Sensor networks and applications

Routing (hierarchical). LEACH. TEEN.

LEACH protocol (revisited)

- 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 (revisited)

- 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 (revisited)

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 themselves.
3. All non-CH nodes select one CH that they want to belong to (based on the received signal strength, for example), then notify the CH about the decision.
4. All CHs assign a TDMA schedule to their nodes within the 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 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: $E[\#CH] = \sum_{i=1}^{N} P_i(t) = k$

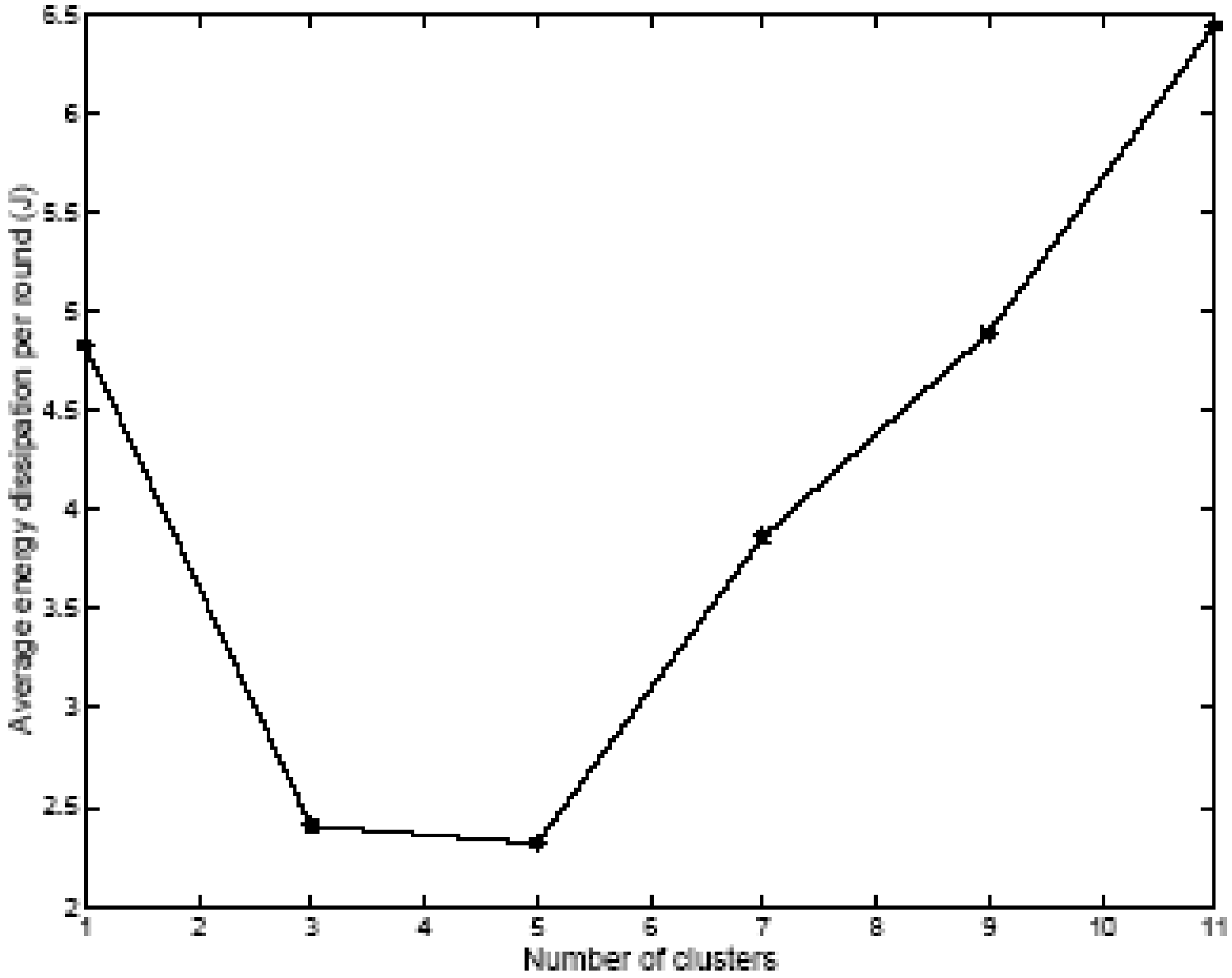
  where *N* is the number of network nodes

Setup (cont'd)

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

- 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.

- The **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-REQ** mesage 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

