Distributed Multi-Tier Energy-Efficient Clustering

Yogesh Kumar Meena , Amit Singh, and Anup Singh Chandel

***Abstract*—Wireless sensor networking has huge potential of its exploitation in various fields like weather monitoring, battle field surveillance and security systems also. The services provided by wireless sensor networks (WSN) are based on the various sensor nodes deployed in area to cover or sense. These sensor nodes are energy constraints i.e. have limited energy source. So for better utilization of sensor network, we should manage the energy consumption of WSN. There are various ways to manage energy consumption in the sensor nodes and in WSN. Our research work is mainly based on hierarchical and clustering approaches. We proposed an efficient way of using hybrid energy-efficient distributed clustering (HEED) algorithm for energy saving by the use of multi layer architecture. By using 2-tier architecture in the clustering and operation of sensor nodes we have gained an increase in the network lifetime of the WSN. In this paper, we describe our distributed multi-tier energy-efficient clustering (DMEC) approach to save the energy of sensor network and increased lifetime of the network.**

***Index Terms*—Clustering, energy efficiency, multi tier, network lifetime. sensor networks.**

I. Introduction

The Sensor networks have emerged as an important field in the research areas. The main difference in WSN and Ad Hoc network is less mobility and dense deployment of sensor nodes. A wireless sensor network typically consists of a large number of inexpensive, small, low-power communicating devices called sensor nodes and one or more computing centers. Advances in energy-efficient design and wireless technologies have enabled the manufacture of the small devices to support several important wireless applications, including real-time multimedia communication [1], medical application, surveillance using WSNs [2], and home networking applications [3]. In WSNs, the sensor nodes have the ability to sense, process data, and communicate with one another. But in most of the cases like battle field monitoring, sensor nodes must be left unattended. In such cases recharging or replacing batteries of these nodes become difficult or impossible. So there is need for proper energy management of these sensor nodes so that network lifetime becomes longer.

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Network lifetime can be defined as the time elapsed until first or last node in the network depletes its energy i.e. node become dead. Both of cases have been considered in our paper and results have been compared. Basic architecture of sensor nodes have mainly five components: (i) Memory that stores programs and intermediate data, (ii) A limited power supply (e.g., battery) also includes power unit for managing power usages, (iii) A transceiver that performs the functions of both a transmitter and receiver with a limited transmission range, (iv) a controller that processes all the data and controls the other components and (v) A sensor device that senses the ambient environment.

We can divide Wireless Sensor Networks uses in a wide range of exciting applications such as target field imaging, intrusion detection, weather monitoring, security and tactical surveillance; distributed computing; the detection of ambient conditions such as temperature, movement, sound, and light or the presence of specific objects, inventory control, and disaster management. WSN applications are mainly of four types: (i) environmental data collection, (ii) security monitoring, (iii) node tracking, and (iv) hybrid networks.

Most of energy consumption occurs in data transmission, signal processing, and hardware operations. Wasteful energy consumption occurs in a sensor node due to idle listening of media, overhearing, retransmitting the packet due to collision of packets and handling of packets. Several protocols have been proposed for minimizing the wasteful energy consumption of sensor node. There is useful energy consumption also that occurs due to (i) transmission/reception of data, (ii) processing query request, and (iii) forwarding queries/data to neighboring nodes.

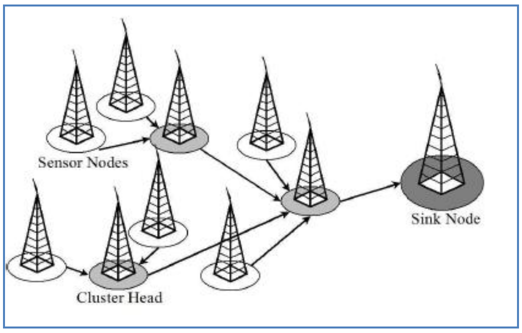

Fig. 1. Cluster based sensor network model.

