ROUTING in Wireless Sensor Networks*

* Jamal Al-Karaki & Ahmed Kamal « Routing Techniques for Wireless Sensor Networks »

Taxonomy of routing in WSN

- Flat
  - Data Centric
  - Location-based
- Hierarchical

Data-centric routing

Data-centric Routing

- Sink broadcast queries and waits for data
- Attribute-based naming specifies the properties of data

Data-centric Routing

- **Flooding/Gossiping**
- **SPIN - Sensor Protocols for Information via Negotiation**
- **Directed Diffusion**
- **Energy-aware Routing**
- **GBR - Gradient-Based Routing**

- **Rumor Routing**

- **COUGAR**
- **ACQUIRE**

Data-centric Routing

- **Flooding**
  - Sensors broadcast every packet they receive
  - Relay of packet till the destination or TTL=0
- **Gossiping**
  - Sensors send a received packet to a randomly selected neighbor or set of neighbors

Flooding/Gossiping

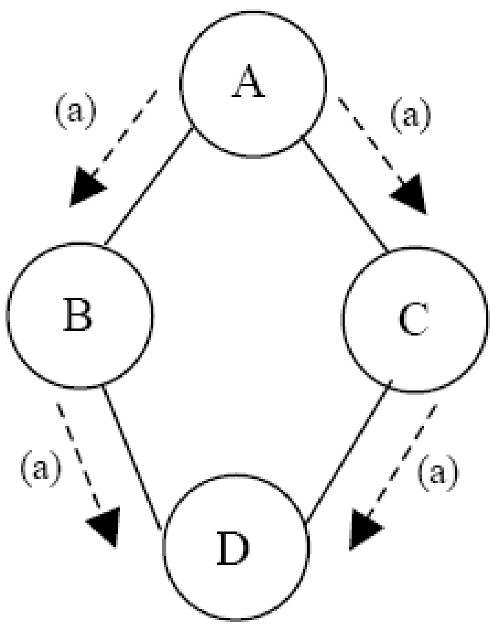


Fig. 1: The implosion problem. Node A starts by flooding its data to all of its neighbors. D gets two same copies of data eventually, which is not necessary.

