A Survey on Sensor Networks

Donghyun Kang, Dongkwon Lee
Contents

- Introduction
- Sensor Networks Communication Architecture
- Protocol Stack
  - Physical Layer
  - Data Link Layer
  - Network Layer
  - Transport Layer
  - Application Layer
- Conclusion
Introduction

- Recent advancement in wireless communications and electronics has enabled...

- Sensor Node
  - Consist of **sensing, data processing, and communicating components**
    - Cooperating – The nodes are fitted with an onboard processor
    - **Use processing abilities**
  - Low-cost, Low-power, Multifunctional, Small size
Introduction

- Sensor Network
  - Be composed of a large number of sensor nodes that are densely deployed
  - Position of sensor nodes need not be predetermined
  - Cooperate effort of sensor nodes
  - Wide range of applications are ensured
    - Health
    - Military
    - Home
Introduction

- Protocols for traditional wireless ad hoc network are not well suited to the sensor networks

<table>
<thead>
<tr>
<th>Feature</th>
<th>Sensor network</th>
<th>Traditional wireless ad hoc network</th>
</tr>
</thead>
<tbody>
<tr>
<td># of sensor nodes</td>
<td>Very large</td>
<td>Not that large</td>
</tr>
<tr>
<td>Density</td>
<td>Densely deployed</td>
<td>Low density</td>
</tr>
<tr>
<td>Failure</td>
<td>Prone to failures</td>
<td>Low failure</td>
</tr>
<tr>
<td>Topology</td>
<td>Frequently changed</td>
<td>Rarely changed</td>
</tr>
<tr>
<td>Communication</td>
<td>Broadcast communication</td>
<td>Point to point communication</td>
</tr>
<tr>
<td>Resource</td>
<td>Limited in power, computation capacities and memory</td>
<td>Not that limited</td>
</tr>
<tr>
<td>Global identification</td>
<td>May not have</td>
<td>Yes</td>
</tr>
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  - Design Factors
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Sensor Networks Communication Architecture

- Overview
  - Sensor nodes
    - Sensor field
  - Sink
Sensor Networks Communication Architecture

- Many Design Factors
  - Fault Tolerance
  - Scalability
  - Production Costs
  - Hardware Constraints
  - Sensor Network Topology
  - Environment
  - Transmission Media
  - Power Consumption
Design Factors

- Fault Tolerance
  - Ability to sustain sensor network functionalities without any interruption due to sensor node failures

- Scalability
  - Hundreds ~ millions of sensor nodes

- Production Costs
Design Factors

- Hardware Constraints
  - Sensing unit
    - Sensors
    - Analog signal
  - ADC
    - Analog to Digital Converter
  - Processing unit
  - Transceiver unit
  - Power unit
  - Application-dependent components
    - Location finding system, mobilizer, power generator, ...
- Size (weight) & power constraint
Design Factors

- Sensor Network Topology
  - Pre-deployment & deployment
  - Post-deployment
  - Redeployment
- Environment
Design Factors

- Transmission Media
  - Radio
  - Infrared
  - Optical media (light)

- Power Consumption
  - Lifetime
  - Conservation & management
  - Power-aware protocols & algorithms
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Protocol Stack

- **Layers**
  - **Physical Layer**
    - Transmission & receiving techniques
  - **Data Link Layer**
    - Medium access control protocol w/ considering constraints
  - **Network Layer**
    - Take care of routing the data supplied by the transport layer
  - **Transport Layer**
    - Help to maintain the flow of data
  - **Application Layer**
    - Application software
Protocol Stack

- **Planes**
  - **Power management plane**
    - Manage how a sensor node uses its power
  - **Mobility management plane**
    - Detect and register the movement of sensor nodes
  - **Task management plane**
    - Balance and schedule the sensing tasks
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Physical Layer

- Be responsible for
  - Frequency selection
  - Carrier frequency generation
  - Signal detection
  - Modulation
  - Data encryption
- 915 MHz ISM band has been widely suggested for sensor networks
Physical Layer

