CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF ELECTRICAL ENGINEERING

DEPARTMENT OF TELECOMMUNICATION ENGINEERING

B(E)2M32BTSA - Wireless Technologies

Routing in Wireless Sensor Networks

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Outline

Overview of Wireless Sensor Networks (WSN)

- Key characteristics

Routing in WSN

- Routing process and stages
- Routing metrics
- Classification of protocols
- Principle of selected routing protocols
  - From flooding to location-based protocols

Wireless Sensor Networks

Wireless Sensor Network (WSN)

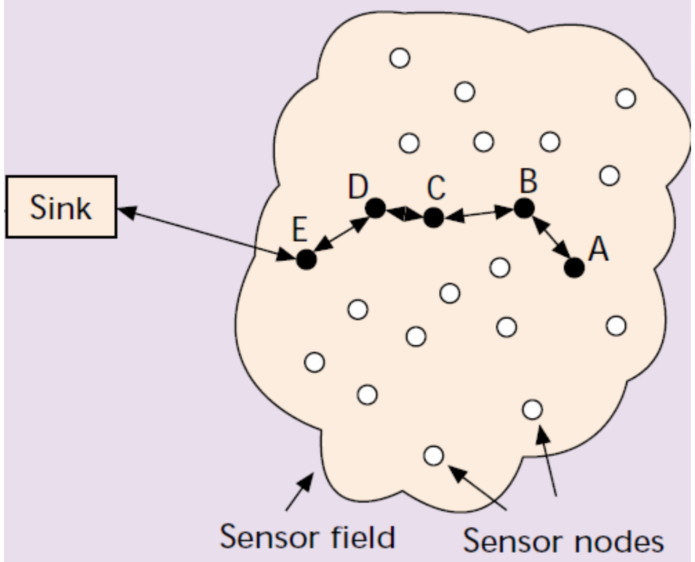
- **Set of nodes** (sensors) distributed in a field and exchanging information
- From **tens or hundreds** to **thousands nodes** in network
- Deployed in **structured** or **unstructured** manner
- **Wide range of traffic patterns** depending on application

Each **Node** (Sensor) can act as

- **Source**
  - Generates data to be sent
- **Sink / Destination**
  - Receives data generated by Source
- **Relay** of data (Source to Sink)

Key characteristics of nodes (sensors)

- Low **cost**
- Low **energy** consumption (battery life-time)
  - Limited **computing** and **processing** capabilities
  - Limited **communication range**

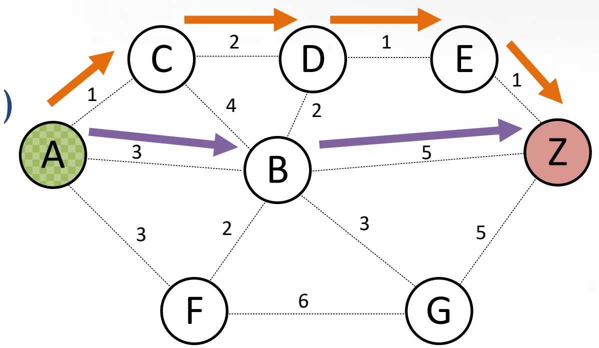


I.F. Akyildiz et al, "A survey on Sensor Networks," IEEE Communications magazine, 2002.

Routing Protocols

General types of routing protocols for computer networks

- **Distance Vector** (DV)
  - Keep routing tables (Destination, Next hop, Hop count)
  - Selects the shortest path hops
    - Simple, but disregards communication channels
- **Links state** (LS)
  - Routing table with route metric
  - Consider status of communication links between nodes
    - High overhead for route management



Challenges and issues for WSN routing

- Dynamic time varying wireless channel and topology (movement, fading, …)
- Asymmetric wireless channels (multipath propagation, interference, …)
- Limited resources for route management (signaling)
- Energy constraint for nodes

→ DV and LS in their basic form may not be good solutions for WSN

Routing process

Route **discovery**

- Find possible (suitable) routes between Source and Sink nodes
  - Including **cost** of routes

Route **selection**

- Select the **most suitable route** among all routes found during discovery
  - Depends on routing metric and complexity

Route **maintenance**

- Keep **information** about route status **up-to-date**
  - Mobility, interference, battery depletion, new node, …