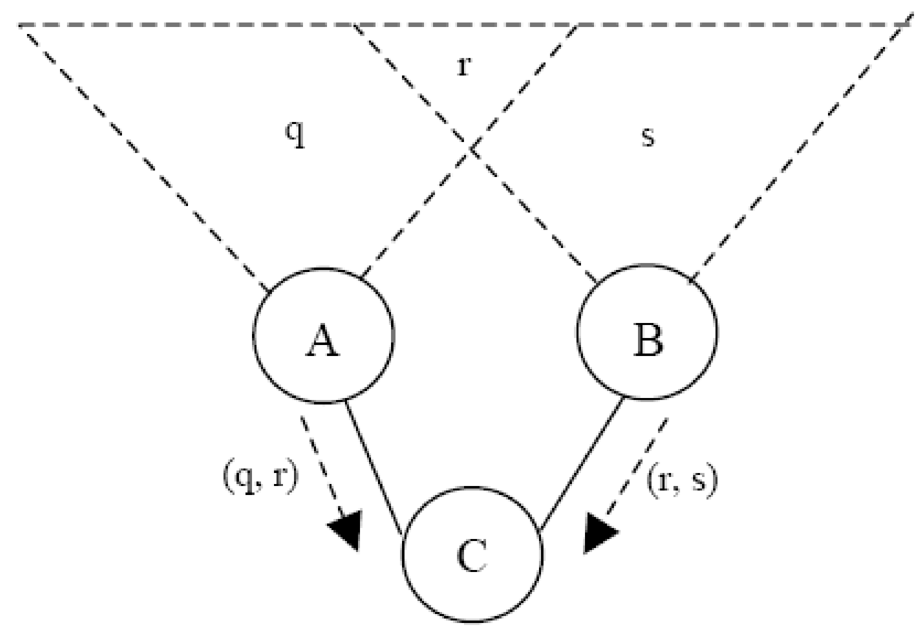
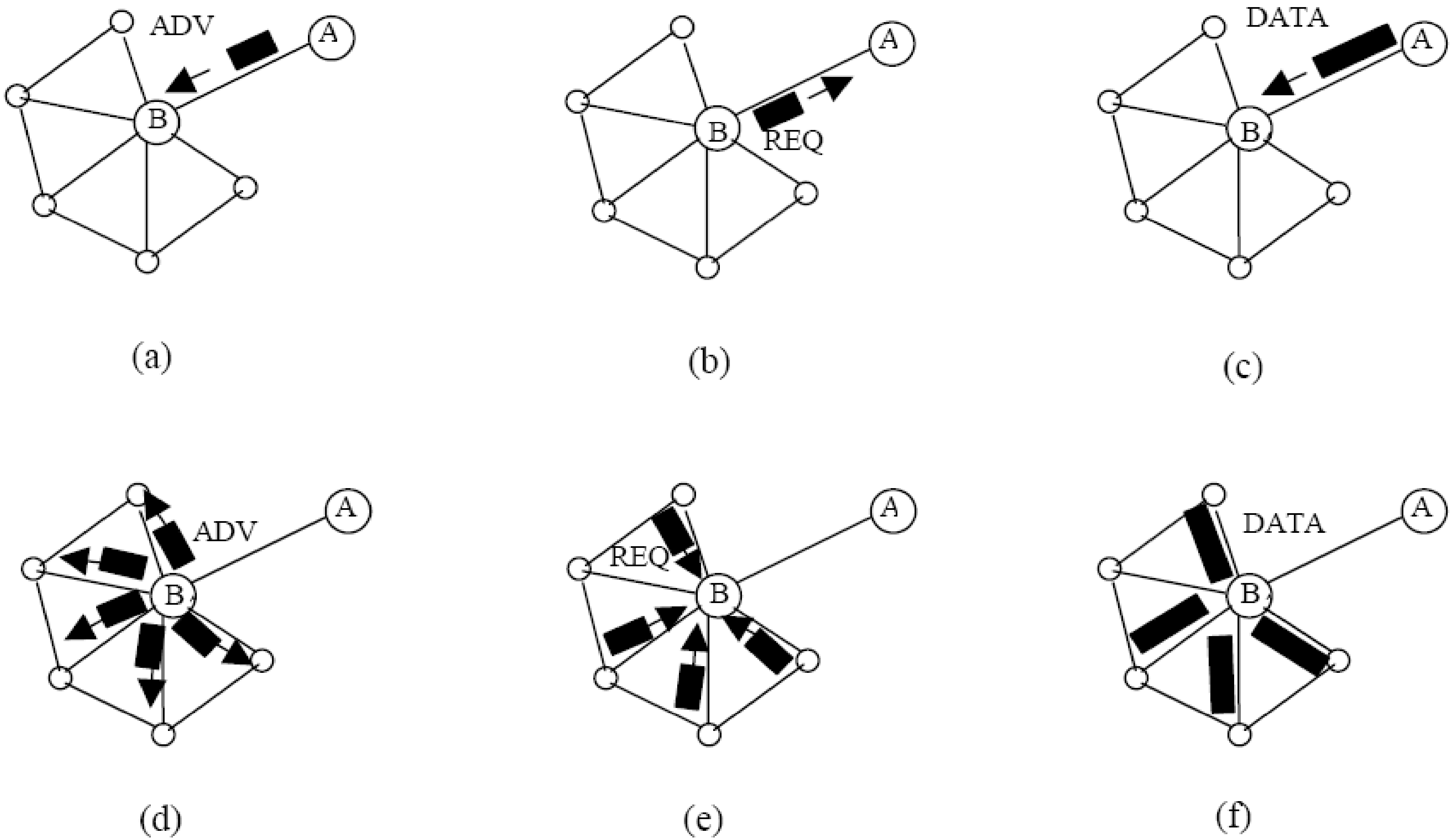


Fig. 2: The overlap problem. Two sensors cover an overlapping geographic region and C gets same copy of data form these sensors.

SPIN

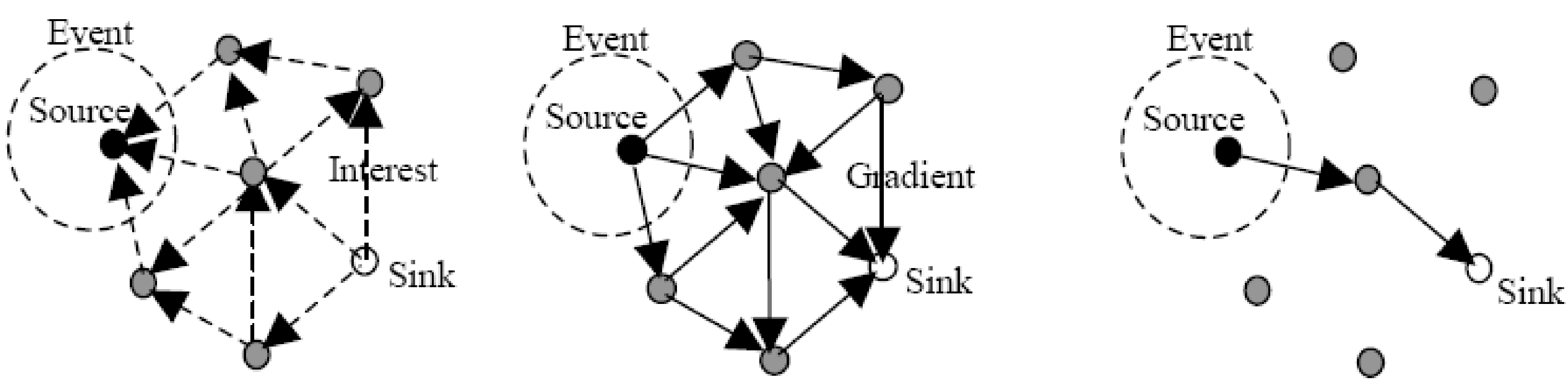


Directed Diffusion

- Uses a naming scheme for the data to save energy
- Attribute-value pairs for data and queries on-demand (Interests)
- Interests are broadcasted by the sink (query) to its neighbors (caching), which can do in-network aggregation
- Gradients = reply links to an interest (path establishment)

