Energy Management in IoT-Clustering

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Outline

Clustering objectives in wireless sensor networks

LEACH(Low-Energy Adaptive Clustering Hierarchy) Protocol

LEACH Successor Protocols

WSNs

(Wireless Sensor Networks)

Uses thousands of resource-constrained sensors to monitor their surroundings.

→ Topology management is crucial in solving problems associated with resource management, scalability, and reliability.

WSN Topology Management

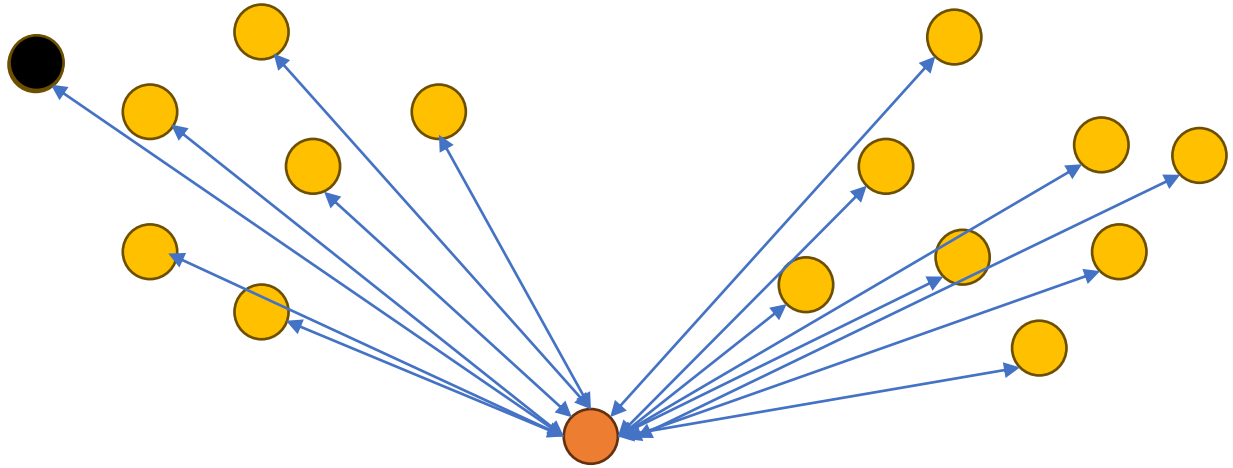
- Direct Communication with the Base Station
- Minimum Energy multi-hop routing (using such sensor networks and radio models)
- Clustering

Direct Communication with the Base Station

Sensors communicate directly to the Base Station

- Large amount of transmission power from each node to the BS

Q: Which node is likely to die first?

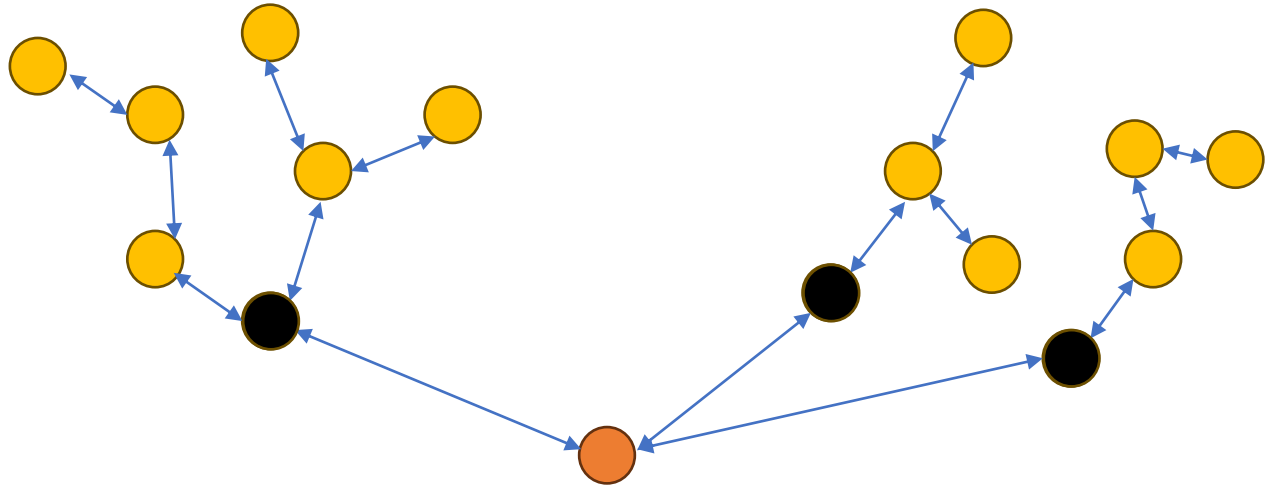


Minimum energy multi-hop routing (MTE)

Nodes route through intermediate nodes to the BS

- Each data message goes through n transmits and receives; therefore, total energy expenditure may be larger than direct transmission

Q: Which node is likely to die first?



