International Journal of Information Technology and Knowledge Management
January-June 2011, Volume 4, No. 1, pp. 227-231

PERFORMANCE EVALUATION OF CLUSTER-BASED ROUTING PROTOCOLS USED IN HETEROGENEOUS WIRELESS SENSOR NETWORKS

Rajni Meelu[1] & Rohit Anand[2]

WSNs are highly affected by the energy dissipation of the nodes. In fact, sensor nodes are usually used to collect and report application-specific data to the monitoring node, known as a sink node. A primary goal in the design of wireless sensor networks is lifetime maximization, constrained by the energy capacity of batteries. Clustering technique is one of the most efficient techniques which cater to the requirement of energy conservation in wireless sensor networks. This paper analyzes the performance of (DEEC) Distributed energy efficient clustering protocol in context to network lifetime, energy consumption and energy balancing. Also a new clustering protocol has been proposed for further prolonging the network life. Simulation results reveal that the lifetime of proposed routing protocol is 40% longer than DEEC and shows that energy is well balanced as compare to DEEC.
Keywords: Wireless Sensor Networks, Energy Efficiency, Cluster Formation, Network Lifetime

1. Introduction

A sensor network is a set of small autonomous systems, called sensor nodes which cooperate to solve at least one common application. Their tasks include some kind of perception of physical parameters. The main function wireless sensor node is to sense and collect data from a certain domain, process them and transmit it to the sink where the application lies. Sometimes sensor nodes are called as motes or they are referred as smart dust and they contain radio transceiver and are battery powered.

In WSN, energy conservation is a critical issue that has been addressed by substantial research works [1] [2]. Clustering has been proven particularly energy efficient in sensor networks [3] [4]. The nodes form clusters which include one cluster head and the cluster members. Cluster heads (CHs) has the capability to process, filter and aggregate the data sent by sensors belonging to their cluster, thus reducing network load and alleviating the bandwidth [6]. This cluster head then send this data to the base station through single hop or multi-hop. Thus in clustered network data transmission is classified into two stages: intra-cluster communication and inter cluster communication. Notice that base station is usually located at the center of the experimental environment so that less power is consumed in data transmission from CHs to the base station. It is shown in [5] that multihop inter-cluster communication mode is more energy efficient because of the characteristics of wireless channel.

In this paper we study the Distributed Energy Efficient Clustering (DEEC) protocol by evaluating dead nodes for network lifetime, energy consumption and energy balancing and later new clustering protocol has been introduced which is the modified form of DEEC and it further improves the performance.

[1,2]Department of ECE, N.C.College of Engg., Israna, Panipat
Email: rajni.meelu@gmail.com[1], roh_anand@rediffmail.com[2]

The remainder of the paper is organized as follows. Section 2 describes the energy model used and the assumptions used for the work. Section 3 details the DEEC routing protocol and the description of proposed algorithm is given in Section 4. Further, the simulation results are shown in section 5 and finally Section 6 gives concluding remarks.

2. Preliminaries

2.1. Energy Consumption Model

In this experiment we use a simplified energy model proposed in [7] which is shown in Figure 1. In this both free space (d^2 power loss) and the multi path fading (d^4 power loss) channel models were used depending on the distance between the transmitter and the receiver. If this distance is less than a threshold, the free space (fs) model is used; otherwise, the multi path (mp) model is used. Thus, to transmit an L^- bits message over a distance d, the radio expends (1):

$$E_{TX}(l,d) = E_{TX-elec}(l) + E_{TX-amp}(l, d) \qquad (1)$$

and then :

$$E_{TX}(l,d) = \begin{cases} lE_{elec} + l\varepsilon_{fs} d^2 & \text{if } d < d_o \\ lE_{elec} + l\varepsilon_{mp} d^4 & \text{if } d \geq d_o \end{cases} \qquad (2)$$

where the threshold d_o is defined by (3):

$$d_o = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \quad (3)$$

The electronics energy depends on many factors such as the digital coding, the modulation, the filtering, and the spreading of the signal, whereas the amplifier energy, $\varepsilon_{fs} d^2$ or $\varepsilon_{mp} d^4$, depends on the distance to the receiver and the acceptable bit-error rate.