Direct Diffusion

- Energy saving and delay done with caching
- No need for global addressing (neighbor-to-neighbor mechanism)



(a) Interest propagation

(b) Initial gradients setup

(c) Data delivery along reinforced

Energy Aware Routing

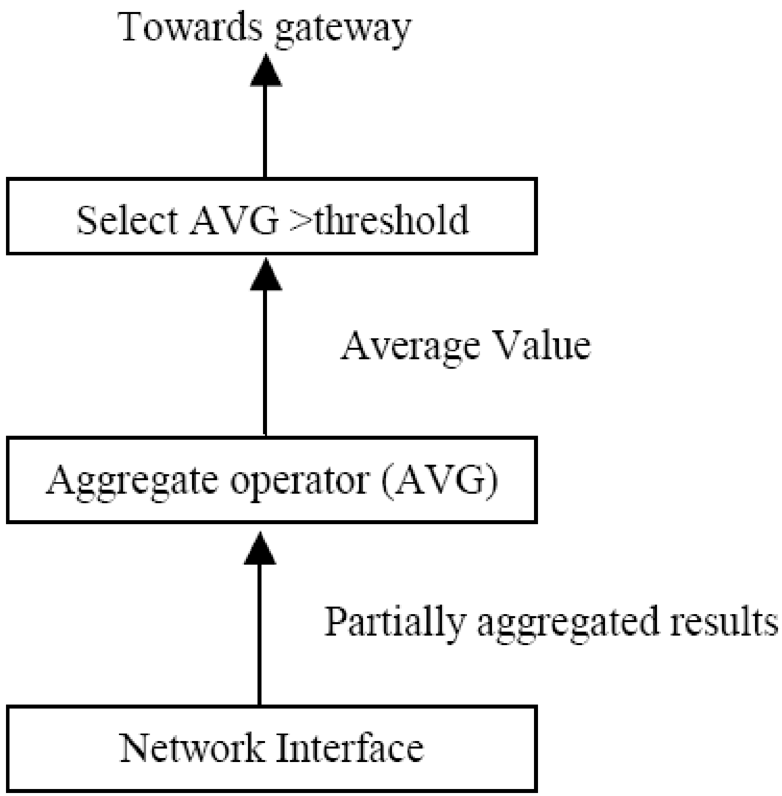
- Occasional use of a set of sub-optimal paths
- Multiple paths used with certain probability
- Increase of the total lifetime of the network
- Hinders the ability for recovering from node failure

Gradient-Based Routing

- Slightly changed version of Directed Diffusion
- Keep the number of hops to the sink when an interest is created (height of the node)
- Node’s height – neighbors height = gradient of the link
- Node forward packet to the link with largest gradient

COUGAR

- Views the network as a huge distributed database
- Declarative queries to abstract query processing from network layer functions
- Introduces a new query layer that specifies a query plan and a leader that that will execute the plan and perform data aggregation and transmission to the sink



Query plan at a leader node

COUGAR

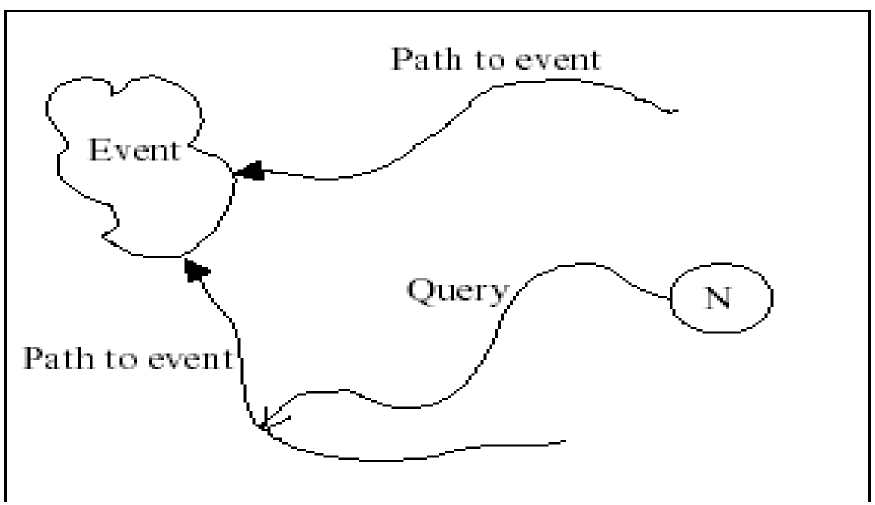
- Disadvantages
  - Additional query layer brings overhead in terms of energy consumption and storage
  - In network data computation requires synchronization (i.e. wait for all data before sending data)
  - Dynamically maintenance of leader nodes to prevent failure

