Performance Evolution of EACP Protocol for System Optimization in Heterogeneous Sensor Network

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Abstract - Sensor network is an important area for the research in last few years. Much of work is deal with homogeneous sensor network but in practically heterogeneous sensor network play a vital role in several applications. In sensor network energy efficiency is always a challenge, there are many protocols are developed to increase the lifetime of the system. Energy Aware Clustering Protocol for heterogeneous sensor network was developed to increase the lifetime of system as well effectively reduce the delay in packet transmission. In this paper we evaluate the performance of EACP protocol in respect to lifetime and energy deception. Using simulation compare the result of EACP protocol with Stable Election Protocol and Cluster Based Routing Protocol for wireless sensor network.

Keywords - *Heterogeneous Sensor Network, Wireless Sensor Network, Energy Efficient Protocol*

1. Introduction

The phenomenal advances in wireless technologies and significant growth of wireless network services make wireless communication to send the information across many domains. Wireless communications play important role in distributed sensor systems [1]. Wireless Sensor Network is consisting of low cost, low power tiny sensing devices that sensing an event from the physical object or process. Sensor network having powerful interface between physical world and computing world; through this there are large number of applications are developed; home automation, disaster management, building monitoring, healthcare, precision agriculture, military surveillance.

In wireless sensor network energy optimization is a key issue which normally depends on finite energy sources. Batteries are used as finite energy resources due to them are in small sizes and easily deploy in harsh environment. Since these batteries are normally not chargeable or not replaceable [2]; these small energy is the only power supply to the sensor node and play an important role in determining the lifetime of the network. Most of the research work primarily focuses on energy consumption and system lifetime of the network. Most of the protocols designed for wireless sensor network assume that the sensors having the same capabilities in terms of energy, storage, processing, and communication capabilities. Such type of wireless sensor network called homogeneous wireless sensor network. If such type of network having same energy consumption rate then same lifetime for all sensors. The assumption of homogeneous sensors may not be practical because even if the sensors use the identical hardware and environmental condition it may happened that they having same communication sensing model [3,4].

Another problem with homogeneous sensors that practically sensing application required heterogeneous sensor in order to enhance the reliability and extended the network lifetime of the system. Heterogeneous means different in some aspects like energy, link or computational capabilities. In home sensor networks is the application of Heterogeneous wireless sensor network were some sensor are fixed in position and some are moveable equipped with different batteries. Heterogeneity provides numerous advantages over the homogeneity i.e. it improves the network life time, improving the reliability of data transmission and decreasing the latency of data transportation.

In this paper we analyze the performance. of Energy Aware Clustering protocol which is an energy efficient probabilistic clustering protocol for heterogeneous sensor network.

2. Related Work

W. R. Heinzelman [5] proposed clustering based hierarchical protocol , Low Energy Adaptive clustering

Hierarchy Protocol (LEACH) ; it worked only on homogeneous nodes and the algorithm designed in such a way that every node having chance to become cluster head. The whole working is divided in to two phase Setup phase and Steady Phase. In setup phase on the basis of thresh-hold value the node become cluster head. Cluster broadcast advertising message to member nodes. In the steady phase nodes are communicated to cluster head on the basis of TDMA scheme. The paper assumes all the nodes begin with same energy – this assumption may not be realistic and selecting cluster heads is favourable in the beginning but unfavourable in later rounds.

J.H Aylor [6] proposed Resource Oriented Protocol for system lifetime Optimization for Heterogeneous Sensor Networks , The protocol is primarily divides into two parts; the first part topology formation all sensor reports there characteristics to local cluster head and this cluster head aggregate these characteristics and reports to powerful sensors. The second part decision phase largest resource capacity nodes will negotiate with their peers to calculate an optimal topology of the network. ROP cannot always produce good result in longer system lifetime especially in heterogeneous networks. Instead it balances the resources among the sensor network and saving the energy and processing time which helpful in increasing overall system lifetime.

