Introduction to Wireless Sensor Networks

Wireless Network

- Wireless networks are telephone or computer networks that use radio as their carrier or physical layer.

- Primary usage:
  - Wireless Personal Area Networking (WPAN)
  - Wireless Local Area Networking (WLAN)
  - Wireless Wide Area Networking (WWAN)

ISM Band

- The **I**ndustrial, **S**cientific and **M**edical radio bands are the industrial equivalent of the "Citizens Band". No license is required.

- 900 MHz band:
  - Range: 902-928 MHz
  - Wavelength: 33.3 CM
- 2.4 GHz band:
  - Range: 2400-2483.5 MHz
  - Wavelength: 12.2 CM
- 5.8 GHz band:
  - Range: 5.725GHz-5.850 GHz
  - Wavelength: 5.2 CM

Wireless Personal Area Networking

- A WPAN is a network interconnecting devices centered around an individual person's workspace - in which the connections are wireless.
- One such technology is Bluetooth, which was used as the basis for IEEE 802.15.

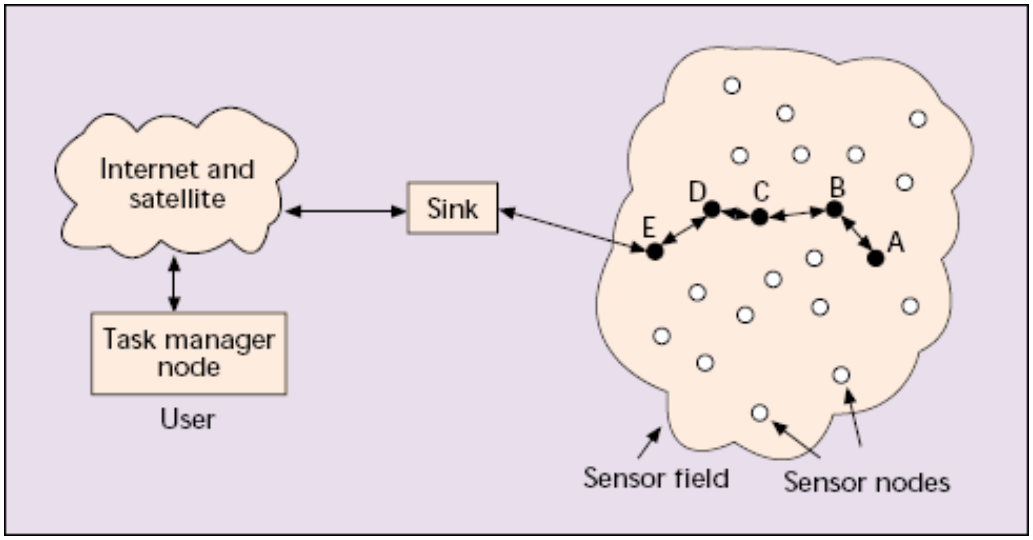
Wireless Local Area Networking

- A wireless LAN is one in which a mobile user can connect to a local area network (LAN) through a wireless (radio) connection.
- A standard, IEEE 802.11, specifies the technologies for wireless LANs.

Sensor Network

- A sensor network is a computer network of many, spacially distributed devices using sensors to monitor conditions at different locations, such as temperature, sound, vibration, pressure, motion or pollutants.
- Involve three areas: sensing, communications, and computation (hardware, software, algorithms).
- Applications: military, environmental, medical, home, and other commercial.

Sensor Network



- Sensor nodes scattered in a sensor field
  - Each nodes has the capabilities to collect data and route data back to the sink (Base Station).
  - Protocols and algorithms with self-organization capabilities.
  - Nodes have to cooperate and partially process sensed data.

Sensor Network

- The design of the sensor network is influenced by many factors, including:
  - fault tolerance
  - scalability
  - production costs
  - operating environment
  - sensor network topology
  - hardware constraints
  - transmission media
  - power consumption

Design Factors of Sensor Network

- Fault Tolerance
  - Some sensor nodes may fail or be blocked due to lack of power, or have physical damage or environmental interference.
  - The failure of sensor nodes should not affect the overall task of the sensor network.
  - The reliability is modeled in using the Poisson distribution: $R_k(t) = \exp(-\lambda_k t)$, where λ_k is the failure rate of sensor node k, and t is the time period.

Design Factors of Sensor Network

- Scalability
  - The number of sensor nodes deployed in studying a phenomenon may be on the order of hundreds or thousands.
  - New schemes must be utilize the high density of the sensor networks.
  - The density μ can be calculated according to as $\mu(R) = (N * \pi R^2) / A$, where N is the number of scattered sensor nodes in region A, and R is the radio transmission range.

Design Factors of Sensor Network

- Production Costs
  - The cost of a single node is very important to justify the overall cost of the network.
  - If the cost is more expensive than deploying traditional sensors, the sensor network is not cost-justified.

- Hardware Constraints
  - A sensor node is made up of four basic components: sensing unit, processing unit, transceiver unit, and power unit.
  - They may also have additional application-dependent components such as a location finding system, power generator, and mobilizer.
  - The required all of these subunits may be smaller than even a cubic centimeter.