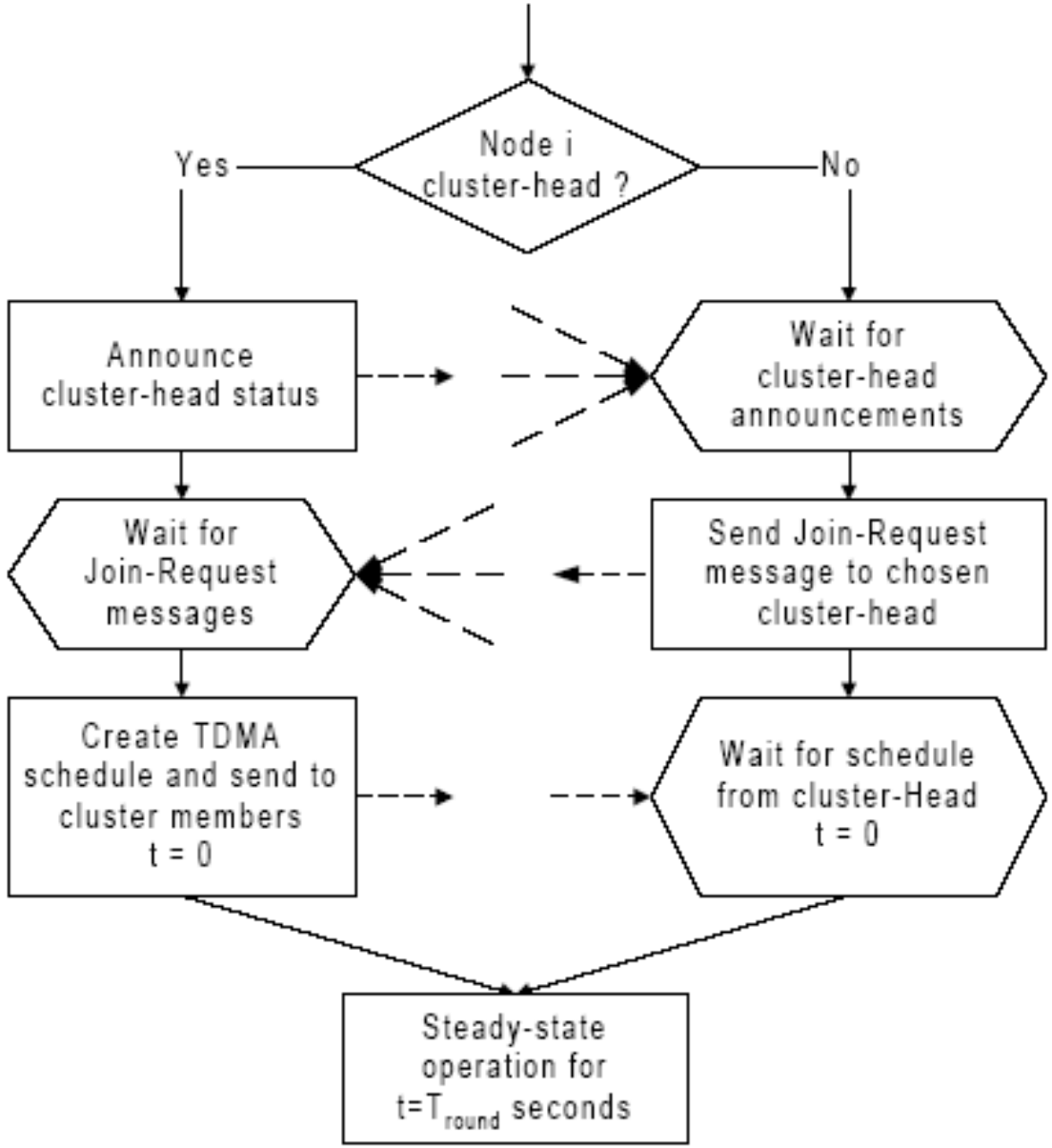
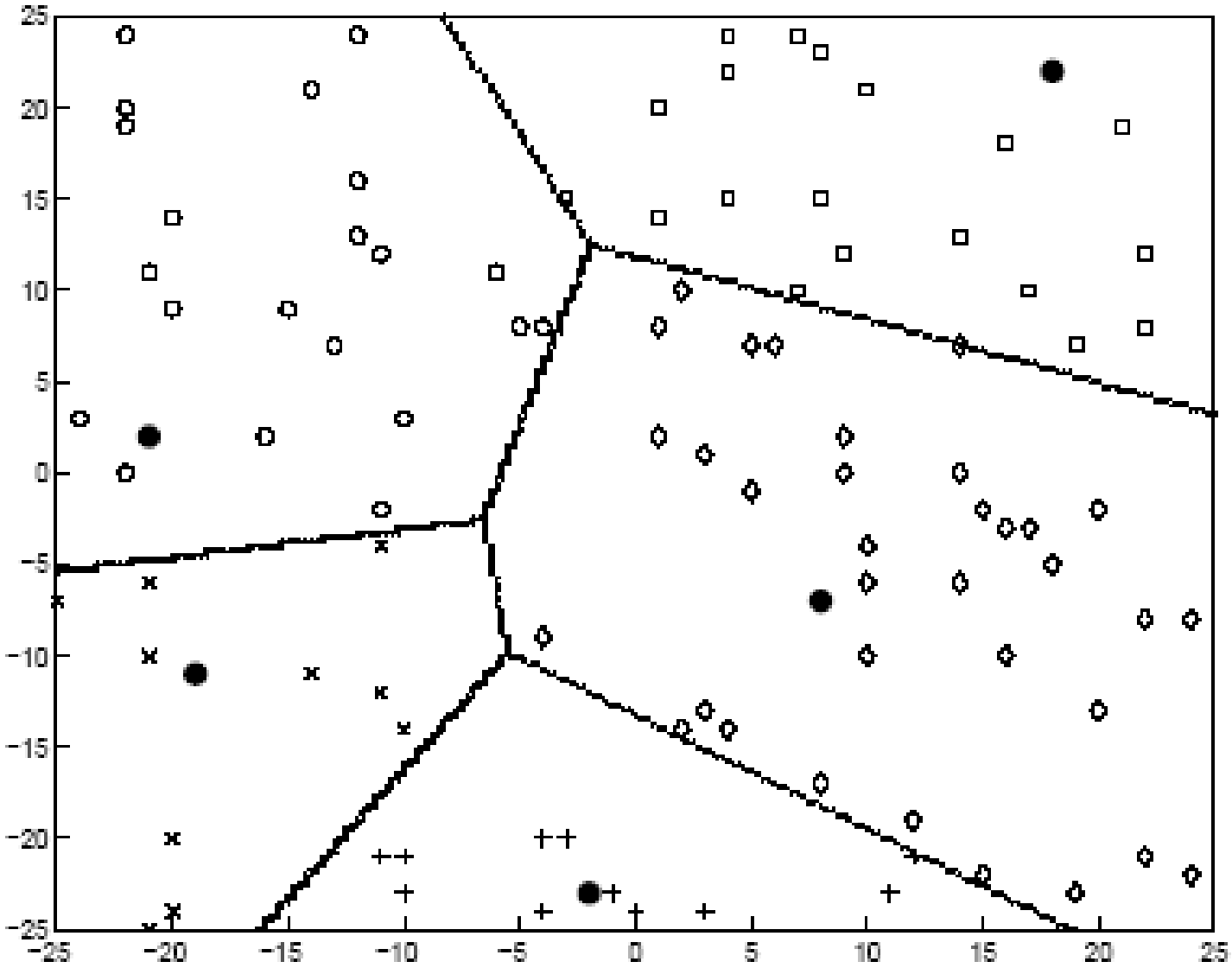


