ROUTING PROTOCOL IN WIRELESS SENSOR AND ACTUATOR NETWORK

CONTENTS

Challenges in WSANs

- Energy Limitation ,small battery, no autonomous recharching – needs effective routing to conserve battery
- Cannot use standard IP-based protocols – not possible to build global addressing scheme
- Sensor nodes are mostly stationary – needs effective routing protocols
- Limited storage and processing – needs data filtering
- Redundancy of sensor data – needs data aggregation and effective routing protocols to handle energy and bandwidth

Challenges in WSANs

- Almost all flow sensed data from multiple regions to a particular sink
- Constrained by transmission power, processing capacity, storage – need careful resource management
- Application - In case of monitoring applications, static routes can be reused to maintain efficient delivery of the observations throughout the lifetime of the network. On the other hand, in event-based applications, since the nodes are usually in sleep mode

Network Dynamics

- Static Events – More of static deployment
  - Reactive mode – simply generating traffic when reporting
  - Forest monitoring (early detection)
- Dynamic Events – Mobility
  - Periodic mode – generate significant traffic to be routed
  - Target detection
  - Tracking (Zebranet)

Node deployment

- Deterministic
  - Sensors are manually placed
  - Data is routed through pre-determined paths
- Self-organizing
  - Sensors are scattered randomly – ad hoc infrastructure
  - Position of sink or cluster head is crucial (energy efficiency and performance)

Data Delivery Models

- Continuous – each sensor sends data periodically
- Event-Driven – Transmission of data is triggered when an event occurs
- Query-Driven – Transmission of data when query ss generated by the sink
- Hybrid – Combination of continuous, event-driven and query-driven

- **Routing protocol is highly influenced by the data delivery models** for minimization of energy consumption and route stability
- Example – for habitat monitoring where data is continuously transmitted to the sink, hierarchical routing is preferred (Why?)

Node capabilities

- Homogenous – equal capacity in terms of computation, communication and power
- Heterogenous – in some applications cluster head is more powerful
  - Relaying
  - Sensing
  - Aggregation
  - Multiple sensor modality like temperature, pressure, humidity, motion – reading can be at different rates, diverse quality and multiple data delivery models
  - **Routing protocol – data routing more challenging**

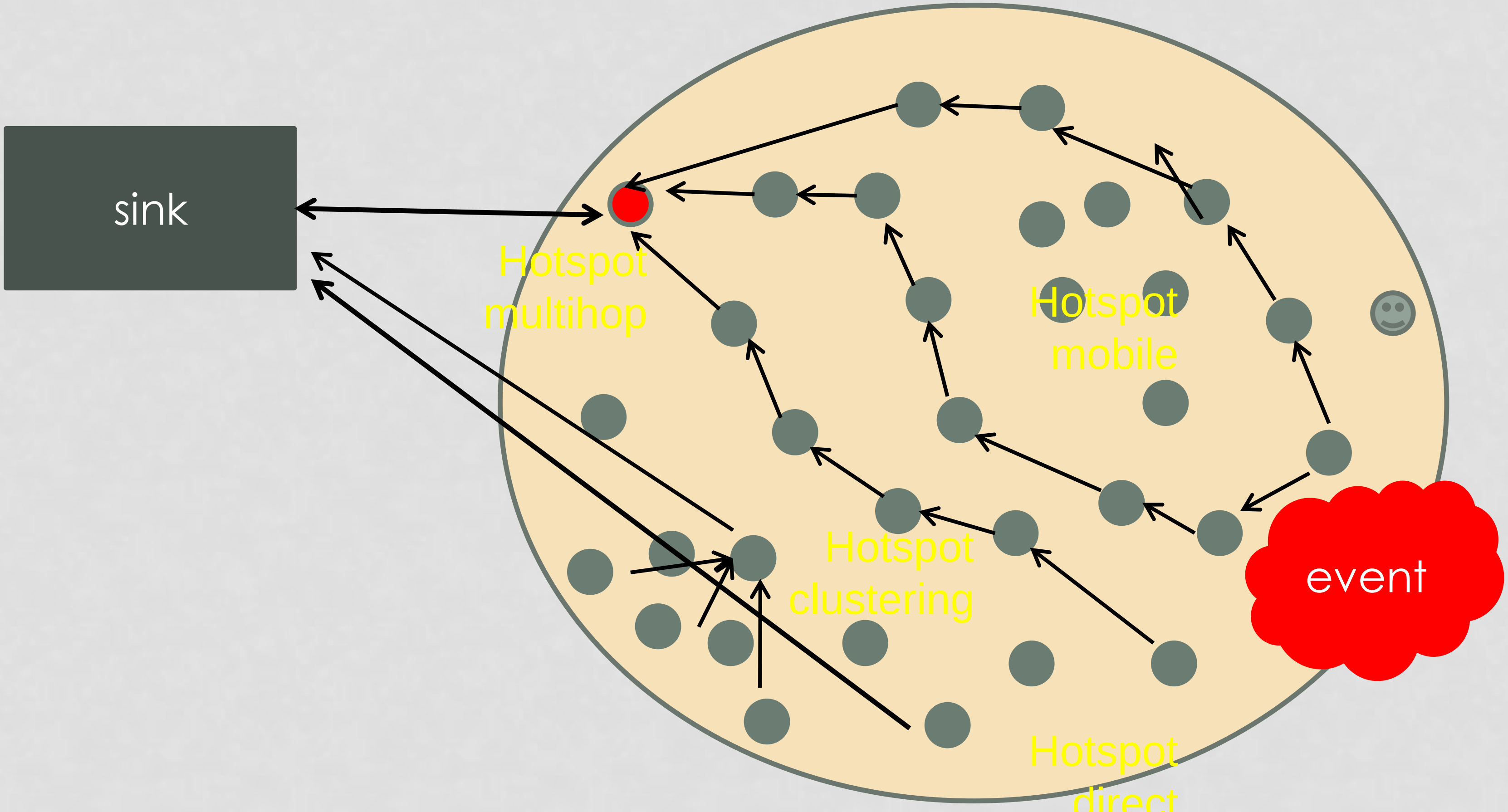
Data aggregation

- Combination of data from multiple sources
  - Suppression, Min, max, average
  - Signal processing – data fusion (beamforming)
- Computation is less energy consuming than communication – substantial energy saving by reduction of data
- Some applications use more powerful and specialized nodes

Energy Limitation

- Due to the resource limitations such as battery power, sensor networks observe frequent failure – node and link failure.
- Useful metric in routing protocol performance is network survivability
- Widespread adoption these networks should be able to heal from any abnormal behavior such as node failure, network disruption and denial of service
- Therefore self-healing is required to heal from any of these behaviors

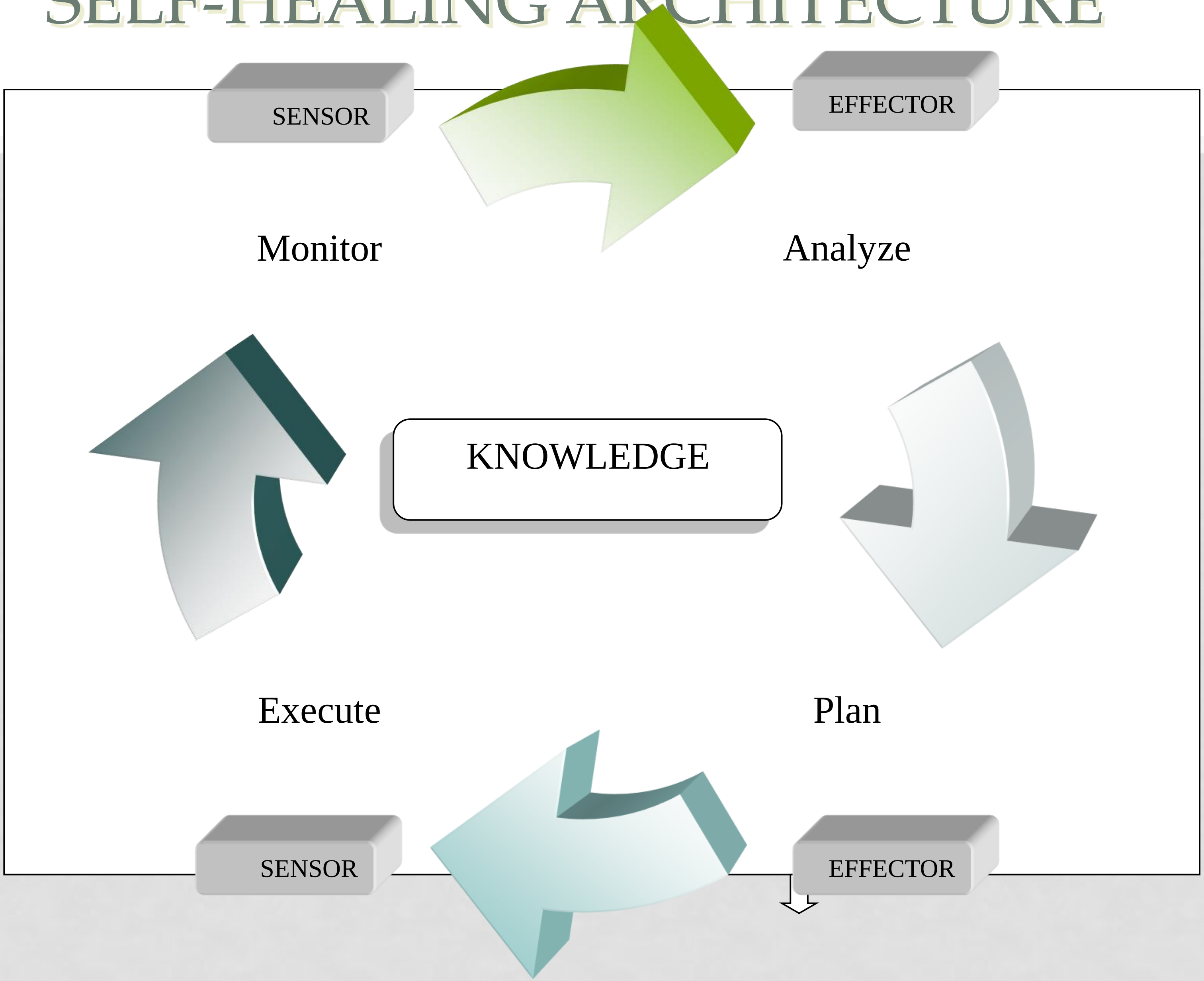
WSN situation



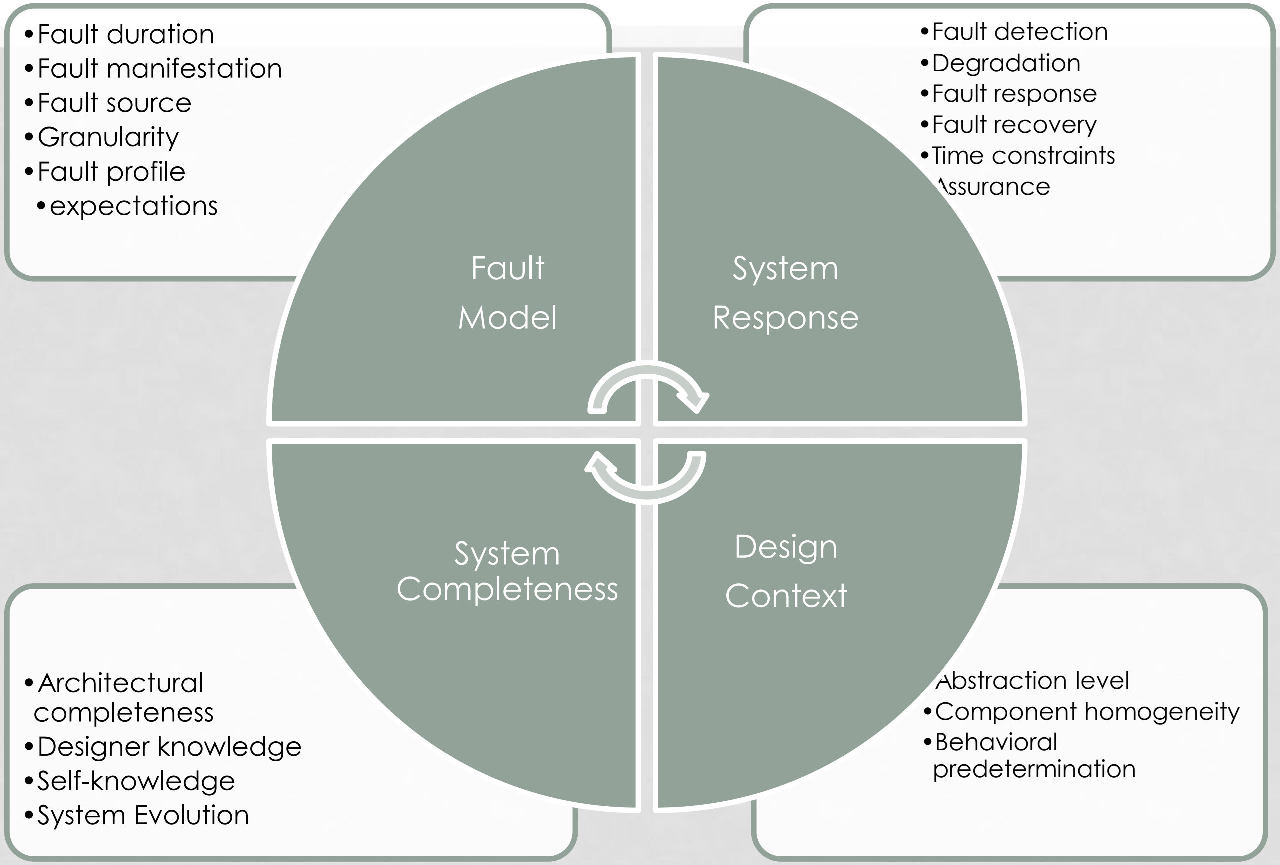
Energy consideration

	Direct	Multihop	Clustering	Mobile without cluster
Route	S->BS	S>S>S>BS	S->CH ->BS	S->MA ->BS
Energy	4th power	2nd power	2nd/4th power	2nd power
Problems	Nodes further from BS deplete energy – routing hole outside	Nodes near BS deplete energy- routing hole near BS	CH deplete energy quickly	All nodes communicate with MA – all nodes deplete energy

SELF-HEALING ARCHITECTURE

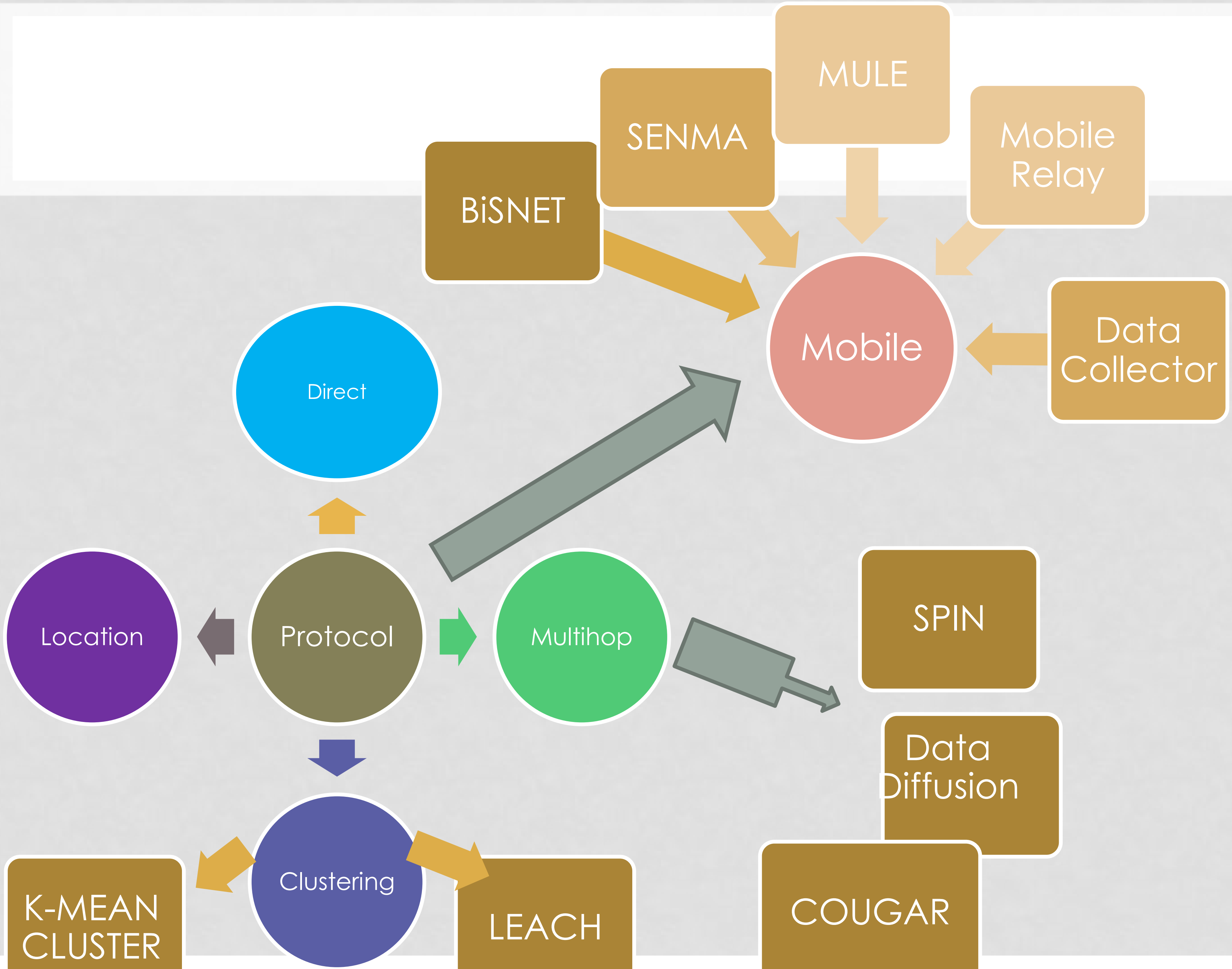


Self-Healing Architecture



SASHA

- Self-healing hybrid sensor network using natural immune system concepts
- Automatic fault recognition and response
- Adaptive architecture to learn and evolve with unknown faults – self-healing
- Looking at faulty sensor readings - which need self-healing
- Co-ordination between monitoring nodes


MULE
SENMA
Mobile Relay
BiSNET
Mobile
Data Collector
Direct
Location
Protocol
Multihop
SPIN
Data Diffusion
Clustering
K-MEAN CLUSTER
LEACH
COUGAR

Radio energy model in wsn (Heizelman, 2000)

- The energy consumed in transmitting one message of size k bits over a transmission distance d, is given by
- Hence, the total energy consumption when sensor receives a message and forwards it over a distance d is given by $E_{tot}(d) = k\left(2E_{elec} + \varepsilon d^{\lambda}\right)$

$$E_{Tx}(k,d) = k\left(E_{elec} + \varepsilon_{Amp} d^{\lambda}\right) = E_{elec}k + \varepsilon_{Amp} k d^{\lambda}$$

Where k = length of the message

d = transmission distance between transmitter and receiver

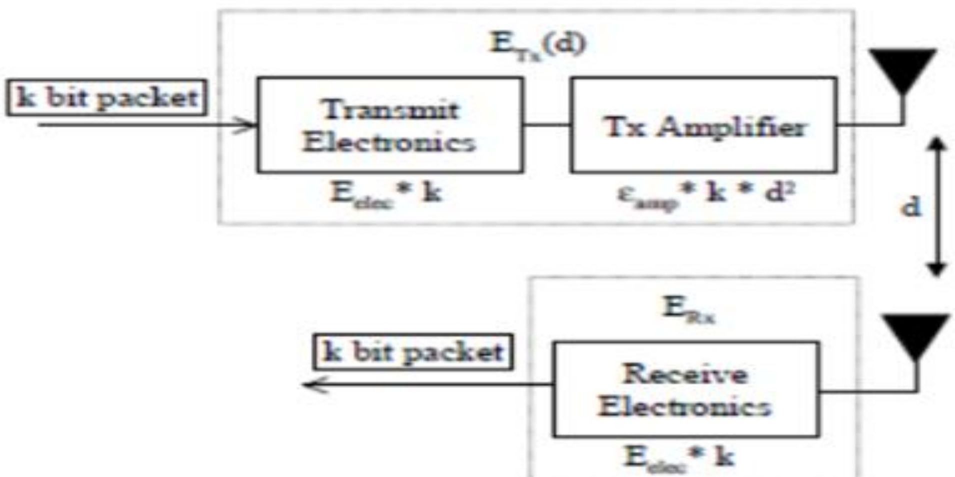
E_{elec} = electronic energy

$_{Amp}$= transmitter amplifier

λ= path-loss component ($2 \leq \lambda \leq 4$)

