Overview of Wireless Sensor Network

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Outline

- Introduction
- Applications
- System Architecture
- Protocols for Sensor Networks

Introduction

A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants and to **cooperatively** pass their data through the network to a main location

Introduction

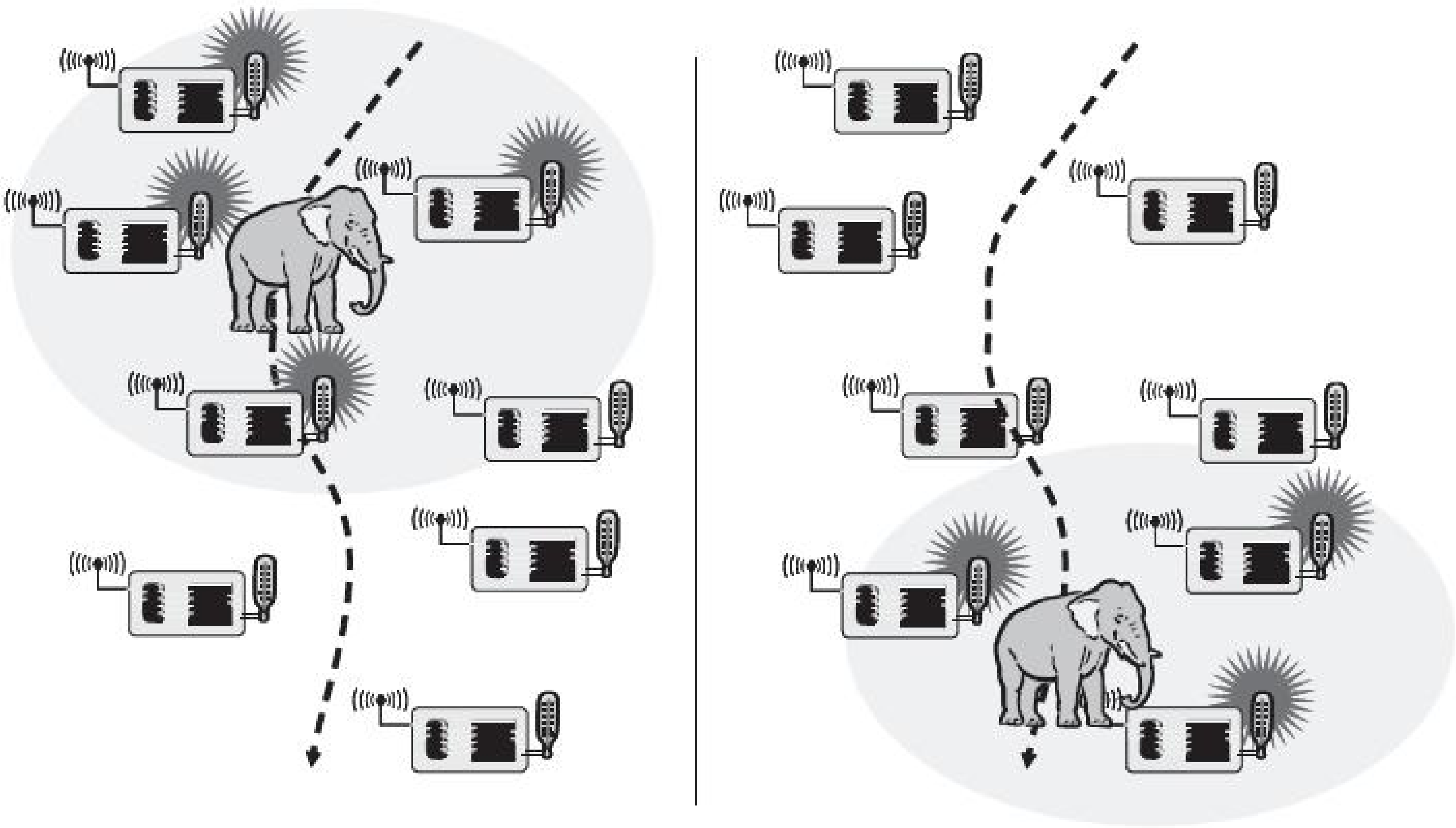
- Sensor nodes are low power multi-functioning devices operating in an unattended environment with limited computations and sensing capabilities.
- Sensor nodes are equipped with small, often irreplaceable batteries with limited power capacities.
- Lifetime of the WSNs depend on the lifetime of the sensor nodes.

Introduction

- It is no longer treated any more as an interesting research topic only
- Increasing number of sensor network deployments for real-life applications
- 127 millions of sensor nodes operational in 2011 particularly in the field of industrial applications
- Future is explosive growth in usage of sensors with advent of IoT.
- WSN is integral part of all IoT deployments

WSN Industries

Habitat Monitoring



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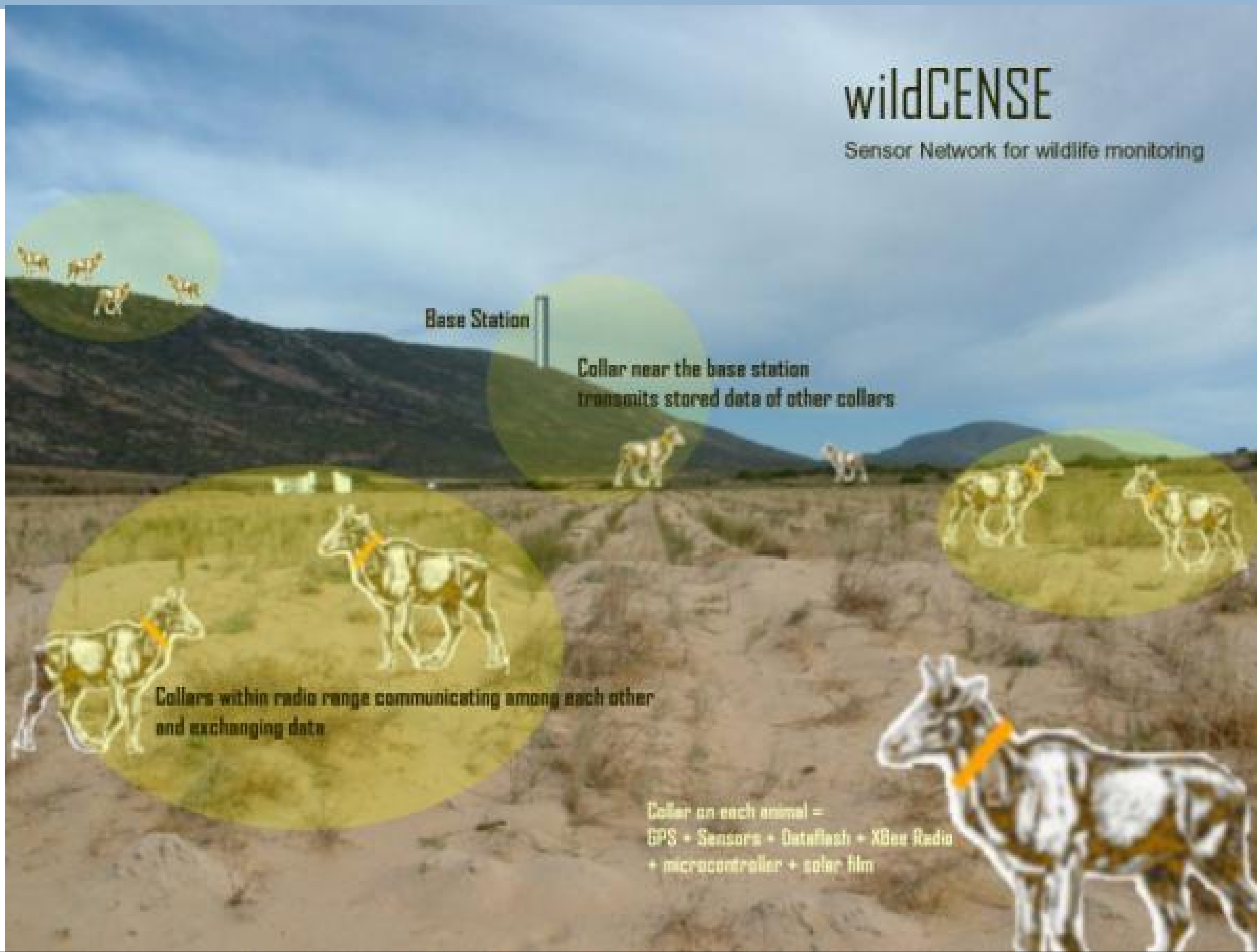


