Project Distributed Algorithms

Distributed Algorithm for Dynamic Network with LEACH and LEACH-C

Lamine Diop - EPITA

October 14, 2025

Project Overview

- Study energy-efficient protocols in **Wireless Sensor Networks (WSNs)**.
- Focus on **LEACH (Low-Energy Adaptive Clustering Hierarchy)** and **LEACH-C (Centralized)** protocols.
- Implement and simulate these protocols in **dynamic networks** where nodes (cattle) move randomly.
- Use **distributed algorithms** for scalability and adaptability.

Context: Wireless Sensor Networks (WSNs)

- **WSNs** consist of sensor nodes that collect data and transmit it to a base station.
- Used in applications like **smart agriculture**, **environmental monitoring**, and **healthcare**.
- In agriculture, deployed sensor nodes can track health, location, and behavior in real-time.
- **Problem:** Energy efficiency is crucial since sensors are battery-powered and difficult to recharge in remote environments.

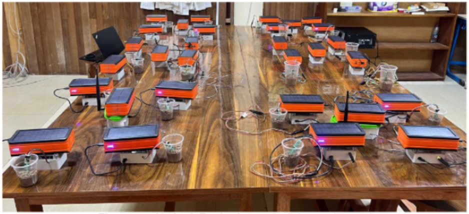


Figure: Smart agriculture using sensor networks

Example: Cattle Monitoring in Dynamic Networks

- In a **dynamic network**, nodes (sensor-equipped cattle) constantly move across a large field.

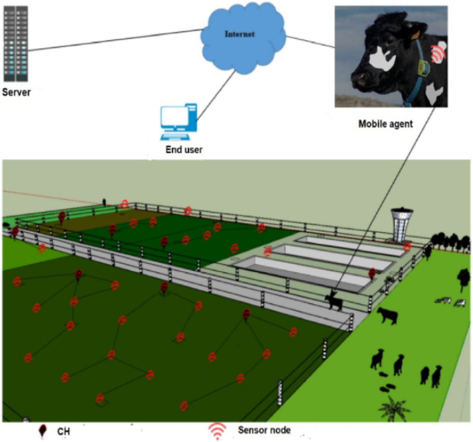


Figure: Dynamic cattle monitoring using WSNs [1]

Example: Cattle Monitoring in Dynamic Networks

- Traditional static clustering algorithms like **LEACH** may not adapt well to changing network topologies because **the muted round pitfall** (i.e, round without cluster head).

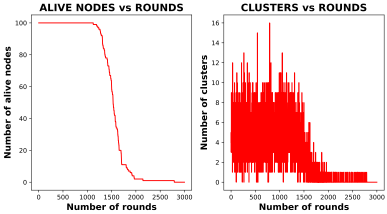


Figure: Dynamic cattle monitoring using WSNs

- **LEACH-C** (centralized) [2] can help by reorganizing clusters based on node mobility, but is energy-consuming due to frequent transmission of coordinates and energy data to the base station for each round.

Example: Cattle Monitoring in Dynamic Networks

- **Goal:** The challenge is to ensure that sensor nodes communicate efficiently, balance energy consumption, and maximize network lifetime.

Parameter	**Value**
Number of nodes	100 nodes
Initial energy per node	0.5 Joules
Area dimensions	$100 \times 100\, m^2$
Base station location	$(0, -100)$
Election probability (p)	0.05
Packet length	2000 bits
Initial energy (E_0)	0.5 Joules
Transmission/reception energy (E_{elec})	50×10^{-9} Joules
Amplifier energy for free space (E_{fs})	10×10^{-12} Joules
Amplifier energy for multipath (E_{mp})	0.0013×10^{-12} Joules
Data aggregation energy (E_{da})	5×10^{-9} Joules
Node max movement	5 meters per round

Table: Simulation Parameters for Cattle Monitoring in Dynamic Networks

Example: Cattle Monitoring in Dynamic Networks

- SACHE (Stable Adaptive Cluster Head Election)

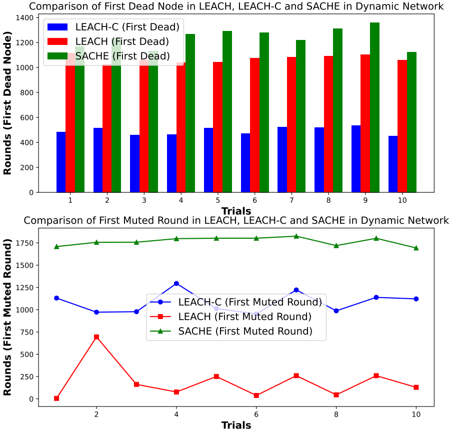


Figure: Execution of SACHE

Energy Model

Energy consumption model:

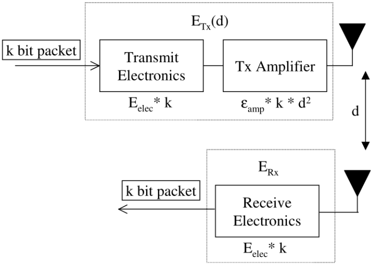
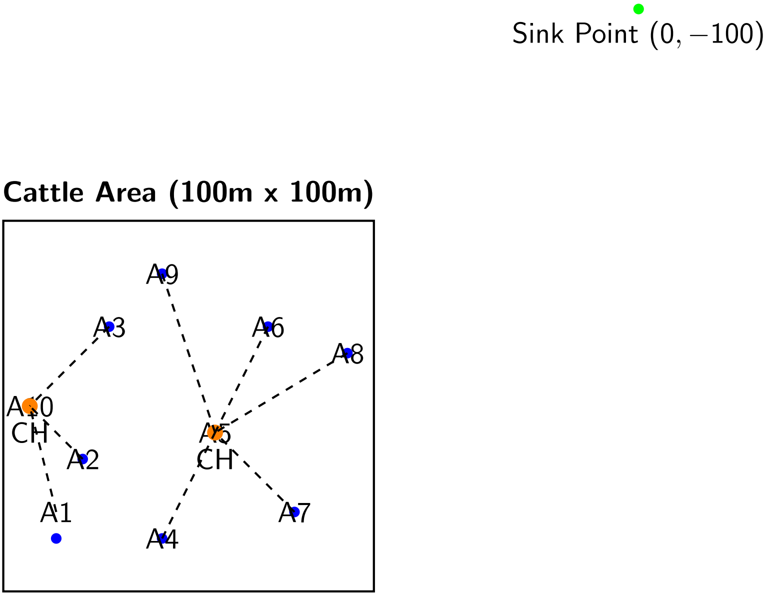


Figure: First order radio model [3]

$$E_{Tx}(l,d) = \begin{cases} E_{elec} \cdot l + E_{fs} \cdot l \cdot d^2 & \text{if } d \leq d_0 \\ E_{elec} \cdot l + E_{mp} \cdot l \cdot d^4 & \text{if } d > d_0 \end{cases}$$

- E_{elec}, E_{fs}, E_{mp} are energy constants.
- d_0 is the threshold distance between free-space and multi-path models.

Simulation Environment



Simulation Scenarios

Test parameters:

$(l, p, n) \in [(2000, 0.05, 100), (4000, 0.1, 200), \ldots]$

where:

- l: Data packet size (bits).
- p: User activity probability.
- n: Number of sensor nodes.

Performance Metrics

- Dead/Alive Node Count
- Packets sent to CH / BS
- Remaining Energy per Node
- First Muted Round (FMR) / First Dead Node (FDN)
- Dynamic Load Balancing Index (DLBI)
- Relative Silence Period Index (RSPI)

Dynamic Load Balancing Index (DLBI)

$$\mathrm{DLBI} = \frac{1}{N}\sum_{r=1}^{N}\mathrm{DLBI}_r \tag{1}$$

Where:

$$\mathrm{DLBI}_r = 1 - \frac{\sum_{j=1}^{m_r}(L_{j,r} - \bar{L}_r)^2}{m_r \cdot \bar{L}_r^2} \tag{2}$$

- $L_{j,r}$: Load handled by CH ch_j in round r.
- $\bar{L}_r$: Average load across all CHs in round r.

Relative Silence Period Index (RSPI)

$$\mathrm{RSPI} = 2 \times \frac{\left(1 - \frac{FR_{\text{muted}}}{R_{\text{max}}}\right) \times \left(1 - \frac{LR_{\text{dead}}}{R_{\text{max}}}\right)}{\left(1 - \frac{FR_{\text{muted}}}{R_{\text{max}}}\right) + \left(1 - \frac{LR_{\text{dead}}}{R_{\text{max}}}\right)} \tag{3}$$

- FR_{muted}: First muted round.
- LR_{dead}: Last dead round.
- R_{max}: Maximum round number, can be fixed by user or not.

Conclusion

- The project aims to extend LEACH and LEACH-C for dynamic networks highlighting their cons and pros.
- Focus on energy efficiency and real-world scenarios like sensor-based cattle control.
- Develop and simulate protocols and analyze performance with key metrics.

Evaluation Criteria

1. Correct implementation of LEACH and LEACH-C protocols in dynamic network using **Simpy** for distributed algorithm.
2. Comprehensive simulations with performance metrics.
3. Analysis of energy efficiency for dynamic networks.
4. Clear and organized report, including well-structured results.

Project Deliverables

- **Python Code:** Implementation of LEACH and LEACH-C algorithms for dynamic networks.
- **Report (Max 10 pages):**
  - Design and methodology.
  - Performance analysis with given metrics.
  - Comparison between static and dynamic networks.
- **Deadline:** 5 November 2025, 23:42

[1] Hamayadji Abdoul Aziz et al. "A collaborative WSN-IoT-Animal for large-scale data collection". In: *IET Smart Cities* (). DOI: https://doi.org/10.1049/smc2.12089.

[2] W. B. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan. "An application-specific protocol architecture for wireless micro sensor networks". In: *IEEE Trans. Wireless Commun.* 1.4 (2002), pp. 660–670.

[3] N. Wang and H. Zhu. "An energy efficient algorithm based on LEACH protocol". In: *Proc. - 2012 Int. Conf. Comput. Sci. Electron. Eng. ICCSEE 2012*. Vol. 2. 2012, pp. 339–342.