A Self-organized Sensor Data Path Selection Method in Internet of Things

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May 4, 2019

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Contents

Applications of EH-WSNs

- Smart parking
  - It is necessary to deploy a number of nodes which can check the presence of cars in different locations [1].
- Smart agriculture
  - To measure a couple of parameters in different parts of the farmland such as the humidity of the soil, the temperature, and the intensity of sunlight [1].
- And so on ...

Energy Harvesting Wireless Sensor Networks (EH-WSNs)

Components of EH-WSNs: they consist of a large number of nodes. These nodes are equipped with following 5 units [2]:

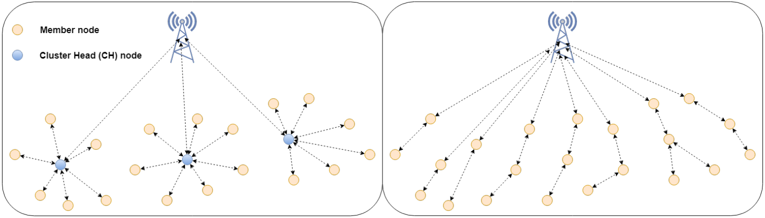
- A central processing unit
- A wireless transceiver unit
- One or multiple sensors unit
- An energy storage unit
- An energy harvesting unit **(the source of energy!)**

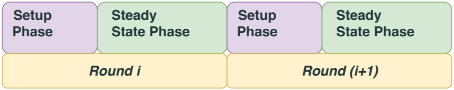
Problems of EH-WSNs

- Even though EH-WSNs could harvest energy from the environment, the collected energy and the real demand do not meet because of stochastic nature of harvested energy, thus such networks suffer from intermittent failure [2].
- Due to the limited range of EH-WSNs, they rely on multihop transmission to deliver their packets to the base station located far away [2].
- **Therefore protocols should support multihop transmission and perform as energy-efficient as possible.**
- Protocols are either **flat** or **hierarchical** [1].
- It has been shown that hierarchical protocols are significantly more energy-efficient than flat protocols [1].

Current protocols for EH-WSNs

- In hierarchical protocols, two decisions mainly determine the energy-efficiency of the protocols [1].
    - Clustering: it divides the network into some separate clusters.
    - Cluster Head Selection: it defines the CH of each cluster





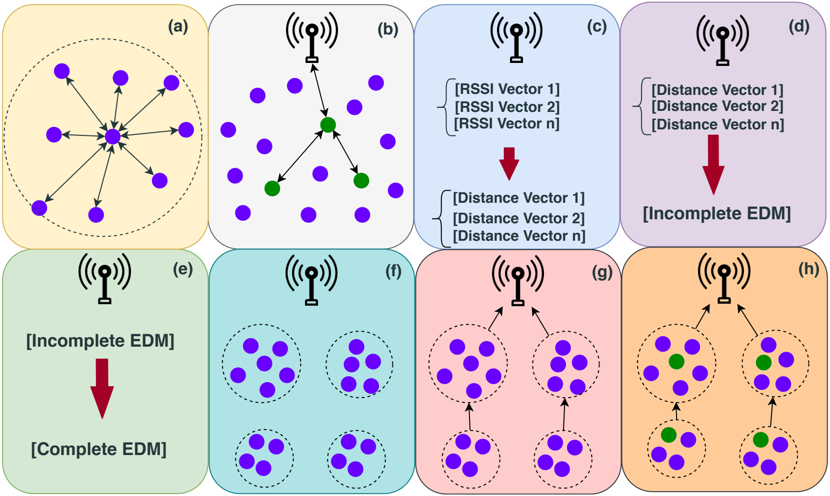
Current protocols for EH-WSNs

- Non-classic protocols (LEACH [3], DEARER [1], EPSO-CEO [4], and WOA-C [5])
  - Pros
    - They do not rely on GPS.
  - Cons
    - They form inefficient clusters.
- Classic protocols (KCA [6] and Mk-means [7])
  - Pros
    - They can form clusters efficiently.
  - Cons
    - They rely on GPS module [8].
      - GPS increases implementation cost [8].
      - GPS increases energy consumption [8].
      - GPS works poorly in indoor applications [8].