Also, the energy consumed in the message reception is given by

$$E_{rx} = E_{elec} k$$



Energy Model

- The simplified energy consumption model in BIMAS is defined as given below :
-
- ***$Energy_{trans}$ = $Energy_{elec}$ X a + $Energy_{amp}$ X d X a***
- ***$Energy_{recv}$ = $Energy_{elec}$ X a***
- ***$Energy_{sense}$ = $Energy_{cpu}$ X a***
-
- where a is the data rate or length of data packets, d is the transmission distance (a) and some typical values for the parameters are (Heizelman, 2000) :
-
- ***$Energy_{cpu}$*** *= 60 $X10^{-9}$ J/bit,*
- ***$Energy_{elec}$*** *= 45 $X10^{-9}$ J/bit,*
- ***$Energy_{amp}$*** *= 10 X 10^{-12} J/bit/m^2 (when n = 2),*
- *or,* ***$Energy_{amp}$*** *= 0:001 X 10^{-12} J/bit/m^4 (when n = 4),*
- ***$Energy_{elec}$*** *= 135 X 10^{-9} J/bit*

- This energy model is extracted from (Liu and Lin, 2003) (Priscilla and Callaway, 2002)

Assuming that,

Energyelec= ₠ , Energyamp= ₳, Energycpu = ₵

Total Energy Consumption = Energytrans + Energyrecv + Energysense

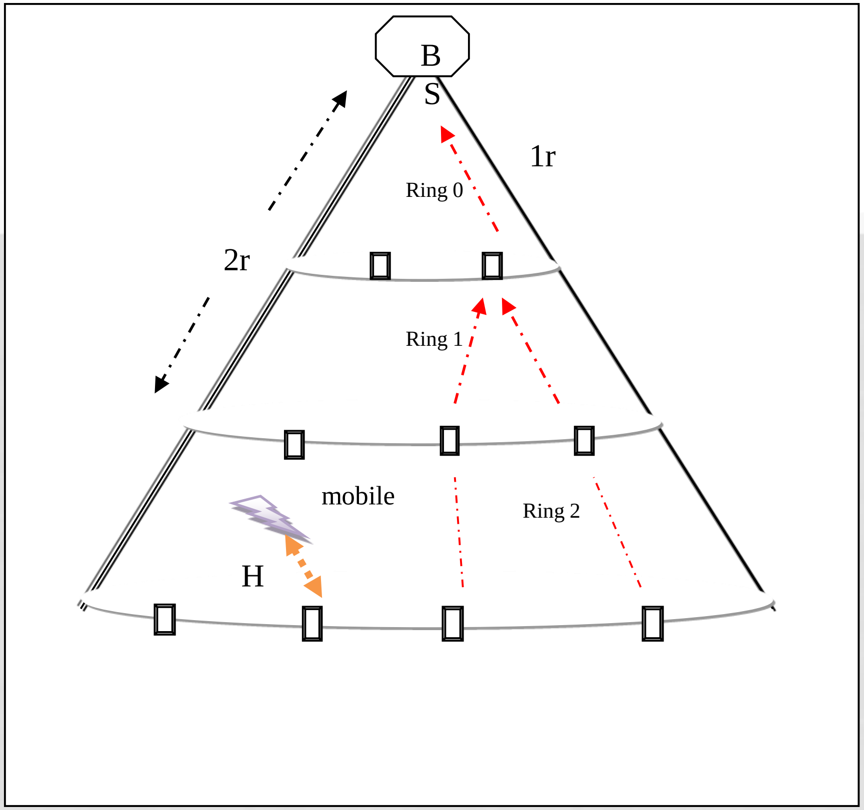
= Energyelec X a + Energyamp X d2 X a + Energyelec X a + Energycpu X a

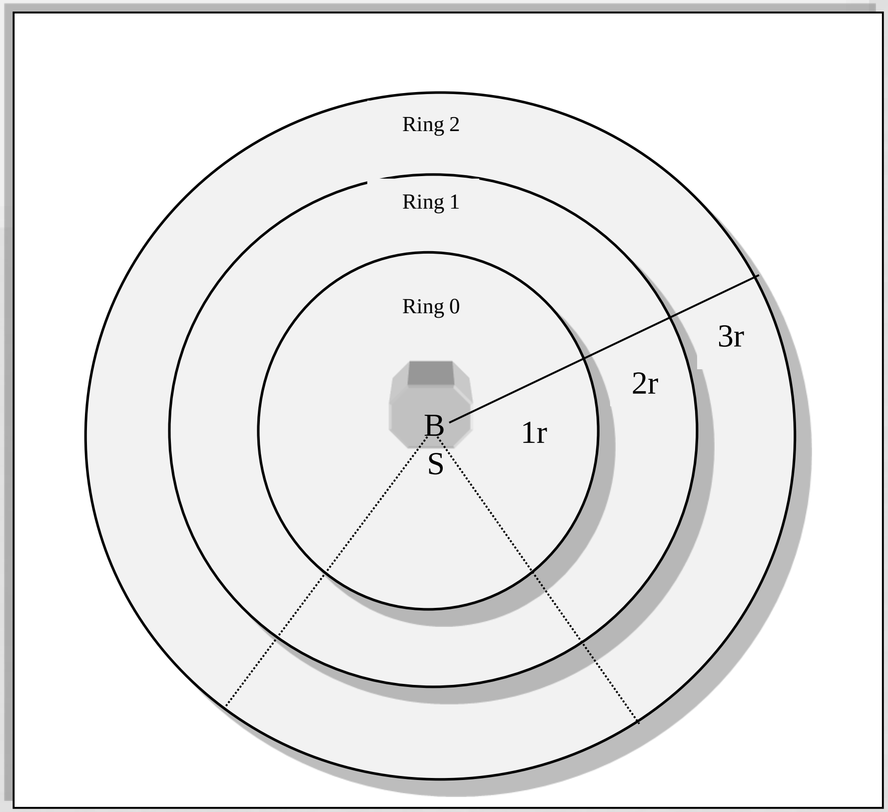
Therefore:
Total Energy Consumption = a (2 ₠c + ₳ X d^2 + ₵)

Energy consumption α a
Energy consumption α d

Total energy consumption is directly proportional to the length of data packets. Thus if the length of data packet is reduced, total energy consumption is reduced as well.

Energy consumption is also proportional to d^2 which is the transmission distance less than the threshold value and total energy consumption is also proportional to d^4 (Liu and Lin, 2003)(Heizelman et. al., 2002).

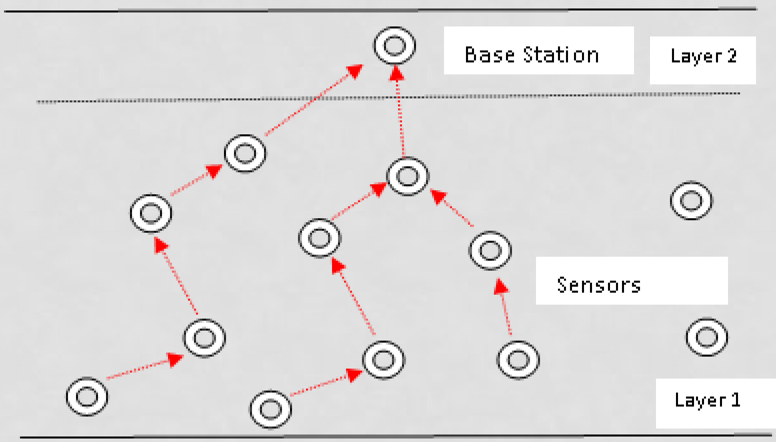




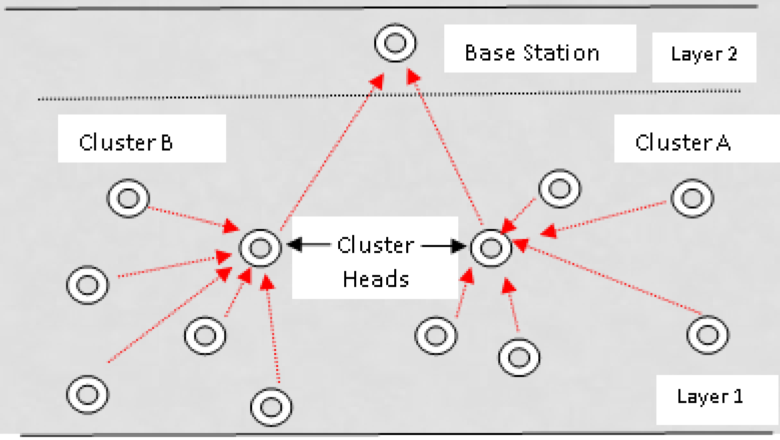
. The deployment area consists of a circle with radius *r* and the ring is located in a rectangle with L x L square area. The base station is assumed to be located in the centre of the circle and the circle is partitioned into *m* rings, namely ring 0, ring 1 till ring m. The distance between two adjacent rings is r meter and total area consists of L = m x r meters. Ring 0 has radius of r meters, ring 1 with 2r meters and ring 2 with 3r meters respectively

Energy Model

- Energy Consumption using Multihop Routing

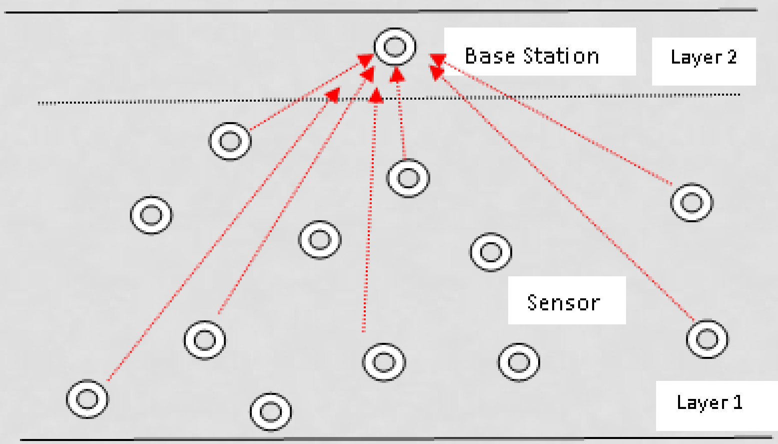


- Energy Consumption using Cluster Head

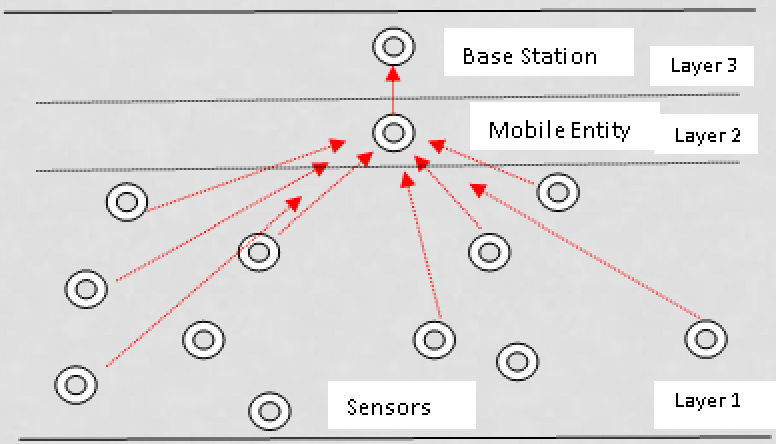


Energy Model

- **Energy Consumption using Direct Transmission**



- **Energy Consumption using Mobile with Direct Transmission**



Simple scenario

Energy Transmit

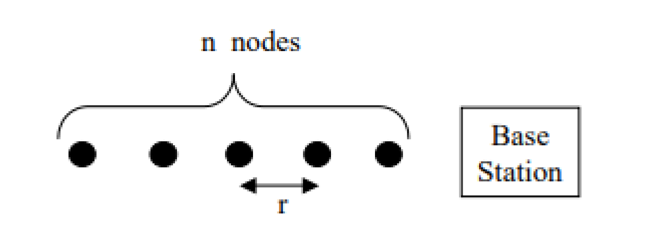
$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d)$$
$$E_{Tx}(k,d) = E_{elec} * k + \epsilon_{amp} * k * d^2$$

Energy Receive

$$E_{Rx}(k) = E_{Rx-elec}(k)$$
$$E_{Rx}(k) = E_{elec} * k$$

Direct Communication - If we consider the energy expended transmitting a single k-bit message from a node located a distance nr from the base station (d = nr)

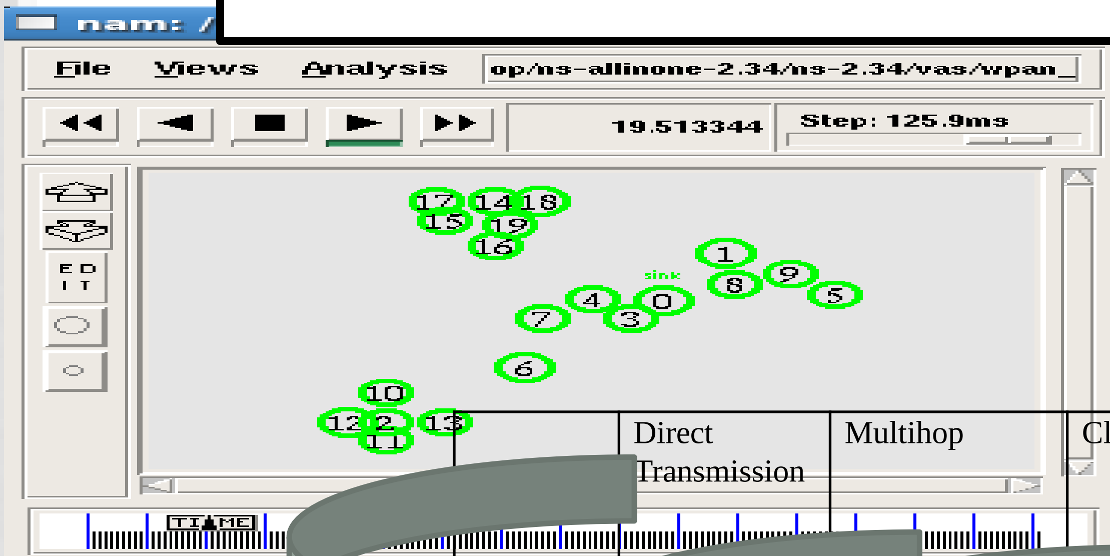
$$\begin{aligned} E_{direct} &= E_{Tx}(k, d = n * r) \\ &= E_{elec} * k + \epsilon_{amp} * k * (nr)^2 \\ &= k(E_{elec} + \epsilon_{amp} n^2 r^2) \end{aligned}$$



Multihop – the node located a distance nr from the base station would require n transmits a distance r and n-1 receives (d = r).

$$\begin{aligned} E_{MTE} &= n * E_{Tx}(k, d = r) + (n-1) * E_{Rx}(k) \\ &= n(E_{elec} * k + \epsilon_{amp} * k * r^2) + (n-1) * E_{elec} * k \\ &= k((2n-1)E_{elec} + \epsilon_{amp} n r^2) \end{aligned}$$

Simple scenario



Energy =2nd power of distance,all nodes

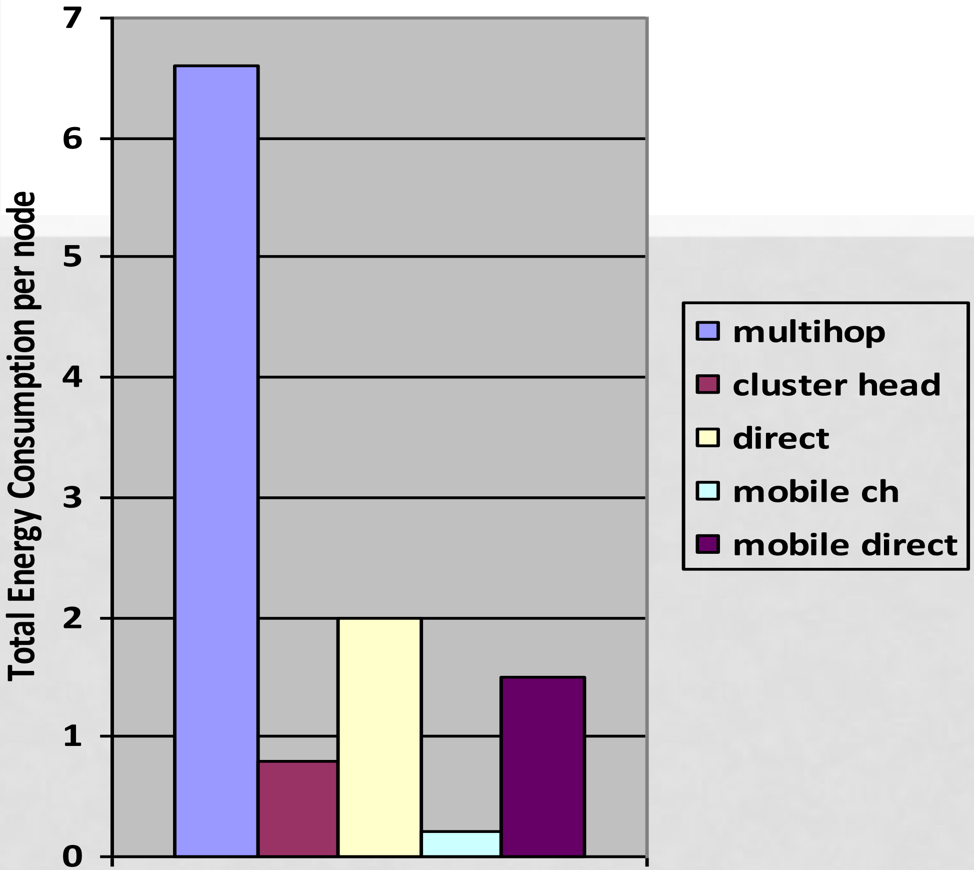
Energy =4th power of distance

Energy =2nd power of distance

Energy =4 power of distance

Energy =2 power of distance,more transmissions

	Direct Transmission	Multihop	Clustering	Mobile with Clustering (BIMAS)	Mobile with Direct
[illegible]	{17,sink}	{19,16,4,sink}	{17,16,sink}	{[illegible]mobile,sink	{17,mobile,sink}
Energy	Very High	High	Medium	Low	Medium
Delay	Very Low	Low	Low	High	Medium
Hop Number	1	3	2	3	2
Lifetime	Very Low	Low	Medium	High	High