Application-oriented Packaging

Indoor, general-purpose MICA-sensor

Indoor base station

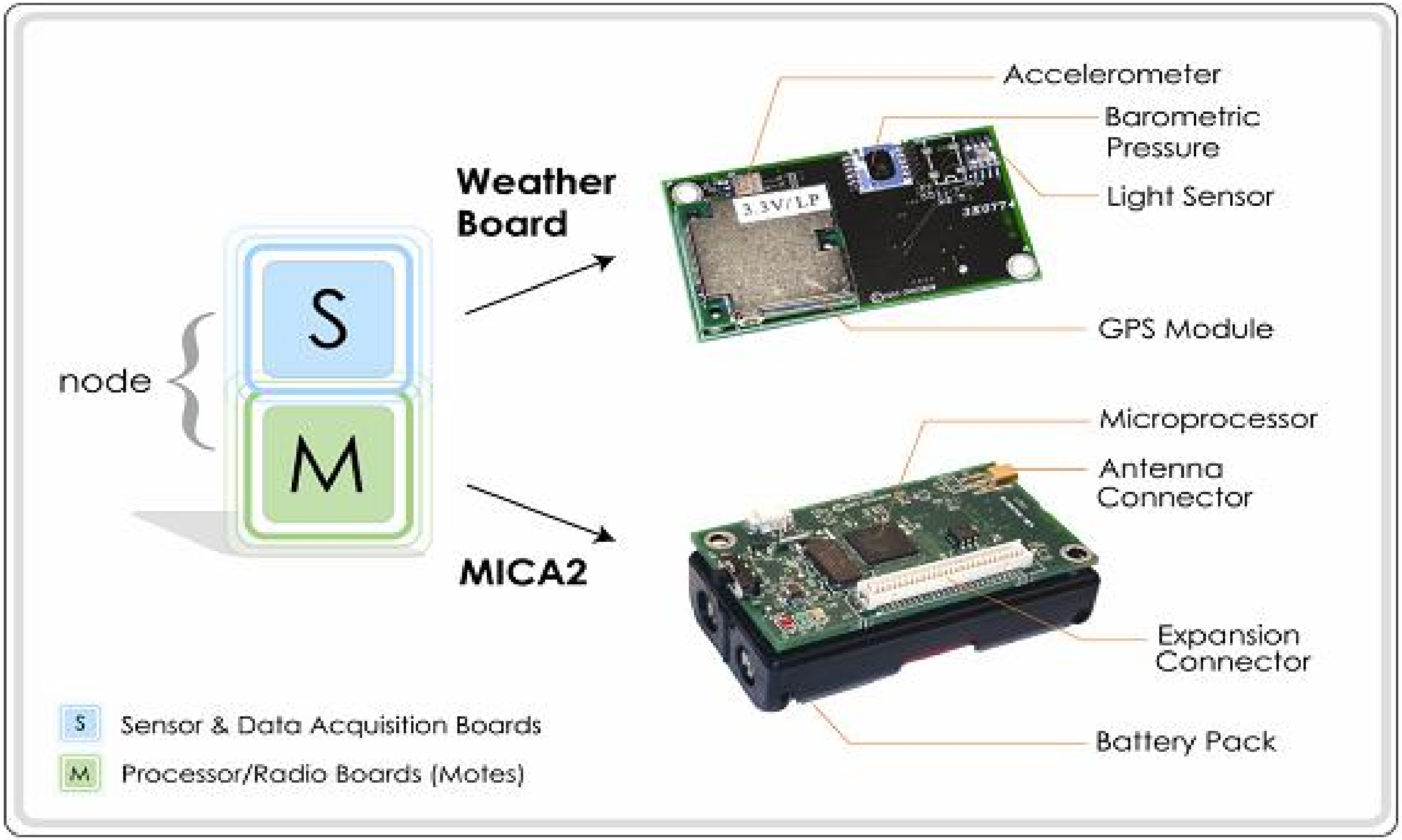
Outdoor multi-sensor system

Outdoor Temp.-Re Humidity sensor

Motion Detection Sensor (MSP410)

Industrial/outdoor housing for sensors and Stargate gateway

Basic Anatomy of a Sensor Node



What are motes?

Motes mainly consist of mainly three parts:-

1) a low cost and power microcontroller
2) one or more sensors
3) transceiver

Mica 2 Motes

- These motes sold by Crossbow were originally developed at the University of California Berkeley.

- The MICA2 motes are based on the ATmega128L AVR microprocessor. The motes run using TinyOS as the operating system.

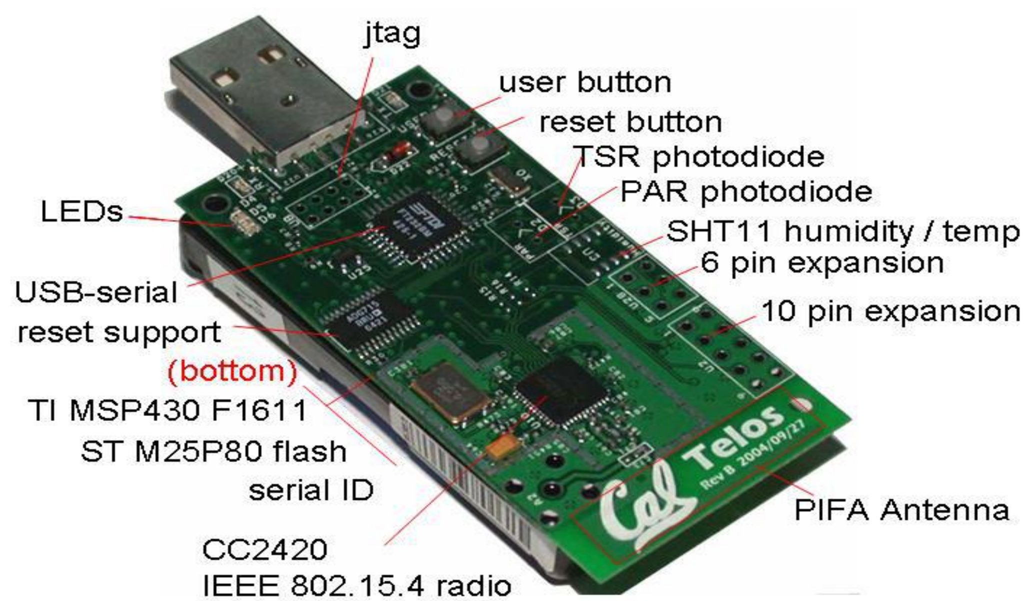
- Mica2 mote is one of the most popular and commercially available sensors which are marketed by CrossBow technologies (now MEMSIC).

MICA 2 MOTE

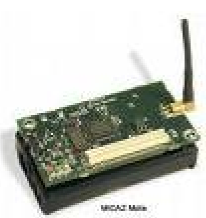
Ref:http://www.xbow.com/Products/Product_pdf_files/Wireless_pdf/MICA2_Datasheet.pdf

TelosB Motes

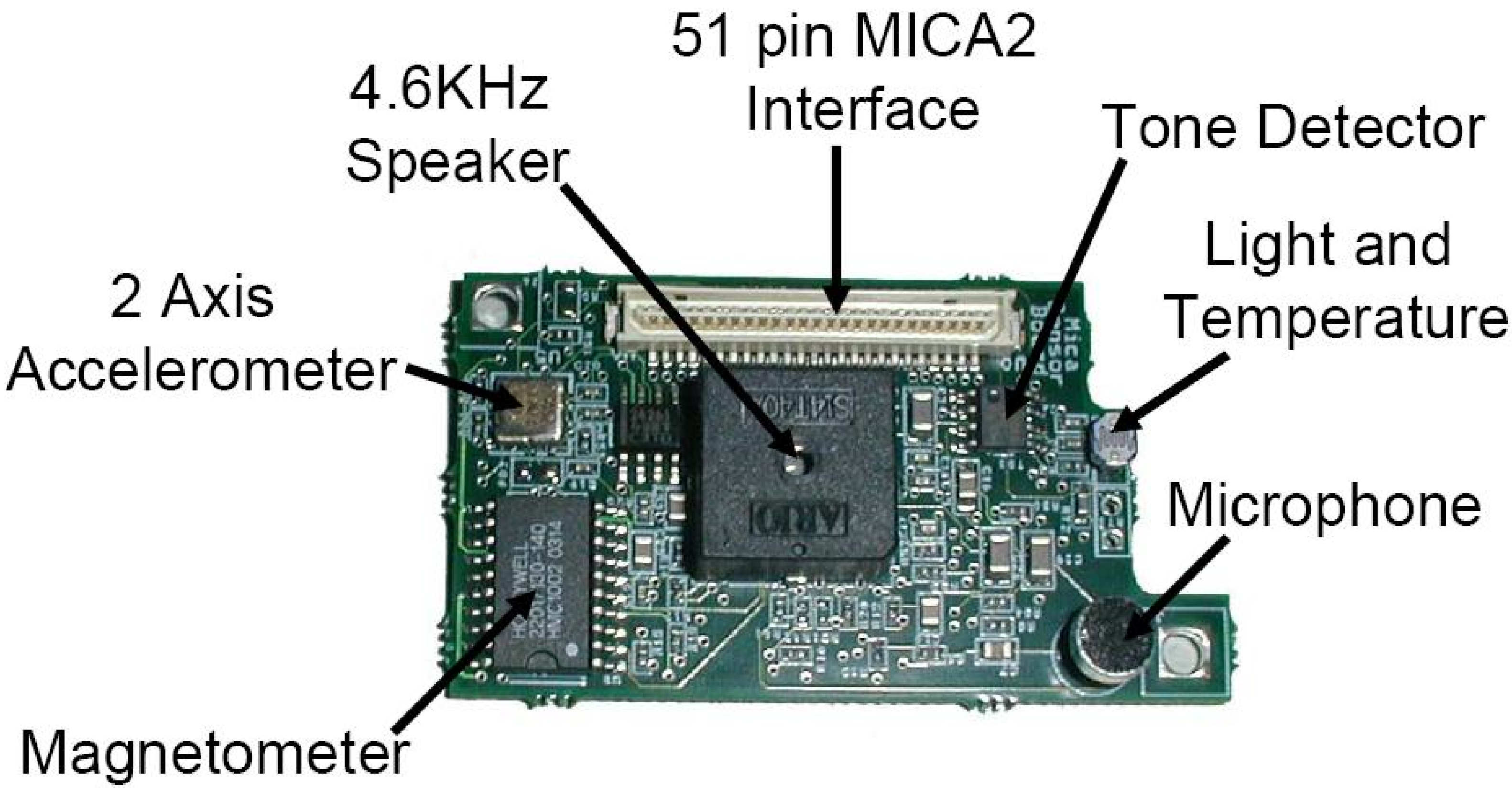
- Telosb motes have USB programming capability
- An IEEE 802.15.4 compliant, high data rate radio with integrated antenna, a low-power MCU
- There are also equipped with extended memory and an optional sensor suite



