ANALYSIS ON DEPLOYMENT COST AND NETWORK PERFORMANCE FOR HETEROGENEOUS WIRELESS SENSOR NETWORKS

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ABSTRACT

A wireless sensor network is an autonomous system of sensor connected by wireless devices without any fixed infrastructure support. One of the major issues in wireless sensor network is developing a cost effective routing protocol which has a significant impact on the overall network performance in the sensor network. In this paper, we have considered three types of nodes with different battery energy. The key role of the proposed protocol is to maximize the network performance without increasing the network deployment cost. We have compared the quantitative analysis of different protocols in terms of their network deployment cost. Our analysis and simulation results demonstrate that the proposed scheme can achieve higher network performance and lower network deployment cost as compared to the existing protocols.

KEYWORDS

Heterogeneous, Clustering, Cost, Lifetime, Sensor Networks

1. INTRODUCTION

Advances in wireless communication made it possible to develop Wireless Sensor Networks (WSNs) consisting of small devices, which collect information by cooperating with each other. These small sensing devices are called nodes and consist of CPU (for data processing), memory (for data storage), battery (for energy) and transceiver (for receiving and sending signals or data from one node to another). The size of each sensor node varies with applications. For example, in some military or surveillance applications it might be microscopically small. The cost of these devices depends on its parameters like memory size, processing speed and battery as described in [1].

LEACH [2] uses the paradigm of data fusion to reduce the amount of data transmitted between sensor nodes and the base station. Data fusion combines one or more data packets from different sensor nodes in a cluster to produce a single packet. It selects a small number of cluster heads (CHs) by a random scheme which collects and fuses data from sensor nodes and transmits the result to the base station or sink. LEACH uses randomization to rotate the CHs and achieves improvement in lifetime by a factor of 8 as compared to the direct approach [2].

The most works in [3], [4] and [5] that consider a heterogeneous network model assume two different types of sensors are deployed with the more powerful sensors having greater processing power and better hardware specifications compared to the normal sensor nodes. The energy consumption and lifetime of a heterogeneous network have been analyzed in [6] on the assumption that a given number of high-end sensors and a subset of them will be active CHs at any point of time.

Placing few heterogeneous nodes in wireless sensor network is an effective way to increase the network lifetime. In this paper, we study the operation of a heterogeneous clustered sensor network with three types of nodes. Type-3 and type-2 nodes are equipped with more battery energy than the type-1 node. All the nodes are uniformly distributed over the square field and they are not mobile. Under this model, we have developed a new cluster–based protocol that significantly increases the network performance without increasing the network deployment cost. In this paper, our focus is to maximize the lifetime of the network without increasing the deployment cost of the network.

The rest of the paper is organized as follows. Section 2 dealt with the related work. In section 3, we have presented network model under consideration and quantitative analysis that attempts to estimate the network cost. In section 4, we have compared our proposed scheme with existing protocols by simulation and discussion. Finally, section 5 concludes the paper.

2. RELATED WORK

In this section, we review specific prior studies that dealt with the heterogeneity in the energy of sensor nodes. In [7], the author questioned the behaviour of clustering protocols in the presence of heterogeneity in clustered wireless sensor networks. In [8], the authors examined the performance and energy consumption of the wireless sensor networks, in a field where there are two types of sensors. They consider nodes that are fewer but more powerful that belong to an overlay. All the other nodes have to report to these overlay nodes, and the overlay nodes aggregate the data and send it to the sink. The drawback of this method is that there is no dynamic election of the cluster heads among the two types of nodes, and as a result nodes that are far away from the powerful nodes will die first. The authors estimate the optimal percentage of powerful nodes in the field, but this result is very difficult to use when heterogeneity is a result of operation of the sensor network and not a choice of optimal setting.

In [9], the authors have investigated the existing clustering algorithms. The algorithms have been classified and some representatives are described in each category. After analyzing the strengths and the weaknesses of each category, an important characteristic of WSNs is pointed out for further improvement of energy efficiency for WSNs. The proposed algorithm can be further improved by equalizing the cluster lifetime by taking into account that the directional data traffic burdens the clusters differently. In [10], the authors have studied the impact of heterogeneity of sensor nodes in terms of their energy and proposed a heterogeneous – aware protocol to prolong the time interval before the death of the first node, which is crucial for many applications where the feedback from the sensor network must be reliable.