ACQUIERE

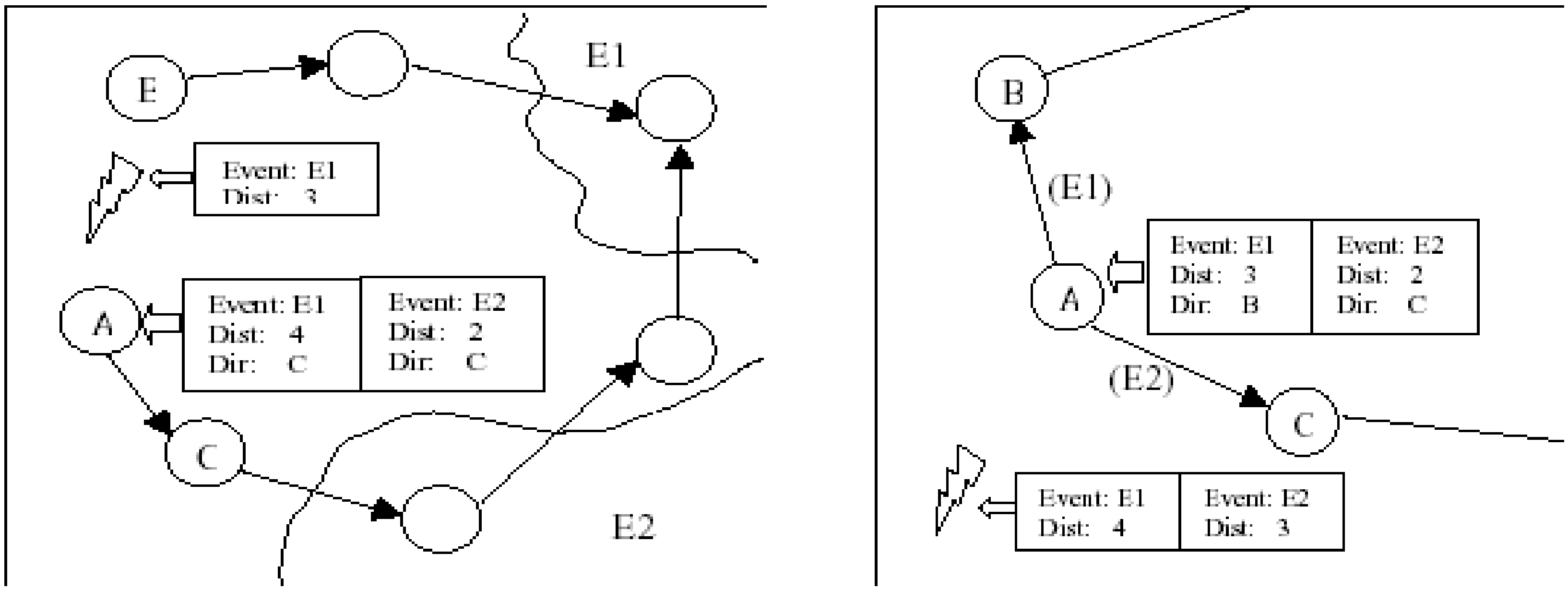
- The network is viewed as a distributed database
- Node receiving a complex query from the sink tries to respond partially and then forwards packet to a neighbor
  - Use of pre-cached information
  - If cache information is not up to date ➔ node gathers information from neighbors within look ahead of d hops
- After the query is answered, result is returned to the sink by using the reverse path or the shortest path

Rumor Routing

- Variation of Directed Diffusion
  - Flood event information instead of flooding queries
- When a node receives a query it checks its event table
  - returns source – destination path or
  - forwards randomly the query

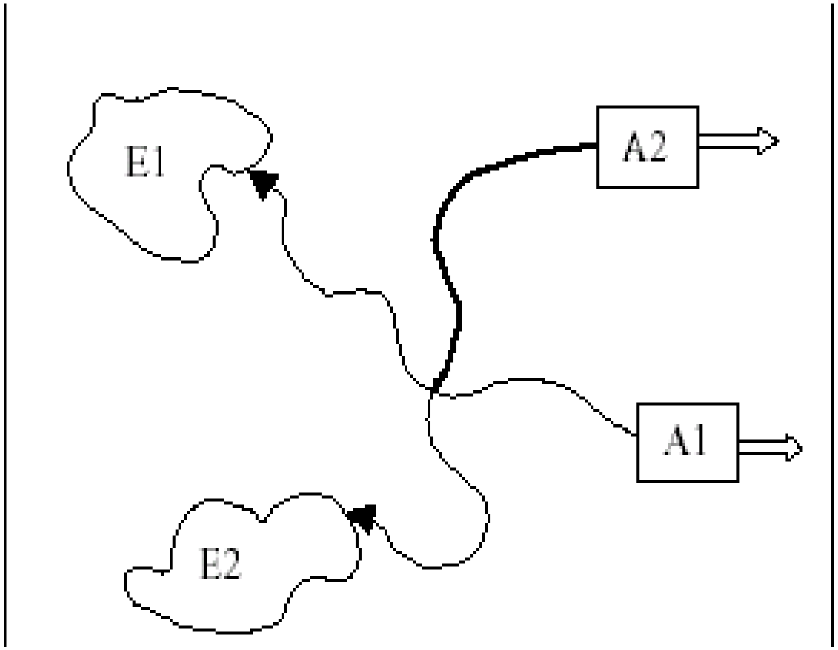


Rumor Routing



- A node that witnessed an event generates an agent (packet) that spreads in the network the event information
- When an agent visits a node they synchronize their event tables