Design Factors of Sensor Network

- Sensor Network Topology
  - Issues related to topology maintenance and change in three phases:
    - Pre-deployment and deployment phase:
      - Sensor nodes can be either thrown in mass or placed one by one in the sensor field.
    - Post-deployment phase:
      - Topology changes are due to change nodes' position, reachability, available energy, malfunctioning, and task details.
    - Re-deployment of additional nodes phase:
      - Additional sensor nodes can be redeployed at any time to replace malfunctioning nodes or due to changes in task dynamics.

Design Factors of Sensor Network

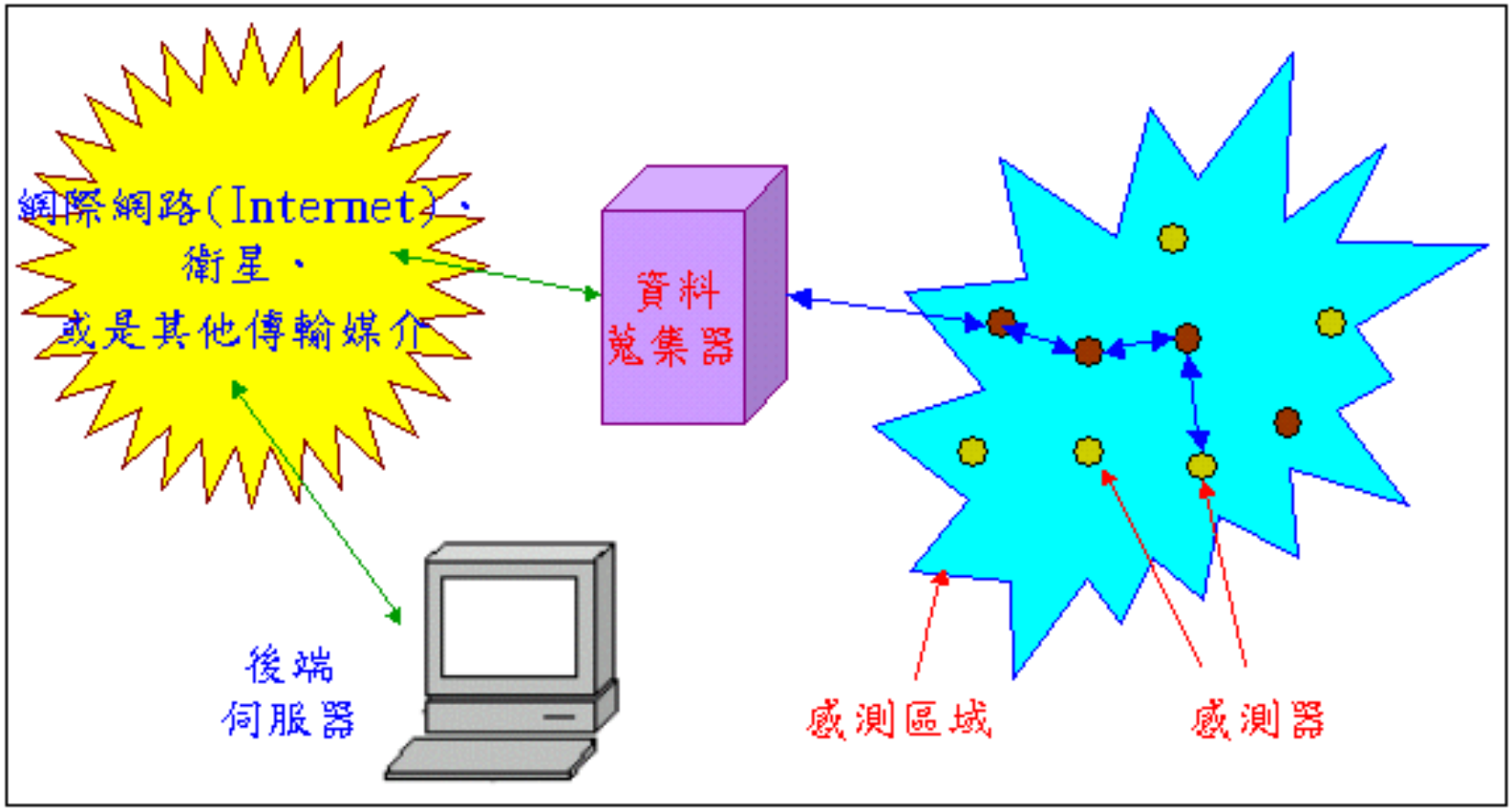
- Environment
  - Sensor nodes are densely deployed either very close or directly inside the phenomenon to be observed.
  - They may be working in the interior of large machinery, at the bottom of an ocean, in a biologically or chemically contaminated field, in a battlefield beyond the enemy lines, and in a home or large building.

- Transmission Media
  - In a multi-hop sensor network, communicating nodes are linked by a wireless medium.
  - These links can be formed by radio, infrared, or optical media.
  - The chosen transmission medium must be available worldwide.

