Sensor networks and applications

Routing (flat, hierarchical)

Content

- Networking layer
  - WSN topology
  - Routing
    - Routing planning issues
    - Network and routing modeling
    - **Routing protocols**
      - Flat
      - Hierarchic
      - Location-based

Flat routing

Flat routing

- The network nodes are **equal**.
- Sensor nodes **cooperate** to fulfil the common task.
- Unique ID assignment is not always possible because of the high number of nodes => **data-centric** routing

Data-centric routing:

- The BS sends queries towards certain areas and waits for the answers from the sensors in the area.
- **Attribute-based addressing** is needid to specify the type of expected data.

Flat routing algorithms

- SPIN – Sensor Protocols for Information via Negotiation
- Directed diffusion
- Rumor routing

SPIN

- SPIN – Sensor Protocols for Information via Negotiation
- **Spreads all data** to all nodes, thus the required information can be accessed from any node at once.
- protocol family, that is...
  - able to adapt to nodes' resources.
  - based on **preliminary data negotiations**.
  - Time-driven.
- Idea: Nearby nodes have the same (or very similar) data, so it is enough to transmit those data that are not available at the neighbors.

SPIN (cont'd)

Meta-data:

- All data are labelled with a descriptor (meta-dat) that describes the data.
- Nodes negotiate based on meta-data before the actual data transmission takes place. Thus, redundant data transmission can be avoided.
- Semantics of meta-data is application specific, it is not defined in SPIN.
  - E.g., the unique ID of a sensor node can be used as meta-data, since it can describes what area is covered by the sensor.

SPIN (cont'd)

- 3 phases of SPIN protocol:
  - (1) data advertisement: **ADV** / (2) data request: **REQ** / (3) data transmission: **DATA**
- Protocol steps:
  - If a sensor node aquires new data, it advertises the data by its meta-data by **ADV** broadcast.
  - If one of its neighbor is interested in the new data, it requests for it (**REQ**). The new data is transmitted by the source in a **DATA** message.
  - When the neighbor receives the (new) data, it starts advertising it to its neighbors (GOTO 1)
- As a consequence, the new data eventually spreads out into the whole network.

SPIN (cont'd)

- Variants of SPIN protocol family:
  - **SPIN-1**: see above
  - **SPIN-2**: Version 1 extended with an energy-aware negotiation phase: If a node has too low energy it will not participate in data advertisement and transmission.
  - **SPIN-BC**: Optimized for broadcast channel
  - **SPIN-PP**: Optimized for point-to-point (hop-by-hop) communication.
  - **SPIN-EC**: Variant of SPIN-PP by adding some energy heuristics.
  - **SPIN-RL**: Optimized for „lossy" channels.

SPIN (cont’d)

Advantages:

- The amount of data transmitted is smaller compared to classical floodingbecause of meta-data negotiations. (no „data explosion”)
- Energy adaptivity yields energy efficient operation.
- Can be applied when sensors can be mobile.
  - There is no need for knowing all neighbor.

Disadvantages:

- It is not 100% sure that all data reach those who are interested.
  - E.g., if direct neighbors are not interested in the data, they will not relay it.

Directed diffusion (DD)

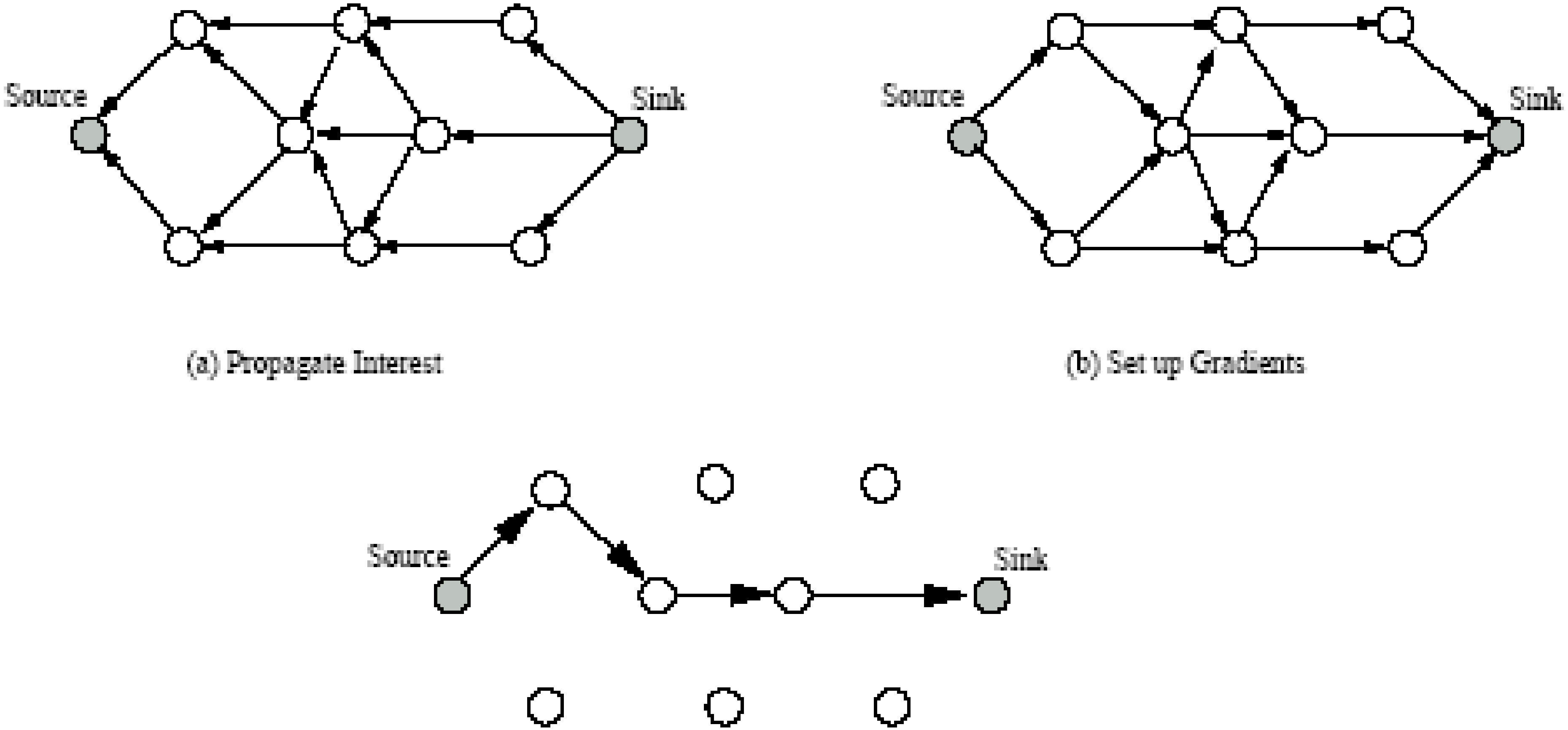
- **Data-centric** (DC) and application-aware protocol.
  - Data aquired by the sensor is described by an **attribute-value pair**.
  - Many sources send data to a single destination (BS – base station).
  - **Aggregation** is possible by combining data streams!

- <u>Idea</u>: Data coming from diferent nodes can be aggregated <u>within the network</u>.

