A Survey on Sensor Networks

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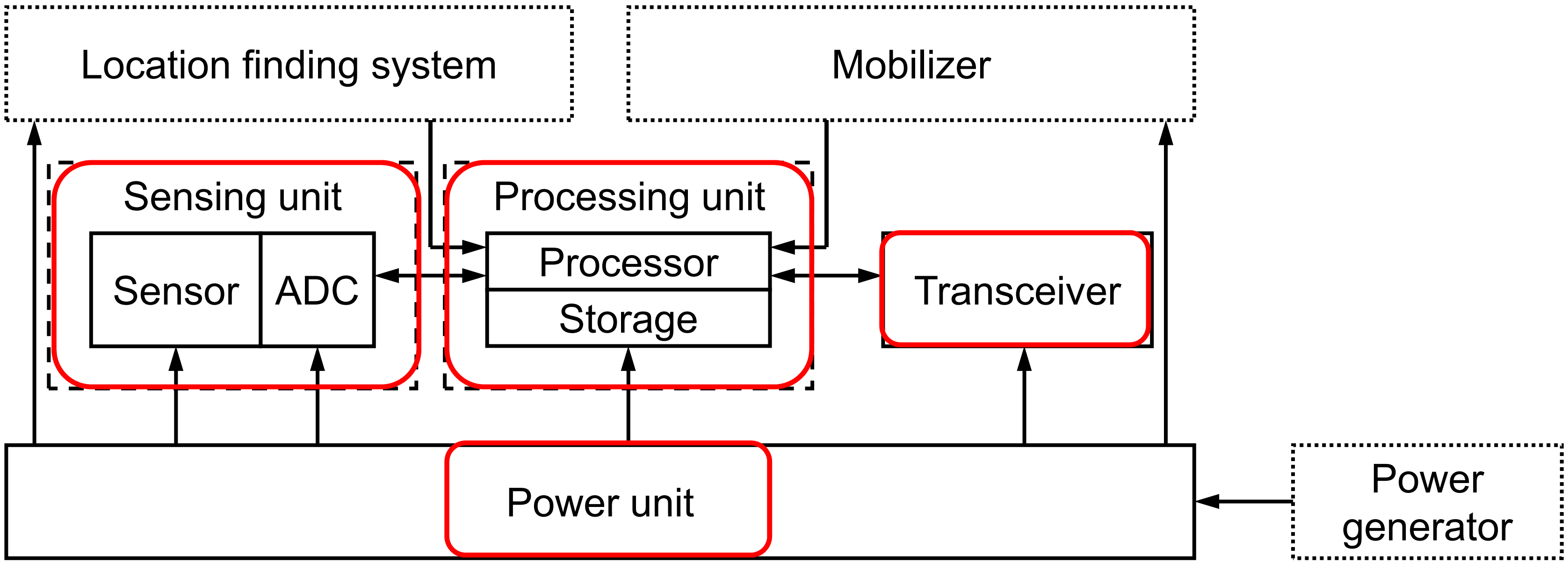
Contents

- **What is Sensor Network?**
  - **Sensor**
    - A transducer that converts a physical, chemical, or biological parameter into an electrical signal
  - **Sensor network**
    - Composed of a large number of sensor nodes
      - Wireless communication, densely deployed
    - The position of sensor nodes need not be engineered or pre-determined
      - Protocols and algorithms must possess self-organizing capabilities

- **Components of a sensor node**



Introduction

- **Application areas**
  - **Military**
    - Target tracking, surveillance, and reconnaissance
  - **Health**
    - monitor patients and assist disabled patients
  - **Other commercial applications**
    - managing inventory, monitoring product quality, and monitoring disaster areas