In [4], the authors presented a cost-based comparative study of homogeneous and heterogeneous clustered wireless sensor networks. They proposed a method to estimate the optimal distribution among different types of sensors, but again this result is hard to use if the heterogeneity is due to the operation of the network. They also studied the case of multi hop routing within each cluster (called M-LEACH). Again the drawback of the method is that only powerful nodes can become cluster heads (even though not all powerful nodes are used in each round.) Furthermore, M-LEACH is valid under many assumptions and only when the population of the nodes is very large.

The cluster-based routing protocols are investigated in several research studies. The work in [11] shows that a 2-tier architecture is more energy efficient when hierarchical clusters are deployed at specific locations. In [12], the authors described a multi-level hierarchical clustering algorithm, where the parameters for minimum energy consumption are obtained using stochastic geometry.

Cluster-based approaches are suitable for habitat and environment monitoring, which requires a continuous stream of sensor data. Directed diffusion and its variations are used for event-based monitoring. In [13], the authors described a directed diffusion protocol where query (task) is disseminated into the network using hop-by-hop communication. When the query is traversed, the gradients (interests) are established for the result return path. Finally, the result is routed using the path based on gradients and interests.

In [7], the authors have analyzed a method to elect cluster heads according to the energy left in each node. The drawback of this method is that this decision was made per round and assumed that the total energy left in the network was known. The assumption of global knowledge of the energy left in the whole network makes this method difficult to implement. Even a centralized approach of this method would be very complicated and very slow, as the feedback should be reliably delivered to each sensor in every round.

Recently, the works in [14] and [15] addresses a cluster head election method using fuzzy logic to overcome the defects of LEACH. They have investigated that the network lifetime can be prolonged by using fuzzy variables in homogeneous network system.

3. NETWORK MODEL AND ASSUMPTIONS

In LEACH there is an optimal percentage popt of nodes that has to become cluster heads in each round assuming uniform distribution of nodes in space utilize in [13] and [7]. If the nodes are homogeneous, which means that all the nodes in the field have the same initial energy, the LEACH protocol guarantees that everyone of them will become a cluster head exactly once every 1/popt rounds. In this paper, we have referred 1/ popt as epoch of the clustered sensor network to the number of rounds. Initially each node can become a cluster head with a probability popt. On average, popt*Q nodes must become cluster heads per round per epoch. Nodes that are elected to be cluster heads in the current round can no longer become cluster heads in the same epoch. The non-elected nodes belong to the set G and in order to maintain a steady number of cluster heads per round, the probability of nodes ε G to become a cluster head increases after each round in the same epoch. The decision is made at the beginning of each round by each node s ε G independently choosing a random number in [0, 1]. If the random number is less than a threshold T(s) then the node becomes a cluster head in the current round. The threshold is set as:

$$T(s) = \begin{cases} \dfrac{p_{opt}}{1 - p_{opt}.(r \bmod \dfrac{1}{p_{opt}})} & if \quad s \in G \\ 0 & otherwise \end{cases} \tag{1}$$

where r is the current round number .The election probability of nodes s ε G to become cluster heads increases in each round in the same epoch and becomes equal to 1in the last round of the epoch. We defined round as a time interval when all the cluster members have to transmit their data to their cluster head. In this paper, we have explained how the election process of cluster heads should be adapted appropriately to deal with heterogeneous nodes, which means that not all the nodes in the field have the same initial energy.