Ref:http://www.eecs.berkeley.edu/~culler/eecs194/labs/lab1/telosb.JPG



One Example Sensor Board - MTS310

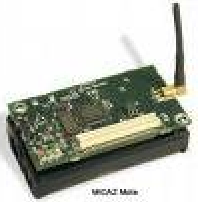


One More Sensor Board - MTS400/420

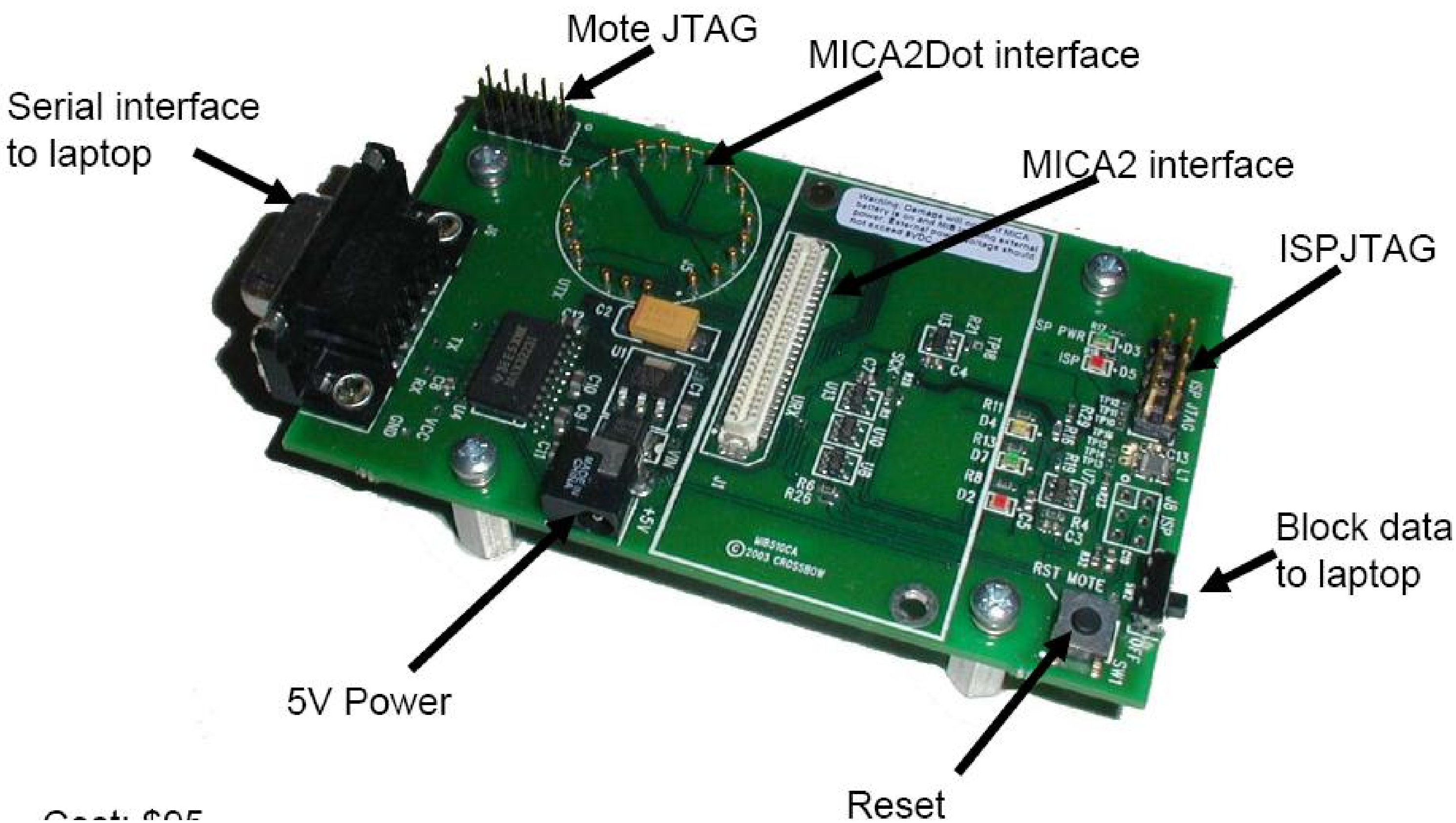
- Besides the functions of MTS 300, it mainly adds GPS functionality

- Further Reading
  - http://firebug.sourceforge.net/gps_tests.htm

Hardware Setup Overview

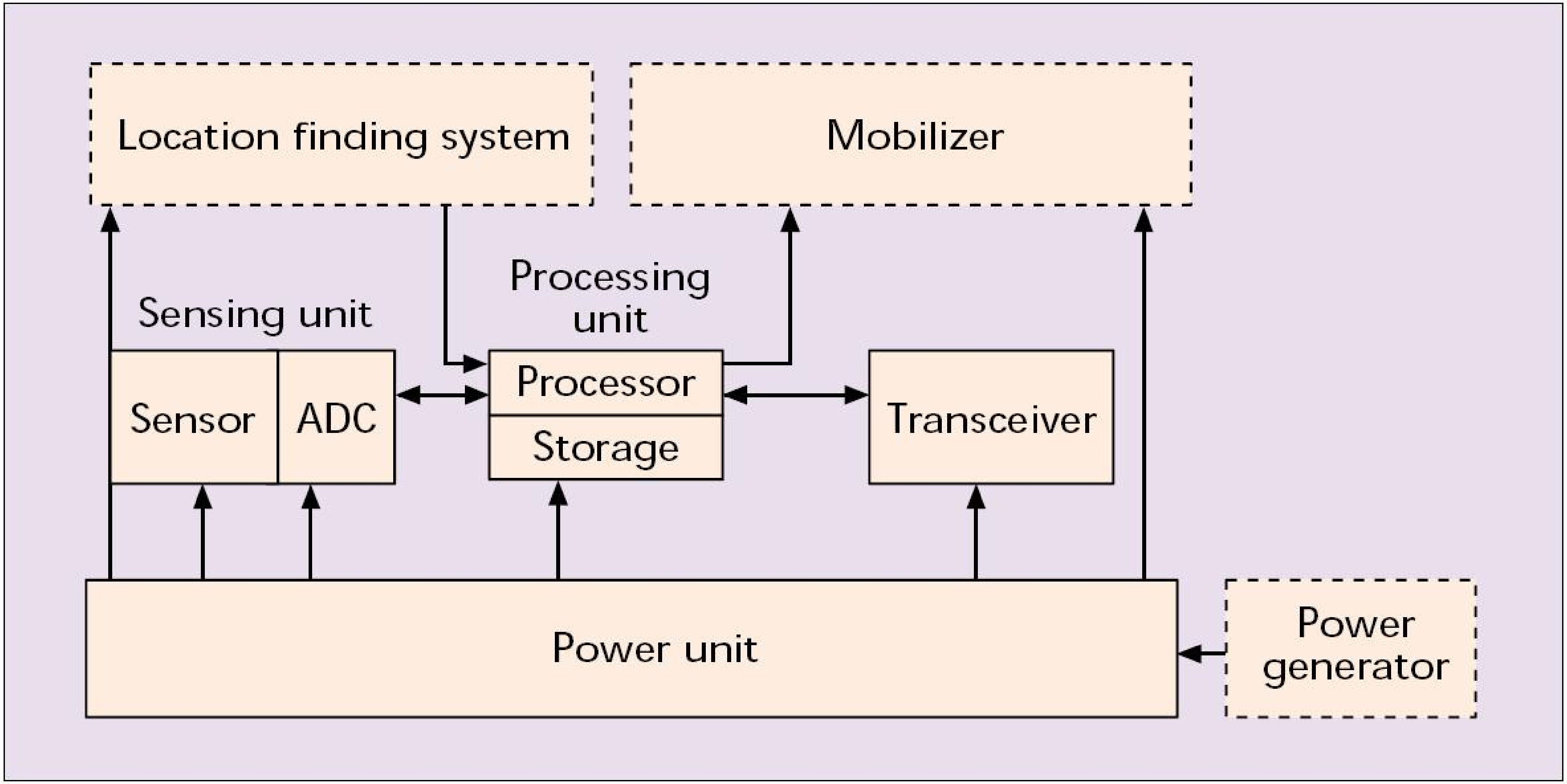


Programming Board (MIB510)



Programming Board (MIB520)