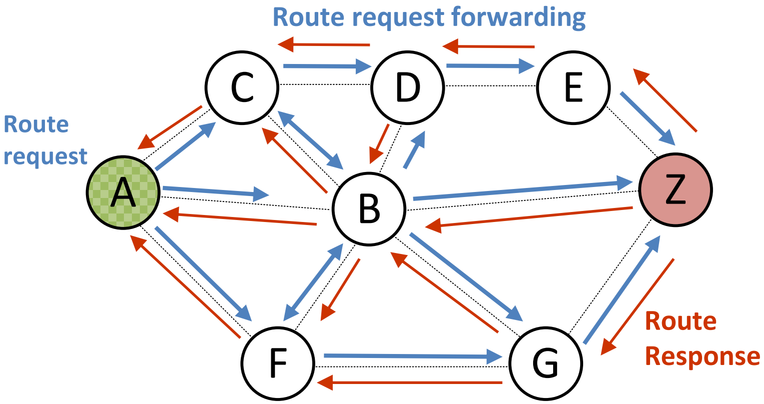
Route discovery

Discover possible **routes** between Source and Sink

- All routes or only routes fulfilling requirement(s) (e.g., max number of hops, latency, etc.)

Procedure

- Route **request** packet sent **by Source to neighbor nodes**
  - Number of neighbors
- **Neighbor nodes forward** Route **request** packet to their neighbors
  - Repeated until Route request reaches Sink
  - Who forwards and how Route request is forwarded depends on specific protocol
  - Record route metric(s) (depends on protocol)
- Route **response** sent **by Sink to Source**
  - Sent **via the same route** as Route Request



Route selection

Select the most suitable route out of all available routes found during Route discovery

Route *r* selected if its **metric m_i** is

- Minimal (e.g., energy consumption)

$$r = \min_i \{m_i\}$$

- Maximal (e.g., throughput)

$$r = \max_i \{m_i\}$$

- With constraint(s)
  - For example, maximize throughput while energy consumption is below a threshold; or minimize energy consumption while a certain throughput is ensured

Route selection metrics

Number of hops

Energy consumption (or **efficiency**)

- Energy consumed for communication

Network life-time

- Time before the first node dies; balance energy (avoid nodes with low energy)

Delay

- Time required to deliver information from Source to Sink

Packet delivery ratio (reliability)

- Ratio of packets delivered (from Source to Sink) to all sent packets (in a time limit)

Route stability

- Fluctuation of route selection metric (e.g. channel quality, node energy,…)

Management cost (overhead)

- Amount of redundant information needed to deliver packets (route discovery,…)

Throughput/data rate/capacity/…

- Amount of information (bits, packets,…) delivered over a period of time

… and others including combinations of these metric

Route maintenance

Mobility of nodes, dynamic channel, battery depletion, new node, …

- Varying **availability** of routes
  - Acknowledging packets (symmetric channel)
- Varying route **quality**
  - Acknowledging packets (known Tx power)
  - Report quality of channels among neighbors

→ need for **awareness of route status if communication is in progress**

Route maintenance provides monitoring of route parameters

- Keep **information** about all available routes **up to date**
- Allow **dynamic selection** of the most suitable path in each time

Trade-off between **overhead** and **freshness** of route status

Classification of WSN routing protocols

When the protocol operates?

- **Proactive** (table driven)
  - Routing table kept up-to-date even if no communication is requested
    - Update periodically or even driven (change of topology, channel, energy,…)
    - Route ready whenever needed
    - Overhead to maintain up-to-date tables → energy cost
- **Reactive** (on-demand, source initiated)
  - Route found if needed
    - Delay and overhead due route discovery and selection
    - No overhead if no communication is in progress (sleep)
- **Hybrid** (combination of both)

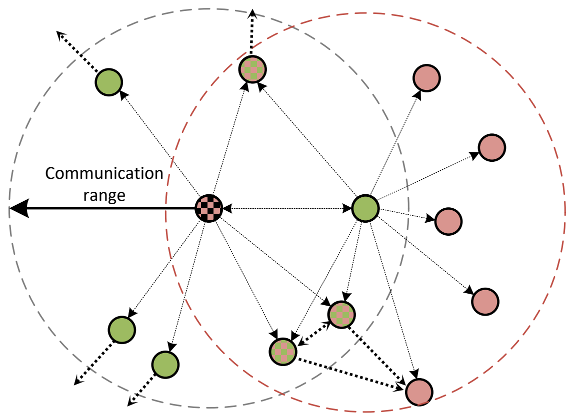
What is **topology** of the network?