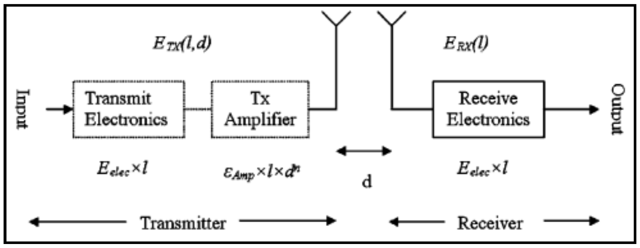

Fig. 1: Radio Energy Dissipation Model

To receive this message the radio expends energy:

$$E_{RX}(l) = lE_{elec} \quad (4)$$

It is assumed that the sensed information is highly correlated, thus the cluster head can always aggregate the data gathered from its members into a single length-fixed packet.

Table 1
Radio Parameters Used

Symbol	Value
ε_{fs}	10pJ/bit/m^2
ε_{mp}	0.0013pJ/bit/m^4
E_{DA}	5nJ/bit/message
E_{elec}	50nJ/bit

2.2. Assumptions

Here in this section, heterogeneous network model has been assumed which exists practically. Let there are S total number of nodes which are distributed randomly within a N×N square region as shown in Figure 2. Before we detail our protocol, we make the following assumptions:

1) Base station is located at the centre of the network area.
2) The data packet length is L bits.
3) All the network nodes can reach the base station.
4) CHs can transmit data to the BS and cluster members send their data to the CHs to which they belong.
5) Every sensor node is having a data packet to transmit in a fixed time.
6) All the sensor nodes are assumed to be stationary.
7) The sensing range of a node is smaller than the transmission range.

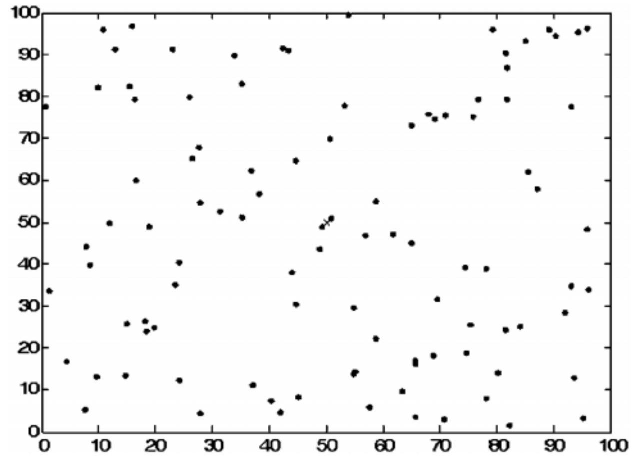

Fig. 2: Random Network of 100 Nodes

3. DESCRIPTION AND ANALYSIS OF DEEC PROTOCOL

DEEC [11] is a distributed clustering scheme for heterogeneous wireless sensor networks. In DEEC the cluster-heads are elected by a probability based on the ratio between residual energy of each node and the average energy of the network. The epochs of being cluster-heads for nodes are different according to their initial and residual energy. The nodes with high initial and residual energy will have more chances to be the cluster-heads than the nodes with low energy. There are two types of heterogeneous networks i.e. two-level heterogeneous network and multi-level heterogeneous network model so that the proposed clustering algorithm should consider the discrepancy of initial energy of sensor nodes. But for this work we consider multi-level heterogeneous network model.

In two-level heterogeneous networks, there are two types of sensor nodes viz. advanced nodes and normal nodes. Let E_0 is the initial energy of the normal nodes and x is the fraction of advanced nodes which own a times more energy than normal nodes. Thus there are xS advanced nodes equipped with $E_0(1 + a)$ initial energy and $S(1 – x)$ normal nodes equipped with E_0 initial energy. Thus total initial energy for two-level heterogeneous network is given by:

$$E_{total} = S(1-x)E_0 + Sx\,E_0(1+a) = S\,E_0(1+ax) \quad (5)$$

In multi-level heterogeneous network, initial energy of nodes randomly distributed over the close set $[E_0, E_0(1 + a_{max})]$. Thus total initial energy is computed as:

$$E_{total} = \sum_{i=1}^{S} E_0(1+a_i) = E_0(S + \sum_{i=1}^{S} a_i) \quad (6)$$

Let node s_i becomes a cluster head for t_s rounds. Thus in DEEC we choose different t_s based on the residual energy

$E_i(r)$ of node s_i at round r. Let $p_i = 1/t_s$ be the average probability to be a cluster-head during t_s rounds.