Node Architecture

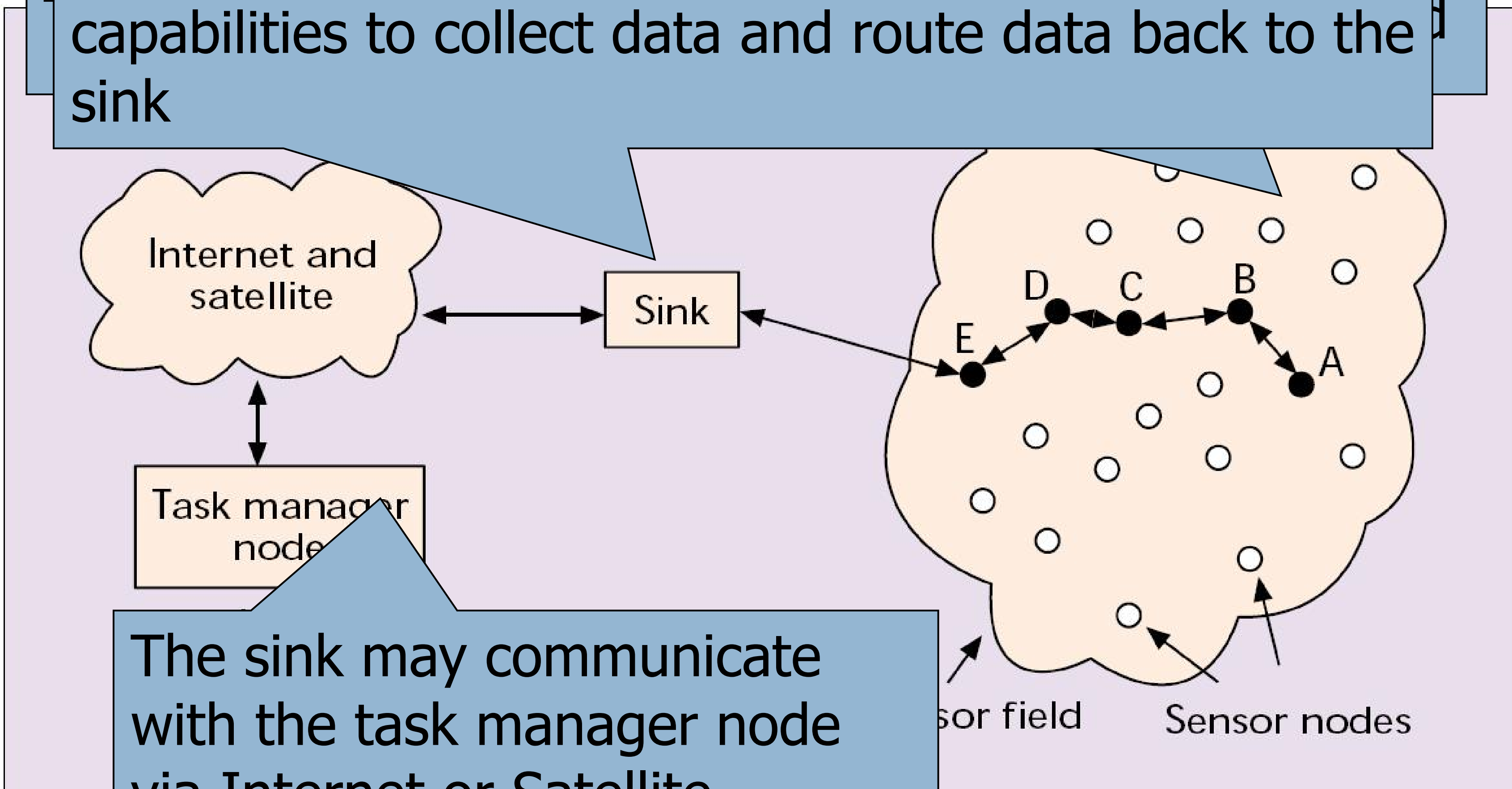


Introduction

- WSN is ad-hoc collection of sensor nodes deployed in a random fashion
- The position of sensor nodes need not be engineered
- Nodes possess self-organizing capabilities
- Cooperative functioning
- Limited processing capabilities

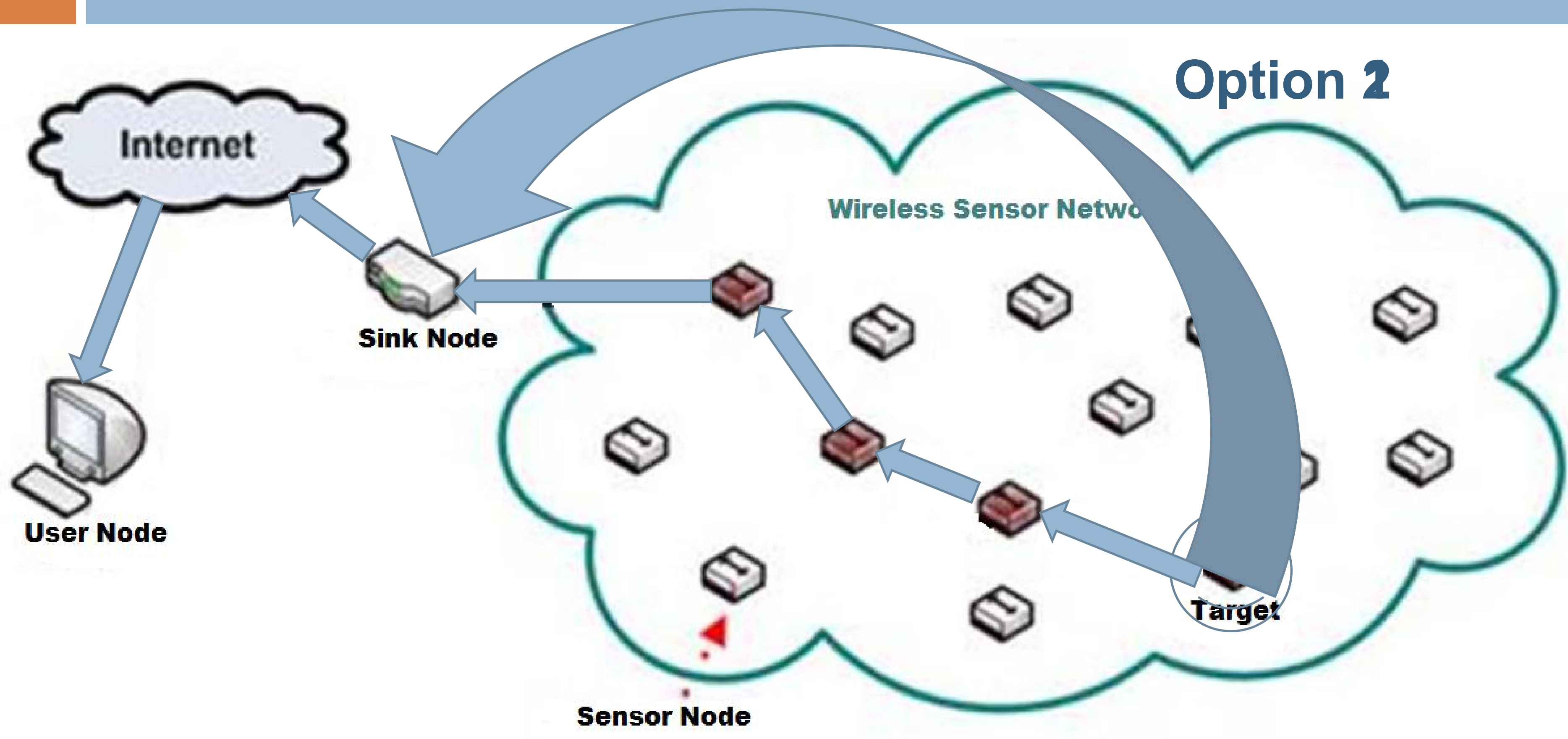
Communication Architecture

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.

Communication Paradigms



WSN vs MANET

- The *number* of sensor nodes in a sensor network is much more than the nodes in an ad hoc network
- Sensor nodes are *densely deployed*
- Sensor nodes are prone to *failures*
- The topology of a sensor network may change very frequently
- Sensor nodes mainly use *broadcast* communication paradigm whereas most ad hoc networks are based on *point-to-point* communications
- Sensor nodes are limited in *power, computational capacities,* and *memory*
- Sensor nodes may *not have global ID* because of the large amount of overhead and large number of sensors

Characteristics

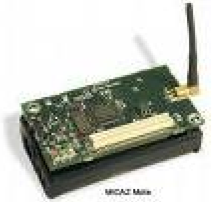
- Power consumption constrains for nodes using batteries or energy harvesting
- Ability to cope with node failures
- Mobility of nodes
- Dynamic network topology
- Communication failures
- Heterogeneity of nodes
- Scalability to large scale of deployment
- Ability to withstand harsh environmental conditions
- Ease of use
- Unattended operation
- Power consumption

Introduction – Constraints

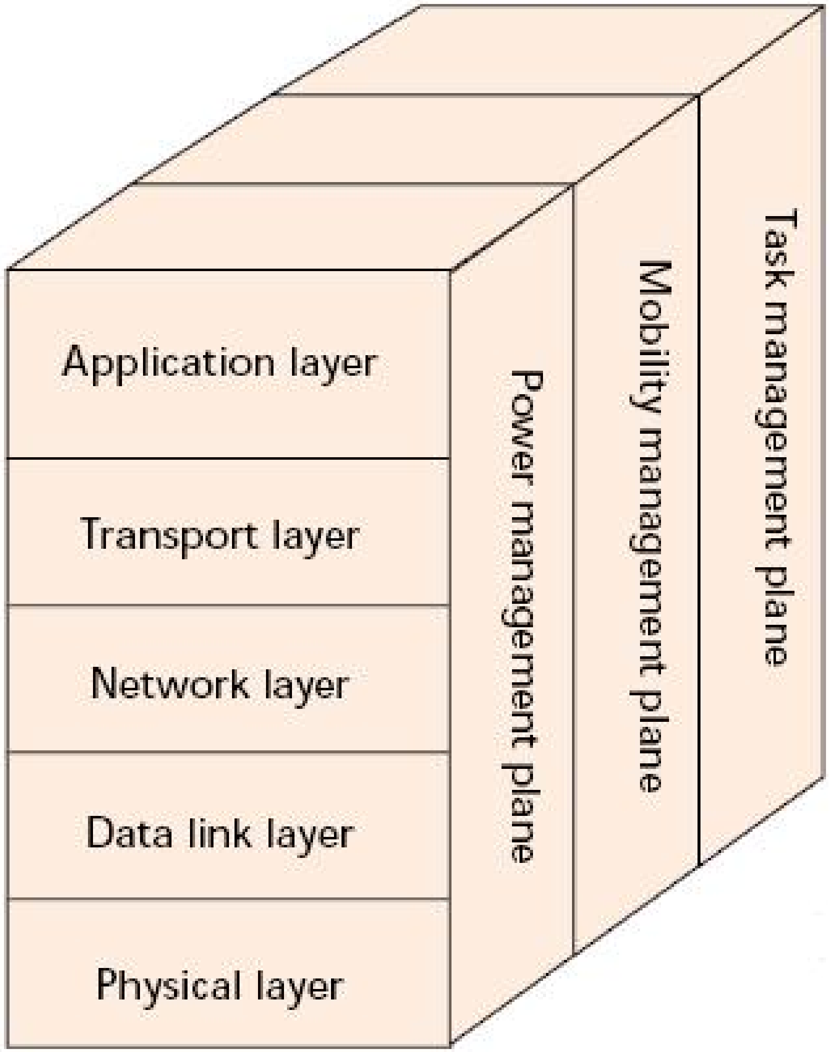
- Limitations
  - Energy Constraints
  - Bandwidth
  - Processing Capabilities
- All layers must be energy aware
- Ultimate goal is to maximize the lifetime of the network

Introduction

- The main task of a sensor node in a sensor field is to detect events, perform quick local data processing, and then transmit the data
- Power consumption can hence be divided into three domains: *sensing, communication, and data processing*
- It can be easily assumed that data transmission is the dominating factor in power consumption compared to other processes



Protocol Stack



The Management Planes

- Power management plane manages how a sensor node manages its power. Ex. Turn off the transceiver or when a node is low in power it broadcasts a message to its neighbor saying it can not participate in routing
- Mobility Management plane detects mobility and triggers actions needed to handle mobility
- Task Management plane balances and schedules sensing tasks

The Physical Layer

- The physical layer is responsible for frequency selection, carrier frequency generation, signal detection, modulation and data encryption. Thus far, the 915 MHz ISM band has been widely suggested for sensor networks.

