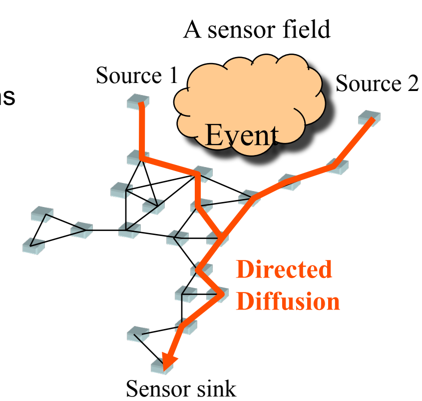
Low-power listening

Synchronized low-power listening



Example - Directed Diffusion

- **Name data** (not nodes), use physicality
- **Sensors publish** event notifications and **users subscribe** to specific types.
- optimize path with **gradient-based feedback**
- Opportunistic **in-network aggregation** and **nested queries.**



Directed Diffusion

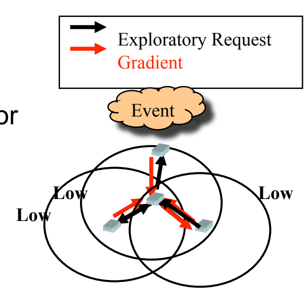
- Expressing an Interest
  - Using attribute-value pairs
  - E.g.,

Type = Wheeled vehicle	// detect vehicle location
Interval = 20 ms	// send events every 20ms
Duration = 10 s	// Send for next 10 s
Field = [x1, y1, x2, y2]	// from sensors in this area

- Uses publish/subscribe
  - Inquirer expresses an interest, *I,* using attribute values
  - Sensor sources that can service *I,* reply with data

Gradient-based Routing

- Inquirer (sink) broadcasts exploratory interest, ***i1***
  - Intended to discover routes between source and sink
- Neighbors update interest-cache and forwards ***i1***
- Gradient for ***i1*** set up to upstream neighbor
  - No source routes
  - Gradient – a weighted reverse link
  - Low gradient → Few packets per unit time needed



Bidirectional gradients established on all links through flooding

Examples - TinyDB

TinySQL:

SELECT <aggregates>, <attributes>
[FROM {sensors | <buffer>}]
[WHERE <predicates>]
[GROUP BY <exprs>]
[SAMPLE PERIOD <const> | ONCE]
[INTO <buffer>]
[TRIGGER ACTION <command>]

Data Model

- Entire sensor network as one single, infinitely-long logical table: *sensors*
- Columns consist of all the *attributes* defined in the network
- Typical attributes:
  - Sensor readings
  - Meta-data: node id, location, etc.
  - Internal states: routing tree parent, timestamp, queue length, etc.
- Nodes return NULL for unknown attributes
- On server, all attributes are defined in catalog.xml

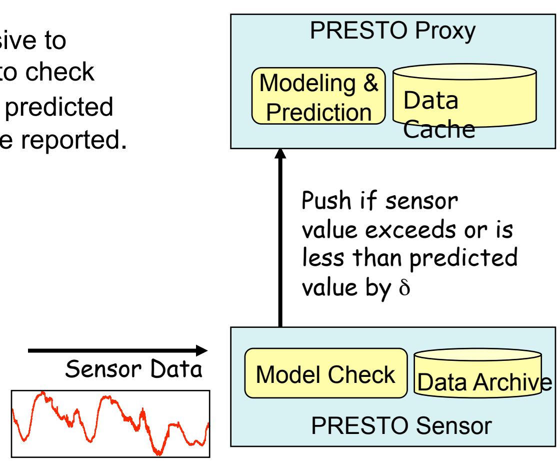
Acquisitional Query Processing

- What's really new & different about databases on (mote-based) sensor networks?
- This paper's answer:
  - Long running queries on physically embedded devices that control when and where and with what frequency data is collected
  - Versus traditional DBMS where data is provided *a priori*
- For a distributed, embedded sensing environment, ACQP provides a framework for addressing issues of
  - When, where, and how often data is sensed/sampled
  - Which data is delivered

PRESTO: Model-driven Push

Insight:

- Models are expensive to create, but simple to check
- Data which can be predicted does not need to be reported.



Operating Systems

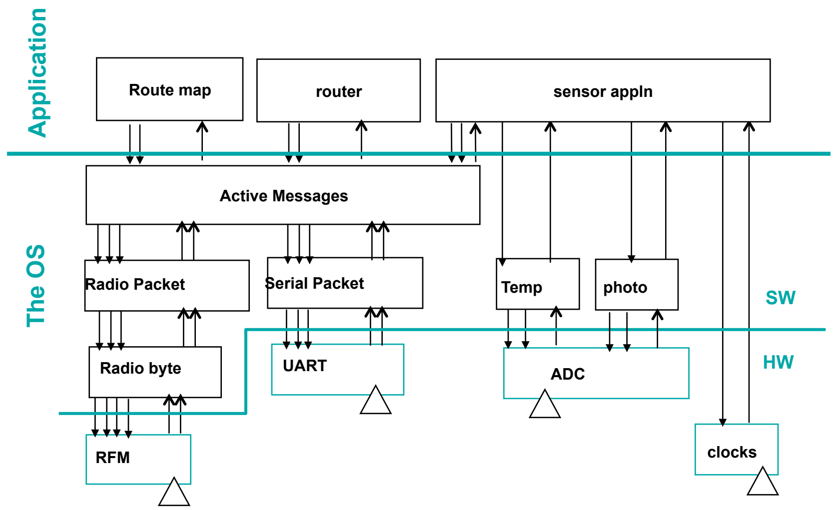
What features does an operating system need?