There are several protocols proposed for reducing the useful consumption of energy in sensor nodes like clustering algorithms: HEED, LEACH, TL-LEACH, EEGS etc [4], [5], [6], [7]. An efficient way to reduce energy consumption in WSN is the use of multi-tier architecture in clustering. The algorithm presented in this paper is using combination of hierarchical and multi-tier schemes for saving energy in any sensor network. We introduce multiple levels of clusterhead nodes such that only highest level of clusterheads transmits data to base station. In Fig. 1 we have shown the simple architecture of cluster based sensor network model.

This paper is organized as follows. In Section II, we describe the main features of our network model. In Section III, we discuss about the related works done in this area of reducing power consumption WSN. In Section IV, we extend the analysis of our proposed protocol and also discuss the energy equation used for deriving multi tier approach for energy efficient sensor network. In Section V contains the simulation results and related discussion. Finally, Section VI gives concluding remarks and direction for future work.

II. Area of Concern

A. Network Model

We take a square field of area M×M. In this square field a set of sensor nodes are deployed. This sensor network has following properties:

- Nodes in the network are location unaware i.e. they are not equipped with GPS.
- Nodes are stationary.
- All nodes have similar capabilities (processing/communication), and equal significance.
- The power level (battery) of each node is same at the time of deployment.
- Each node has fixed no. of discrete transmission power levels.
- The network serves multiple mobile/stationary observers, which implies that energy consumption is not similar for all sensor nodes.
- The base station is located inside the square area such that communication between base station and sensor node is subject to multi-path fading.
- All nodes sense the environment and transmit message of equal length.
- A subset of sensor nodes is chosen to be level one Cluster Heads and a subset of level one CH (cluster head) is chosen to be level two cluster heads.
- The cluster heads receive and fuse data from the non-cluster head or lower level cluster head nodes, in addition to sensing the environment. They also sense the environment.
- The second level cluster heads transmit their data to base station for two-tier sensor network.

The properties discussed above are used in the forming of sensor network model for our simulation. We try to integrate common properties of sensor network models described in other papers presented for energy saving schemes.

In our model, we don't make any assumption about the following parameters:

1) Homogeneity of node dispersion in the area where nodes are deployed,
2) The density of the network,
3) Distribution of energy consumption in sensor network.

In the following Fig.2 we take the first level architecture of our model where basic features of network are defined:

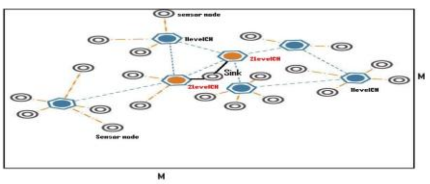

Fig. 2. Network model showing dimensions

We know that nodes in our model are homogeneous. In these nodes, some nodes work as clusterheads. Each node transmits its data to the closest clusterhead. In our proposed algorithm, sensor network is multi-tiered so one or more of the cluster heads are chosen as the second level clusterheads and will receive data from the set of first level cluster heads in their range. These second level cluster heads will finally transmit data to the base station.

B. Concerning Points

The main concerning points for our protocol are the clustering technique and its multi-tier application. Assume that N nodes are dispersed in a field and all the properties of our network model holds. Our aim is to identify a set of cluster heads for the first level which covers the entire field and this is applicable for 2^{nd} level cluster heads also. The following requirements must be met:

1) Clustering is completely distributed. Each node independently makes its decisions based on local information.
2) Clustering terminates within a fixed number of iterations (regardless of network diameter).
3) At the end of each clustering process, each node is either a cluster head, or a non-head node (which we refer to as regular node) that belongs to exactly one cluster.
4) Clustering should be efficient in terms of processing complexity and message exchange.
5) Cluster heads are well-distributed over the sensor field.

We should also take care of these points for second level of clustering process.

III. Related Work

There are many protocols for reducing energy in useful as well as wasteful sources. We can categorize them into mainly four types: (i) hardware design improvement, (ii) OS level improvement, (iii) mac-layer protocols, and (iv) location aware techniques. Here we focus on routing protocol proposed for improving energy efficiency of sensor network.

Data dissemination protocols proposed for sensor networks consider energy efficiency a primary goal. SPIN attempts to reduce the cost of flooding data assuming that the network is source-centric (i.e., sensors announce any observed event to interested observers). Directed diffusion , on the other hand, selects the most efficient paths to forward requests and replies on, assuming that the network is data-centric (i.e., queries and data are forwarded according to interested observers).

