# A Survey on Sensor Networks

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# Abstract

- This article presented a survey of protocols and algorithms proposed thus far for sensor networks
- Also attempt an investigation into pertaining design constraints and outline the use of certain tools to meet the design objectives

# Overview

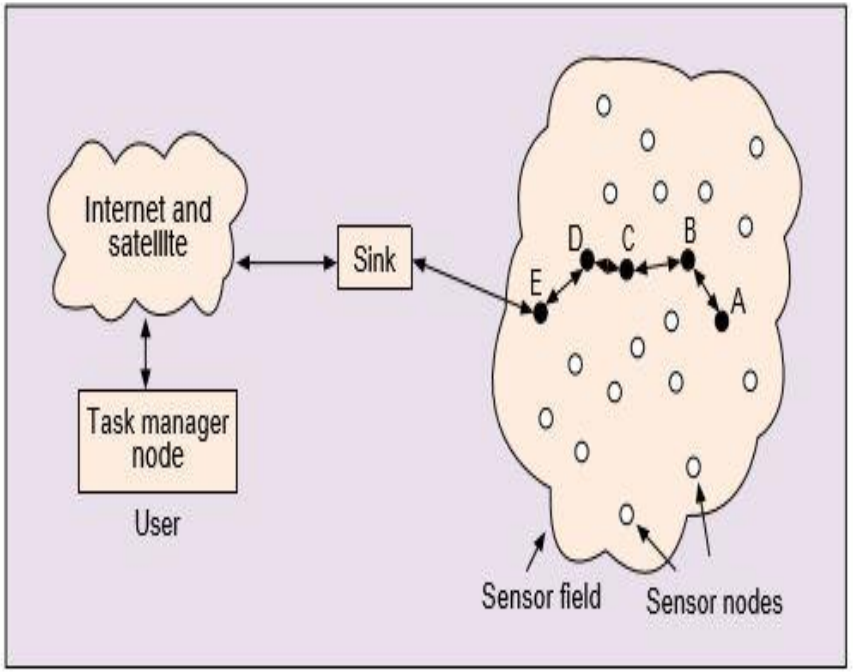
- Introduction
- Sensor networks communication architecture
  - Design factors
  - Protocol stack
    - Physical layer
    - Data link layer
    - Network layer
    - Transport layer
    - Application layer
- Conclusion

# Introduction

- A sensor network is composed of a large number of sensor nodes
- The position of sensor nodes need not be engineered or predetermined
  - sensor network protocols and algorithms must possess self-organizing capabilities.
- A wide range applications for sensor network
  - Apply in military, health and home etc.

# Sensor networks communication architecture

- Each of these scattered sensor nodes has the capabilities to collect data and route data back to the ***sink***
- Data are routed back to the sink by a multihop infrastructureless architecture through the sink
- The sink may communicate with the ***task manager node*** via Internet or satellite



# Design factor

- **Includes**
  - fault tolerance
  - scalability
  - production costs
  - operating environment
  - sensor network topology
  - hardware constraints
  - transmission media
  - power consumption

- These factors serve as a guideline to design a protocol or an algorithm for sensor networks.
- They can be used to compare different schemes.