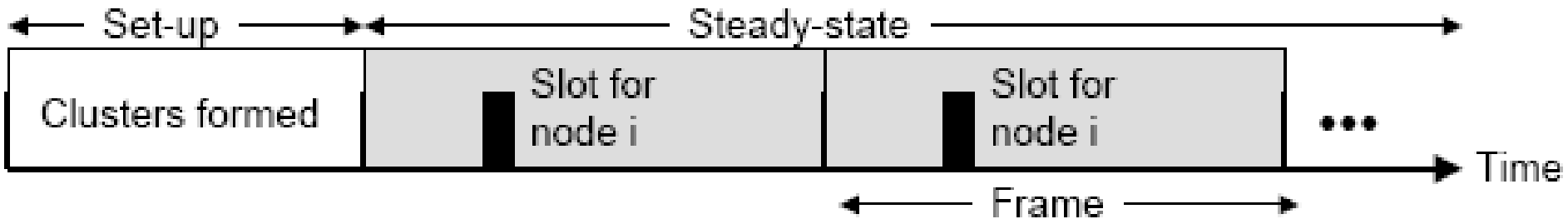
Figure 3-3: Flow-graph of the distributed cluster formation algorithm for LEACH.

Setup – cluster formation



Steady state

- The communication is broken down to frames:



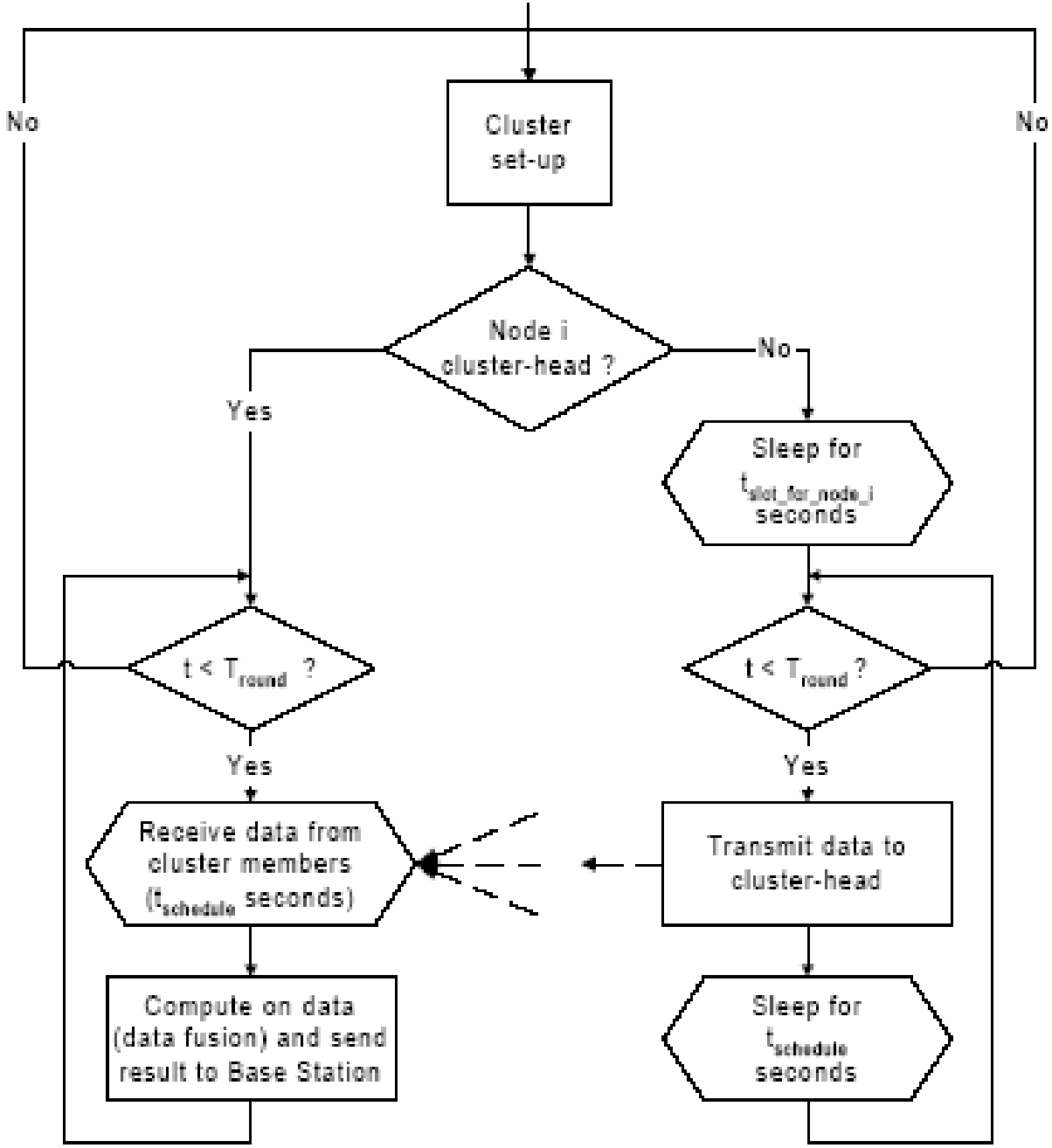
- Nodes can only send one packet within a frame to the BS in the **allocated fixed time slot**.
- The frame length is proportional to the number of nodes within the cluster.
  - Note: There are *k* nodes in a cluster on the average, but the actual value can be significantly different from that!

