



Mobile and Sensor Systems

Lecture 5: Sensor Systems and Mac Layer Routing

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Sensors and Sensor Networks



A sensor is a device which allows “sensing” of the environment. It is usually small and resource constrained.

A **sensor network** is composed of a large number of sensor nodes, which are deployed either inside the phenomenon or very close to it.

- Sometimes Random deployment
- Cooperative capabilities



What’s in this lecture



- We will describe sensor networks in general and the properties of sensor nodes
- We will introduce sensor network MAC Layer issues and some solutions.



Sensor Systems vs Standard or Mobile Systems



- Sensor nodes are limited in power, computational capacities and memory.
- Sensor nodes are prone to failures (especially because they are often deployed in challenging conditions)
- The topology of a sensor network might not change frequently:
 - Many deployment involved sensors with fixed location
 - Some deployments may have mobile sensors



Example applications



Seismic Structure response



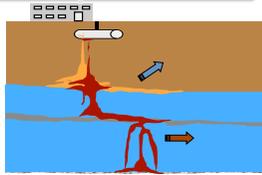
Marine Microorganisms



- Micro-sensors, on-board processing, wireless interfaces feasible at very small scale--can monitor phenomena "up close"

- Enables spatially and temporally dense environmental monitoring

Embedded Networked Sensing will reveal previously unobservable phenomena



Contaminant Transport

Ecosystems, Biocomplexity



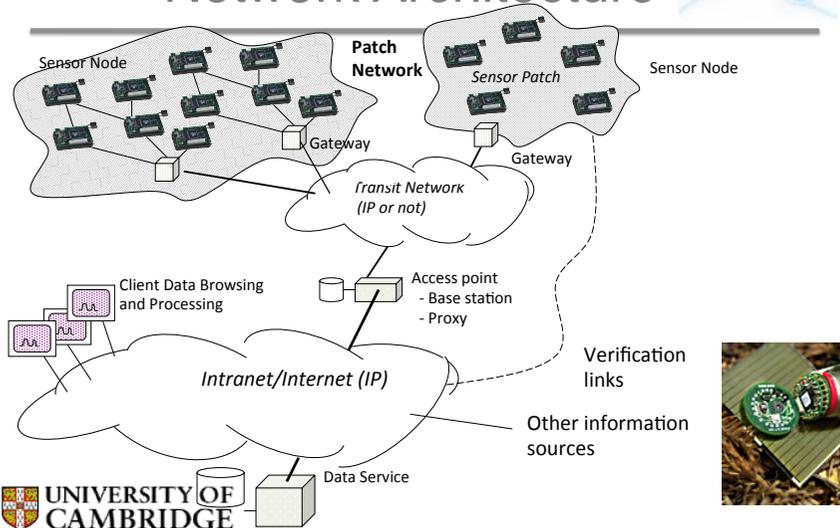
Experimental Platform



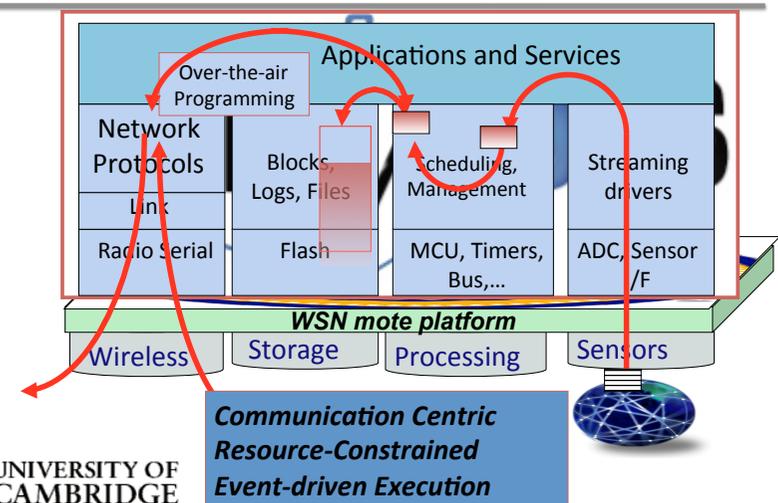
- Standards Based
 - USB
 - Radio:
 - IEEE 802.15.4 (CC2420 radio)
 - Zigbee: Ultralow power
- 8-bit microprocessor, 4MHz CPU
 - ATMEGA 128, ATMEL 8535, or Motorola HCS08
- ~4Kb RAM
 - holds run-time state (values of the variables) of the program
- ~128Kb programmable Flash memory
 - holds the application program
 - Downloaded via a programmer-board or wirelessly
- Additional Flash memory storage space