The probability threshold that each node s_i use to determine whether itself to become a cluster-head in each round, is as follows:

$$T(Si) = \begin{cases} \frac{p_i}{1-p_i(r \bmod \frac{1}{p_i})} & \text{if } s_i \in G \\ 0 & \text{otherwise} \end{cases} \quad (7)$$

where G is the set of nodes that are eligible to be cluster heads at round r. The weighted probabilities for normal and advanced nodes is given by Eq. (8) from [9]

$$p_{adv} = \frac{p_{opt}}{1+ax}, \quad p_{nrm} = \frac{p_{opt}(1+a)}{(1+ax)} \quad (8)$$

Therefore, p_i is given by

$$p_i = \begin{cases} \frac{p_{opt}E_i(r)}{(1+ax)\bar{E}(r)} & \text{if } s_i \text{ is the normal node} \\ \frac{p_{opt}(1+a)E_i(r)}{(1+ax)\bar{E}(r)} & \text{if } s_i \text{ is the advanced node} \end{cases} \quad (9)$$

where $E_i(r)$ denotes the residual energy of node s_i and $\bar{E}(r)$ is the average energy of the network at round r and the estimate of is given by Eq. (10)

$$\bar{E}(r) = \frac{1}{S} E_{total}\left(1-\frac{r}{R}\right) \quad (10)$$

where R denotes the total rounds of the network lifetime and it can be approximated as

$$R = \frac{E_{total}}{E_{round}} \quad (11)$$

Thus we can evaluate the total energy dissipated in the network during a round is equal to

$$E_{round} = L(2SE_{elec} + SE_{DA} + k\varepsilon_{mp}d^4_{toBS} + S\varepsilon_{fs}d^2_{toCH}) \quad (12)$$

where k is the number of clusters, E_{DA} is the data aggregation cost expended in CH and BS and d_{toCH} is the average distance between cluster members and the cluster-head. Thus we get [10, 8]

$$d_{toCH} = \frac{N}{\sqrt{2\pi k}}, \quad d_{toBS} = 0.765\frac{N}{2} \quad (13)$$

and the optimal value of k is then given by Eq. (14) which minimizes E_{round}.

$$k_{opt} = \frac{\sqrt{S}}{\sqrt{2\pi}}\frac{\sqrt{\varepsilon_{fs}}}{\sqrt{\varepsilon_{mp}}}\frac{N}{d^2_{toBS}} \quad (14)$$

Using Eq. (13) and (14), we can obtain the energy E_{round} dissipated during a round and thus we can compute the network lifetime R by Eq. (11).

4. PROPOSED ALGORITHM

The algorithm proposed in this section is the modification of DEEC protocol. It is named as Clustering Technique for Routing in Wireless Sensor Networks (CTRWSN) is a self-organizing, dynamic clustering method that divides dynamically, the network on a number of a priori fixed clusters [12]. The operation of CTRWSN is broken up into rounds where each round consists of a clustering stage and distributed multi-hop routing stage.

In clustering stage, for every transmission round the node s_i calculate the probability threshold $T(s_i)$ and choose random number between 0 and 1 same as DEEC. If the number is less than threshold $T(s_i)$, the node s_i becomes a cluster-head during the current round. The CHs then broadcast the message to the network and declare themselves as cluster heads. Hearing this message, each regular node chooses its closest cluster head with the largest received signal strength and then informs the cluster head by sending a JOIN – CLU (join cluster) message. But when the node gets no message from any cluster-head, it makes itself as cluster-head. The cluster head sets up a TDMA schedule and transmits it to the nodes in the cluster. In this the node can pass to sleep mode when it is not transmitting. After the TDMA schedule is known by all nodes in the cluster, the clustering phase is completed and the next stage begins.

In distributed multi-hop routing stage, the nodes transmit their data towards the cluster-head. For intra cluster communication TDMA technique is used which blocks the collision of messages as described in the above stage. As the cluster-head receives data from all of its cluster members, it performs compression and sends it to the BS.