Ossama Younis and Sonia Fahmy [7] proposed Hierarchical, Hybrid Energy Efficient Distributed protocol is a probabilistic protocol which is not emphasizing on node homogeneity. It works on initial energy of the node. HEED periodically selects cluster heads according to residual energy in them and second parameter i.e. node degree as their weight for selecting cluster heads. HEED achieved to prolong the lifetime by distributing energy construction, minimizing control overhead and creating a well distributing cluster head.

Dilip Kumara, and R.B. Patel [8] proposed Energy efficient heterogeneous clustered scheme for wireless sensor networks based on weighted election probabilities. According to proposed scheme each node become a cluster head according to the residual energy in each node. Cluster head send aggreegateed data to Base Station.One of the popular protocol Stable election Protocol [9] based on weighted election probabilities for Heterogeneous Sensor Network proposed by G. Smaragdakis and A. Bestavros ; it works similarly as LEACH the only difference is some nodes are more powerful than other nodes. Cluster Based Routing Protocol is the one of the popular protocol for cluster based communication.

3. Energy Aware Clustering Protocol

Aware Clustering Protocol (EACP) worked on heterogeneous sensor nodes [10], it focuses on only energy heterogeneity rest of the link and computational heterogeneity is same for all nodes. In such types of heterogeneous network; nodes are powered by different energy resources i.e. some nodes may be powered by AA battery or AAA battery and some nodes are powered by mains. This type of network is useful for monitoring and automation applications in home like environments and industrial security Energy applications.

1. **Reporting & Cluster Head selection** : In this phase all the nodes in network send their residual energy to the Base Station (BS) using multi-hop communication ; BS sort these energy in ascending order and elect 5% nodes as cluster head. Finally BS sends the message to elected nodes "You are the cluster head.

2. **Cluster Formation :** After selecting the cluster head; CH send token to all nodes within its rage " I am the Cluster Head" , on the basis of the strength of signal node will decide whether they are part of that cluster head or not. As shown in figure 1, accordingly node will send their residual energy as well as acknowledgment to the Cluster Head

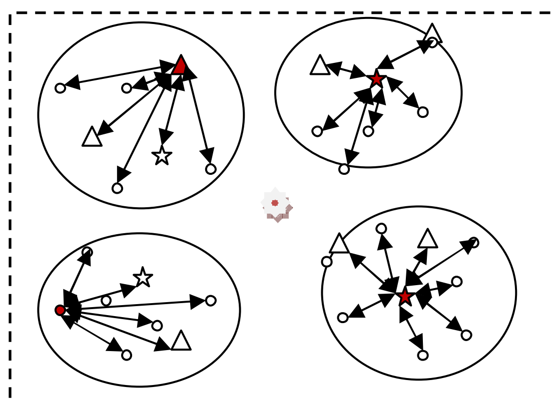

Figure 1. Cluster Formation

3. **Secondary Cluster Head Election:** After forming cluster for reducing delay and increasing the lifetime of the network; Cluster head elect a secondary cluster head by sorting the residual energy of cluster's nodes find highest residual energy node and send the message "You are the Secondary Cluster Head". This S.CH active when cluster head having a long waiting queue or when residual energy of cluster head less than 50%. When energy of Cluster head goes below 50%, the secondary cluster head

become cluster head and this process continuously work until it find the cluster head that is powered by mains. This technique is useful for load balancing and reducing the delay.

4. **Inter Cluster Communication**: In this phase cluster head aggregate the data and using Open Shortest Path First method packets send to base station. OSPF protocol also called link state protocol; it is easy to implement and produce the effective result through simulation we evaluate the performance of EACP protocol.

4. Quantitative Analysis

In this section using first order radio communication model, quantitative analyze the EACP protocol and find the energy dissipation , time for message transfer ,optimal number of cluster and system lifetime are analytically determined.

$$E_{T_{ij}} = E_{elc} \cdot p + E_{amp} \cdot n \cdot \left(d_{ij}\right)^2 \quad (1)$$

$$E_{T\,ij} = E_{elc} \cdot p + E_{amp} \cdot n \cdot \left(d_{ij}\right)^4 \quad (2)$$

$$E_{R_{ij}} = E_{elc} \cdot p \quad (3)$$

EACP protocol used the following parameter the energy consumption and finding optimal number of cluster in the network.