- Signal propagation effects & Power Efficiency
  - Minimum output power (proportional to $distance^{2\sim4}$)
  - Multi-hop communication
- Modulation schemes
  - Binary modulation
  - M-ary modulation
- UWB(Ultra Wideband) / IR(Impulse Radio)
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    - Error Control
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Data Link layer

- It ensures reliable point-to-point and point-to-multipoint connections in a communication network

- It is responsible for ...
  - Multiplexing of data streams
  - Data frame detection
  - **Medium access control (MAC)**
    - Two goals in a sensor network
      - The creation of network infrastructure
      - Share resources fairly and efficiently
  - Error control
MAC (Medium Access Control)

- Existing MAC Protocols Cannot Be Used
  - Existing MAC protocols
    - Versus Cellular system
      - Base station – mobile node <-> no central controlling agent
      - Goal: provision of high quality of service (QoS) & bandwidth efficiency
      - Power conservation is secondary important (Replenishing battery, unlimited power supplement) <-> it is primary importance in a sensor network
    - Versus Bluetooth and the mobile ad hoc network (MANET)
      - Bluetooth
        - Star network (master node – up to 7 slave nodes)
        - Transmission power: ~20dBm & transmission range: order of tens of meters
      - MANET
        - Goal: the provision of high QoS under mobile conditions
        - Power is not important (Replaceable battery)
        - <-> Less mobility rate, frequent topology change
        - <-> sensor network has more larger number of nodes.
        - <-> ~0dBm transmission power and less radio range
MAC (Medium Access Control)

- MAC for Sensor Networks
  - Demand-based schemes may be unsuitable for sensor networks
    - Large messaging overhead & link setup delay
      - *Fixed allocation and Random access version are suggested*
  - SMACS & EAR
  - CSMA-based Medium Access
  - Hybrid TDMA-FDMA based
- Power Saving Operation
SMACS and EAR

SMACS: Self-Organizing Medium Access Control for Sensor Networks
- Distributed infrastructure-building protocol
  - Enable nodes to discover their neighbors and establish transmission/reception schedules for global communication without any global or local master nodes
- Neighbor discovery and channel assignment phases are combined
  - Hear all their neighbors -> form a connected network
- Communication link – pair of time slots operating at a randomly chosen but fixed frequency <Power conservation>
  - Available bandwidth >> maximum data rate for sensor nodes
- No network wide synchronization

EAR: Eaves-drop-And-Register Algorithm
- Offer continuous service to the mobile nodes under both mobile and stationary conditions
- Decide when to drop connections while minimizing messaging overhead
- Transparent with SMACS; EAR + SMACS available
- Network is assumed to be mainly static and mobile node has a number of stationary nodes

Drawback
- Possibility that members already belonging to different subnets might never get connected
MAC (Medium Access Control)

- CSMA-Based Medium Access
  - CSMA: A carrier sense multiple access
  - Traditional CSMA-based schemes
    - Fundamental assumption of stochastically distributed traffic
    - Tend to support independent point-to-point flows
    - \textit{Must be able to support variable but highly correlated and dominantly periodic traffic}
  - Listening mechanism & backoff scheme
    - Constant listen period – energy efficient
    - Introduction of random delay $\rightarrow$ Robustness against repeated collisions
    - Fixed window & backup schemes $\rightarrow$ maintain proportional fairness
- ARC (Adaptive transmission rate control)
  - Achieve medium access fairness
  - Control the data origination rate of a node in order to allow the route-through traffic to propagate
  - Linear increase and multiplicative decrease approach
MAC (Medium Access Control)

- Hybrid TDMA/FDMA Based
  - T(F)DMA: Time/Frequency division multiple access
  - Assumption
    - System is made up of energy-constrained sensor nodes that communicate to a single nearby high-powered base station
      - The machine monitoring application of sensor networks with strict data latency requirements is considered
  - If the transmitter consumes more power → TDMA
  - If the receiver consumes more power → FDMA
MAC (Medium Access Control)