- **Flat**
  - All nodes of equal importance and type of operation
- **Hierarchical**
  - Cluster head/gateway collects information from sources
- **(Location-based)**
  - Location of nodes known

Flooding

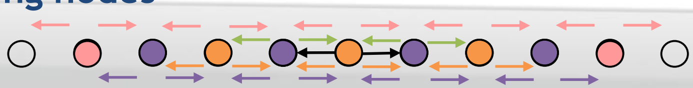
Received message is forwarded by all nodes

- No need for maintenance of any tables, topology, or route information
- Messages received multiple times by nodes → huge overhead



Example (each user has **2 neighbors**)

- 1st Tx: source sends msg to both neighbors – 2 msgs received by 2 new recipients
- 2nd Tx: both recipients send msg – 4 msgs received by 3 recipients, 2 new
- 3nd Tx: three recipients send msg – 6 msgs received by 4 recipients, 2 new
- 4th Tx: four recipients send msg – 8 msgs received by 5 recipients, 2 new
- 5th Tx: five recipients send msg – 10 msgs received by 6 recipients, 2 new
- Sum: **15 messages** (1+2+3+4+5) transmitted and **30 messages** (2+4+6+8+10) received to reach **10 neighboring nodes**



Simple improvements of Flooding

Improvements (for wireless)

- **Single message repetition only**
  - Do not forward the same message again
    - The same message is not transmitted again by the same device if already sent
- **Reception from multiple-directions**
  - Same message received from different directions → do not forward
    - All neighbors most likely covered
    - Need for knowledge of locations of nodes or coordination among nodes
- **Close nodes**
  - **Two nodes close to each other** → similar coverage → **similar set of neighbors**
  - Do not forward message by receiver if Source (or transmitter) is close
    - Determine close nodes based on location information or received signal level

Expanding Ring Search

Time-To-Live (TTL)

- Defines how many time the message can be forwarded, then discarded

Initial transmission of message with **TTL = 1**

TTL increased every time destination is not reached

- Wait for Route response before increase (*2 x H_r*, *H_r* is the number of hops)
- Delay