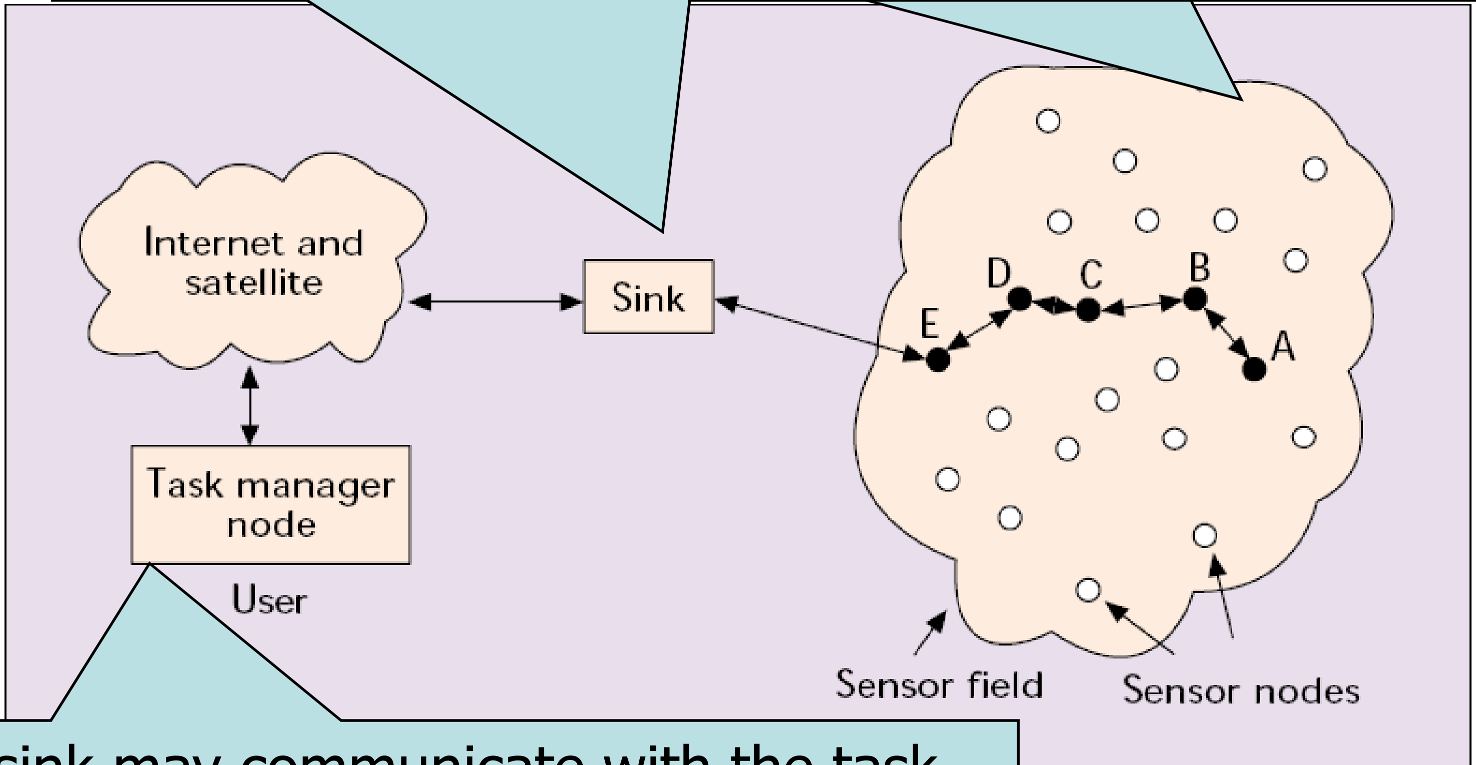
Introduction

- **Differences between sensor network & ad hoc network**
  - **The number of sensor nodes is much more than ad hoc network.**
  - **Densely deployed**
  - **Prone to failures**
  - **The topology of sensor network changes very frequently**
  - **Mainly use a broadcast communication paradigm**
  - **Sensor nodes are limited in power, computational capacities, and memory**
  - **May not have global ID**

Sensor Networks Communication Architecture

The

Each of these scattered sensor nodes has the capabilities to collect data and route data back to the sink



The sink may communicate with the task manager node via Internet or Satellite.

- **Design factors**
  - **Fault tolerance**
    - Sensor nodes may fail
      - Lack of power, physical damage, or environmental interference
  - **Scalability**
    - Large number of nodes, high density
  - **Production costs**
    - Since the sensor networks consist of a large number of nodes, the cost of a single node is very important.
    - The cost of sensors node has to be kept low.
  - **Hardware constraints**
    - Small size, limited power

