BIJIT - BVICAM's International Journal of Information Technology
Bharati Vidyapeeth's Institute of Computer Applications and Management, New Delhi

EECHDA: Energy Efficient Clustering Hierarchy and Data Accumulation For Sensor Networks

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Abstract - A wireless sensor network with a large number of tiny sensor nodes can be used as an effective tool for gathering data for various applications under different situations. One of the major issues in wireless sensor network is developing an energy–efficient routing protocol which has a significant impact on the overall lifetime of the sensor network. Clustering sensor nodes is an effective technique in wireless sensor networks which can increase network energy efficiency, scalability and lifetime. In this paper, we have proposed an energy–efficient clustering based protocol for wireless sensor networks. We have considered a set of cluster heads for control and management of the network. On rotation basis, a cluster head receives data from the neighboring nodes and transmits the aggregated data to the base station. Adopting this approach, Energy Efficient Clustering Hierarchy and Data Accumulation (EECHDA) is better than existing protocols in terms of energy consumption and network lifetime. Our simulation results demonstrated that EECHDA is able to prolong the time interval of the death of first node in the network.

Index Terms -wireless sensor networks; clustering; energy efficient; aggregation; lifetime

1. INTRODUCTION

With the development of the information society, sensors are facing ever more new challenges. Detection and monitoring requirements are becoming more complicated and difficult. They trend from single variable to multiple variables; from one point to a plane; from one sensor to a set of sensors; from simple to complex and cooperative. Networking the sensors to empower them with the ability to coordinate on a larger sensing task will revolutionize information gathering and processing in many situations. Networks of sensors can greatly improve environment monitoring for many civil and military applications. Furthermore, many environments may be unsuitable for humans and thus the use of sensors is the only solution; in some places, although accessible, in general it is more effective to place small autonomous sensors than to use humans for collection of data.

By integrating sensing, signal processing, and communications functions, a sensor network provides a natural platform for hierarchical and efficient information processing. It allows information to be processed on different levels of abstraction, ranging from detailed microscopic examination of specific targets to a macroscopic view of the aggregate behavior of targets. With focus on applications requiring tight coupling with the physical world, as opposed to the personal communication focus of conventional wireless networks, wireless sensor networks pose significantly different design, implementation, and deployment challenges.

As a microelectronic device, the main task of a sensor node is to detect phenomena, carry out data processing timely and locally, and transmit or receive data. A typical sensor node is generally composed of four components [1], [2], [3], [4], [5], [6], [7], [8]: a power supply unit; a sensing unit; a computing/processing unit; and a communicating unit. The sensing node is powered by a limited battery, which is impossible to replace or recharge in most application scenarios. Except for the power unit, the entire network layer in WSNs is responsible for data delivery from source to destination via well-selected routes [9], [10]. Due to the unique characteristics of Wireless Sensor Networks (WSNs), many of the network layer protocols designed for conventional networks may not fit with the requirements of WSNs. The following principles must be considered in WSN network layer protocols:

1. Energy efficiency is always a dominant consideration.
2. Routing is often data centric.
3. Data aggregation/fusion is desirable, but only useful if it does not affect the collaborative efforts among sensor nodes.
4. An ideal sensor network has attribute-based addressing and location awareness.
5. Protocols are most likely application specific.

Depending on how the hierarchical structure is formed, hierarchical protocols can be grouped as reserved tree based, chain based, or clustering based. Among these, the clustering-based approach has received increased attention because of its effectiveness, lower complexity, and flexibility.

In WSNs, a cluster head (CH) is generally a sensor node, which has severe resource limitations, and cluster heads are selected dynamically; therefore, clusters are dynamic within the network, but sensor nodes are often in stationary position. This would reduce the overall energy consumed for data communication over the whole WSN.

Clustering-based schemes also have the advantages of load balancing, and scalability when the network size grows. Challenges faced by such clustering-based approaches include

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how to select the cluster heads and how to organize the clusters. The clustering strategy could be single-hop cluster or multi hop cluster, based on the distance between the cluster heads and their members. According to the hierarchy of clusters, the clustering strategies can also be grouped into single-level or multilevel clustering.