Directed diffusion

- Way of communication:
  - If the BS needs information, it sends a query to the network by broadcast:.
    - query = task to complete by the network
  - The query diffuses into the network step-by-step, all nodes relay it to its neighbors (hop-by-hop).
  - Nodes set up <u>gradients</u>:
    - gradient = attribute-value pair + direction
    - E.g., all nodes set their gradients to the node from which it received the query.
    - The size of the gradient can be different from node to node.
  - Data transmission can happed backwards <u>toward the greatest gradient</u>.
    - Data can be aggregated on the way towards the sink.

Directed diffusion



(a) Propagate Interest

(b) Set up Gradients

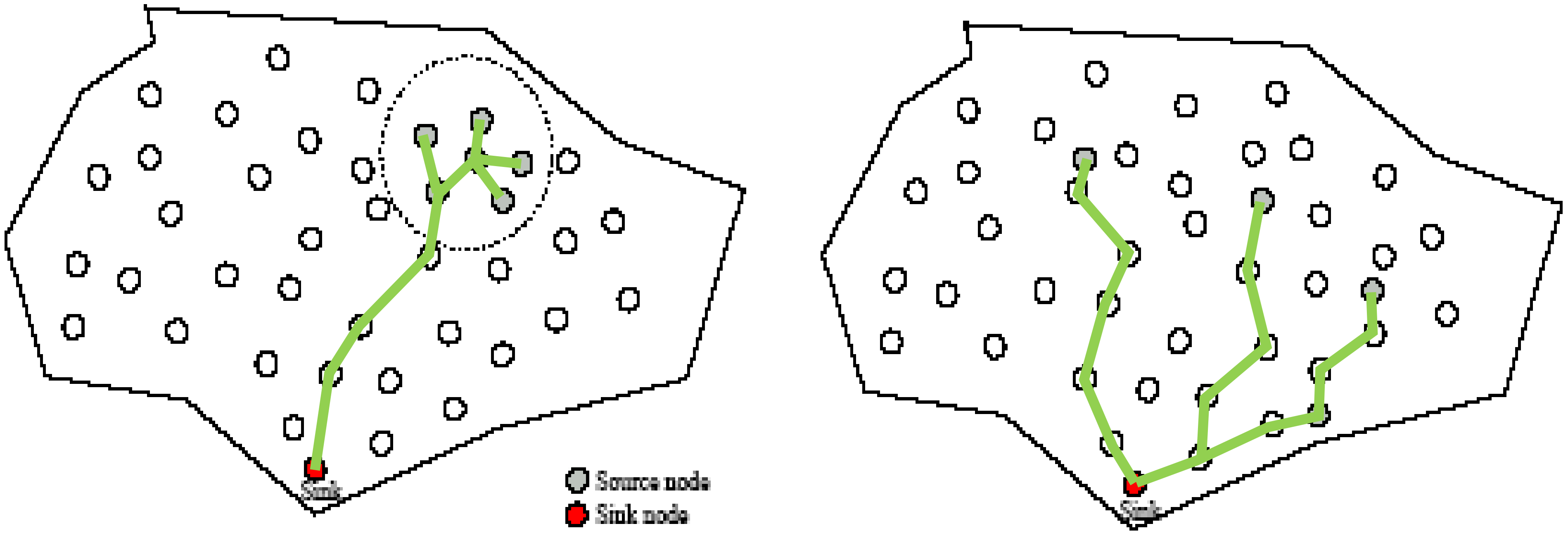
(c) Send data and path Reinforcement

3. ábra. Példa kérés terjesztésre szenzorhálózatban.

Directed diffusion

- The BS repeats the query periodically even when it starts to collect information.
  - E.g., information relaying is not always guaranteed.
- The goal is to build up an **„efficient" tree** along which the **information can be aggregated**.
- The efficiency of data aggregation depends heavily on:
  - number and location of nodes;
  - network communication topology;
  - the event model.

Directed diffusion - example



(a) Event Radius Model (b) Random Source Model

- Event models:
  - ER – Event Radius
  - RS – Random Sources
- Aggregation is much more efficient for the ER model.

Directed diffusion

Advantages:

- It is not necessary to know the topology.
- Data traffic is demand-based. ☺

Disadvantages:

- Data traffic is only demand-based. ☹
- The query propagates to the target node(s) by flooding, even if only a small subset of nodes are interested in answering it.
- Maching queries with available data is also energy consuming.

Rumor routing

- Variant of directed diffusion.
  - Avoids flooding of queries.

- Idea: Instead of flooding, it is enough to drive the queries only to the nodes that monitored the event **or they know about it**.

- Useful for applications where...
  - the number of events are small, and the number of queries are high;
  - geographic routing can not be applied

Rumor routing

- Solution: The event should be propagated as well, not just the query!
  - When a node senses an event, it adds this to its local event table.
  - It creates a „long-life” agent packet.
  - The agent starts to spread the information within the network.
  - The information is recorded by the nodes who receive the agent.
  - When a query arrives, any node can answer it instead of broadcasting, if it knows the way to the source (i.e., the agent visited the node before).

Rumor routing

- Nodes only maintain a single route between the source and destination, in contrast to directed diffusion.
- The lifetime (i.e., TTL field) of a query and the agent is a parameter of the protocol
- Planning the path for an agent is non-trivial, and it has a high impact on efficiency..

Advantage:

- Energy can be spared by avoiding flooding.

Drawback:

- It only works when the number of events is small.
  - If there are too many event in the network, the cost of maintainin gthe event tables can be very high, if there is no interest towards the events.

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Hierarchic routing

LEACH, TEEN, APTEEN

Routing paradigms

- Routing protocols based on network structure
  - Flat
  - **Hierarchical**
    - LEACH, TEEN, APTEEN
  - Location-based
  - other...

Hierarchical routing

- Hierarchical = **cluster-based**
- In a hierarchical architecture...
  - the nodes have **different** roles,
  - (Typically) the nodes with more energy and computing resources deal with information processing and transmission.
- Advantage: calability(?), efficient communication
- Hierarchical routing has two layers:
  - The tasks of layer 1 are **cluster formation** and **cluster-head election**.
  - The actual routing takes place in layer 2.
- *In most of the cases the interesting question is not the routing itself but the claster formation and cluster head management!*

LEACH protocol

- LEACH = Low Energy Adaptive Clustering Hierarchy
- Cluster-based solution with **distributed cluster formation**
- Cluster heads (CHs) are elected randomly, and the role of cluster head is changed from time to time.
- The **CH aggregates** and **compresses** the data coming from the sensor nodes, then **sends** them to the BS.
- TDMA/CDMA MAC for intra-cluster and extra-cluster communication to avoid collisions.
- Data gathering is centralized and periodic.

LEACH

- Assumptions:
  - All nodes are within radio range of BS.
  - All nodes have the resources to become a CH.
  - All nodes are able to use CDMA and TDMA for communication.
  - All nodes send data periodically.
  - Data coming from neighbors are strongly correlated.

LEACH

- 2 phases of the protocol:
  - setup phase
    - cluster formation
    - cluster head election
  - steady phase
    - controlling data transmission

- The network gets back to the setup phase periodically.

LEACH

Setup phase

1. All nodes draw a random number *r*. If *r* is smaller than a threshold value, then the node becomes a CH.
2. All CHs advertise itself.
3. All non-CH nodes selects one CH that it wants to belong to (based on the received signal strength, for example), then notifies the CH about its decision.
4. All CHs assign a TDMA schedule to its nodes within cluster.

Steady phase

1. Nodes sense and transmit data to the CH.
2. The CH collects the data, aggregates it and sends to the BS using CDMA code.