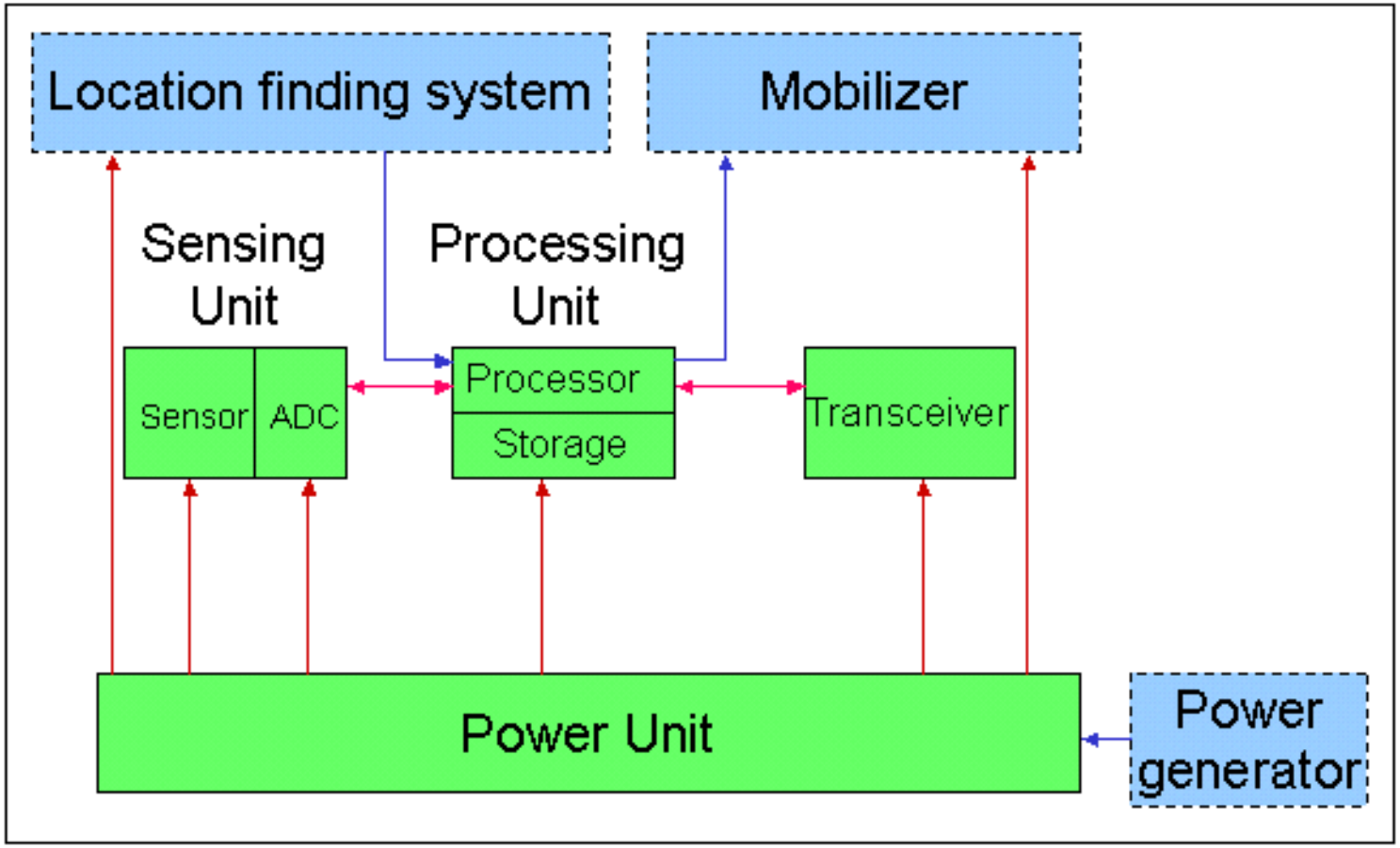
Design Factors of Sensor Network

- Power Consumption
  - The wireless sensor node, being a microelectronic device, can only be equipped with a limited power source.
  - The malfunctioning of a few nodes can cause significant topological changes and might require rerouting of packets and reorganization of the network.
  - Power consumption can hence be divided into three domains: sensing, communication, and data processing.

Generic System Architecture (感測網路系統基本架構)