In this section, we described a radio communication model that is used in the quantitative analysis of our proposed protocol. The main goal of hierarchical cluster-based routing protocol is to efficiently maintain the energy consumption of sensor nodes by involving them in single-hop communication within a cluster and by performing data aggregation and fusion in other to decrease the number of transmitted messages to sink and transmission distance of sensor nodes. To simplify the network model, we adopt a few reasonable assumptions as follows: 1) Q sensors are uniformly dispersed within a square field (200m * 200m); 2) All sensors and BS are stationary after deployment; 3) The communication is based on the single-hop; 4) Communication is symmetric and a sensor can compute the approximate distance based on the received signal strength if the transmission power is given; 5) All sensors are of equal significance. We use a simplified model shown in [16] for the radio hardware energy dissipation as follows. To transmit an L –bit data to a distance d, the radio expands:

$$E_{Tx}(L,d) = \begin{matrix} L*E_{elec} + L*\varepsilon_{fs}*d^{2} & if\, d \le d_{0} \\ L*E_{elec} + L*\varepsilon_{mp}*d^{4} & if\, d \ge d_{0} \end{matrix}$$

The first item presents the energy consumption of radio dissipation, while the second presents the energy consumption for amplifying radio. Depending on the transmission distance both the free space εfs and the multi-path fading εmp channel models are used. When receiving this data, the radio expends: $E_{Rx}(L) = L*E_{elec}$. Additionally, the operation of data aggregation consumes the energy as E_{DA}.

Consider the hierarchical cluster based WSN with two hundred of sensor nodes dispersed in a square field as shown in Figure 1. BS, an observer is located outside the field remotely. The observed field is composed of several clusters. Each cluster has one CH which acts as a local control centre to coordinate the data transmissions. We have assumed that the cluster head election is based on the weighted probability and residual energy of the node. All of these components are based on the following assumptions and the radio model. To simplify the network model, we have adopted some assumptions for our mechanism.

1) The WSN consist of heterogeneous sensor nodes.

2) The BS is located at the outside field of the network.

3) Few sensor nodes have different initial energy which creates heterogeneity in system.

4) All sensor nodes and BS are stationary after deployment.

3.1. Quantitative analysis of proposed scheme

In this section, we present the quantitative analysis of proposed protocol in a heterogeneous network. We have assumed three types of nodes type-3, type-2 nodes are embedded with extra battery energy than the type-1 nodes. Type-3 and type-2 nodes of λ and μ time respectively have more energy than the type-1 nodes in order to prolong the lifetime of the sensor network. Intuitively, type-3 and type-2 nodes have to become cluster heads more often than the type-1 nodes, which decreases the energy consumption. The new heterogeneous setting has changed the total initial deployment cost of the network. Let E1 be the battery energy of type-1 nodes, E2 be the battery energy of type-2 nodes and E3 be the battery energy of the type-3 nodes. The generalize deployment cost model of type i node is as follows:

$$C_i = \alpha_i + \beta_i * E_i \tag{2}$$

where α_i is the hardware cost of the node, while β_i accounts for the battery cost of the node. We could also use β to model the weight of the battery. In many commercial sensor nodes, the weight and volume of the node is occupied by the battery. The higher the required battery energy, the larger the weight of the battery, and hence larger is the size and weight of the node. We have assumed the following variables to determine the overall network deployment cost which is given below:

E_3=Energy of type-3 node.

E_2=Energy of type-2 node.

E_1=Energy of type-1 node.

$$E_3 = E_1 * (1+\mu) \tag{3}$$

$$E_2 = E_1 * (1+\lambda) \tag{4}$$

Using equation 3 and equation 4, the cost of deployment of different nodes is given below:

C_3=Cost of type-2 node.

C_2=Cost of type-1 node.

C_1=Cost of type-1 node.

C_{T3}=Total initial cost of type-3 nodes.

C_{T2}= Total initial cost of type-2 nodes.

C_{T1}= Total initial energy of type-1 nodes.

$$C_3 = \alpha_3 + \beta_3 * E_3 \tag{5}$$

$$C_2 = \alpha_2 + \beta_2 * E_2 \tag{6}$$

$$C_1 = \alpha_1 + \beta_1 * E_1 \tag{7}$$

$$C_{T3} = Q*\gamma*\chi*C_3 \tag{8}$$

$C_{T2}=Q*\gamma*(1-\chi)*C_2$ (9)

$C_{T1}=Q*(1-\gamma)*C_1$ (10)

Using equation 8, equation 9 and equation 10, the total network cost is estimated as follows:

$C_{direct}= C_{T3}+ C_{T2}+ C_{T1}$ (11)

Using equations-8, equation-9 and equation 10, the cost of different protocols are simplified as given below:

$C_{direct}= Q*\gamma*\chi*C_3+ Q*\gamma*(1-\chi)*C_2+Q*(1-\gamma)*C_1$

The above equation is simplified as follows:

$C_{direct}= Q*(C_1-\gamma*(C_1 +C_2+ \chi*(C_1-C_3)))$ (12)

$C_{heteroleach}= Q*(C_1-\gamma*(C_1 +C_2+ \chi*(C_1-C_3)))$ (13)

$C_{proposed}= Q*(C_1-\gamma*(C_1 +C_2+ \chi*(C_1-C_3)))$ (14)

$C_{leach}= Q*C_1$ (15)

$C_{sep}= C_{T2}+ C_{T1}$

$C_{sep}= Q*\gamma*C_2+Q*(1-\gamma)*C_1$ (16)

$C_{sep}= Q*(C_1-\gamma*(C_1-C_2))$

Where C_{direct} is the cost of the heterogeneous network when direct transmission is used to transmits the messages to the base station, C_{leach} denotes the deployment cost of the nodes in the homogeneous network in LEACH protocol, C_{sep} defines the deployment cost of the nodes in heterogeneous SEP network system where two types of nodes are considered, $C_{heteroleach}$ reports on the deployment cost of the nodes in heterogeneous LEACH protocol and $C_{proposed}$ denotes the deployment cost of the nodes in the proposed heterogeneous network. Firstly, we will estimate the difference in deployment cost ratio of direct transmission with LEACH protocol is given below as:

$$C_{DL} = \frac{C_{direct} - C_{leach}}{C_{direct}} \quad (17)$$

$$C_{HL} = \frac{C_{heteroleach} - C_{leach}}{C_{heteroleach}} \quad (18)$$

$$C_{SL} = \frac{C_{sep} - C_{leach}}{C_{sep}} \quad (19)$$

Where C_{DL} represents the deployment cost ratio of direct transmission with respect to LEACH (homogeneous), C_{HL} denotes the deployment cost ratio of HeteroLEACH with respect to LEACH, and C_{SL} accounts the deployment cost ratio of SEP with respect to LEACH.

$$C_{PL} = \frac{C_{poposed} - C_{leach}}{C_{proposed}} \quad (20)$$

$$C_{SP} = \frac{C_{sep} - C_{proposed}}{C_{proposed}} \quad (21)$$

C_{PL} denotes the deployment cost ratio of proposed scheme with respect to LEACH, and C_{SP} accounts the deployment cost ratio of SEP with respect to proposed scheme.

3.2 Algorithm

This algorithm deals with the cluster head election probability of nodes within a sensor network. Suppose E_1 is the initial energy of each type-1 nodes. The energy of each type-3 nodes is E_3 and each type-2 nodes is E_2.The total initial energy of the new heterogeneous network setting is increased by a factor of $1 + \gamma * \Delta$. Thus, the stages of development may be stated as follows:

3.2.1 Initialization Phase

Step1: Initialize the area for the sensing system with their x and y co-ordinates.

3.2.2 Energy Details Phase

Step2: Here, each node has some energy values assigned to them, this energy value is assumed as cost for path Adjacency Matrix of the route while implementing shortest path.

3.2.3 Cluster Head Election Phase

Step 3: In Case of heterogeneous scenario, the average number of cluster heads per round per epoch is equal to ($1 + \gamma * \Delta$)*Q *$\acute{\Gamma}_1$ .The weighed probabilities for type-1, type-2 and type-3 nodes are given below:

Step 3.1: Cluster head election probability for type-1 nodes as given below.

$$\Gamma_{type-1} = \frac{p_{opt}}{1 + \gamma * \Delta}$$

$$\Delta = \lambda - \chi * (\lambda - \mu)$$

Step 3.2: Cluster head election probability for type-2 nodes as given below.

$$\Gamma_{type-2} = \frac{p_{opt}}{1 + \gamma * \Delta}(1 + \lambda)$$

Step 3.3: Cluster head election probability for type-3 nodes as given below.

$$\Gamma_{type-3} = \frac{p_{opt}}{1+\gamma * \Delta}(1+\mu)$$

Step 4: A selected cluster head broadcasts an advertised message over neighbour nodes.

