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PERFORMANCE ANALYSIS OF ENERGY EFFICIENT CLUSTERING SCHEME IN HIERARCHICAL WIRELESS SENSOR NETWORKS

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ABSTRACT

With the advancement in wireless sensor networks (WSNs) sensors are gaining significance in the physical world. WSNs gained the attention of researchers in many challenging aspects. The most important challenge in these networks is energy conservation. One of the best solution in making WSNs energy-efficient is to cluster the networks. In clustering, the nodes are partitioned into some clusters and then some nodes, called cluster heads, are chosen to be the head of each cluster. In a clustered wireless sensor network, the regular nodes sense the field and send their sensed information to the cluster head, then, after gathering and collecting the data, the cluster head transmits them to the base station. Clustering the nodes in wireless sensor networks has many advantages, including scalability, energy efficiency and reducing routing delay. Some of the clustering objectives considered in this paper include fault tolerance, increased connectivity, data aggregation and collision avoidance. For simulation, the network simulator tool (NS2) is used. The performance of the proposed scheme has been shown in graphs for the metrics namely, energy consumption, delay and packet delivery ratio.

KEYWORDS: Wireless Sensor Networks, Flat Topology, Clustering methodology, Adaptive Distributed Topology Control algorithm (ADTCA), Gateway Nodes.

INTRODUCTION

Wireless sensor networks are web of sensor nodes. Each sensor nodes typically comprises of one or more sensing elements, a data processing unit, receiver/transmitter radio and a power source which is normally a battery. The sensed information is gathered, processed and then routed to the desired end user through an assigned sink point, referred as base station. WSNs finds its applications in military and civilian applications like environment monitoring, object tracking, bio-medical applications and gathering meteorological variables like temperature and pressure, disaster management and so on. The major advantage of WSNs is their ability to operate in unattended situations, where human life is infeasible. Given the vast area to be covered, the short life expectancy of the battery operated sensors and the possibility of nodes to be destroyed while deployments, huge population of sensor nodes are expected in most of the wireless sensor network applications. Researchers uncover hundreds or even a huge number of sensor nodes to be involved. These sensor nodes are energy constrained, thereby designing energy-aware algorithms becomes an important factor for increasing the lifetime of sensors.

Clustering

In order to support data aggregation, nodes can be partitioned into a number of small groups called clusters. This phenomenon of grouping sensor nodes into clusters is called clustering. Each cluster would have a leader, commonly referred to as cluster-head (CH) . A CH might be chosen by the sensor nodes in the cluster or pre-allocated by the network designer [1]. A CH may likewise be one of the sensors or a node that is generally richer in resources. The cluster membership may be fixed or variable. There are several advantages in clustering phenomenon. The basic advantage is that, it supports network scalability. It can localize the route setup within the cluster. Clustering can also maintain communication bandwidth. Additionally clustering can stabilize the network topology at the level of sensors. Clustering reduce energy consumption and prolong network lifetime by lessening number of nodes taking part in the transmission. It reduces routing delay $n > k$ implies it is more

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effective if the data is routed among k CHs rather than n nodes. A CH can schedule activities in the cluster so that the nodes can switch to the low-power sleep mode more often and reduce the rate of energy consumption. Moreover, a CH can aggregate the data gathered by the sensors in its cluster.

Clustering can be classified into centralized, distributed and hybrid clustering methodologies. Centralized clustering is the one in which, a centralized architecture is utilized as a part of the clustering process i.e. a fixed CH and the rest of the nodes in the cluster act as member nodes. Distributed clustering is one in which, there is no fixed central CH and this continuous changing from node to node based on some parameters, for example residual energy. Hybrid clustering is one which is formed as the resulting combination of both the above mentioned mechanisms. If a centralized architecture is used in a WSN and the central node fails, the whole network will collapse and hence there is no guarantee for reliability in centralized clustering mechanism. Hence the reliability of a WSN can be enhanced by using distributed architecture. Distributed architecture is used in WSNs for some particular reasons like sensor nodes prone to failure, better collection of data and give backup in case of failure of the central node. Likewise, nodes sensing and forwarding the redundant information can be minimized. They have to be self-organized, since there is no centralized body to allocate the resources.

