Sensors

Mika Nupponen

S-72.333

Postgraduate Course in Radio Communications

Contents

Introduction I

Definitions:

- Sensor:
  A device that measures or detects a real-world condition, such as motion, heat or light and converts the condition into an analog or digital representation. An optical sensor detects the intensity or brightness of light, or the intensity of red, green and blue for color systems.
- Wireless sensor network
  A network of RF transceivers, sensors, machine controllers, microcontrollers, and user interface devices with at least two nodes communicating by means of wireless transmissions.

Introduction II

- A modern wireless sensor network is composed of large number of sensor nodes that are densely deployed either inside of phenomenon or very close to it.
- The position of sensor nodes need not to be predetermined
  - Random deployment (for example in inaccessible terrains
  - Protocols and algorithms must posses self-organizing capabilities
- Cooperation of sensor nodes
- Onboard processor -> carry out simple computations and transmits only the required and partially processed data
- Applications:
  - Health: monitor patients & assist disabled patients
  - Military: sensing technique for military command, control, communications, computing, intelligence surveillance, reconnaissance and targeting systems
  - Other: managing inventory, monitoring product quality, and monitoring disaster areas

Introduction III

Sensors	*Size*: small (e.g., micro-electro mechanical systems (MEMS)), large (e.g., radars, satellites) *Number*: small, large *Type*: passive (e.g., acoustic, seismic, video, IR, magnetic), active (e.g., radar, ladar) *Composition or mix*: homogeneous (same types of sensors), heterogeneous (different types of sensors) *Spatial coverage*: dense, sparse *Deployment*: fixed and planned (e.g., factory networks), ad hoc (e.g., air-dropped) *Dynamics*: stationary (e.g., seismic sensors), mobile (e.g., on robot vehicles)
Sensing entities of interest	*Extent*: distributed (e.g., environmental monitoring), localized (e.g., target tracking) *Mobility*: static, dynamic *Nature*: cooperative (e.g., air traffic control), non-cooperative (e.g., military targets)
Operating environment	Benign (factory floor), adverse (battlefield)
Communication	*Networking*: wired, wireless *Bandwidth*: high, low
Processing architecture	Centralized (all data sent to central site), distributed (located at sensor or other sites), hybrid
Energy availability	Constrained (e.g., in small sensors), unconstrained (e.g., in large sensors)

Figure 1. Attributes of sensor networks.

Sensor Networks vs. Ad hoc Networks

- Number of sensor nodes in sensor network higher than nodes in Ad hoc network
- Sensor nodes are densely deployed
- Sensor nodes are prone to failures
- The topology of sensor network changes very frequently
- Sensor nodes mainly use broadcast communication paradigm
- Sensor nodes are limited in power, computational capacities, and memory
- Sensor nodes may not have global identification ID

History of Research in Sensor Networks

As with many technologies, defense applications have been a driver for research and in sensor networks.

- Early Research
  - During the cold war, the Sound Surveillance System (SOSUS): a system of acoustic sensors on the ocean bottom to detect and track Soviet submarines
  - Networks of air defense radars
- Distributed Sensor Networks Program at the Defense Advanced Research Projects Agency (DSN, DARPA, 1980)
- Military Sensor Networks in the 1980s and 1990s
  - From platform centric warfare to Network-centric warfare
  - For example: Cooperative Engage capability (CEC , U.S. Navy): multiple radars collecting data on air targets etc.
  - Measurement are associated by a processing node with reporting responsibility and shared with other nodes
  - Since all nodes have access to essentially the same information a common operation picture can be obtained.