Step 5: The neighbour nodes collect advertised messages during a given time interval and the send a join message to nearest cluster head for all nodes within the range of any specific cluster head.

3.2.4 Data Transfer Phase

Step 6: After the cluster head selection is done each non cluster head node sends data to the cluster head.

Step 7: Now the cluster head maintains the energy information of each node connected and forms a single packet that is to pass to its base station.

4 VALIDATION OF ANALYSIS

In this section, we validate our analysis using simulations. We have also compared the performance of different protocols under same settings of the network parameters.

4.1. Simulation Environment

The simulation is done in Matlab. Let us assume a heterogeneous sensor network with 100 numbers of sensor nodes are randomly distributed in the 200 * 200 m2 area, as shown in Figure 1 , we denote with 'o' a type-1 node, with '+' a type-2 node, with '^' a type-3 node. The base station, with 'x' is located at point (100, 350).The values used in the first order radio model are described in Table 1. In this section, we have evaluated the performance of the proposed protocol. This means that the horizontal and vertical coordinates of each sensor are randomly selected between 0 and maximum value of the dimension. The size of the message that nodes send to their cluster heads as well as the size of the message that a cluster head sends to the base station is set to 50 bytes.

4.2. Simulation Results

In this section, we have simulated different protocols in the same environment. The results of simulations are shown in Figures 2 -5.

Figure 2 and Figure 3 indicates the network lifetime when the first node dies or runs out of energy and they also shows that the proposed scheme extends the lifetime of the network as compared with existing protocols. Indeed proposed protocol is more efficient than Direct Transmission (DT), HeteroLEACH and SEP protocol. Figures 4-5 show the deployment cost ratio of DT, HeteroLEACH, SEP and proposed scheme with LEACH in terms of variation in number of powerful nodes and energy factor in the network. As the number of powerful nodes increases in the network the deployment cost of the network will definitely increase and also the weight of the system will increase. Here, we have analyzed that the deployment cost ratio increase in SEP as compared with proposed scheme for the same performance. The proposed scheme is much better than the DT, HetroLEACH and SEP protocol in terms of lifetime and network deployment cost.

4.3. Discussions

In figures, we have presented how deployment cost analysis can be used to determine the performance of the network system. Also we have analyzed and compared the network deployment cost and performance of the proposed system with the DT, HeteroLEACH and SEP protocol. The network deployment cost of DT, HeteroLEACH, Proposed protocol is increased by a factor of 23% with respect to LEACH (homogeneous network), and the deployment cost of the SEP protocol is increased by a factor of 40% with respect to LEACH protocol. In proposed scheme, the deployment cost is reduced by 17% without much affecting the performance of the network system.

5 CONCLUSIONS

The deployment cost is the major factor in developing the wireless sensor networks. In this paper, we have proposed a hierarchical cluster based protocol to analyze the network lifetime and deployment cost of the network with existing protocols. We have evaluated the performance of the proposed scheme with existing protocols using Matlab. The simulation results and quantitative analysis show that the proposed scheme can reduce the network deployment cost by a factor of 17% and also extend the lifetime performance of the network. For future work, proposed protocol can be extended to deal with clustered sensor networks with more levels of hierarchy and types of nodes.