Topology control: Topology control preserves desirable properties of a wireless network (*e.g.*, K-connectivity) through reduced transmission powers. A comprehensive survey on existing topology control schemes can be found in [8]. We review several representative works here. In the scheme proposed in [9], a node chooses to relay through other nodes only when less power is used. The network is shown to be strongly connected if every node only keeps the links with the nodes in its "enclosure" defined by the relay regions.

Power aware routing: Singh et al. proposed five power-aware routing metrics to reduce energy consumption and extend system lifetime [10]. The implementation of a minimum energy routing protocol based on DSR was discussed in [10, 11]. An online power aware routing scheme is proposed to optimize system lifetime in [12]. Chang and Tassiulas studied the problem of maximizing the lifetime of a network with known data rates [13]. Chang et al. formulated the problem of choosing routes and transmission power of each node to maximize the system lifetime as a linear programming problem and discussed two centralized algorithms [13].

Sleep management: Recent studies showed that significant energy savings can be achieved by turning wireless radios off when not in use. In this approach, only a small number of nodes remain active to maintain continuous service of a network and all other nodes are scheduled to sleep.

A hierarchical network is analyzed in [14]. Their network model contains three types of nodes: sensors, compressor/aggregation nodes, and sinks. They consider both Voronoi tessellation and a Johnson-Mehl tessellation. A multi-level clustering algorithm is presented in [15][17]. The authors of this paper assume that all sensors transmit at the same power level, that each sensor uses 1 unit of energy to transmit or receive 1 unit of data, and that the sensors are a distributed in a square grid with the base station (processing center) at the center of the square. We make assumptions similar to [16]: the sensor power is tunable such that energy expended in transmission depends on distance, receive energy is constant, but the base station is inside of the square grid. We assume that the sensors are distributed according to a homogeneous spatial Poisson process, as do the authors of [16].

IV. The DMEC Protocol

The goal of the protocol is to enhance the lifetime of the network. Therefore cluster head is primarily chosen on the basis of residual energy of each node for both levels. The secondary parameter for clustering is the node degree.

A. *Clustering Parameters*

1) Cluster radius: Cluster radius is determined by the transmission level of the node. As a sensor node has 6 discrete transmission power levels. For the first level of cluster heads nodes will transmit at lower power level (third smallest) and at highest level for transmission at second level of cluster heads because each node should be able to transmit to the base station in case cluster head is at the corner of the square area.
2) Weight used in clusterhead selection: The primary parameter used for the selection of cluster head is the residual energy of the node. To solve the cases when a node is in the range of two or more cluster heads, a secondary parameter node degree is used.

B. *Protocol Operation*

In our protocol DMEC clustering is done in two stages. In the first stage k1 number of cluster heads are chosen for the first level based on the optimum number of cluster heads as proved in[17] in the setup1 seconds based on the primary and secondary parameters of cluster head selection .

In each iteration of the algorithm the nodes select one of the tentative cluster heads as their cluster head. Let ch1 be the set of total number of cluster heads at the first level. After clustering at the first level second level of clustering starts in which only the set of ch1 nodes takes part. From the set ch1 cluster heads for the second level is chosen in Tgen2 seconds. The regular nodes transmit data to the first level cluster heads which aggregate and transmit that data to the second level cluster head. Finally second level cluster heads transmit the data to base station. The total time elapsed before generation of new clusters is

Ttotal=Tgen1+Tgen2+Tcom

i.e after every Ttotal seconds clustering for the first level starts. In coming Fig. 2 and 3 we show the network architecture of first level sensor network and two-tier sensor network.