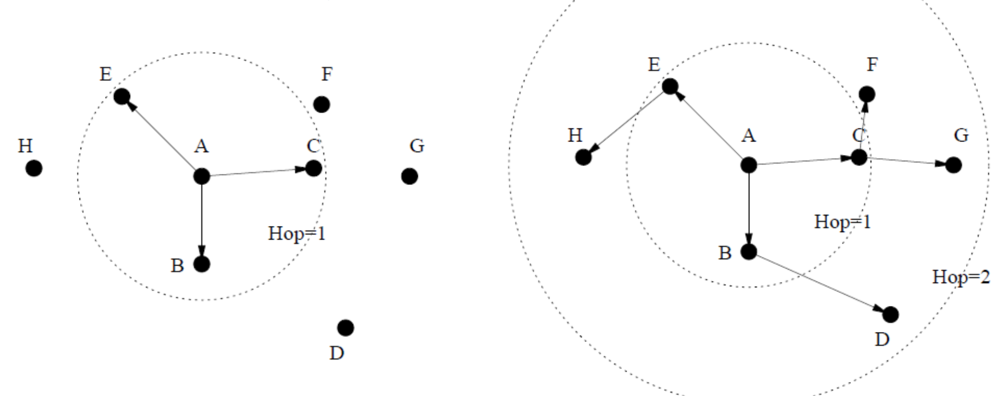
$$T_{TTL\_ERS} = 2\sum_{i=1}^{H_r} i$$

i… ring (hop index), *i=1…H_r*

- TTL increased typically by one or two

Works well for small networks only

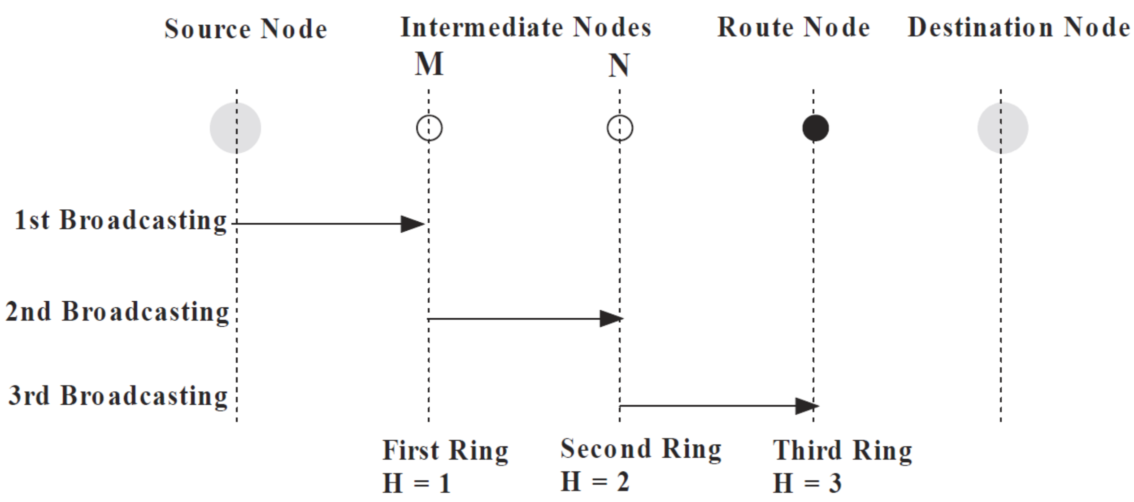
- Source and Sink are far from each other → too many transmissions
  - Energy cost

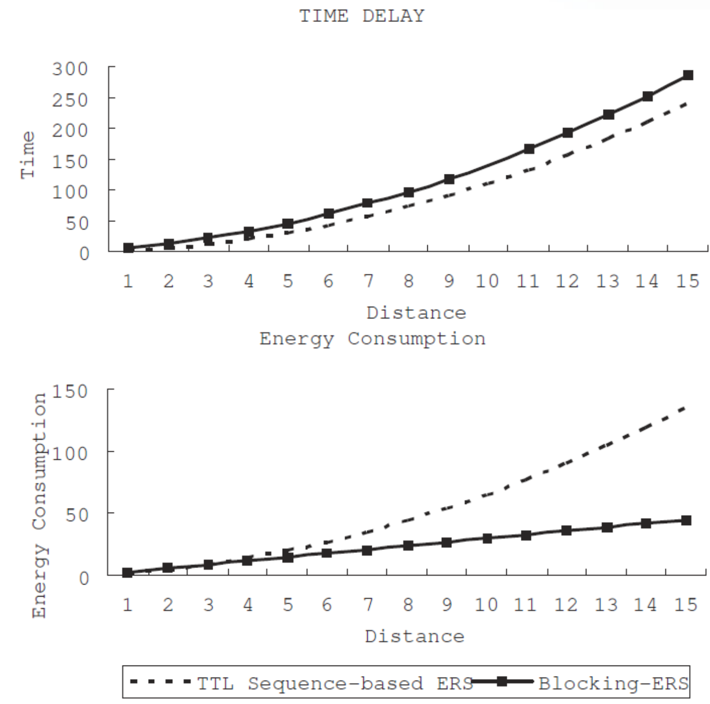


Blocking ERS

Based on common ERS, but…

- **Message not retransmitted by Source**, retransmission done by node(s) in *N-th* hop
- How to identify if nodes should retransmit the message?
  - If route is found Source sends **Stop instruction** to stop flooding
  - Waiting period to see if a route was found or not
    - 2 x hop number (TTL)
    - → slightly increased packet delay (request transmission)