Direct Communication with BS

MTE

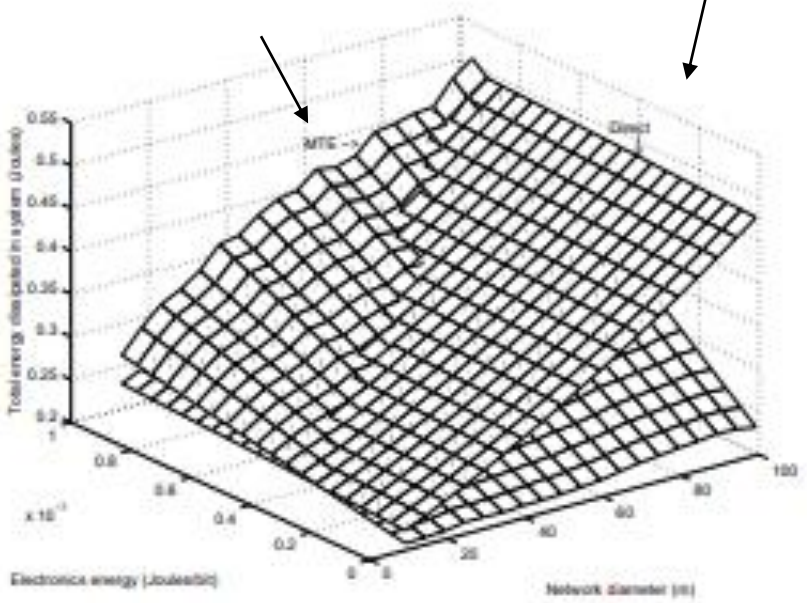


Figure 4. Total energy dissipated in the 100-node random network using direct communication and MTE routing (i.e., E_{direct} and E_{MTE}). $\epsilon_{amp} = 100$ pJ/bit/m^2, and the messages are 2000 bits.

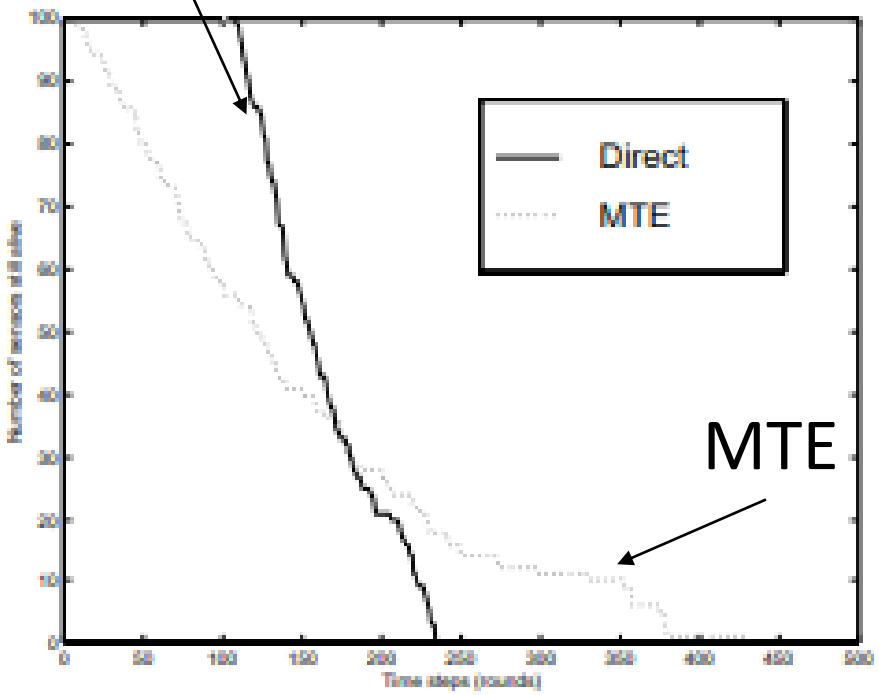


Figure 5. System lifetime using direct transmission and MTE routing with 0.5 J/node.