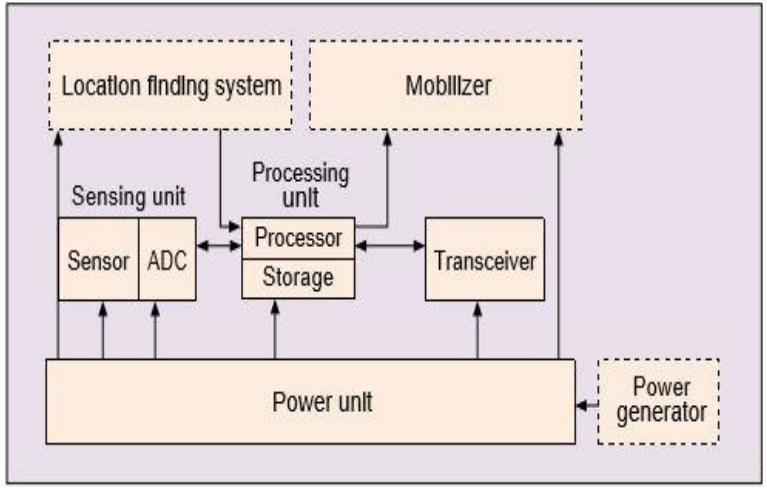
# Design factor

- **Fault Tolerance**
  - Why fails
    - Lack of power, or have physical damage or environmental interference
  - Fault tolerance is the ability to keep sensor network functionalities without any interruption due to sensor node failures

- **Scalability**
  - The number of sensor nodes deployed in studying a phenomenon may be on the order of **hundreds** or **thousands**.
  - New schemes must be able to work with this number of nodes and utilize the high density of the sensor networks

# Design factor

- **Hardware constrains**
  - Components of a sensor node
  - Size
    - Matchbox-sized module
  - Consume extremely low power
  - Operate in high volumetric densities
  - Have low production cost and be dispensable
  - Be autonomous and operate unattended
  - Be adaptive to the environment



# Design factor

- **Production costs**
  - Since sensor networks consist of a large number of sensor nodes, **the cost of a single node** is very important to justify the overall cost of the network
  - The cost of a sensor node should be much **less than US$1**

- **Sensor network topology**
  - Pre-deployment and deployment phase
    - Sensor nodes can be either thrown in as a mass or placed one by one in the sensor field.
  - Post-deployment phase
    - Sensor network topologies are prone to frequent changes after deployment
  - Redeployment of additional phase
    - Addition of new nodes poses a need to reorganize the network

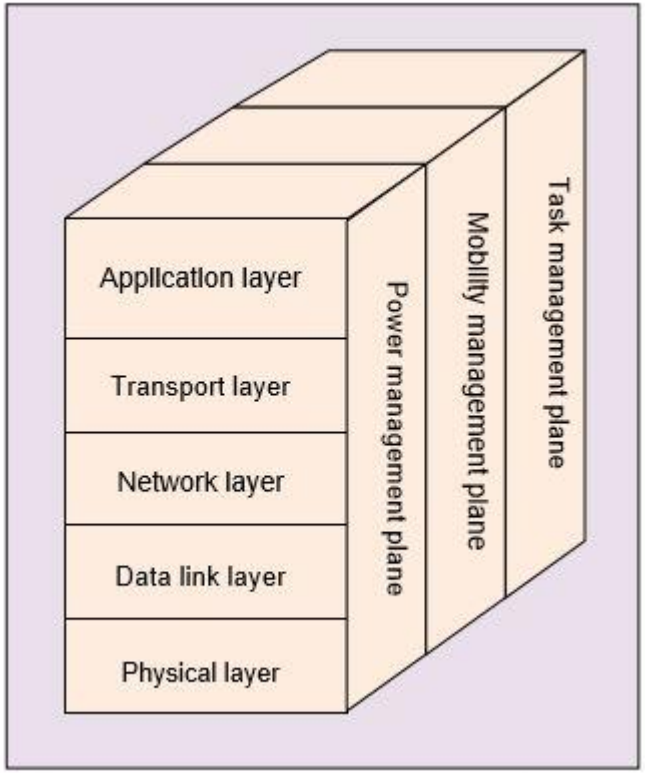
# Design factor

- **Environment**
  - Sensor nodes are densely deployed
  - They usually work unattended in remote geographic areas
- **Transmission media**
  - Industrial, scientific and medical(ISM) bands
    - Offer license-free communication in most countries
  - Infrared communication
    - License-free and robust to interference
    - Requirement of a line of sight between sender and receiver
- **Power consumption**
  - Only be equipped with a limited power source (< 0.5 Ah, 1.2 V)
  - Node lifetime is strongly dependent on battery lifetime