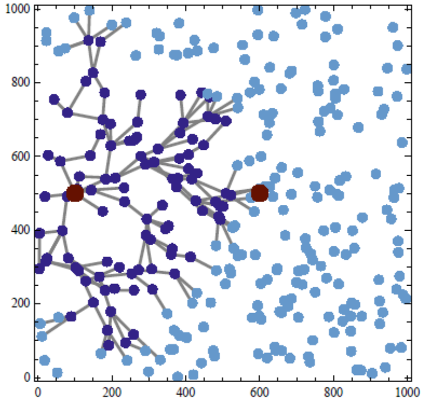


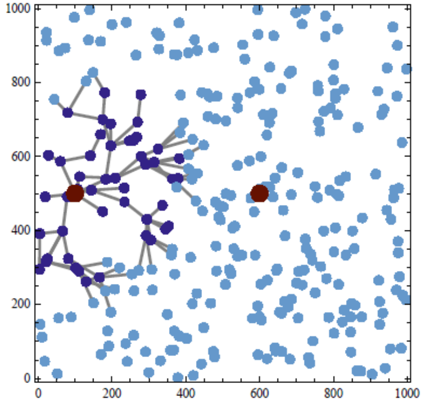
Two-sides ERS

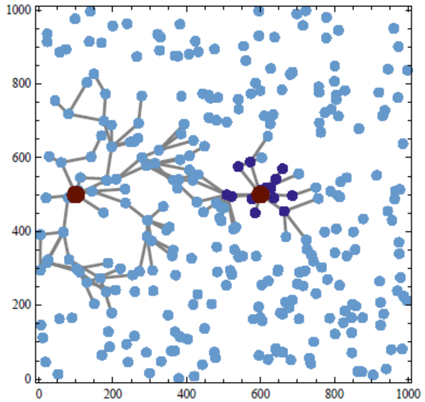
ERS conducted by Source and Sink nodes

Objective

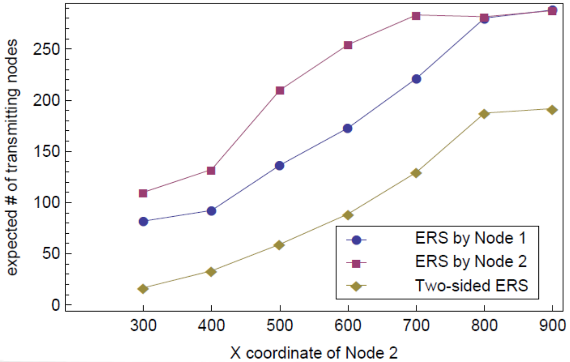
- **Find an intermediate node with sub-path to sink and source**







Number of nodes involved in forwarding is lower than for one-side ERS

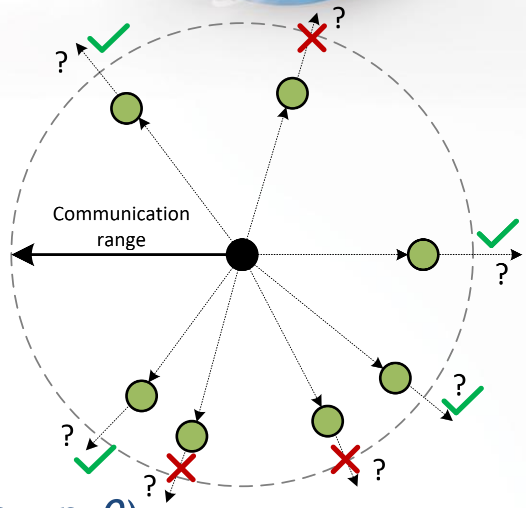


S. Shamoun, D. Sarne, " Two-Sided Expanding Ring Search," COMSNETS 2014.

Gossiping

Improved flooding

- **Message not forwarded by all neighbors**

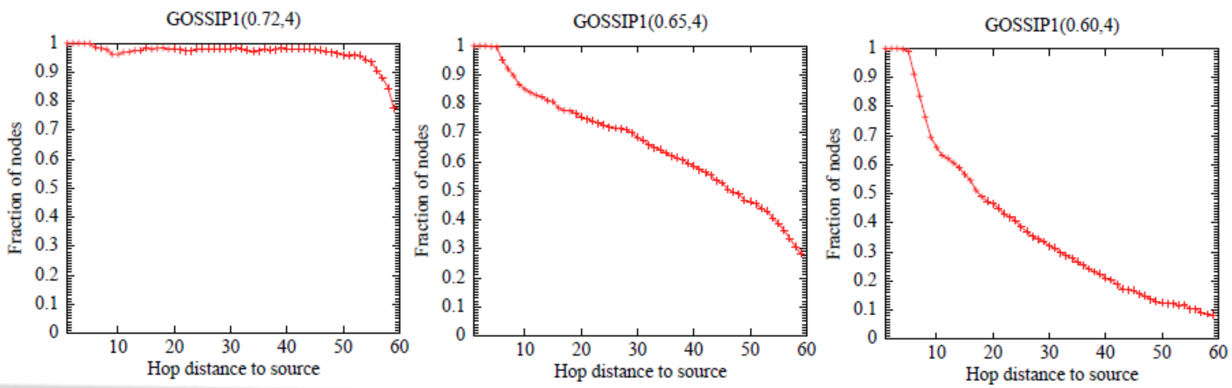


GOSSIP1(p)

- Source sends message with probability *p=1*
- Node who receives the message
  - **Forwards it with probability *p*** (if *p=1* → flooding)
  - **Discards it with probability *1-p*** → saving *1-p* messages
- If node receives the same message again, it is discarded (i.e., *p=0*)
- Problem
  - Only few neighbors around Source – message might not be forwarded at all

GOSSIP1(p,k)

- Hops *i=1…k*: $p_i=1$
- Hops *i>k*: $p_i=p$
- How to set p, k ?