The principle of data aggregation or data fusion is to minimize traffic load (in terms of number and/or length of packets) by eliminating redundancy. It applies a novel data-centric approach to replace the traditional address-centric approach in data forwarding [11]. Specifically, when an intermediate node receives data from multiple source nodes, instead of forwarding all of them directly, it checks the contents of incoming data and then combines them by eliminating redundant information under the constraints of acceptable accuracy.

In this paper, the main scenario of interest is a cluster based WSN with static homogeneous nodes and energy constrained sensor nodes. All nodes in the network act as sensor nodes collecting information from the environment, apart from they can act as a cluster-head, forwarding the aggregated information to the base station (BS). Each cluster is formed by a set of sensor nodes, one of them assume the role of CH. The cluster head node stores the information it receives and performs the aggregation tasks sending periodical messages to the BS. The proposed routing scheme in this paper is suitable for continuous monitoring of numerous widespread sensors, which are at a large distance from the BS.

The paper is organized as follows: Following the introduction, section 2 summarizes some related work in this area. Section 3 presents our cluster-based hierarchy approach. In Section 4, we perform quantitative analysis for the proposed protocol. Section 5 evaluates the performance of the proposed protocol. Finally, section 6 concludes the paper and provides possible future directions.

2. RELATED WORK

The cluster-based routing protocols are investigated in several research studies. For example, the work in [5] shows that a 2-tier architecture is more energy efficient when hierarchical clusters are deployed at specific locations. In [3], 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 [4], authors have 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 [6], a variation of directed diffusion, use rumor routing to flood events and route queries; this approach is suitable for a large number of queries and a fewer events.

In [7], authors have analyzed a method to elect cluster heads according to the energy left in each node. 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.

In [12], it proposes a maximum energy cluster head routing protocol which has self configuration and hierarchical tree routing properties. The proposed protocol improved LEACH in several aspects such as it constructs clusters based on radio range and the number of cluster members and the cluster topology in the network is distributed more equally.

In [13], a novel self –organizing energy efficient hybrid protocol based on LEACH is presented, combining cluster based architecture and multiple-hop routing. Multi-hop routing is utilized for inter-cluster communication between Clusterheads and the base station, instead of direct transmission in order to minimize transmission energy.

LEACH [14][15]16][17][18] is one of the most popular hierarchical routing algorithms for clustering of WSNs. In LEACH, a small number of clusters are formed in a self – organized manner. Thus it is a suitable solution for energy efficiency in the sensor network. Although, LEACH is a sound solution in data gathering, but it has certain issues and have several limitations:

LEACH does not address the problem that some nodes are close to each other and thus redundant data may be transferred to the base station.

Cluster heads are not selected in a distributed manner it is possible that too many CHs are located in a specific area that may not produce good clusters.

On an average five CH nodes transmit the fused data from their cluster to the base station.

In [19] [20], the authors worked on the heterogeneous sensor nodes and evaluated the energy efficiency. The performance measures that have been considered are network lifetime, number of cluster heads, stability, throughput and energy of the system.

3. CLUSTER BASED HIERARCHY ARCHITECTURE

As previously described, LEACH has some issues. In the proposed protocol we have tried to solve these problems. The protocols optimize energy cost when gathering data. In addition, it distributes energy fairly.

The proposed routing scheme is based on the fact that the energy consumed to send a message to a distant node is far greater than the energy needed for a short range transmission. The CHs are responsible for transmitting messages to the distant base station. At one time, only one member of the member node is active and the remaining members are in sleep mode. The task of transmission to the base station is uniformly distributed among all the CHs.

We now describe a few terms that are used in defining our protocol. A CH is a sensor node that transmits an aggregated sensor data to the distant base station. Non-cluster heads are sensor nodes that transmit the collected data to their cluster head. Each cluster has a head-set that consists of several non-cluster heads nodes. A round consists of two stages: a cluster head election phase and a data transfer phase. In a cluster head election phase, the head-sets are chosen for the pre-determined number of clusters. In the data transfer phase, the CHs nodes transmit aggregated data to the base station.

3.1. Cluster Head Election Phase

In the proposed model, the number of clusters, q, are pre-determined for the wireless sensor network. At the beginning, a set of CHs are chosen on random basis. The sensor nodes closer to the base station can directly send their messages to the base station. Thus they become the member of a cluster. These cluster heads send a short range announces a Join Request message to the nearby nodes. The member nodes receive the advertisements and choose their cluster heads based on the distance. Each member sensor node sends an acknowledgment message to its cluster head. The cluster heads act as local control centers to coordinate the data transmissions in their cluster and are also responsible to send aggregated messages to the distant base station.