Steady state (cont'd)

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

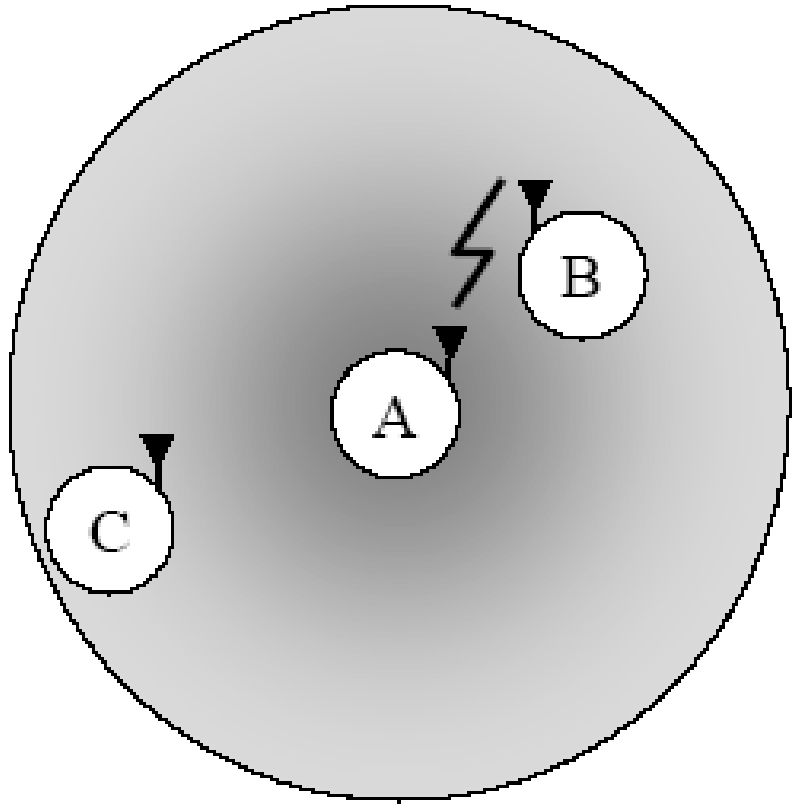
- CH nodes
  - stay awake continuously
  - aggregate and pre-process the gathered data;
  - send the information to the BS (requires high energy)

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**

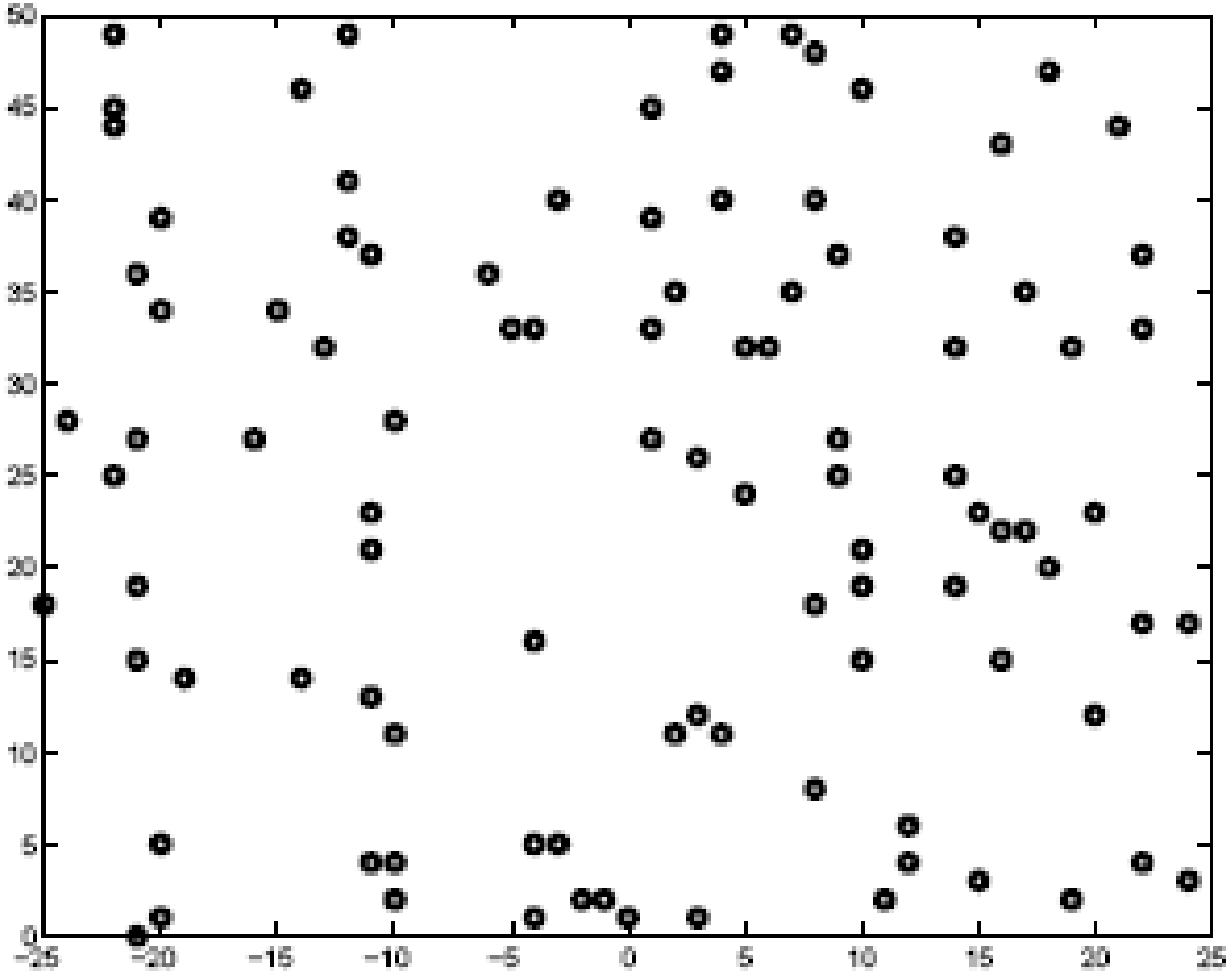
Direct communication:

- All nodes send packets directly to the BS.