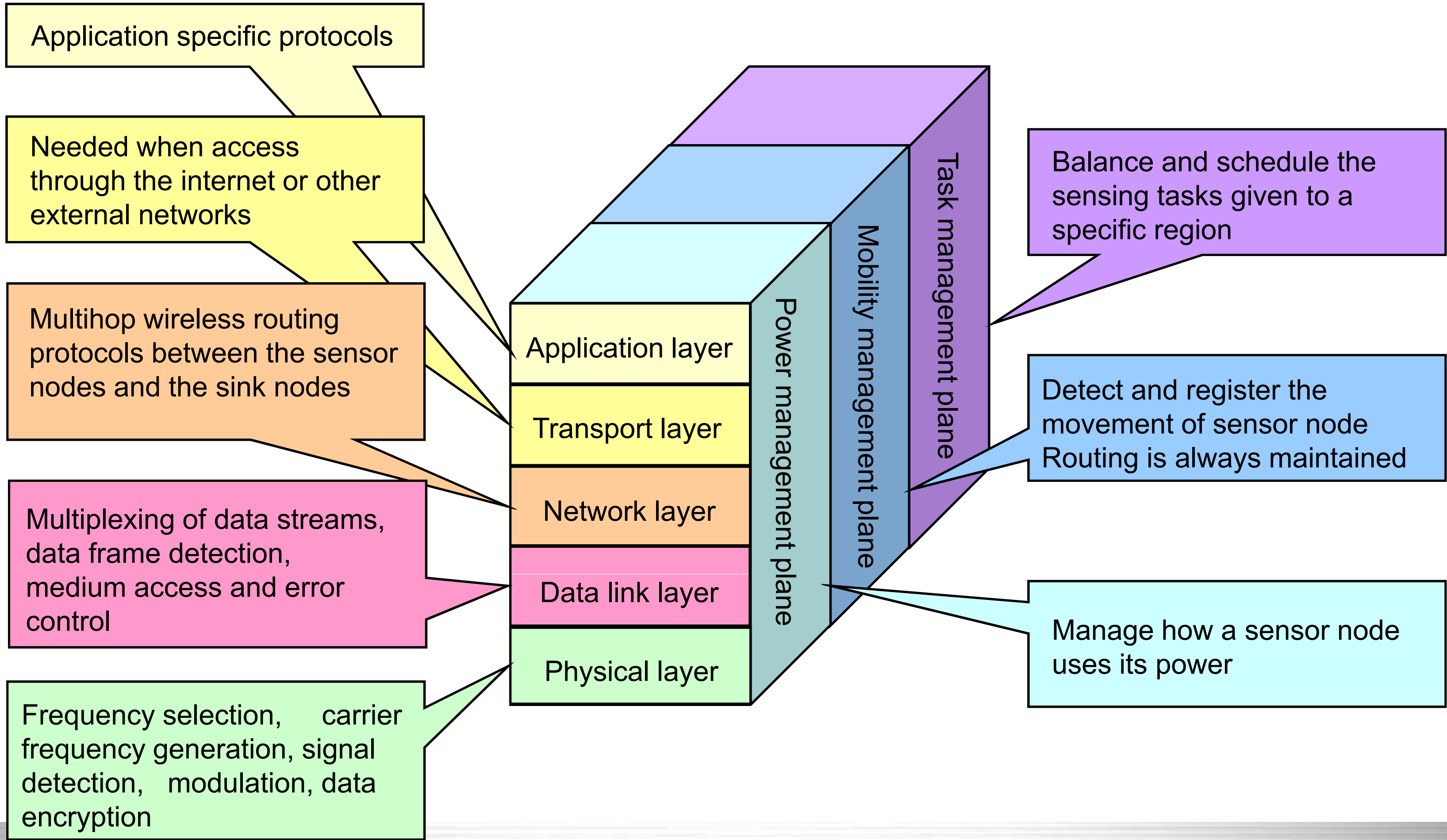
Sensor Networks Communication Architecture

- **Design factors**
  - **Sensor network topology**
    - Node deployment strategy
      - Predeployment and deployment phase
        - can be thrown in mass or placed one by one in the sensor field.
      - Post-deployment phase
        - prone to frequent changes after deployment.
      - Redeployment of additional nodes phase
        - addition of new nodes poses a need to re-organize the network.
  - **Environment**
    - The interior of large machinery
    - At the bottom of an ocean
    - In home or large building

- **Design factors**
  - **Transmission media**
    - RF
    - Infrared
      - license-free and robust to interference
  - **Power consumption**
    - Node lifetime strong dependent on battery lifetime
    - Power consumption can be divided into three domains
      - Sensing, data processing, and communication

■ Protocol stack

- Used by the sink and sensor nodes



Physical Layer

- **Responsibility**
  - **Frequency selection**
  - **Carrier frequency generation**
  - **Signal detection**
  - **Modulation**
  - **Data encryption**

- **Signal propagation effects**
- **Energy-efficiency being pursued**

Physical Layer

- **Open research issues**
  - **Modulation schemes**
    - Simple and low-power modulation schemes
  - **Strategies to overcome signal propagation effects**
  - **Hardware design**
    - Tiny, low-power, low-cost transceiver, sensing, and processing units need to be designed.
    - Power-efficient hardware management strategy