5. SIMULATION RESULTS

In this section, we compare the performance of two protocols i.e. DEEC protocol and CTRWSN using MATLAB. The parameter values used for simulation are given in Table 2. The reference network used in our simulation has 100 nodes which are randomly distributed over 100m×100m square region. As described earlier that BS is located at the center of the network region, therefore it is placed at distance 50m×50m from the origin. The radio parameters used in our simulation are given in Table 1.

Table 2
Simulation Parameters

Parameter	Value
Network field	100m×100m
d_0	87m
r	5000
E_0	0.5J
a	1
Data packet size	4000 bits
p_{opt}	0.1

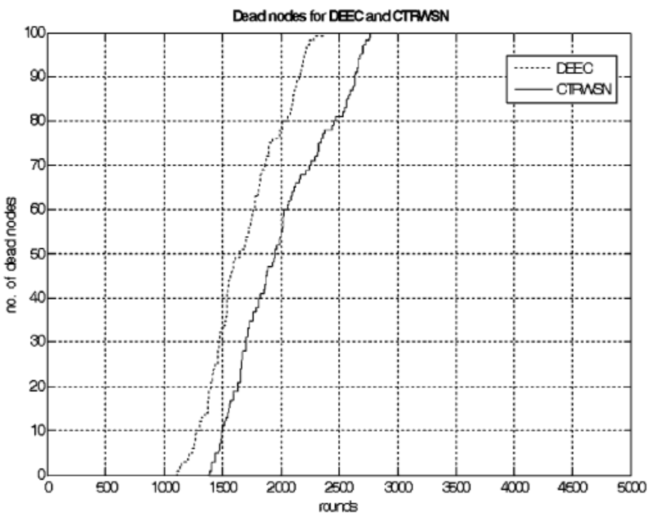

Fig. 1: Number of Dead Nodes for DEEC and CTWRSN

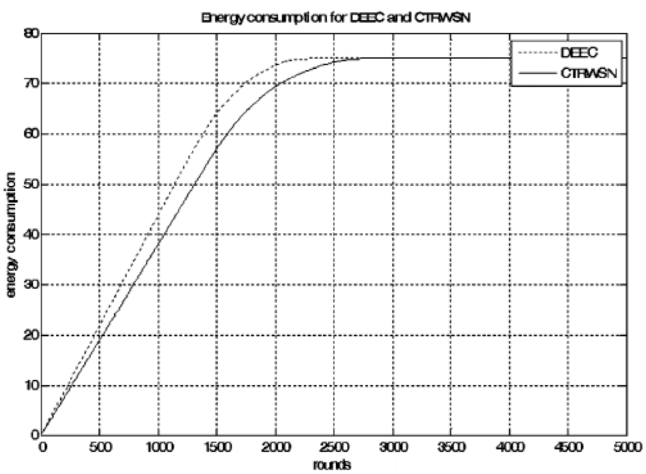

Fig. 2: Energy Consumption in DEEC and CTWRSN

Figure 1 shows the comparison graph of above said protocols showing number of dead nodes w.r.t number of transmission rounds. This figure shows that in DEEC first dead node occurs at round r = 1115 and in CTRWSN it occurs at 1389th round. And the all nodes die at 2361st and 2766th round in DEEC and CTRWSN protocol respectively. Thus we can say that the proposed algorithm CTRWSN has approximately 40% longer lifetime as compare to DEEC.

Figure 2 gives the energy consumption for the two protocols and it reveals that CTRWSN consumes less energy in comparison to DEEC which helps to extend the network lifetime. Here approximately 16.4% of energy is saved by using CTRWSN.

Figure 3 gives the graph for energy balancing in the network and it shows that proposed protocol balances the energy consumption among nodes in a better way in comparison to DEEC. It results due to multi-hop routing and the technique of forming small clusters near to the base station so that less power is consumed in intra-cluster communication for CHs near to BS and thus they can be used to relay traffic of the clusters which are far away from BS. In this way, the energy can be well distributed among nodes and thus it helps in prolonging the network lifetime.