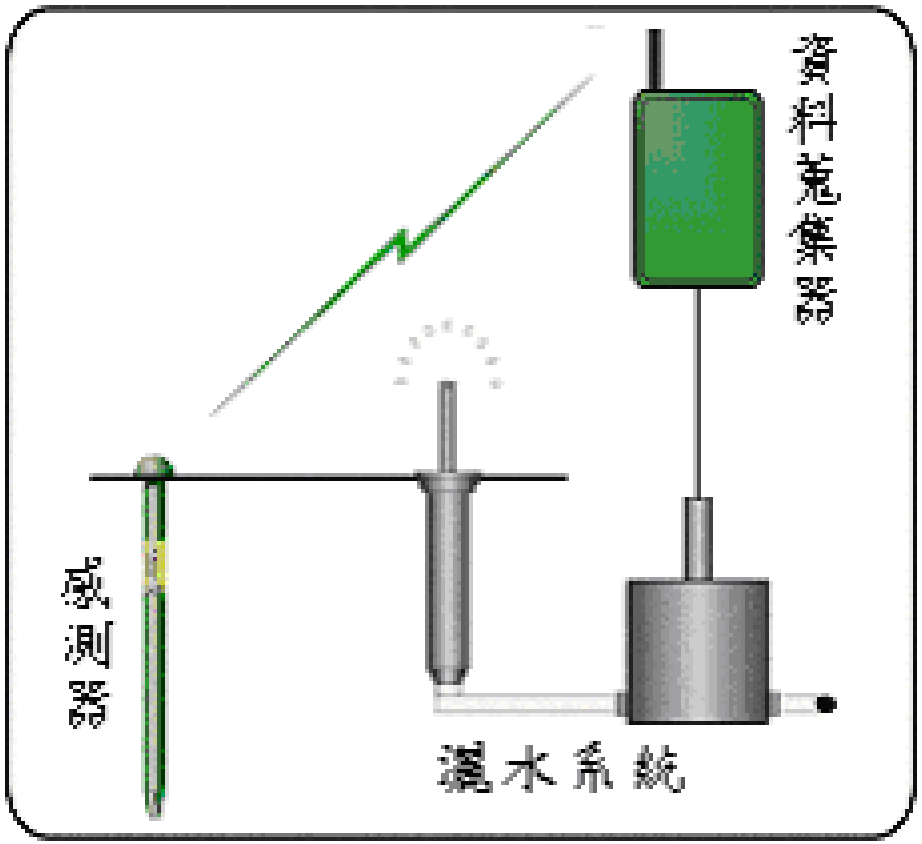


Sensor Hardware (感測器硬體設計)



Example 1

- Digital Sun公司所發展的自動灑水系統「S.Sense Wireless Sensor」

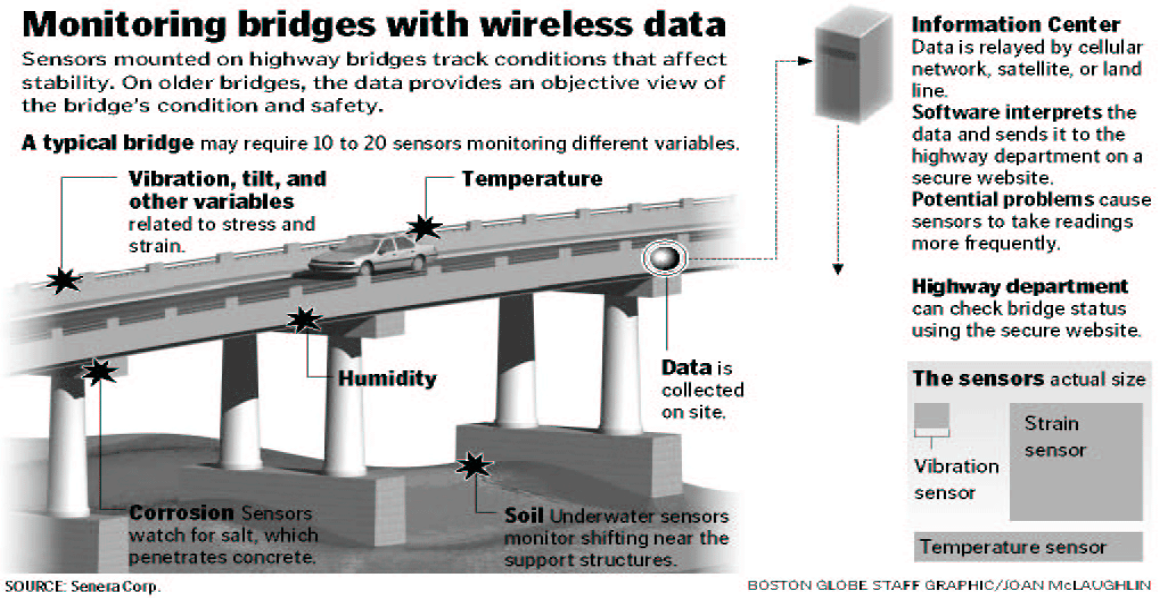


Example 2

- 展覽會場的保全系統 -- Sensicast ART
- 在博物館、圖書館、畫廊、藝術品展覽會場，防止有價值的藝術品或展覽品遭到竊盜、不經意的觸摸、任意搬動等情形。
- 主要有兩個模組：
  - OAS 物件警告系統(Object Alarm System)：感測裝置安裝在藝術品底部或背面，藉由偵測燈光的亮度是否改變、測量是否遭受到振動等因素，來確保展覽品的安全。
  - EMS 環境管理系統(Environment Management System)：安裝在展覽會場的牆角、天花板等，偵測展覽環境的溫度、溼度是否超過安全值，以保護展覽品的品質。