Energy used by amplifier to transmit for shorter distance $_s$

- Energy used by amplifier to transmit for shorter distance - e_l
- Energy used in electronics circuit to transmit or receive the signal **- E_{tr}**
- Energy consumed for beam forming - E_b

In the clustered network, the cluster head is responsible for relaying the packets transmitted from the entire sensor within the cluster. In radio communication model energy loss for fusing one bit data is constant. The mathematical equation for transmission and receiving of p bit packet from node i to j calculated as in equation 1, 2 and 3.

4.1 Reporting and Election Phase

For a sensor network of n nodes, the optimal number of clusters is given as k. All nodes are assumed to be at the different 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 selects a given number of cluster heads on the basis of energy level. For each cluster, the corresponding cluster head chooses a set of m associates, based on signal analysis.

For uniformly distributed clusters, each cluster contains $\frac{n}{k}$ nodes. Using Equation 2 and Equation 3, the energy consumed by a cluster head is estimated as follows:

$$E_{CH-elec} = \left\{ \{lE_e + l_{\epsilon s} d^2\} + \left\{ \left(\frac{n}{k} - 1\right) \right\} l(E_e + E_{BF}) \right\} \quad (4)$$

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 $(\frac{n}{k} - 1)$ messages from the sensor nodes of the same cluster.

Energy consumed by non-cluster head sensor nodes is estimated as follows:

$$E_{non-CH-elec} = \{klE_e + klE_{BF} + lE_e + l_{\epsilon s} d^2\} \quad (5)$$

The energy consumed to receive message from k cluster heads is shown in first part of equation 5 and second part of equation represent the energy consumed to transmit the decision to respective cluster head.

4.2 Optimum Number of Clusters

The optimal number of cluster in wireless sensor network depends on the position of base station in the network. In EACP protocol we assume that base-station is located at the center of square region. The optimal number of cluster k_{opt} determined by

$$k_{opt} = \sqrt{\frac{n}{2\pi}} \sqrt{\frac{e_s}{\epsilon_l (d_{ij})^4 - (2m-1)E_e - mE_B}} M \quad (6)$$

Where n is the number of node in the network and M is the area of network. Kopt is valuable variable to manage the energy consumption of the network. If in wireless sensor network the construction of cluster is not constructed in optimized way the energy is consumed exponentially.

4.3 Election of Secondary Cluster Head

For load balancing in the cluster, secondary cluster head is elected by CH. Secondary cluster head is selected on two parameters

- Energy of residual energy of nodes
- Distance from cluster head

Cluster head is selected any node as a secondary cluster head by formula 7 which would have the least F.

$$F_i = \alpha \times \frac{E_{total}}{E_{remind-1}} + \beta \times d_{toCH} \quad (7)$$

Were E_{total}l is initial energy of each node and Erenind-1 is the energy of each node in this time and d_{toCH} is the distance of each node to CH. The initial part of this formula would cause selecting node with the most energy in cluster and the second part of that one would specify a node with the least distance to CH, two coefficients *α*, *β* have been used to increase or de-crease the significance of each part which is the energy significance or distance to cluster head.

During data transfer phase, the node transmit message to their cluster head and cluster head transmit aggregated message to a distant base station. The minimum energy required for the transmission of the packet so that it is successfully received by the receiver can be calculated by receiving cluster head as [11]

$$E_t = E_{tx} + E_r - E_{rx} + M \quad (8)$$

Where E_r is the minimum power level required for correct packet reception and *M* is a power margin introduced to take into account channel and interference power level fluctuations, i.e. to make the transmission more reliable in view of the fact that the channel is not symmetric. We assumed that *M* is the same for each terminal and its value should be properly set as a function of network density, terminal speed and channel conditions.