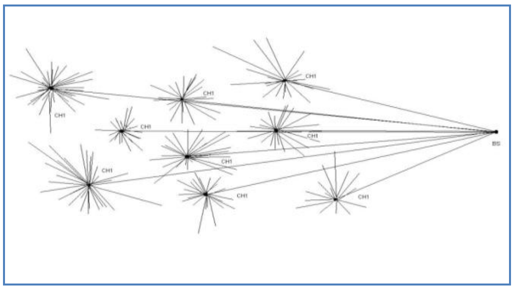

Fig. 3. First level network architecture

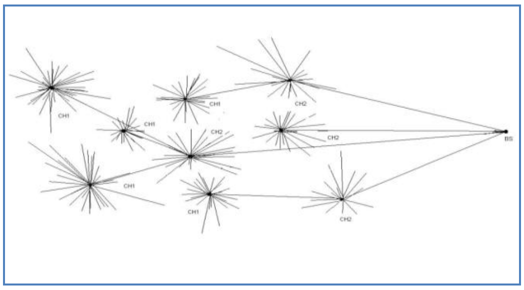

Fig. 4. Second level network architecture

C. *Energy Equations:*

In our model, for transmitting and receiving, we use standard energy equation. We use the energy equation for transmission of an l-bit message for distance d, and for reception of a message. The energy consumed by a node during transmission of an l-bit message a distance of d is

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$E_{Tx} = lE_{elect} + l\varepsilon_{fs}d^2$ Where distance d is smaller than a threshold distance d_0.

If distance d is greater than the threshold distance d_0, the energy equation will be $E_{Tx} = lE_{elect} + l\varepsilon_{fs}d^4$.

The energy consumed in receiving an l-bit message is $E_{Rx} = lE_{elect}$. The node can fuse (aggregate) data. The energy required for this process is lE_f.

These basic energy equations we used in our model for getting the optimum no. of cluster heads for different level as well as for getting energy dissipated in each operation.

D. Algorithm:

As our network architecture defines, we have to run our clustering process for two different levels. For first level, we initialize with some certain no. of nodes (optimum no. of cluster heads) and after completing first level process, we go for 2nd level clustering.

The energy equations clarify the energy consumption for each level of clustering process as well as the data transmission and reception processes. There are some assumptions made regarding network operation those are proved by different lemmas.

The clustering process algorithm or pseudo code is described below:

The parameters used in the protocols are:

S_{cnbr}- set of neighbor nodes within the cluster range of node at current power level

S_{cCH} - set of tentative and final cluster heads of current level

CH_{prob} – current level cluster head probability

n – node

Node id – id of the cluster head

energy – residual energy of the cluster head

cost – avg. cost of transmission from all nodes in the cluster range to the cluster head

I. **Initialization**

1. Current_Level ← Min_Level
2. do_Iteration ← TRUE

II. **Repeat**

1. S_{cnbr} ← {v: v is current level node and lies in my cluster range}
2. Compute and broadcast cost to S_{cnbr}
3. CH_Current_Level ← Current _Level
4. is_Current_Level_CH ← FALSE
5. CH_{prob} ← max(C_{prob} $\frac{E_{residual}}{E_{max}}$, $P_{current\_level\_min}$)

III. **Repeat**

1. If((S_{cCH} ← {v: v is current level (cluster_head tentative_cluster_head) }))
2. my_cluster_head ← Least cost (S_{cCH})
3. If(my_cluster_head = self)
4. If(CH_{prob} = 1)
5. CH_Current_Level ← CH_Current_Level + 1
6. Cluster_head_msg(BROADCAST, nodeID, CH_Current_Level, cost)
7. is_Current_Level_CH ← TRUE
8. Else
9. CH_Current_Level ← tentative
10. Cluster_head_msg(BROADCAST, nodeID, CH_Current_Level, cost)
11. Else If (CH_{prob} = 1)
12. CH_Current_Level ← CH_Current_Level + 1
13. Cluster_head_msg(BROADCAST, nodeID, CH_Current_Level, cost)
14. is_Current_Level_CH ← TRUE
15. Else If(Random(0,1) ≤ CH_{prob})
16. CH_Current_Level ← tentative
17. Cluster_head_msg(BROADCAST, nodeID, CH_Current_Level, cost)
18. $CH_{previous}$ ← CH_{prob}
19. CH_{prob} ← min(CH_{prob} × 2, 1)

