Compressed Data Aggregation and Routing in WSN using Optimal Clustering Protocol

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Abstract: There is a difference in energy consumption among the nodes in cluster-based wireless sensor networks due to the non-uniform distribution of nodes. Based on this issue, we are proposing an efficient data aggregation tree based on the previous clustering architecture for communication and routing. Here, using fuzzy logic methodology, parameters such as Residual Power, Node Density and Load cluster heads are chosen. The inter-cluster routing algorithm balances the energy consumption between the heads of the cluster by changing energy consumption between clusters. Then data compression is applied using data correlation model to reduce energy consumption.

Keywords: wireless sensor network; fuzzy logic; inter-cluster routing algorithm; energy consumption.

1. Introduction

1.1 Wireless Sensor Networks (WSN)

Wireless Sensor Networks (WSN) consists of intelligent, teensy sensor nodes capable of sensing different types of phenomenon using sensor modules and wirelessly transmitting the specific data to a sink node. WSNs gather and measure all data and provide specific users with different sensing information. Typically, these sensor nodes are installed in huge proportions (from a few to thousands) and in environments where human control is exceedingly difficult. Sensors must therefore be spread randomly and must use limited power storage units such as batteries. Sensor nodes therefore need to work with each other to create a self-organized network, and they need to be fitted with energy-efficient modules and protocols to reduce energy consumption and ensure long life of the network [1].

One of WSN's important tasks is to collect and relay the relevant parameters to the base station. Sensors are typically deployed in a dangerous atmosphere and battery replacement is difficult, making energy usage one of the most important considerations of protocol design. In WSN, sensors share information to each other through wireless signal and all neighbors receive the data transmitted by a sensor, thus the overhead communication is the large energy wastage of the sensor. Data aggregation is among the most effective ways of reducing overhead communication and many schemes for eliminating redundant transmissions have been proposed [2,3].

A sensor network consists of a lot of of sensors with capabilities in computing, communication, and sensing that can spread across a geographical region. Their restricted processing power, range and storage space limits the use of standard data processing algorithms and the amount of intermediate results that can be deposited on the sensor nodes. Thus, well-organized routing in WSNs is needed for the easiest way of compressed data aggregation [4,5].

1.2. Aggregation of cluster-based data in WSN

In the wireless sensor region data aggregation is an important technique because data packet reduction can reduce energy consumption, increase network life, and increase the effective data transmission ratio. The principle of clustering can be used to increase the efficiency of data aggregation in a hierarchical network in terms of target monitoring. Static clustering and the other dynamic clustering are the two types of clustering methods.

To increase data aggregation efficiency in a hierarchical network in terms of target tracking the concept of clustering can be used. The two types of
clustering methods are static clustering and the other dynamic clustering. Statically clustered networks
divide the network proactively into many clusters. Data aggregation via static clustering uses pre- elected cluster heads for data aggregation, so data can be quickly and easily transmitted to the sink node with relatively low overhead. Dynamically clustered networks create a cluster reactively in the vicinity of the event sensing nodes. Upon event detection, a certain sensor node (preferably the one with the most energy or closest to the event) that has sensed a target will be elected as a cluster head, while all the other nodes that also sensed the target will become general cluster nodes that are located in a single hop range of the cluster head. All the data are collected and aggregated by the cluster head, and then sent to the sink. The advantage of this technique is that only the necessary nodes will participate in the data aggregation, considerably preserving energy of the other sensor nodes [1]. Some of the advantages of cluster-based Data aggregation are robustness, accuracy in information, less redundancy, minimized traffic load and energy conservation. The cluster heads are also known as the data aggregator nodes which combine the data in order to send it to the base station [6, 7].
To meet these objectives, a data correlation-based compression model and relay based inter-cluster routing algorithm are proposed and applied in the cluster based WSN. This is an extension to our previous work [8] in which a fuzzy based optimal clustering protocol is proposed for maximizing lifetime in WSN. The rest of the paper is organized as follows. Section II provides various researches conducted in relation to our proposed work. Section III explains about the design strategy and the proposed method. Section IV shows the result and discussion of our proposed method and finally section V concludes the improvement in the proposed technique by comparing existing techniques.