EODSR implements route selection metric. The new route selection metric needs the link cost computation. The link cost computation includes the parameters those are used to minimize the energy per packet and balance the load. The link and route cost of EODSR is derived from [11]. The load is distributed based on the residual battery energy and queue length. Hence, the link cost is calculated as

$$L_{Ci} = \omega\left(\frac{E_t}{E_{ri}} + \frac{ERX}{E_{r(i+1)}}\right) + \delta\, log\left(1 + QL_{pi}\right) \quad (9)$$

Were E_t is the minimum transmit power between i(sender) and i+1(receiver) , L_{cp} is the the link cost between node i and i+1 L_{ci}, Eri is residual battery energy of node i, $E_{r(i+1)}$ is residual battery energy of node i+1, *PRX* is a power to receive packet, QL_{pi} is queue length of node i, and ω and δ are weight factors for energy and load aware cost computation respectively. Current queue length is important parameter to determine the delay of the link and predict energy consumption of the sender node. If there are more packets in the queues, the sender node will spent more energy to send queued packets than the node with fewer packets in the queues. A large link cost usually indicates that the link has less remaining energy, more energy consumption due to transmitting and receiving, and more packets those are paid out the energy of the sender node.

$$L_{\prod} = Max\{L_{Ci}\} \quad (10)$$

Where $L_{\prod}$ is the route cost of α. The link with large link cost on the route is considered as the cost of the route. The worst link along the route determines the cost of the route. We need to modify the RREQ packet header to include the route cost. This value is attached in the route request packet. This protocol favors the path with minimum value of the route cost. The objective functions as follows:

$$R = Min\left(L_{\prod}\right) \quad (11)$$

In EODSR, the nodes calculate the delay time when they receive the first RREQs. Receiving nodes record these RREQs ids (which include the packet source node id and RREQ sequence number) and delay time δ in EOrequest_table and rebroadcast them immediately. The waiting time γ is calculated for each first arrived RREQ as follow.

$$\gamma = \vartheta \frac{E_t}{E_{rp}} \quad (12)$$

4.4 Packet Delivery Fraction

This is the ratio of total number of packets successfully received by the destination nodes to the number of packets sent by the source nodes. Packet delivery fraction is an important metric as it describes the loss rate. Thus packet delivery fraction in turn reflects the maximum throughput that the network can support. For all our simulations we have kept the number of data packets sent out as constant, so the number of packets successfully received at their destinations will give us a comparison as to how efficient the underlying routing algorithm is under similar traffic load. Packets may not be delivered to the destination mainly because of one of the following reasons: packet collisions in 802.11 layer, network partitions, routing loop and interface queue drop.

$$PDF = \frac{Number\ of\ packet\ Received\ by\ Destination}{Number\ of\ packets\ Sent\ by\ Source} \quad (23)$$

A high value of PDF indicates that most of the packets are being delivered to the higher layers and is a positive sign of the protocol performance.

4.5 Energy Consumption per Successful Data Delivery

It is denoted by ECSDD. It is the ratio of total network energy consumption to the number of data packets successfully delivered to the sink. The network energy consumption includes all the energy consumptions except MAC layer controls.

$$ECSDD = \frac{\sum_{p=1}^{N}(E_{ip} - E_{rp})}{Total\ Number\ of\ Packets\ Received} \quad (24)$$

Where E_{iK} is initial energy of node k E_{rK} is remain energy level of node k at the end of simulation N is the number of nodes in the network. A less value of ECSDD indicates that most of that packets being delivered with less energy and is an achievement sign of protocol on energy efficiency.

4.6 Life Time of Network

This is one of important metrics to evaluate the energy efficiency of the protocols with respect to network partition. In wireless sensor networks, especially in those with densely distributed nodes, the death of the first node seldom leads to the total failure of the network. With number of dead nodes increasing, the network is partitioned. Even with partitioning, end-to-end transmissions may still be feasible in each partition argue that network is alive if there exists at least one pair of adjacent nodes working, since they could transmit to each other and keep the network alive.

Taking into consideration the statistical mean effect and the large number of repeated experiments under equivalent scenarios, we adopt the firt definition for analysis of this thesis.