Sensor Network Research in the 21st century

- Small and inexpensive sensors based upon microelectromechanical system (MEMS) technology, wireless networking and inexpensive low-power processors allow the deployment allow the deployment of wireless ad hoc networks for various applications.
- Development of low-cost, low-power & multifunctional sensor nodes that are small in size.
- State of the art of sensor networks:
  multihop wireless sensor networks

Communication Architecture

- Sensor nodes are scattered in a sensor field
- Nodes collect data and route data back to the sink
- The sink may communicate with task manager node via Internet or satellite

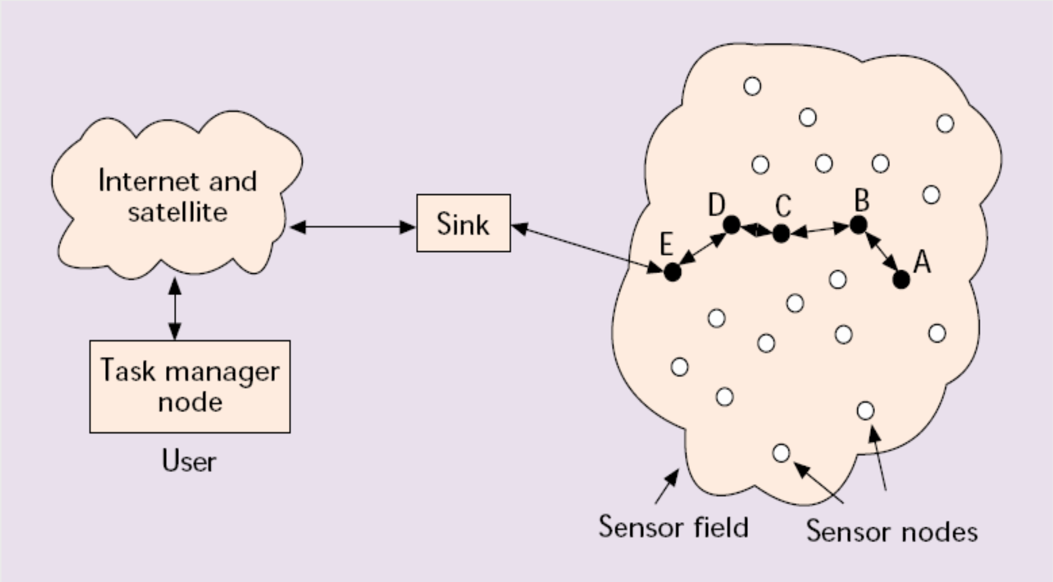

Figure 1. sensor nodes, sink and task manager node.

Design factors

- Fault tolerance:
  - Nodes may fail or be blocked due to power lack of power or environmental interference etc.
  - The failure of nodes should not affect the overall task of the S. Net.
- Scalability
  - The node density can range from few sensors nodes to few hundred nodes in a region
- Production cost
  - Cost of single node vs. overall cost of network
- Hardware Constraints
  - Node has four basic components (See figure 2).