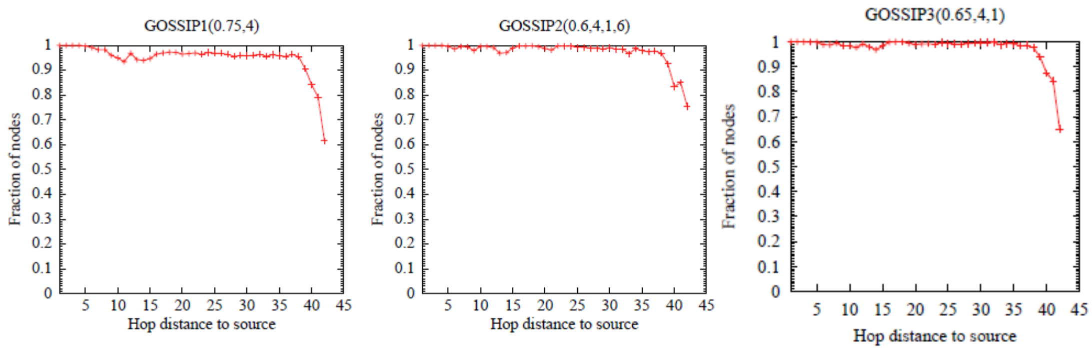
Heuristic optimization of Gossiping

GOSSIP2 (p,k,p2,n) - new parameters *n* and *p2*

- **Less than n neighbors → all neighbors** gossip with probability *p2*, *p2>p*
- Problem – messages are still dying out
  - *p x n* messages should be received back → if not, messages are dying

GOSSIP3 (p,k,m)

- Do **not broadcast message immediately**
- Wait for a certain interval and **broadcast to all only if less than *m* copies are received**

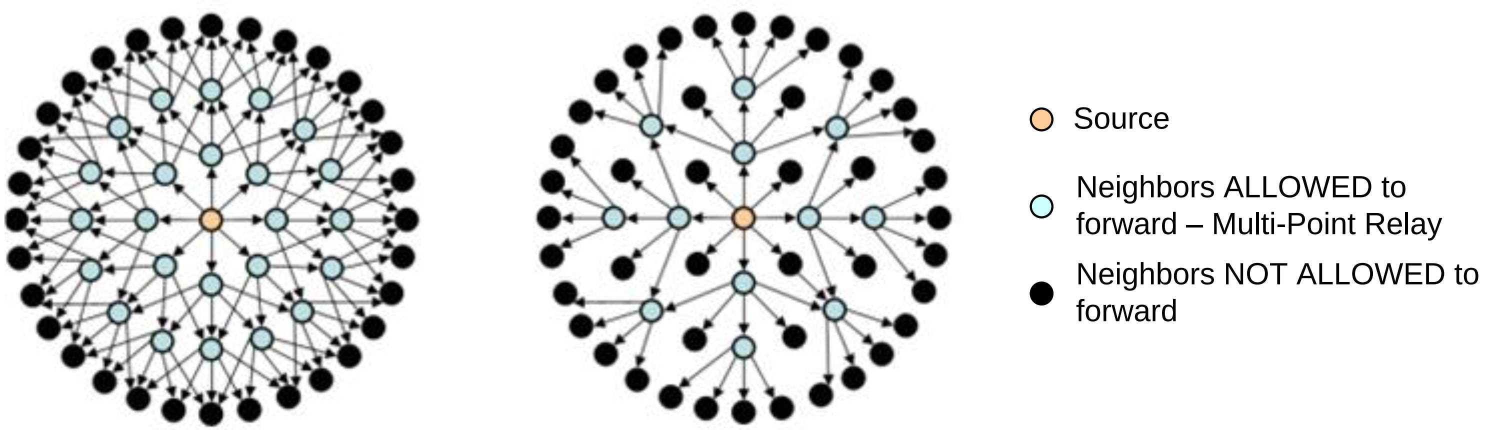


Optimized Link State Routing (OLSR)

Proactive protocol **avoiding duplication of message forwarding**

Neighbor nodes classified as

- **Common neighbors**
  - **NOT allowed to forward** messages (reduce "flooding" effect)
- **Multi-Point Relay** (MPR)
  - **ALLOWED to forward** messages
  - Selected so that Source can reach any node within two hops via selected MPR