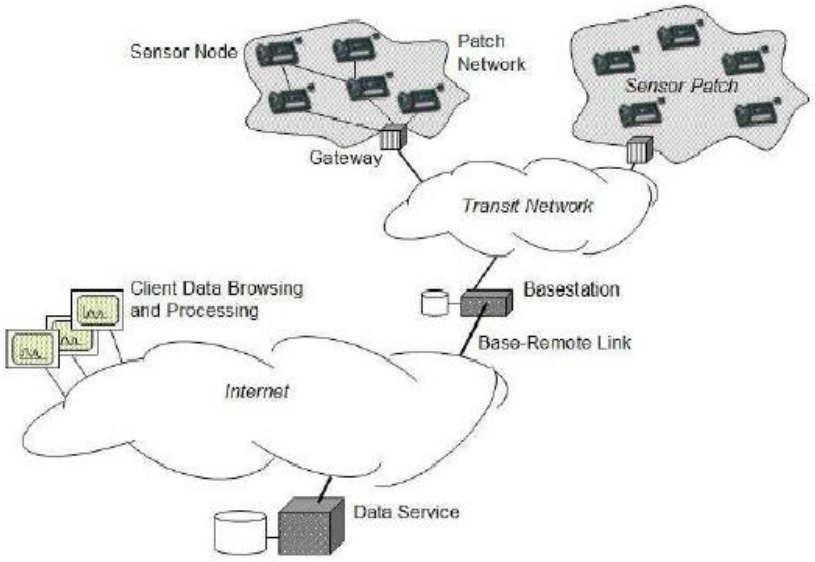
Example 3

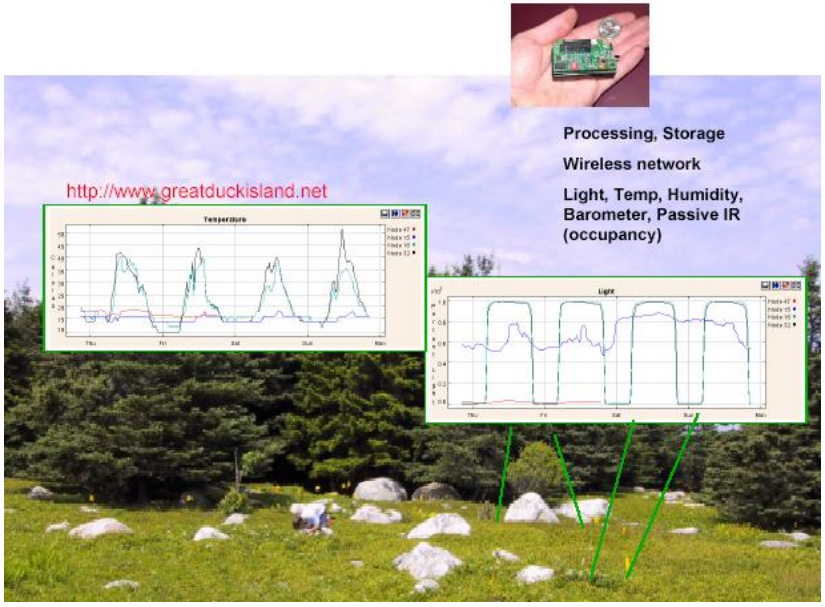
- Senera的橋樑安全監控系統
  - (89. 8.27)聯絡高雄與屏東之間的高屏大橋突然斷裂，造成多位民眾受傷
  - Senera的感測系統，用於監視橋樑、高架橋、高速公路等道路環境。對於許多老舊的橋樑，橋墩長期受到溪水的沖刷，本感測器能夠放置在橋墩底部、用以感測橋墩結構；亦可放置在橋樑兩側或底部，蒐集橋樑的溫度、溼度、振動幅度、橋墩被侵蝕程度等，期望能減少斷橋所造成生命財產的損失。



Example 4

- Habitat Monitoring on Great Duck Island
  - 遠端利用Mote形成的sensor network觀察動物的棲息地環境。
  - Mote可以供環境光線、溫度…等變化的sensor node，藉由形成的Wireless Sensor Network可以遠端觀察環境，並且長時間蒐集環境的變化資料。





Types of Routing Protocol for WSN

- Single-hop Networks
  - The network consists of n nodes, and packets are transmitted from sources to destinations directly.
- Multi-hop Networks
  - The final destination of a packet might not be reached directly and the other nodes can be used to route the packet to the final destination.

Flat Routing Protocols

- Flat Networks
  - Every incoming packet is sent out on every outgoing line except the one it arrived on.
  - Vast numbers of duplicate packets are generated.
  - Routing Protocols: Directed Diffusion, SPIN.

The Directed Diffusion Protocol

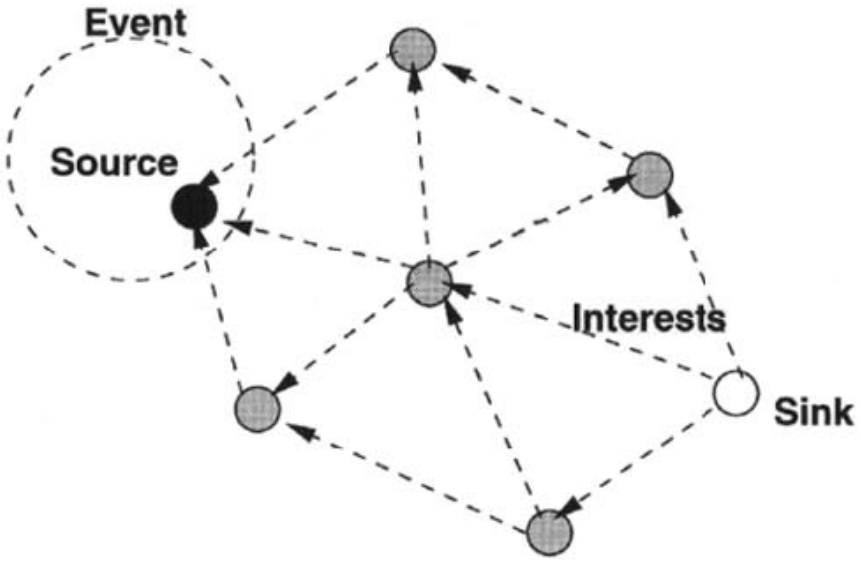
- Directed Diffusion consists of several elements:
  - Interests
  - Data messages
  - Gradients
  - Reinforcements