Canonical SensorNet Network Architecture



What happens in the node



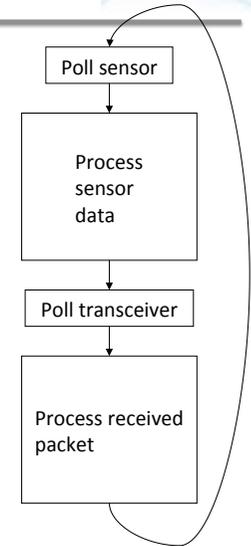
What Operating System runs on a sensor?

- Operating system useful to simplify programming tasks and to allow more control over operations of the system
- But what can we do with such a constrained device?
- Given the kind of applications needed it is important to support concurrency... [frequent and parallel collection from different sensors]



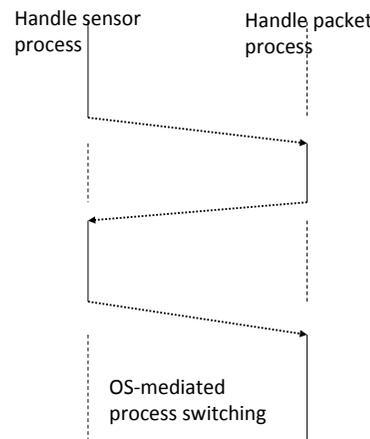
Main issue: How to support concurrency

- Simplest option: No concurrency, sequential processing of tasks
 - Not satisfactory: Risk of missing data (e.g., from transceiver) when processing data, etc.
 - ! Interrupts/asynchronous operation has to be supported
- Why concurrency is needed
 - Sensor node's CPU has to service the radio modem, the actual sensors, perform computation for application, execute communication protocol software, etc.



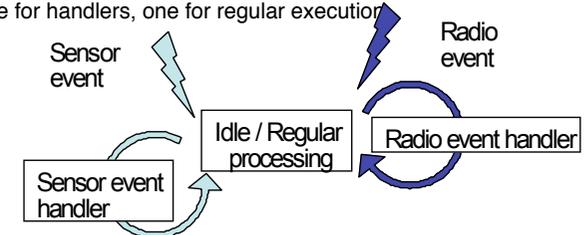
Traditional concurrency: Processes

- Traditional OS: processes/threads
 - Based on interrupts, context switching
 - But: memory overhead, execution overhead
- concurrency mismatch
 - One process per protocol entails too many context switches
 - Many tasks in WSN small with respect to context switching overhead



Event-based concurrency

- Alternative: Switch to **event-based programming model**
 - Perform regular processing or be idle
 - React to events when they happen immediately
 - Basically: interrupt handler
- Problem: must not remain in interrupt handler too long
 - Danger of losing events
 - Only save data, post information that event has happened, then return
 - ! **Run-to-completion** principle
 - Two contexts: one for handlers, one for regular execution



TinyOS: Tasks and Command/Event Handlers



- TinyOS: an OS for sensor networks
- Event handlers must run to completion
 - Must not wait an indeterminate amount of time
 - Only a **request** to perform some action
- Tasks, on the other hand, can perform arbitrary, long computation
 - Also have to be run to completion
 - But can be interrupted by handlers

! No need for stack management, tasks are atomic with respect to each other



Energy Management



- Processing is not the greatest source of energy consumption
- **The main source of energy consumption is the radio**
- Strategy: *limit communication* and
- But also: *idle listening by the radio is expensive. Put the radio to sleep when idle*