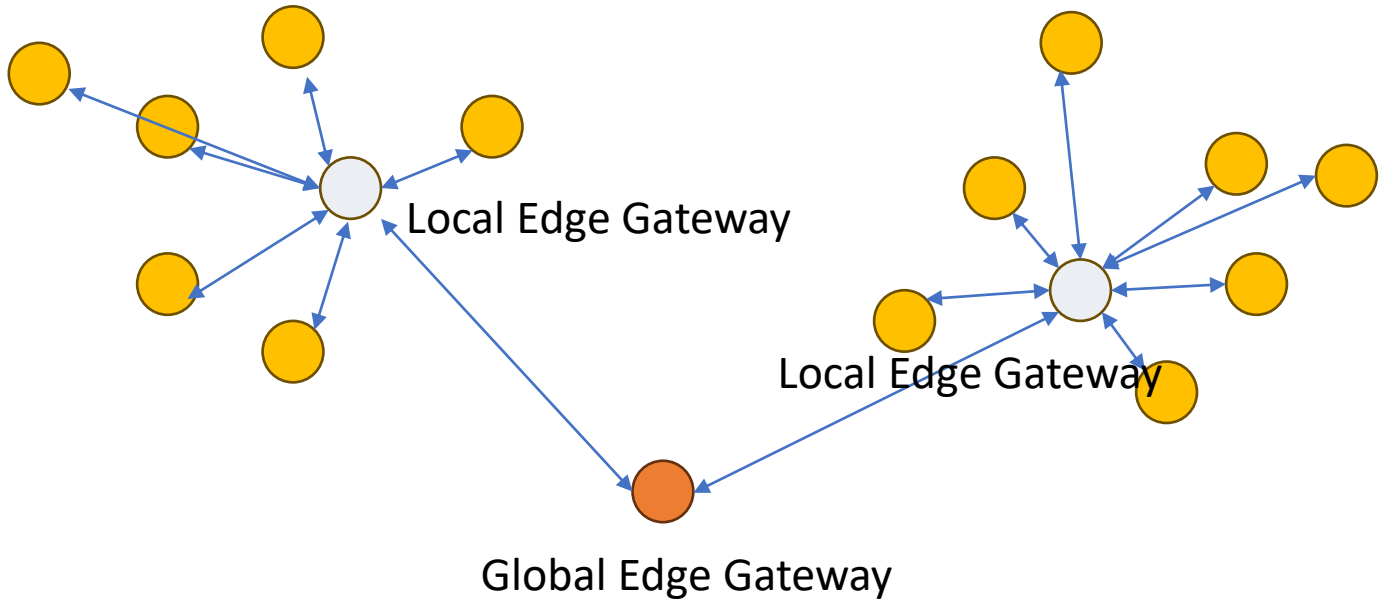
Trade-offs?

Clustering

Nodes are organized into a group called clusters, which has one or more Cluster Heads(Local BS). Local BS communicates with the global BS.

Q: How can you fix the problem of having a fixed Local BS?

(e.g., local BS must be in high energy mode)



Paper 1: Clustering Objectives in wireless sensor networks

Clustering techniques are reviewed based on objectives achieved by clustering; Quality of Service(QoS), fault tolerance, load balancing, etc.

Clustering techniques are evaluated based on heterogeneity and mobility

Provide statistical model to motivate using clustering for network management

Clustering: Basic Concepts

Ad-Hoc network

Determine possible neighbors to establish connections and determine best neighbor for hop-by-hop data transmission

Cluster

Nodes group up to improve the efficiency of the network by managing resources and rotating responsibilities among nodes **to provide fairness** (of the energy resources)