Data Link Layer

- **Responsibility**
  - **Multiplexing of data streams**
  - **Data frame detection**
  - **Medium access control**
  - **Error control**

- **Medium Access Control**
  - **Goals**
    - Creation of the network infrastructure
    - Fairly and efficiently share communication resources between sensor nodes

■ Reasons existing MAC protocols cannot be used

	Sensor	**Others**
Topology	No central controlling agent	Infrastructure-based (Cellular)
Number of nodes	> 1,000	< 8 (Bluetooth)
Primary Goal	Energy efficiency	QoS and Bandwidth efficiency (Cellular, MANET)
Conclusion	None of existing MAC protocols can be directly used in sensor networks	

Data Link Layer

- **Self-Organizing Medium Access Control for Sensor Networks (SMACS)**
  - Kind of distributed infrastructure-building protocol
  - Enables nodes to discover their neighbors
  - Establish transmission/reception schedules for communication
  - Not need for any local or global master nodes

- **Eavesdrop-And-Register(EAR) algorithm**
  - Enables seamless connection of mobile nodes

Data Link Layer

- **CSMA-Based Medium Access**
  - **CSMA based medium access scheme has 2 components**
    - Listening mechanism
    - Backoff scheme
      - Robustness against repeated collisions.

- **Hybrid TDMA/FDMA Based**
  - **Centrally controlled MAC scheme**
  - **While a pure TDMA scheme dedicates the full bandwidth to a single sensor node, a pure FDMA scheme allocates minimum signal bandwidth per node.**

Data Link Layer

- **Power saving modes of operation**
  - **turn the transceiver off when it is not required**
  - **This can be ineffective due to startup costs**

- **Error control**
  - **Simple error control is recommended**
  - **FEC (Forward Error Correction)**
  - **ARQ (Automatic Repeat request)**

Data Link Layer

- **Open research issues**
  - **MAC for mobile sensor networks**
  - **Error control coding schemes**
  - **Power-saving modes of operation**

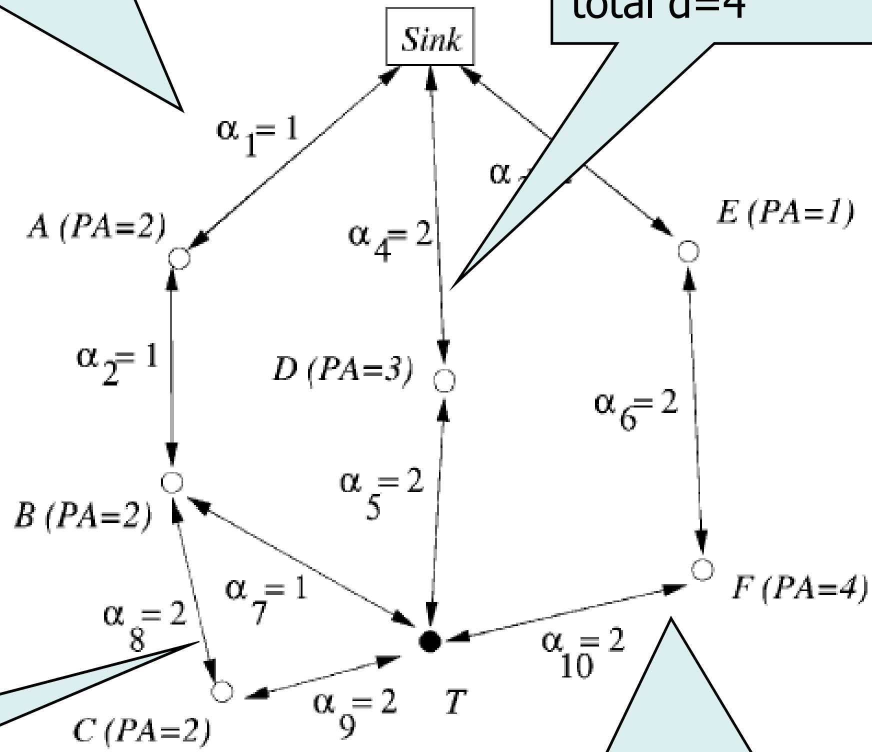
Network Layer

- **Responsibility**
  - Provides special multi-hop wireless protocols between sensor nodes and the sink node
- **Design principles**
  - Power efficiency is important consideration
  - Sensor networks are mostly data-centric
  - Data aggregation is useful only when it does not hinder the collaborative effort of the sensor nodes
  - Attribute-based addressing

- **Energy-efficient route**
  - **Based on available power (PA) or the energy required (α) for transmission in the links**
    - Maximum PA route
    - Minimum energy route
    - Minimum hop route

Route 1:
Sink-A-B-T, total PA=4, total α=3

Route 3: Sink-D-T,
total PA=3,
total α=4



Route 2:
Sink-A-B-C-T, total PA=6, total α=6

Fig. 4.