Directed Diffusion - Interest & Data

- Interest
  - type = wheeled vehicle
  - interval = 1 s
  - rect = [-100, 200, 200, 400]
  - timestamp = 01:20:40 // hh:mm:ss
  - expiresAt = 01:30:40
- Data
  - type = wheeled vehicle // type of vehicle seen
  - instance = trunk // instance of this type
  - location = [125, 220]// node location
  - intensity = 0.6 // signal amplitude measure
  - confidence = 0.85 // confidence in the match
  - timestamp = 01:20:40 // local event generation time

Directed Diffusion - Interest Propagation

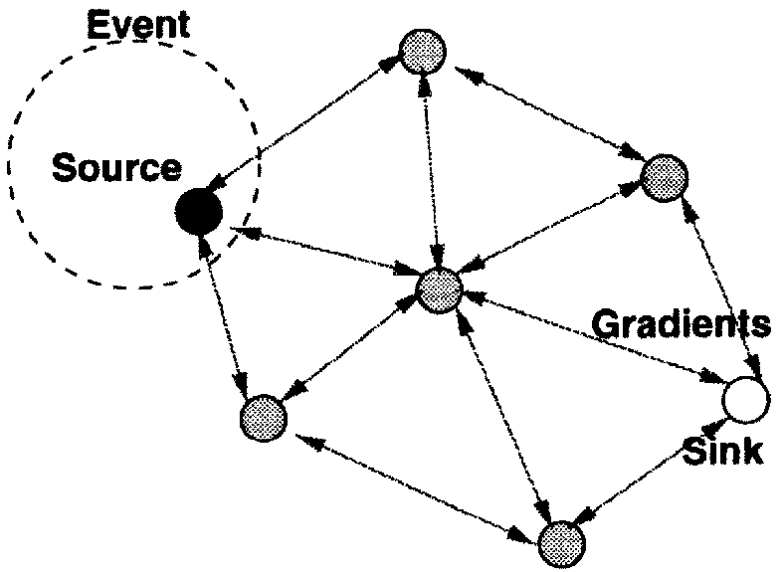
- The sink periodically broadcasts an interest message to each of its neighbors.



- Every node maintains an interest cache.

Directed Diffusion - Gradient Establishment

- That every pair of neighboring nodes establishes a gradient toward each other.
- This technique can enable fast recovery from failed paths or reinforcement of empirically better paths.

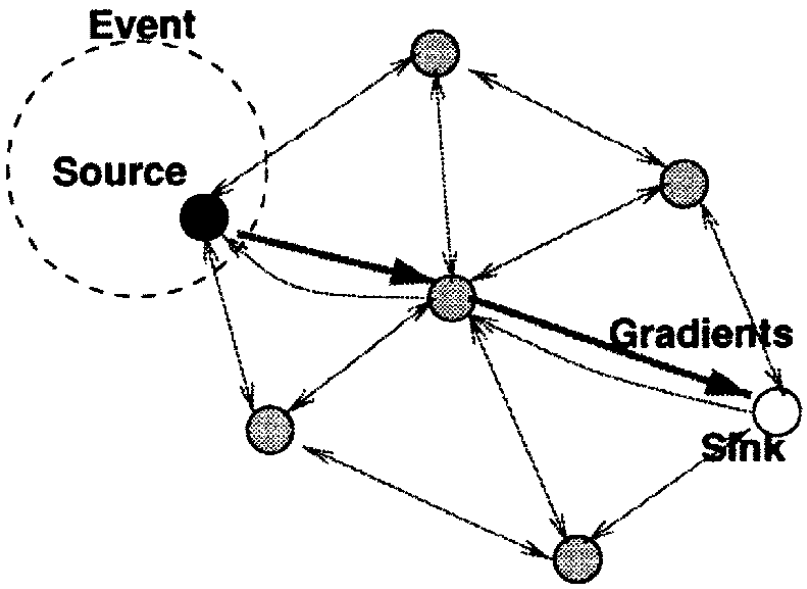


Directed Diffusion - Data Propagation

- A sensor node that detects a target, it computes the highest requested event rate among all its outgoing gradients.
- To resend a received data message, a node needs to examine the matching interest entry's gradient list.

Directed Diffusion - Reinforcement

- The node might choose that neighbor from whom it first received the latest event matching the interest to reinforce.



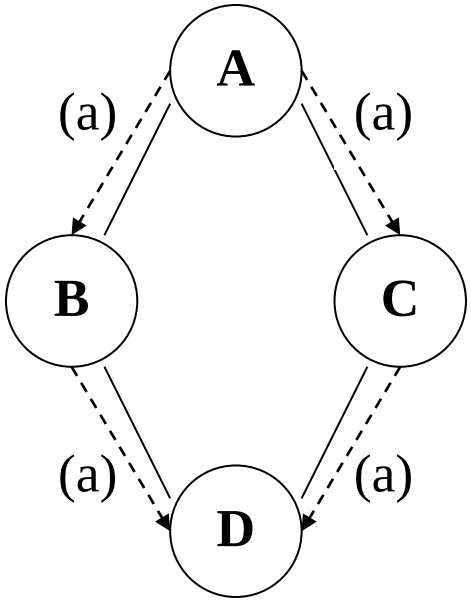
- It is very reactive to changes in path quality.