MTE

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

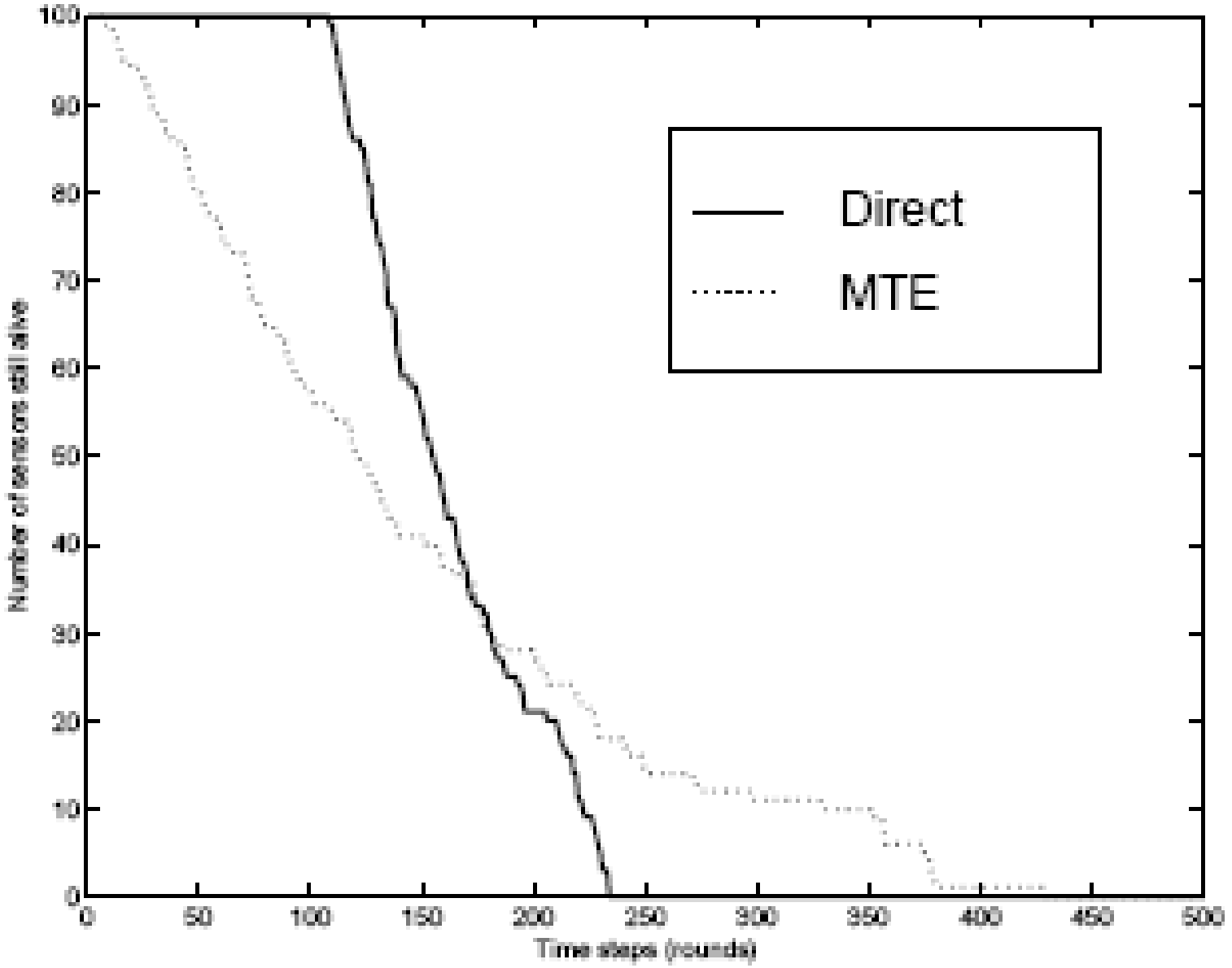
Performance analysis



examined topology

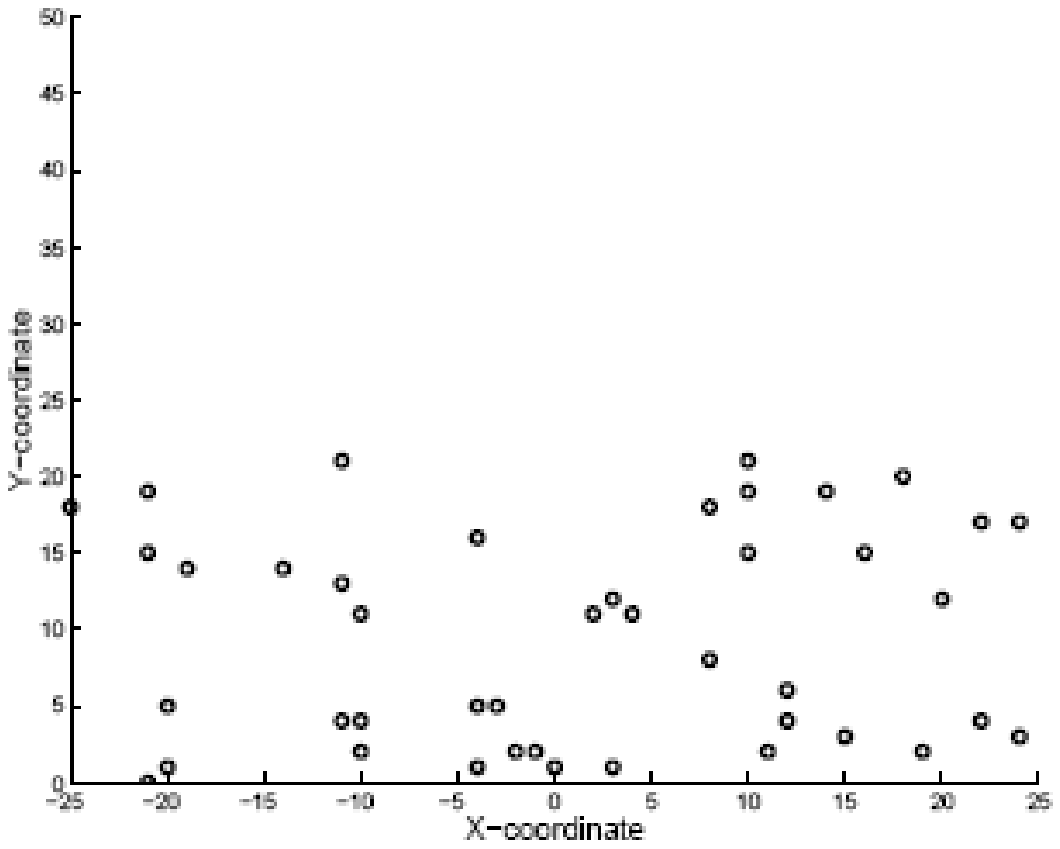
BS coordinates:
(x=0, y=-100)