LITERATURE SURVEY

In sensor networks, the sensor nodes deployed in harsh or unstructured environments are regularly controlled by irreplaceable batteries with a restricted amount of energy supply. Ideally we would like the sensor network to perform its functionality as long as possible. Optimal routing maximizes the network functionality by minimizing the total energy consumption and optimizing the network-wide load balance to sustain the lifetime of sensor networks have been an crucial task in sensor network implementation.

A variety of protocols have been proposed to enhance the life of WSN and for routing the right information to the base station. Employing clustering techniques in routing protocols can hierarchically organize the network topology and prolongs the lifetime of a wireless sensor network, and contributes to overall system scalability. Various protocols [2] like LEACH, HEED, PEGASIS, TEEN, and APTEEN are available to route the information from node to base station in WSN.

In the Low-Energy Adaptive Clustering Hierarchy (LEACH) uses a randomized periodical rotation of CHs to balance the energy load among the sensors. LEACH-C (Centralized) [3] utilizes a centralized controller to choose CHs. The fundamental drawbacks of this algorithm are nonautomatic CH choice and the prerequisite that the position of all sensors must be known. LEACH’s stochastic algorithm is extended in [4] with a deterministic CH choice. Simulation results prove that an increase of network lifetime can be attained compared with the original LEACH protocol. The Ad-hoc Network Design Algorithm (ANDA) [5] maximizes the network lifetime by finding the optimal cluster size and the optimal assignment of sensors to CHs but needs a priori knowledge of the number of CHs, number of sensors in the network, and the location of all sensors. The Weighted Clustering Algorithm (WCA) [6] considers the number of neighbors, transmission power, mobility, and battery usage in selecting clusters. It restricts the number of sensors in a cluster so that CHs can handle the load without degradation in performance. These clustering techniques depend on synchronous clocking for the exchange of information among sensors which typically restricts these algorithms to smaller networks [7]. In [8], the distributed topology control using the cooperative communication (DTCC) algorithm is proposed to give a connected network topology with minimal total energy consumption.

In order to provide reliable communication in wireless ad-hoc networks, maintaining network connectivity is essential. An implementation of the linked cluster architecture may consider the following tasks: cluster formation, cluster connectivity, and cluster reorganization. In order not to depend on a central controller, clustering is done by adaptive distributed control techniques via random waiting timers. To this end, the Adaptive Distributed Topology Control Algorithm (ADTCA) organizes clusters and links in three phases: (I) CH selection; (II) gateway selection, and (III) cluster reformation. In Phase I, CHs are chosen and cluster members are assigned. A decentralized algorithm [8] is used to form the network into clusters. Each sensor operates independently, monitoring communication among its neighbors. Depending on the number of neighbors and a randomized timer, every sensor either joins a nearby cluster, or else forms a new cluster with itself as CH. In Phase II, based on bidirectional message exchanges and the cluster architecture, sensors are chosen as gateways in a fully distributed way. Once the network topology is specified, maintenance of the linked cluster architecture becomes an issue. In Phase III, localized criterions governing cluster reformation are described and illustrated via simulations. This proposed self-configuration protocol is energy efficient, scalable, and may increase the lifetime of the network. Several aspects of this cluster-based topology control are studied.

THE ADAPTIVE DISTRIBUTED TOPOLOGY CONTROL ALGORITHM

This section describes a randomized distributed algorithm that forms clusters and reselects CHs effectively. The network setup is performed in three phases: "clustering", "data transmission", and "restructuring the clusters". The main assumptions on the network are that (a) the sensors are in fixed but unknown locations, (b) all connections between sensors are bidirectional, and (c) all sensors have the similar transmitting range.