2. Literature Review

W. S. Jung et al [1] have proposed a hybrid protocol for improving data aggregation efficiency in target tracking applications of wireless sensor networks. By taking a hybrid approach and adaptively selecting the appropriate data aggregation method, considerable improvements were achieved. Using multi-hop clusters or more complex static clustering could also increase the performance of each protocol. However, the flooding technique used to switch aggregation methods in adaptive clustering-based data aggregation protocol may produce large amounts of overhead.
A. Dabirmoghaddam et al [6] have proposed a single-cluster network and analytically characterize the optimal cluster size subject to its distance from the sink as well as the degree of correlation. Contrary to existing approaches, their findings show that heterogeneous sized clusters, where the clusters for away from the sink are larger, are more energy-efficient. They also proposed a heuristic greedy clustering algorithm to find a near-optimal solution to the problem of energy-efficient clustering. The proposed scheme has the effectiveness of heterogeneous-sized clusters in WSNs. However, there occurs computational complexity in the proposed scheme.
T. Fukabori et al [9] have proposed a new and effective data aggregation scheme based on clustering. Their scheme consists of three parts namely, the clustering of nodes by using the Expectation-Maximization (EM) algorithm, generating trajectory of the sink node by using the solution to Traveling Salesman Problem (TSP), and aggregating the data collected from the WSN nodes by using a cluster adapted Directed Diffusion mechanism. The proposed scheme can increase efficiency for different numbers and distributions of nodes. However, as the number of nodes increases the efficiency decreases.
G. S. Chhabra and D. Sharma [4] have proposed an improved version which uses both cluster and tree-based protocols. The proposed protocol improves the power consumption by

improving First Node Death (FND). Here the network lifetime is maximized by balancing the energy consumption. And the communication overhead is reduced. However there occur some of the energy issues in this proposed scheme.

A. Takeda et al [10] have proposed a scalable structured p2p network which supports data aggregation. In the proposed p2p network, each node forwards partial statistical results to other nodes, and each node aggregates partial statistical results in order to calculate a complete statistical result. Since, the data aggregation process does not need any specific protocols, the communication cost of is very low. However, where not simulated here.

M. M. R. Mozumdar et al [11] have proposed a data aggregation in a partially connected sensor network. The algorithm reduces the traffic flow inside the network by adaptively selecting the shortest route for packet routing to the cluster leader. They also describe a simulation framework for functional analysis. The algorithm can work in a fully connected sensor network and it is best for a partially connected network. However the time synchronization is not addressed here.

Mishra et al [12] have proposed a new data delivery protocol in large scale wireless sensor networks for solving the problem of unbalance of energy consumption between the nodes. It is an improvement of the cluster-based sensor networks such as LEACH. Basically there are two main ideas in their proposed model (FDDA). First, data is sent to one main cluster head i.e. Central Cluster Head (CCH) and this CCH sends this aggregated data to the base station directly. Second, whenever the energy level of a cluster head becomes low below a threshold value it is replaced by a back up sensor node which acts as a cluster head node temporarily. However there occurs imbalance in the energy consumption between the nodes.

M. H. Anisi et al [13] have proposed an energy-efficient Network data aggregation approach in WSN. The proposed approach uses the advantages of both cluster based and tree based approaches. In this approach, the whole network consists of some clusters with the same size. Each node is related to a routing sub tree and each sub tree overwhelms a cluster and the root node of each sub tree is the head node of the related cluster. In the proposed approach, all the nodes transmit their data to their neighbor instead of their cluster head. Therefore, the communication distance is reduced and the energy consumption of each node, each cluster and the average energy consumption of the whole networks is reduced and the network lifetime is increased. Also, in the proposed approach, the most appropriate parent according to some benchmarks will be selected for each node which can balance the network load.

K. Kinoshita et al [14] have proposed a more accurate and adaptive energy estimation method that does not depend on the length of the period. In addition to this, a data gathering scheme that is optimized for the environmental energy-based sensor network is proposed. This environmental energy harvesting framework enables accurate power estimation. However, since the transmission range of ADV is limited in the proposed clustering, there will be non-CH nodes that have received no ADV from any CHs.