3.2. Data Transfer Phase

Once clusters and TDMA-based schedules are formed, data transmission begins. The non-cluster head nodes collect the sensor data and transmit the data to the cluster head, in their allotted timer slots. The cluster-head node must keep its radio turned on to receive the data from the nodes in the cluster. After, some pre-determined time interval, the next non cluster head member becomes a cluster head and the current cluster head becomes a non cluster head member. The energy of the cluster head is drained out more as compared to a non cluster head member; because it has to do more work than the other nodes. In other rounds the higher energy nodes become cluster heads.

4. NETWORK MODEL ANALYSIS

In this section, we describe a radio energy model that is used in the analysis of EECHDA protocol. The energy dissipation, number of frames, time for message transfer, and the optimum number of clusters are analytically determined.

4.1. Radio Energy Dissipation Model

We have used the same radio model as described in [17], where for a shorter distance transmission, such as within clusters, the energy consumed by a transmit amplifier is proportional to d2 where d is the distance between the transmitter unit and the receiver unit. However, for a longer distance transmission, such as from a cluster head to the base station, the energy consumed is proportional to d4. Using the given radio model, the energy consumed to transmit an m-bit message for a longer distance, d, is given by:

$$E_{TL} = E(m, d^4) \tag{1}$$

Similarly, the energy consumed to transmit an m-bit message for a shorter distance is given by:

$$E_{TS} = E(m, d^2) \tag{2}$$

Moreover, the energy consumed to receive the m-bit message is given by:

$$E_{RX} = E(m) + \text{EDA} \tag{3}$$

where E(m) presents the energy consumption of radio dissipation. Additionally, the operation of data aggregation approach consumes the energy as EDA . The constants used in the radio model are given in Table 1.

4.2. Energy Consumption in Election Phase

For a sensor network of N nodes, the optimal number of clusters is given as q. All nodes are assumed to be at the same energy level at the beginning. The amount of consumed energy is same for all the clusters. At the start of the election phase, the base station randomly selects a given number of cluster heads. Initially, the cluster heads broadcast messages to all the sensor nodes in their neighborhood. Next, the sensor nodes receive messages from one or more cluster heads and choose their cluster head using the received signal strength. After this, the sensor nodes transmit their decision to their corresponding cluster heads. Finally, the cluster heads receive messages from their sensor nodes and remember their corresponding nodes. For uniformly distributed clusters, each cluster contains N/q nodes. Using Equation 2 and Equation 3, the energy consumed by a cluster head is estimated as follows:

$$E_{CH} = E_{TS} + (\frac{N}{q} - 1).E_{RX} + E_{DA} \tag{4}$$

The first part of Equation 4 represents the energy consumed to transmit the advertisement message; this energy consumption is based on a shorter distance energy dissipation model. The second part of Equation 4 represents the energy consumed to receive (N/q-1) messages from the sensor nodes of the same cluster. Equation 4 can be simplified as follows:

$$E_{CH} = m.Q.\frac{N}{q} + m.E_{DA}.(\frac{N}{q} - 1) + m.\tau.d^2 \tag{5}$$

Using Equation 2 and Equation 3, the energy consumed by non-cluster head sensor nodes is estimated as follows:

$$E_{NCH} = \{q.E(m) + E(m, d^2)\} \tag{6}$$

The first part of Equation 6 shows the energy consumed to receive messages from q cluster heads; it is assumed that a sensor node receive messages from all the cluster heads. The second part of Equation 6 shows the energy consumed to transmit the decision to the corresponding cluster head. Equation 6 can be simplified as follows:

$$E_{NCH} = \{(q+1).m.Q + q.m.E_{DA} + m.\tau.d^2)\} \tag{7}$$

4.3. Energy Consumption in Data transfer Phase

During data transfer phase, the nodes transmit messages to their cluster head and cluster heads transmit aggregated messages to a distant base station. The energy consumed by a cluster head is as follows:

$$E_{CH/f} = \{m.Q + m.\mu.d^4\} + \{\frac{N}{q}.m.(Q + E_{DA})\} \tag{8}$$

The first part of Equation 8 shows the energy consumed to transmit a message to the distant base station. The second part of Equation 8 shows the energy consumed to receive messages from the remaining (N/q) nodes that are non cluster head nodes. Equation 8 can be simplified as follows:

$$E_{CH/f} = m.(.\mu.d^4 + \frac{N}{q}.(Q + E_{DA})) \tag{9}$$

The energy, ENCH/ f, consumed by a non-cluster head node to transmit the sensor data to the cluster head is given below:

$$E_{NCH/f} = E_{TS} \tag{10}$$

For circular clusters with a uniform distribution of sensor nodes and a network diameter of A, the average value of d2 is given as:

$$E[d^2] = \left(\frac{A^2}{2\pi q}\right)$$

and Equation 10 can be simplified as follows:

$$E_{NCH} = m.(Q + \tau\frac{A^2}{2\pi q}) \tag{11}$$

In one round, Df data frames are transmitted. The number of frames transmitted by each cluster is Df /q. The Df /q frames are uniformly divided among N/q nodes of the cluster. Each cluster head frame transmission needs N/ q −1 non-cluster head frames. For simplification of equations, the fractions G1 and G2 are given as below:

$$G_1 = \left(\frac{1}{\frac{N}{q}}\right)\frac{1}{q} \tag{12}$$

$$G_2 = \left(\frac{\frac{N}{q} - 1}{\frac{N}{q} - 1}\right)\frac{1}{q} \tag{13}$$

The energy consumptions in a data transfer stage of each cluster are as follows:

$$E_{DT} = G_1.D_f.E_{CH/f} \tag{14}$$

$$E_{NDT} = G_2.D_f.E_{NCH/f} \tag{15}$$

4.4. Energy Computed for one round

There are q clusters and N nodes. Each round consists of a cluster head election phase and a data transfer phase. The energy consumed in one iteration of cluster is as follows:

$$E_{CH/iter/cluster} = E_{CH} + E_{DT} \tag{16}$$

$$E_{NCH/iter/cluster} = E_{NCH} + E_{NDT} \tag{17}$$

Since there are N/q nodes in a cluster, the ECH/iter/cluster is uniformly divided among the cluster members, as given below:

$$E_{CH/N} = E_{CH/iter/cluster} \tag{18}$$

Similarly, there are {(N/q)−1} non-cluster head nodes in a cluster. The ENCH/iter/cluster is uniformly distributed among all the non-cluster head members as follows:

$$E_{NCH/N} = \frac{E_{NCH/iter/cluster}}{(\frac{N}{q} - 1)} \tag{19}$$

The start energy, Es, is energy of a sensor node at the initial start time. An estimation of Es is given below:

$$E_S = E_{CH/N} + \left(\frac{N}{q} - 1\right)E_{NCH/N} \tag{20}$$

Using Equation 18, Equation 19 and Equation 20, Es can be described as below:

$$E_S = \left(E_{CH/iter/cluster} + E_{NCH/iter/cluster}\right) \tag{21}$$

4.5. Optimum number of clusters

In a cluster, the energy consumed to transmit an aggregated reading to the base station is as follows:

$$E_C = E_{CH/f} + \left(\frac{N}{q} - 1\right)E_{NCH/f} \tag{22}$$

The first part of Equation 22 is due to the energy consumption by cluster head. The second part of Equation 22 is due to (N/q-1) non-cluster head nodes. The total energy consumed by q clusters is as follows:

$$E_{T/f} = q.E_C \tag{23}$$

The total energy consumed by q clusters is given below:

$$E_{T/f} = q\left\{m\mu d^4 + \left(\frac{N}{q} - 1\right)mQ + \left(\frac{N}{q} - \right)mE_{DA}\right\} + q\left\{\left(\frac{N}{q} - 1\right)\left(mQ + m\tau\frac{A^2}{2\pi q}\right)\right\} \tag{24}$$