The SPIN Protocol

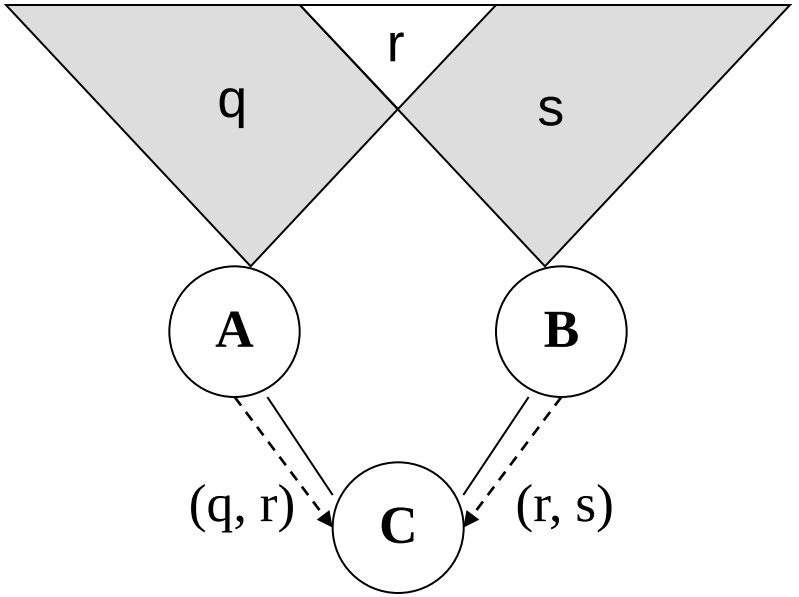
- Sensor Protocols for Information via Negotiation.
- Start with a source node sending its data to all of its neighbors.

SPIN - Flooding deficiencies

- Implosion & Overlap



Implosion Problem



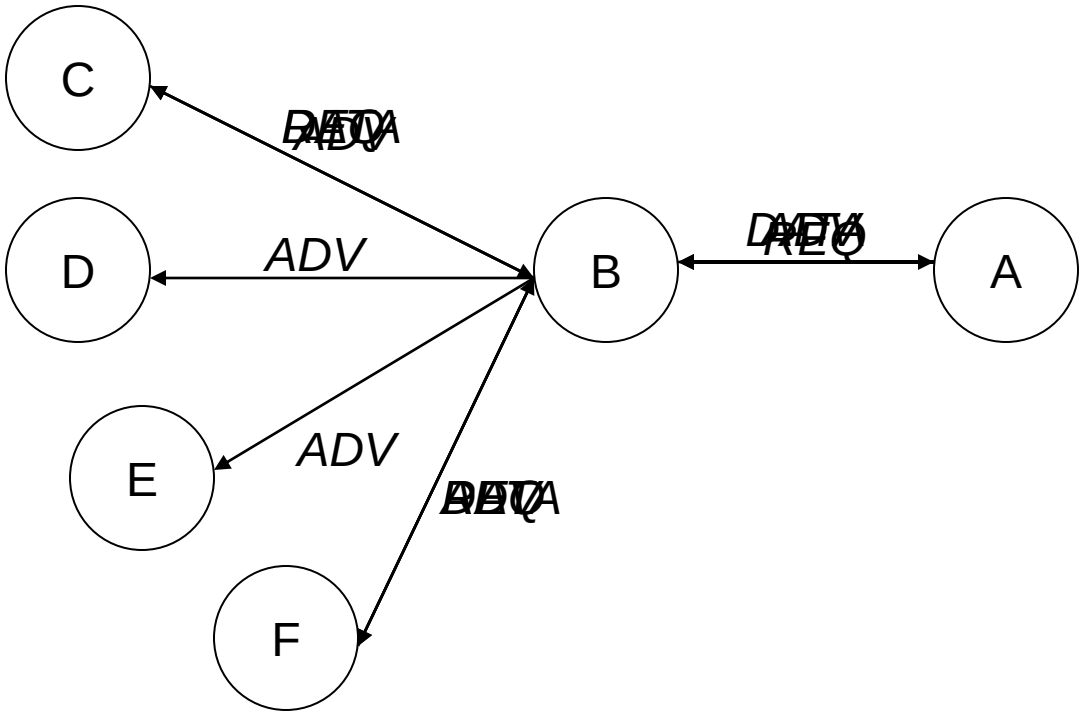
Overlap Problem

SPIN-1 - three types of messages

- ADV
  - When a SPIN node has data to share, it can advertise an ADV message containing meta-data.
- REQ
  - A SPIN node sends an REQ message when it wishes to receive some actual data.
- DATA
  - DATA messages contain actual sensor data with a meta-data header.

The SPIN-1 Protocol

- Steps



The SPIN-2 Protocol

- When energy is plentiful, SPIN-2 nodes communicate using the same 3-stage protocol as SPIN-1 nodes.