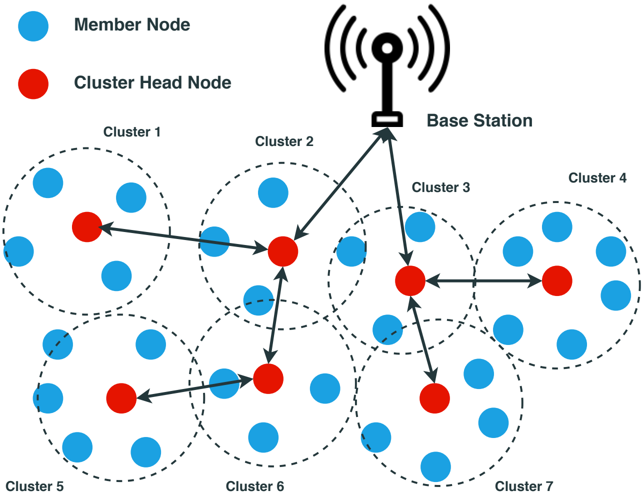
Our proposed protocol

- Our proposed protocol clusters the whole network efficiently using agglomerative clustering without assuming that nodes are equipped by GPS.
- It selects reliable CHs which lead to the lowest energy consumption according to an ILP optimization problem using QGSA.
- It consists of eight steps which seven of them are just done at the initialization phase, the last step is required to be operated at the beginning of each round.
- Our game changer is the mathematical idea that a noisy or semi-complete Euclidean distance matrix could be reconstructed by an acceptable accuracy.

Our proposed protocol



Our proposed protocol



Our proposed protocol

Steps of our protocols

1. RSSI vector measurement and collection.

$$\begin{cases} \hat{s}_1 = [\cdot]_{(N+1)\times 1} & \text{node number } 1 \\ \vdots & \quad\vdots \\ \hat{s}_{(N+1)} = [\cdot]_{(N+1)\times 1} & \text{node number } (N+1) \end{cases} \tag{1}$$

2. Transmission of RSSI vector collection to the BS.
3. Distance estimation based on RSSI [9].

$$\begin{cases} \hat{d}_1 = [\cdot]_{(N+1)\times 1} & \text{node number } 1 \\ \vdots & \quad\vdots \\ \hat{d}_{(N+1)} = [\cdot]_{(N+1)\times 1} & \text{node number } (N+1) \end{cases} \tag{2}$$

4. The BS merges all vectors into an incomplete EDM.

$$\hat{D} = [\hat{d}_1, \hat{d}_2, \cdots, \hat{d}_{(N+1)}]_{(N+1)\times(N+1)} \tag{3}$$

Our proposed protocol

- The BS completes the incomplete EDM by solving EDM completion problem [10].

$$\hat{D} \Longrightarrow D \tag{4}$$

- The BS applies agglomerative clustering and forms clusters.

$$J_{opt} = \sqrt{\frac{N\varepsilon_{fs}}{2\pi\varepsilon_{mp}}} \frac{L}{d_{toBS}^2} \tag{5}$$

- The BS forms a tree using the minimum cost spanning tree to enable intercluster communication.

$$m_{ij} = \frac{1}{C_i C_j} \sum_{k=1}^{C_i} \sum_{l=1}^{C_j} D_{kl} \tag{6}$$

- The BS selects the optimal CH for each cluster.

$$minimize \quad R(\ell) \sum_{i=1}^{C_j} x_i(\Lambda_{ij} + \Delta_{ij}(\ell)) \tag{7}$$

Our proposed protocol

- Λ_{ij} is the energy consumption of members of the jth cluster in case the ith node in the cluster is selected as the CH which is calculated as follows:

$$\Lambda_{ij}(\ell) = \sum_{k \neq i}^{C_j} \Gamma_{ki}(d_{ki}) \tag{8}$$

- And $\Delta_{ij}(\ell)$ is the energy consumption of the CH is given by:

$$\Delta_{jn} = \Psi_{jn} + \Omega_{jn} \tag{9}$$

- where Ψ_{jn} is the energy to receive data from its members aggregate and forward them to the next hop (n), Ω_{jn} is the energy to receive packets of its subclusters and relay them to the next hop. Ψ_{jn} is calculated as follows:

$$\Psi_{jn} = L_p(C_j - 1)e_{elec} + L_p C_j e_{da} + \Gamma_{jn}(d_{jn}) \tag{10}$$

Our proposed protocol

- where $L_p(C_j - 1)e_{elec}$ is the energy consumption to receive packets from $(C_j - 1)$ members, $L_p C_j e_{da}$ is the amount of energy required to perform data aggregation, and $L_p \Gamma_{jn}(d_{jn})$ is the required energy to send them to the next hop. Ω_{jn} is calculated as follows:

$$\Omega_{jn} = Z_j L_p e_{elec} + Z_j \Gamma_{jn}(d_{jn}) \tag{11}$$

- where $Z_j L_p e_{elec}$ is the energy consumption to receive packets from Z_j subclusters, $Z_j \Gamma_{jn}(d_{jn})$ is the energy required to send them to the next hop. Consequently, the energy update function for the jth CH node is given by:

$$E_j(\ell + 1) = E_j(\ell) + H_j(\ell) - R(\ell) \times \Delta_{jn} \tag{12}$$

Our proposed protocol

- Reliability constraint is that the sum of RE and harvested energy minus energy consumption ($\Delta_{ij}(\ell)$) for the CH during ℓth round should be positive which is as follows:

$$\textit{subject to} \quad \sum_{i=1}^{C_j} x_i \Big(E_i(\ell) + H_i(\ell) - R(\ell)\Delta_{ij}(\ell) \Big) \geq 0 \tag{13}$$

$$\sum_{i=1}^{C_j} x_i = 1, \quad x_i \in \{0, 1\} \tag{14}$$

- Equation 13 implies that for the selected CH in the jth cluster sum of RE and harvested energy should be more than energy consumption to guarantee reliability. Equation 14 limits the ILP to select one node as CH.