LEACH

Problems:

- It is non-trivial how to set the threshold value for the nodes to become a CH.
  - It can be a problem when the node density in inhomogeneous, so there will be no CH in a given area with some probability.
- The dynamic and periodic cluster formation can consume considerable amount of energy.
- The protocol assumes that all nodes have the same amount energy in every round.

Possible extenion: A particular node chooses its random number based on its enery level. (I.e., depleted nodes will be CHs with smaller probability).

LEACH performance evaluation

Setup phase

Step 1: Selecting cluster heads.

- **Goal**:
  - All nodes should be CHs for the same amount of time.
  - CHs should be distributed evenly in the network.

- **Solution**: Node *i* is to be CH with probability $P_i(t)$ at time t when the (r+1)th period starts.

- Average number of CHs in a round is *k*, so: $E[\#CH] = \sum_{i=1}^{N} P_i(t) = k$

  where *N* is the number of network nodes

Setup (cont'd)

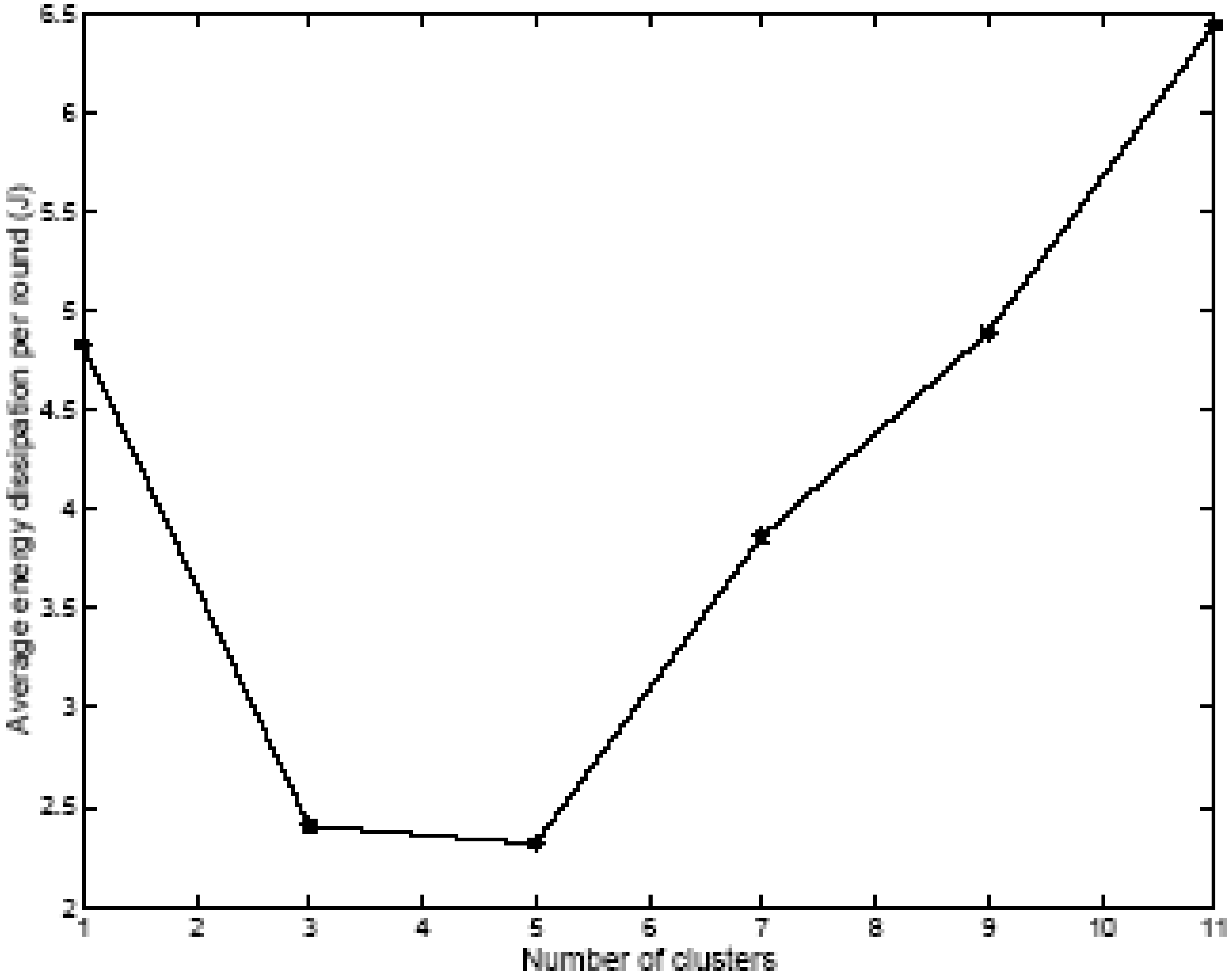
- The target is that each node is to become a CH once in every *N*/*k* rounds:

$$P_i(t) = \frac{k}{N - k \cdot (r \bmod (N/k))}$$

  if node *i* hasn't been a CH in the last (*r* mod (*N*/*k*)) rounds.

- The optimal *k* value can be derived analytically.
  - If *k* is too small, the CHs were too far away from each other.
  - If *k* is too big, there will be too many direct communications with the BS.

Setup phase (cont'd)



Setup phase (cont'd)

Step 2: Announcing cluster heads (CHs).

- Non-persistent CSMA MAC protocol is used.

- Every CH sends an ADV (advertisement) packet with broadcasting for all nodes:
  1. because of CSMA there will be no hidden terminal problem;
  2. no nodes will be left out of clusters.

- AThe ADV packet contains the ID and the announcement message.

Setup phase (cont'd)

Step 3: Selecting cluster head

- All non-CH nodes have to choose a CH based on the announcements (e.g., based on received signal strength).
- Nodes send back a join-REQmesage for the chosen CH using non-persistent CSMA.
  - Join-REQ body: node ID; CH ID, message type
- Nodes use high energy to send the Join-REQ message!
  - thus the hidden terminal problem can be avoided
  - No need for RTS-CTS signaling.

Setup phase (cont'd)

Step 4: TDMA scheduling.

- All CHs assign a TDMA time slice to all the nodes within its cluster.
  - Advantage: Nodes can go to sleep outside their own time slot.
- The network then switches to steady state for a fixed time.