Rumor Routing



- When two agents meet they synchronize their event tables

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

Location-based Routing

Location-based Routing

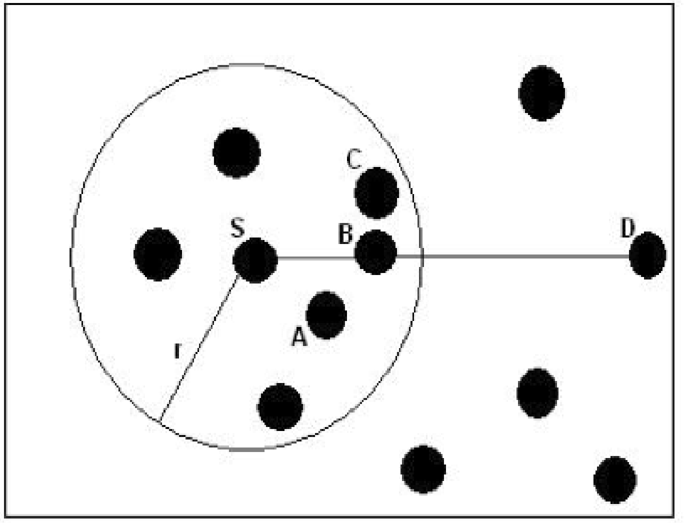
- GPS-based localization of sensors
- Routing uses the information on sensor's position
- Most of protocols work for mobile sensors

Location-based Protocols

- **GR - G**eographic **R**outing
- **GAF - G**eographic **A**daptive **F**idelity
- **GEAR - G**eographic and **E**nergy **A**ware **R**outing

Geographic Routing

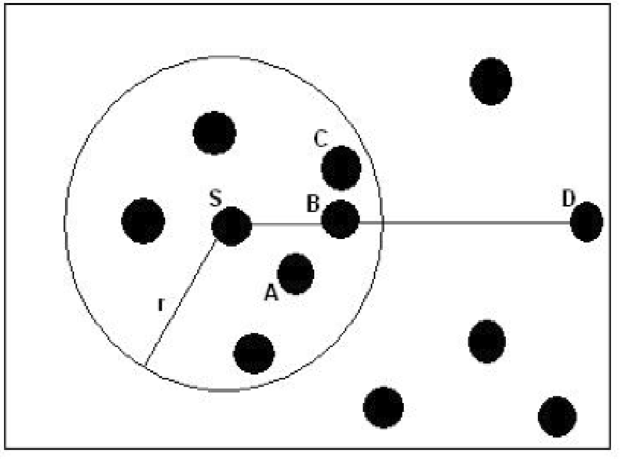
- Nodes use GPS to determine their position
- Nodes know the location of their neighbors



« r » : the radio range

Geographic Routing

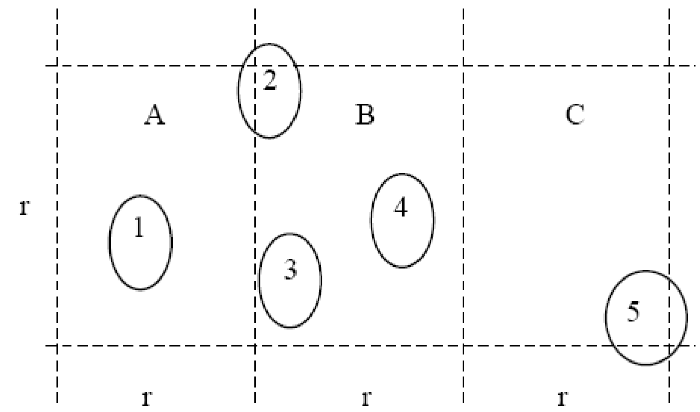
- Greedy strategy
  - Most forward within « r » (closest neighbor to the destination, e.g. C)
  - Nearest forward progress (e.g. A)
  - Nearest forward progress with compas (nearest on the line between source and destination, e.g. B)