The Physical Layer

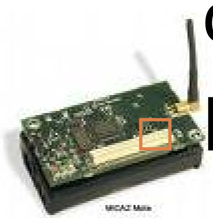
- The choice of a good modulation scheme is critical for reliable communication in a sensor network.
- Binary and M-ary modulation
- A low-power direct sequence spread-spectrum modem architecture
- Ultra wideband (UWB) or impulse radio (IR)
- Low transmission power and simple transceiver circuitry make UWB an attractive candidate for sensor networks.

The Physical Layer – Open issues

- Simple low power modulation scheme
- Strategies to overcome signal propagation effects
- Hardware design - Tiny, low-power, low-cost transceiver, sensing, and processing units need to be designed

Data Link Layer

- The data link layer is responsible for the multiplexing of data streams, data frame detection, medium access and error control
- Error Control - Two important modes of error control
  - Forward Error Correction (FEC)
  - Automatic Repeat Request (ARQ)
- ARQ in multihop sensor network environments is limited by the additional retransmission energy cost and overhead.
- Decoding complexity is greater in FEC



Data Link Layer

- Link reliability important for some applications
- The BER is *inversely proportional to* the received signal-to-noise ratio and the transmitter power level
- Reliable data communication can be provided either by increasing the output transmit power *or the use of suitable FEC*

Data Link Layer

- Since power is always an issue in WSN, FEC is the available option
- Take into account the *additional processing power that goes into encoding and decoding*
- Simple error control codes with low-complexity encoding and decoding might present the best solutions for sensor networks

MAC Layer

- MAC layer in other wireless networks
  - In **Cellular network** a mobile node is only a single hop away from the nearest base station. The primary goal of the MAC protocol in such systems is the provision of high quality of service (QoS) and bandwidth efficiency. Power consumption is considered secondary. Medium access is invariably inclined toward a dedicated resource assignment strategy
  - ***Bluetooth and the mobile ad hoc network*** **(MANET)** are probably the closest peers to sensor networks. The MAC protocol in a MANET has the primary goal of providing high QoS under mobile conditions. Although the nodes are portable battery-powered devices, which can be replaced/recharged by the user, and hence power consumption is only of secondary importance
  - **WSN** has much larger number of nodes. X’sion power and communication range is very small. Topology changes are more frequent. The primary importance is of power conservation.

MAC Layer

- The MAC protocol in a wireless multi-hop self-organizing sensor network must achieve two goals
  - The first is the creation of the network infrastructure
  - The second objective is to fairly and efficiently share communication resources between sensor nodes
- Proposed schemes in literature
  - Self-Organizing Medium Access Control for Sensor Networks (SMACS)
  - CSMA-Based Medium Access
  - Adaptive Transmission Rate Control (ARC)
  - Hybrid TDMA/FDMA-Based

MAC Layer

MAC protocol	Channel access mode	Sensor network specifics	Power conservation
SMACS	Fixed allocation of duplex time slots at fixed frequency	Exploitation of large available bandwidth compared to sensor data rate	Random wake up during setup and turning radio off while idle
CSMA-based	Contention-based random access	Application phase shift and pretransmit delay	Constant listening time for energy efficiency
Hybrid TDMA/FDMA	Centralized frequency and time division	Optimum number of channels calculated for minimum system energy	Hardware-based approach for system energy minimization

DLL and MAC – Open issues

- To prolong network lifetime, a sensor node must enter into periods of reduced activity when running low on battery power. The enumeration and transition management of states for these nodes is open to research

Network Layer

- Most important function of the network layer is to forward the messages generated from sensor nodes to sink nodes in an energy efficient manner
- Other network layer like the one in Internet uses global addressing for packet forwarding
- In WSN, global addressing may be inefficient because of small message size compared to address length
- WSN normally uses content-based addressing or geographical addressing

Network Layer - Addressing

- Content-based addressing
  - Also called as Data centric addressing
  - Node is located by data available with it
- Geographic Addressing
  - Special case of content-based addressing

- Ex: In directed diffusion, the sink node issues a interest message, specifying a set of attributes to describe desired data. The nodes that can produce sensor data matching the interest replies.

Network Layer - Addressing

<type,temperature,EQ>
<threshold-from-below,20,IS>
<x-coordinate,20,LE>
<x-coordinate,0,GE>
<y-coordinate,20,LE>
<y-coordinate,0,GE>
<interval,0.05,IS>
<duration,10,IS>
<class,interest,IS>

Interest Message

<type,temperature,IS>
<x-coordinate,10,IS>
<y-coordinate,10,IS>

Temperature Sensor

<type,temperature,IS>
<x-coordinate,10,IS>
<y-coordinate,10,IS>
<temperature,20.01,IS>
<class,data,IS>

Data Message

Network Layer – Addressing

- Geographic Addressing
  - The sink node queries some data from sensors located in some specific region
  - Example
    - Specify a single point
    - Specify a circle with center and radius
    - Specify rectangle with few points
    - Specify a polygon/polytope with list of points
  - Sensor can check whether its position lies within region of interest and accordingly react

Localization and Positioning

- Event detection may not be particularly useful if WSN cannot provide any information where the event has occurred
- Manually configuring the location of sensor node during deployment is generally not an option
- GPS may not be appropriate solution either as cost increases and it does not work indoors
- Few approaches are discussed in literature on how sensor node can learn its position
- Optimization still possible

Routing

- No global addressing
- Redundant data traffic
- Multiple-source single-destination network
- Careful resource management
  - Transmission power
  - On-board energy
  - Processing capacity
  - Storage

System Architecture & Designing

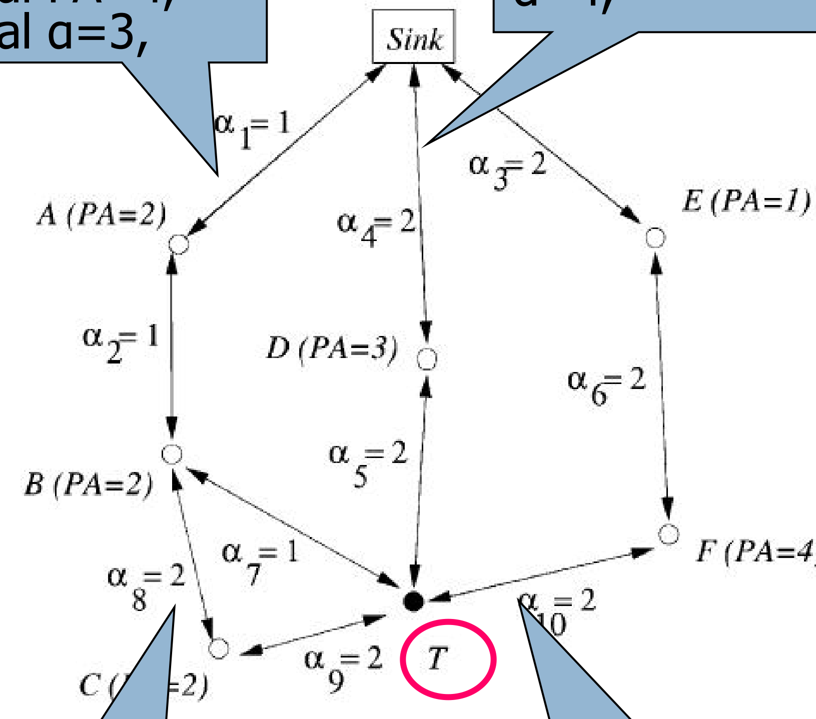
- Data Delivery Models
  - Continuous
  - Event-driven
  - Query-driven
  - Hybrid
- Node Capabilities
  - Homogenous
  - Heterogeneous
  - Nodes dedicated to a particular task (relaying, sensing, aggregation)

Power efficiency

- Node T is the *source node* that senses the phenomena
- PA is the *available power*
- α is the *energy required* to transmit a data packet through the related link

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,

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

Power efficiency

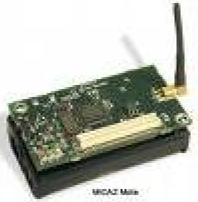
- Maximum available power (PA) route
  - Select Route 2 (x)
  - Select Route 4 (o)
- Minimum energy (ME) route
  - Select Route 1
- Minimum hop (MH) route
  - Select Route 3 (if α the same then MH=ME)
- Maximum minimum PA node route
  - Select Route 3
  - Preclude the risk of using up a sensor node with low PA.