I. Shin et al [15] have proposed a stable backbone tree construction algorithm using multi-hop clusters for wireless sensor networks (WSNs). The hierarchical cluster structure has advantages in data fusion and aggregation. They propose a distributed algorithm to create a stable backbone by selecting the nodes with higher energy or degree as the cluster heads. This increases the overall network lifetime. Moreover, their proposed algorithm balances energy consumption by distributing the traffic load among nodes around the cluster head.

Yu et al [16] a cluster-based routing protocol for wireless sensor networks with nonuniform node distribution is proposed, which includes an energy-aware clustering algorithm EADC and a cluster-based routing algorithm. EADC uses competition range to construct clusters of even sizes. At the same time, the routing algorithm increases forwarding tasks of the nodes in scarcely covered areas by forcing cluster heads to choose nodes with higher energy and fewer member nodes as their next hops, and finally, achieves load balance among cluster heads. This protocol can balance the energy consumption among nodes and increase the network lifetime significantly.

D. S. Mantri et al [17] have proposed a Bandwidth Efficient Cluster-based Data Aggregation (BECDA) algorithm which provides effective data gathering with in-network aggregation. It uses the correlation of data within the packet for performing data aggregation. Intra and inter-cluster aggregation is applied on randomly distributed nodes with variable data generation rate. In existing cluster based data aggregation approaches, the load at the CH will be more leading to the quick energy drain of the CH, since all the members transmit their sensed data to the optimal cluster head [18]. Moreover, due to redundancy in data, the aggregation overhead will be more. The inter-cluster communication should ensure failure free transmission and energy efficiency. Hence the objective of this works are reducing the data redundancy, minimizing the load and energy drain rate of the cluster head and ensuring energy efficient inter-cluster communication in cluster based data aggregation.

3. Proposed Solution

3.1 Overview

In this paper we propose a compressed data aggregation technique for communication based on the previous clustering architecture. It consists of compressed data aggregation and inter-cluster routing phases. In compressed aggregation phase, the data correlation and data compression method is used as an energy saving method. With this, the compression ratio is calculated from the data correlation and the cluster size.

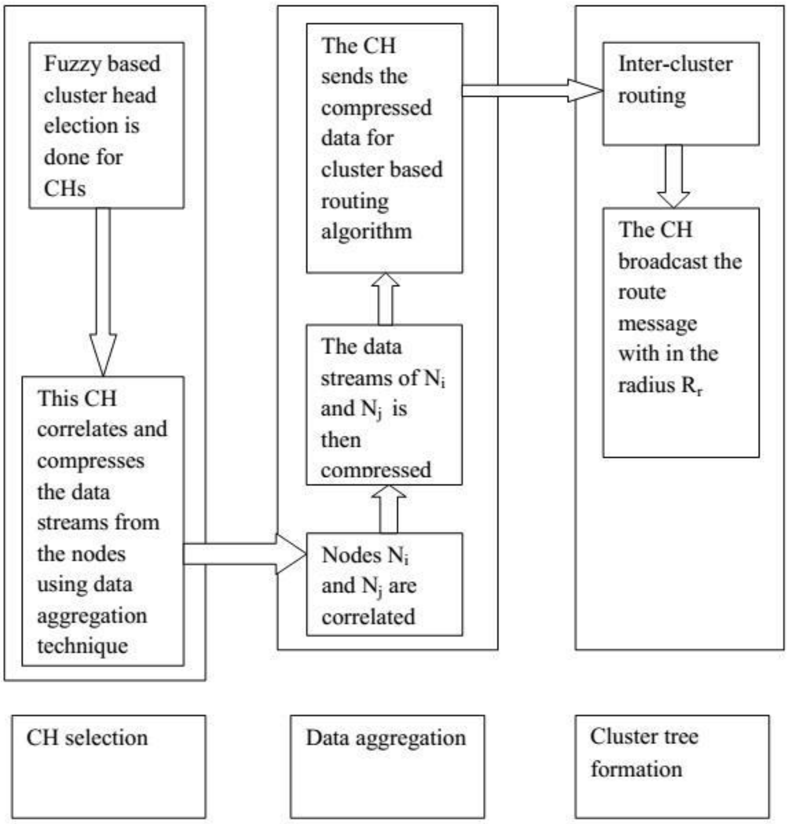

Figure.1 Block Diagram of proposed cluster-based data aggregation and routing in WSN

The Cluster Head (CH) aggregates and compresses the collected readings and transmits a single representative message to the sink. The size of the compressed message depends on the joint entropy of the cluster.