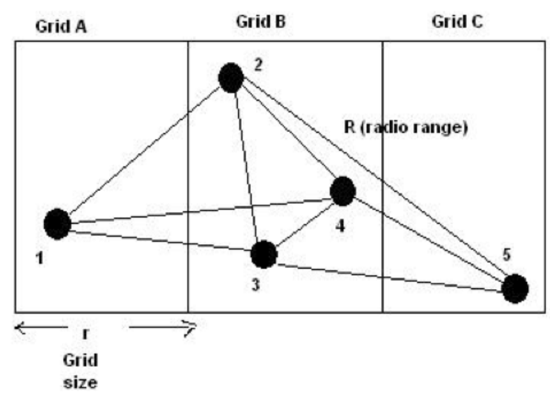
« r » is the radio range

Geographic **A**daptive **F**idelity

- "Virtual grid" to cover the area
- Nodes use GPS to bind to some cell in the grid
- One master node/cell (equivalent nodes, slaves, turn off)

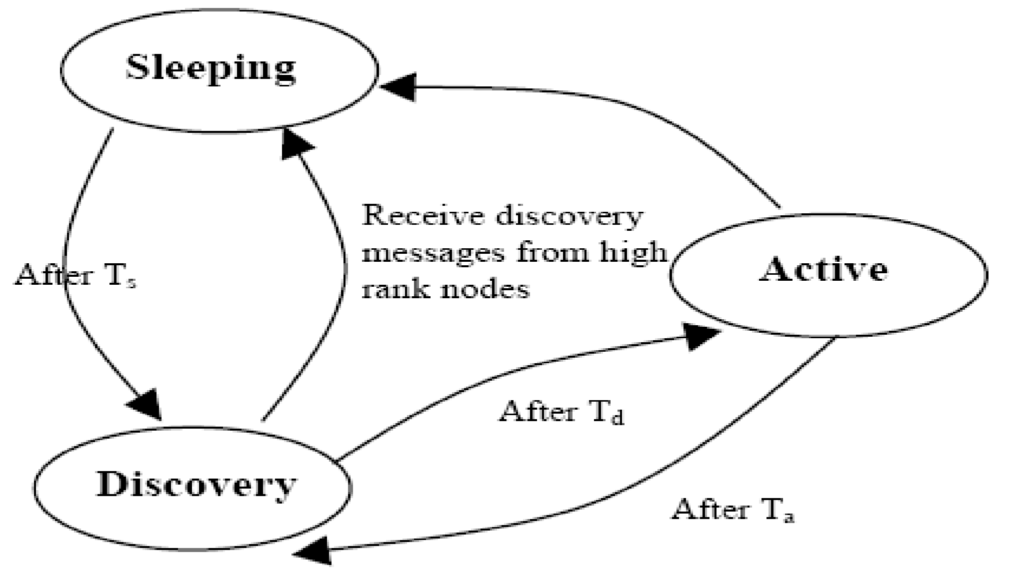


r<R/√5, R is the radio range



Geographic **A**daptive **F**idelity

- Three States
  - Discovery
  - Active
  - Sleep
- No aggregation/fusion
- Handle mobility
- As good as a normal Ad hoc in terms of latency and packet loss (saving energy)



Geographic and Energy Aware Routing

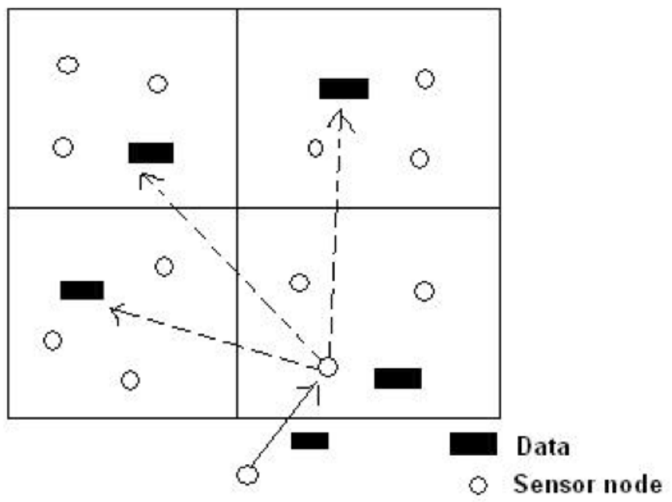
- Introduced to efficiently propagate queries (similar to Direct Diffusion restricted to the interest region)

- Uses heuristics to route packets
  - Energy aware neighbor selection
  - Geographically-informed neighbor selection

- Costs of reaching destination through neighbors
  - Estimated : Residual energy and distance to destination
  - Learned : Accounts for routing around holes (propagated one hop back when the packet reached the destination)

Geographic and Energy Aware Routing

- Two-Phase protocol
  - Forwarding towards the region
    - the neighbor closest to the target region
    - no neighbor found (hole) – use learning cost or random
  - Forwarding within the region
    - Classic flooding or
    - Geographic recursive flooding