The optimum number of q for minimum consumed energy can be determined as follows:

$$\frac{dE_T}{dk} = 0$$

$$q = \sqrt{\frac{N}{2\pi}}\sqrt{\frac{\tau}{\mu.d^4 - Q_{DA}}}A \tag{30}$$

5. SIMULATION RESULTS

Wireless sensor networks (WSNs) contain 200 number of sensor nodes equipped with sensing, computing and communication abilities. Each node has the ability to sense elements of its environment, performs simple computations, and communicates among its peers or directly to an external base station (BS) as shown in Figure 1. Deployment of a sensor network is in random fashion. In this section, we have evaluated the effectiveness performance of the EECHDA through simulations. We have considered first order radio model and the simulation parameters for our model are mentioned in the Table 1.To validate the performance of EECHDA, we have simulated direct and EECHDA wireless sensor network in a field with dimensions M × M as shown in Figure 2. All the sensor nodes are randomly distributed over the sensor field. This means that the horizontal and vertical coordinates of each sensor are randomly selected between 0 and maximum value of the dimension. The base station is located far away from the network. The size of the message that nodes send to their cluster heads as well as the size of the (aggregate) message that a cluster head sends to the base station is set to 50 bytes.

We have simulated EECHDA and Direct protocol in the same environment. The results of EECHDA and Direct simulations are shown in Figures 3 -6.

Figure 3 shows, the variation in the energy consumed per node with respect to the number of clusters and network diameter. The x-axis and y-axis represent the number of clusters and the energy consumed in one round, respectively. Figure 4, shows the energy consumption with respect to the number of clusters. As expected, the energy consumption is reduced when the number of clusters is increased. However, the rate of reduction in energy consumption is reduced for higher cluster sizes. Figure 5, illustrates the energy consumption with respect to the network diameter. The energy consumption is increased when the network diameter is increased in direct transmission protocol. We have also evaluated the network lifetime by examining the round when the first and last node dies in the network. Figures 6(a)-6(b), shows that the proposed protocol offers a much longer lifetime than direct transmission. Here, direct transmission means that each node transmits its data directly to the base station or sink. This extends the network lifetime by 50% in EECHDA over Direct. However, EECHDA requires less energy consumption in cluster configuration than the direct configuration. Thus, the proposed protocol is energy efficient.

Parameters	Symbol	Value
Network area	M x M	(0,0) to (200,200)
Number of nodes	N	200
Location of BS	Outside	(100,100),(100,300)
Data aggregation energy	EDA	5nJ/bit/report
Energy consumed by the amplifier to transmit at a shorter distance	τ	10pJ/bit/m2
Energy consumed by the amplifier to transmit at a long distance	μ	0.0013pJ/bit/m4
Energy consumed in the electronic circuit to transmit or receive the signal	Q	50nJ/bit
Initial energy of node	E0	0.5J
Packet Size	m	50bytes
Number of cluster heads	q	20

Table1: Simulation Parameters

6. CONCLUSIONS AND FUTURE WORK

In this paper, we have developed EECHDA, clustering based network protocol that minimizes energy usage and the quantitative results indicate that the energy consumption can be systematically decreased by including more clusters in networks. Both theoretical analysis and simulation results show that EECHDA has significant gain in network lifetime over direct transmission under the assumption that nodes are randomly and densely deployed. We have also examined the energy of the battery drain rate is less in case of clustered network than the direct transmission in the same network. Simulation results show that the network lifetime is extended by 50% in EECHDA over direct transmission. One of the future works will include the study of an energy efficient algorithm through data accumulation in a mobile sensor network.

REFERENCES

[1]. G. Asada et al., Wireless Integrated Network Sensors: Low Power Systems on a Chip,24th IEEE Eur. Solid-State Circuits Conf., 9–12, The Hague, the Netherlands, 1998.

[2]. J. Hill and D. Culler, A Wireless Embedded Sensor Architecture for System Level Optimization, University of California Berkeley Technical Report, 2002.

[3]. J.M. Kahn, R.H. Katz, and K.S.J. Pister, Next Century Challenges: Mobile Networking for Smart Dust, ACM MOBICOM, 271–278, Seattle, 1999.

[4]. R. Min et al., Low-Power Wireless Sensor Networks, IEEE VLSID 2001, 205–210, India, 2001.

[5]. G.J. Pottie and L.P. Clare, Wireless Integrated Network Sensors: towards Low Cost and Robust Self Organizing Security Networks, Processiding of SPIE 1998, 3577, 86–95, and 1999.