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Figures and Tables

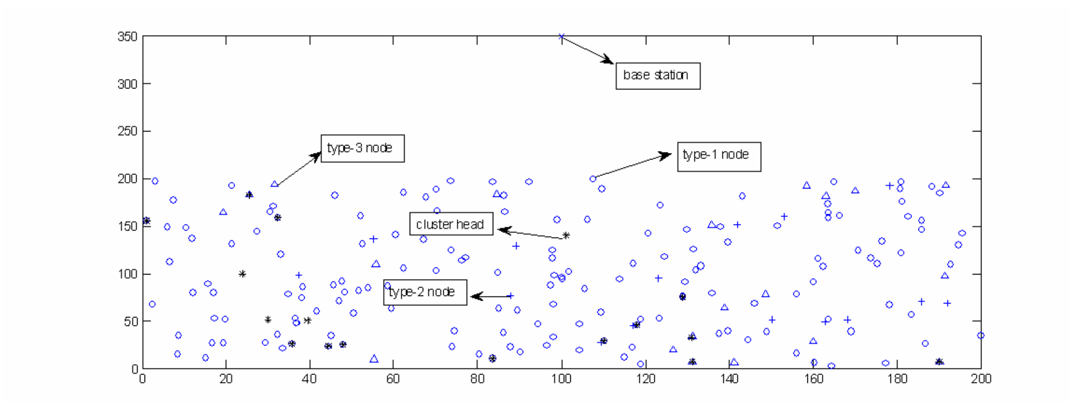

Figure 1: Heterogeneous network

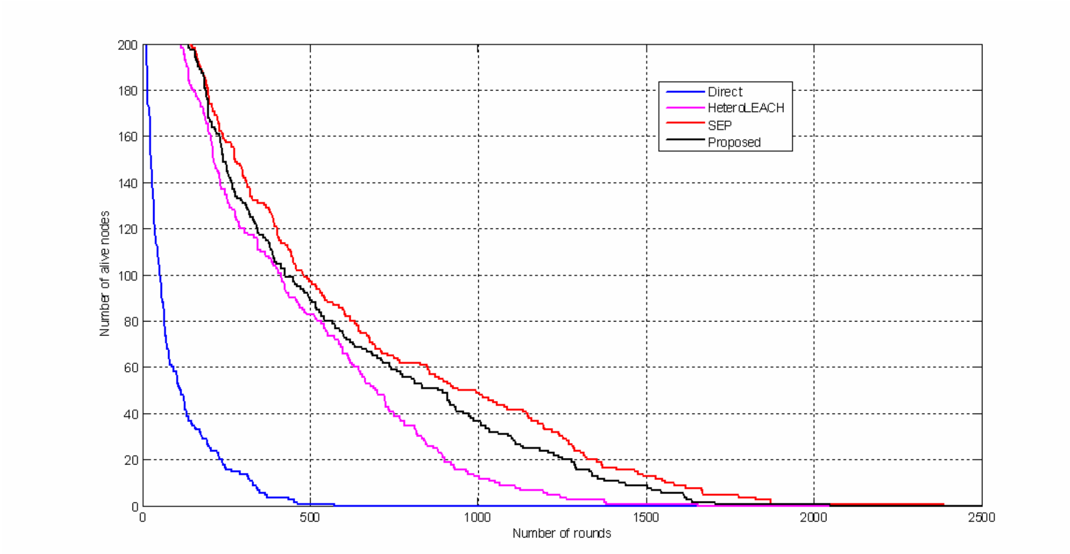

Figure 2: Network lifetime

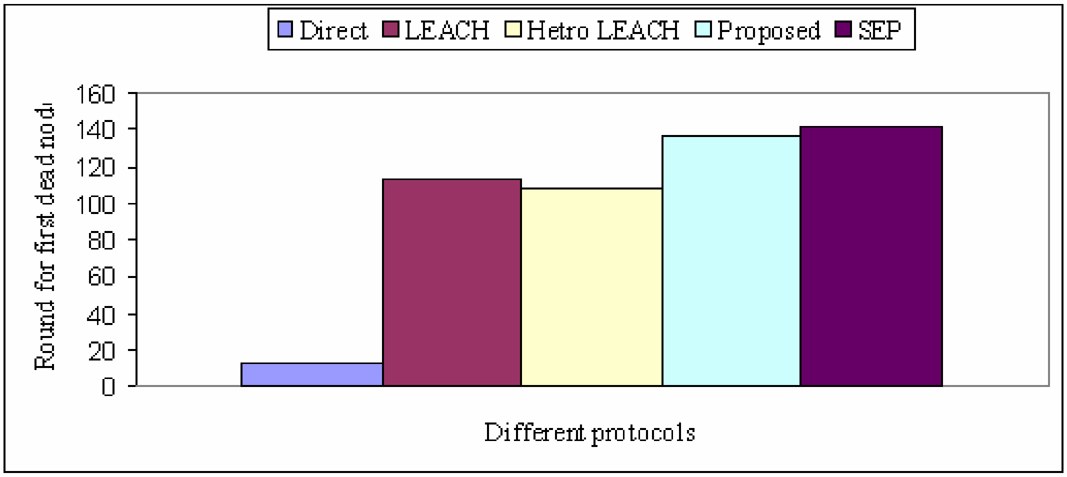

Figure 3: Round for first dead node over round.

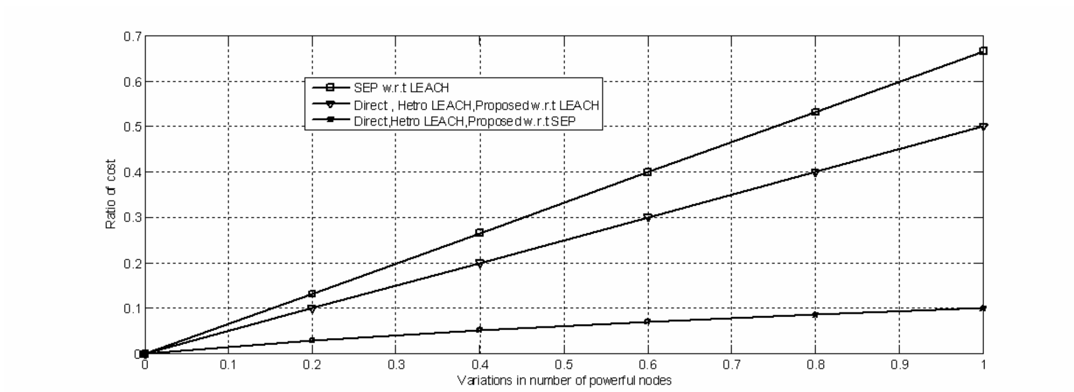

Figure 4: Deployment cost ratio over variations in number of powerful nodes (type-3, type-2).