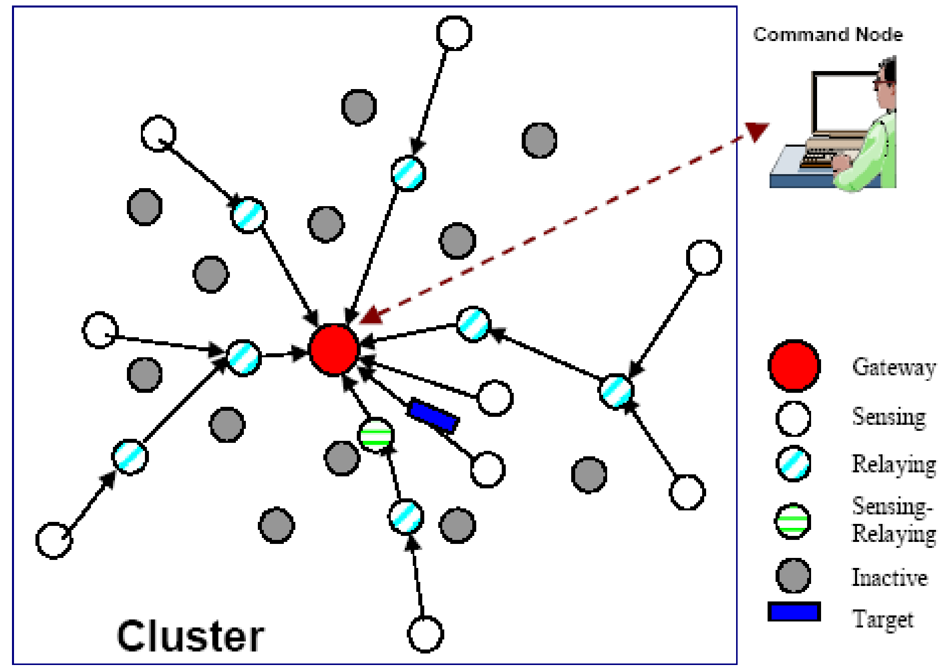


Geographic recursive flooding

Hierarchical Routing

Hierarchical Routing

- Cluster-based
- Single or Multi-hop communication within a particular cluster
- Data aggregation/fusion decreases the number of the transmitted packets



States of nodes inside a cluster

Hierarchical Routing

- **LEACH – Low-Energy Adaptive Clustering Hierarchy**
- **PEGASIS - Power-Efficient GAthering in Sensor Information Systems**
- **TEEN - Threshold sensitive Energy Efficient sensor Network protocol**
- **APTEEN - Adaptive Threshold TEEN**
- **MECN - Minimum Energy Communication Networks**

LEACH

- Cluster based routing including a distributed cluster formation layer
- Cluster-heads compress and aggregate data within the cluster and send it to the base station
- Use TDMA/CDMA to reduce inter-cluster/intra-cluster collisions
- Cluster-heads rotate randomly in order to balance the energy consumption
- Operates in a two phase rounds
  - Setup phase : cluster organization
  - Steady phase : data transfer

LEACH

- **SetUp Phase at round "n"**
  - A sensor **s** selects a random number v in [0,1]
  - If $v<T(n)$ then **s** becomes cluster head, T(n) depends on n, the percentage of desired cluster heads, the set of nodes not selected in the past etc ...
  - Each cluster head broadcasts its status to the network
  - A non cluster head attaches to a cluster head based on the signal strength of the cluster head advertisement
  - A cluster head assigns slots and schedules the transmission inside its cluster using TDMA

LEACH

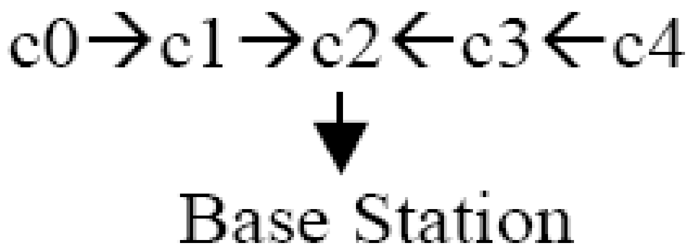
- **Steady Phase at round "n"**
  - Each member of a cluster can send data to its cluster head
  - A cluster head aggregates the received data and sends it to the base station using CDMA

LEACH

- Advantages
  - Completely distributed and no global knowledge of the network
  - Increases the network lifetime compared to SPIN or Directed Diffusion
- Disadvantages
  - Assumes cluster heads communicate directly to the base station
  - Dynamic changing of clustering brings extra overhead (advertisements, etc)

PEGASIS

- Chain-based transmission
  - One node in the chain (chain head) sends to the base station aggregated data
  - Chain head dynamically changes following the round robin strategy
- Chain formed using a greedy strategy