Until $CH_{previous}$ = 1

6. If (is_Current_Level_CH = FALSE)
7. If((S_{cCH} ← {v: v is current level cluster_head }))
8. my_cluster_head ← Least cost (S_{cCH})
9. Else
10. CH_Current_Level ← CH_Current_Level + 1
11. Cluster_head_msg(BROADCAST, nodeID, CH_Current_Level, cost)
12. is_Current_Level_CH ← TRUE
13. Else
14. CH_Current_Level ← CH_Current_Level + 1
15. Cluster_head_msg(BROADCAST, nodeID, CH_Current_Level, cost)
16. is_Current_Level_CH ← TRUE
17. Current_Level ← Current_Level + 1
18. If(Current_Level Max_Level)
19. do_Iteration ← FALSE
20. my_cluster_head ← Sink
21. Else If(is_Current_Level_CH = FALSE)
22. do_Iteration ← FALSE

Until(do_Iteration = FALSE)

E. Lemmas and Mathematical work:

Consider a 2-level sensor network having N nodes. In N nodes, k_1 level 1 cluster heads and k_2 level 2 cluster heads. First the non-cluster head nodes send their data to the level 1 cluster head nodes. So by using equation for this, the expected energy consumed per bit by non cluster head node will be

$$\frac{E_{non-CH}}{l} = E_{elect} + \frac{\varepsilon_{fs} M^2}{\pi k_1}$$

The level 1 cluster head nodes receive the data and fuse it. The expected energy expended can be expressed by

$$\frac{E_{CH}}{l} = \left(\frac{N}{k_1} - 1\right) E_{elect} + \frac{N}{k_1} E_F$$

Next, the level 1 cluster heads transmit their data to the level 2 cluster heads. The expected energy per bit expended in a level 1 cluster head node is

$$\frac{E_{CH\,1}}{l} = E_{elect} + \frac{\varepsilon_{fs} M^2}{\pi k_2}$$

The level 2 cluster heads receive the data from the level 1 cluster head nodes and fuse them. The expected energy per bit expended per level 2 cluster head node can be expressed by

$$\frac{E_{CH2}}{l} = \left(\frac{k_1}{k_2} - 1\right) E_{elect} + \frac{k_1}{k_2} E_F$$

where the expression $\left(\frac{k_1}{k_2} - 1\right)$ and $\frac{k_1}{k_2}$ can be explained by observing that K_1 is the equivalent to N for basic equation and K_2 is equivalent to the k.

By using these equations we can compute the optimum no. of cluster heads for each level. We can also get the general equation for z-level network. We remove the most complicated equation used for calculating the optimum no. of cluster heads for each level. There are some other assumptions also made but they can be proved as proved in HEED [4]. So we have not shown those assumptions here.

V. Simulation and Result

In the simulation process, we take care of our network model parameters as well as constraints defined in algorithm designed for two-tier architecture. Like HEED, we assume that 100 nodes are uniformly distributed. But we make our clustering process limited to the network of size 100×100.

The simulation parameters taken for our work are:

TABLE I: Simulation Parameter

Parameter	Value
Network grid	From (0,0) to (100,100)
Sink	At (50,50)
Threshold distance(□$_0$)	75 m
Cluster radius	25 m
E_{elect}	50 nJ/bit
ε_{fs}	10 pJ/bit/□^{2}
ε_{mp}	0.0013 pJ/bit/□^{4}
E_{fusion}	5 nJ/bit/signal
Data packet size	16 bytes
Packet header size	34 bytes
Simulation time per run	8000 seconds
Network Operation time	40 seconds
Initial energy	2 J/battery

By I it is clear that we take most generalized assumption so that by simulation result, we can easily show the gain of our proposed protocol. We compare the network life time of our protocol with HEED-AMRP. Since HEED is already superior to another clustering processes so we didn't consider those protocols for comparison. We take the various no. of nodes(25-100) deployed them and then find out the network life time. The network life time is considered as two types:

i. When first node dies

ii. Until the last node dies.

We take data for various nodes deployed in the network and generate graph for those outputs. For getting better result, we take average of various simulation results.

A node is considered "dead" if it has lost 99.9% of its initial energy. For our protocol, we used the optimal no. of cluster heads by using mathematical equation so this provide better result aggregation in comparison to HEED approach. Initially when they have been have simulated for 25 nodes there was not much significant gain in the avg. energy consumption of the nodes as shown in Fig. 4 and Fig. 5. There was about 3.75 percent gain in the energy for 25 nodes as shown in FIG. 5.3 but as the number of nodes increases, the gain in the percentage of avg. energy consumption in DMEC increases significantly over HEED i.e., up to 15.9 percent less energy is consumed per node in DMEC than HEED. The simulation results shows that DMEC performs much better than HEED for large number of nodes (n>50).