LS

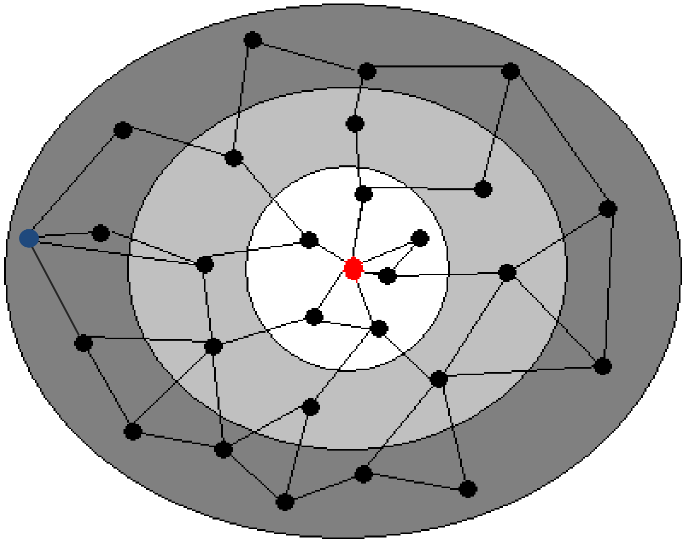
OLSR

Principle analogical to Gossiping

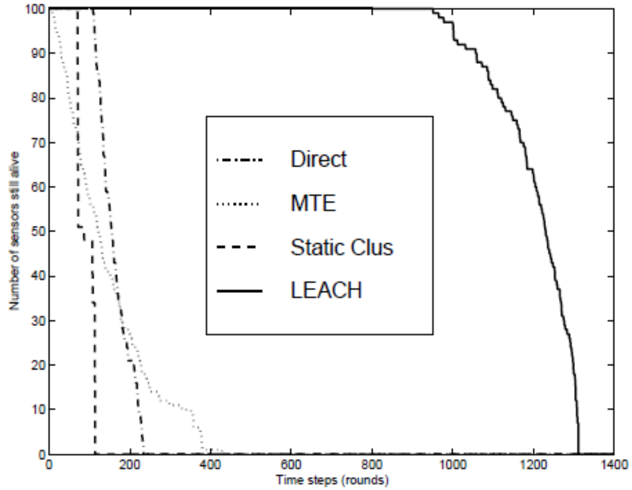
Fisheye State Routing (FSR)

Frequency of **routing table updates proportional to distance**

- Information **updated frequently** among **local nodes** (close nodes)
  - Messages sent to close Sink are selected according to up to date info
- Information about **distant nodes** are updated **less frequently**
  - Keeping up-to-date knowledge is too expensive → update less often
  - Source sends message according to its knowledge
    - Maybe inaccurate route, but first few hops are well known
  - Route is updated in each hop
    - Every node, which receives message updates remaining path to Sink according to its knowledge of paths



Low-Energy Adaptive Clustering Hierarchy (LEACH)



MTE...Minimum Transmission Energy

Network life-time improvement

Cluster-based protocol

- Nodes send messages to "**Cluster head**" (CH)
- **CH role rotates among nodes**
  - **Balance energy** consumption among nodes
  - **Distributed** algorithm

CH selection process and clustering

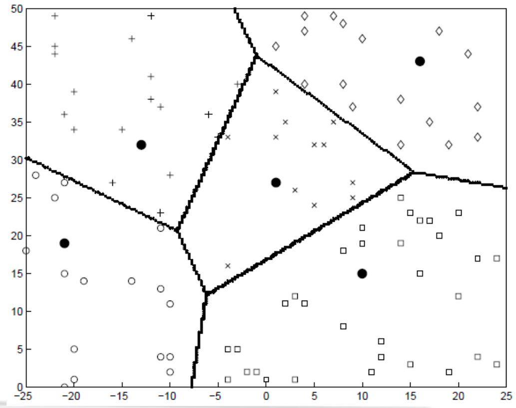
- Define **percentage of nodes needed to be CHs - *P***
- Each node indicate its willingness to be CH

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

if $rand < T(n)$ → node *n* becomes CH

P... targeted percentage of CHs
G... nodes that has NOT been CH within 1/P rounds
r... round number (starting with round 0)

- CHs distribute advertisement message (using CSMA)
  - All nodes same transmit power
- Non-CH are assigned to clusters (CHs)
  - According to received power from CHs
  - Inform CH about membership in the cluster (CSMA)



Communication within cluster using TDMA (+CDMA)

W.R. Heinzelman, "Energy-Efficient Communication Protocol for Wireless Microsensor Networks," HICSS, 2000.