Clustering: Taxonomy

Cluster phase: **Grouping** and allocating responsibilities

Voronoi: 2D and 3D network environment is divided into clusters

Chain: Nodes connect to reach CH

Spectrum: Angles of nodes and distances to the CH matters

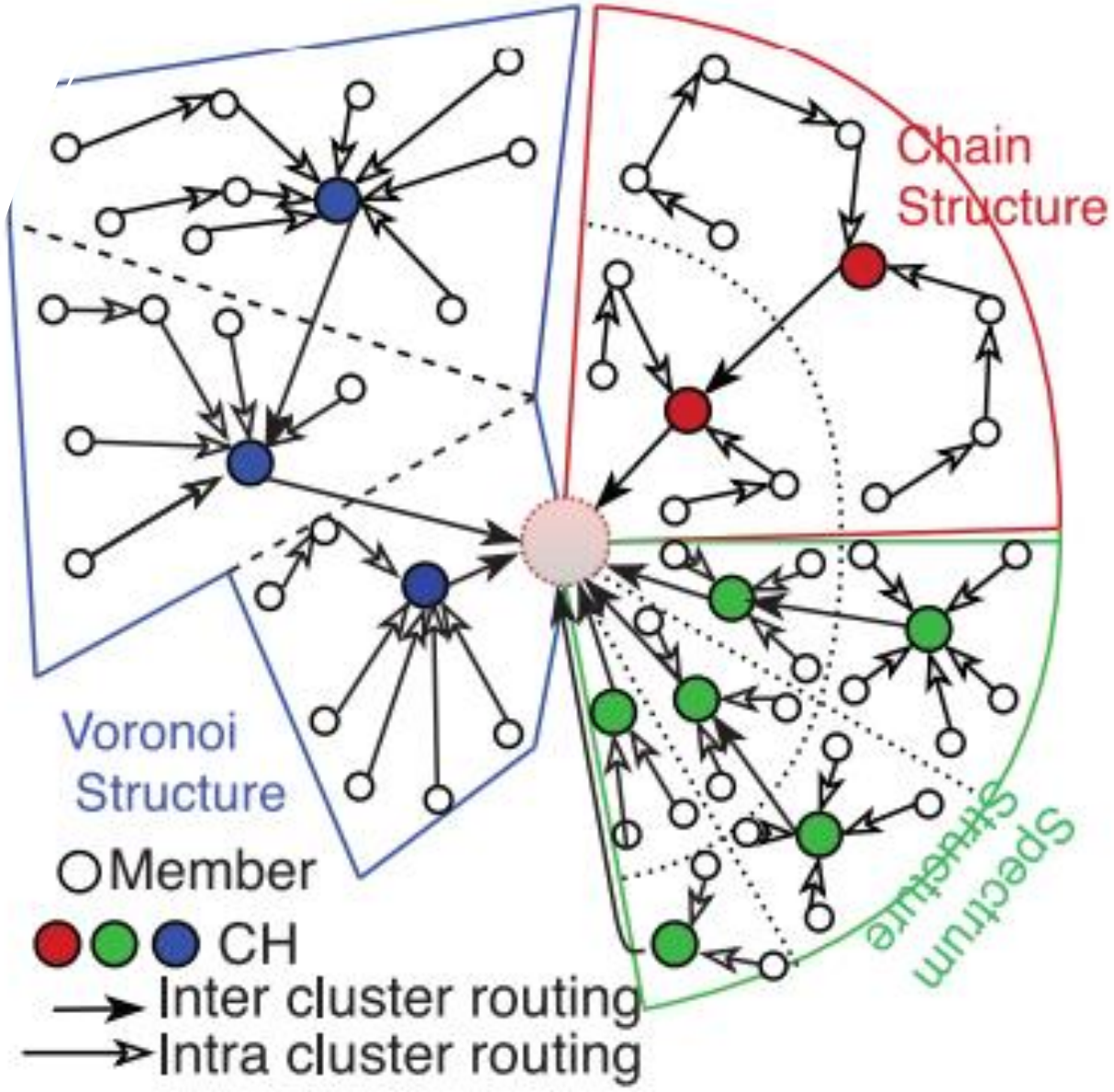


Fig. 1. Different structures of clustering techniques.

Clustering: Cluster Routing

Intra-cluster routing:

Indirect communication between node and CH

- Pros: Reduce energy consumptions

- Cons: QoS issues such as increasing delay

Inter-cluster routing:

Allows communication between clusters without using the BS

- Pros: Improves efficiency by resource sharing and running distributed tasks

Clustering: Establishment Methods

Group nodes then Select one or more nodes as CH(s)

- similarity of service in applications sharing the same network
- data gathering and data fusion algorithm
- support different QoS parameters

Determine CHs then Invite other nodes to join a neighbor

- distance to CH and/or distance of CH to BS
- similarity of the applications running on the members
- respect to data fusion or hosting requested services by the CH

General CH Selection Methods

1. Resource-rich nodes are predetermined as CHs

- Most WSNs are homogeneous and resource-constrained

2. Randomness

- Beneficial in homogeneous networks but dynamicity may create run-time problems like chronic energy consumption

3. Conscious CH selection

- Improve the efficiency of the network by selecting, re-selecting, or replacing CHs with appropriate nodes

General CH Selection Methods

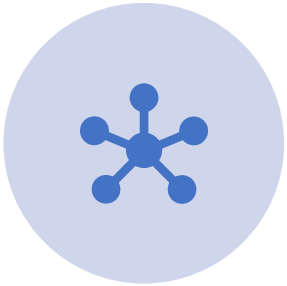
Centralized CH selection method:

- The central node gather information and analyze, compare, and process for selecting CHs.
- High overhead may be a problem (when CHs are re-selected regularly)

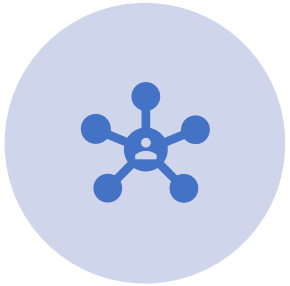
Distributed CH selection method:

- Has less overhead
- Having limited network information may lead to not fulfilling all network requirements

Node Heterogeneity



High network efficiency by sharing available resources to different nodes



Resource-rich nodes and resource-poor nodes can work together to keep themselves alive for longer

Good for selecting CHs (more resources)

Not efficient for allocating and managing resources

Role of CH

- Usually NOT in charge of complicated tasks
- Energy and data forwarding resources
- Some utilize CHs for data fusion

  … need of computation power

Clustering Objectives

Energy Consumption

- Main goal of clustering techniques:

  to balance energy consumption and improve network lifetime

- Routing in WSN nodes may cause unbalanced energy consumption

  - Intermediate nodes may consume more energy

  - Tradeoffs in using direct communication method

- Heterogeneous/homogeneous networks

  - Selecting CHs is more complicated in homogeneous network because all nodes have the same resources

  - Being heterogeneous makes CH selection a multi-objective problem

Energy Consumption: techniques

- CH Duty Rotation

Rotate CHs to balance energy consumption

- Hierarchical clustering

Divide the network into different layers/ use unbalanced clustering (layer closer to BS consume more energy)

- Balanced clustering

Location distribution of nodes are unbalanced, so clusters need to be balanced to have fair energy consumption.