- Qualitative overview

<table>
<thead>
<tr>
<th>MAC protocol</th>
<th>Channel access mode</th>
<th>Sensor network specifics</th>
<th>Power conservation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMACS and EAR [13]</td>
<td>Fixed allocation of duplex time slots at fixed frequency</td>
<td>Exploitation of large available bandwidth compared to sensor data rate</td>
<td>Random wake up during setup and turning radio off while idle</td>
</tr>
<tr>
<td>Hybrid TDMA/FDMA [8]</td>
<td>Centralized frequency and time division</td>
<td>Optimum number of channels calculated for minimum system energy</td>
<td>Hardware-based approach for system energy minimization</td>
</tr>
<tr>
<td>CSMA-based [9]</td>
<td>Contention-based random access</td>
<td>Application phase shift and pretransmit delay</td>
<td>Constant listening time for energy efficiency</td>
</tr>
</tbody>
</table>
MAC (Medium Access Control)

- Power Saving Modes of Operation
  - Regardless of medium access scheme
  - Example: Turn the transceiver off when it is not required
  - Dependent to its hardware
  - Characterized by Less power consumption ↔ latency overhead
## Error Control

- **Automatic repeat request (ARQ)**
- **Forward Error Correction (FEC)**

### Example of FEC

<table>
<thead>
<tr>
<th>Original Data</th>
<th>Checksum</th>
<th>Error Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 1 0 1</td>
<td>1 1 1 0</td>
<td>0 0 0 1</td>
</tr>
<tr>
<td>0 1 1 0</td>
<td>1 1 1 0</td>
<td>0 0 0 1</td>
</tr>
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**Correct the Error**
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  - Network Layer
    - Power efficiency routing (choose path)
    - Data centric routing (choose source/sink node)
    - Data aggregation
    - Sensor network schemes
  - Transport Layer
  - Application Layer
- Conclusion
Network Layer

- Power efficiency routing (choose path)
- Data centric routing (choose source/sink node)
- Data aggregation
- Sensor network schemes
Network Layer

- Power efficiency routing
- Routing paths (PA : Available power, $\alpha$ : required power)
  - Route 1 : T–B–A–Sink (PA : 4, $\alpha$ : 3)
  - Route 2 : T–C–B–A–Sink (PA : 6, $\alpha$ : 6)
  - Route 3 : T–D–Sink (PA : 3, $\alpha$ : 4)
  - Route 4 : T–F–E–Sink (PA : 5, $\alpha$ : 6)
Network Layer

- Power efficiency routing
- Routing paths (PA: Available power, $\alpha$: required power)
  - Route 1: T–B–A–Sink (PA: 4, $\alpha$: 3)
  - Route 2: T–C–B–A–Sink (PA: 6, $\alpha$: 6)
  - Route 3: T–D–Sink (PA: 3, $\alpha$: 4)
  - Route 4: T–F–E–Sink (PA: 5, $\alpha$: 6)

- Maximum PA route
Power efficiency routing

Routing paths (PA : Available power, $\alpha$ : required power)

- Route 1 : T–B–A–Sink (PA : 4, $\alpha$ : 3)
- Route 2 : T–C–B–A–Sink (PA : 6, $\alpha$ : 6)
- Route 3 : T–D–Sink (PA : 3, $\alpha$ : 4)
- Route 4 : T–F–E–Sink (PA : 5, $\alpha$ : 6)

Minimum energy ($\alpha$) route
Network Layer

- Power efficiency routing
- Routing paths (PA: Available power, \( \alpha \): required power)
  - Route 1: T–B–A–Sink (PA: 4, \( \alpha \): 3)
  - Route 2: T–C–B–A–Sink (PA: 6, \( \alpha \): 6)
  - Route 3: T–D–Sink (PA: 3, \( \alpha \): 4)
  - Route 4: T–F–E–Sink (PA: 5, \( \alpha \): 6)