Our proposed protocol

- But as large ILPs are generally intractable, using approximation methods or heuristic methods (e.g., simulated annealing, particle swarm, ant colony, etc) instead of deterministic methods could decrease the com- putational effort and processing time.
- We employ a QGSA approach which is a binary method. On the other hand, our problem is a binary problem so utilizing QGSA for our problem is appropriate.
- Although metaheuristic algorithms do not guarantee the optimality, they give a sub-optimal solution in a reasonable amount of time.

Numerical Experiment

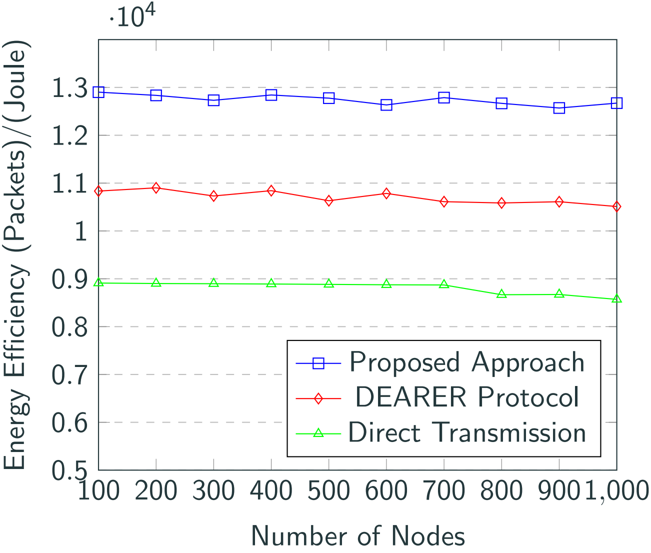
- The network energy efficiency η is the ratio between the number of successfully delivered packets throughout the network lifetime and the total harvested energy by all nodes during the network lifetime. The *Energy Efficiency* is defined as follows [1]:

$$\eta = \lim_{L\to\infty} \frac{\sum_{\ell=1}^{L}\sum_{i=1}^{N} P_i(\ell)}{\sum_{\ell=1}^{L}\sum_{i=1}^{N} H_i(\ell)} \quad (Packet/Joule) \tag{15}$$

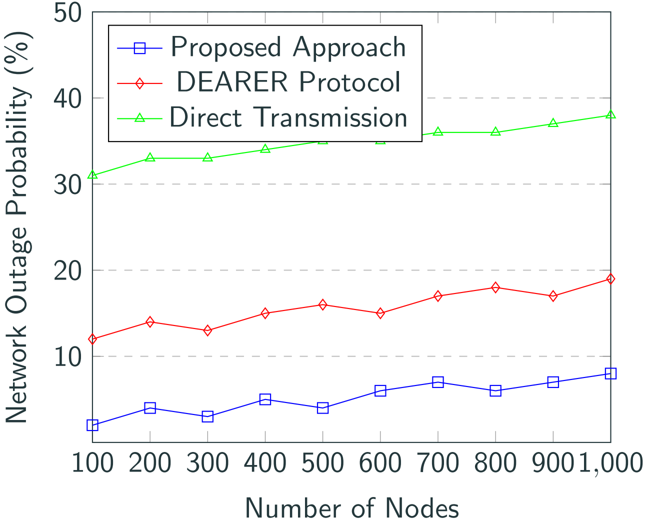
- The packet loss percentage ζ is the ratio between failed packets throughout the network lifetime and total generated packets by nodes. The *Packet Loss Percentage* is defined as follows [1]:

$$\zeta = \lim_{L\to\infty} \frac{\sum_{\ell=1}^{L}\sum_{i=1}^{N} P_i(\ell)}{\sum_{\ell=1}^{L}\sum_{i=1}^{N} A_i(\ell)} \tag{16}$$

Our proposed protocol



Our proposed protocol



Conclusion

- We have proposed a protocol which even though does not rely on GPS can benefit from a classical clustering approach.
- Our game changer is the mathematical idea that a noisy or semi-complete Euclidean distance matrix could be reconstructed by an acceptable accuracy.
- We have formulated the CH selection problem as an ILP problem and solved it by QGSA.
- The results show that the proposed approach surpasses current approaches which do not assume that nodes are equipped GPS.

Any Question?

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