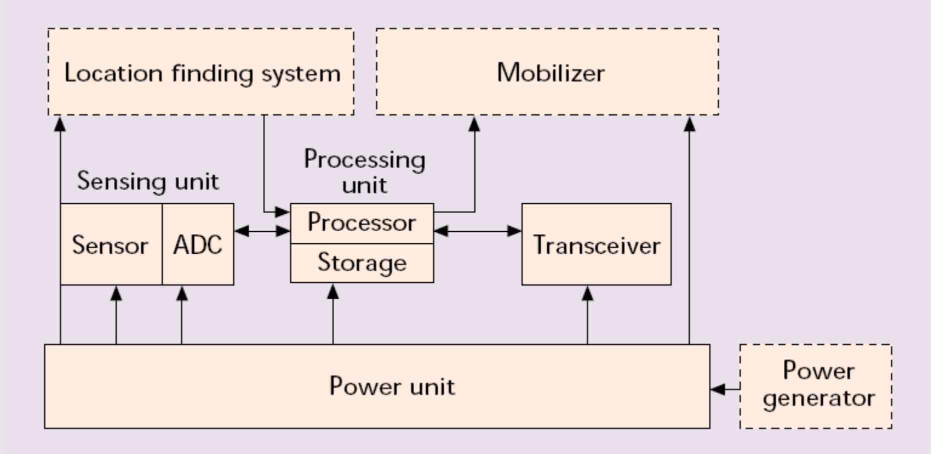

Figure 2. The components of sensor node

Design factors II

- Sensor network Topology
  - Sensor nodes can be either thrown in a mass or placed one by one in the sensor field
  - Topology changes due to sensor node position, reachability (interference, noise etc), energy etc.
- Environment
  - Sensors usually very close or directly inside the phenomenon to be observed
- Transmission Media
  - In multihop sensor network nodes are linked by a wireless media (radio, infrared or optical media)
- Power Consumption
  - Mobile devices usually battery driven -> power aware protocols?

Protocol Stack

- The protocol stack used in by sink and sensor nodes in figure 3.
- This protocol stack
  - combines power and routing awareness
  - integrates data with networking protocols
  - Communicates power efficiently through the wireless medium
  - Promotes cooperative efforts of sensor nodes

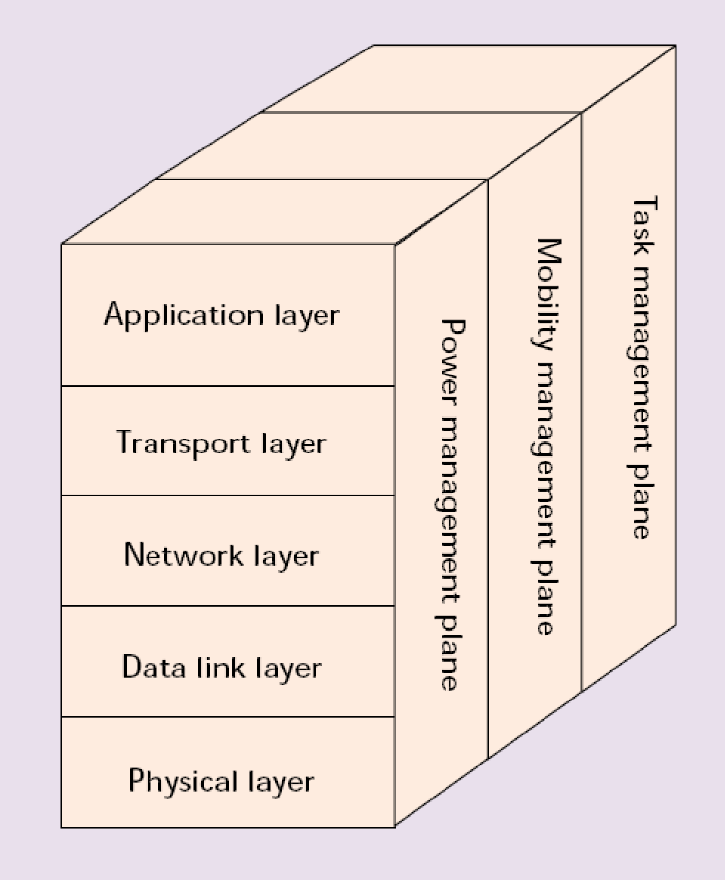

Figure 3. Protocol stack

The Physical layer

- The physical layer is responsible frequency selection, carrier frequency generation, signal detection, modulation and data encryption.
- The choice of good modulation scheme is critical for reliable communication.
  - Binary Modulation needs less energy than M-ary modulation
  - Direct Sequence Spread Spectrum is low power (transmission and security)
  - Ultra wideband (UWB) uses low power, does well under multi-path and has simple Tx/Rx
- Low transmission power and simple transceiver circuitry make UWB an attractive candidate for sensor networks.

The Data Link Layer

- The data layer is responsible for the multiplexing of data streams, data frame detection, medium access and error control.
  - Point-to-point and point-to-multipoint connections.
- MAC layer tasks in multihop wireless sensor networks
  - Creation of the network infrastructure
  - Fairly and efficiently share communications resources between nodes.
- Existing MAC protocols (may) not be suitable
  - In infrastructure networks a mobile node is only one hop away from base station
  - Bluetooth and mobile ad hoc network (MANET) are closest to sensor networks
  - The importance of power conservation to prolong network lifetime means that Bluetooth or MANET protocols can not be used directly.