- Minimum hop(node) route
Network Layer

- Power efficiency routing
- Routing paths (PA : Available power, α : required power)
  - Route 1 : T–B–A–Sink (PA : 4, α : 3)
  - Route 2 : T–C–B–A–Sink (PA : 6, α : 6)
  - Route 3 : T–D–Sink (PA : 3, α : 4)
  - Route 4 : T–F–E–Sink (PA : 5, α : 6)
- Maximum ‘minimum PA’ route
Network Layer

- Data Centric Routing
  - Interest dissemination from sink nodes
  - Advertise available data from sensor nodes
Network Layer

- Data aggregation
  - To avoid implosion and overlap
Network Layer

- Sensor network schemes
  - SMECN
  - FLOODING
  - GOSSIPING
  - SPIN
  - SAR
  - LEACH
  - Directed Diffusion
Network Layer

- SMECN (Small Minimum Energy Communication Network)
  - Creates a subgraph of the sensor network that contains the minimum energy path
Network Layer

- **FLOODING**
  - Old technique, broadcast data to all neighbor nodes regardless if they receive before or not
  - Implosion, Overlap, Resource blindness problem

- **GOSSIPING**
  - Sends data to one random neighbor node
  - Avoid implosion problem, low performance
SPIN (Sensor Protocols for Information via Negotiation)

- Sends data to sensor nodes only if they are interested
- 3 types of message; ADV, REQ, DATA
Network Layer

- **SAR** (Sequential Assignment Routing)
  - Creates multiple trees where the root of each tree is a one hop neighbor from the sink
  - Trees grow outward from the sink
  - Choose path based on energy resources, additive QoS metric, packet’s priority level.
LEACH (Low-Energy Adaptive Clustering Hierarchy)
- Forms clusters to minimize energy dissipation
- Randomly select sensor nodes as cluster heads
- High energy dissipation in communicating with the base station is spread to all sensor nodes
- Two phases
Network Layer

- **LEACH** (Low-Energy Adaptive Clustering Hierarchy)
  - **Setup Phase**
    - Cluster heads are selected randomly
    - Each sensor node is associated with its cluster head
  - **Steady Phase**
    - Sensor nodes begin sensing and sending data to head
    - Cluster heads aggregate data and send it to the base station
Network Layer

- Directed Diffusion
  1. Sink sends interest
  2. Gradients are set up
  3. Source sends the data
  4. Sinkrefreshes and reinforces the interest

- Based on data centric routing
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Transport Layer

- Access to Internet or other external network
- Hybrid approach
  - TCP(sink – internet) + UDP(sink – sensor nodes)
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    - Largely unexplored region
    - Application layer protocols
- Conclusion
Application Layer

- Largely unexplored region
- Application layer protocols
  - SMP
  - TADAP
  - SQDDP
Application Layer

- **SMP** (Sensor Management Protocol)
  - System admin interacts with sensor networks
  - Administrative tasks
    - Introducing rules about data aggregation, attribute based naming and clustering to sensor nodes
    - Exchanging data related to the location finding algorithms
    - Time synchronization
    - Moving sensor nodes
    - Turning sensor nodes on/off
    - Querying network configuration, nodes’ status
    - Reconfiguring sensor networks
    - Authentication, security
Application Layer

- **TADAP** (Task Assignment and Data Advertisement Protocol)
  - Efficient interest dissemination interface
    - Interest dissemination by users
    - Data advertisement by sensor nodes
  - Helps data-centric routings in lower layers
Application Layer

- **SQDDP (Sensor Query and Data Dissemination Protocol)**
  - Provides user applications with interfaces to issue query, respond to queries and collecting incoming replies
  - Attribute, location based querying
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Conclusion

- Realization of sensor networks needs to satisfy constraints.

- Since the constraints are specific for sensor networks, new wireless ad hoc networking techniques are required.