Load Balancing

- A data transfer load can result in unbalanced energy consumption, network congestion, data loss, and inefficiency in supporting real-time and data-intensive applications
- May solve “Hot spot problem”, where some nodes in a network transfer high volume of data than others
- In heterogeneous network, nodes with more resources transfer more data to support load balancing

-> More layers and CHs will help increase the chance of using different CHs in routing data from nodes to BS

Fault tolerance

- Caused by battery depletion, transceiver and processor failure, connectivity failure and node failures
- These may cause data loss if fault happens in sensors or CHs.

Techniques to replace failed nodes keeps network stable:

- **Detect Failure**: first nodes and CHs are evaluated on regular basis

- **Spare CHs(nodes):** the spares replace faulty nodes as hotspots

- **Re-clustering**: choose the CH again if this induce less overhead than keeping spare CHs updated

Network Topology Management

- Each CH is responsible for managing the topology of the WSN to keep them connected, reliable and stable

Two aspects that should be managed:

- Stability

Can make the network infrastructure more reliable in terms of connectivity, QoS, fault tolerance, etc.

- Scalability

WSNs should be able to scale up to hundreds and thousands of nodes and keep the network connected. Communication overhead may be another challenge to support scalability.

Paper 2: Energy-Efficient Communication Protocol for Wireless Microsensor Networks

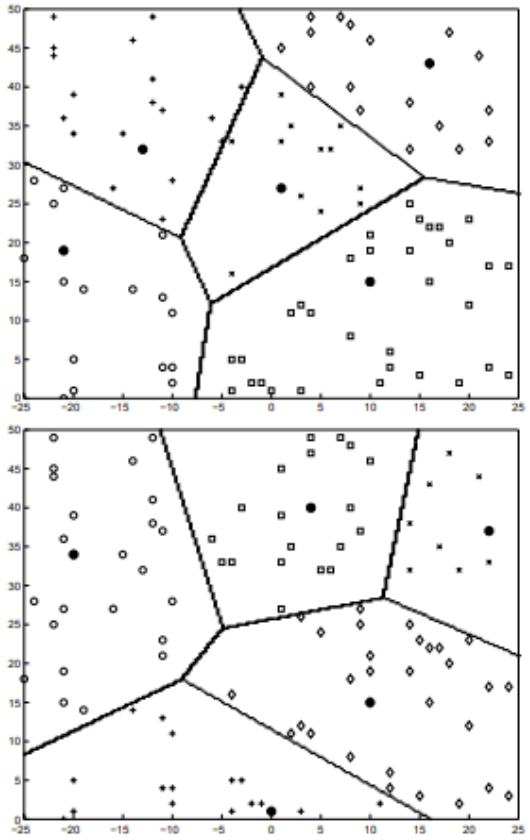


Figure 7. Dynamic clusters: (a) cluster-head nodes = C at time t_1 (b) cluster-head nodes = Ct at time $t_1 + d$. All nodes marked with a given symbol belong to the same cluster, and the cluster-head nodes are marked with a •.

LEACH Protocol

Low-Energy Adaptive Clustering Hierarchy Protocol

A clustering-based protocol that choose different CH randomly every round. This protocol evenly distributes the energy load among the sensors in the network.

Contributions of LEACH

- Enable **scalability** and **robustness** for dynamic networks
- Incorporate **data fusion** into the routing protocol to reduce the amount of data being sent to the base station
- Distribute **energy dissipation evenly** throughout the sensors, doubling the useful system lifetime for networks

Key features of LEACH

Localized coordination and control for cluster set-up and operation

Randomized rotation of cluster “base stations” or “cluster heads” and the corresponding clusters

Local compression to reduce global communication

Rounds

Set-up phase:

CH selection, cluster formation and assignment of a TDMA schedule by the CH for member nodes are performed

Steady-state phase:

Transmission of sensed data from member nodes to the CH and CH to the BS are performed using the TDMA schedule

Set-up Phase

Nodes will become a CH in the probability of:

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

Where P = 0.05 (could be arranged), r = round #

Set-Up Phase

Cluster setup phase:

- All CH will send out an advertisement to the non-CHs.
- Receiving the advertisement, the non-CHs become the part of the cluster that has the CH with the strongest signal

Schedule Creation:

- non-CHs send back a response to the strongest neighbor CH using a CSMA MAC protocol to become a member of the cluster.
- CH creates a TDMA schedule from the information sent back about members of the cluster and broadcasts this schedule.