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

Data-centric Routing

- *Requires attribute-based naming*
  - Querying an attribute of the phenomenon, rather than querying an individual node
  - Ex: “the areas where the temperature is over 70°F” is a more common query than “the temperature read by a certain node”



Data aggregation

- A technique used to solve the implosion and overlap problems in data-centric routing

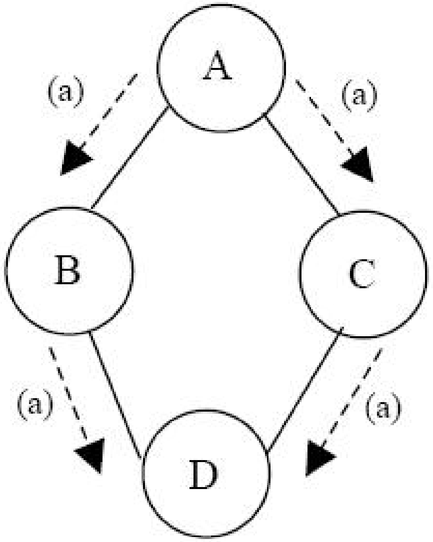


Fig. 1: The implosion problem. Node A starts by flooding its data to all of its neighbors. D gets two same copies of data eventually, which is not necessary.

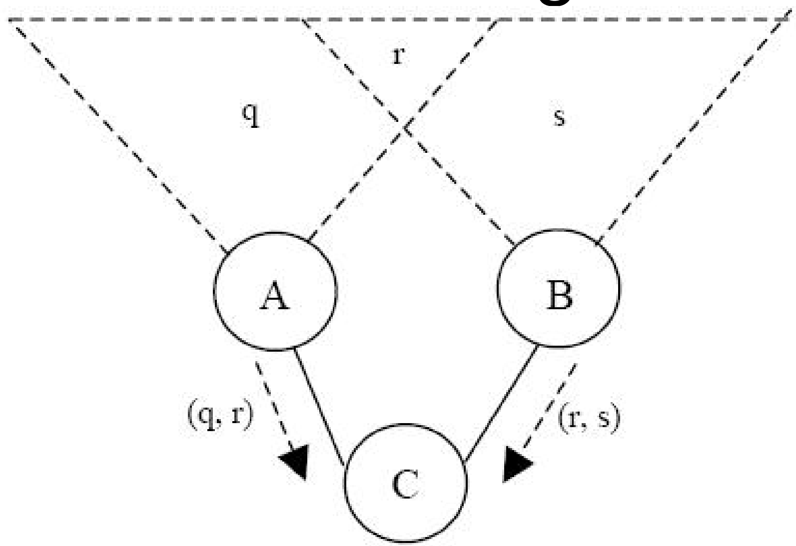
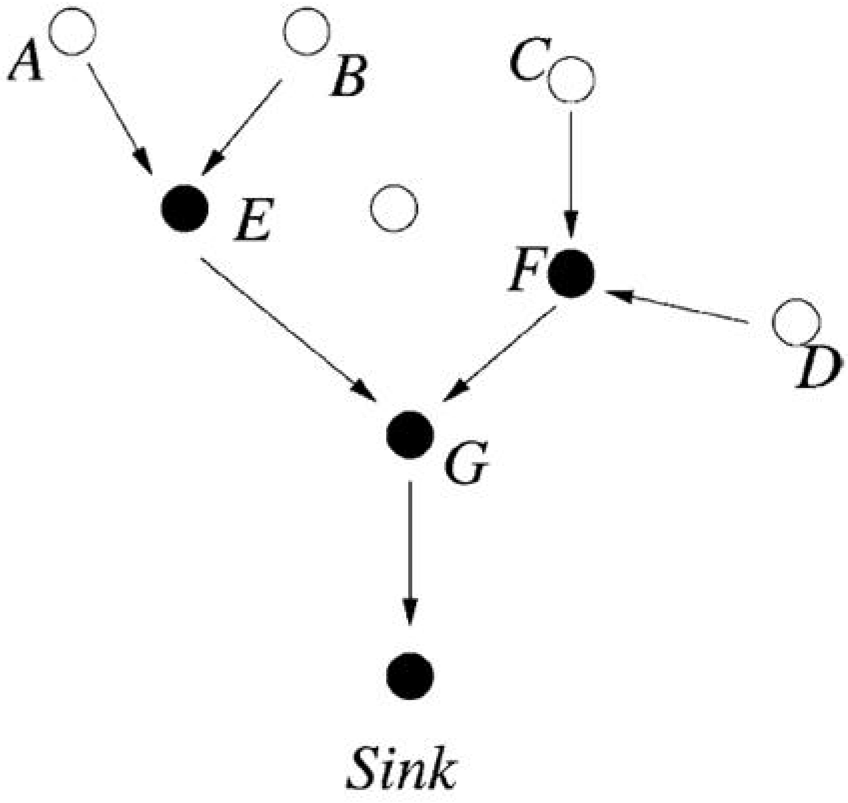


Fig. 2: The overlap problem. Two sensors cover an overlapping geographic region and C gets same copy of data form these sensors.

- Data coming from multiple sensor nodes with the same attribute of phenomenon are aggregated

Data aggregation – continue



- Sensor network is usually perceived as a reverse multicast tree.

Data aggregation - continue

- Data aggregation can be perceived as a set of automated methods of combining the data as it comes from many sensor nodes into a set of meaningful information
- With this respect, data aggregation can also be labelled as data fusion

Internetworking

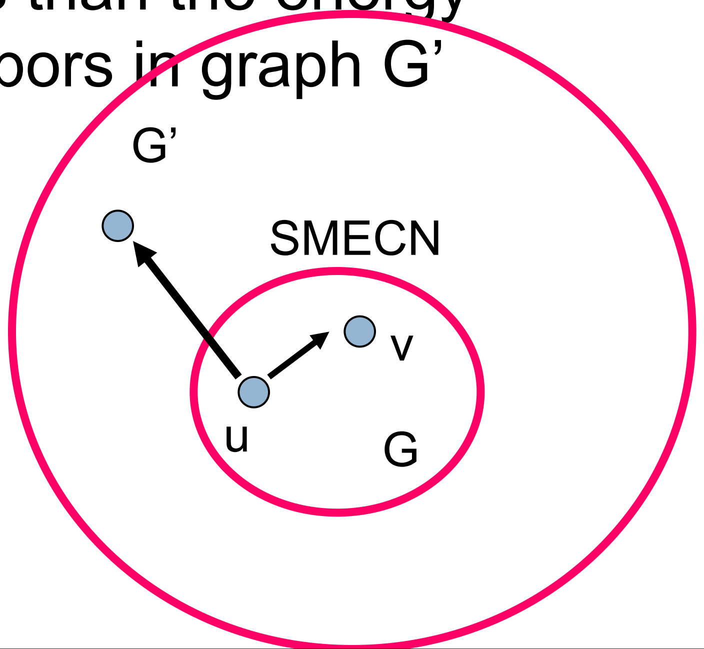
- One important function of the network layer is to provide internetworking with external networks such as other sensor networks, command and control systems and the Internet
- Sink nodes can be used as a gateway to other network
- Create a backbone by connecting sink nodes together and make it access other network via a gateway

Some schemes proposed for the sensor network

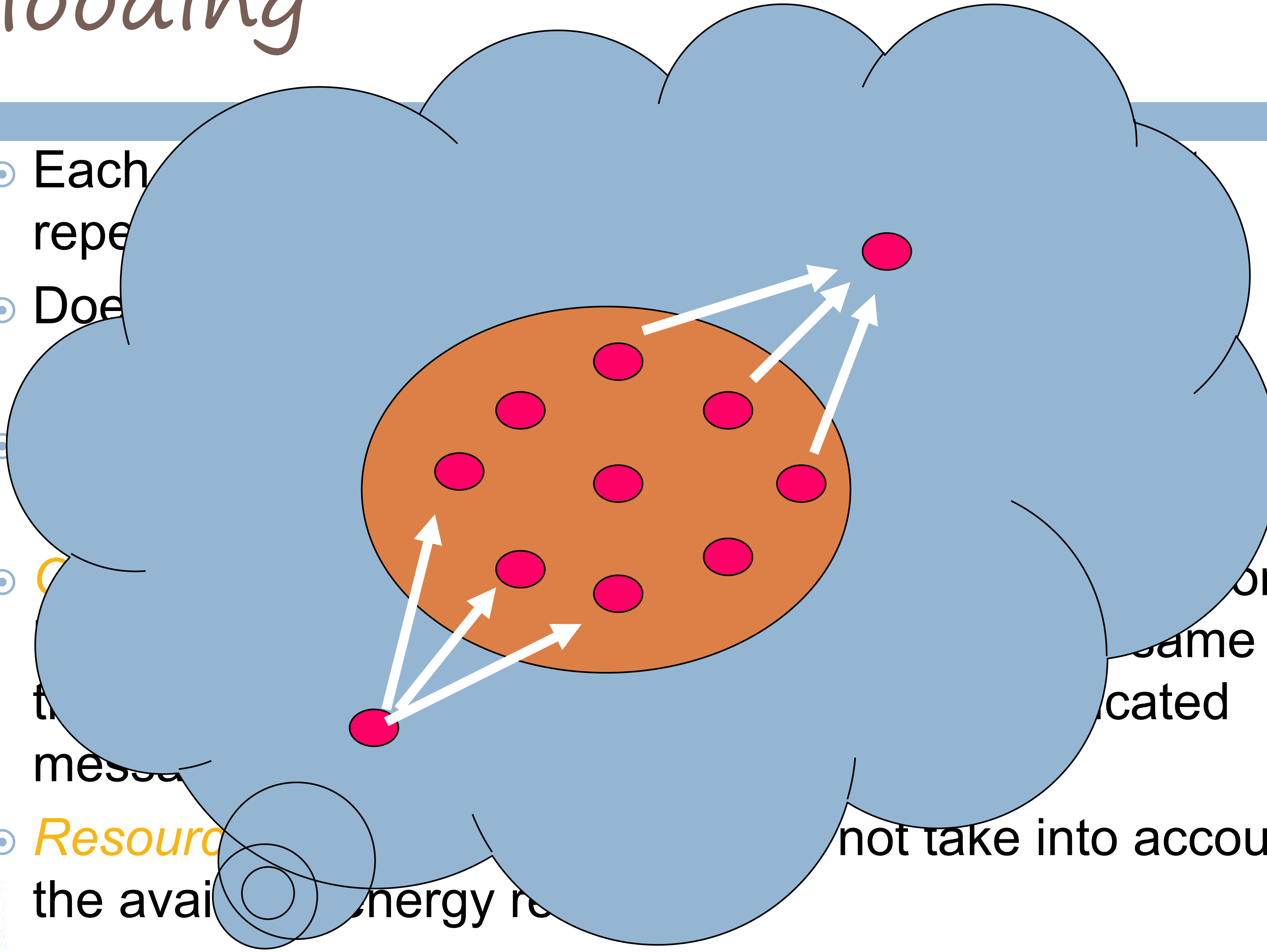
- Small minimum energy communication network (SMECN)
- Flooding
- Gossiping
- Sensor protocols for information via negotiation (SPIN)
- Sequential assignment routing (SAR)
- Low-energy adaptive clustering hierarchy (LEACH)