# Protocol Stack

- **The protocol stack is used by the sink and sensor nodes**

- **Consists of**
  - physical layer
  - data link layer
  - network layer
  - transport layer
  - application layer
  - power management plane
  - Mobility management plane
  - task management plane



# Protocol Stack

- Management planes make sensor nodes work together in **a power efficient way**, route data in a **mobile** sensor network, and **share resources** between sensor nodes

- **Power management plane**
  - manages how a sensor node uses its power

- **Mobility management plane**
  - **detects** and **registers** the movement of sensor nodes

- **Task management plane**
  - **Balances** and **schedules** the sensing tasks given to a specific region

# Physical Layer

- Is responsible for frequency selection, carrier frequency generation, signal detection, modulation, and data encryption
- **915 MHz** industrial, scientific, and medical (ISM) band has been widely suggested for sensor networks
- **Signal propagation effects**
  - The minimum output power required to transmit a signal over a distance d is proportional to $d^n$ , where 2 < =n < 4
  - **Multihop communication** in a sensor network can effectively overcome shadowing and path loss effects
  - Energy-efficient physical layer solutions

# Physical Layer

- **Energy-efficiency being pursued**
  - M-ary and Binary modulation

| | |
|---|---|
| M-ary modulation | • reduces the transmit on-time by sending multiple bits per symbol<br>• results in complex circuitry and increased radio power consumption |
| Binary modulation | more energy-efficient under startup power dominant conditions |

  - Ultra wideband (UWB) or impulse radio (IR)
    - Used for baseband pulse radar and ranging system
    - Employ baseband transmission, require no intermediate or carrier frequencies
    - Low transmission power and simple transceiver

- **Open research issues**
  - Modulation schemes
  - Strategies to overcome signal propagation effects
  - Hardware design

# Data link Layer

- The data link layer is responsible for the multiplexing of data streams, data frame detection, medium access and error control

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

- **Error control**
- **Medium access control**

# Error control

- **Two important modes**
  - **Forward error correction(FEC)**
    - A given BER(channel bit error rate) can be achieved at lower transmit powers with the use of FEC
    - Decoding complexity is great
    - If the associated processing power is greater than the coding gain, then the whole process in is energy -inefficient
  - **Automatic repeat request(ARQ)**
    - Limited by the additional retransmission energy cost and overhead

- So, other coding schemes remain unexplored

# Medium access control

- **Mac protocol**
  - Two goals
    - Creation of the network infrastructure
    - Fairly and efficiently share communication resources between sensor nodes
  - Existing MAC protocol cannot be used
    - The primary goal of the existing MAC protocol is the provision of high QoS and bandwidth efficiency
  - New request for MAC protocol for sensor network
    - Have built-in power conservation, mobility management and failure recovery strategies

# Medium access control

- Some MAC protocols proposed for sensor network
  - SMACS and EAR algorithm
  - CSMA based medium access
  - Hybrid TDMA/FDMA based

# SMACS and the EAR algorithm

- **The SMACS protocol – Self-Organizing Medium Access Control for Sensor Network**
  - Achieves network start-up and link-layer organization
  - The neighbor discovery and channel assignment phases are combined
  - A communication link consists of a pair of time slots operating at a randomly chosen, but fixed frequency.
  - Power conservation is achieved by using a random wake-up schedule during the connection phase and by turning the radio off during idle time slots

# SMACS and the EAR algorithm(cont')

- **The EAR algorithm – Eavesdrop-And-Register**
  - enables seamless connection of mobile nodes
  - offers continuous service to mobile nodes under both mobile and stationary conditions
  - drawback : the possibility that members already belonging to different subnets might never get connected.