The reason behind better performance of DMEC over HEED is use of multi-tier architecture. As the energy consumed depends on the square of the distance covered by transmission, hence higher the transmission level more the energy consumed. So if we split the distance D into two parts D_1 and D_2 than $D_1^2 + D_2^2 < (D_1+D_2)^2$. Hence $D_1^2 + D_2^2 < D^2$ so by dividing the transmission in two parts we are effectively saving the consumption of energy.

Secondly in the 2-tier architecture as there are less number of cluster heads for the highest level so the number of nodes transmitting at highest power are less in DMEC as compared to HEED. And as these cluster heads are changed after every network operation time, the energy dissipation among nodes is averaged. Hence overall consumption of energy per node in DMEC becomes less than HEED.

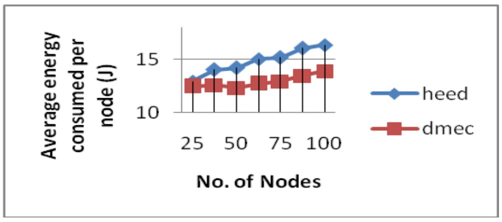

Fig. 5. Average energy consumption per node.

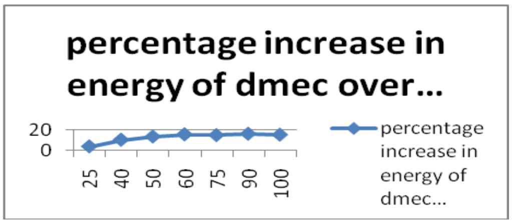

Fig. 6. Percentage increase in the residual energy in DMEC as compared to HEED

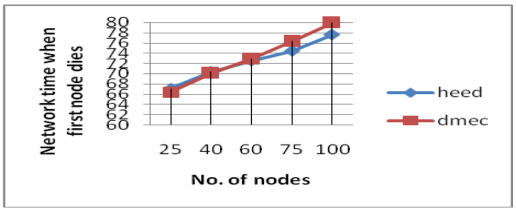

Fig. 7. Network lifetime (When first node dies)

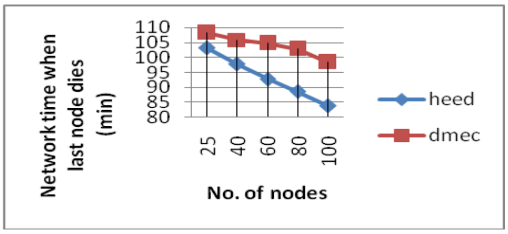

Fig. 8. Network lifetime (when last node dies)

As shown in fig 7 the network lifetime when the last node dies is greater for DMEC than HEED the any number of nodes. The difference in the lifetime of both algorithms increases as the number nodes increases. Network lifetime when the first node dies is less for DMEC than HEED for small number of nodes as shown in Fig. 6 i.e., DMEC underperforms for small number of nodes but with an increase in the number of nodes, the lifetime for DMEC increases than HEED.

As we have already explained, that the average Power consumption of nodes is less in DMEC therefore there is increase in network lifetime of DMEC for high number of nodes As we see in Fig 6, for smaller number of nodes HEED is performing better than DMEC, it is due to energy consumed in clustering overhead as there are not enough nodes to nullify out this overhead by averaging among themselves. While with higher number of nodes, this clustering overhead becomes negligible in comparison to the total dissipation of energy in all nodes.

VI. Conclusions and Future Work

We proposed the two layer architecture for sensor network and developed protocol for it. Using this protocol we get efficient gain over latest and well – established protocol in clustered sensor network type. Energy consumption per node, network life time (when first node dies and when last node dies), both show sufficient improvement in comparison to earlier algorithm HEED. We take single hope architecture for communication for our simulation work. By simulation results, it is clear that by multi – tier deployment of clustering process decreases the energy consumption per node and increase the network life. This work can be extended for muti-hoped network. Instead of fixed nodes these nodes can be mobile

References

[1] BabakNikmard and Salman Taherizadeh, "Using mobile agent in clustering method for energy consumption in wireless sensor network," *International Conference on Computer and Communication Technology* (ICCCT), pp.153-158, 2010.