Multihop

$a\,(Energy_{amp}\ X\ nd^2 + (2n\text{-}1)Energy_{elec} + Energy_{cpu})$

Cluster Head

$a\,(Energy_{amp}\ X\ d^2 + nEnergy_{elec} + Energy_{cpu})$

Direct Transmission

$a\,(Energy_{amp}\ X\ n2d^2 + Energy_{elec} + Energy_{cpu})$

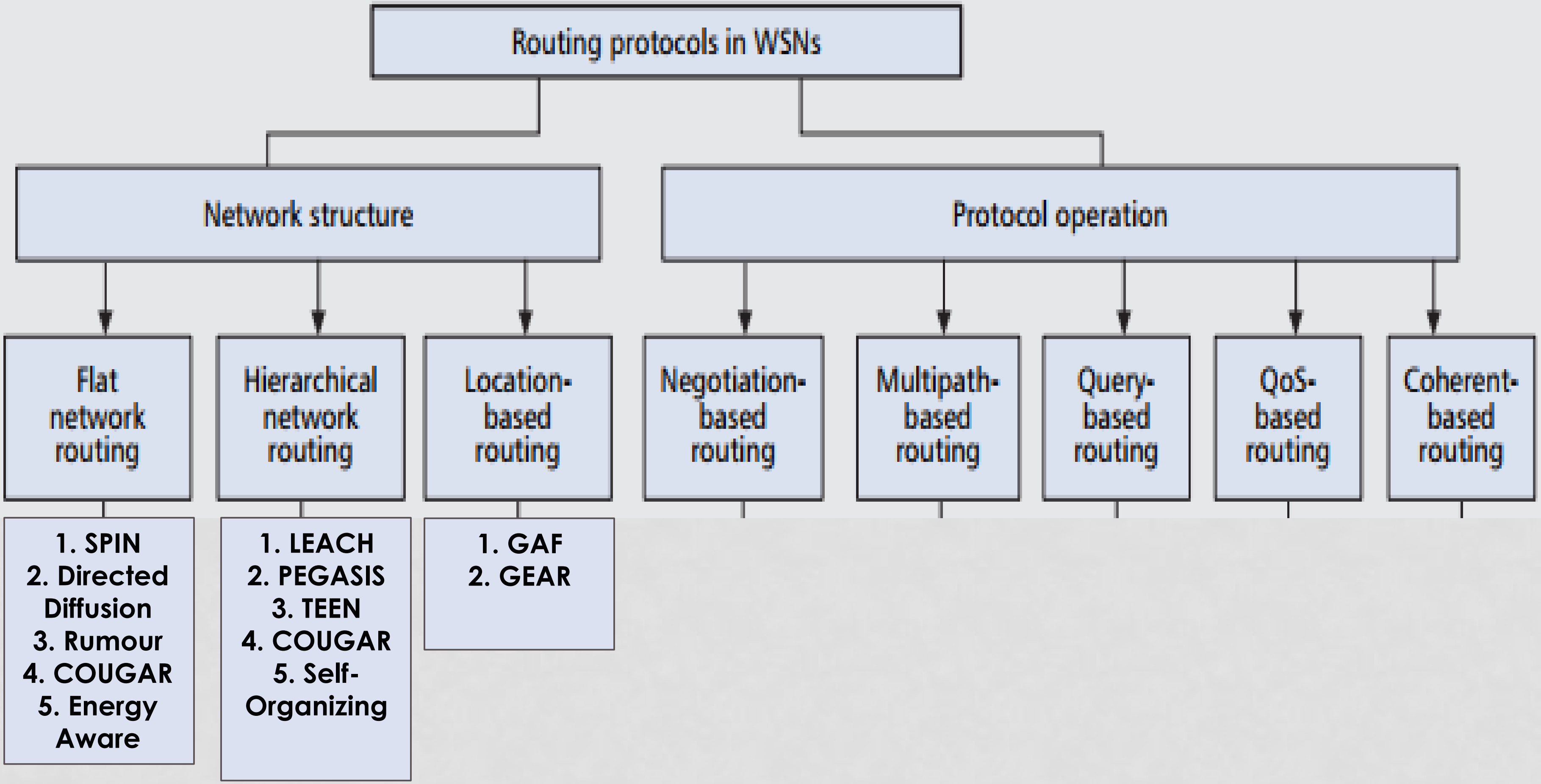
Mobile Agent

$a\,(Energy_{amp}\ X\ H^2 + Energy_{elec} + Energy_{cpu})$

where $H < d$

Energy Consumption Analysis

Routing hierarchy



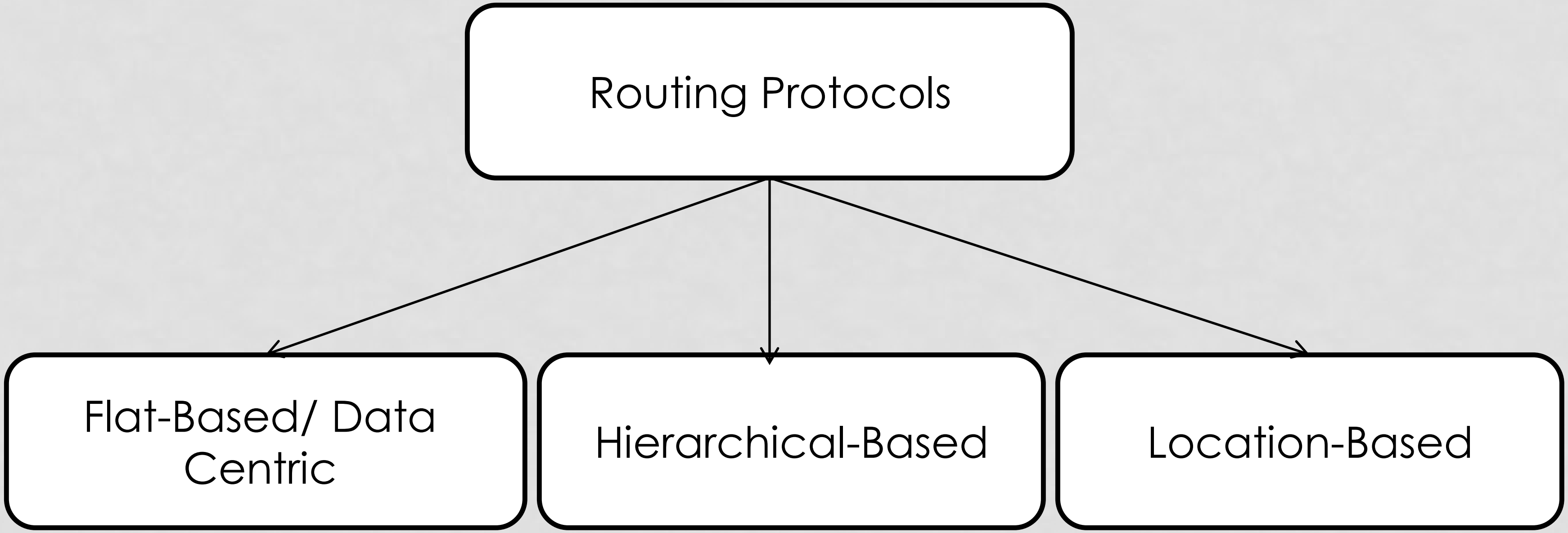
Routing Metrics

- Minimum Hop Count
- Energy
  - Minimum energy consumed per packeT
  - Maximum time to network partition
  - Minimum variance in node power levels
  - Maximum (average) energy capacity
  - Maximum minimum energy capacity
- Expected Transmission Count (ETX)
- Expected Transmission Time (ETT)

Lifetime vs Energy efficiency

- System lifetime
- (a) the duration of time until some node depletes all its energy; or
- (b) the duration of time until the QoS of applications cannot be guaranteed;
- (c) the duration of time until the network has been disjoined.
- Energy efficiency - Energy efficiency means the number of packets that can be transmitted successfully using a unit of energy
- Reliability - Ratio of successfully received packets over the total number of packets transmitted.

Routing Structure



Routing protocol survey

- ***<u>Traditional technique</u>***
  - <u>Flooding</u>
  - <u>Gossiping</u>

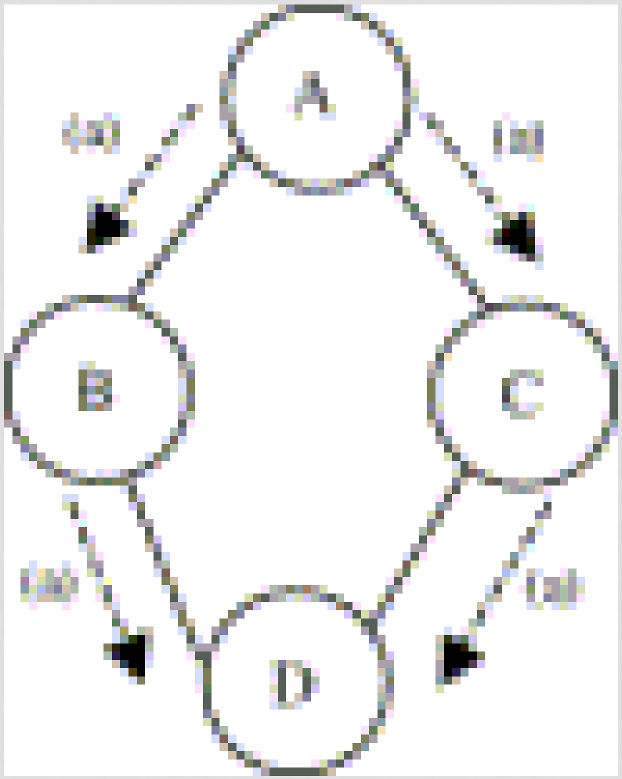
- Current routing technique
  - Flat-routing
  - Hierarchical-routing
  - Location-based routing

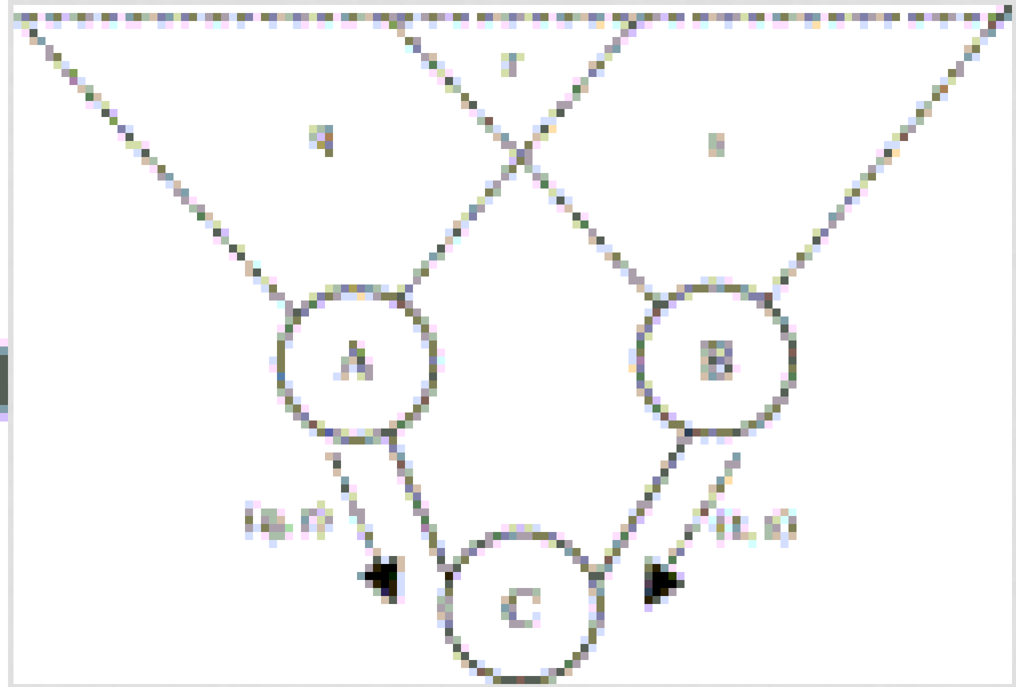
[1]Ian F. Akyildiz, Weilian Su, Yogesh Sankarasubramaniam, and Erdal Cayirci Georgia Institute of Technology" A Survey on Sensor Networks"
IEEE Communications Magazine • August 2002

Flooding

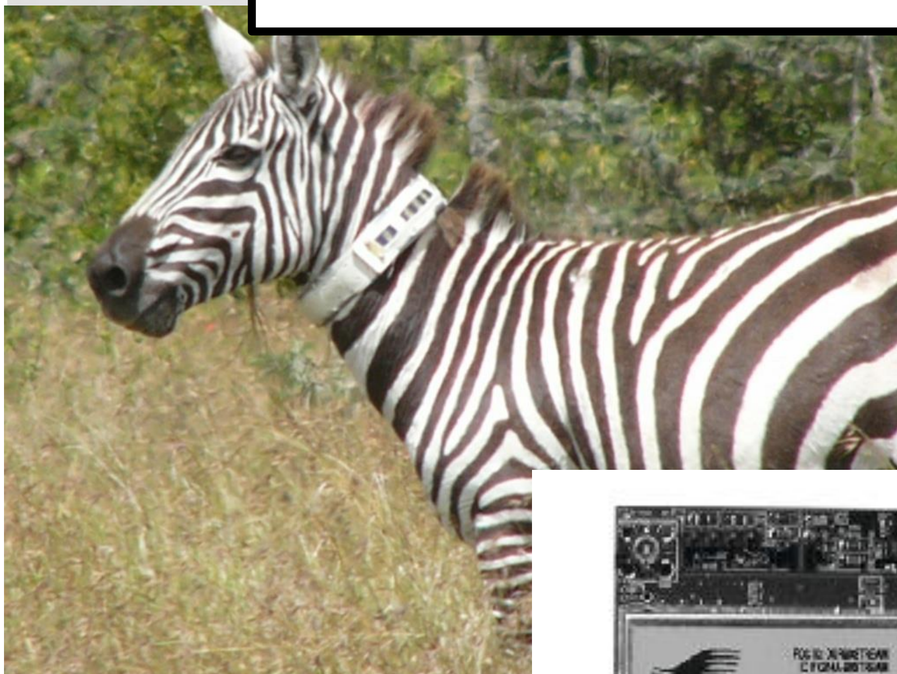
- A classical mechanisms to relay data in sensor networks without the need for any routing algorithms and topology maintenance.
- Each sensor receiving data broadcasts it to all neighbors
- drawbacks:
  - Implosion
  - Overlap
  - Resource blindness

FLOODING





Example of Flooding



The Main Idea

The ZebraNet Wildlife Tracker is an application to track zebras on the field

Special GPS equipped collars are attached to zebras.

Main operations

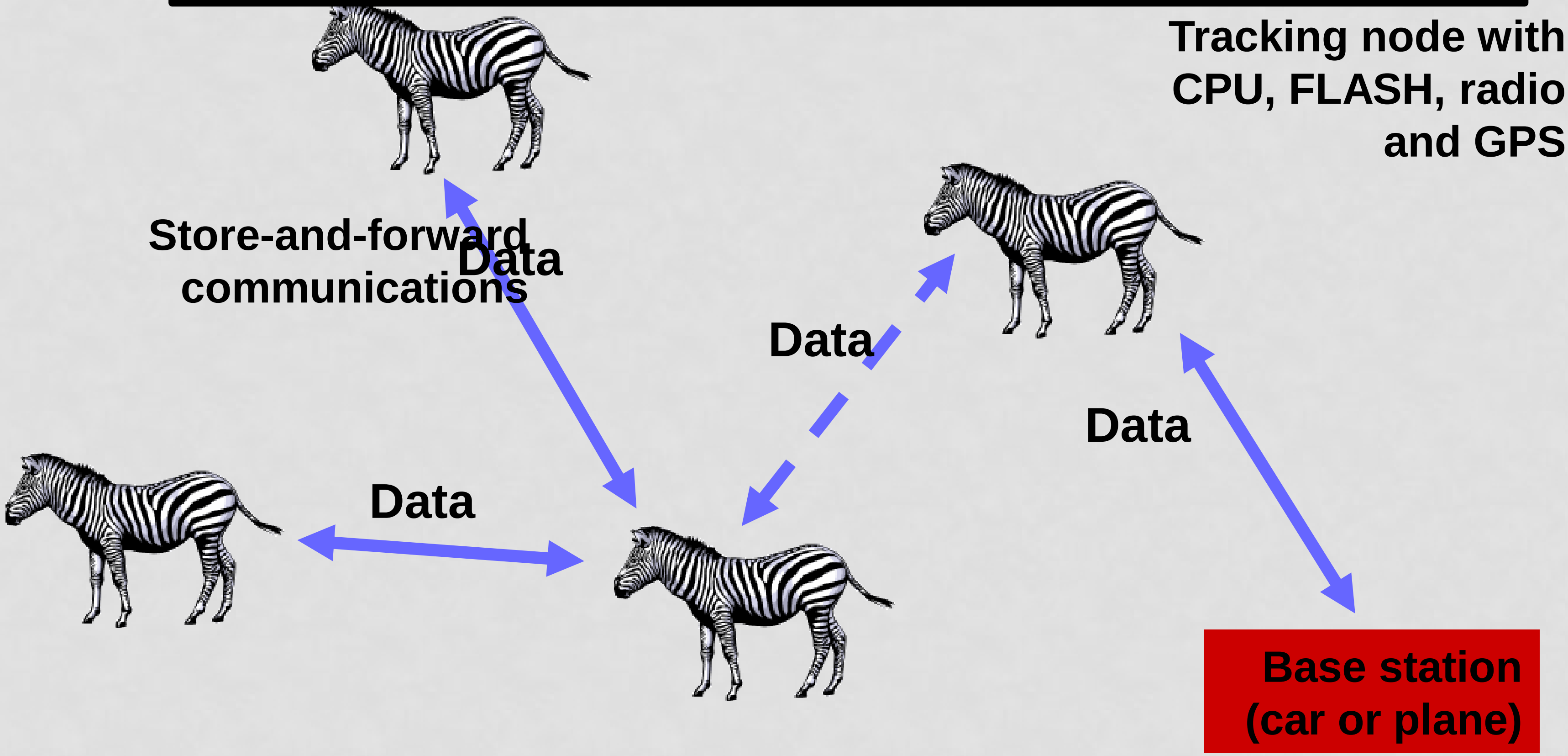
- ***Monitoring***

- Sensor nodes are required to detect and track the movement states of mobile objects

Reporting

- The nodes that sense the objects need to report their discoveries to the applications
- These two operations are interleaved during the entire object tracking process

ZebraNet as Computing Research



Possible network protocols

- Flooding network protocol
  - Simple
  - Given that the Zebras move extensively there is a high data homing rate
  - Large amount of data (requires large bandwidth, large storage and much energy)

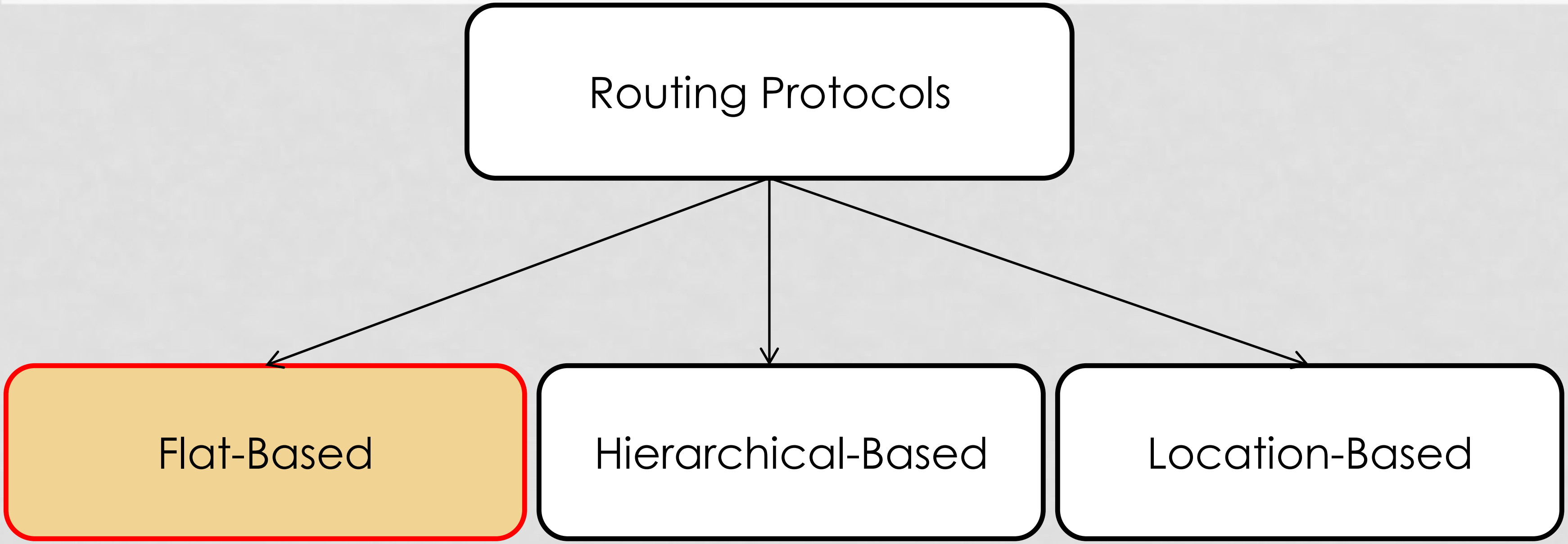
Gossiping

- A slightly enhanced version of flooding where the receiving node sends the packet to a randomly selected neighbor which picks another neighbor to forward the packet to and so on.