# CSMA based medium access

- **CSMA based medium access scheme has two important components**
  - The listening mechanism – power conservation
  - The backoff scheme – fairness in the network

- **Adaptive transmission rate control(ARC)**
  - The ARC controls the data origination rate of a node in order to allow the route-through traffic to propagate
  - Route-through traffic is preferred over the originating traffic
    - Linear increase and multiplicative decrease approach
    - Since dropping route-through traffic is costlier, the associated penalty is lesser

# Hybrid TDMA/FDMA based

- Centrally controlled MAC scheme
- The system is made up of energy constrained sensor nodes that communicate to a single, nearby, high powered base station(<10m)
- A pure TDMA scheme dedicates the full bandwidth to a single sensor node

  A pure FDMA scheme allocates minimum signal bandwidth per node
  - TDMA is not always preferred due to the associated time synchronization costs

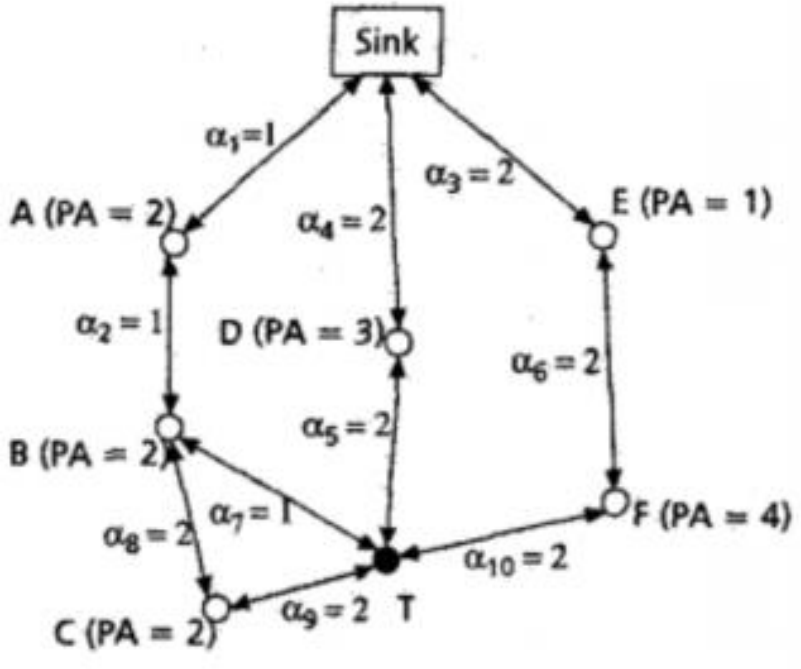
# Data link layer

- **Power saving modes of operation**
  - Turn the transceiver off when it is not required
    - Not exactly
  - There can be a number of such useful modes of operation for the wireless sensor node
    - Depending on the number of states of the micro-processor, memory, A/D convertor and the transceiver

- **Open research issues**
  - MAC for mobile issues – to deal with more extensive mobility
  - Determination of lower bounds on the energy required for sensor network self-organization
  - Error control coding schemes – to explore the feasibility
  - Power-saving mode of operation

# Network Layer

- Designed Principles：
  - Power efficiency
  - Data centric routing
  - Data aggregation
  - Sensor network schemes