In inter-cluster routing phase, a routing tree is constructed for the elected CHs. Using a relay, the CH chooses the next CH. This relay is measured by the residual energy of CH, node density, network load and maximum initial energy of nodes. This inter-cluster routing algorithm balances the energy consumption among cluster heads by adjusting intra-cluster energy consumption and inter-cluster energy consumption.

3.2 Optimal Clustering Protocol

A cluster head (CH) should possess high residual energy and low load since it involves lot of data forwarding operations. Similarly, it should have minimum distance to the sink and cover a greater number of nodes. Hence the CH is selected based on the metrics Residual Energy (Eres), Distance to the sink (D), Node Density (NDi) and Load. Fuzzy logic is used for CH selection since it considers all possible combinations of these conflicting metrics and accurately estimates the possibility of a node becoming CH and the cluster size.

The steps involved in this clustering protocol is as follows [8]

1) At time t, several provisional cluster heads (PCH) are elected in a random manner to compete for final cluster heads.
2) Excluding the chosen PCH, the remaining nodes broadcasts a HELLO message at fixed power level.
3) Each PCH which receives HELLO message estimates the distance and appends the node ID to its route cache.
4) Finally, for each PCH, the parameters such as Residual Energy (Eres), Node Density (NDi) and Load are gathered.
5) Utilizing the estimated parameter values, each node analyzes the parameters condition using fuzzy logic technique.
6) When a PCH estimates its possibility to become the cluster head, broadcasts a desire message (D_Mes) establishing its desire to become CH.
7) However, when PCH finds that there is another PCH with the greater criteria to get selected as CH, it just declares its desire cancellation (DCL_Mes) message.
8) After CH election, each CH broadcasts a cluster advertisement (CL_ADV) message through the network. Ordinary sensors nodes in the network join the nearby CH.

3.3 Data Correlation Model

The sensor nodes within the WSN are considered statistically identical information sources with an assumption that the readings are normally distributed with mean zero and variance. In case of degree of data correlation (DDC), the assumption is dependency between sample readings exponentially decreases with distance at a fixed rate. So if the distance is more, the correlation will be less.

Hence, in order to evaluate the DDC of the two-time series, we define the following two metrics magnitude (MG) and distance (D).

The readings of two sensor nodes Ni and Nj are said to be correlated, if

(i) MGi = MGj

where MGi and MGj are the magnitudes of the readings of Ni and Nj

(ii) Dij < Dth

where Dij is the distance between Ni and Nj and Dth is the distance threshold

We can represent the two nodes as 2-dimensional points. Node Ni has coordinate (MGi, Di) and Node Nj has coordinate (MGj, Dj). The DDC between the two nodes is based on these coordinates estimated using the Euclidean Distance.

Euclidean distance monitors the root of square differences between coordinates of a pair of objects. Therefore the Euclidean Distance between the nodes Ni and Nj is given by [6],

$$DDCi = \sqrt{\sum_{k=1}^{n} (x_{ik} - x_{jk})^2} \text{ , n = 2.} \qquad (1)$$

Where,
xi1 = MGi, xi2 = Di and
xj1 = MGj, xj2 = Dj.
This data correlation model is used to allocate the optimal set of data rates to the sensor nodes. Here the Power Exponential model is used as a covariance function for this data correlation model.
The Power Exponential model for the covariance function with the distance *d* is given by [6]:

$$K_{\mu}^{PE}(d) = \exp(-(\frac{d}{t_1})^{t_2}), \qquad (2)$$

3.3 Data Compression Model
Using the data compression model, the size of the compressed message depends upon the joint entropy. Here the correlated data streams are encoded independently, and then decoded jointly at one receiver.
The data streams in the nodes Ni and Nj are said to be correlated, such that the data stream in node Ni is X and the data stream in node Nj is Y
The correlated data streams X and Y is generated by making n independent drawings from a joint probability distribution P(X = x, Y = y).
In fig. 2 Encoder 1 receives data stream X and then transmits a coded message to the decoder, each character of X is encoded by the RX bits.