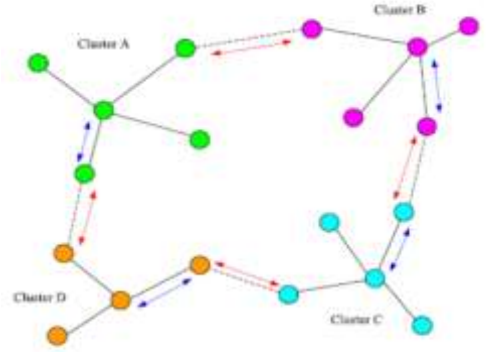

Fig-1: System Architecture

Phase I: Cluster Formation

When sensors are initially deployed, the ADTCA from [9] may be used to partition the sensors into clusters. The following subsections review the mechanisms of the ADTCA scheme for cluster formation.

Clusterhead Selection:

Every sensor sets an random waiting timer, broadcasts its presence via a "Hello" signal, and listens for its neighbor's "Hello". For initiating new clusters the sensors that hear many neighbors are great possibility, those with few neighbors should choose to wait. Based on each "new" Hello message received sensors update their neighbor information and decrease the random waiting time. This tells those sensors with many neighbors to become CHs. If a neighbor declares itself to be a CH, the sensor cancels its own timer and joins the neighbor's new cluster. If the timer expires, then the sensor declares itself to be a CH, a focal point of a new cluster. The sensors can coordinate themselves into sensible clusters, by adjusting randomized waiting timers, which can then be used as a reason for further communication and data processing. After applying the ADTCA, there are three various types of sensors: (1) the CHs (2) sensors with an assigned cluster ID (3) sensors without an assigned cluster ID, which will join any nearby cluster and become 2-hop sensors. Hence, the topology of the wireless sensor network is now represented by hierarchical collection of clusters.

Gateway Selection:

Observe that CH selection induces non-overlapping clusters. Likewise, to interconnect two neighboring non-overlapping clusters, one cluster member from each cluster must become a gateway. This subsection presents a method of choosing distributed gateways for neighboring non-overlapping clusters. As in CH determination, random waiting times and local information are applied to select gateways and further attain communication between clusters. The procedure for selecting gateways is summarized as follows. Let n_i indicate sensor n in cluster i and m_j indicate sensor m in cluster j. G_{ij} will indicate the gateway sensor that connects cluster i to cluster j. dn_im_j is the distance between sensors n_i and m_j, which could be estimated by received signal strength. The parameter ß controls the rate at which the timers increase or decrease in response to the reception of messages from nearby sensors. Note that in gateway selection, a CH might have the capacity to communicate with a nearby cluster directly. Along these, a larger counter (10ß) is assigned to the CH so as to be chosen as a gateway for this situation. Otherwise, each cluster member follows a regular control rate ß to increase the counter and reduce the waiting time.

As a result each cluster i assigns a single member to communicate with each nearby cluster j. The waiting timers help to see that the chosen member is one of the nearest members even though the topology of the system is

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unknown. If the clusters are too far apart (outside the range of communication R), no gateway sensors will be assigned.

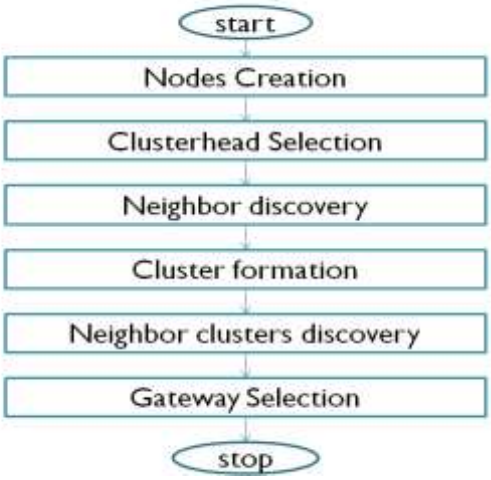

Fig-2: Cluster Formation

Phase II: Data transmission

During data transmission phase, the Intra-cluster communication and Inter-cluster communication takes place. The member nodes transmit information to their CHs, which is called Intra-cluster communication. The CHs communicate through gateway nodes to transmit information to the base station, which is known as Inter-cluster communication.

