Wireless Sensor Networks

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Introduction

- Wireless sensor networks –
  - Sensing
  - Computation
  - Communication
- Large number of tiny nodes that can assemble and configure themselves are deployed to create a mesh network
- These devices use advanced mesh networking protocols
- The protocols seek out and exploit every communication path by hopping data from node to node in search of the destination
  - Like water filling the every room of a submerged ship
- Capabilities of a single tiny device are minimal
- Composition of hundreds of devices offers radical new technological possibilities

Introduction

- Unlike traditional wireless devices, wireless sensor nodes do not need to communicate directly with the nearest high-power control tower or base station, but only with their local peers.
- No pre-deployed infrastructure, each individual sensor or actuator becomes part of the overall infrastructure.
- The flexible mesh architectures dynamically adapt to support introduction of new nodes or expand to cover a larger geographic region.
  - As long as there is sufficient density, a single network of nodes can grow to cover limitless area.
- The system can automatically adapt to compensate for node failures.
- The vision of mesh networking is based on strength in numbers.
  - Unlike cell phone systems that deny service when too many phones are active in a small area, the interconnection of a wireless sensor network only grows stronger as nodes are added.

Introduction

- Participants in an ad hoc network can be devices close to a human user, interacting with humans

- On the other hand, in case of sensor networks, instead of focusing on interaction with humans, we focus on interacting with ***environment***
  - Network is ***embedded*** in environment
  - Nodes in the network are equipped with ***sensing*** and ***actuation*** to measure/influence environment
  - Nodes process information and communicate it wirelessly

MANET vs. sensor network

- Many commonalities: Self-organization, energy efficiency, (often) wireless multi-hop
- Many differences
  - MANETs depend on more powerful (also expensive) equipment, with higher data rates and more resources
  - MANETs are often used for human-in-loop applications
  - Sensor Networks are generally application specific; MANETs comparably uniform
  - ***Environment interaction***: core of Sensor Network, absent in MANET
  - ***Scale***: Sensor Networks might be much larger
  - ***Energy***: Sensor Networks have tighter requirements, and complex maintenance issues
  - ***Dependability/QoS***: in Sensor Networks, individual node may be dispensable, QoS is different because of different applications
  - ***Data centric*** networking in sensor networks; *id-centric* networking in MANETs
  - ***Mobility***: different mobility patterns

Application Examples

- Disaster relief operations
  - Drop sensor nodes from an aircraft over a wildfire
  - Each node measures temperature
  - Derive a “temperature map”
- Biodiversity mapping
  - Use sensor nodes to observe wildlife
- Intelligent buildings (or bridges)
  - Reduce energy wastage by proper humidity, ventilation, air conditioning (HVAC) control
  - Needs measurements about room occupancy, temperature, air flow, …
  - Monitor mechanical stress after earthquakes
- Logistics
  - Equip goods (parcels, containers) with a sensor node
  - Track their whereabouts – ***total asset management***
- Precision agriculture
  - Bring out fertilizer/pesticides/irrigation only where needed

Application Examples

- Facility management
  - Intrusion detection into industrial sites
  - Control of leakages in chemical plants, …
- Machine surveillance and preventive maintenance
  - Embed sensing/control functions into places where no cable has gone before
- Medicine and health care
  - Post-operative or intensive care
  - Long-term surveillance of chronically ill patients or the elderly
- Telematics
  - Provide better traffic control by obtaining finer-grained information about traffic conditions
  - ***Intelligent roadside***
  - Cars as the sensor nodes

Design Challenges

- Coping with the harsh resource constraints placed on the individual devices
  - kilobytes of memory must implement complex, distributed, ad-hoc networking protocols
  - can store only a small amount of data
  - processors run at < 10 MIPS
  - not enough horsepower to do real signal processing
  - devices be produced in vast quantities and must be small and inexpensive
    - leading to resource constraints
  - underlying energy constraints end up creating computational and storage limitations
    - leading to a new set of architectural issues

Design Challenges

- Constraint on power consumption
  - As physical size decreases, so does energy capacity
  - Must use low duty cycle operation to extend lifetime beyond a few days
- Poor communication bandwidth
  - Current radios achieve about 10 Kbps per mote
  - Note that raw channel capacity is much greater
  - Zigbee radios now available at 250 Kbps
    - *But with small packets one node can only transmit around 25 kbps*

Design Challenges

- flexibility and universality are the other requirements
- devices must be used in a wide range of application scenarios
- auto-configuration is necessary
- nodes in the network need to collaborate towards a joint goal
- pre-processing data in network (as opposed to at the edge) can greatly improve efficiency
- network design focuses on ***data***, not on ***node identifies***
- things to be done locally (on node or among nearby neighbors) as far as possible
- tradeoff required between invested energy and accuracy

Requirements

- Required to provide ***answers***
  - Not just move bits through the network
- Quality of service
  - Traditional QoS metrics do not apply
  - Still, right answers to be provided at the right time
- Fault tolerance
  - Be robust against node failure
  - Nodes may run out of energy or destructed physically
- Lifetime
  - Definition of lifetime depends on application
  - Lifetime of individual nodes relatively unimportant
  - The ***network*** should fulfill its task as long as possible

Requirements

- Scalability
  - Should support large number of nodes
- Density of nodes can be widely varying
  - Application-dependent
  - Large or small number of nodes per unit area,
- Programmability
  - Re-programming of nodes in the field might be necessary
  - Improves flexibility
- Maintainability
  - Needs to adapt to changes, self-monitoring, adapt operation
  - Needs to incorporate possible additional resources, e.g., newly deployed nodes

Participatory roles

- ***Sources*** of data: different kinds of sensors
  - measure data, report them “somewhere”
- ***Sinks*** of data: part of the network or external entity, such as PDA, gateway
  - Interested in receiving data from the network
  - ***Actuators*** which control some device based on data, usually also a sink

Interaction patterns

- ***Interaction patterns*** between sources and sinks are classified depending on application types
  - ***Event detection***: Nodes locally detect events (maybe jointly with nearby neighbors), report these events to interested sinks
    - ***Event classification*** additional option
  - ***Periodic measurement***
  - ***Function approximation:*** Use sensor network to approximate a function of space and/or time (e.g., temperature map)
  - ***Edge detection:*** Find edges (or other structures) in such a function (e.g., where is the zero degree border line?)
  - ***Tracking*:** Report (or at least, know) position of an observed intruder

Deployment options

- ***Random deployment***
  - Dropped from aircraft !
  - Usually uniform random distribution for nodes over finite area is assumed
- ***Regular deployment***
  - Well planned
  - E.g., in preventive maintenance
  - Not necessarily geometric structure, but this is often a convenient assumption
- ***Mobile*** sensor nodes
  - Can move to compensate for deployment shortcomings
  - Can be passively moved around by some external force (wind, water)
  - Can actively seek out “interesting” areas

References

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