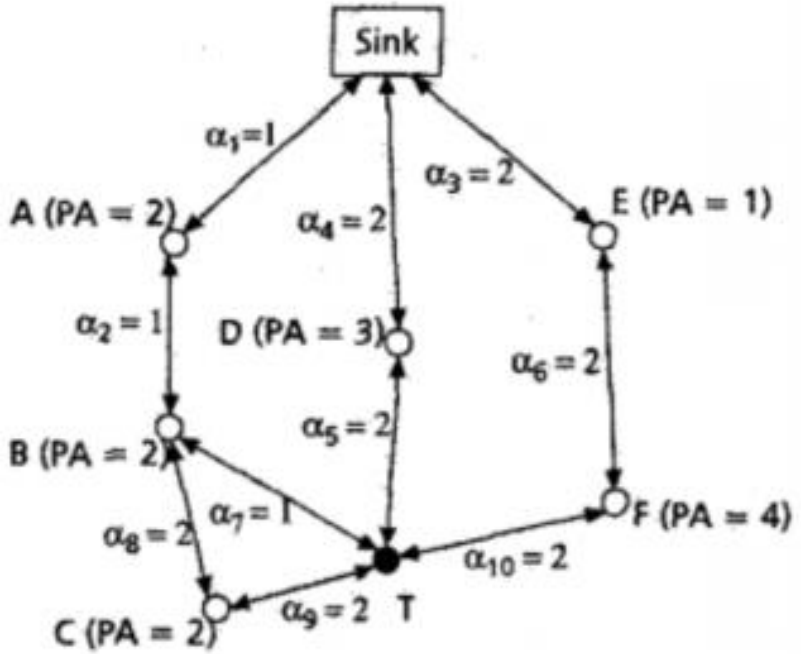



Power efficiency of the routes.

PA: available power in the node.
α：energy required.

# Network Layer

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




PA: available power in the node.
α : energy required.

# Network Layer

Maximum PA route

Route 2 : T–C–B–A–Sink (PA : 6, : 6)

Minimum energy($\alpha$) route

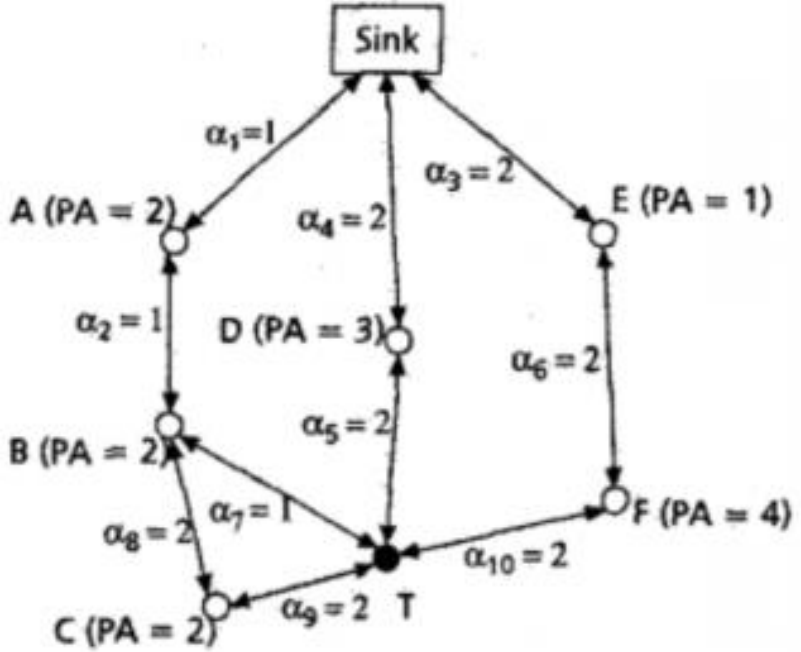
Route 1 : T–B–A–Sink (PA : 4, : 3)

Minimum hop(node) route

Route 3 : T–D–Sink (PA : 3, : 4)

Maximum ‘minimum PA’ route

Route 3 : T–D–Sink (PA : 3, : 4)




PA: available power in the node.
α : energy required.

# Network Layer

- Routing may be based on the data-centric approach.
- Data-centric routing requires attribute-based naming.
  - Users are more interested in attribute rather than the individual node.
- Data aggregation is a technique used to solve the implosion and overlap problems in data-centric routing.

# Network Layer

- We will introduce several schemes for sensor networks.
  - Small Minimum Energy Communication Network
  - FLOODING
  - GOSSIPING
  - Sensor Protocols for Information via Negotiation
  - Sequential Assignment Routing
  - Low-Energy Adaptive Clustering Hierarchy
  - Directed Diffusion

# Network Layer

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

# Network Layer

- **FLOODING**

- Each node receiving a data by broadcasting, unless a maximum number of hops for the packet is reached or the destination of the packet is the node itself.