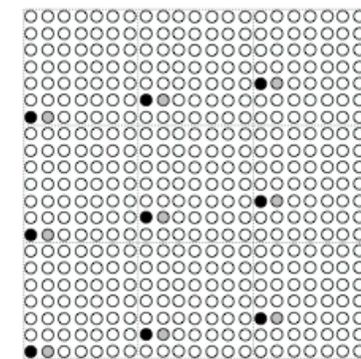
Radio Duty Cycling



- Basic strategy: switch off the radio of all sensors at specific intervals
 - Very precise synchronization
 - Still probable idle time for sensors which do not communicate
- More refined strategy
 - Wave of switch off time depending on topology
 - Still probably overestimate of the communication needs of some sensors (traffic might be varying across the network)



Wave Duty Cycling



Dynamic duty cycling



- More refined strategies have been proposed which aim to allow sensors which transmit more to stay more awake and others to sleep more.
- The basic idea of most of these approaches is to keep nodes awake only when the need to transmit or receive
 - But how is this known?



S-MAC



- SYNC phase divided into time slots using CSMA and backoff to send schedule to neighbours
- Y chooses a slot and if no signal was received before it will start to transmit its schedule to X otherwise wait for next wake up of X
- RTS phase: X listens for RTS packets (CSMA contention)
- CTS phase: X sends one and extends its wake up time

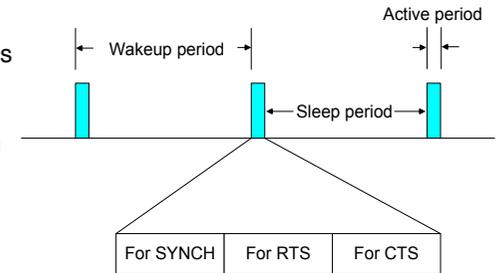


Sensor-MAC (S-MAC)



- idle listening is particularly unsuitable if average data rate is low
 - Most of the time, nothing happens
- Idea: Switch nodes off, ensure that neighboring nodes turn on simultaneously to allow packet exchange (rendez-vous)

- Only in these **active periods**, packet exchanges happen
- Need to also exchange wakeup schedule between neighbors
- When awake, essentially perform RTS/CTS phases
- Use SYNC, RTS, CTS phases



S-MAC synchronized islands



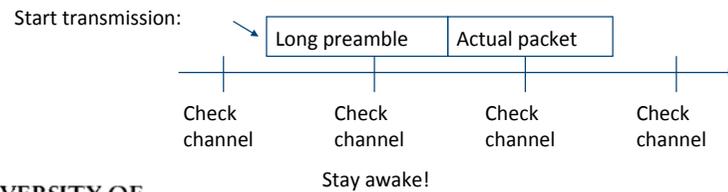
- Nodes try to pick up schedule synchronization from neighboring nodes
- If no neighbor found, nodes pick some schedule to start with
- If additional nodes join, some node might learn about two different schedules from different nodes
 - “Synchronized islands”
- To bridge this gap, it has to follow both schemes and use more energy



Preamble Sampling



- So far: Periodic sleeping supported by some means to synchronize wake up of nodes to ensure rendez-vous between sender and receiver
- Alternative option: Don't try to explicitly synchronize nodes
 - Have receiver sleep and only periodically sample the channel
- Use **long preambles** to ensure that receiver stays awake to catch actual packet. Example: BMAC and WiseMAC



Ad hoc & sensor networks - Ch 5: MAC protocols

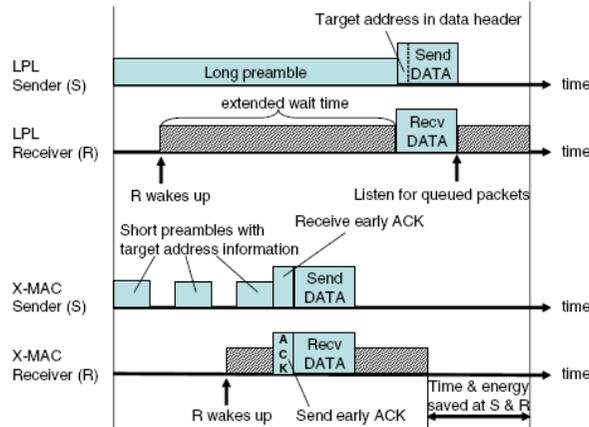
Problems with this technique



- A node waking up while preamble is transmitted needs to stay awake until the end to know if he is the target receiver!
- Also it might be that the receiver is awake much earlier than the end of the preamble
- This means that energy consumption is very dependent on network density
- Can you think of alternative solutions?