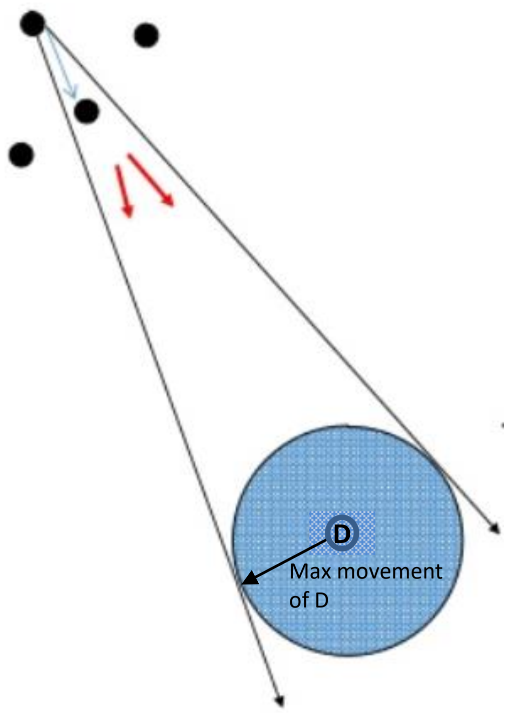
Distance Routing Effect Algorithm for Mobility (DREAM)

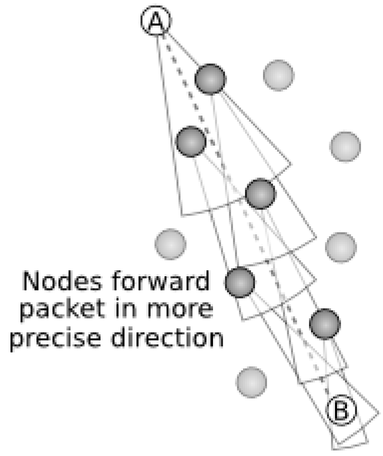
Each **node distributes** (by flooding) its **position**

- Nodes have **knowledge of position of all nodes**

Messages carry **location of Source and Sink**

- Message is directed towards Sink's position in each hop in a segment of a circle





Location Aided Routing (LAR)

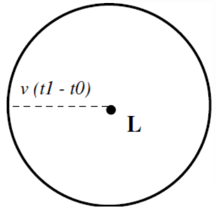
Flooding limited by exploitation of **location information**

Messages carry **Source and Destination location info**

Packet routed in direction of geographical location of Sink

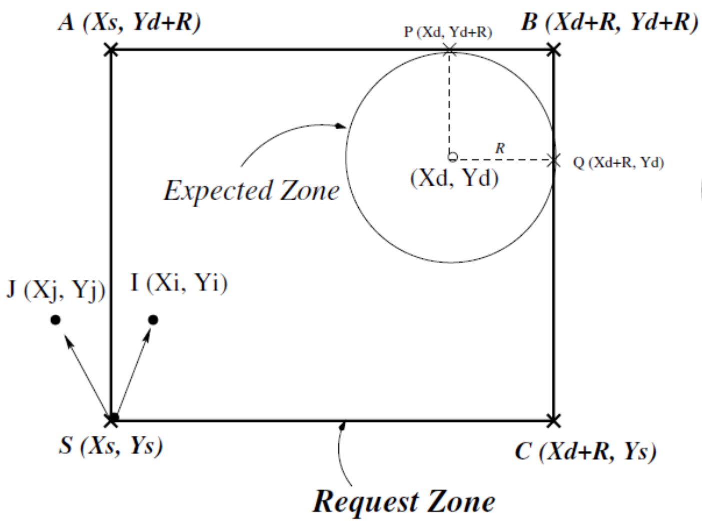
Expected zone

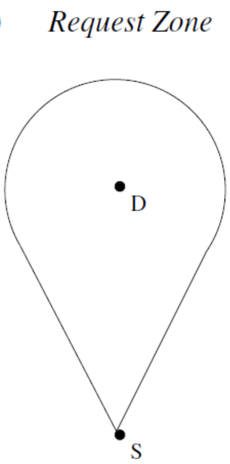
- Expected position of Sink
  - Area given by last known position of Sink and possible/estimated movement



Request zone

- Given by location of Source node and Expected zone
- Node outside zone: **discards message**





Y.B. Ko, N.H. Vaida, "Location-Aided Routing (LAR) in mobile ad hoc networks," Wireless Networks, 2000.

Questions?

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