Setup - flowchart

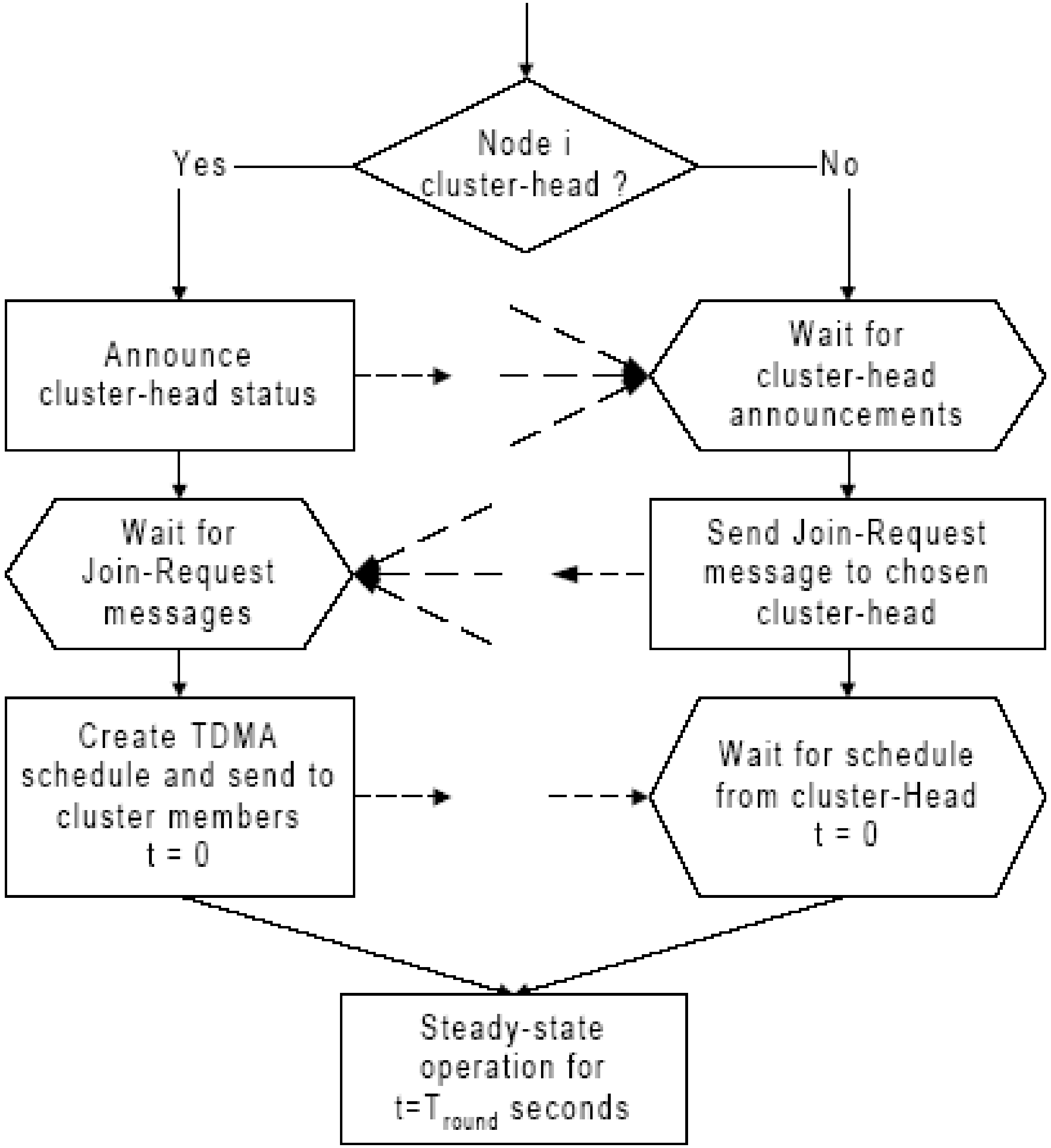
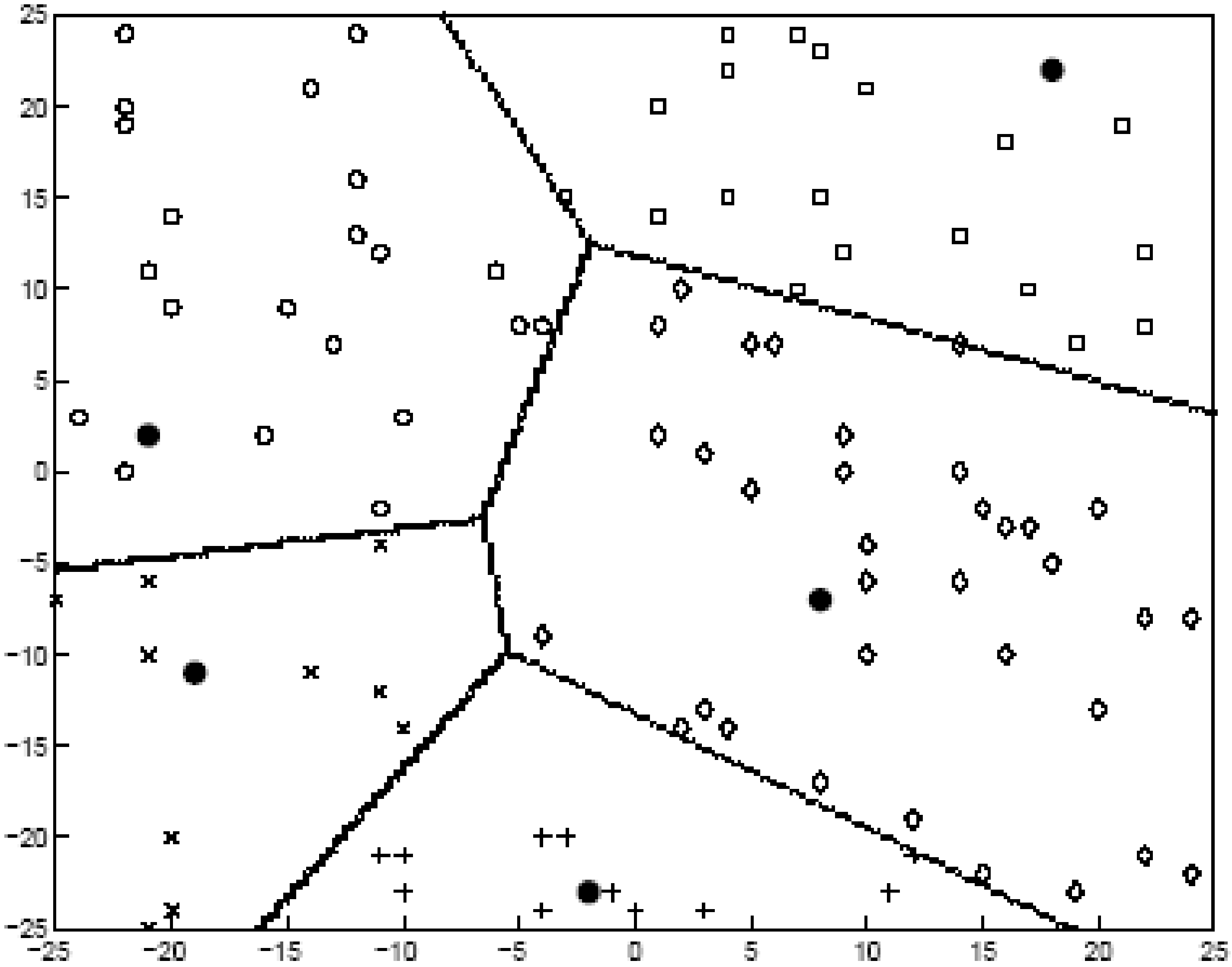


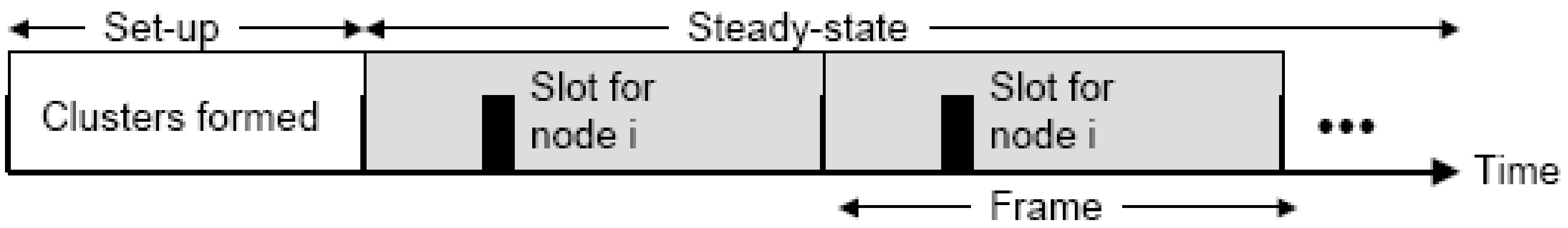
Figure 3-3: Flow-graph of the distributed cluster formation algorithm for LEACH.