XMAC



XMAC



- Short preamble
 - Reduce latency and reduce energy consumption
- Target in preamble
 - Minimize overhearing problem.
- Adding wait time between preambles
 - Reduces latency for the case where destination is awake before preamble completes.



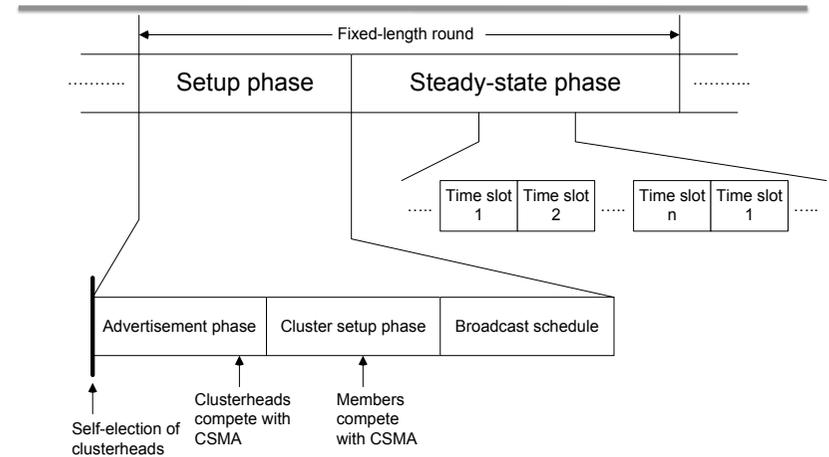
Low-Energy Adaptive Clustering Hierarchy (LEACH)



- Given: dense network of nodes, reporting to a central sink, each node can reach sink directly
- Idea: Group nodes into “**clusters**”, controlled by **clusterhead**
 - Setup phase; details: later
 - About 5% of nodes become clusterhead (depends on scenario)
 - Role of clusterhead is rotated to share the burden
 - Clusterheads advertise themselves, ordinary nodes join CH with strongest signal
 - Clusterheads organize
 - CDMA code for all member transmissions
 - TDMA schedule to be used within a cluster
- In steady state operation
 - CHs collect & aggregate data from all cluster members
 - Report aggregated data to sink using CSMA



LEACH rounds

Summary



- We have described sensor nodes properties and sensor nodes operation
- We have introduced various MAC layer sensor network protocols



References



- TinyOS tutorial: <http://www.tinyos.net/tinyos-1.x/doc/tutorial/>
- SMAC: Ye, W., Heidemann, J., and Estrin, D. 2004. Medium access control with coordinated adaptive sleeping for wireless sensor networks. *IEEE/ACM Trans. Netw.* 12, 3 (Jun. 2004), 493-506.
- WISEMAC: El-Hoiydi, A. and Decotignie, J. 2004. WiseMAC: an ultra low power MAC protocol for the downlink of infrastructure wireless sensor networks. In *Proceedings of the Ninth international Symposium on Computers and Communications 2004 Volume 2 (Iscc'04) - Volume 02* (June 28 - July 01, 2004). ISCC. IEEE Computer Society, Washington, DC, 244-251.
- X-MAC: M. Buettner, G. V. Yee, E. Anderson, and R. Han, "X-MAC: a short preamble MAC protocol for duty-cycled wireless sensor networks," in *Proceedings of the 4th international conference on Embedded networked sensor systems* Boulder, Colorado, USA: ACM, 2006.
- LEACH: Wendi Heinzelman, Anantha Chandrakasan, and Hari Balakrishnan, *Energy-Efficient Communication Protocols for Wireless Microsensor Networks*, Proc. Hawaiian Int'l Conf. on Systems Science, January 2000.