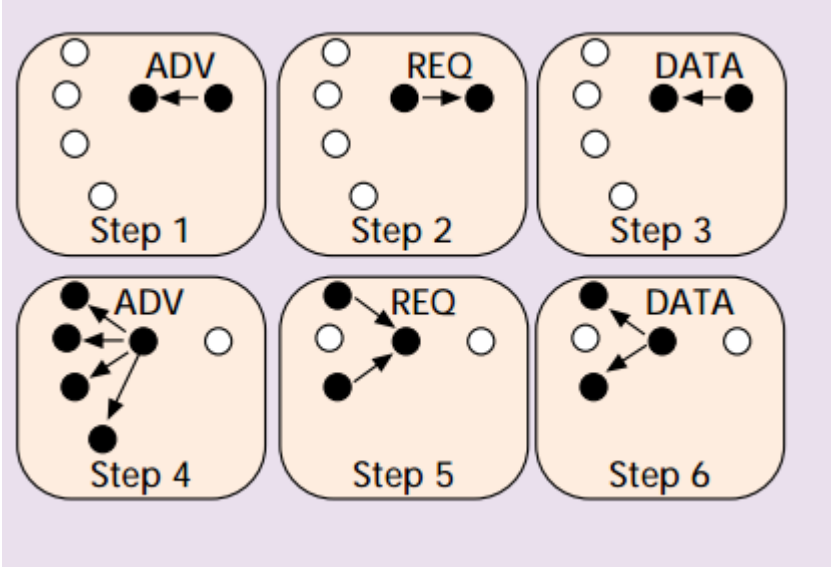
- Advantage:
  - Not require costly topology.
  - Not require complex route discovery algorithms.

# Network Layer

- **GOSSIPING**
- Sends data to one random neighbor node. Once receiving the data, choose another node.
- Advantage:
  - Avoid implosion problem
- Disadvantage:
  - Low performance(long time for transfering)

# Network Layer

- **Sensor Protocols for Information via Negotiation (SPIN)**
  - 3 types of message: ADV, REQ, DATA.
  - Send the interest to neighbor,
  - Only send data to sensor nodes that they are interested.



# Network Layer

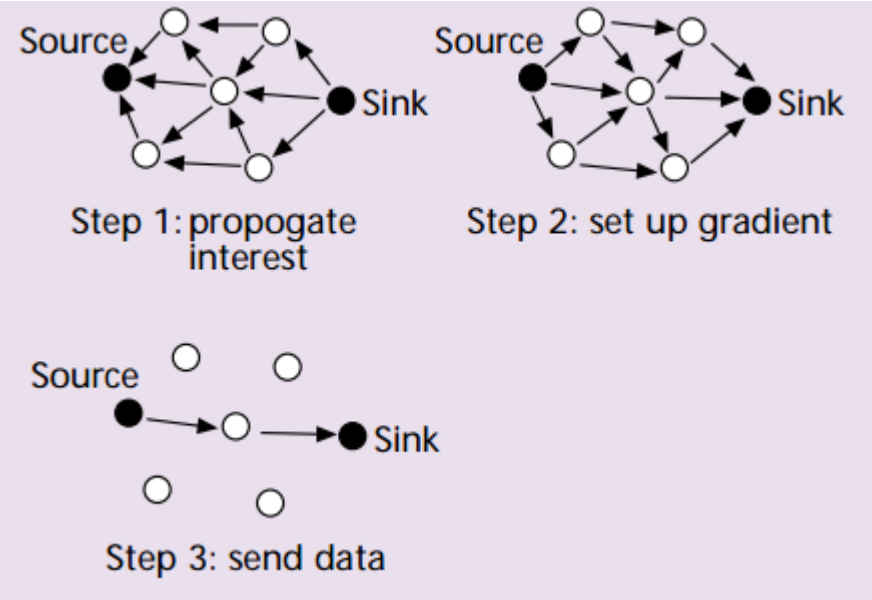
- **Sequential Assignment Routing (SAR)**
  - SAR algorithm creates multiple trees where the root of each tree is a one-hop neighbor from sink.
  - Each tree grows outward from the sink while avoiding nodes with very low throughput.