- When a SPIN-2 node observes that its energy is approaching a low-energy threshold, it adapts by reducing its participation in the protocol.

Hierarchical Routing Protocols

- Hierarchical Networks
  - The main aim of hierarchical routing is to efficiently maintain the energy consumption of sensor nodes.
  - Performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink.
  - Routing Protocols: LEACH, PEGASIS, TEEN.

The LEACH Protocol

- Low-Energy Adaptive Clustering Hierarchy.
- Distributed cluster formation technique that enables self-organization of large numbers of nodes.

LEACH - Cluster

- Algorithms for adapting clusters and rotating cluster head positions to evenly distribute the energy load among all the nodes.
- The nodes organize themselves into local clusters, with one node acting as the cluster head.
- The cluster head performs signal processing functions on the data, and transmits data to the remote BS.

LEACH - Set-up phase

- Cluster Head
  - Each cluster head node broadcasts an advertisement message (ADV) let all the other nodes that they have chosen this role for the current round.
- Non-Cluster Head
  - They transmits a join-request message (Join-REQ) back to the chosen cluster head.

LEACH - Set-up phase

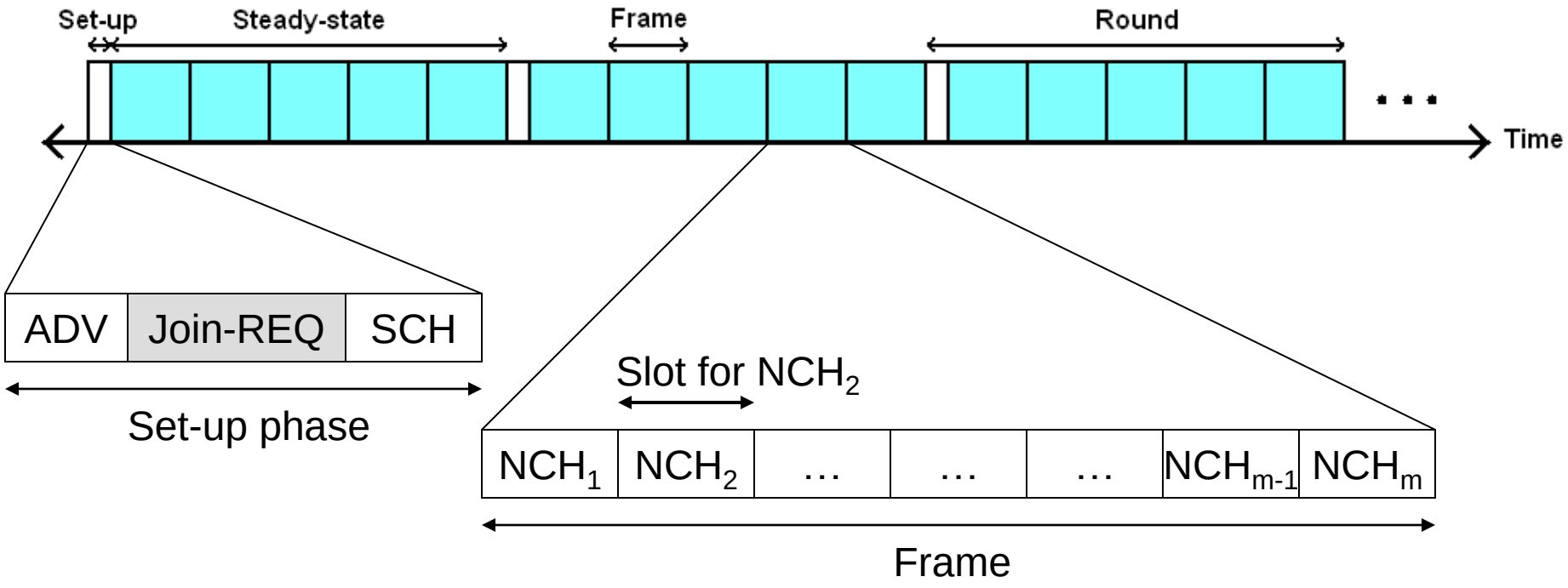
- The cluster head node sets up a TDMA schedule and transmits this schedule to the nodes in the cluster.
- Ensures that there are no collisions among data messages.
- Allows the radio components to be turned off at all times except during their transmit time.

LEACH - Steady-state phase

- Broken into frames, where nodes send their data to the cluster head at most once per frame during their allocated transmission slot.
- Once the cluster head receives all the data, it performs data aggregation.

LEACH - Time line

- Time line showing LEACH operation



References

- Wireless ISP Frequency Bands
  - http://www.beagle-ears.com/lars/engineer/wireless/bands.htm
- Sensor network
  - http://en.wikipedia.org/wiki/Sensor_network
- Wireless Networking Tutorial
  - http://www.tutorial-reports.com/wireless/
- Introduction to Wireless Networks
  - http://www.csie.nctu.edu.tw/~yctseng/WirelessNet05-02/contents.html
- New frontier for wireless Sensor networks
  - http://www.networkworld.com/news/2004/0607sensors.html
- Wireless sensor networks: a survey
  - http://www.ece.gatech.edu/research/labs/bwn/sensornets.pdf