➢ Advantage: avoid the implosion

➢ Drawback: Transmission delay

Network Structure Categorization



- All the nodes are treated equally and have the same functionality

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Flat/data centric routing

- Not feasible to assign global identifiers
- Sheer number of nodes and random deployment
- Therefore data is transmitted to from every sensor node
- The sink sends queries to certain regions and waits for data
- Attribute based naming is necessary

Flat-Based Routing Protocols

1. Sensor Protocol for Information Negotiation (SPIN):

- Sending meta-data to neighboring nodes, instead of data
- Requesting for the desired data

❖ Avoid redundant data transmission - negotiation

❖ Adaptation to remaining energy ➡ increase network lifetime

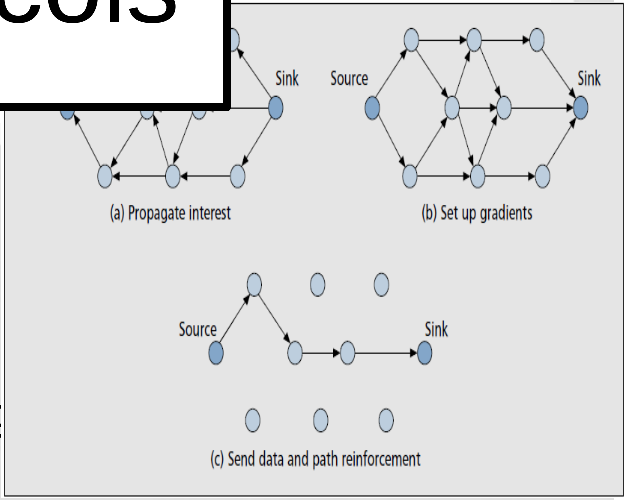
2. Directed Diffusion:

- BS continuously sends query to the neighboring nodes
- Node with the desired data transmit all the way back to BS

❖ Saving energy by selecting the optimal return path

❖ Not practical for continuous data demand cases

Flat-Based Routing Protocols



(a) Propagate interest
(b) Set up gradients
(c) Send data and path reinforcement

3. Rumor Routing:

- Variation of Directed Diffusion
- Each node has an event table
- Event agent flooding instead of query flooding

❖ Significant energy saving

❖ Good for when number of events is less than queries

4. Minimum Cost Forwarding Algorithm (MCFA):

- Each node knows the least cost path between itself and BS
- Least cost path can be acquired via initialization

❖ Saving energy by selecting the optimal return path

❖ Good for small networks

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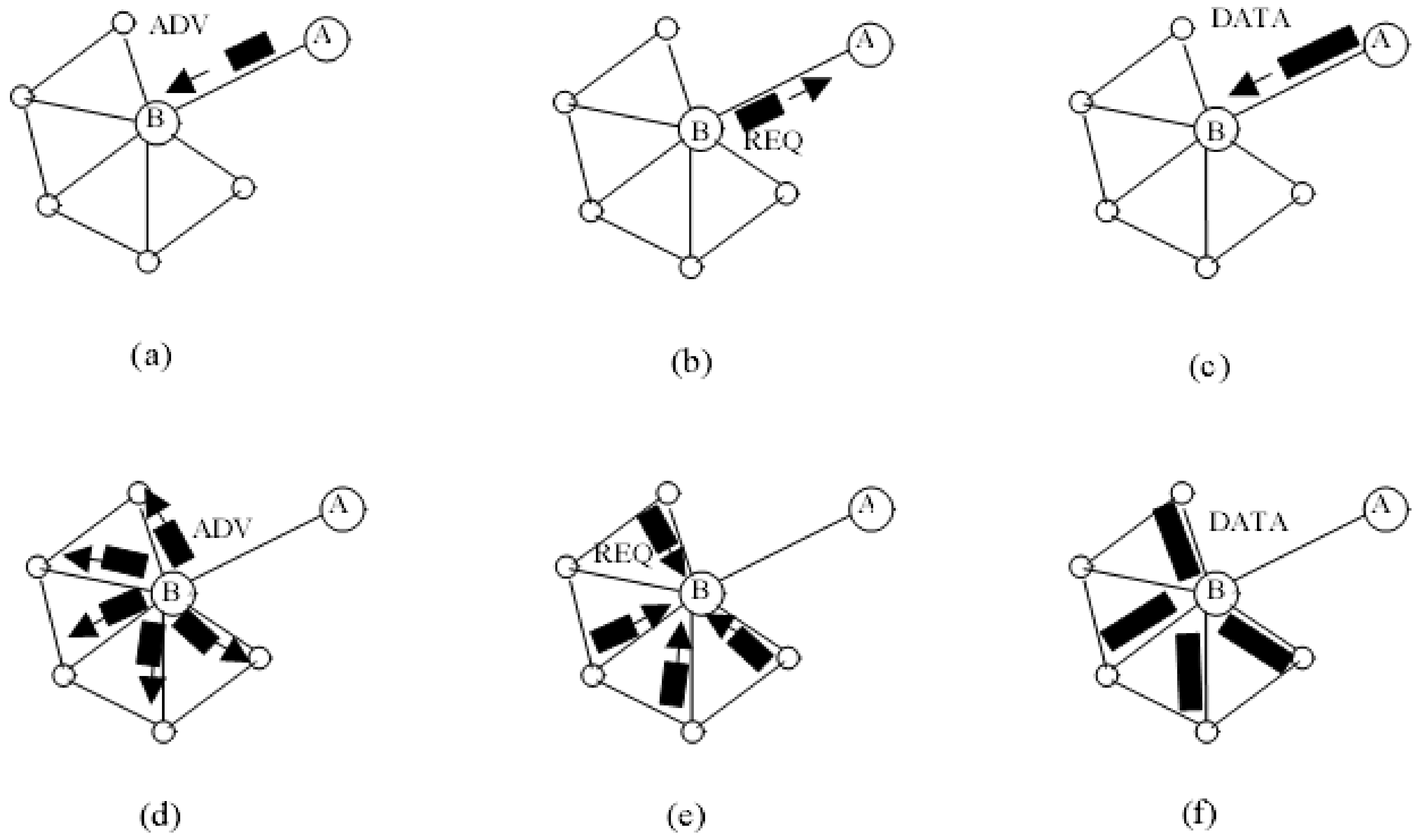
SPIN

- A family of adaptive protocols called Sensor Protocols for Information via Negotiation
- assign a high-level name to completely describe their collected data (called meta-data)
- Use thee types of messages ADV (advertisement), REQ (request) and DATA

[1]W. Heinzelman, J. Kulik, and H. Balakrishnan, "Adaptive Protocols for Information Dissemination in Wireless Sensor Networks," *Proc. 5th ACM/IEEE Mobicom*, Seattle, WA, Aug. 1999. pp. 174–85.

SPIN



SPIN

- Topological changes are localized
- provides more energy savings (3.5) than flooding, and metadata negotiation almost halves the redundant data.

- Drawback: SPIN's data advertisement mechanism cannot guarantee delivery of data.

- Not good for intrusion detection which require reliable delivery of data

Flat-routing

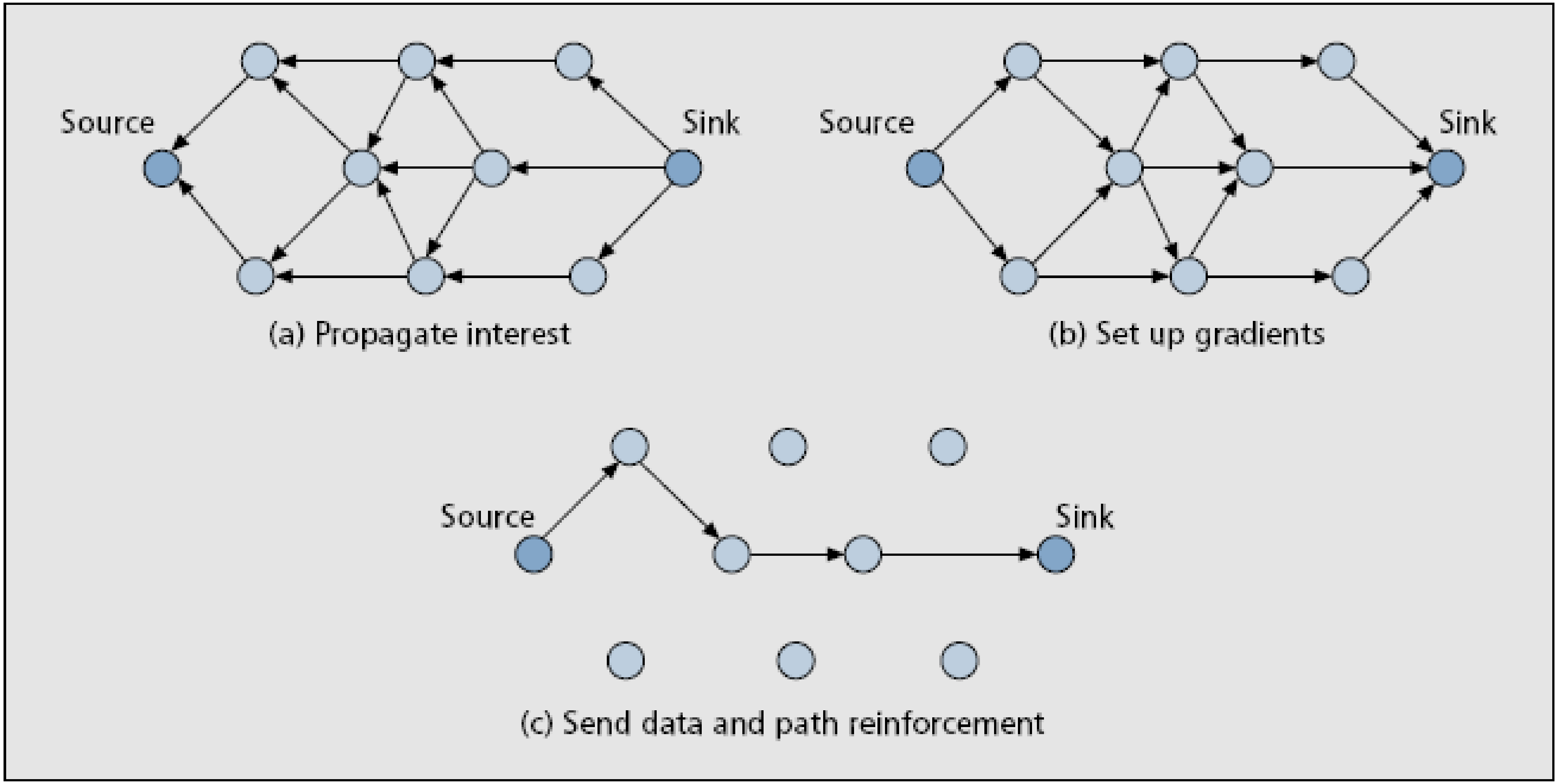
- SPIN (Sensor Protocols for Information via Negotiation)
- ***DD (Directed diffusion)***
- Rumor routing

DD

- Uses naming scheme for data (to get rid of network layer routing)
- Propagate interest – uses attribute value pairs - Name of objects, interval, duration, geographical area
- Interest is broadcast by sink to neighbours
- Set up gradients
- Send data and path reinforcement

[1]C. Intanagonwiwat, R. Govindan, and D. Estrin, "Directed Diffusion: a Scalable and Robust Communication Paradigm for Sensor Networks," *Proc. ACM Mobi- Com 2000*, Boston, MA, 2000, pp.56–67.

DD



Source
Sink
(a) Propagate interest
Source
Sink
(b) Set up gradients
Source
Sink
(c) Send data and path reinforcement

DD

- Directed diffusion differs from SPIN in two aspects.
  - Query method – sink queries data
  - Communication method – neighbor to neighbor
  - Energy efficient – on demand basis
- directed diffusion may not be applied to applications that require continuous data delivery (e.g., environmental monitoring)
- Matching data to queries might require some extra overhead

Flat-routing

- SPIN (Sensor Protocols for Information via Negotiation)
- DD (Directed diffusion)
- ***<u>Rumor routing</u>***

Rumor routing

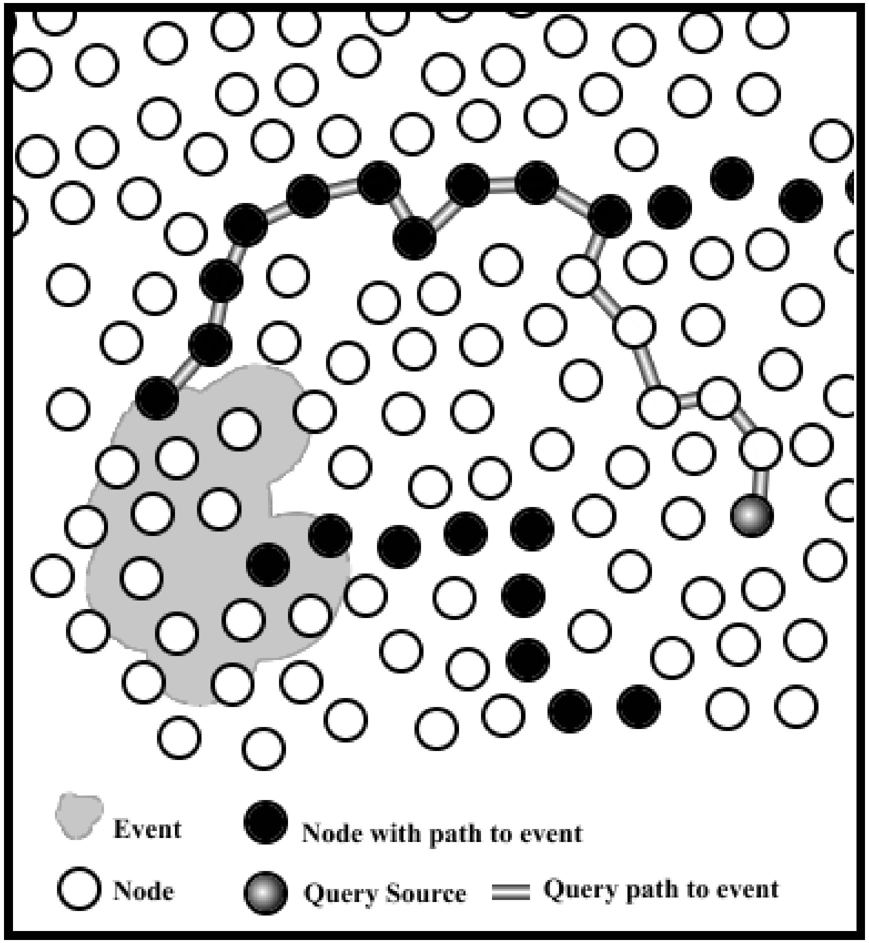
- A variation of directed diffusion, DD floods the entire network
- In some cases there is only little amount of data requested thus the use of flooding is unnecessary
- Use an events table and a agent
- The number of events is small and the number of queries is large

[1]D. Braginsky and D. Estrin, “Rumor Routing Algorithm for Sensor Networks,” *Proc. 1st Wksp. Sensor Networks and Apps.*, Atlanta, GA, Oct. 2002.

Rumor routing

- Employs long-lived packets called agents
- When a node detects an event, it adds such event to its local table and generates an agent
- Agents travel the network in order to propagate information about local events to distant nodes.
- When a node generates a query for an event, the nodes that know the route can respond to the query by referring its event table.

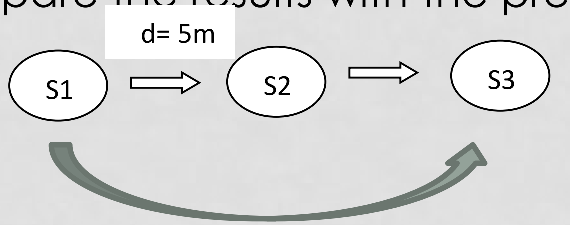
Rumor routing



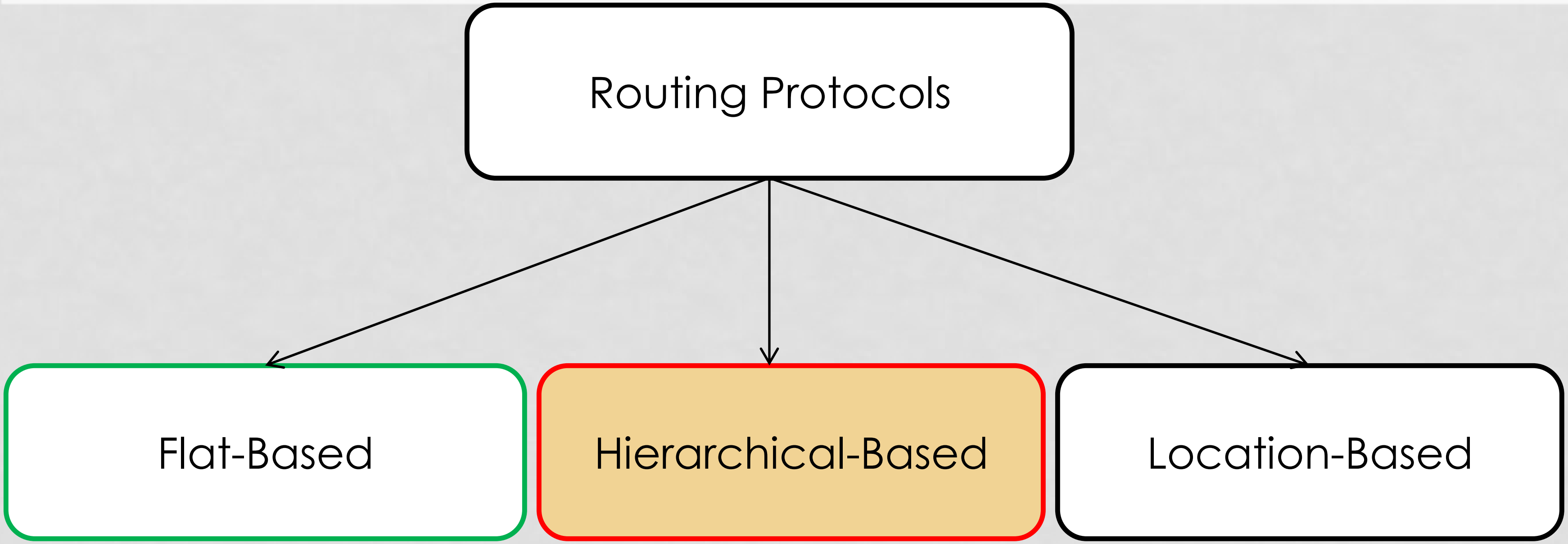
Question ?

- Is it more energy efficient to use direct transmission (from S1 to S3) or minimum per-transmission energy routing or multihop (S1 to S3).
- How many nodes are required so that direct transmission consumes the same amount of energy as multihop
- Discuss the situation in b and explain under what circumstances that direct transmission is suitable.
- As we know, energy consumption is directly proportional to data packet size. Calculate to show that how doubling the packet size can increase the total energy consumption. Compare the results with the previous. (you may just use direct transmission only).
- Energy consumption = $Energy_{elec}$ X a + $Energy_{amp}$ X d^2 X a
-
- Energy consumption a a
- Energy consumption a d

- Energy consumption is directly proportional to the distance. Calculate to show that how doubling the distance d can increase the total energy consumption. Compare the results with the previous. (you may just use direct transmission only).