Steady Phase

Data Transmission:

- Data transmission occurs using the TDMA schedule
- Each non-cluster-head node turns off until the node's allocated transmission time
- CH keeps its receiver on at all time.
- When all the data is received, CH performs signal processing functions to compress the data into a single signal.
- This signal is sent to the base station and is a high-energy transmission.

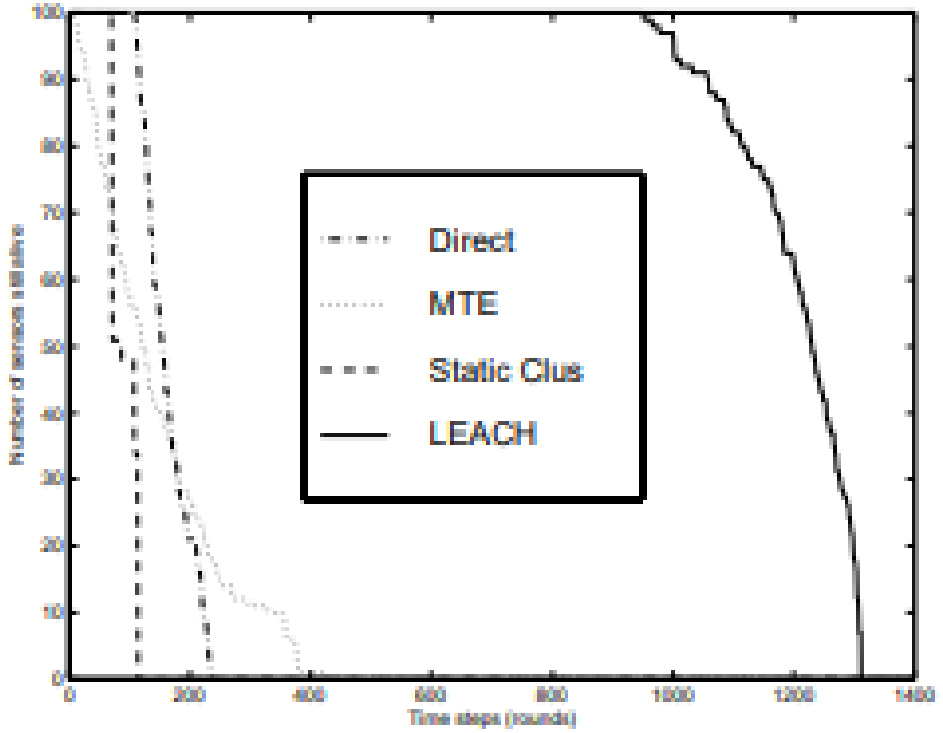


Figure 11. System lifetime using direct transmission, MTE routing, static clustering, and LEACH with 0.5 J/node.