SMECN

- Small minimum energy communication network (SMECN)
  - Use small subgraph for 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’



Flooding

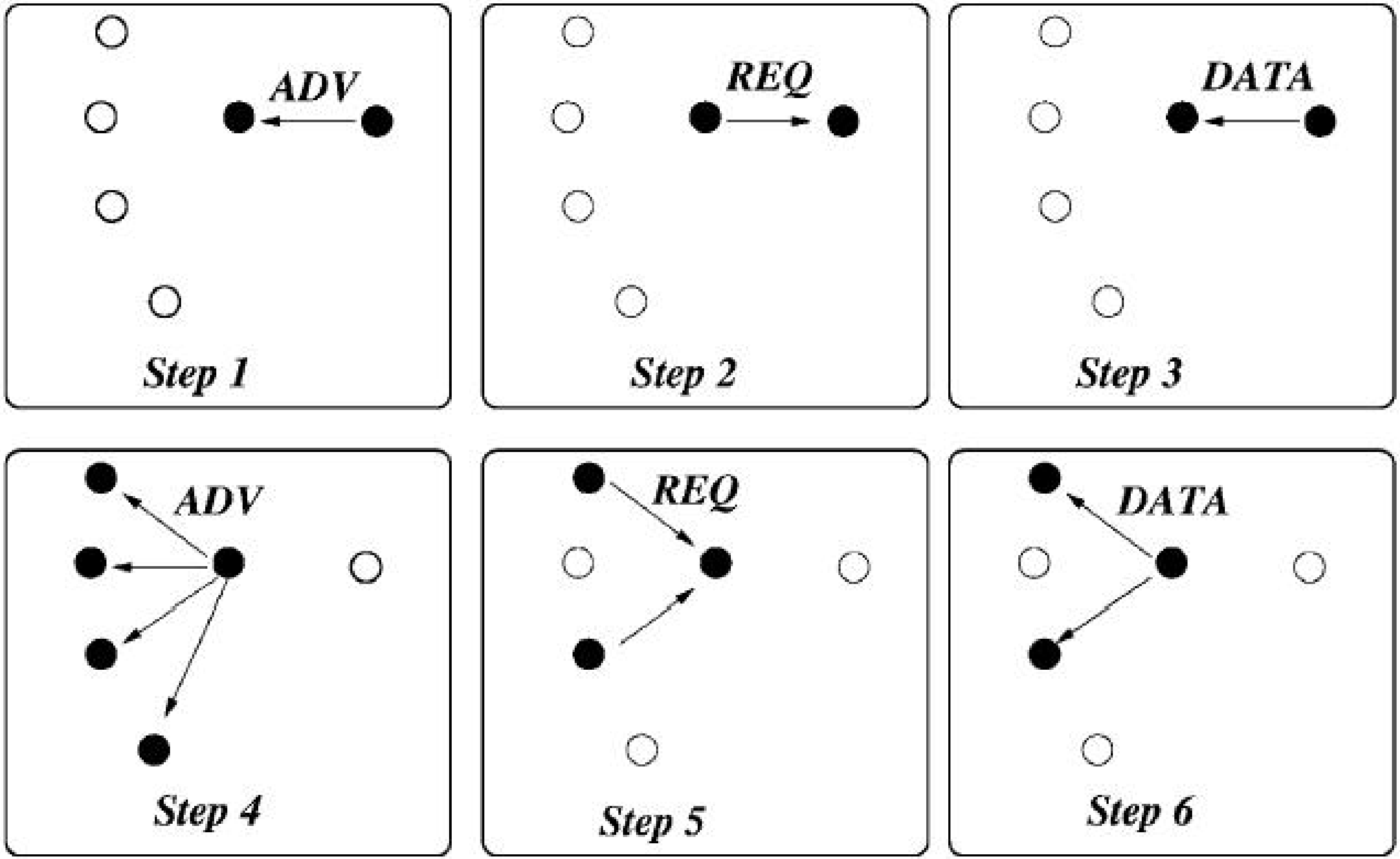


- Each ... repe...
- Doe...
- ...
- *C...* ...on, ... same th... ...icated mess...
- *Resourc...* ... not take into account the avai... energy r...

Gossiping

- A derivation of flooding
- Nodes send the incoming packets to a randomly selected neighbor
- Avoids the implosion problem
- It takes a long time to propagate the message to all sensor nodes

SPIN


ADV
Step 1
REQ
Step 2
DATA
Step 3
ADV
Step 4
REQ
Step 5
DATA
Step 6

SAR

- Sequenti
  - A set
    mana
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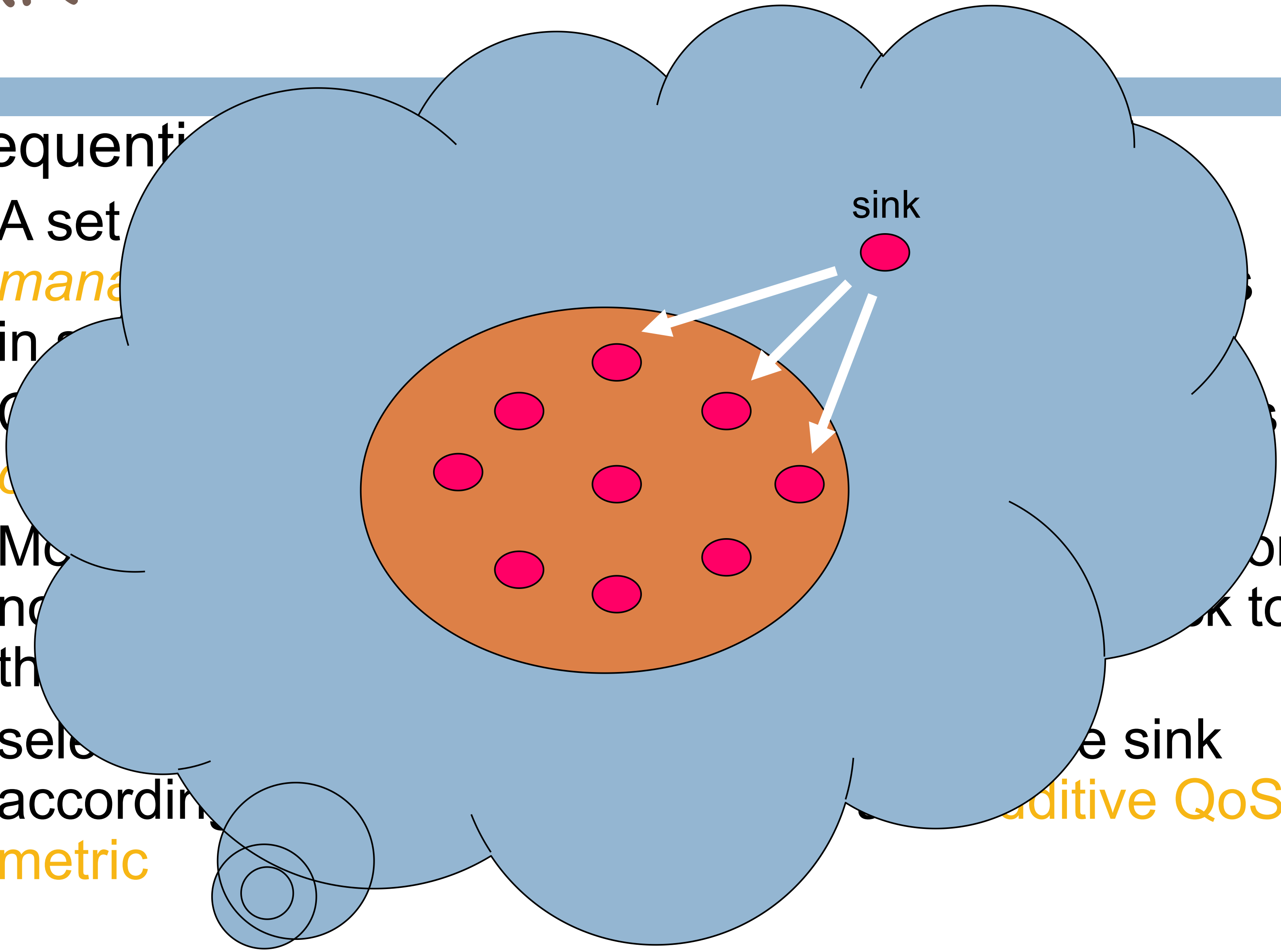
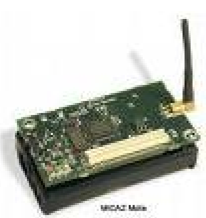




LEACH

- Low-energy adaptive clustering hierarchy (LEACH)
  - Randomly select sensor nodes as *cluster-heads*, so the *high energy dissipation* in communicating with the *base station* is spread to all sensor nodes in the sensor network.
  - Set-up phase
    - each sensor node chooses a random number between 0 and 1
    - If this random number is less than the threshold T(n), the sensor node is a cluster-head.