Phase III: Cluster Reformation

This subsection presents two methods of selecting a new CH for an existing cluster. If the energy E_i of CH i is less than a threshold level η then sensor i broadcasts a message to its cluster members to begin the reselection procedure. Only those sensors with energy larger than η are eligible. The motivation for forming subclusters is to provide a way to do multi-hop communication within a cluster, which might be required because sensors are no more than 2 hops away from the initial CH and sensors may be up to 4 hops away from the new CH. Hence, sensors in a cluster may be further classified as: (1) subcluster member, (2) subCH, or (3) CH. Subclusters and subCHs are generated by applying this distributed protocol to the cluster topology.

For real applications, it is possible that the CH may malfunction before broadcasting the reselection message. One solution is that if a certain amount of time has passed with no messages from the CH, then all sensors begin their timers and apply the algorithm. As a result, restructuring the cluster formation of the network may be required when the CH malfunctions or when none of the cluster members satisfy the energy constraint. In this case, it may necessary to re-initialize the network into new clusters to help balance the energy burden. Such reformation may also be useful in the event that the network topology changes or the sensors move.

ENERGY CONSUMPTION ANALYSIS

This section analyzes the energy consumption of the ADTCA when executing the three phases: CH selection, gateway selection, and cluster reorganization. The total power requirements include both the power required to transmit messages and the power required to receive or process messages.

The energy consumed in transmission depends on distance. The energy dissipated during transmission and reception using the following formulas:

Energy Consumption formula for sending a k-bit message to a distance ‘d’ is

$$E_{Tx}(k,d) = E_{Tx\text{-}elec}(k) + E_{Tx\text{-}amp}(k,d) \quad (1)$$

$$E_{Tx}(k,d) = E_{elec} * k + E_{amp} * k * d^2 \quad (2)$$

Energy Consumption formula for receiving a k-bit message is

$$E_{Rx}(k) = E_{Rx\text{-}elec}(k) \quad (3)$$

$$E_{Rx}(k) = E_{elec} * k \quad (4)$$

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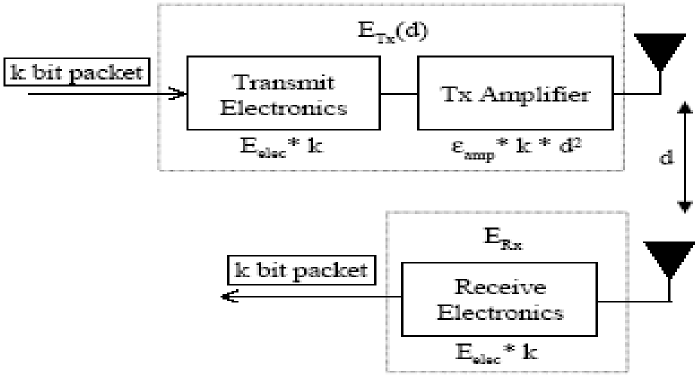

Fig -3: Energy Consumption Model for WSN

where E_{Tx} is the amount of energy consumed by each node, E_{Rx} is the amount of energy for receiving k bit packet, E_{elec} is the energy dissipated, E_{fs} is the free space propagation, E_{amp} is the multiple fading channel parameter, d is the transmission distance and k is message length and d_0 is the initial value of d where d_0 and d are calculated as:

$$d_0 = \frac{E_{fs}}{E_{amp}} \tag{5}$$

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{6}$$

where (x1, y1) and (x2, y2) are the coordinates of reference nodes.

Table1. Comparison of various parameters of existing and proposed algorithms

Parameters	**Existing Method** Energy Consumption(J)	**Implemented Method** Energy Consumption(J)
Create/Receive a Data message Create/Receive a Signal message	25.6µJ 3.2µJ	25.6µJ 3.2µJ
Send a Data message Send a Signal message	209.92µJ 26.24µJ	209.92µJ 26.24µJ
Number Of Nodes	24	24
Total Energy consumed	3.709mJ	1.059mJ

SIMULATION RESULTS

The performance of Adaptive Distributed Topology Control algorithm is evaluated through NS2 Network Simulator. A random network is deployed in an area 1500X500 m^2 is considered. Number of nodes is varied from 100-500. Initially the nodes are placed randomly in the specified area. The simulated traffic is CBR with TCP source and sink.