Setup – cluster formation



Steady state

- The communication is broken down to frames:



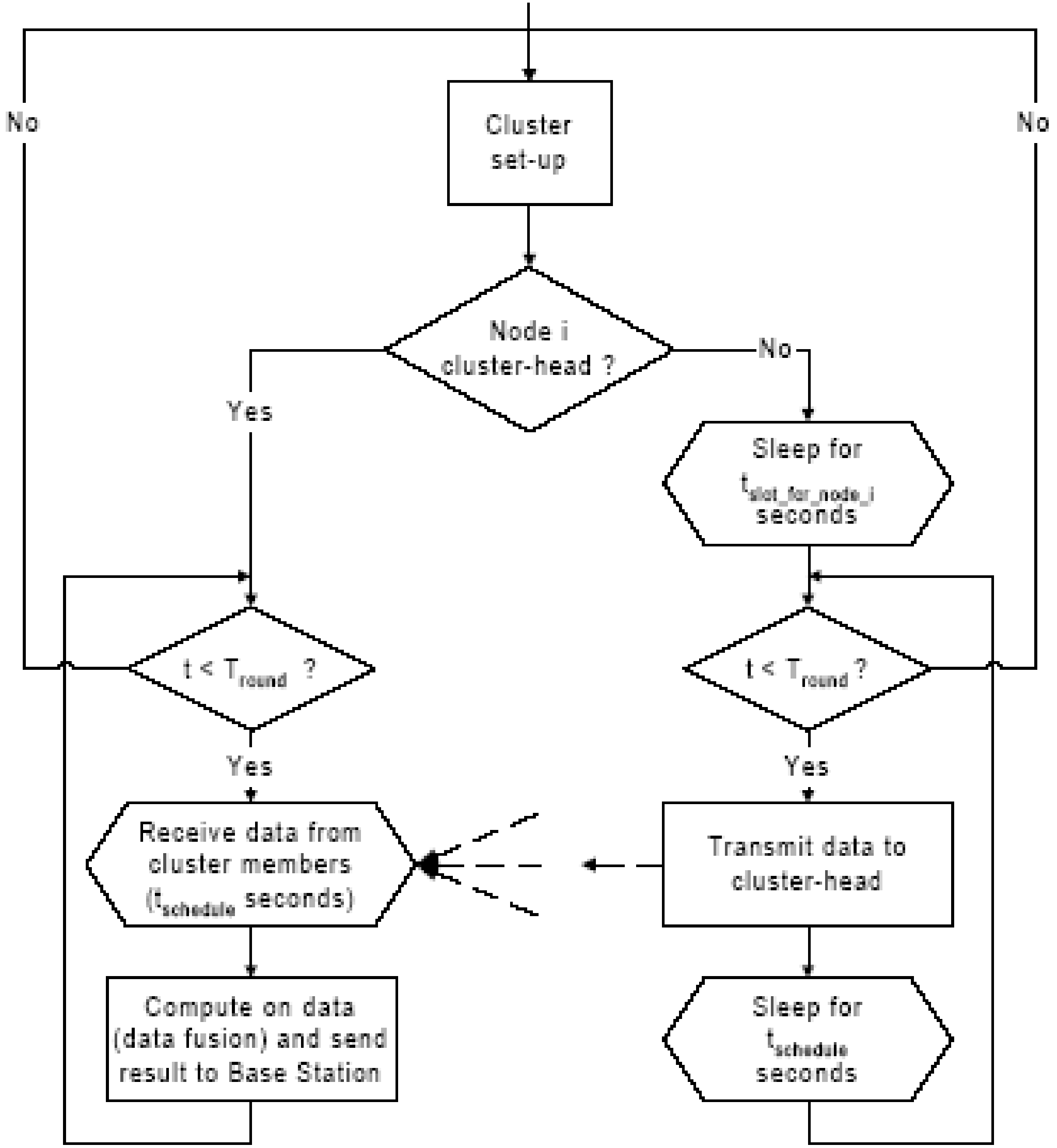
- Nodes can only send one packet within a frame to the BS in the allocated fixed time slot.
- The frame length is proportional to the number of nodes within the cluster.
  - There are k node in a cluster on the average, but the actual value can be significantly different from that!

Steady state (cont’d)

- Non-CH sensors
  - teljesítményszabályozást based on the received signal strength (RSSI) of the CH;
  - go to sleep between two allocated time slots.

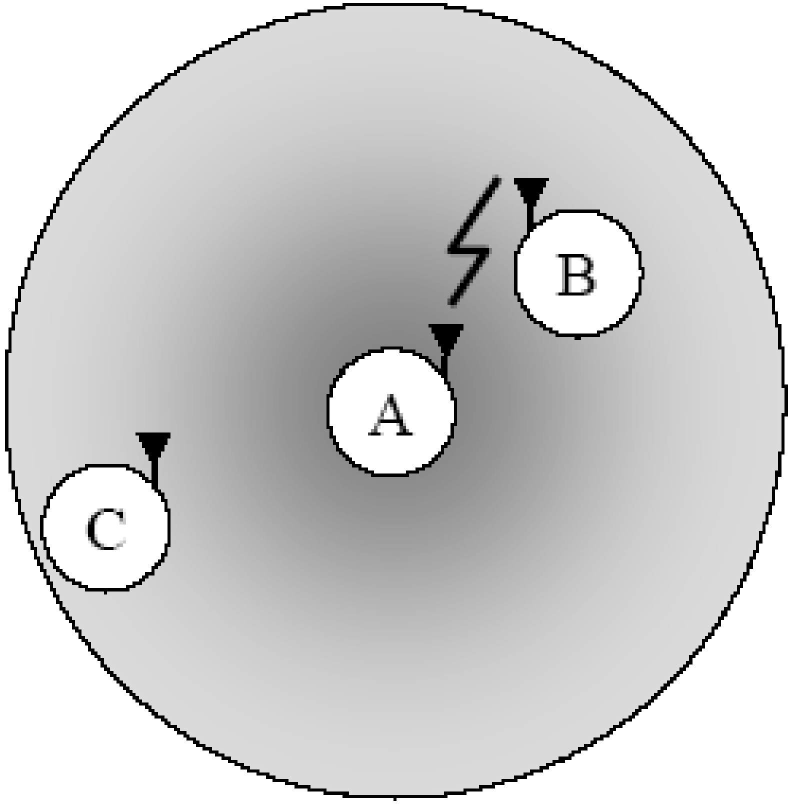
- CH nodes
  - stay awake continuously
  - aggregates and pre-processes the gathered data;
  - sends the information to the BS. (Requires high energy!)

Steady state



Steady state

- Problem: The in-cluster communication can affect the neighborig clusters.
- Solution: DS-SS (direct-sequential spread spectrum)
  - with different codes in different clusters,
  - but same code within the cluster
- CDMA ≠ DS-SS + TDMA
  - CH only listens to a particular CDMA code



LEACH-C(entralized)

Advantage:

- Optimal cluster formation (energy, BW, ...)

Drawbacks:

- All nodes communicate with the BS in every round.
- Coordinates of the nodes should be known.