Network Structure Categorization



- Higher energy nodes for transmission, lower energy nodes for sensing
- Two layer routing
- Increasing the life time

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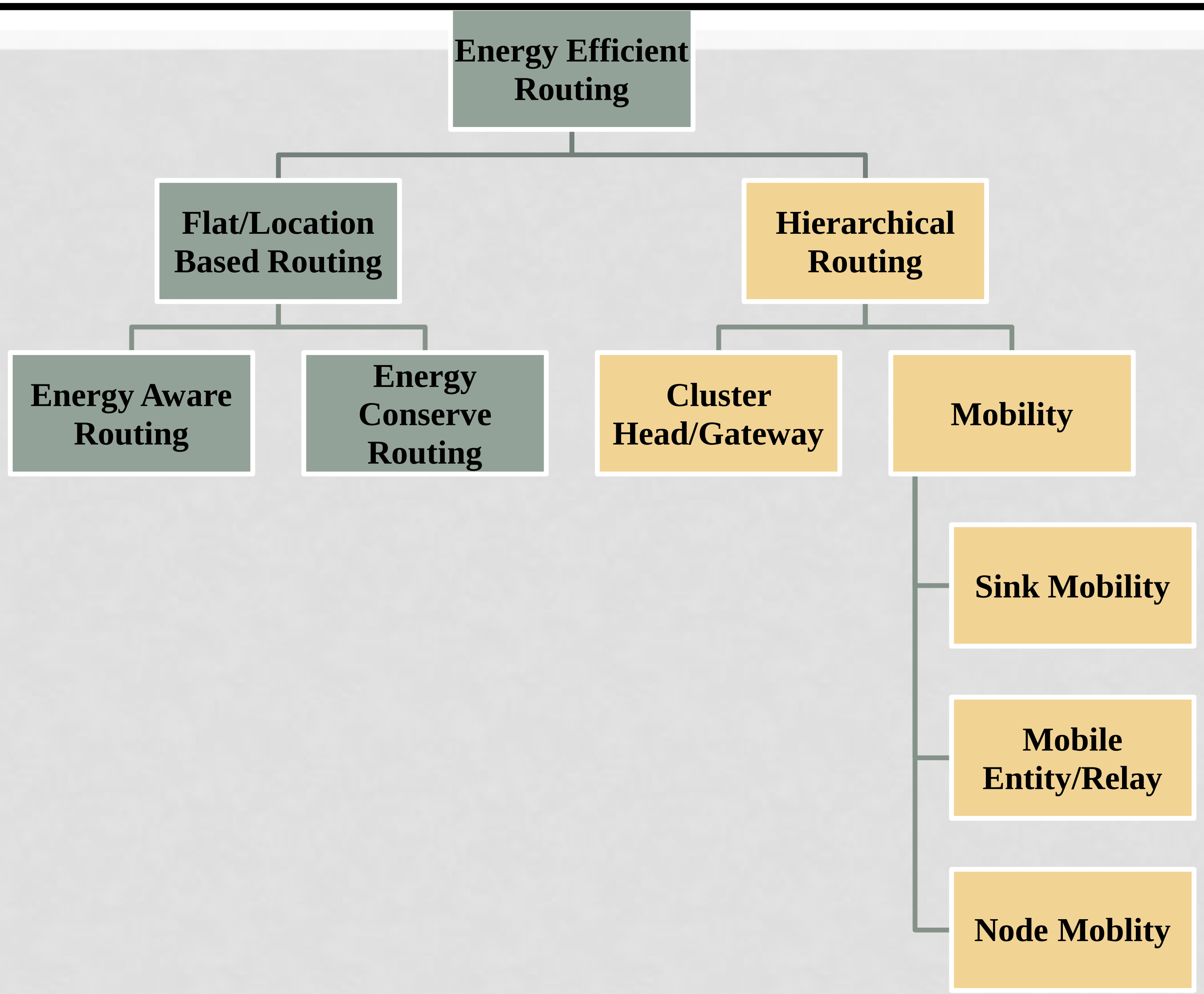
Hierarchical

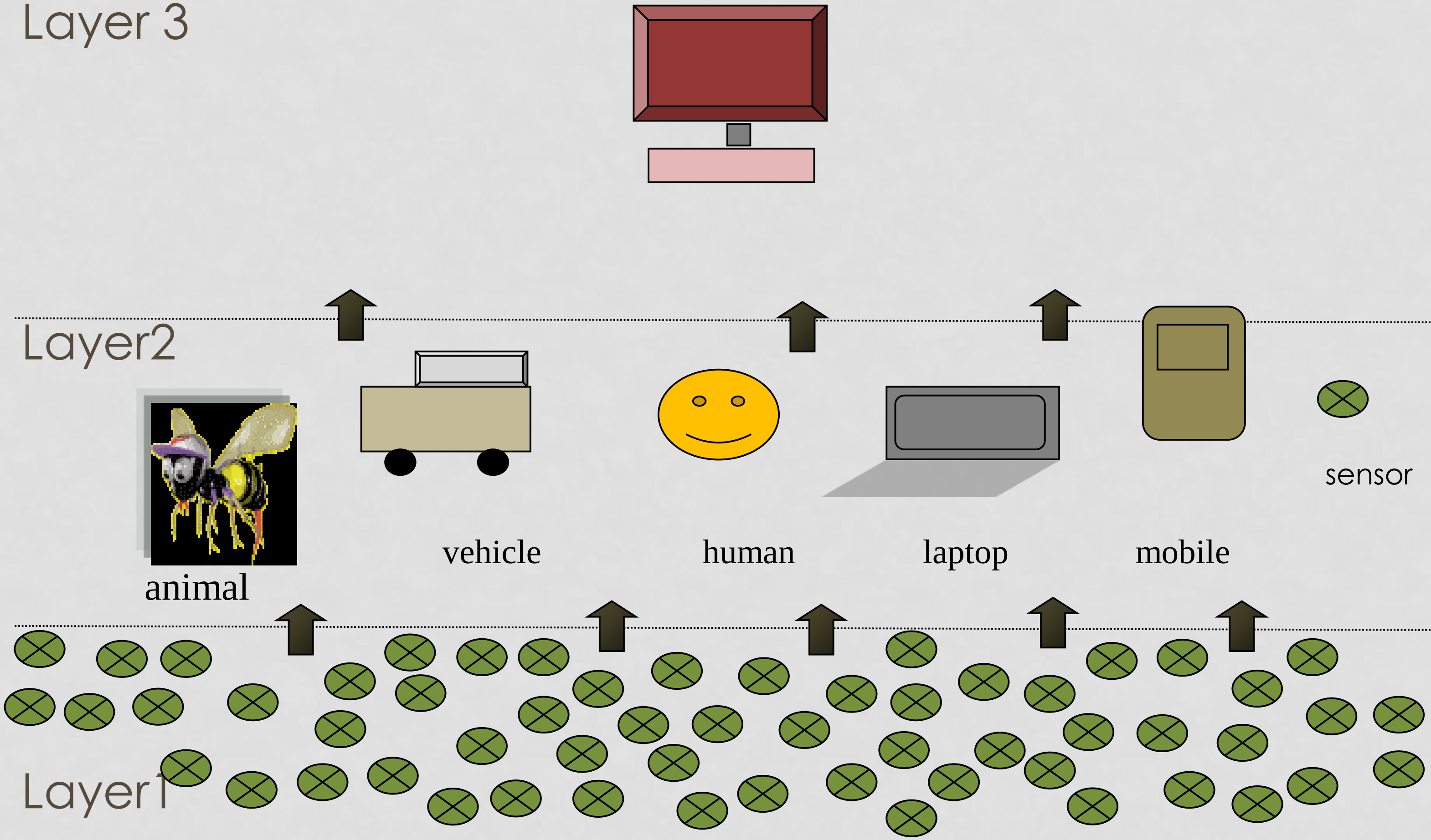
- A single-tier network can cause the gateway to overload with the increase in sensor density.
- Causes latency in communication
- Also not scalable for a large set of sensors covering a wider area
- Hierarchical can tackle these issues by clustering thus allow multihop communication and perform data aggregation within the cluster only

Hierarchical routing

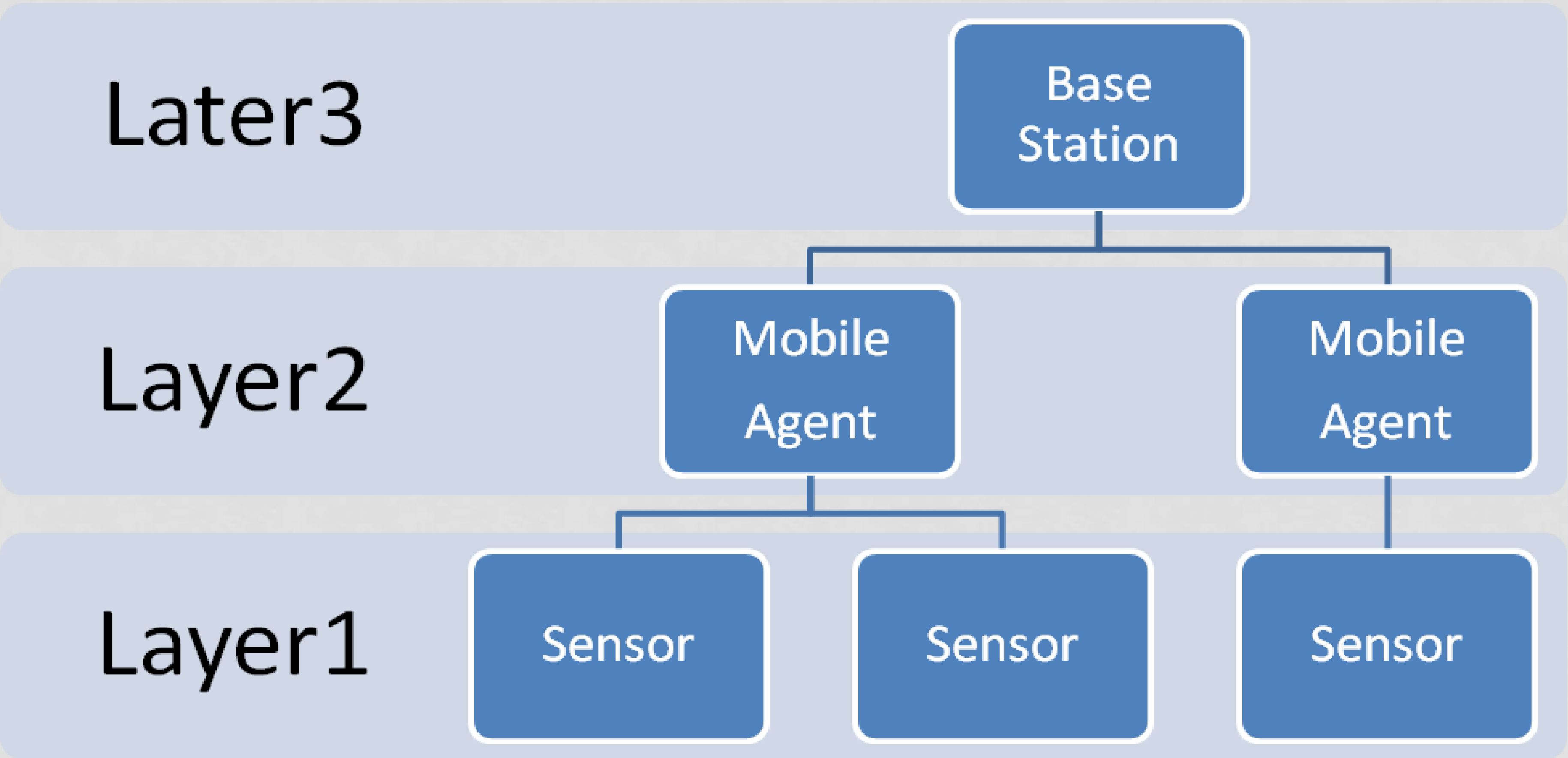


Three-tier Architecture

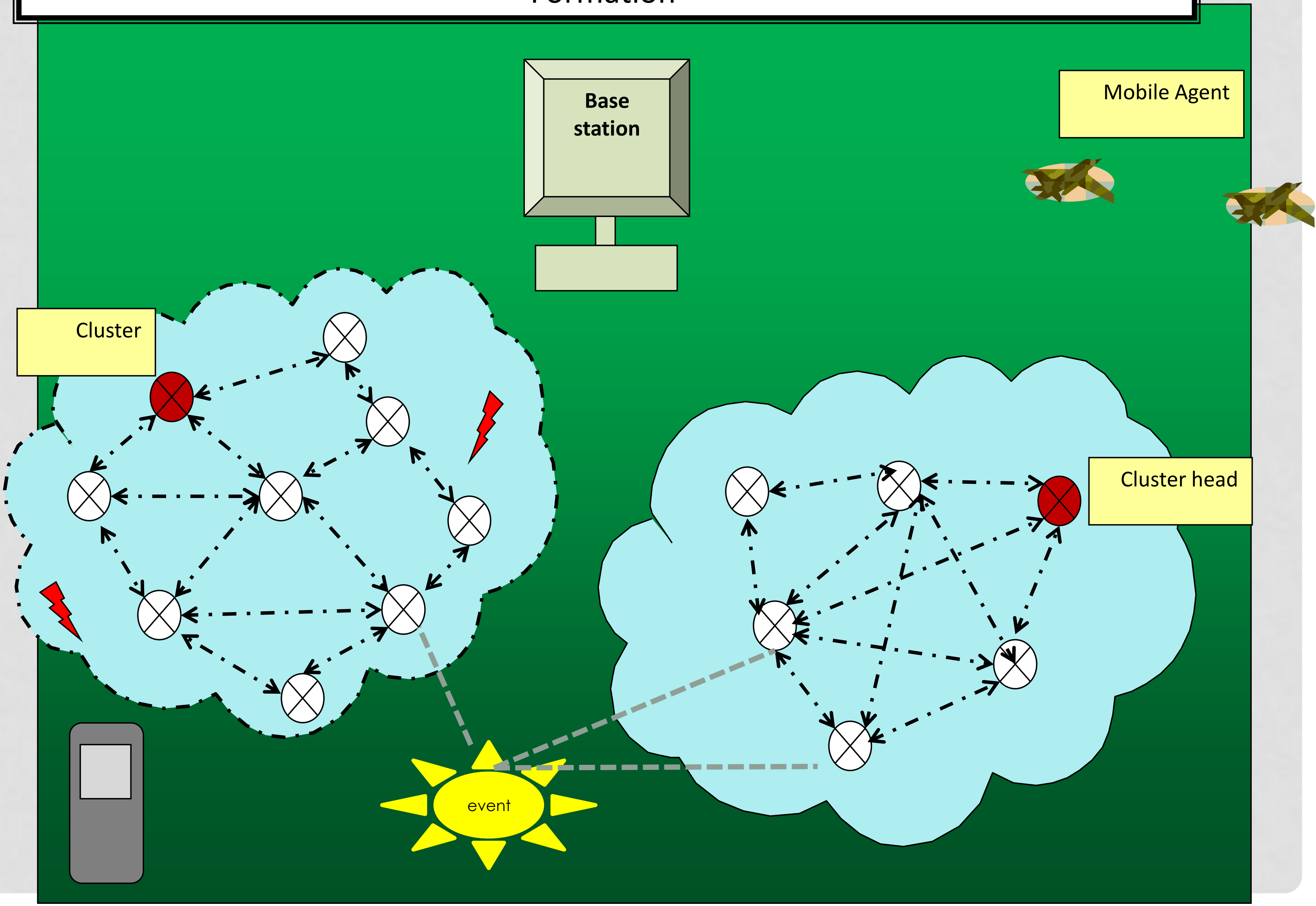
- Layer 3
- Layer2
- Layer1



Architecture



Three-tier Architecture of Sensors, Mobile Agent and Base Station with Cluster Formation



Hierarchical Routing

1. Low Energy Adaptive Clustering Hierarchy(LEACH):

- LEACH is a hierarchical, self-organizing protocol which tries to distribute energy utilization to a randomly chosen cluster head from within the cluster
- The cluster head is elected on a rotational basis so that every sensor node can become a cluster head at any point in time
- The protocol also looks at data fusion within the routing protocol in order to reduce the amount of information transmitted to the base station.

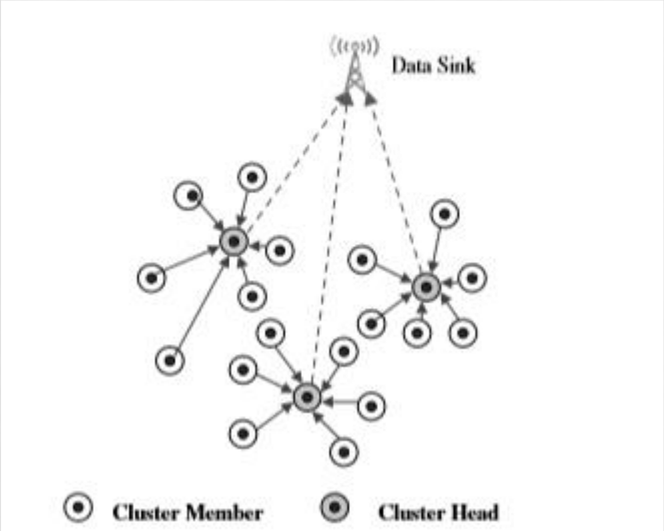
2. Self Organizing Protocol (SOP):

- Mobile sensors to probe the environment
- Stationary nodes as the routers
- LML algorithm for routing

❖ Energy consumption is less than SPIN

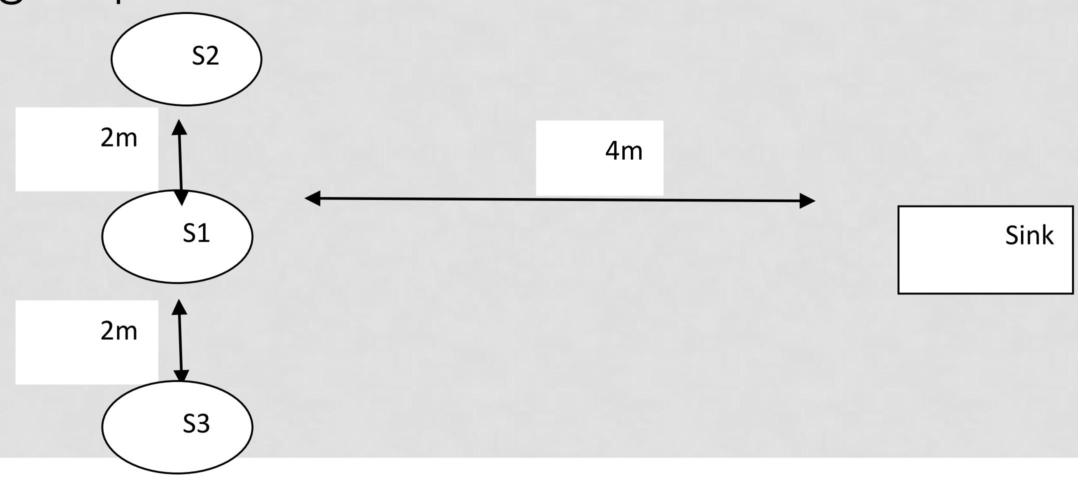
HIERARCHICAL ROUTING

- ***<u>LEACH (Low Energy Adaptive Clustering Hierarchy)</u>***
- PEGASIS (Power-Efficient Gathering in Sensor Information Systems)
- TEEN(APTEEN) (Threshold-Sensitive Energy Efficient Protocols)



Question?

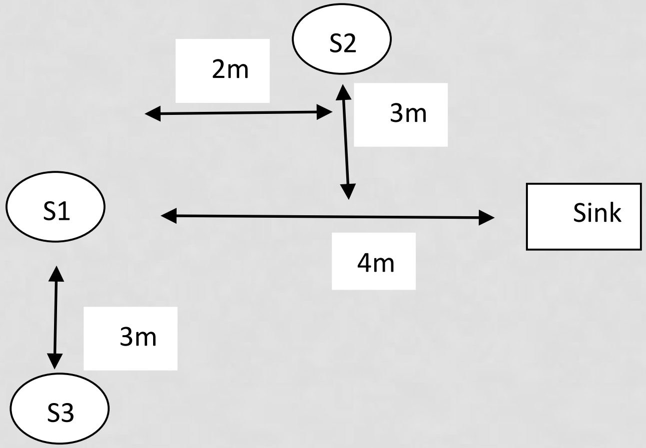
- Find the total energy consumption for three cases a) when S1 is the cluster head, b) when S2 is the cluster head and c) when S3 is the cluster head.
- 2. Which setup would give the most efficient energy consumption, a, b or c?.
- 3. What is the total energy consumption when direct transmission is used without cluster head election.
- Direct better of cluster head better in this setup?
- 4. Calculate the lifetime under all these cases.
- 5. Calculate the lifetime when cluster head election follows the following sequence S1-S1-S2-S3-S3



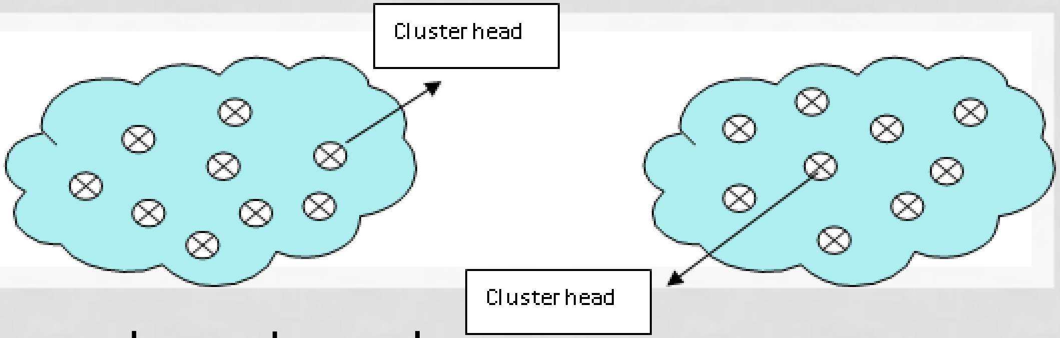
Question?

Node S1 becomes cluster head and S2 and S3 forward the data to S1 and S1 takes the average of the sensor data forwards to node A and in the next rounds node S2 becomes cluster head whereby S1 and S3 forwards to S2 and S2 forwards the average to A and the next round S3 becomes cluster head the process happens in the same manner.

- Calculate the lifetime



LEACH



- LEACH is a cluster-based protocol
- Setup phase
- Steady state phase
- The operation of LEACH is organized into phases or rounds which begin with a set-up phase and conclude with a steady-state phase.
- The set-up phase occurs during cluster formation, whereas the steady-state phase occurs when data are sent to the base station. During an intervening advertisement phase, each node makes a decision whether to become a cluster head for the current round.

[1]. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Microsensor Networks," *Proc. 33rd Hawaii Int'l. Conf. Sys. Sci.*, Jan. 2000.