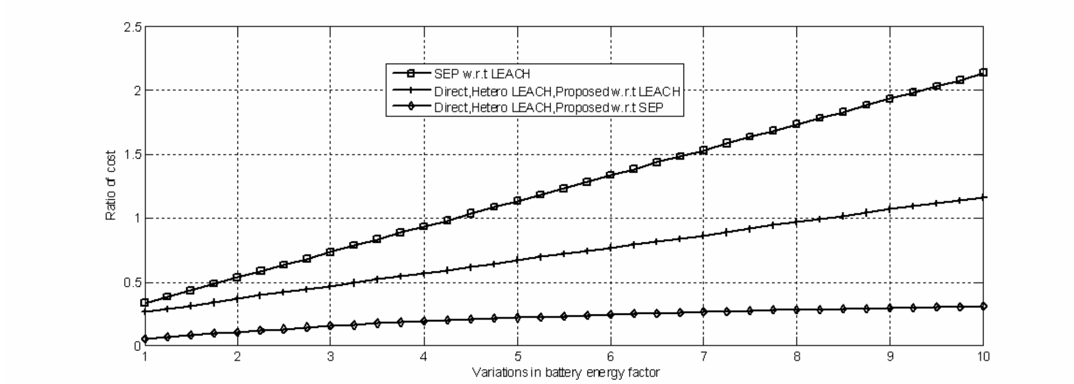

Figure 5. Deployment cost ratio over variations of battery energy factor (μ, λ).

Table 1: Parameter values used in the simulations

Parameters	BS is outside
Network Span	(0,0) to (200,200)
Q	200
d_0	70 m
BS Position	(100,350)
Packet Size	500bytes
E_{DA}	5nJ/bit/report
ε_{fs}	10pJ/bit/m^2
ε_{mp}	0.0013pJ/bit/m^4
E_{elec}	50nJ/bit
E_1	1J
χ	0.5
γ	0.3
λ	3
μ	1

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