The Data Link Layer II

- Several proposals:
  - Self-Organizing medium Access control for Sensor networks (SMACS) & Eavesdrop-And-Register (EAR) algorithm
  - CSMA-based Access
  - Hybrid TDMA/FDMA-based access

MAC Protocol	Channel access mode	Sensor network specifics	Power conservation
SMACS & EAR	Fixed allocation of duplex time slots and time division	Exploitation of large available bandwidth compared to sensor data rate	Random wake up during setup and turning radio off while idle
Hybrid TDMA/FDMA	Centralized frequency and time division	Optimum number of channels calculated for minimum system energy	Hardware based approach for system energy minimization
CSMA-based	Contention-based random access	Pretransmit delay	Constant listening time for energy efficiency

Network Layer

- Special multihop wireless routing protocols between sink node and sensors are needed.
  - Traditional ad hoc routing techniques do not usually fit.
- When design network layer protocols for sensor networks:
  - Power efficiency
  - Sensor networks are data-centric
  - An ideal sensor network has attribute-based addressing and location awareness.

Network Layer II

Routing:

- Energy-efficient routes can be found based on the available power (PA) and the energy required (α) for transmission in the links.
  - For example: Route 1: Sink-A-B-T, total PA = 4, alfa =3.
- Maximum PA route
  - Maximum total PA without including routes that add extra hops
- Minimum Energy route
  - Route that consumes minimum energy
- Minimum hop route
  - Minimum hop to reach the sink
- Maximum minimum PA node route
  - Use rather the route in which the minimum PA is larger than the minimum PAs of the other routes.
  - This scheme prevents the risk of using up a sensor node with low PA much earlier than the others just because it is on the route with nodes that have very high PAs

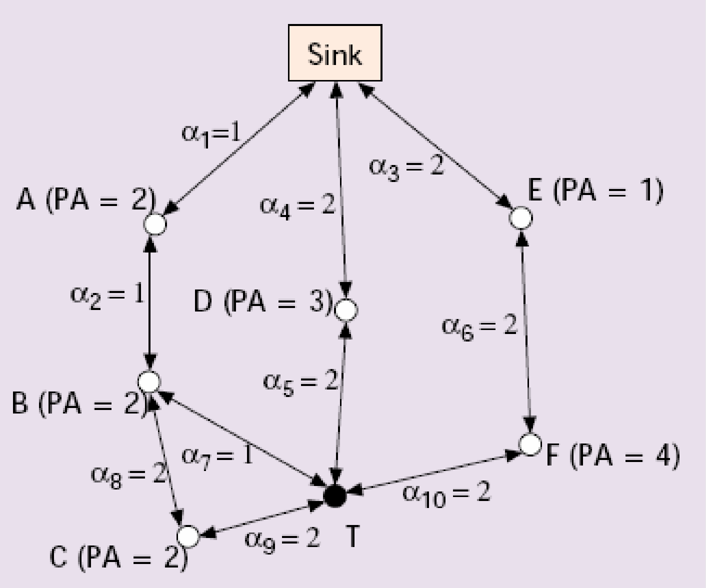

Figure 4. Routing & energy.

Network Layer III

- Data aggregation is technique used to solve overlap problems in data-centric routing
- Sensor network –> reverse multicast tree
- Data coming from multiple sensor nodes are aggregated as if they are about the same attribute of the phenomena when reach the same routing node on the way back to the sink.