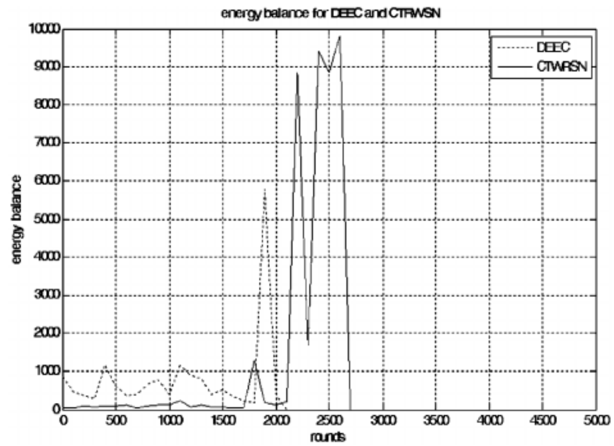

Fig. 3: Energy Balancing in DEEC and CTWRSN

6. CONCLUSION

In this paper, we have analyzed and compared the performance of the two cluster-based routing protocols viz. DEEC and CTWRSN for heterogeneous networks in terms of their network lifetime, energy consumption and the energy balancing. Through the simulation we demonstrate that the proposed algorithm shows good energy distribution and thus prolongs the network lifetime in comparison to DEEC routing protocol.

REFERENCES

[1] M. Cardei, M. T. Thai, Y. Li and W. Wu, "Energy-efficient Target Coverage in Wireless Sensor Networks," Proceedings of 24th Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM), 2005, 3, pp. 1976-1984.

[2] V. Raghunathan, C. Schurgers, S. Park, and M. B. Srivastava, "Energy-Aware Wireless Microsensor Networks," IEEE Signal Processing Magazine, 19, pp. 40-50, 2002.

[3] C. Y. Chong and S. P. Kumar, "Sensor Networks: Evolution, Opportunities and Challenges," Proceedings of the IEEE, 91, No. 8, pp. 1247-1256, Aug 2003.

[4] M. Younis, P. Munshi, G. Gupta and S. M. Elsharkawy, "On Efficient Clustering of Wireless Sensor Networks," Second IEEE Workshop on Dependability and Security in Sensor Networks and Systems, 2006, pp. 78-91.

[5] V. Mhatre and C. Rosenberg, "Design Guidelines for Wireless Sensor Networks: Communication, Clustering and Aggregation," Ad Hoc Networks, 2(1), 2004, 45–63.

[6] L.M.C. Arboleda and N. Nasser, "Comparison of Clustering Algorithms and Protocols for Wireless Sensor Networks," Canadian Conference on Electrical and Computer

Engineering, May 2006, pp. 1787-1792.

[7] W. R. Heinzelman, A. P. Chandrakasan, and H. Bala-Krishnan, “An Application-specific Protocol Architecture for Wireless Microsensor Networks,” IEEE Transactions on Wireless Communications, 1, No. 4, pp. 660–670, 2002.

[8] W.R. Heinzelman, A.P. Chandrakasan, H. Balakrishnan, “An Application-specific Protocol Architecture for Wireless Microsensor Networks,” IEEE Transactions on Wireless Communications, 1(4), 2002, 660–670.

[9] G. Smaragdakis, I. Matta, A. Bestavros, “SEP: A Stable Election Protocol for Clustered Heterogeneous Wireless Sensor Networks,” in: Second International Workshop on Sensor and Actor Network Protocols and Applications (SANPA 2004), 2004.

[10] S. Bandyopadhyay, E.J. Coyle, “An Energy Efficient Hierarchical Clustering Algorithm for Wireless Sensor Networks,” in: Proceeding of INFOCOM 2003, April 2003.

[11] L. Qing, Q. X. Zhu, and M. W. Wang, “Design of a Distributed Energy-efficient Clustering Algorithm for Heterogeneous Wireless Sensor Networks,” Computer Communi-cation, Elsevier, 29, No. 12, pp. 2230–2237, 2006.

[12] Q. Zytoune, Y.Fakhri, D. Aboutajdine, “A Novel Energy Aware Clustering Technique for Routing in Wireless Sensor Networks,” Wireless Sensor Networks, 2, No. 3, pp. 199–266, March 2010.