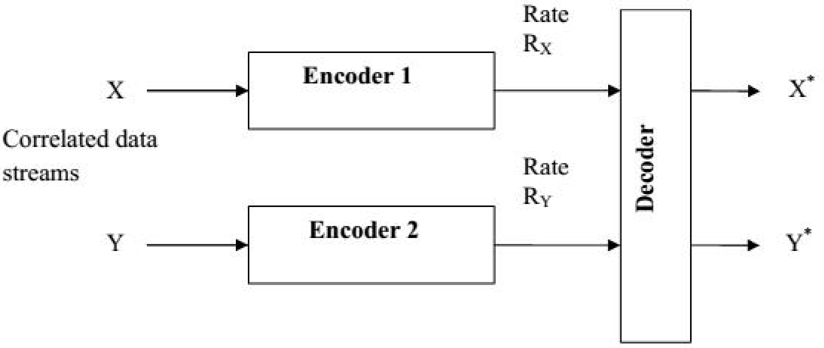

Figure.2 independent encoding and joint decoding of two correlated data streams X and Y
Likewise, encoder 2 receives data stream Y and then transmits a coded message to the decoder, where each character of Y is encoded by a number of RY bits. On receiving these two coded messages, the decoder generates two n-vectors X* and Y *, which represents the estimations of the original data streams X and Y, respectively.
The admissible rate region for the random variables X and Y with joint probability distribution is given by,

$$P(X=x, Y=y) = H(X \mid Y) = -\sum_{y} P(Y=y) \sum P(X=x \mid Y=y).\lg P(X=x \mid Y=y), \qquad (4)$$

By the Slepian-Wolf theorem, the admissible rate region for the pair of rates (RX, RY) satisfies the following three inequalities:

RX ≥ H (X|Y),
RY ≥ H (Y |X),
RX+RY≥H(X,Y),
The separate encoders that ignore the source correlation can achieve rates if only RX + RY ≥ H (X, Y).

4. Simulation Results
4.1 Simulation Model and Parameters

The Network Simulator (NS-2) [19], is used to simulate the proposed architecture. In this simulation, sensor nodes are randomly deployed over a 500-meter x 500-meter region with a transmission range of 40 meters. The sink or BS is located in the top right corner of the topology. The data from the sensors are considered as periodical and with constant size and hence the constant bit rate (CBR) traffic is applied for data generation. The results are averaged over 10 runs. The simulation settings and parameters are summarized in Table-1.

4.2 Performance Metrics

The proposed Cluster based Compressed Data Aggregation and Routing (CCDAR) protocol is compared with the Cluster based Correlated Data Gathering (CCDG) technique [2]. The performance metrics Packet Delivery Ratio and average Energy Consumption are evaluated.

- **Packet Delivery Ratio:** It is the ratio between the number of packets received and the number of packets sent.
- **Packet Drop**: It refers the average number of packets dropped during the transmission
- **Energy Consumption**: It is the amount of energy consumed by the nodes to transmit the data packets to the receiver.
- **Delay**: It is the amount of time taken by the nodes to transmit the data packets.

4.3 Results

The number of nodes as is randomly varied as 25, 50, 75 and 100 and the above performance metrics are evaluated. Clusters are formed such that the average size of each cluster is 10% of the total number of nodes.

Figure 5 shows the delay occurred for both the protocols, when the number of nodes is increased. As the number of nodes increases, the delay increases linearly, as the inter-cluster path length will be high. However, CCDAR chose shortest paths between each CH for inter-cluster routing, the delay is 32% less when compared to CCDG.

Figure 6 and 7 show the packet delivery ratio and packet drop for both the protocols, when the number of nodes is increased. Packet drop of CCG linearly increases from 7000 to 12800 until 75 nodes whereas for CCDAR it increases from 4600 to 6300. Similarly the delivery ratio reduces from 0.56 to 0.37 for CCDG and from 0.6 to 0.4 for CCDAR. This is due to the fact that, when there are more nodes, the load of the CH increases leading to more packet drops. Since CCDAR chose least loaded CH in inter-cluster routing, the packet drop is 43% less and packet delivery ratio is 10% high, when compared to CCDG.