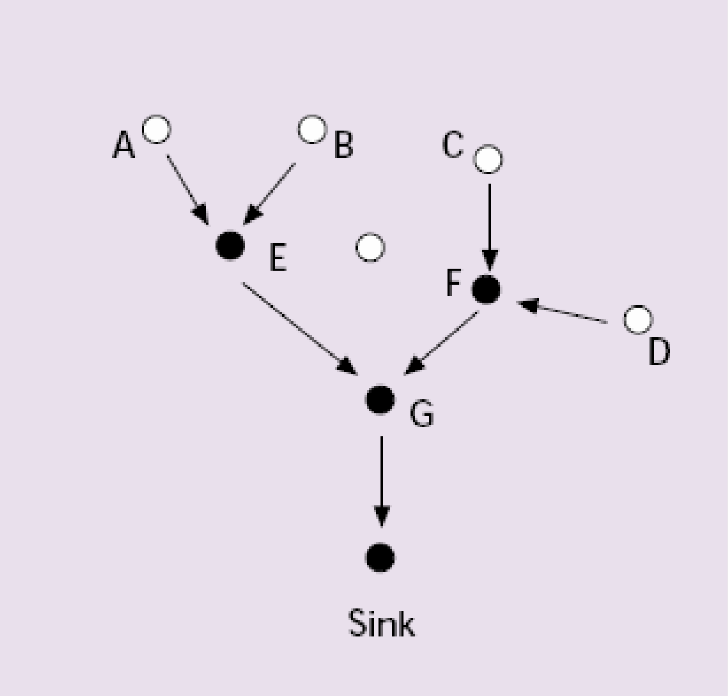

Figure 5. Data aggregation.

Network Layer IV

- Flooding is an old technique for routing.
  - Duplicate messages
  - Overlap
  - Resource blindness
- Solution: Sensor Protocols for Information via Negotiations (SPIN)
  - Send sensor data instead of all the data
  - 3 types of messages: Advertise, Request & Data

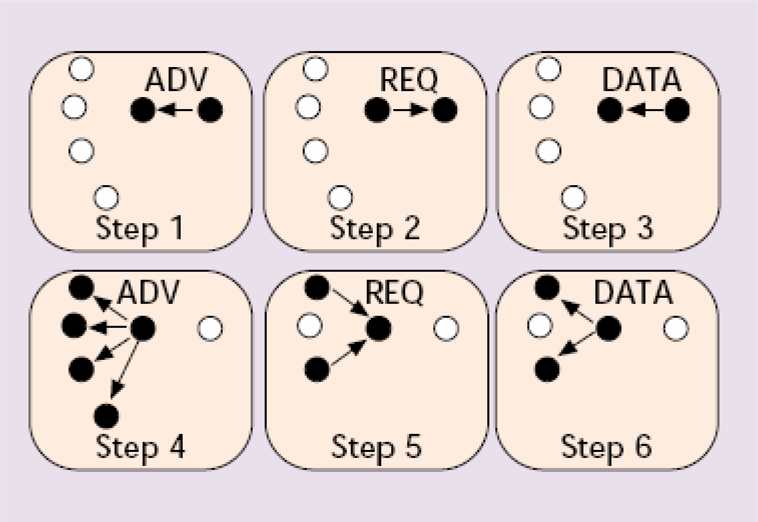

Figure 6. The Spin protocol.

Network Layer V

- The Directed diffusion data dissemination paradigm
  - Sink send out "interest"
  - Each s-node stores the interest entry in its cache
  - Interest entry contains a timestamp and several gradient fields
  - As the interest propagates, the gradients back to sink are set up.
  - When the source has data for the interest, the source sends data along the interest's gradient path.
  - Based on data-centric routing