LEACH

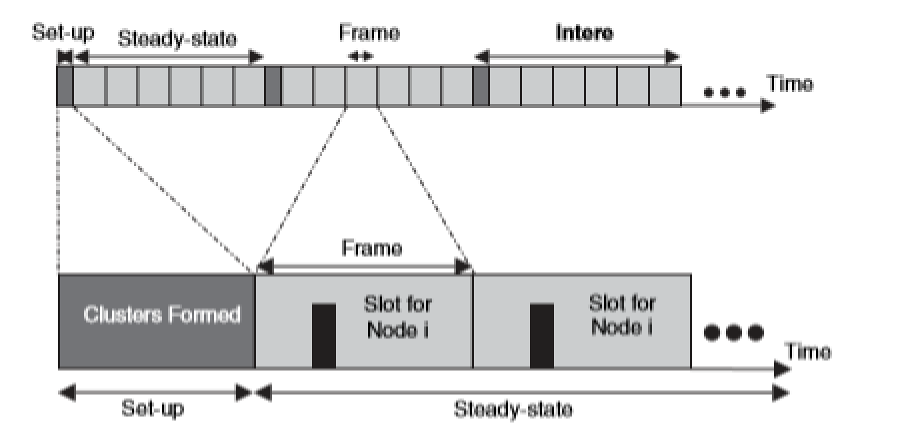
- The decision is made based on prior choices about the number of cluster heads to be elected and on the number of times a node has previously become a cluster head.
- Nodes are assigned values between 0 and 1 and if the value for a certain node is below a threshold criterion then that particular node becomes a cluster head for the current round.
- The threshold value permits each node to become cluster head within certain rounds..

$$T(n) = \begin{cases} \frac{p}{1 - p * (r \bmod 1/p)} & \text{if } n \in G, \\ 0 & \text{otherwise,} \end{cases}$$

p is desired % of Ch, *r* is the current round and *G* is the set of nodes that have been CH in the last 1/p rounds

LEACH

- Once a node has elected itself to be cluster head, it broadcasts an advertisement message to other nodes within the cluster.
- Upon receiving the advertisement message, each non-cluster nodes decide on the cluster to which it belongs, based on the strength of the advertisement signal it has received.
- The node then informs the cluster head of its decision to join that particular cluster



LEACH

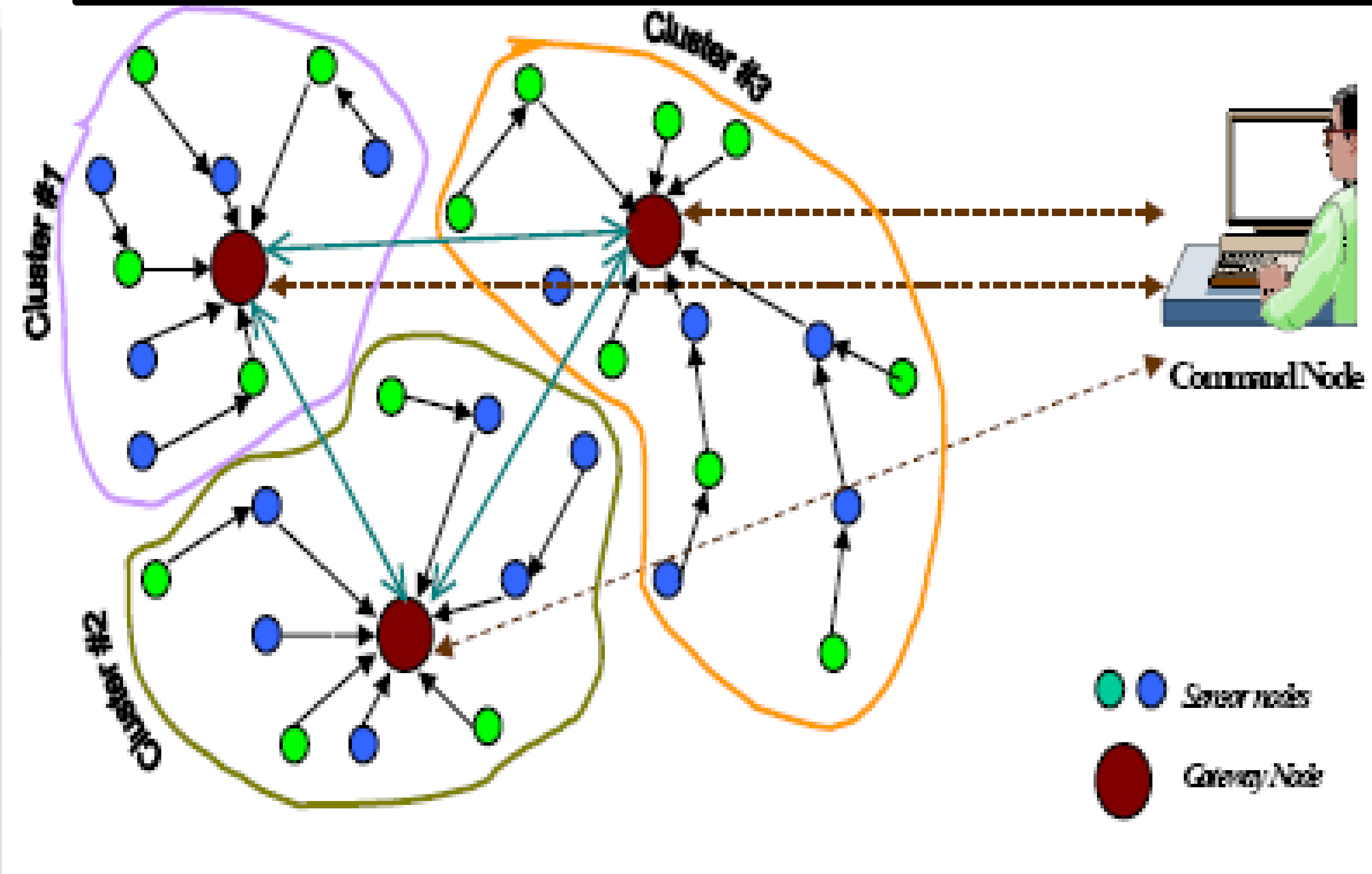


Fig. 1: Multi-gateway clustered sensor network

LEACH

- Drawbacks
  - It is not applicable to networks deployed in large regions – direct transmission (single-hop)
  - The idea of dynamic clustering brings extra overhead – head changes, advertisements
  - The protocol assumes that all nodes begin with the same amount of energy capacity in each election round, assuming that being a CH consumes approximately the same amount of energy fore ach node

Comparison between SPIN LEACH and directed diffusion

	SPIN	LEACH	Directed diffusion
Optimal route	No	No	Yes
Network lifetime	Good	Very good	Good
Resource awareness	Yes	Yes	Yes
Use of meta-data	Yes	No	Yes

[1]W. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Microsensor Networks," *Proc. 33rd Hawaii Int'l. Conf. Sys. Sci.*, Jan. 2000.

Simulation

- LEACH Protocol
- https://www.youtube.com/watch?v=iXfy_f2yDPU

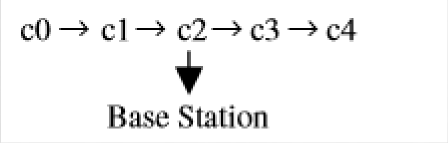
- Clustering Algorithms Wireless Sensor Network Simulator 3 Projects
- https://www.youtube.com/watch?v=C8lZn0NpWow

Hierarchical-routing

- LEACH (Low Energy Adaptive Clustering Hierarchy)
- ***PEGASIS (Power-Efficient Gathering in Sensor Information Systems)***
- TEEN(APTEEN) (Threshold-Sensitive Energy Efficient Protocols)

PEGASIS

- An enhancement over the LEACH protocol is a near optimal chain-based protocol
- increase the lifetime of each node by using collaborative techniques.
- allow only local coordination between nodes and the bandwidth consumed in communication is reduced



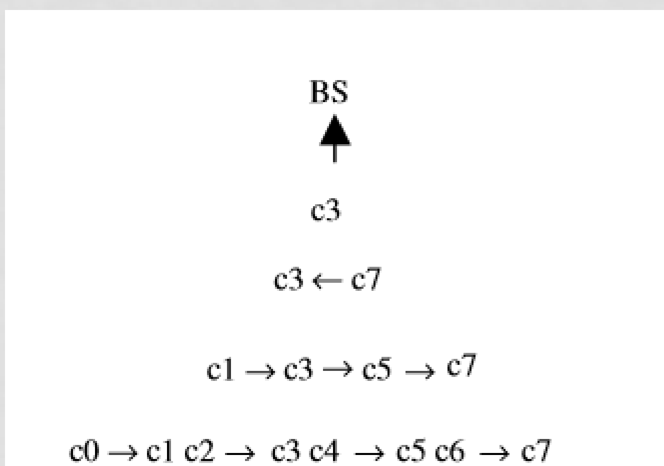
[S. Lindsey and C. Raghavendra, "PEGASIS: Power-Efficient Gathering in Sensor Information Systems," *IEEE Aerospace Conf. Proc.*, 2002, vol. 3, 9–16, pp. 1125–30.

PEGASIS

- Drawbacks:
  - assumes that each sensor node is able to communicate with the BS directly
  - assumes that all sensor nodes have the same level of energy and are likely to die at the same time
  - the single leader can become a bottleneck.
  - excessive data delay

Comparison between PEGASIS and SPIN

- PEGASIS saving energy in several stages
  - In the local gathering , the distance that node transmit
  - The amount of data for CH head to receive
  - Only one node transmits to BS
- Hierachical PEGASIS – Enhancement to PEGASIS



Hierarchical-routing

- LEACH (Low Energy Adaptive Clustering Hierarchy)
- PEGASIS (Power-Efficient Gathering in Sensor Information Systems)
- ***TEEN (Threshold-Sensitive Energy Efficient Protocols)***

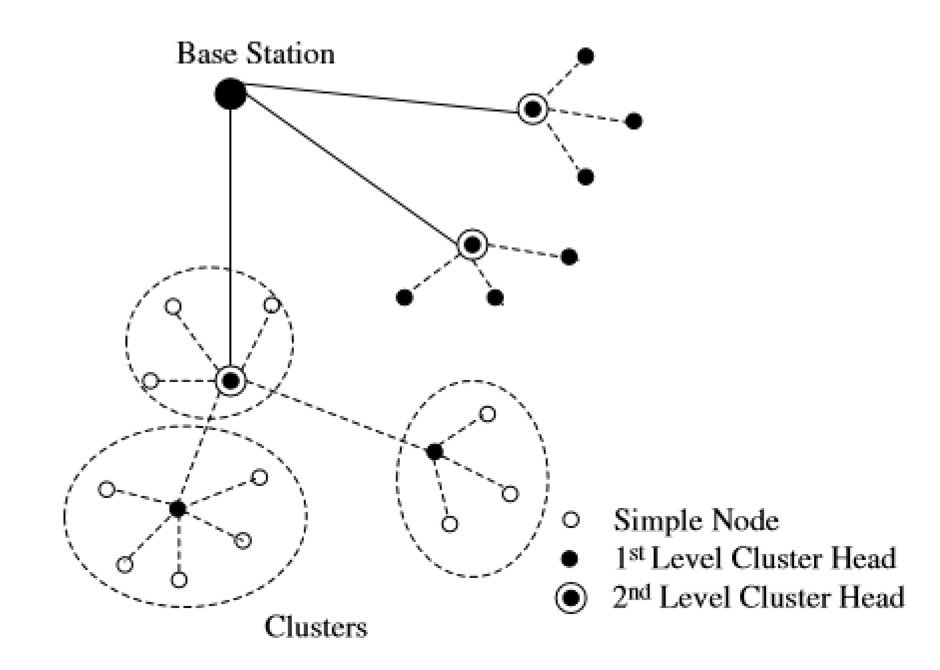
TEEN

- TEEN'S CH sensor sends its members a hard threshold and a soft threshold.
- TEEN'S suitability for time-critical sensing applications
- TEEN is also quite efficient in terms of energy consumption and response time
- TEEN also allows the user to control the energy consumption and accuracy to suit the application.

[1]A. Manjeshwar and D. P. Agarwal, "TEEN: a Routing Protocol for Enhanced Efficiency in Wireless Sensor Networks," *1st Int'l. Wksp. on Parallel and Distrib. Comp. Issues in WirelessNetworks and Mobile Comp.*, April 2001.

TEEN

- Hard threshold– minimum possible value when sensed attribute >= hard threshold
- Soft threshold – changes of attribute >= soft threshold



Hierarchical vs. flat topologies

Hierarchical routing	Flat routing
Reservation-based scheduling	Contention-based scheduling
Collisions avoided	Collision overhead present
Reduced duty cycle due to periodic sleeping	Variable duty cycle by controlling sleep time of nodes
Data aggregation by clusterhead	Node on multihop path aggregates incoming data from neighbors
Simple but non-optimal routing	Routing can be made optimal but with an added complexity.
Requires global and local synchronization	Links formed on the fly without synchronization
Overhead of cluster formation throughout the network	Routes formed only in regions that have data for transmission
Lower latency as multiple hops network formed by cluster- heads always available	Latency in waking up intermediate nodes and setting up the multipath
Energy dissipation is uniform	Energy dissipation depends on traffic patterns
Energy dissipation cannot be controlled	Energy dissipation adapts to traffic pattern
Fair channel allocation	Fairness not guaranteed

JAMAL N. AL-KARAKI, AHMED E. KAMAL," ROUTING TECHNIQUES IN WIRELESS SENSOR NETWORKS: A SURVEY", IEEE Wireless Communications • December 2004

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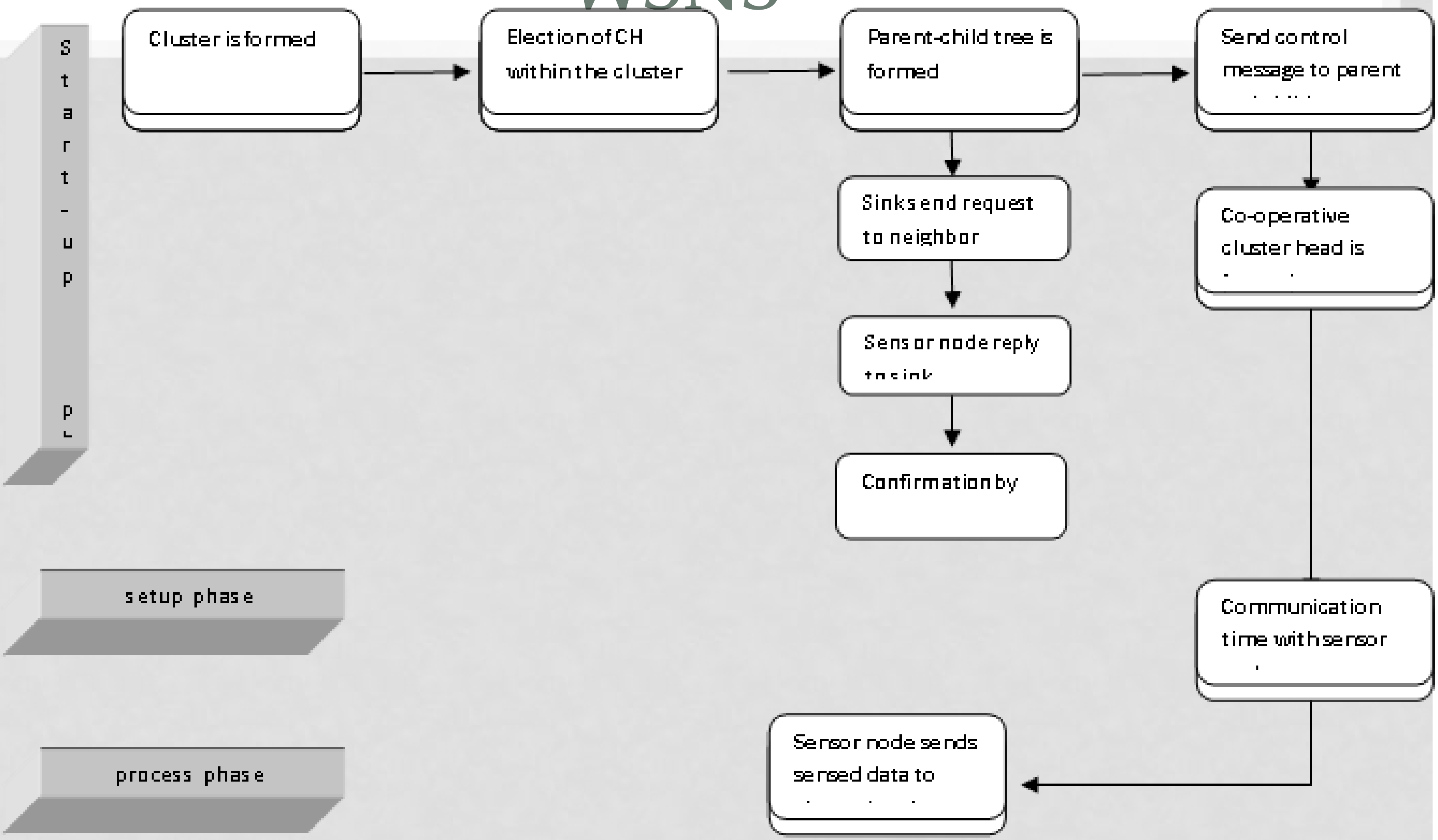
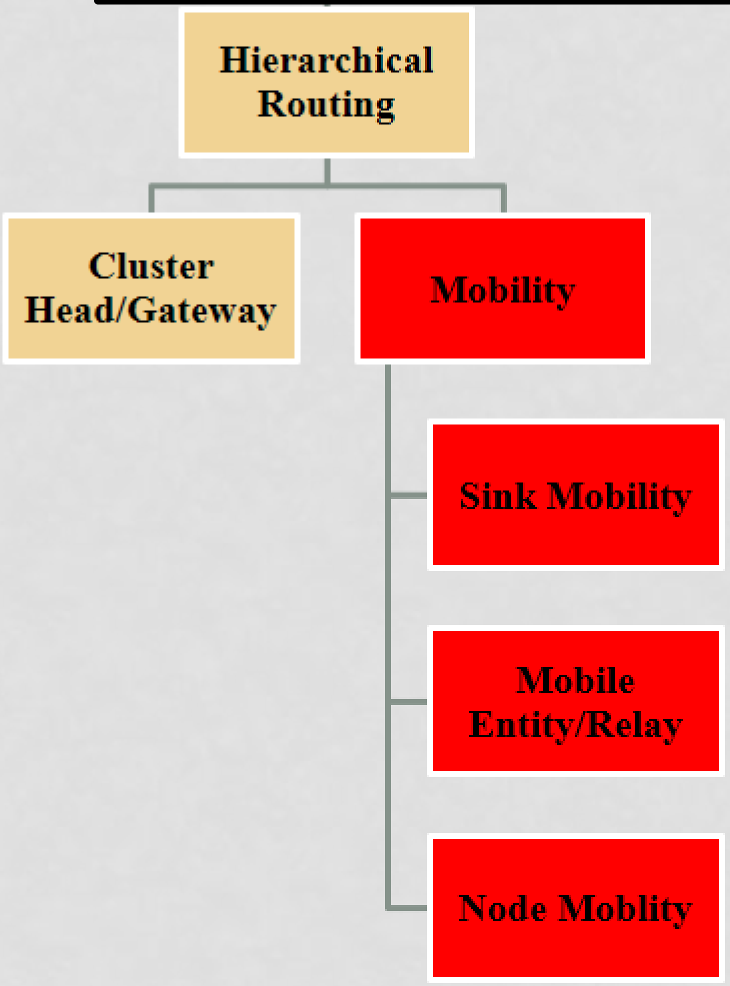
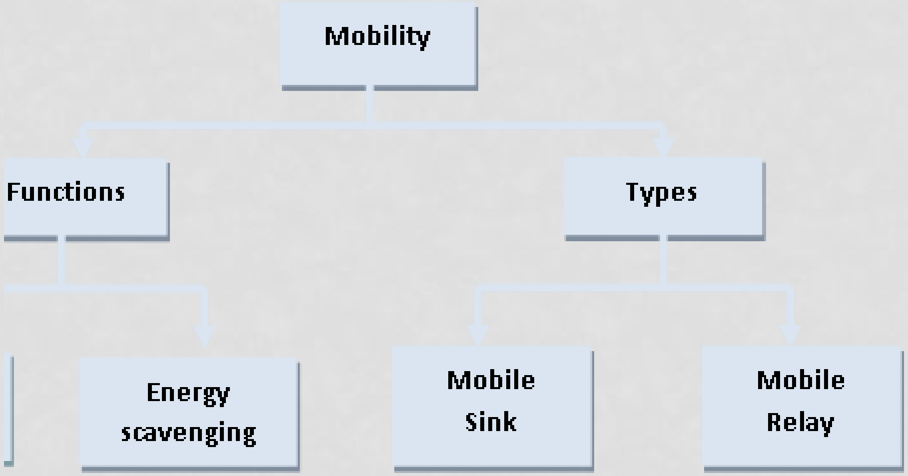
A HIERARCHICAL ROUTING PROTOCOL FOR SURVIVABILITY OF WSNS