Performance analysis

- Compared routing solutions:
  - Direct communication („**Direct**”)
  - Minimum energy multi-hop communications („**MTE**”)
  - **LEACH**

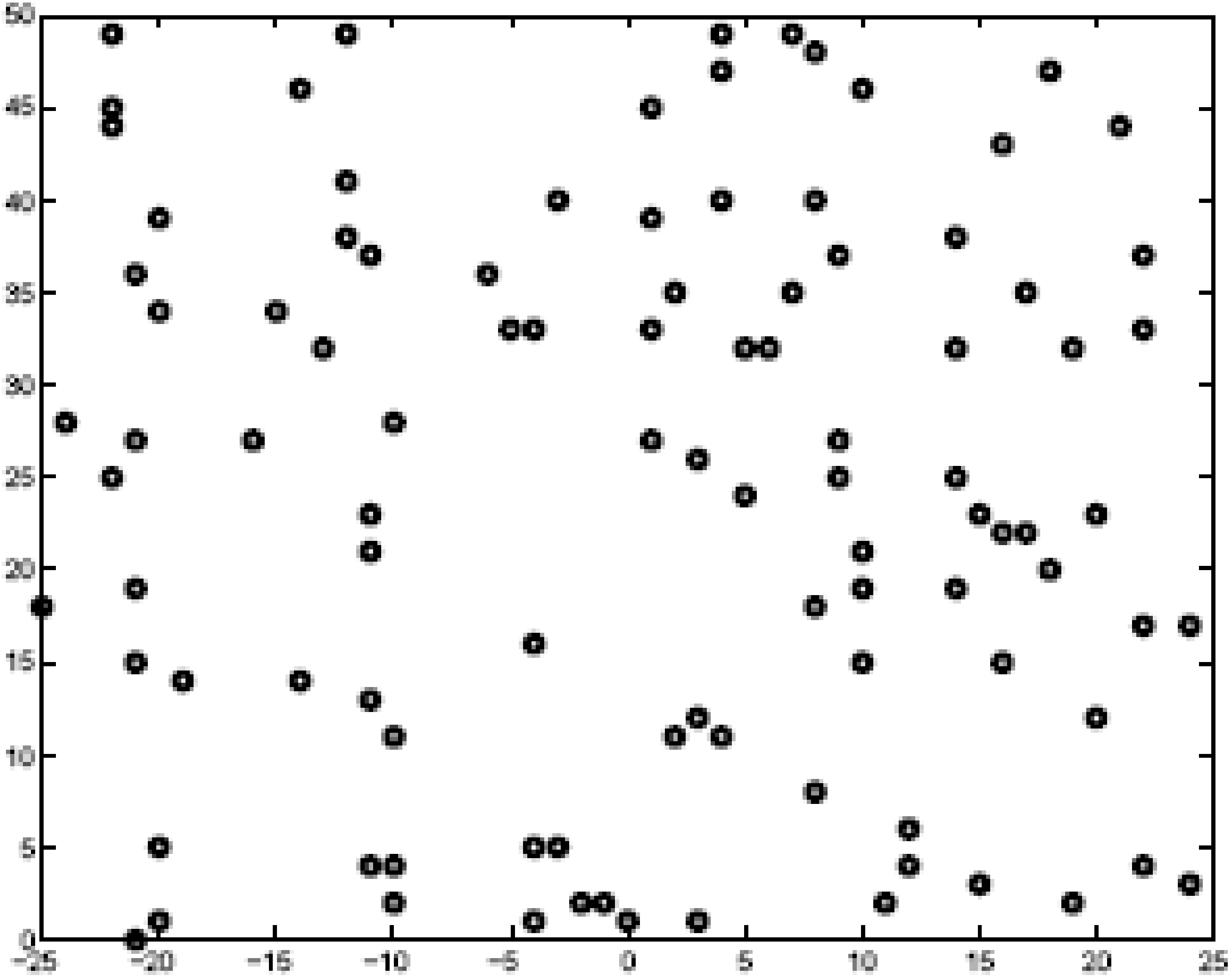
Direct communication:

- All nodes send packets directly to the BS.

MTE

- All nodes send packets only to its closest neighbor on the way towards the BS.