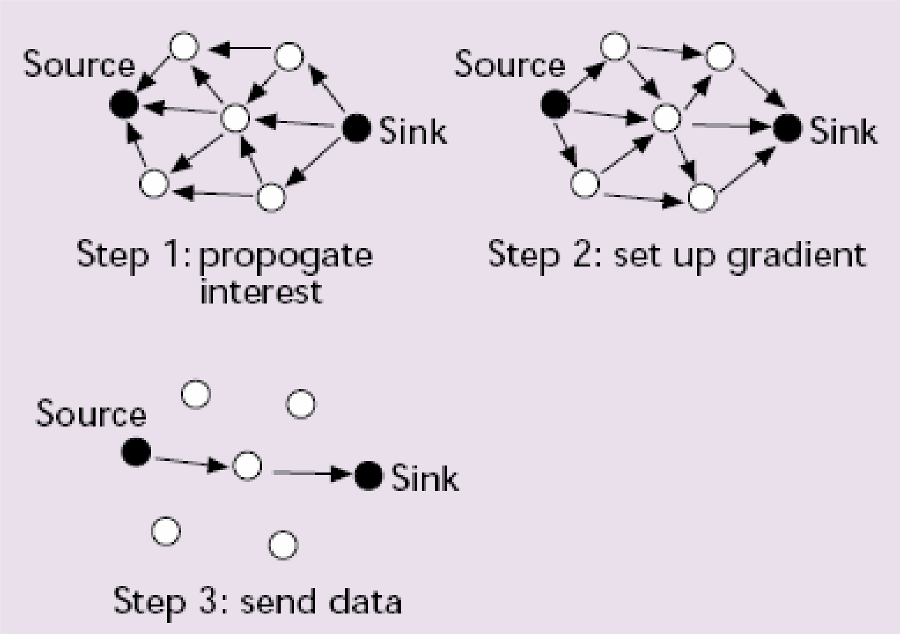

Figure 7. An example of directed diffusion.

Transport Layer

- Transport layer is especially needed when the system is planned to be accessed through the Internet or other external networks.
- TCP: transmission window mechanisms is nor suitable
  - TCP splitting: User <–> Sink: TCP and between the Sink <-> S-node: UDP-type protocol?
- Power consumption, scalability issues and data-centric routing stress the need for new types of transport layer protocols

The Application Layer

Application layer protocols:

- Sensor Management protocol
  - Attribute-based naming and location based addressing
  - Introducing the rules related to data aggregation, attribute based naming and clustering to the sensor nodes
  - Exchanging the data
  - Time synchronization
  - Moving the nodes, turning them on and off etc.
- Task Assignment and Data Advertisement protocol
  - An application layer protocol that provides the user software with efficient interfaces for interest dissemination is useful for lower layer operations like routing
- Sensor Query and Data Dissemination protocol
  - User applications with interfaces to issue queries, respond to queries and collect incoming replies

Conclusions & Technology trends

- Sensors, processors, and communication devices are all getting smaller and cheaper -> single chip solutions.
- MEMS technology will produce sensors that are even more capable and versatile.
- IEEE 802.15 standard for personal area networks (PANs)

New applications

- Infrastructure Security
  - Buildings and facilities can be protected; video, acoustics, other, usually wired.
- Environment and habitat monitoring
  - Temperature, population of birds or other species etc.
- Industrial Sensing
  - Monitoring machine "health" or insertion of sensors into regions inaccessible by humans etc.
  - For Example: IEEE & National Institute for Standards and Technology launched the P1451 Smart Transducer Interface Standard to enable plug-and-play of sensors and networks in industrial environments
- Traffic Control
  - Sensors for detecting vehicles and controlling traffic lights
  - Etc.

References

1. **Sensor networks: an overview** *Tubaishat, M.; Madria, S.;* Potentials, IEEE , Volume: 22 , Issue: 2 , April-May 2003 Pages:20 - 23.
2. **Sensor networks: evolution, opportunities, and challenges** *Chee-Yee Chong; Kumar, S.P.;* Proceedings of the IEEE , Volume: 91 , Issue: 8 , Aug. 2003, Pages:1247 - 1256.
3. **A survey on sensor networks** *Akyildiz, I.F.; Weilian Su; Sankarasubramaniam, Y.; Cayirci, E.;* Communications Magazine, IEEE ,Volume: 40 , Issue: 8 , Aug. 2002 Pages:102 - 114.

HOMEWORK

Calculate possible routes from T to SINK with PA's & required energy. Which route is:

a) Maximum PA route?
b) Minimum energy (ME) route?
c) Minimum hop (MH) route?
d) Maximum minimum PA node route?