The lifetime of a sensor is determined by its energy capacity, its radio radius, the number of its children and their packet arrival rates. If sensor having N_i child nodes. As all N_i child node can send independent packet stream with Poisson distribution we denote λ_{io} as packets generated by node i. The packet arrival rate for sensor i is

$$\lambda = \lambda_{io} + \sum \lambda k \qquad k=1 \text{ to } n \quad (25)$$

$$\lambda = \lambda io + \sum \lambda k \quad (26)$$

The life time for node Ti for sensor Ti is calculated

$$T_i = \frac{E_i}{P_i} = c \cdot \frac{E_i}{{R_i}^n} \cdot \frac{1}{\left(\lambda_{io} + \sum_{k=1}^{N_i} \lambda_k\right) \cdot t} \quad (27)$$

The lifetime of network can be calculated as

$$Ts = \min\{\, Ti \,, i \in \Omega \,\} \quad (28)$$

Where Ω is the set of nodes in the network. Ts have an upper bound.

5. Simulation Result

To evaluate EACP it was simulated using version NS-2.34. The network was set up with sink node and hundred sensor node with different energy resources. EACP is evaluated against three other heterogeneous sensor protocols in order to determine its efficiency. The protocol chosen were Stable Election Protocol and Hybrid Energy Efficient Protocol. SEP was chosen due to the fact that it the very popular protocol in the literature and many protocols are based on it. HEED is chosen since it is based on residual energy and algorithm is terminated in finite iteration.

In simulation we take 100 mobile nodes in our scenario which are moving (with 10 ms Mobility speed) in an area of 1000mx1000m. We used Network Simulator-2.35 simulator for the analytic thinking. The IEEE 802.11 for wireless network is applied as the MAC layer protocol with 2 Mbps data rate. For simulation we used UDP (User Datagram Protocol) for connection and over it data traffic of Constant bit rate (CBR) is employed among source and destination nodes. We take 512 packet size and 1200 m/s simulation times. We give 50 joule energy for each node. The random waypoint model of mobility model is used in a rectangular field. The multiple CBR application is applied over different source and destination nodes. We define pause time 100ms.

Simulation of protocol started with broadcasted at the start of the simulation. Every node in the network then sent a new message every 100 sec. For SEP 5% of nodes have higher energy and rest of nodes have same energy but less then higher once. All the nodes are homogeneous in terms of processing and memory.

5.1 Test Case

Test 1: Optimal no of Cluster head for EACP

Test 2: Best Case, when no of cluster required by network equals to the number nodes elected as cluster head after reporting phase having main supply

Test 3: Normal Case, when some nodes having main supply and AAA or AA battery used.

Test 4: Worst Case, nodes equipped with button battery and having main supply.

Test 5: Packet Delivery Fraction of EACP

Test 6: Energy Consumption per Successful Data Delivery

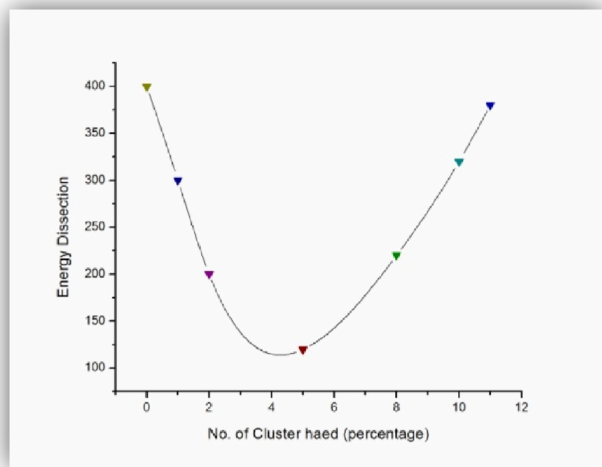

Figure 2. Energy Dissection and No of cluster Head

As shown in figure 2 as number of cluster increases in the network; energy dissection f the network goes down up to optimal value of number of cluster head. Up to optimal number of cluster head network lifetime of the network increased after that it reduces due to extra overhead of communication is increased.