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

Paper 3: A Survey on Successors of LEACH Protocol

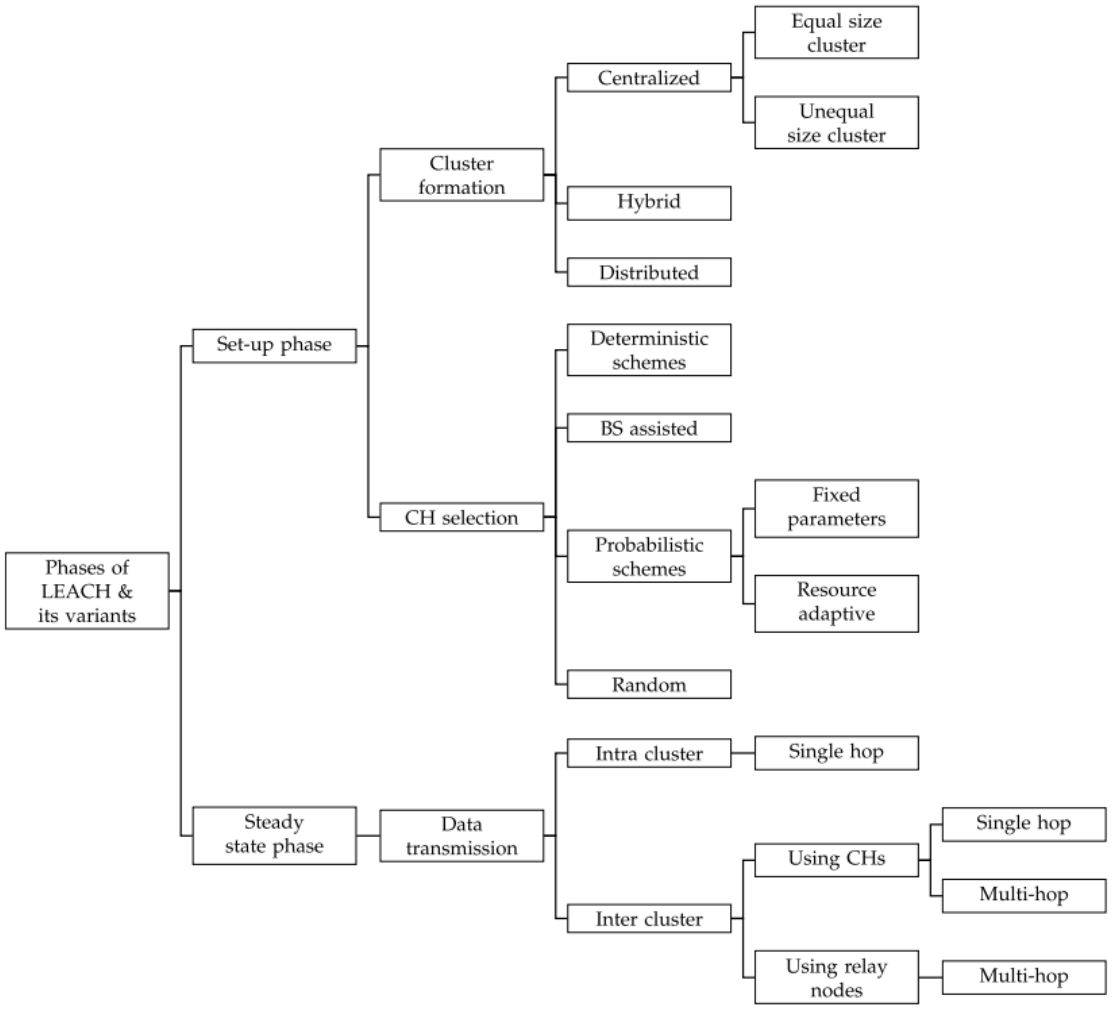


FIGURE 1. Phases of LEACH and its variants in WSN.

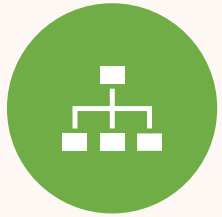
Major goals of LEACH variants

ENERGY EFFICIENT COMMUNICATION IN WSN.

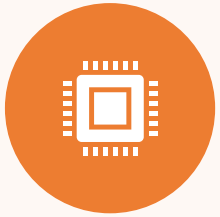
IMPROVEMENT IN SCALABILITY.

INCREASING THE SECURITY IN WSN.

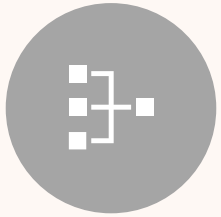
MINIMIZATION OF NETWORK DELAY.



REDUCTION OF COMPLEXITY.



ASSURANCE OF CONNECTIVITY UNDER VARIOUS SCENARIOS.



EQUAL LOAD DISTRIBUTION OVER ENTIRE NETWORK.

IMPROVEMENT OF THE OVERALL PERFORMANCE IN WSN

LEACH-C (LEACH-Centralized)

- Produces excellent clusters by scattering the CH throughout the sensor network
- Since set-up phase is completely executed at the BS, there is no overhead for sensor nodes during the formation of clusters.
- The steady-state phase of LEACH-C is the same as the original LEACH protocol.

LEACH-C

BS calculates the average energy of sensor nodes

- Sensor nodes with energy < average

Is prohibited from participating in the CH selection process

- Sensor nodes with energy > average

The optimal number of clusters K can be calculated using

(while N sensor nodes and M*M sensing area)