Route 4:
Sink-E-F-T, total PA=5, total α=6

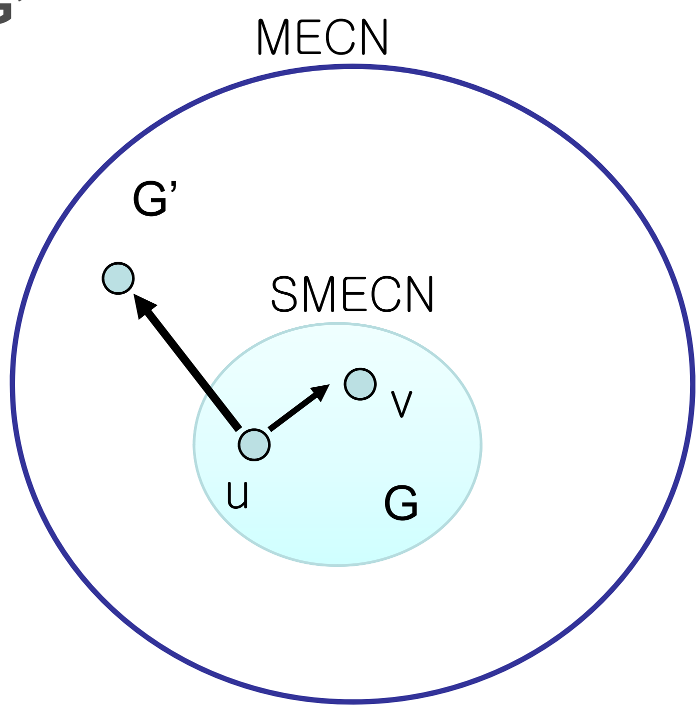
Network Layer

- **Data-centric routing**
  - ***Interest dissemination*** **is performed to assign the sensing tasks to the sensor nodes.**
  - **Two approaches used for interest dissemination:**
    - Sinks broadcast the interest
    - Sensor nodes broadcast an advertisement for the available data and wait for a request from the interested sinks.
  - **attribute-based naming**
    - Querying an attribute of the phenomenon, rather than querying an individual node.
    - “the areas where the temperature is over 70°F” is a more common query than “the temperature read by a certain node”

Network Layer

- **Some schemes proposed for the sensor network**
  - **Small minimum energy communication network (SMECN)**
  - **Flooding**
  - **Gossiping**
  - **Sensor protocols for information via negotiation (SPIN)**
  - **Low-energy adaptive clustering hierarchy (LEACH)**

- **Small minimum energy communication network (SMECN)**
  - **Use small subgraph to communication**
  - **The energy required to transmit data from node u to all its neighbors in subgraph G is less than the energy required to transmit to all its neighbors in graph G'**