	Unix	TinyOS	SOS
Hardware drivers, system init	Yes	Yes	Yes
Loadable programs	Yes	No	Yes
File system	Yes	No	No
Resource allocation (e.g. memory)	Yes	No	Yes
Processes / threads	Yes	No	Sort of
Networking support	Yes	Yes	Yes
IPC	Yes	Yes	Yes
Event scheduling / timers	Yes	Yes	Yes

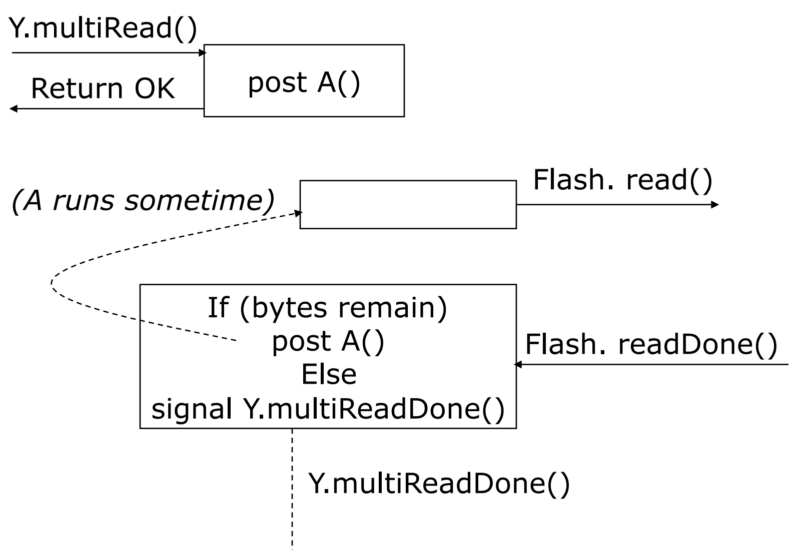
TinyOS & nesC Concepts

- New Language: **nesC.** Basic unit of code = **Component**
- Component
  - Process **Commands** } (used for split-phase)
  - Throws **Events**
  - Has a **Frame** for storing local state
  - Uses **Tasks** for concurrency
- Components *provide* **interfaces**
  - *Used* by other components to communicate with this component
- Components are *wired* to each other in a **configuration** to connect them

Application = Graph of Components

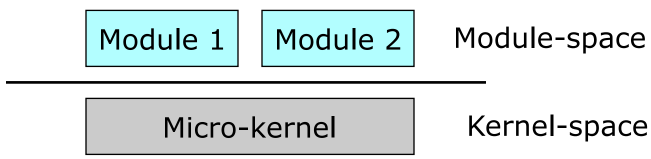


TinyOS Code Structure



SOS

- Micro-kernel architecture
  - User-space, kernel-space separation
  - Supports dynamic, run-time addition of modules
  - Memory protection possible between module & kernel space
- Each application has one or more modules
  - Within a module, interaction uses regular function calls
  - Modules interact by passing ***messages***
  - Modules can retain state, allocate / deallocate memory



Modules: SOS vs TinyOS

```
module Provider
{
   provides interface StdControl;
   provides interface X;
   uses interface Z;
}
implementation
{
   // C code
   ….
}
```

```
static mod_header_t mod_header
                         SOS_MODULE_HEADER =
{
      .mod_id         = DFLT_APP_ID0,
      .state_size     = sizeof(app_state_t),
      .num_timers     = 0,
      .num_sub_func   = 0,
      .num_prov_func  = 0,
      .platform_type  = HW_TYPE ,
      .processor_type = MCU_TYPE,
      .code_id        = ehtons(DFLT_APP_ID0),
      .module_handler = test_msg_handler,
};
```

TinyOS – compile-time

SOS – run-time

SOS - Proto-threads

- Threading implemented as macros

```
#include "pt.h"
struct pt pt;

PT_THREAD(example(struct pt *pt))
{
    PT_BEGIN(pt);
    while(1)
    {
        if(initiate_io())
        {
           timer_start(&timer);
           PT_WAIT_UNTIL(pt, io_completed() || timer_expired(&timer));
           read_data();
        }
    }
   PT_END(pt);
}
```

Wrap-up

- What did we talk about?

- Energy management
  - Esp. duty-cycled radios
- Routing
  - By naming and finding information or locations
- In-network processing
  - Aggregation (tinyDB)
  - Model checking (PRESTO)
- Light weight operating systems