P,the desired percentage to become a cluster-head;

$$T(n) = \begin{cases} \dfrac{P}{1 - P[r \bmod (1/P)]} & \text{if } n \in G, \\ 0 & \text{otherwise,} \end{cases}$$

G , the set of nodes that have not being selected as a cluster-head in the last 1/P rounds.

r,the current round

LEACH

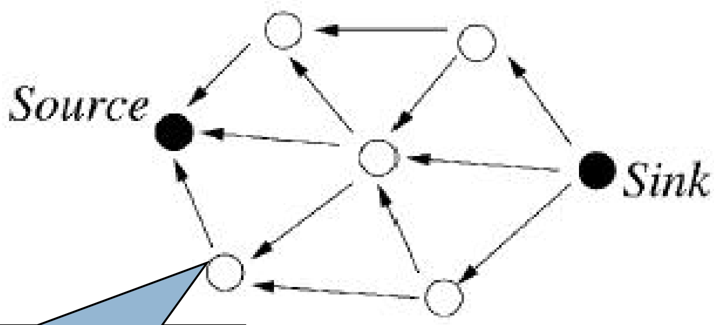
- Set-up phase (cont'd)
  - The cluster-heads advertise to all sensor nodes in the network
  - The sensor nodes inform the appropriate cluster-heads that they will be a member of the cluster. (base on signal strength)
  - Afterwards, the cluster-heads assign the time on which the sensor nodes can send data to the cluster-heads based on a TDMA approach.

LEACH

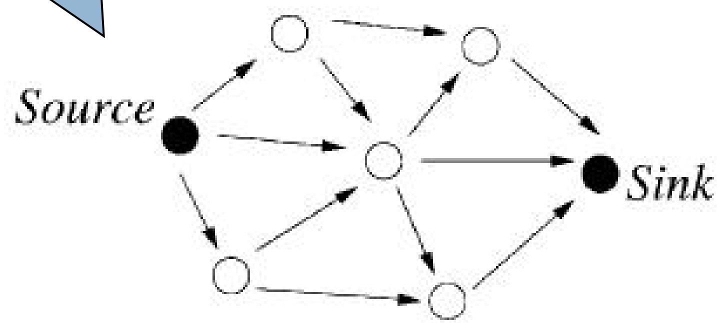
- steady phase (cont’d)
  - the *sensor nodes* can begin sensing and transmitting data to the *cluster-heads*.
  - The cluster-heads also aggregate data from the nodes in their cluster before sending these data to the *base station*.
- After a certain period of time spent on the steady phase, the network
  - goes into the set-up phase again and
  - enters into another round of selecting the cluster-heads.

Directed

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

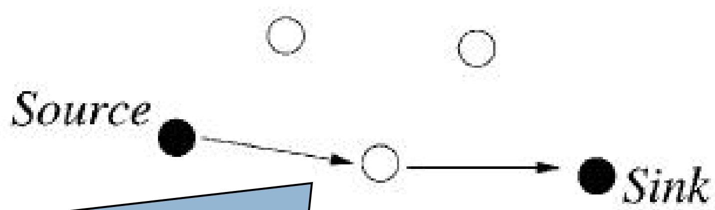


(a)



(b)

the sink sends out interest to sensors



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

(c)

Rumor Routing

- **Rumor Routing**
  - Variation of Directed Diffusion
  - Flood the events instead of the queries
  - Creation of an event ➔ generation of a long live packet travel through the network (agent)
  - Nodes save the event in a local table
  - When a node receives query ➔ checks its table and returns source – destination path

Rumor Routing

- Advantages
  - Can handle node failure
  - Significant energy savings
- Disadvantages
  - Works well **only** with small number of events
  - Overhead through adjusting parameters, like the time to live of the agent

Routing

Routing protocol	Data-centric	Hierarchical	Location-based	QoS	Network-flow	Data aggregation
SPIN	✓					✓
Directed Diffusion	✓					✓
Rumor Routing	✓					✓
Shah et al.	✓		✓			
GBR	✓					✓
CADR	✓					
COUGAR	✓					✓
ACQUIRE	✓					
Fe et al.					✓	
LEACH		✓				✓
TEEN&APTEEN	✓	✓				✓
PEGASIS		✓				✓
Younis et al.		✓	✓			
Subramanian et al.		✓				✓
MECN&SMECN			✓			
GAF		✓	✓			
GEAR			✓			
Chang et al.		✓			✓	
Kalpakis et al.			✓		✓	
Akkaya et al.		✓		✓		
SAR				✓		
SPEED			✓	✓		

Network layer

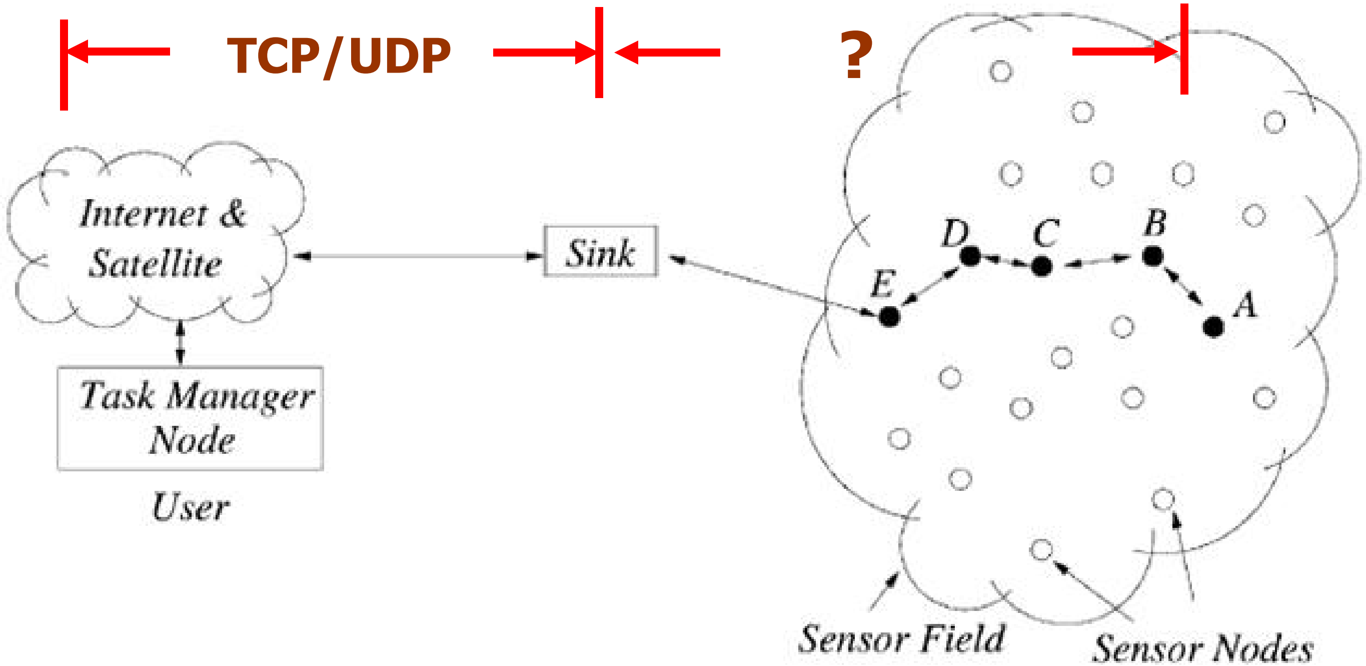
- Open research issues
  - Improved or new protocols to address higher topology changes and higher scalability

Transport layer

- The transport layer is needed when the system is planned to be *accessed through Internet* or other external networks.

Transport layer

- An approach such as *TCP splitting* may be needed to make sensor networks interact with other networks such as Internet.



Transport layer

- Open research issues
  - Hardware constraints such as limited power and memory. Each sensor node cannot store large amounts of data like a server in the internet
  - Acknowledgments are too costly
  - May be needed where UDP-type protocols are used in the sensor network and TCP/UDP protocols in the internet or satellite network.

Application layer

- Potential application layer protocols for sensor networks remains a largely unexplored region
- Some possible application layer protocols
  - Sensor Management Protocol (SMP)
  - Sensor Query and Data Dissemination Protocol (SQDDP)
  - Messanging protocols

Sensor Management Protocol (SMP)

- SMP is a management protocol that provides the software operations needed to perform the following administrative tasks:
  - Introducing the rules related to *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

Sensor Management Protocol (SMP)

- *moving* sensor nodes,
- *turning* sensor nodes *on* and *off*,
- querying the sensor *network configuration* and the *status of nodes*, and *re-configuring* the sensor network,
- *authentication*, *key distribution* and security in data communications.

Sensor Query and Data Dissemination Protocol (SQDDP)

- SQDDP provides user applications with interfaces to *issue queries*, *respond to queries* and *collect incoming replies*
- attribute-based or location-based naming
  - the locations of the nodes that sense temperature higher than 70 ^{0}C
  - Temperatures read by the nodes in region A
- Sensor query and tasking language (SQTL) is proposed

Messanging Protocols

- Many messanging protocols are suggested for sensor and IoT network
- These protocols are light weight in nature and supports transmission of smaller messages
- Protocols like Message Queueing Telemetry Transport (MQTT), Advanced Message Queueing Protocol (AMQP), Extensible Messaging and Presence Protocol (XMPP) etc

WSN Operating Systems

- TinyOS
- Contiki
- MANTIS
- BTnut
- SOS
- Nano-RK
- …….

WSN Simulators

- TOSSIM
- Cooja
- NS-2
- GloMoSim
- OPNET
- Castalia
- SensorSim
- J-Sim
- OMNeT++
- SENS

Conclusion

- WSNs possible today due to technological advancement in various domains
- Envisioned to become an essential part of our lives
- Design constraints need to be satisfied for realization of sensor networks
- Tremendous research efforts being made in different layers of WSNs protocol stack

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Thank You

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