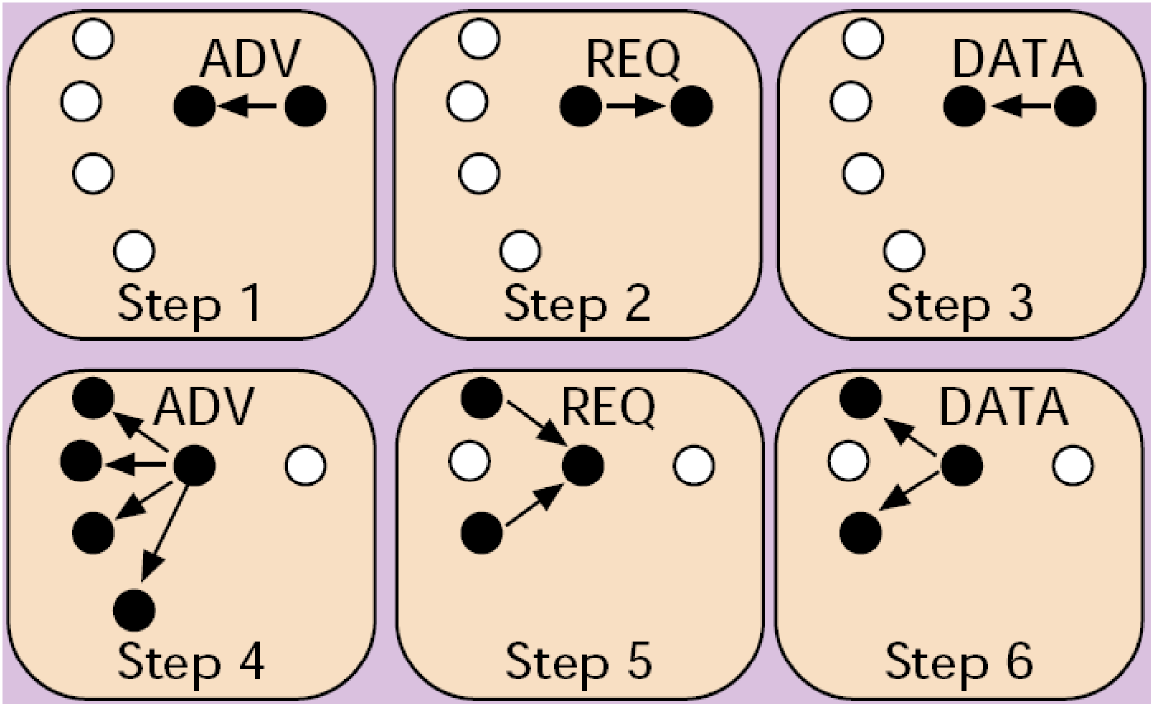


Network Layer

- **Flooding**
  - **Broadcast a data packet to all of neighbors**
  - **Strength : simple**
  - **Weakness : Implosion, overlap, resource blindness**

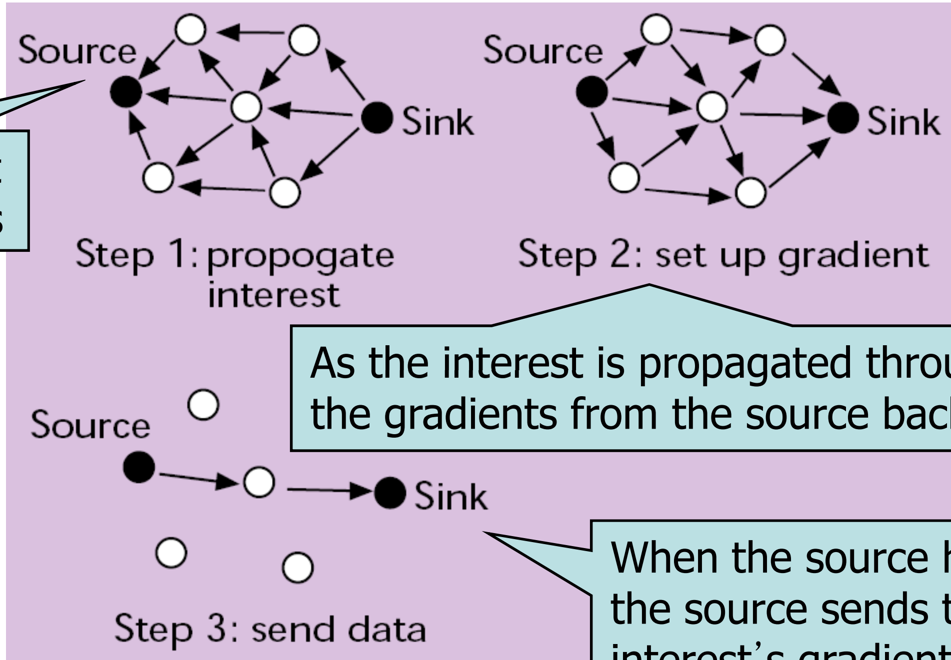
- **Gossiping**
  - **Send a data packet to a randomly selected neighbor**
  - **Strength: Avoids the implosion problem**
  - **Weakness: long propagation delay**

- **Sensor Protocols for Information via Negotiation (SPIN)**
  - **Broadcast limited by negotiation**
  - **Three messages: ADV, REQ, and DATA**



- **Low-Energy Adaptive Clustering Hierarchy (LEACH)**
  - **Randomly select sensor nodes as cluster-heads**
  - **Setup phase**
    - Sensor node chooses a rand(0~1)
    - If rand(0~1) is less than the threshold, the sensor node is a cluster-head
    - The cluster-head advertise to all sensor nodes in the network.
    - Received the advertisement, they determine the cluster to which they want to belong. (based on signal strength)
  - **Steady phase**
    - Sensing and transmitting data to the cluster-heads
    - Cluster-heads aggregate data from the nodes
  - **After a certain period of time spent on the steady phase, the network goes into the setup phase**