PEGASIS

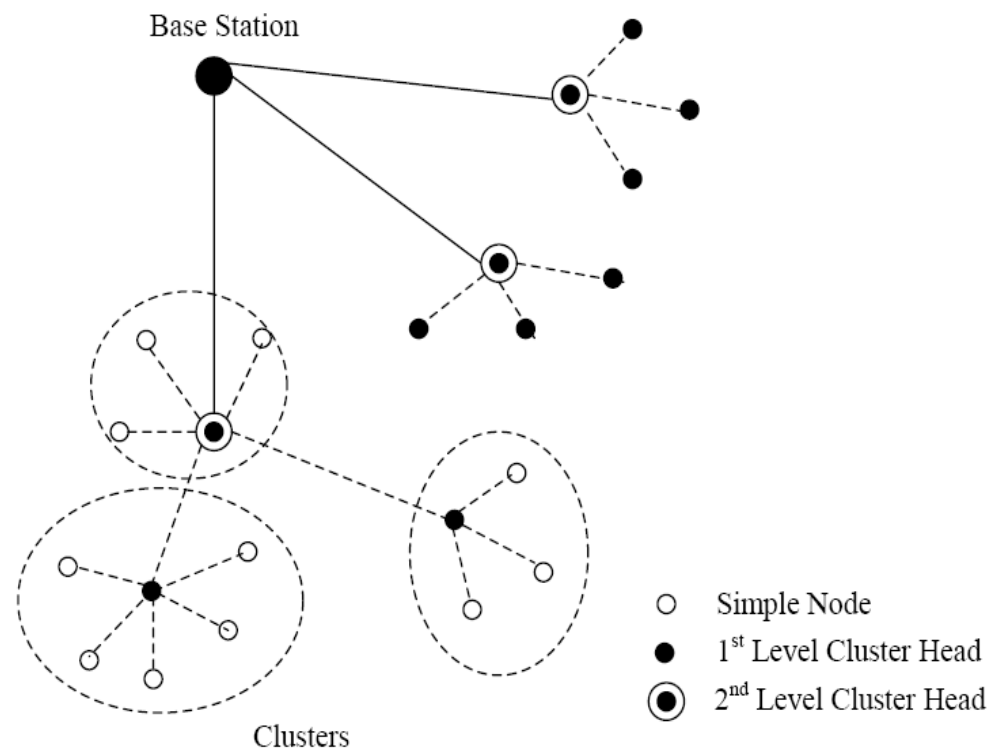
- Advantages
  - Completely distributed and no global knowledge of the network
  - Increases the network lifetime compared to LEACH
- Disadvantages
  - Assumes each node communicates directly to the base station
  - Each node maintains a data-base related to the location of the other nodes in the system

Hierarchical PEGASIS

- Simultaneous transmissions of data messages
- Chain nodes form a tree-like hierarchy
  - Each selected node in a level transmits data to the upper level in the hierarchy
- Avoid collisions and possible signal interference
  - Signal Coding (e.g. CDMA)
  - Only spatially separated nodes can transmit at the same time

TEEN

- Designed for time-critical applications
- Hierarchical clustering
  - Close nodes form clusters of “first level”
  - Cluster heads of “first level” form clusters of “second level”
- Cluster heads broadcast
  - Hard Threshold
  - Soft Threshold (used to reduce the number of transmissions)



APTEEN

- Changes the periodicity or the threshold values of TEEN according to the user will
- Cluster heads broadcast
  - Attributes
  - Thresholds (hard and soft)
  - TDMA schedule
  - Count Time – the time between two reports

TEEN & APTEEN

- Advantage
  - Outperforms LEACH in terms of energy dissipation and total lifetime of the network
- Disadvantage
  - managing multiple levels of clusters

MECN

- Utilizes low power GPS

- Identifies a *relay region* – set of nodes such that the transmission through them is more efficient than the direct transmission

- Find for any two nodes sub-networks to relay the traffic

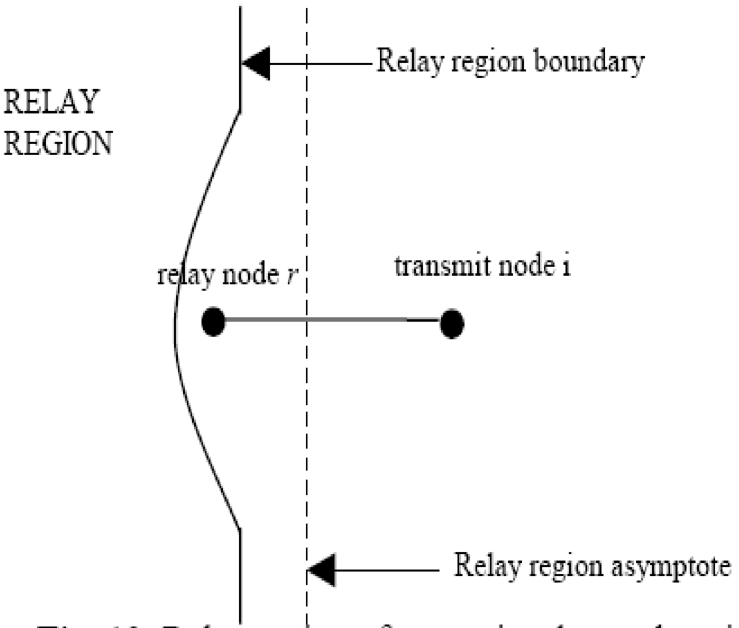


Fig. 10: Relay region of transmit-relay node pair (i, r) in MECN.

Hierarchical vs Flat Routing

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 clusterheads 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