Network lifetime (Direct, MTE)

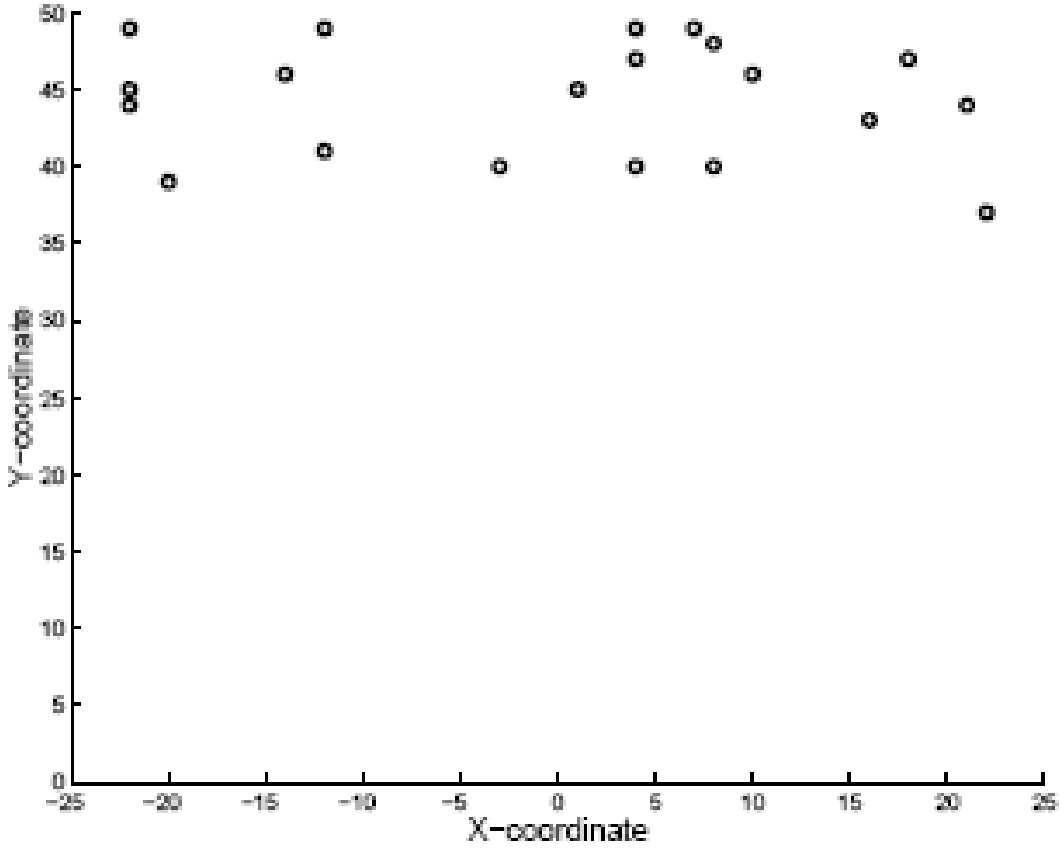


Network lifetime (Direct, MTE)