[6]. G.J. Pottie and W.J. Kaiser, Wireless Integrated Network Sensors, Communication ACM, 43 (5), 51–58, 2000.

[7]. J.M. Rabaey et al., Pico Radio Supports Ad Hoc Ultra-Low Power Wireless Networking, IEEE Computer Mag., 33(7), 42–48, 2000.

[8]. A. Sinha and A. Chandrakasan, Dymamic Power Management in Wireless Sensor Networks, IEEE Design Test Computers, 18(2), 62–74, 2001.

[9]. J. F. Kurose, and K. W. Ross, Computer Networking, a Top-Down Approach Featuring the Internet,1st ed., Addison–Wesley, Longman, MA, 2000.

[10]. A.S. Tanenbaum, Computer Networks, Prentice Hall, Upper Saddle River, NJ, 1996.

[11]. B. Krishnamachari, D. Estrin, and S. Wicker, Impact of Data Aggregation in Wireless Sensor Networks, International Workshop Data Aggregation Wireless Sensor Networks, 575–578, Vienna, Austria, July 2002.

[12]. R.S.Chang, C.J Kuo, An Energy Efficient Routing Mechanism for Wireless Sensor Networks, Advanced Information Networking and Applications,2006,20th International Conference on Publications, Vol.2,April 2006.

[13]. J. Zhao, A.T. Erdogan, A Noval Self Organizing Hybrid Network Protocol for Wireless Sensor Networks,Adaptive Hardware and Systems (AHS 2006),First NASA conference, Publication, June 2006.

[14]. I.F.Akylidiz et al.,Wireless Sensor Networks: a Survey, Computer Networks 38(4),393-422, 2002.

[15]. Akkaya and M.Younis, A survey of Routing protocols in Wireless Sensor Networks,in the Elsevier Ad Hoc Network Journal, Sep 2003.

[16]. W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, “Energy efficient Communication Protocol for Wireless Microsensor Networks,” in Proceedings of the Hawaii International Conference on System Sciences, January 2000.

[17]. W. Heinzelman., Application-Specific Protocol Architectures for Wireless Networks. In PhD thesis, Massachusetts institute of technology, June 2000.

[18]. T. Anker, D. Bickson, D. Dolev, and B. Hod, Efficient Clustering for Improving Network Performance in Wireless Sensor Networks, in Proceedings of the Springer –Verilag Heridelberg (LNCS 4913),221-236, 2008.

[19]. Dilip Kumar, and R.B. Patel, “HCEE: Hierarchical clustered energy efficient protocol for heterogeneous wireless sensor networks”, International Journal of Electronics Engineering, Vol. 1, 1, January 2009, pp.123-126.

[20]. Dilip Kumar, T.C Aseri, and R.B. Patel, “A Two Tier Data Aggregation and Clustering Scheme for Heterogeneous Sensor Networks ”, in the Proceedings of IEEE International Adavnced Computing Conference (IACC-2009),6-7 March,Patiala,India,2009, pp.2053-2058.