The simulation parameters for the environment are as shown in Table 1:

Table 2. Lists the simulation parameters used for network configuration

PARAMETERS	VALUES
Number of Nodes	100
Routing Protocol	AODV
Mac Protocol	802_11
Propagation Model	Two Ray Ground
Terrain Dimensions	1500 X 500
Packet Size	512bits

Performance metrics: The performance of Flat network is compared with Energy Efficient Hierarchical Clustering network. The performance is evaluated considering the following metrics.

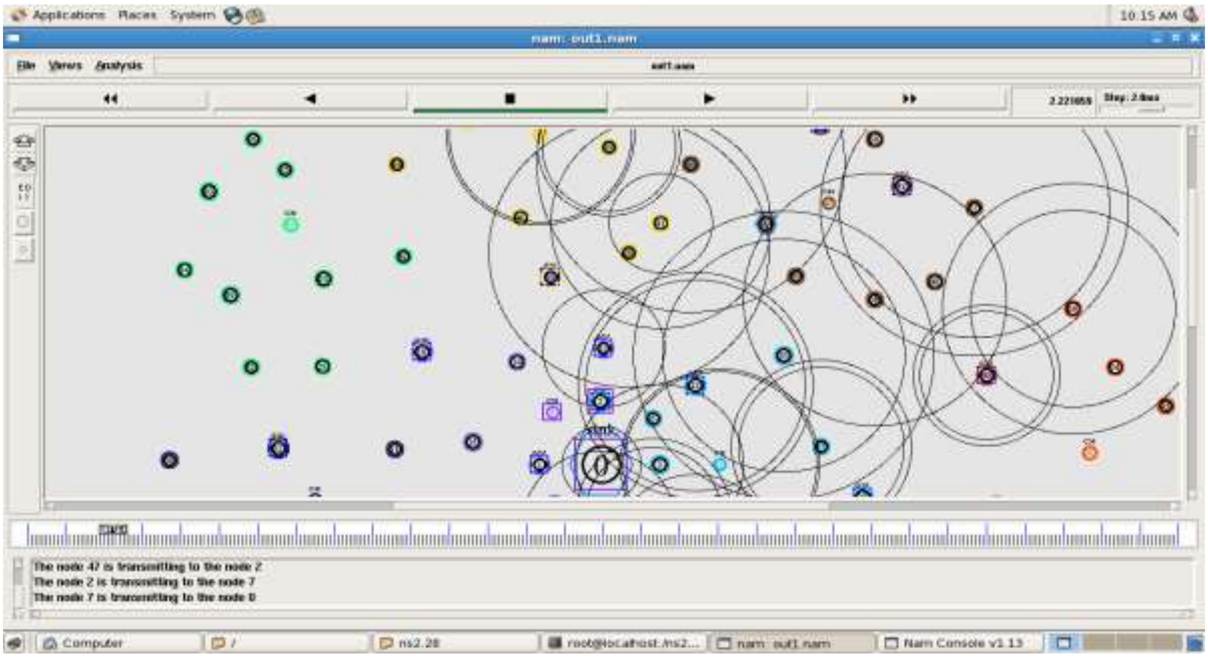

Fig -4: Simulation output of the two level clustering algorithm

Energy Consumption: It is the average energy consumption of all nodes in sending, receiving and forward operations.

Delay: The end-to-end delay is the average time taken by a data packet to arrive at the destination. It also includes the delay caused by route discovery process and the queue in data packet transmission. Only the data packets that successfully delivered to destination are counted.

$$\text{Average delay} = \frac{\sum(\text{arrive time} - \text{send time})}{\sum \text{Number of connections}} \quad (7)$$

The lower value of end to end delay means the better performance of the algorithm. The end to end delay over a path is the summation of delays experienced by all the nodes along the path. In order to compute this metric over a wireless channel, each node needs to monitor the number of packets buffered at the network layer waiting for MAC layer service , as well as measuring the transmission failure probability at the MAC layer. The transmission failure probability is the probability that a MAC layer transmission fails due to either collisions or bad channel quality. Figure 6 shows the end to end delay performance for the 100 nodes network.