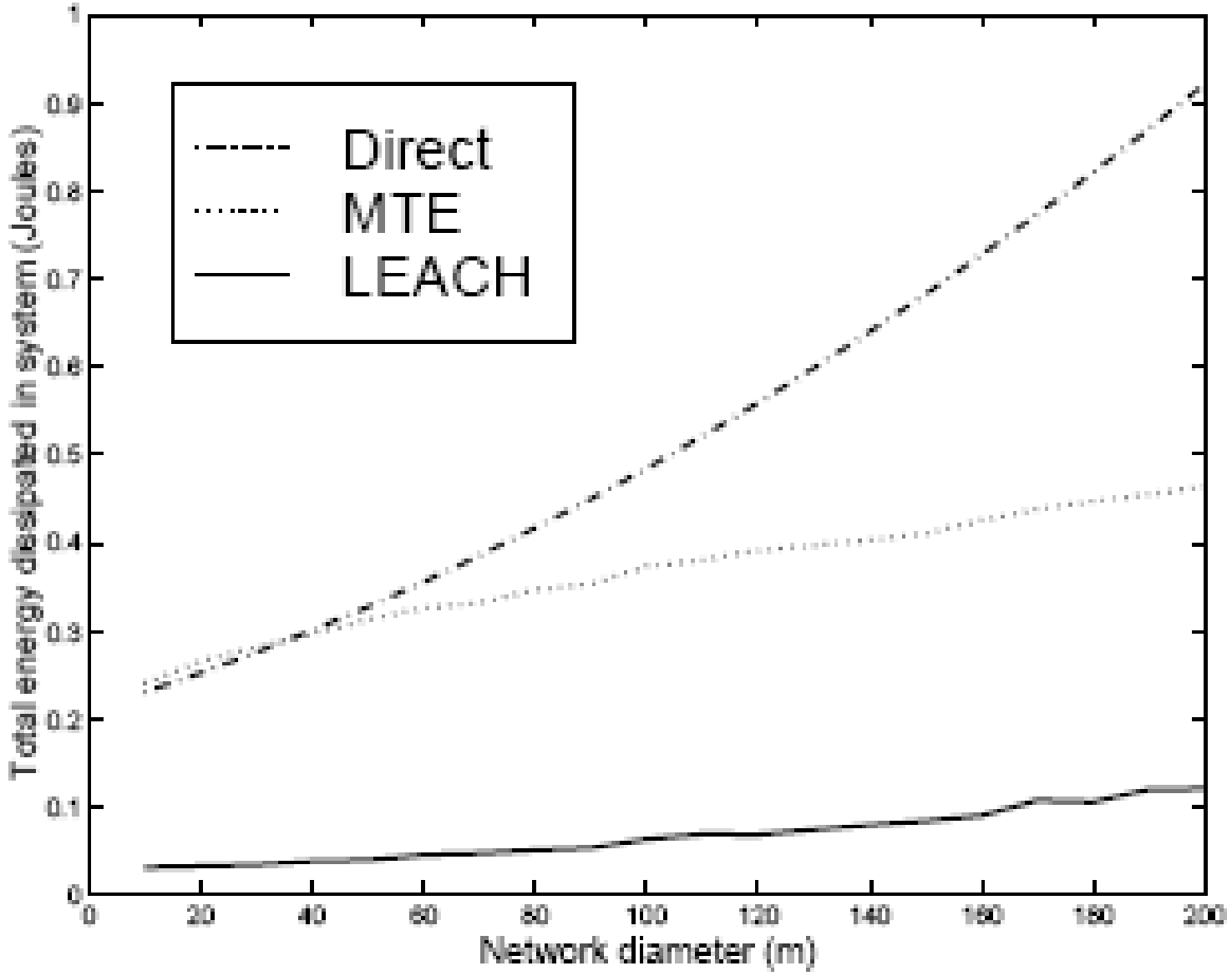
Direct:



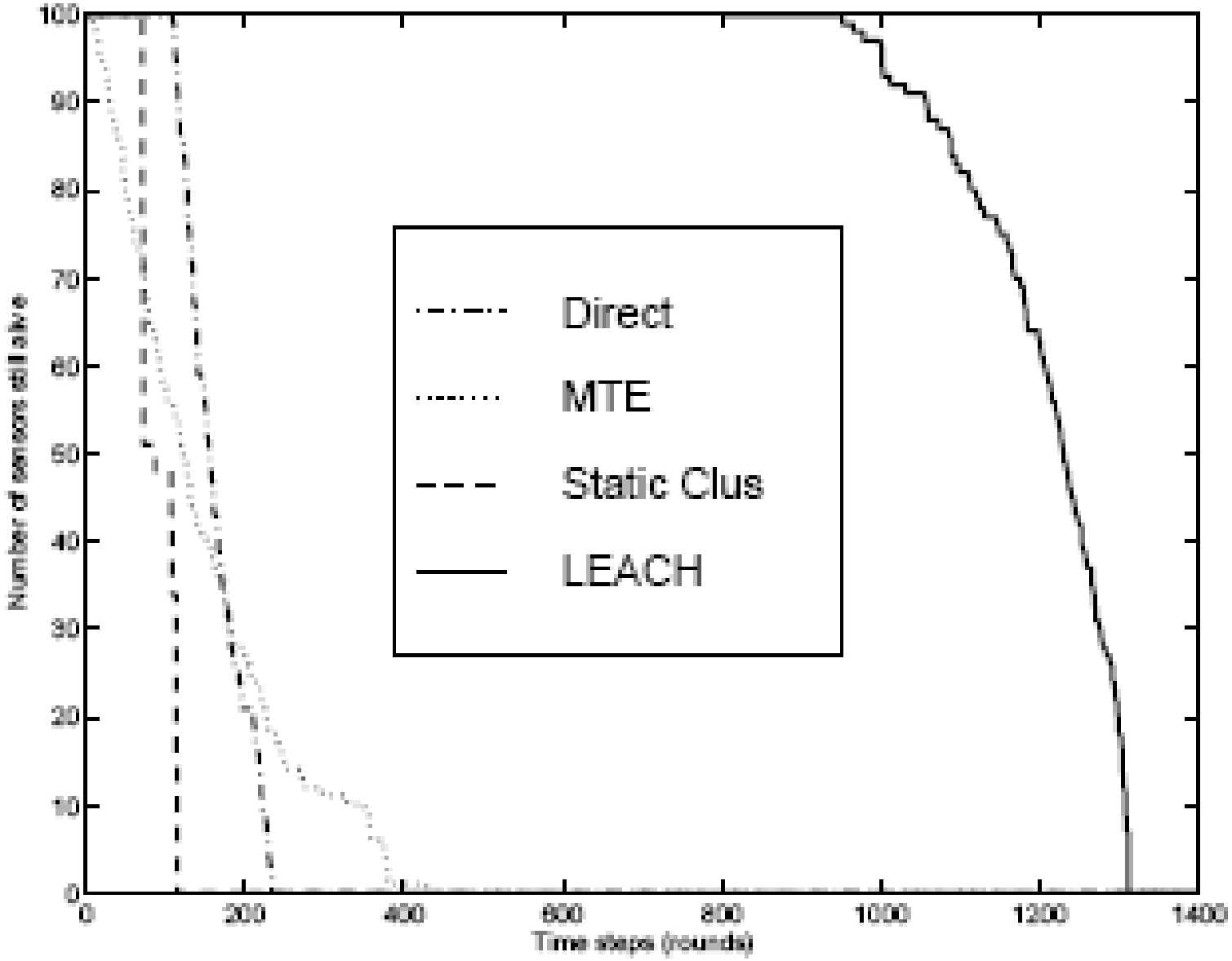
MTE:



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.