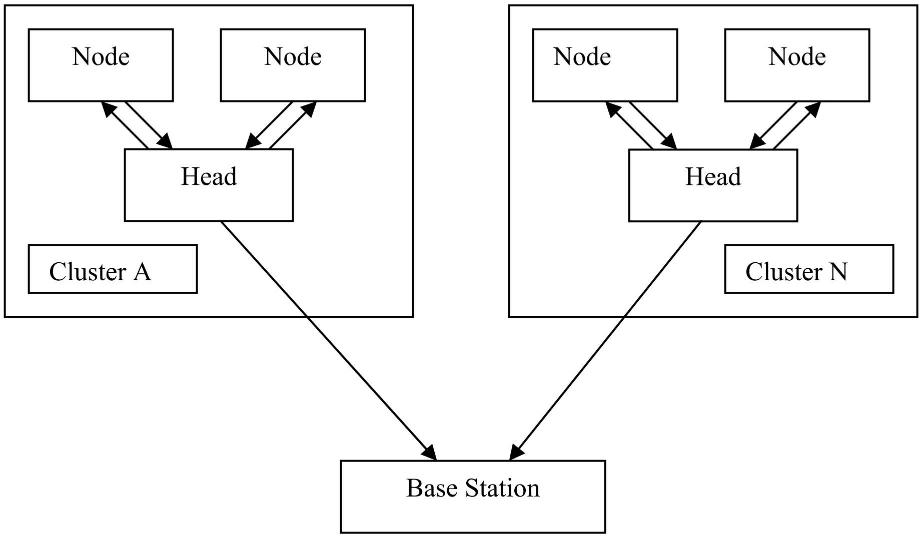

Figure1: Hierarchical clustering architecture

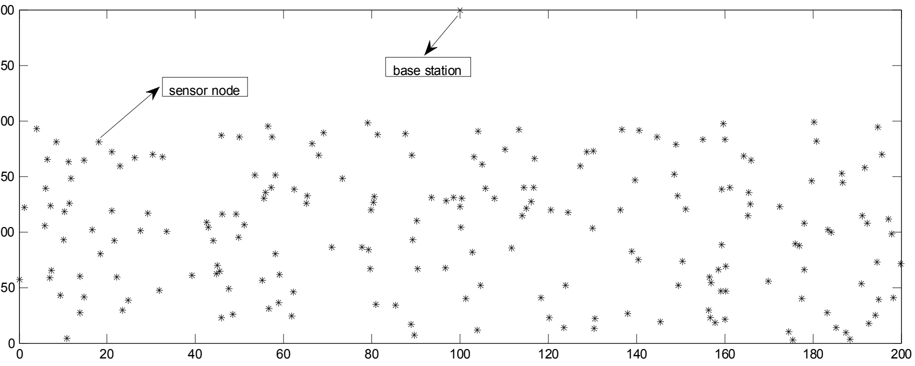

Figure 2: Network model

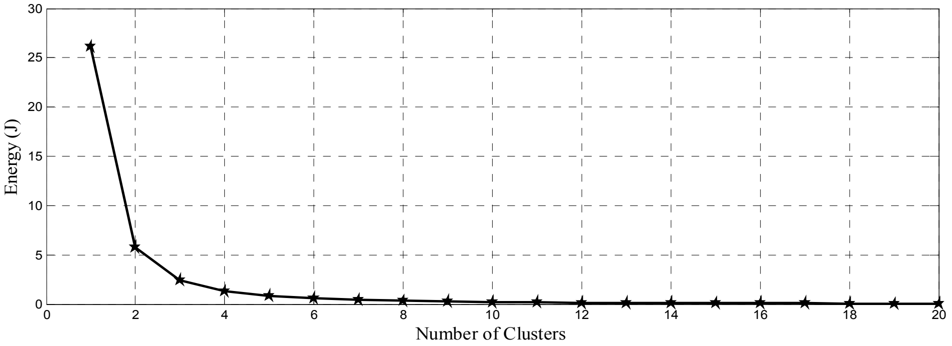

Figure 3: Optimum number of clusters.

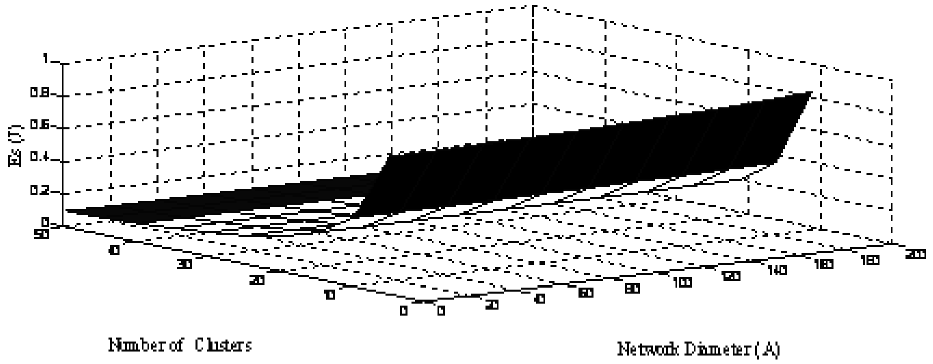

Figure 4: Energy consumed per round with respect to number of clusters.