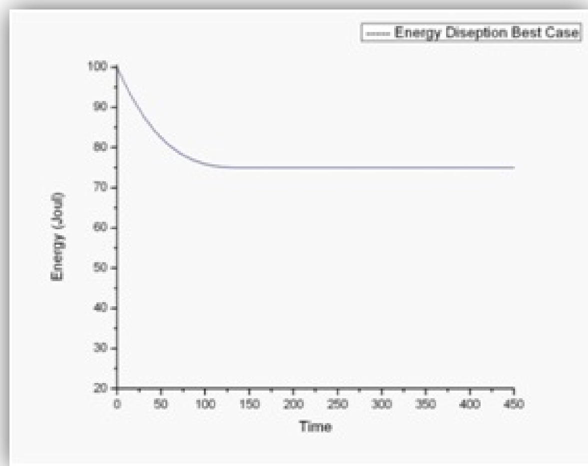

Figure 3. Energy Deceptions in Best Case

The result of Test2 (Figure 3) shows that the EACP effectively optimize the energy in the standard case after 66 Sec. network is stable the no energy lost at cluster head due to the supplied by mains. In this case only member of cluster will only die.

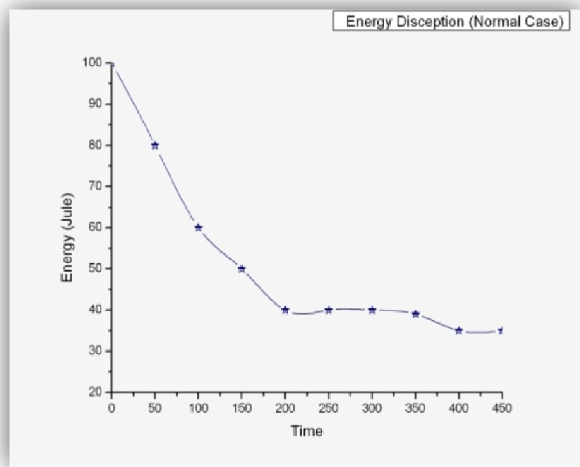

Figure 4. Energy Deception in Normal Case

In test 3 (Figure 4) 50 % of nodes who have main supply become cluster head after the reporting phase the energy lost is going on up to 13 minutes energy after that EACP found the rest of 50 % nodes that are supplied by mains. After 13 minutes no energy lost found at cluster head.

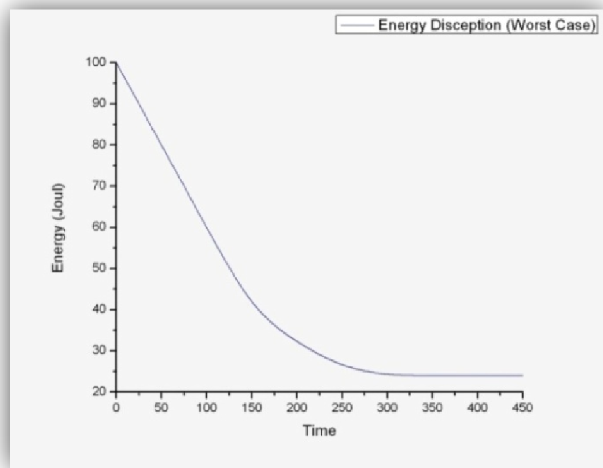

Figure 5. Energy Deceptions in Worst Case

In test 4 (Figure 5) nodes having main supply but equipped with button battery, we found in the result that the energy lost is going on at cluster head up 200 Sec. after that EACP found those nodes having main supply and become the cluster head. This is worst case in which EACP not utilize the energy.