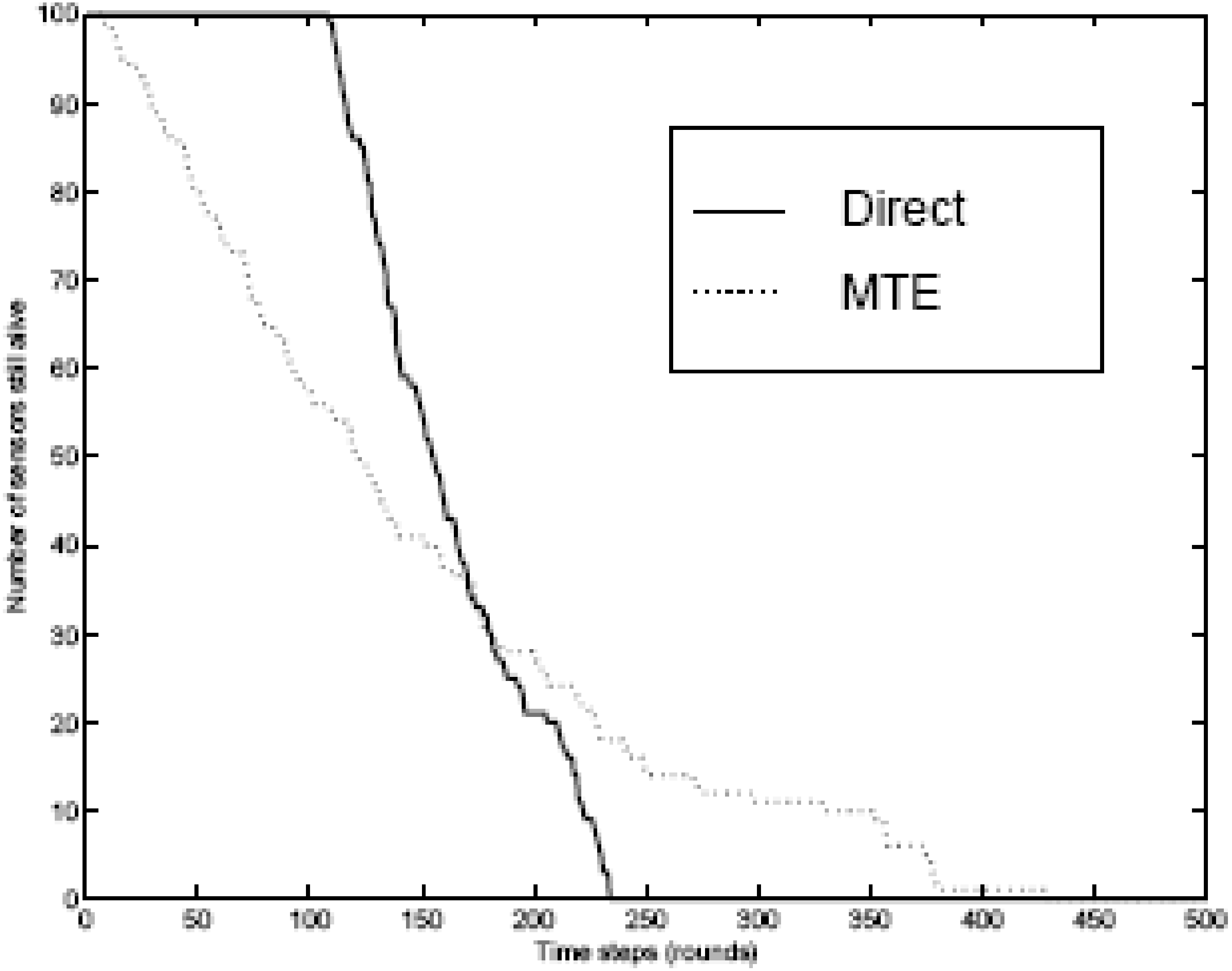
Performance analysis



examined topology

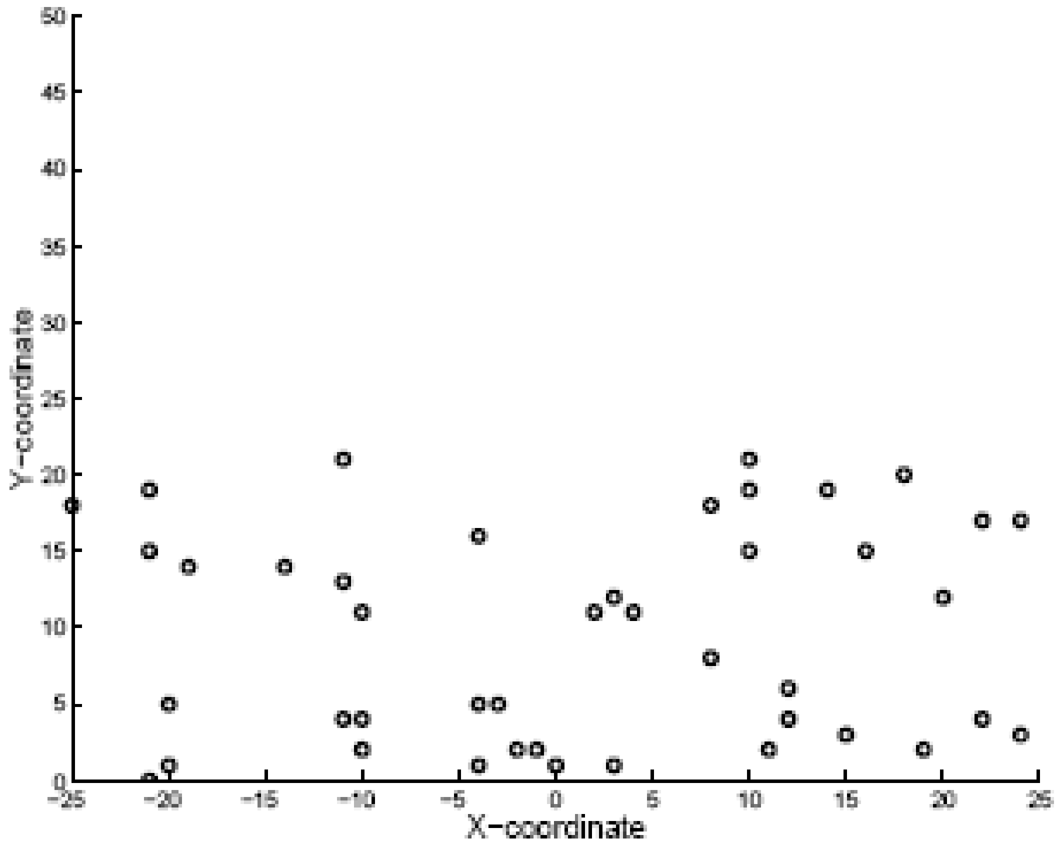
BS coordinates:
(x=0, y=-100)

Network lifetime (Direct, MTE)

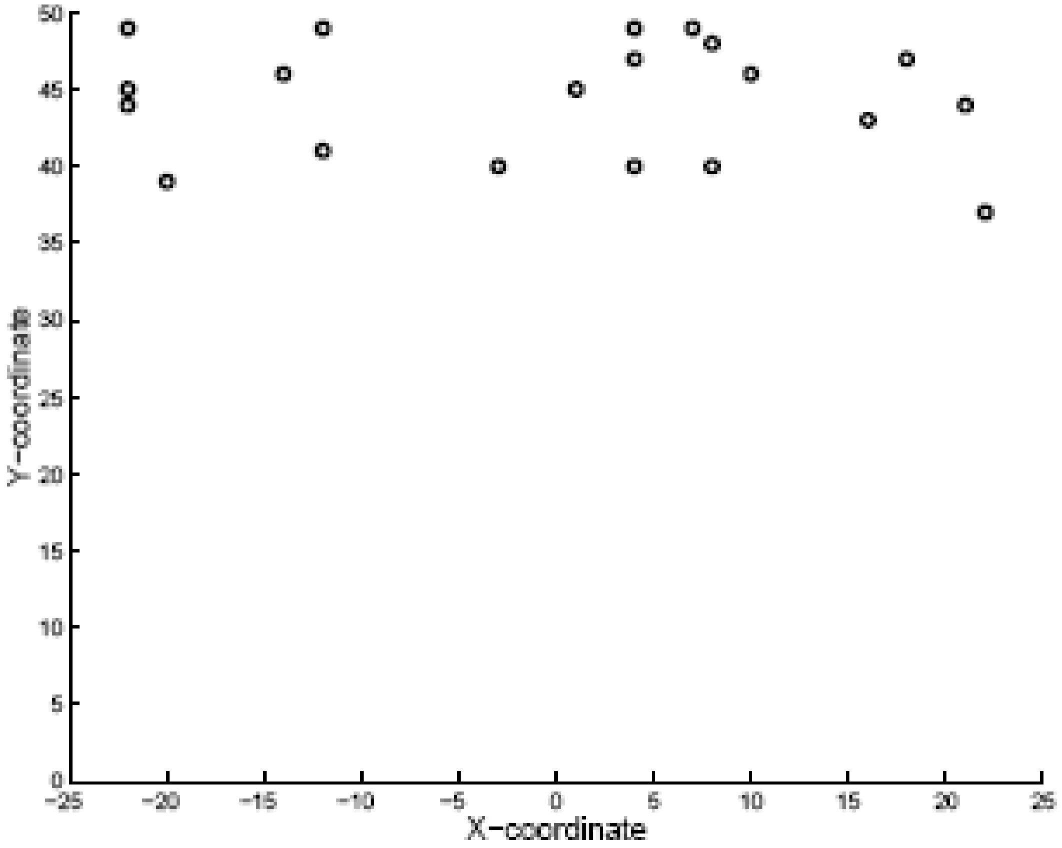


Network lifetime (Direct, MTE)