# Network Layer

- **Low-Energy Adaptive Clustering Hierarchy (LEACH)**
  - Clustering-based protocol.
  - Two phases: setup and steady.
    - Setup:
      cluster heads are selected randomly
      Each sensor node is associated with its cluster head
    - Steady:
      Sensor nodes begin sensing and sending data to head
      Cluster heads aggregate data and sent it to the base station

# Network Layer

- **Directed Diffusion**




1. Sink sends interest
2. Set up gradient
3. Source sends the data
4. Sink must refresh and reinforce the interest when it start to receive data.

# Transport Layer

- It's important when accessing Internet or other external network.
- Hybrid approach
  - TCP(sink -- internet) + UDP(sink – sensor nodes)

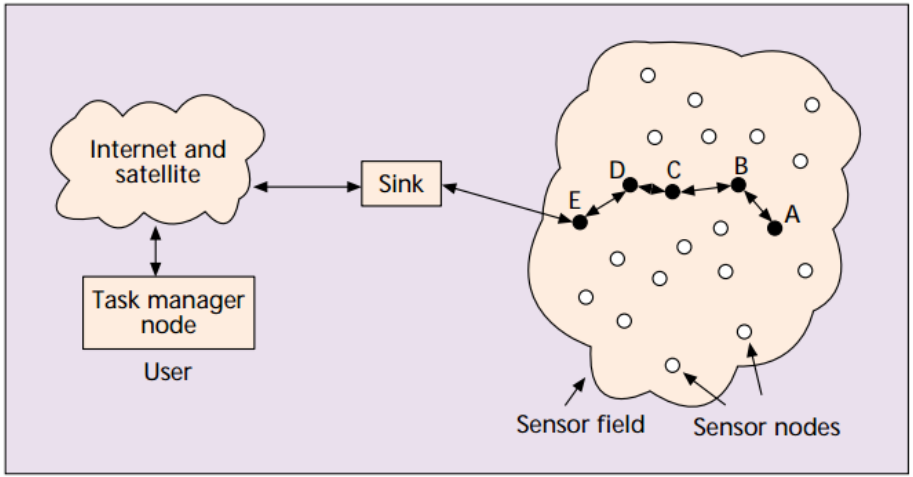



Figure 1. *Sensor nodes scattered in a sensor field.*

# Application Layer

- Potential application layer protocols for sensor networks remain a largely unexplored region.
- Application layer protocols
  - Sensor Management Protocol
  - Task Assignment and Data Advertisement Protocol
  - Sensor Query and Data Dissemination Protocol

# Application Layer

- **SMP (Sensor Management Protocol)**
  - SMP needs to access the nodes by using attribute-based naming and location-based addressing
  - Perform the following administrative tasks:
    - Introducing rules about data aggregation, attribute-based naming, and clustering to the sensor nodes.
    - Exchanging data related to the location finding algorithms
    - Time synchronization of the sensor nodes
    - Turning sensor nodes on/off
    - Querying network configuration and reconfiguring the sensor network.
    - Security

# Application Layer

- **TADAP (Task Assignment and Data Advertisement Protocol)**
  - Another important operation: interest dissemination. By two ways:
    - Interest dissemination by users
    - Data advertisement by sensor nodes

# Application Layer

- **SQDDP (Sensor Query and Data Dissemination Protocol)**
  - SQDDP provides user applications with interfaces to issue query, respond to queries and collecting incoming replies.
  - These queries are generally not issued to particular nodes. Instead, attribute- or location-based naming is preferred.

# 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.