- **Directed Diffusion**
  - **Sets up gradients for data to flow from source to sink during interest dissemination**



the sink sends out interest to sensors

As the interest is propagated throughout the sensor network, the gradients from the source back to the sink are set up

When the source has data for the interest, the source sends the data along the interest's gradient path

- **Open research issues**
  - **Improvement or development network-layer protocols**

Transport Layer

- **Responsibility**
  - **System is planned to be accessed through the other external networks**
- **TCP splitting needed**
  - **To make sensor networks interact with other networks**
  - **Communication between an user node and the sink node**
    - TCP or UDP via the internet or satellite
  - **Communication between the sink node and a sensor node**
    - UDP-type protocol, because each senor node has limited memory
- **Open research issues**
  - **Development of transport layer protocols**

Application Layer

- **Potential application layer protocols for sensor networks remains a largely unexplored region**
- **Application layer protocols**
  - **SMP (Sensor Management Protocol)**
    - Perform administrative tasks
  - **TADAP (Task Assignment and Data Advertisement Protocol)**
    - Interest dissemination
  - **SQDDP (Sensor Query and Data Dissemination Protocol)**
    - Issue queries, respond to queries, and collect replies
- **Open research issues**
  - **Development of application layer protocols**

Conclusion

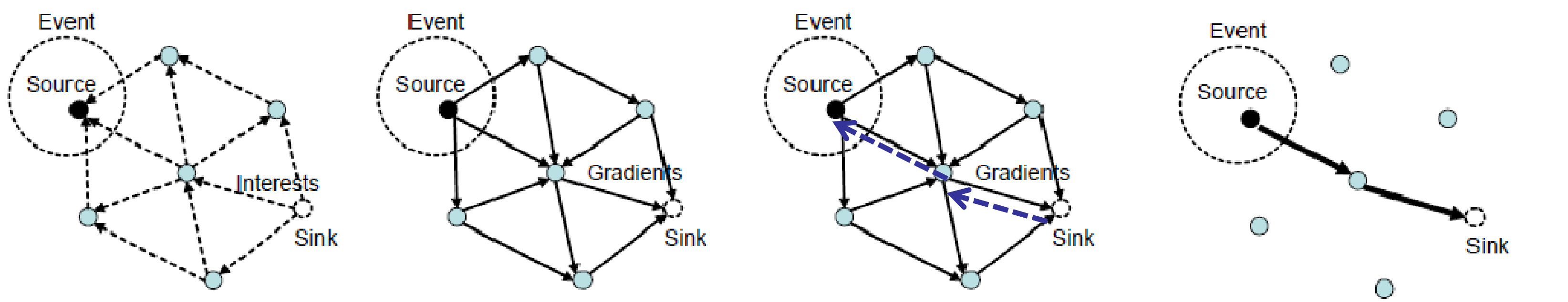
- **In the future, this wide range of application areas will make sensor networks an integral part of our lives.**

- **However, realization of sensor networks needs to satisfy the constraints introduced by factors such as *fault tolerance, scalability, hardware, topology change, environment* and *power consumption*.**

- **Many researchers are currently engaged in developing the technologies needed for different layers of the sensor networks protocol stack.**