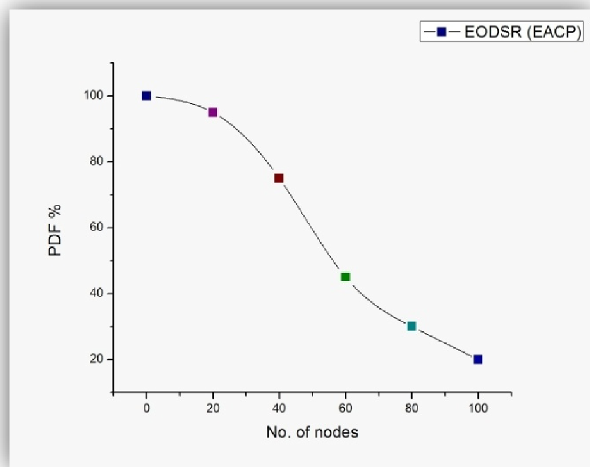

Figure 6. PDF Vs Number of Nodes

The objective of PDF (Test 5) metric is to analyze one of the network performance metrics called PDF. The enhanced protocol provides better performance. PDF of EODSR is shown in the figures 6 EODSR provides considerable improvement of PDF. This indicates that EODSR is more resistive in stressful. This is due to the following reasons. The first is that it uses transmit power control. The transmit power control reduce the collision rate of the packets. Every data packet must be transmitted with appropriate power level. The second, minimum transmit power and residual battery energy level based load distribution secure the nodes from early die due to their energy draw off. Hence, the packet drop rate is less due to the network partition. The third, EODSR never reply the cached routes immediately. Instead of directly reply the cached route, EEDSR has to unicaste the cached route to destination of the RREQ. This reduces the opportunity of utilization of the staled out routes which add to the packet drop rates. EODSR also outperforms by providing sustainable PDFs all over different stresses for all scenarios

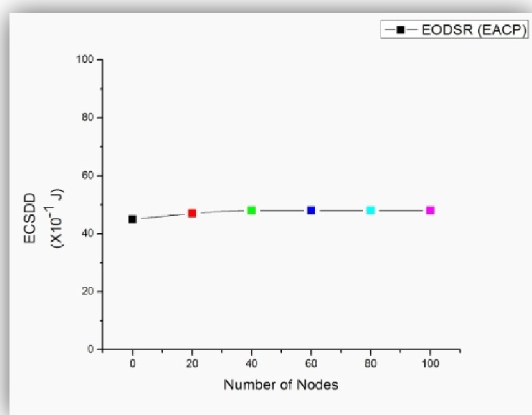

Figure 7. ECSDD Vs Number of Nodes

In Test 6 Energy Consumption per Successful Data Delivery is one of the metrics that used to analyze the energy consumption. This metric addresses mainly the end-to-end energy consumptions to deliver the data packets. The figure 7 shows ECSDD of EODSR. The ECSDD results show that EEDSR consumes less energy to deliver the packet. EEDSR saves 25.97%-70.5% of the energy. This is due to number of improvements applied in EODSR. The first is, implementation of the transmit power control. The transmit power control assigns the minimum transmit power to deliver the packet to the next hop. This mechanism saves unnecessary energy consumption due to maximum power level of transmission. Besides, transmit power control reduces the collision rates which leads to number of retransmissions and routing overhead to deliver the packet to next hop. Retransmissions of the packet and routing overhead increase the energy consumption. The second is implementation of energy aware route selection. The link cost computation comprises the hop-to-hop transmission power. Hence, EEDSR selects the route which takes less power to transmit the packets from source to destination. The third is unicast the cached route to destination. This avoids reply of staled routes which cause retransmissions to deliver a packet

6. Conclusion

EACP provides better lifetime for nodes compared to SEP and CBRP. In addition to reducing energy dissipation, EACP successfully distributes energy-usage among the nodes in the network such that the nodes die randomly and at essentially the same rate. We have used only residual energy for head selection procedure. Presently, EACP consumes higher computational power due to reporting and cluster head selection. The second limitation is that the performances have been compared with standard SEP and CBRP algorithm. Performance of other sensor network head selection like PEGASIS, EEHC, TEEN etc. have not been considered. We only considered energy heterogeneity in future; we take computation heterogeneity as well as link heterogeneity and test the result how it improves the lifetime of system.

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