Packet Delivery Ratio: It is the ratio of the number of packets received successfully and the total number of packets transmitted.

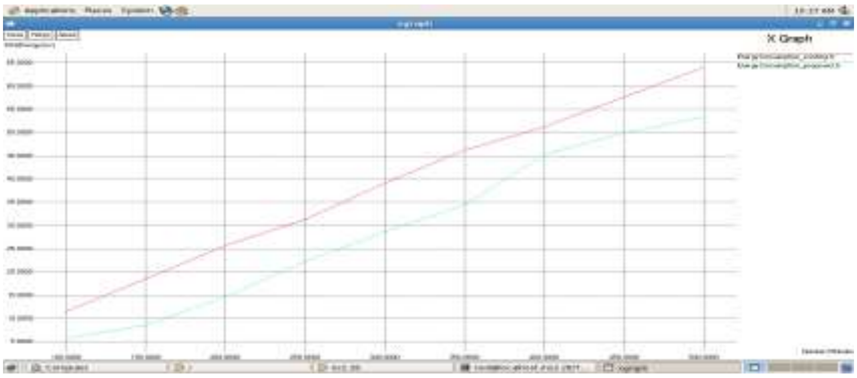

Fig -5: Number of Nodes Vs Energy

From the figure 5, it can be seen that the Energy consumption of the proposed hierarchical network is less when compared with flat network.

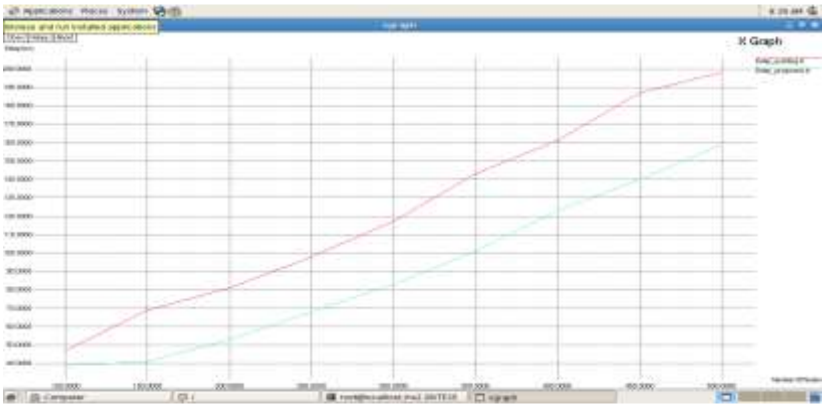

Fig -6: Number of Nodes Vs Delay

Figure 6 shows the results of end-to-end delay when the number of nodes is increased. From the results, we can see that hierarchical network has less delay when compared with flat network.

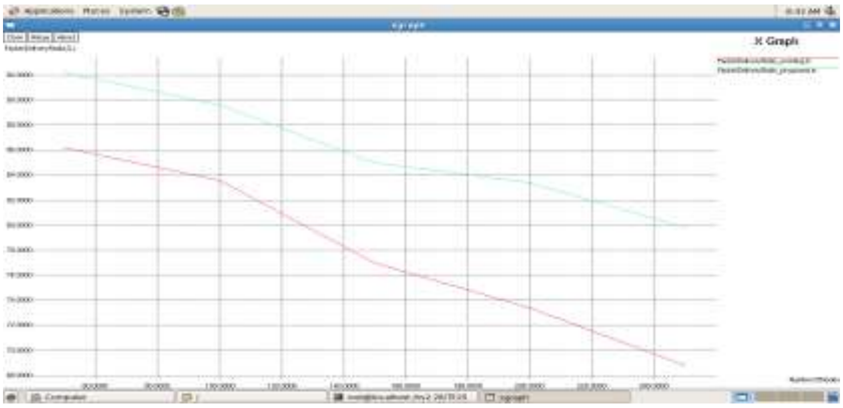

Fig -7: Number of Nodes Vs Packet Delivery Ratio

Figure 7 presents the packet delivery ratio when the number of nodes increases. Hierarchical network achieves good delivery ratio, compared to flat network.