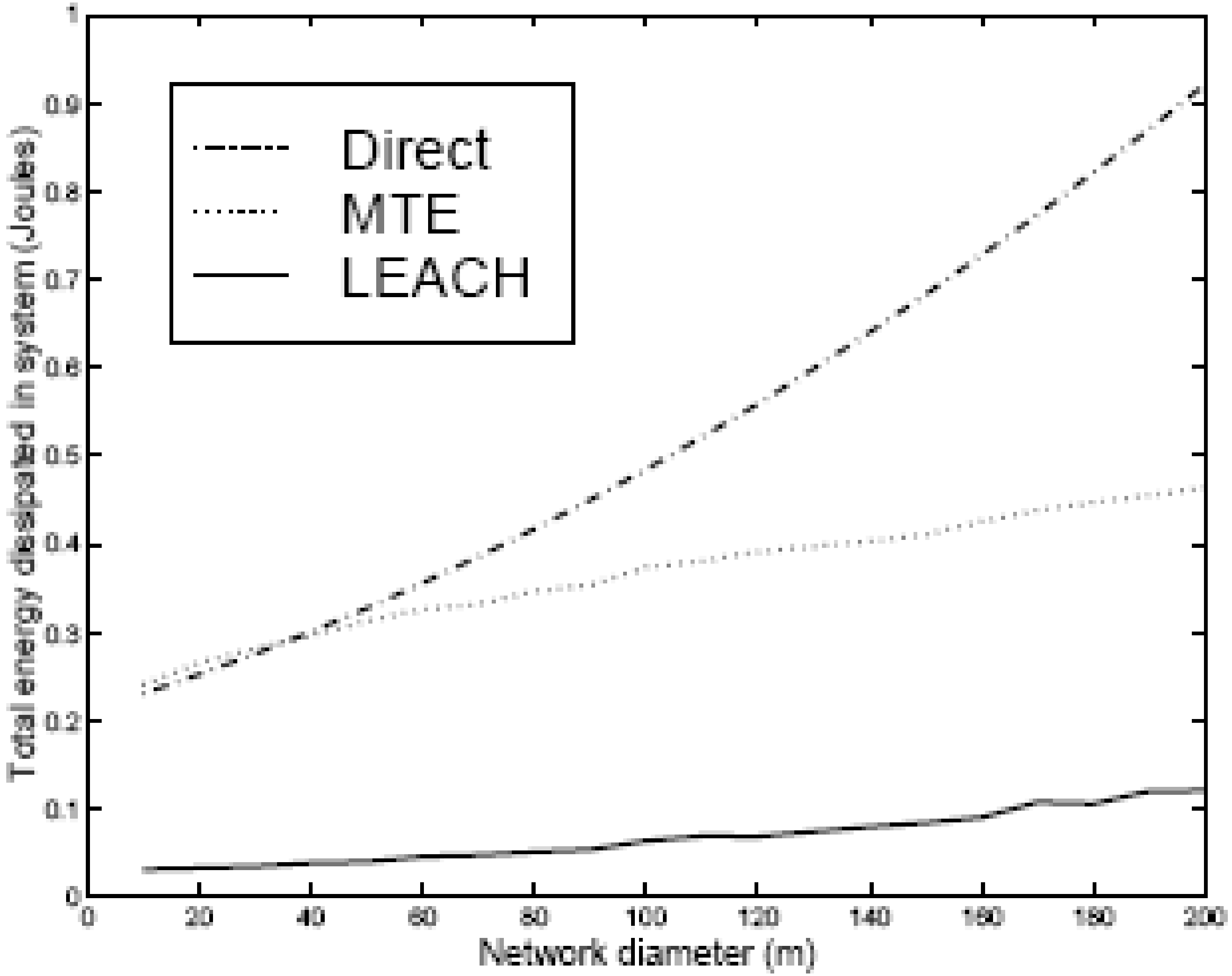
Direct:



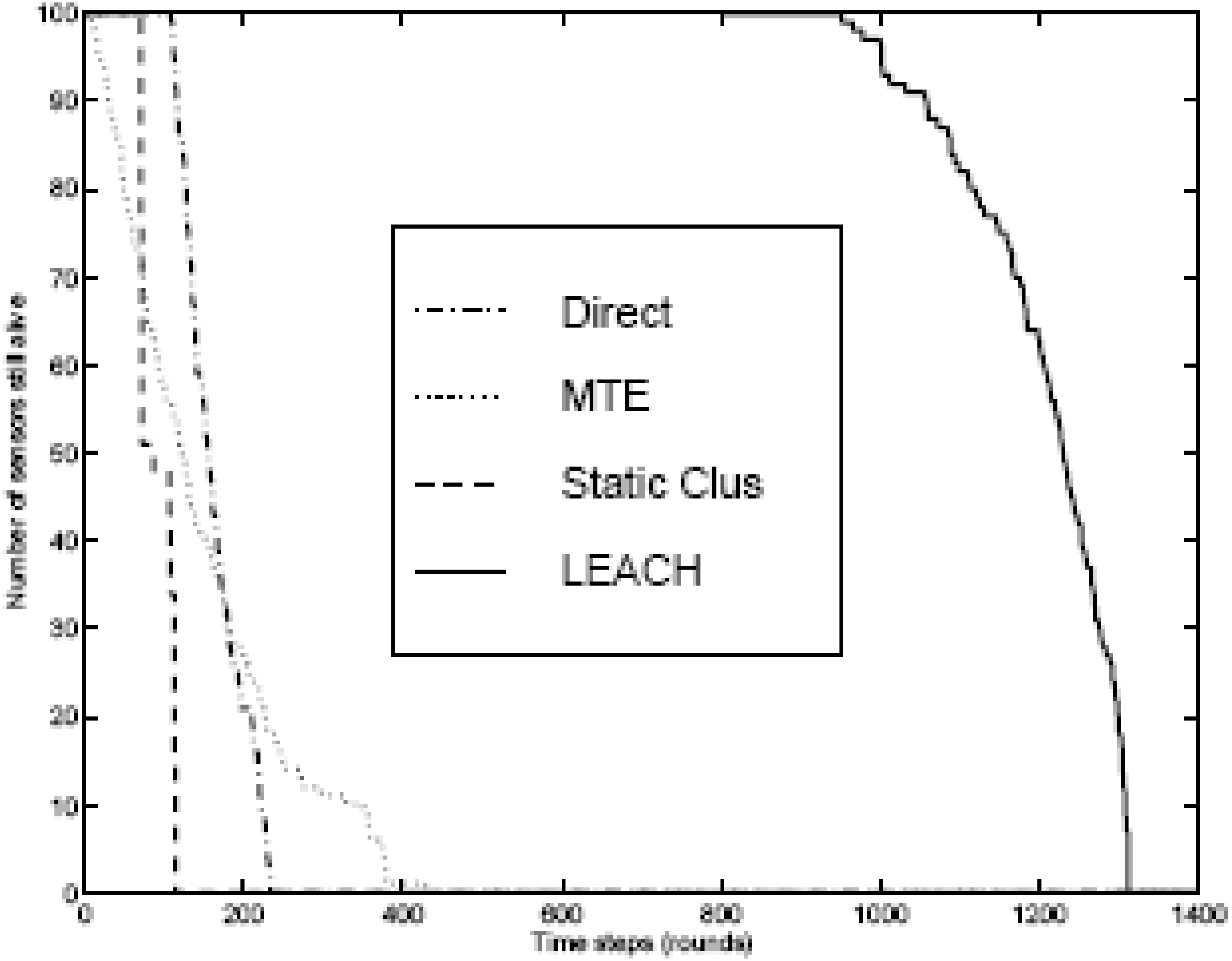
MTE:



Energy consumption



Network lifetime



Network lifetime (2)

Table 2. Lifetimes using different amounts of initial energy for the sensors.

Energy (J/node)	Protocol	Round first node dies	Round last node dies
0.25	Direct	55	117
	MTE	5	221
	Static Clustering	41	67
	LEACH	394	665
0.5	Direct	109	234
	MTE	8	429
	Static Clustering	80	110
	LEACH	932	1312
1	Direct	217	468
	MTE	15	843
	Static Clustering	106	240
	LEACH	1848	2608

LEACH summary

- LEACH = Low-Energy Adaptive Clustering Hierarchy

Main features of LEACH protocol:

- Self-organizing
- Adaptive
- Cluster-based with distributed coordination
- CHs are changed periodically
- Scalable, robust
- Data aggregation for load reduction.