[2] L. Robinson, "Japan's new mobile broadcast company: Multimedia for cars, trains, and handhelds." In *Advances Imaging*, pp 18-22, July 1998.

[3] J. Agre and L. Clare, "An integrated architecture for cooperative sensing networks. computer," vol 33, No. 5, pp106-108, May 2000

[4] Ossama Younis and Sonia Fahmy, HEED: A hybrid energy efficient, distributed clustering apparoach for Ad-hoc sensor networks, *IEEE Transactions on Mobile Computing*, Oct.-Dec. 2004, Volume: 3, Issue: 4, p.p.366 - 379.

[5] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "An application-specific protocol architecture for wireless micro sensor networks," *IEEE Transactions on Wireless Communications*, vol. 1, no. 4, pp. 660–670, October 2002.

[6] V. Loscri', S. Marano, and G. Morabito, "A two-levels hierarchy for low-energy adaptative clustering hierarchy (TL-LEACH).". proceedings VTC2005," Dallas (USA), pp. 1809-1813, Sept, 2005

[7] EECS: An Energy E±cient Clustering Scheme in Wireless Sensor Networks Mao Ye1, Chengfa Li1, Guihai Chen1 and Jie Wu2 1National Laboratory of Novel Software Technology, Nanjing University, China 2Department of Computer Science and Engineering, Florida Atlantic University, USA

[8] John A. Stankovic, Tarek Abdelzaher, Chenyang Lu, Lui Sha, and Jennifer Hou, "Real-time communication and coordination in embedded sensor networks," *Proceedings of the IEEE*, vol. 91, no. 7, 2003.

[9] Volkan Rodoplu and Teresa H. Meng, "Minimum energy mobile wireless networks," *IEEE J. Selected Areas in Communications*, vol. 17(8), 1999.

[10] Suresh Singh, Mike Woo, and C. S. Raghavendra, "Power-aware routing in mobile ad hoc networks," in *Proceedings of the 4th annual ACM/IEEE international conference on Mobile computing and networking*, 1998

[11] Sheetalkumar Doshi, Shweta Bhandare, and Timothy X Brown, "An on-demand minimum energy routing protocol for a wireless ad hoc network," *SIGMOBILE Mob. Comput.Commun. Rev.*, vol. 6, no. 3, pp. 50–66, 2002.

[12] Sheetalkumar Doshi and Timothy X Brown, "Minimum energy routing schemes for a wireless ad hoc network," in *INFOCOM*, 2002.

[13] Jae-Hwan Chang and Leandros Tassiulas, "Energy conserving routing in wireless ad hoc networks," in *INFOCOM*, 2000.

[14] J. B. Baek, G. de Vecianna and X. Su, "Minimimizing energy consumption in large-scale sensor networks through distributed data compression and hierarchical aggregation," *IEEE Journal On selected Areas in Communications*, (22), 6, August 2004, 1130-1140.

[15] S. Bandyopadhyay and E. Coyle, "An energy-efficient hierarchical clustering algorithm for wireless sensor networks," *Proceedings of IEEE INFOCOM*, April 2003.

[16] W. R. Heinzelman, A. Chandrakasan and H. Balakrishnan, "An application-specific protocol architecture for wireless microsensor networks," *IEEE Transactions on Wireless Communications*, vol. 1, no. 4, October 2002, 660-670.

[17] F. Ye, H. Luo, J. Chung, S. Lu, and L. Zhang, "A two-tier data dissemination protocol for large-scale wireless sensor networks," in *Proceedings of the ACM/IEEE International Conference on Mobile Computing and Networking (MOBICOM)*, Atlanta, Georgia, September 2002

[18] S. Gou, T. He, M. Mokbel, J. Stankovic, and T. Abdelzaher, on accurate and efficient statistical counting in sensor based surveillance systems, IEEE MASS, acceptance rate 13%, best paper award, over 250 submitted, Sept. 2008.