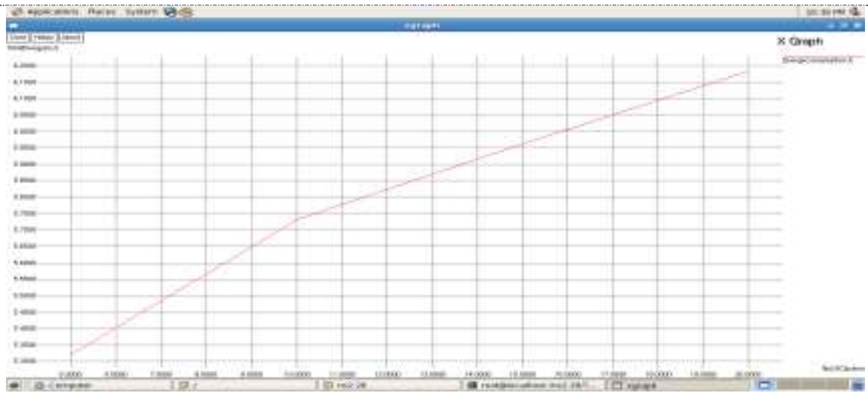

Fig -8: Number of Clusters Vs Energy

From the figure 8, it can be seen that the number of cluster heads affects the consumed energy of a sensor network and were thus able to determine the optimal number of clusters a sensor network requires further.

Fig -9: Number of Clusters Vs Delay

Figure 9 represents the delay when the number of clusters increases.

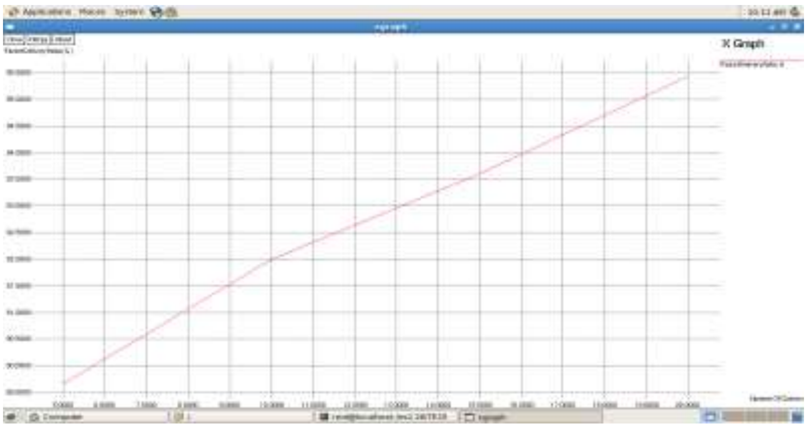

Fig -10: Number of Clusters Vs Packet Delivery Ratio

Figure 10 shows the results of packet delivery ratio when the number of clusters increased.

CONCLUSION

Hierarchical cluster-based network routing is a well-known protocol with special advantages related to scalability and efficient communication for wireless sensor networks. In a hierarchical architecture, CHs can be

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used to process and deliver information efficiently while gateways are responsible for forwarding information between clusters. This implies that the creation of clusters and gateways greatly contributes to system scalability, network lifetime, and energy conservation. In this work, to evaluate the performance of the hierarchical network, an ADTCA algorithm is implemented which increased energy efficiency and also improved the delay and packet delivery ratio over the flat WSN. Therefore, the proposed ADTCA approach may be an efficient way to lower energy consumption since the number of transmitted messages to the destination is decreased by performing data aggregation and fusion in CHs and messages can be relayed with reliable broadcasting in distributed gateways.

Simulations are performed on different networks and the results are compared with that of existing method. Simulation results reveal that the total energy consumption in case of a hierarchical WSN is less than a flat WSN. Similarly the delay and packet delivery ratio are improved. The ADTCA algorithm can further be modified to increase the network lifetime of WSNs. There will be a scope for the improvement by adding the security in the algorithm.

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