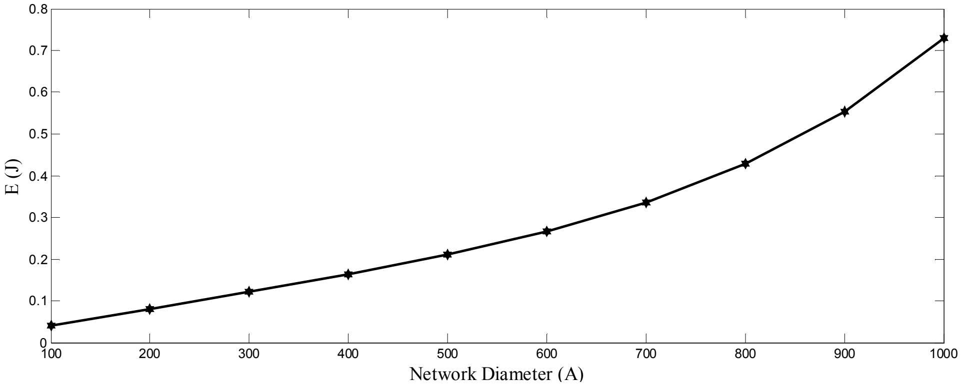

Figure 5: Energy consumed per round in direct transmission over network diameter.

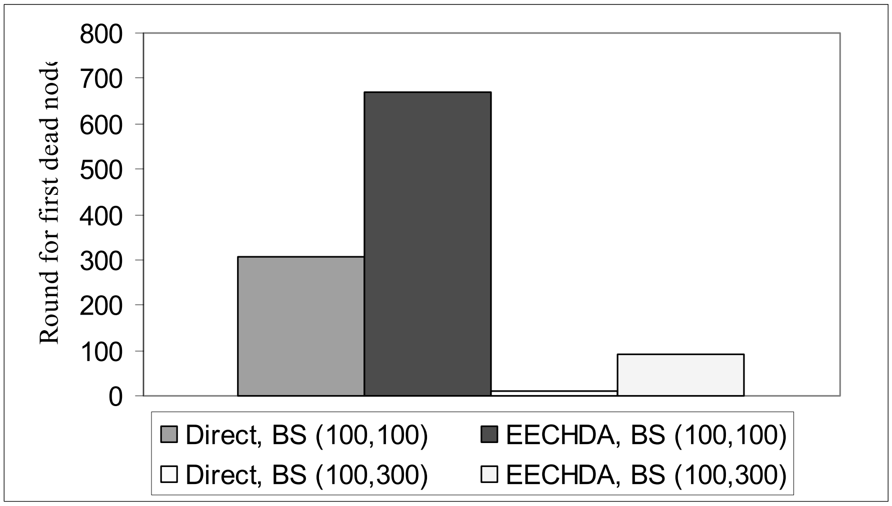

Figure 6 (a): Round for first dead node in EECHDA and Direct.

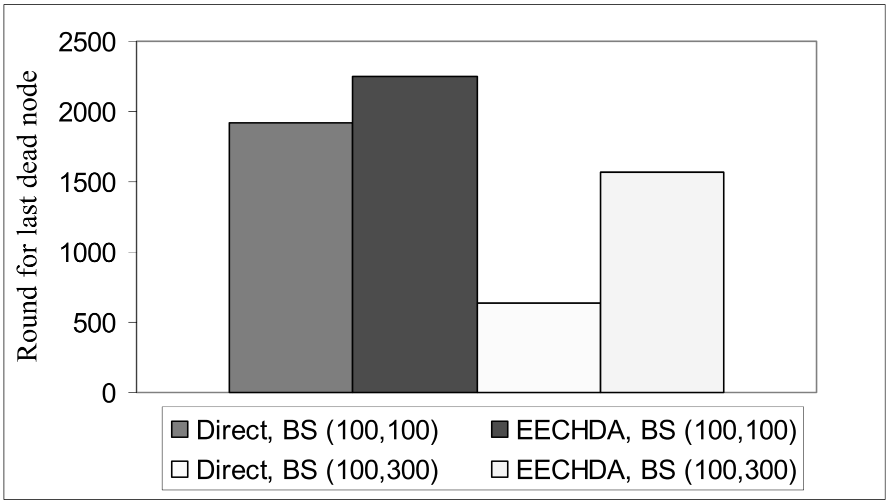

Figure 6(b): Round for last dead node in EECHDA and Direct.