Routing solutions

Hierarchical

Routing paradigms

- Network topology-based solutions
  - Flat
  - **Hierarchical**
    - LEACH, **TEEN, APTEEN**
  - Location based
  - other...

TEEN

- **TEEN** = Threshold-sensitive Energy Efficient sensor Network protocol
- Cluster-based solution.
- Reactive.
- Suitable for time-critical applications.

- Idea: Sensors monitor the environment continuously, but only send data when the measured value is above a certain threshold.

TEEN

- Protocol operation:
  - The cluster head sends a **hard** and **soft threshold** value to all of its sensor nodes.
  - When a monitored **value is above the hard threshold**, the node turns on its radio and sends the data to the cluster head. It also stores the data for itself.
  - Next, the node only sends new data if...
    1. the measured value is still **above the hard threshold**, and
    2. the difference between the old and new data is **larger than the soft threshold**.
- When the cluster head is changed, the new CH sends new threshold values within its cluster.

TEEN

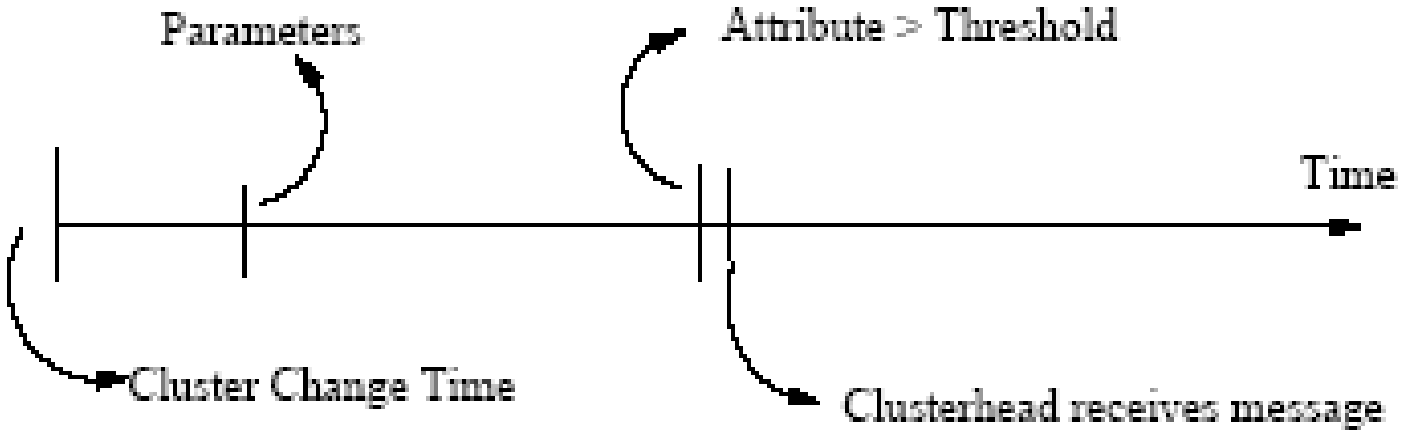
- Advantages:
  - Energy efficient solution.
  - Only relevant data is measured because of the hard threshold.
  - Using the soft threshold, a trade-off between accuracy and data volume can be set.

- Modification: **APTEEN – Adaptive Periodic TEEN**

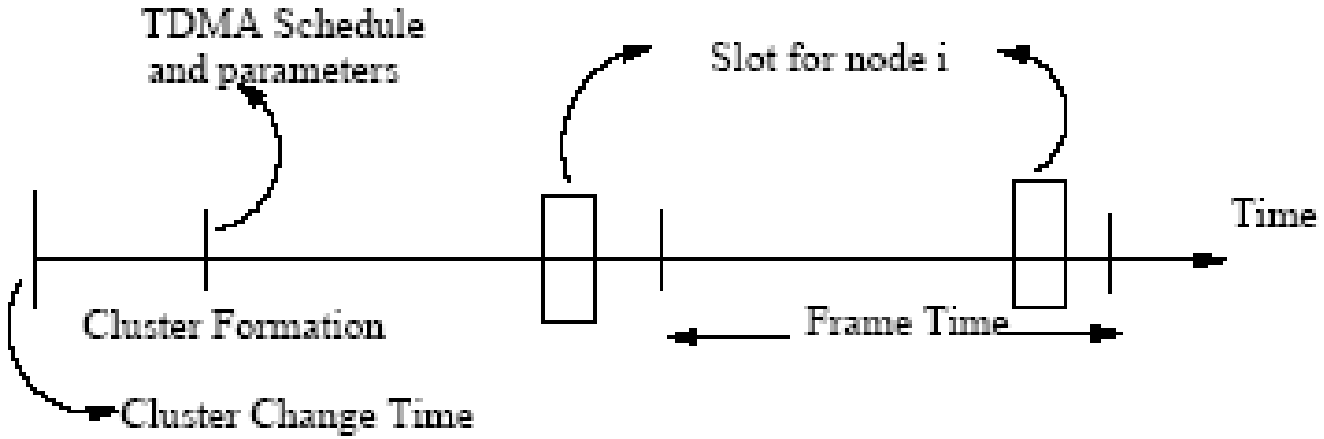
APTEEN

- **Hybrid** protocol: thresholds + periodicity
- Parameters sent by the cluster head:
  - Attribute (physical quantity)
  - Thresholds: hard and soft
  - TDMA scheduling information
  - Max period length
- The use of thresholds is the same as in TEEN.
- All nodes can send data only in their dedicated TDMA slot.
- All nodes must send data at least once in every period (proactive operation)

TEEN and APTEEN



(a) operation of TEEN



(b) operation of APTEEN

APTEEN

Advantages:

- Flexibility by parametrization.
- Reactive and proactive operation.

Drawbacks:

- Complexity (thresholds and periods)
- Clustering and cluster head election.