Directed Diffusion

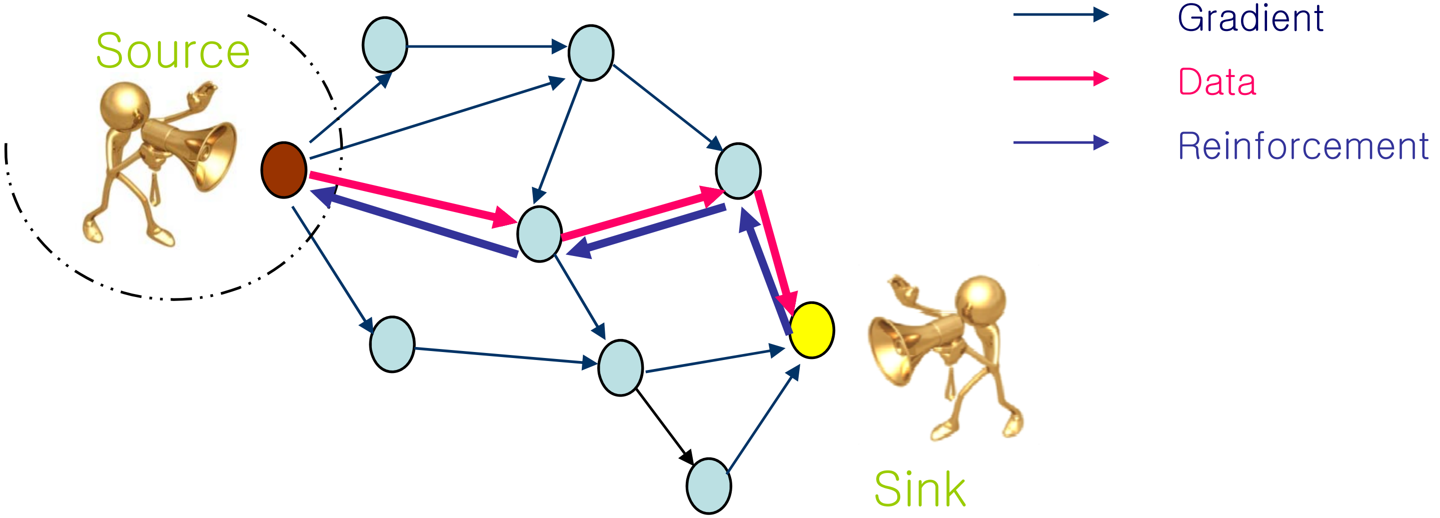
- Interest propagation
- Initial gradients setup
- Reinforcement
- Data delivery along reinforced path



(a) Interest propagation (b) Initial gradients setup (c) reinforcement (d) Data delivery along reinforced path

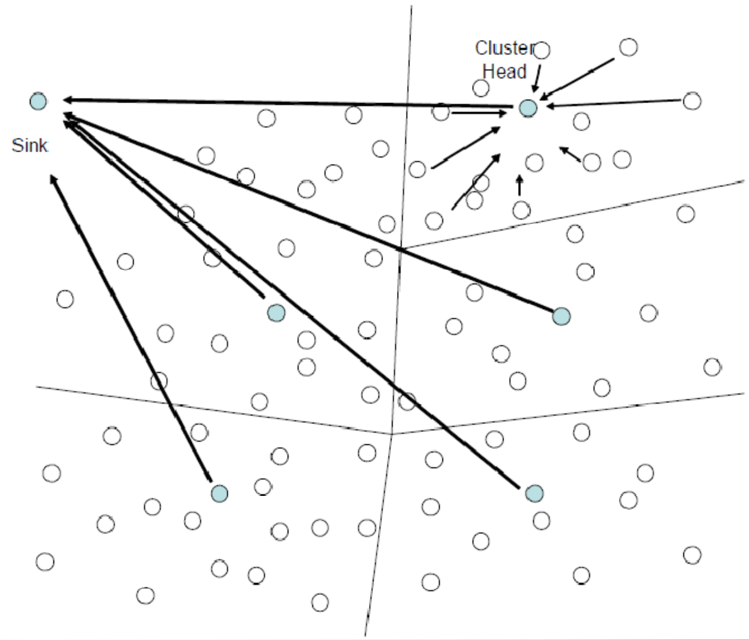
Reinforcement

- **Reinforce one of the neighbor after receiving initial data.**
  - Neighbor(s) from whom new events received.
  - Neighbor who's consistently performing better than others.
  - Neighbor from whom most events received.



LEACH

- **Select cluster-head**
  - **Nodes are selected as the cluster-head node using probability function.**
- **Cluster set-up**
  - **Non-head nodes are select own head-node.**
- **Schedule creation**
- **Data transmission**



SMECN

- **compute energy-efficient sub-network**
  - **There exists a minimum-energy path in sub-graph *G* between nodes *u* and *v* for every pair (*u,v*) of nodes that are connected in *G'***
  - **The power required to transmit data between nodes *u* and *v* is modeled as *p(u; v) = td(u; v)***^{n}
    - where *t* is a constant, *d(u; v)* is the distance between nodes *u* and *v*, and *n*≥2 is the path-loss exponent
  - **The total power consumption between node** u_0 ***and*** u_k **is:**

$$C(r) = \sum_{i=0}^{k-1} (p(u_i, u_{i+1}) + c)$$

  - **If *C(r)* ≤ *C(u,v)*, then *(u,v)* is k-redundant**
    - path *r* = (u_0 , …, u_k), |*r*|=*k*

■ Relay region

- Eliminates k-redundant link
- $R_{u \rightarrow v} = \{ (x,y) : C(u,v,(x,y)) \leq C(u, (x,y)) \}$