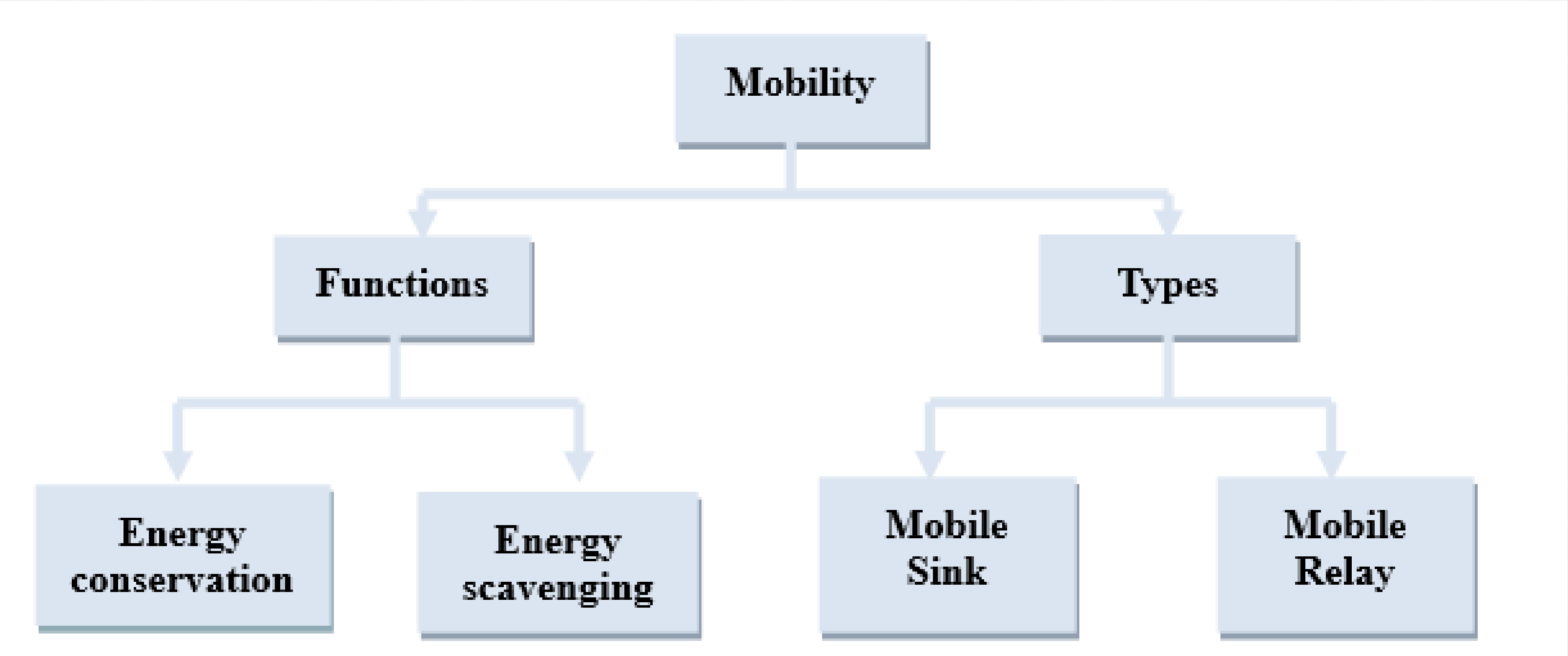


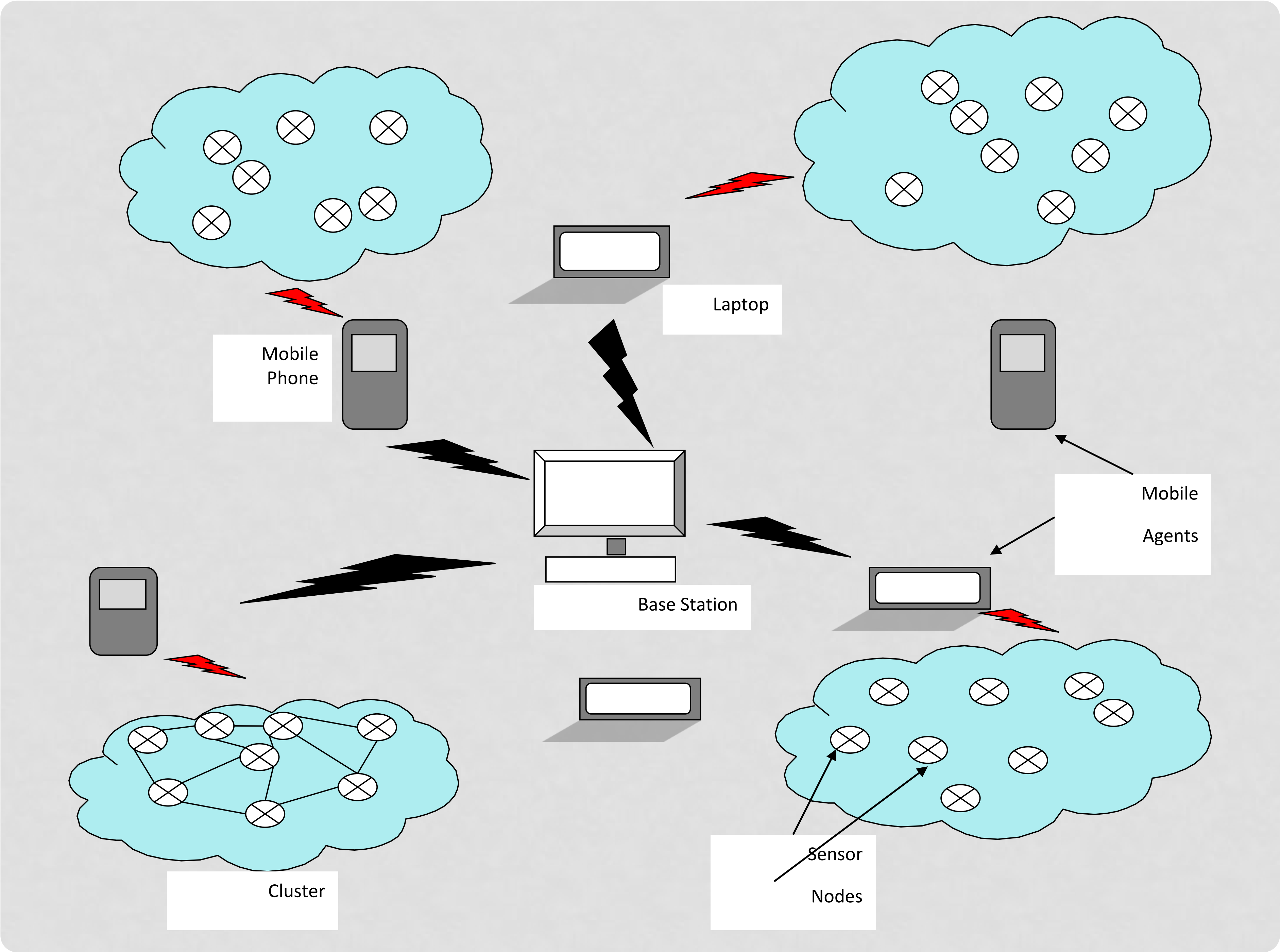
Mobility based hierarchical routing





Mobility based hierarchical routing



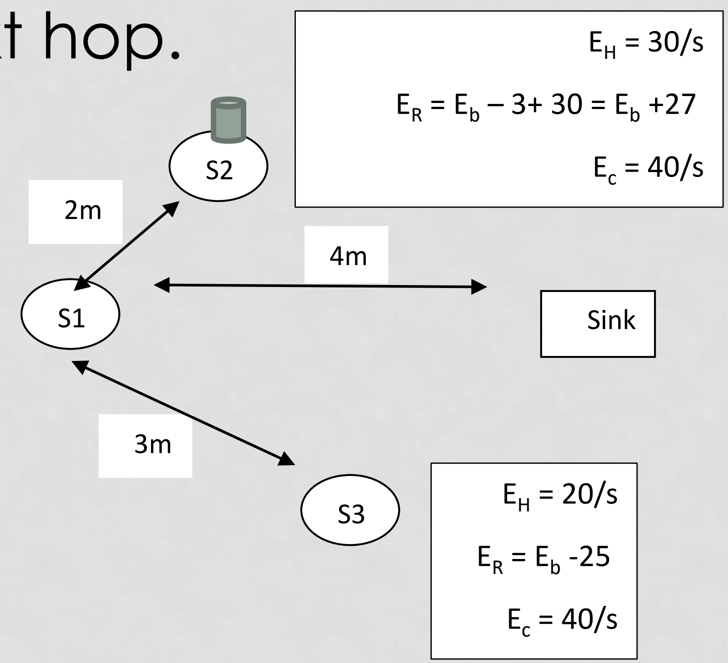

Laptop
Mobile
Phone
Mobile
Agents
Base Station
Cluster
Sensor
Nodes

Energy-Aware Routing to a Mobile Gateway in WSNs

- A less energy-constrained gateway node is deployed within the communication proximity of the sensors and assumes responsibility for organizing certain activities and collecting data from the other sensors in the network.
- A less energy-constrained gateway node is deployed within the communication proximity of the sensors and assumes responsibility for organizing certain activities and collecting data from the other sensors in the network.
- Mobility of the gateway causes a dynamic change in the network topology and these changes in topology should be broadcasted to the network frequently.
- gateway moves in linear strides to reach an intermediate position. An energy efficient route is set up at the initial gateway location to keep receiving packets without interruption until the next intermediate position is reached.

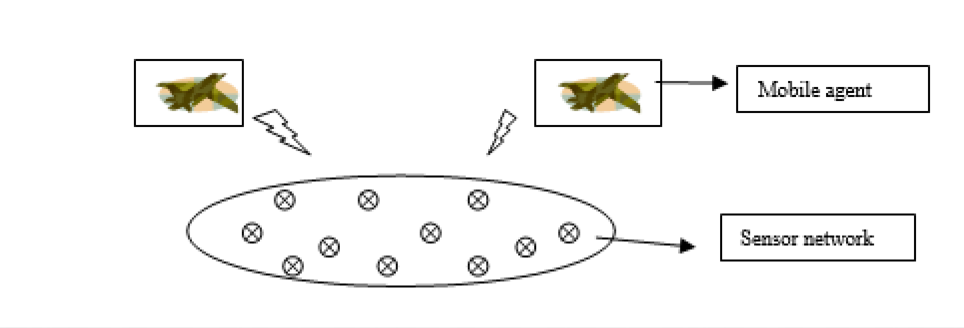
Question ?

- Node S1 can either forward the motion data to node S2 or node S3 depending on the residual energy of the nodes or its energy harvesting capability.
- Give a scenario for energy aware routing, whereby the nodes with the highest remaining energy will be selected as the next hop.



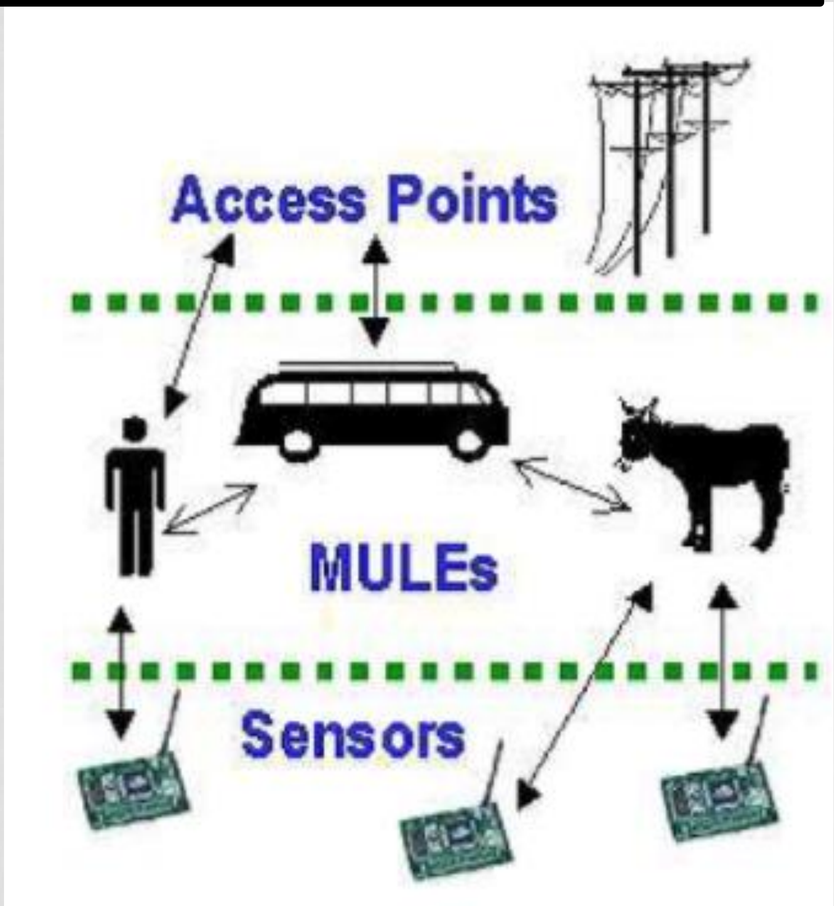
SENMA

- In SENMA, mobile agents (MA) are hardware, not software, units with powerful communication and processing capabilities.
- only MAs are responsible for data collection and therefore sensors spend minimal energy in receiving signals.
- in flat ad hoc architectures the transmitted signal decays at the 4th power of distance whereas in SENMA the signal decays at only the 2nd power of distance.



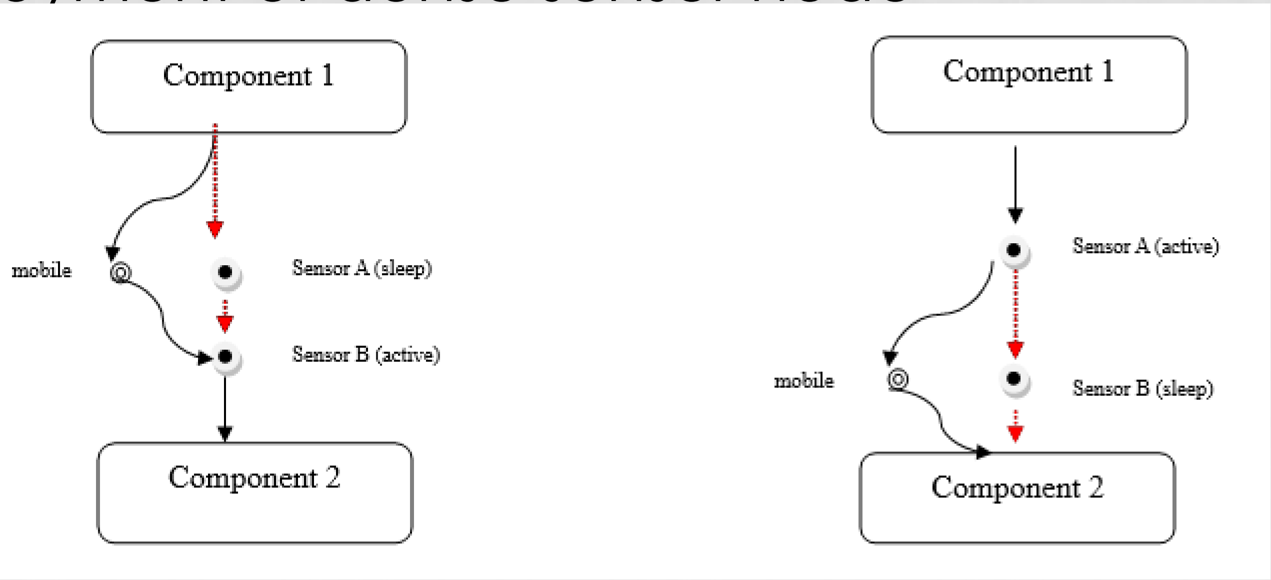
Data MULEs: Modeling a Three-tier Architecture for Sparse Sensor Networks

- MULEs retrieve data from sensors when they come into a closer range to the sensors, and then buffer it and forward to a wired access point.
- The main advantages of MULEs are their huge storage capacities, renewable power and their ability to communicate with sensors and access points.
- The initial movement of MULEs is based on a random walk in which their movement cannot be predicted



Extending the Lifetime of Wireless Sensor Networks through Mobile Relays

- Mobile nodes can move to areas limited in resources, such as areas of low density sensor deployment, and requires mobile nodes to attend to sense the environment. Hardware costs are lower with this approach, when compared to the deployment of dense sensor node



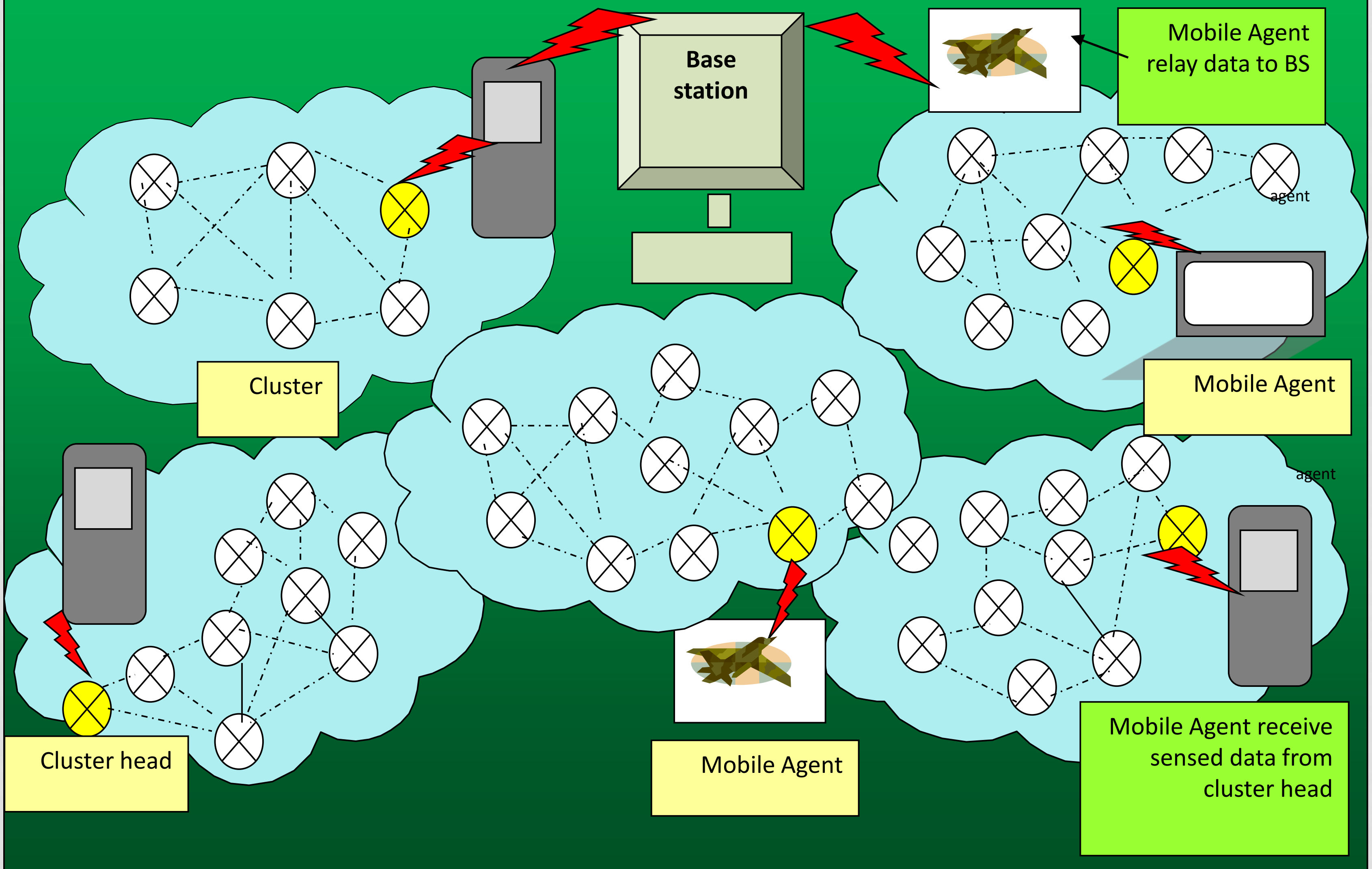
A New Architecture for Hierarchical Sensor Networks with Mobile Data Collectors

- mobile data collectors (MDC) at the upper tier and relay nodes, which act as cluster heads, at the middle tier.
- The MDC uses a fixed trajectory to visit all relay nodes and the base station. Also the MDC is a non power constrained device that collects data from the relay nodes and forwards it to the base station. Two key advantages of this architecture are: (i) the load of routing data to the base station is reduced which results in energy savings for the relay nodes; and (2) the MDC does not need to visit each sensor node frequently, therefore reducing the length of its trajectory. of the MDC.