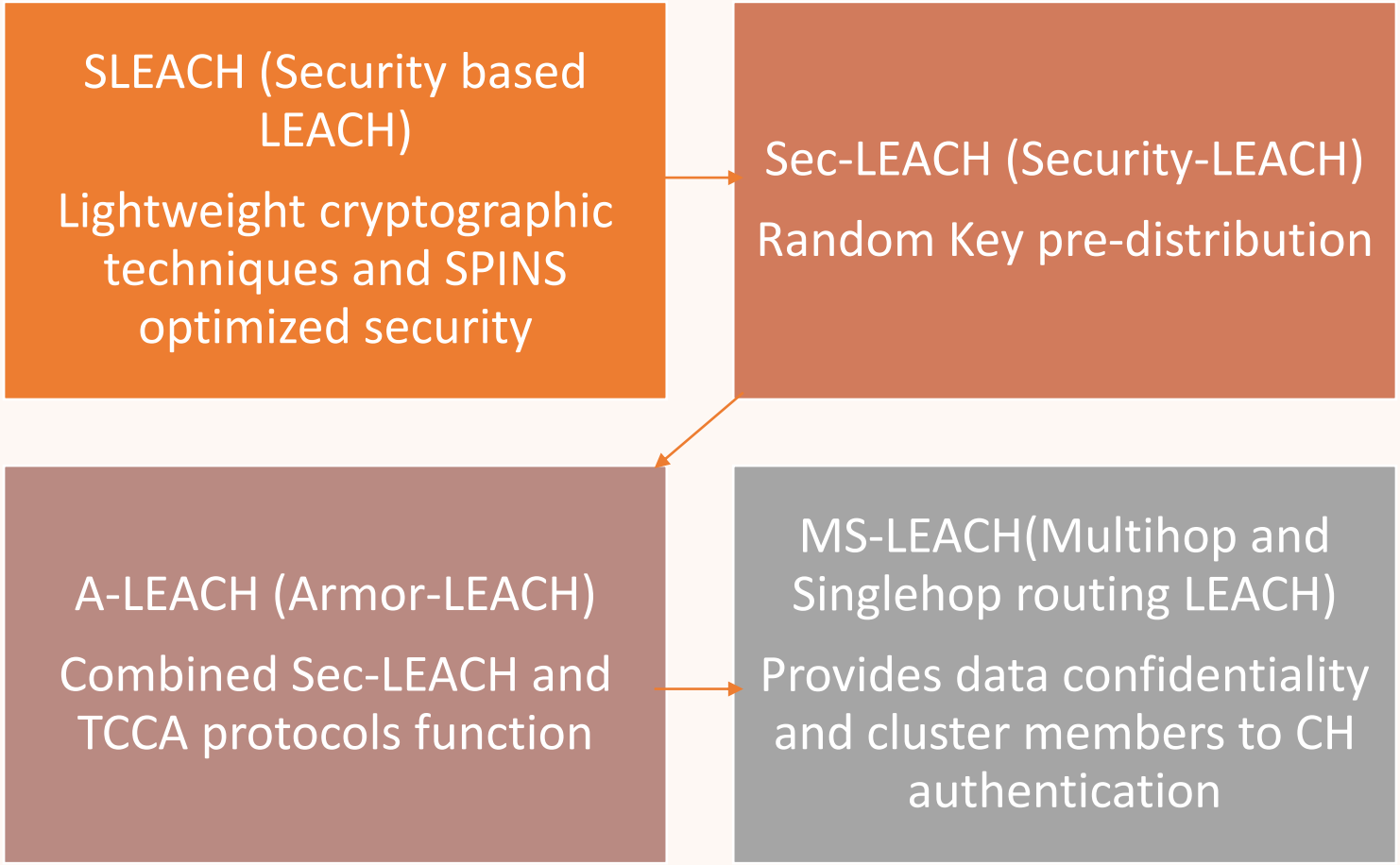
$$K = \sqrt{\frac{N}{2\Pi}\frac{\epsilon_{fs}}{\epsilon_{mp}}\frac{M}{d_{toBS}^2}}$$

Comparison of LEACH and LEACH-C

+ Clusters are managed by the BS so it is more energy efficient

− Every nodes require GPS for location information, which is a costly device and it consumes extra energy. Though it is centralized it is less scalable.

LEACH variants: Security



LEACH variants: Security

SLEACH (Security based LEACH)

Only effective for inside attackers and is not energy efficient

Sec-LEACH (Security-LEACH)

Security is achieved at the cost of higher energy consumption

A-LEACH (Armor-LEACH)

More overhead and energy consumption

MS-LEACH (Multihop and Singlehop routing LEACH)

More control overhead and energy consumption

LEACH Future Goals

- Most of the LEACH variant protocols are designed to **minimize energy consumption**, since sensor nodes are energy constraints.
- **Security**-related issues are not solved with good **energy efficiency**
- While **solar harvesting** is a new promising research area in WSN, only one LEACH variant (solar-LEACH) uses this.
- **Mobility** and **network coverage** is a field in WSN that should be extended
- Most of the centralized variants of LEACH use **GPS** for location information, which is costly and energy consuming. Optimal localization techniques need to be developed.

Conclusion

- **WSN topology management** was crucial in managing, scaling, and providing reliability in using hundreds and thousands of sensor nodes.
- **LEACH** protocol improved clustering by randomly selecting CH every round.
- The main goal of this topic **was energy efficiency**, and its importance lie in improving other objectives such as security and mobility, while containing fair energy efficiency.

Thank you for listening!

Citations

- Amin Shahraki, Amir Taherkordi, Øystein Haugen, Frank Eliassen, Clustering objectives in wireless sensor networks: A survey and research direction analysis, Computer Networks, Volume 180, 2020, 107376, ISSN 1389-1286, https://doi.org/10.1016/j.comnet.2020.107376Links to an external site.. (https://www.sciencedirect.com/science/article/pii/S1389128620303121Links to an external site.)
- . W. R. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, Maui, HI, USA, 2000, pp. 10 pp. vol.2-, doi: 10.1109/HICSS.2000.926982.
- . S. K. Singh, P. Kumar and J. P. Singh, "A Survey on Successors of LEACH Protocol," in IEEE Access, vol. 5, pp. 4298-4328, 2017, doi: 10.1109/ACCESS.2017.2666082.