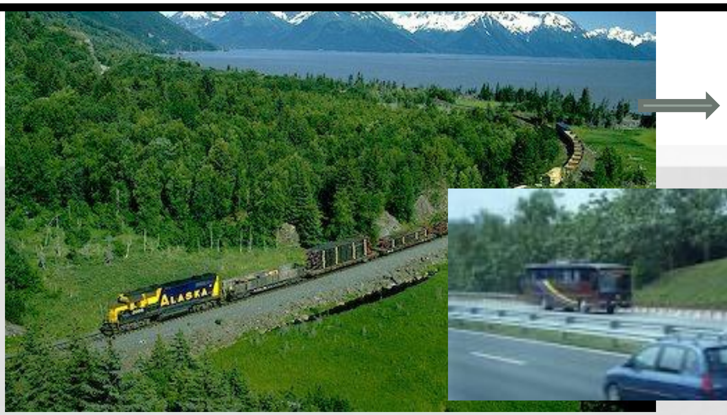
Energy Efficient Computing for Wildlife Tracking: Design Trade-offs and Early Experiences with Zebranet

- The ZebraNet is based on a mobile sensor network in which zebras are dedicated as mobile relays to collect data from sensors. The animals are equipped with collars embedding sensor nodes along with a global positioning system (GPS), flash memory, a dual band radio, wireless transceivers, and a small CPU
- Zebras in this project are designated as peers who exchange data when they are within the communication range. As they are mobile, they will also encounter other zebras along the network and their mobile sensors will exchange data with each other

Three-tier Architecture of Sensors, Mobile Agent and Base Station with Cluster Formation



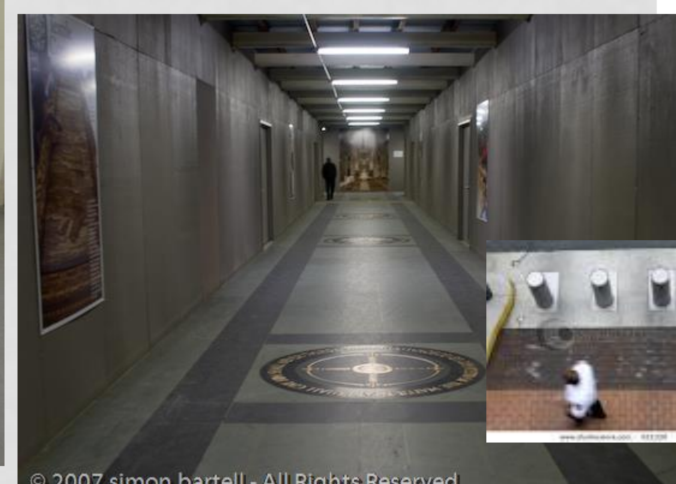
Mobile Agent



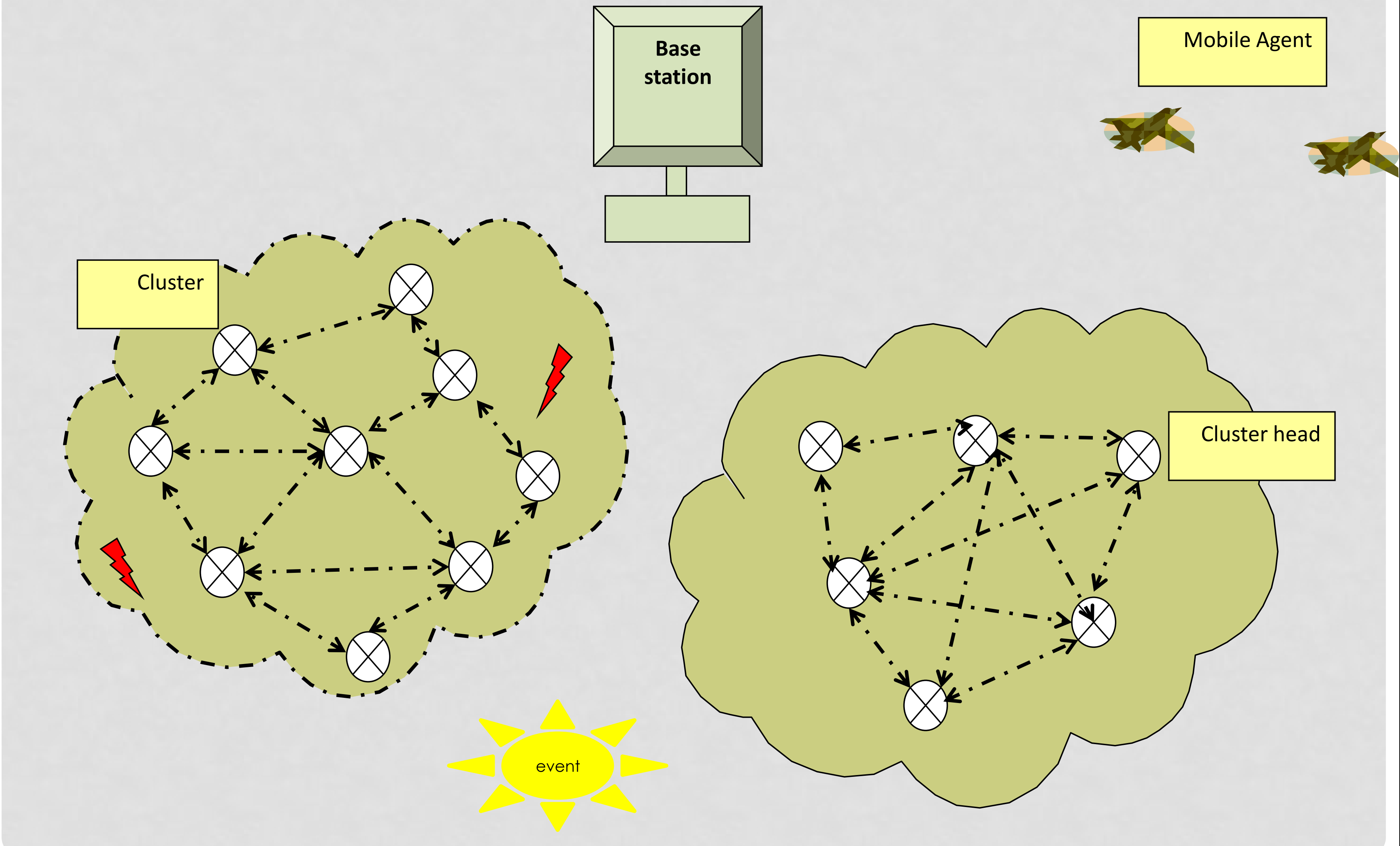
Controlled Mobility

Random Mobility

Random waypoint/chemotaxis
Mobility



Three-tier Architecture of Sensors, Mobile Agent and Base Station with Cluster Formation



Comparative Summary

BiSNET
(P. Boonma, 200

•Mobile agent as software agent

Mobile relay
(Wang et. al., 200

ting, computational

Data Collector
(Bari. A. et. al, 20

Energy Harvesting(Pro
(Mascarenas. D. et. a

Zebranet
(Juang et. al, 20

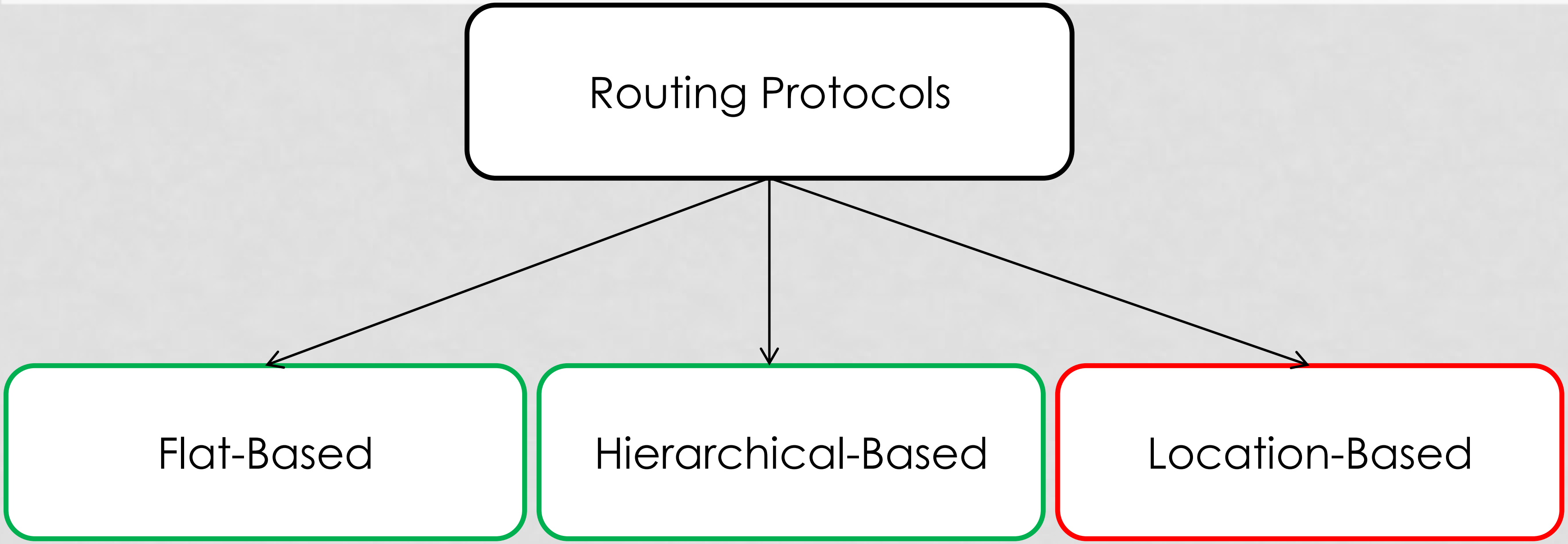
SENMA
(Tong et. al 200

	ZigBee 802.15.4	Bluetooth 802.15.1
Applications:	Monitoring and control	Cable replacement
Data capacity (Kbps):	250	1,000
Range (meters):	70	10
Battery life	years	days
Nodes per network	255 - 65,000	8
Software size (Kbytes):	4 - 32	250
Security	Good	Moderate

Mobile device (Prototype)
(Prem et. al., 2007)

•Mobile agent transmission through bluetooth – BIMAS uses ZigBee

Network Structure Categorization



- Sensor nodes are addressed based on their location
- Location are acquired by GPS or via coordination among nodes

Location-Based Routing

Geographical Adaptive Fidelity (GAF)

- GEAR (Geographic and Energy Aware Routing)
- GEM

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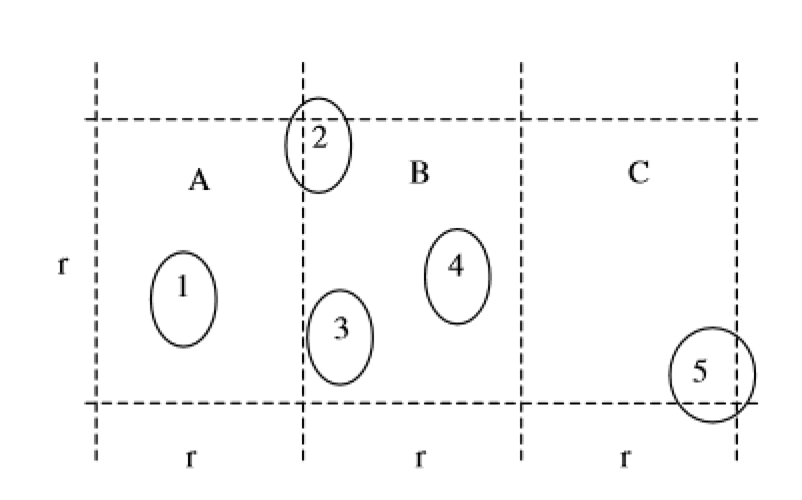
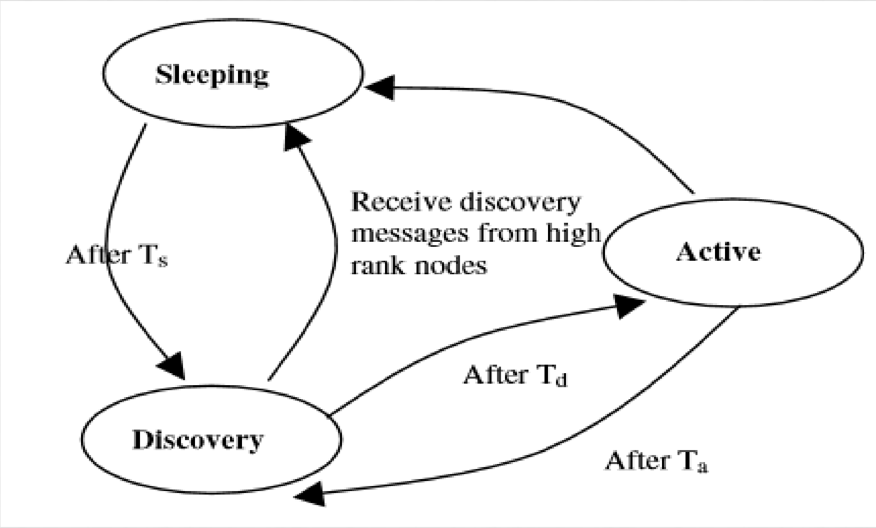
Geographical Adaptive Fidelity (GAF)

- Network divided into zones
- Only one node is awake in each zone, the rest sleep

❖ Conserves energy by turning off unnecessary nodes

❖ Increases the network life time





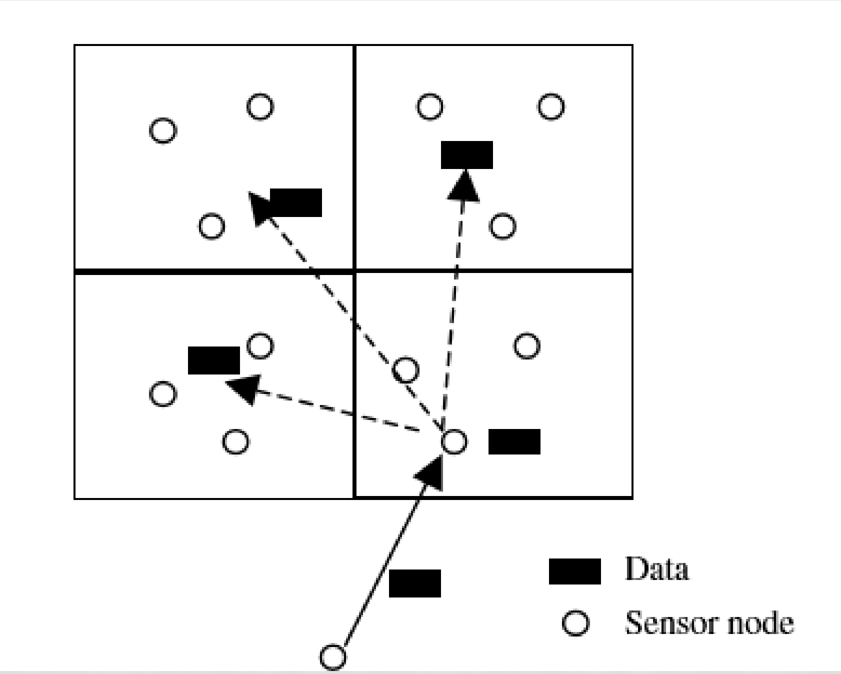
GEAR

- The key idea is to restrict the number of interests in directed diffusion by only considering a certain region rather than sending the interests to the whole network.
- keeps an estimated cost – residual energy and distance to destination
- and a learning cost – refinement of estimated cost considering routing hole

[1]Y. Yu, D. Estrin, and R. Govindan, "Geographical and Energy-Aware Routing:A Recursive Data Dissemination Protocol for Wireless Sensor Networks," UCLA Comp. Sci. Dept. tech. rep., UCLA-CSD TR-010023, May 2001.

GEAR

- The region is divided into four sub regions and four copies of the packet are created
- This splitting and forwarding continuous until the region with only one node is left



Comparison between GPSR *and GEAR*

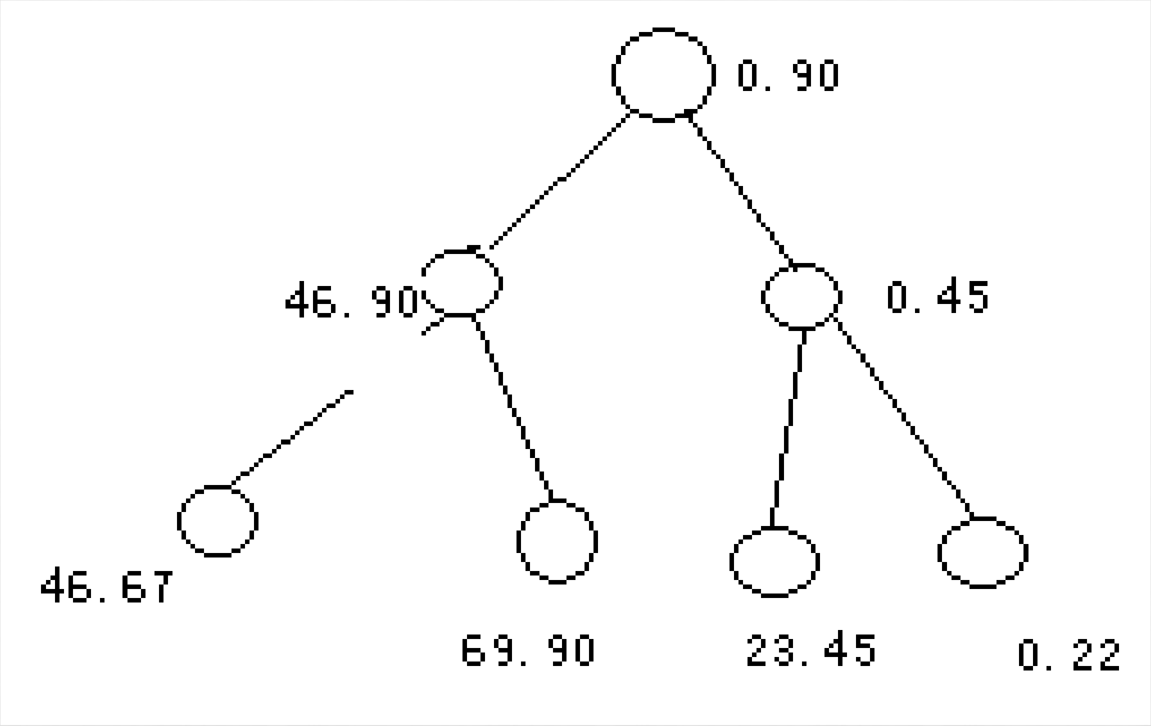
- GPSR：designed for general mobile ad hoc networks
- Two parameter
  - Uniform Traffic
  - Non-uniform Traffic
- For uneven traffic distribution, GEAR delivers 70–80 percent more packets than GPSR. For uniform traffic pairs GEAR delivers 25–35 percent more packets than GPSR.

GEM

- Three type of storage data
  - Local storage
  - External storage
  - Data-centric storage
- Setup phase
  - Set up a tree
  - Feedback the number of tree
  - Assign the virtual degree

GEM

- The main application of relative steady topology sensor network



Routing Protocols based on Protocol Operation

1. Multipath routing
   - Increases fault tolerance
   - Sophisticated case: have back up paths

2. Query-based routing
   - Query transmitted and the date is sent back

3. Negotiation-based routing
   - High-level data description
   - Elimination of redundant data transmission

4. QoS-baed routing
   - Balance between data quality and energy consumption

Simulation

- Routing in Wireless Sensor Networks- Part- I
- https://www.youtube.com/watch?v=OaUE4otTsuc

Multihop	Energy Conserve Routing	Adding energy to 25% static sensor	One mobile relay	Mobile base station
1	**3.76**	**5.4**	**7.8**	**9.67**

Normalized Lifetime

Summary

- WSNs needs have specific characteristics.
- WSNs need specific routing algorithm.
- Large number of algorithms has been designed, but no optimal one!
- Based on the network structure, routing algorithms can be categorized into 3 main groups.
- We briefly discussed some examples of each group.

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Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Microsensor Networks," *Proc. 33rd Hawaii Int'l. Conf. Sys. Sci.*, Jan. 2000.

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Manjeshwar and D. P. Agarwal, "TEEN: a Routing Protocol for Enhanced Efficiency in Wireless Sensor Networks," 1st Int'l. Wksp. on Parallel and Distrib. Comp. Issues in WirelessNetworks and Mobile Comp., April 2001

Y. Yu, D. Estrin, and R. Govindan, "Geographical and Energy-Aware Routing:A Recursive Data Dissemination Protocol
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