Figure 8 shows the results of average energy consumption of both the protocols, when the nodes are increased. From the figure, we can see that the energy consumption becomes constant beyond 25 nodes for both CCDAR and CCDG. CCDAR has 11% less consumption of energy when compared to CCDG, since the CH selection in both intra and inter cluster routing are based on high residual energy.

Figure 9 show the average overhead occurred for the two protocols CCDAR and CCDG. The overhead of both the protocols increase beyond 75 nodes as depicted in the figure. It reaches around 12500 at 100 nodes for CCDAR whereas it reaches around 23000 for CCDG at 100 nodes. It can be observed that there is no additional overhead involved in broadcasting in CCDAR. The overhead reduces by 45% for CCDAR when compared to CCDG.

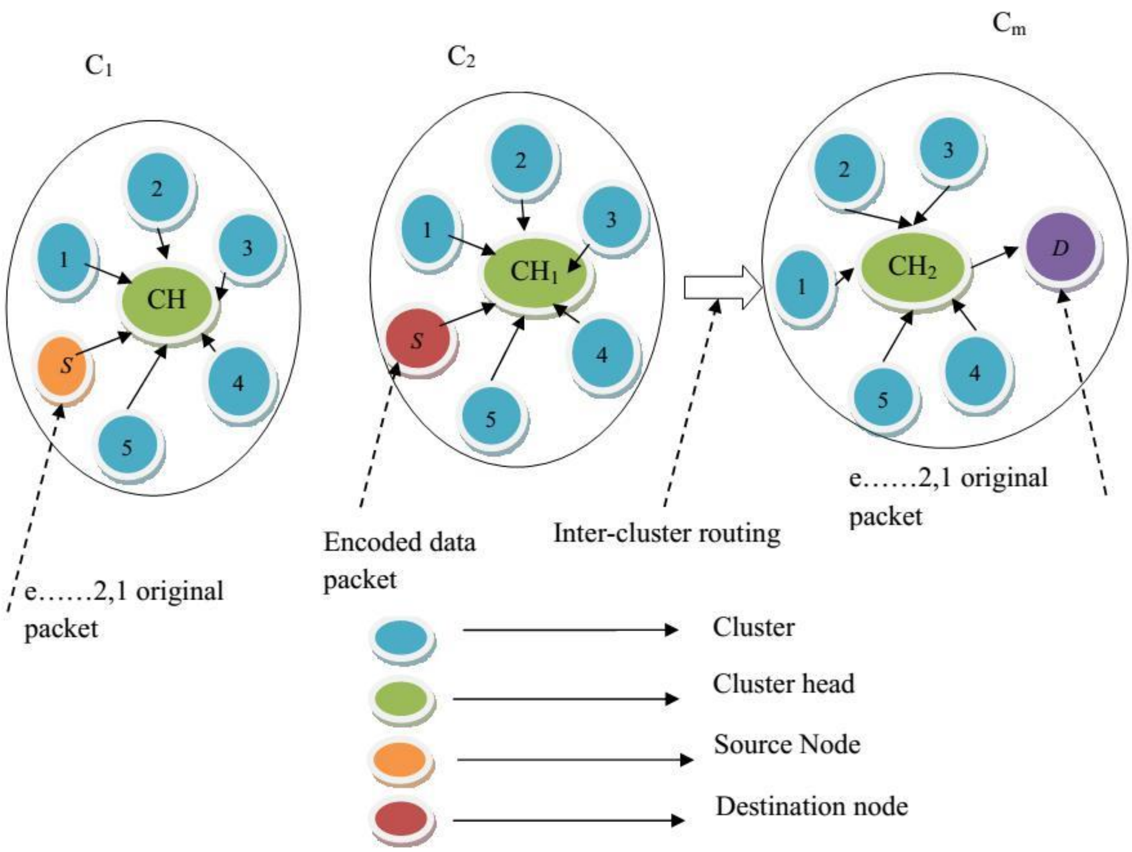

Figure.3 Representation of inter-cluster routing with the encoded data packets

Table 1. Simulation Settings

Number of Nodes	25,50,75 and 100
Area Size	500 X 500m
MAC Protocol	IEEE 802.11
Transmission Range	250m
Simulation Time	50 sec
Traffic Source	CBR
Packet Size	512
Initial Energy	10.J
Receiving Power	0.395
Transmission Power	0.660
Rate	250Kb

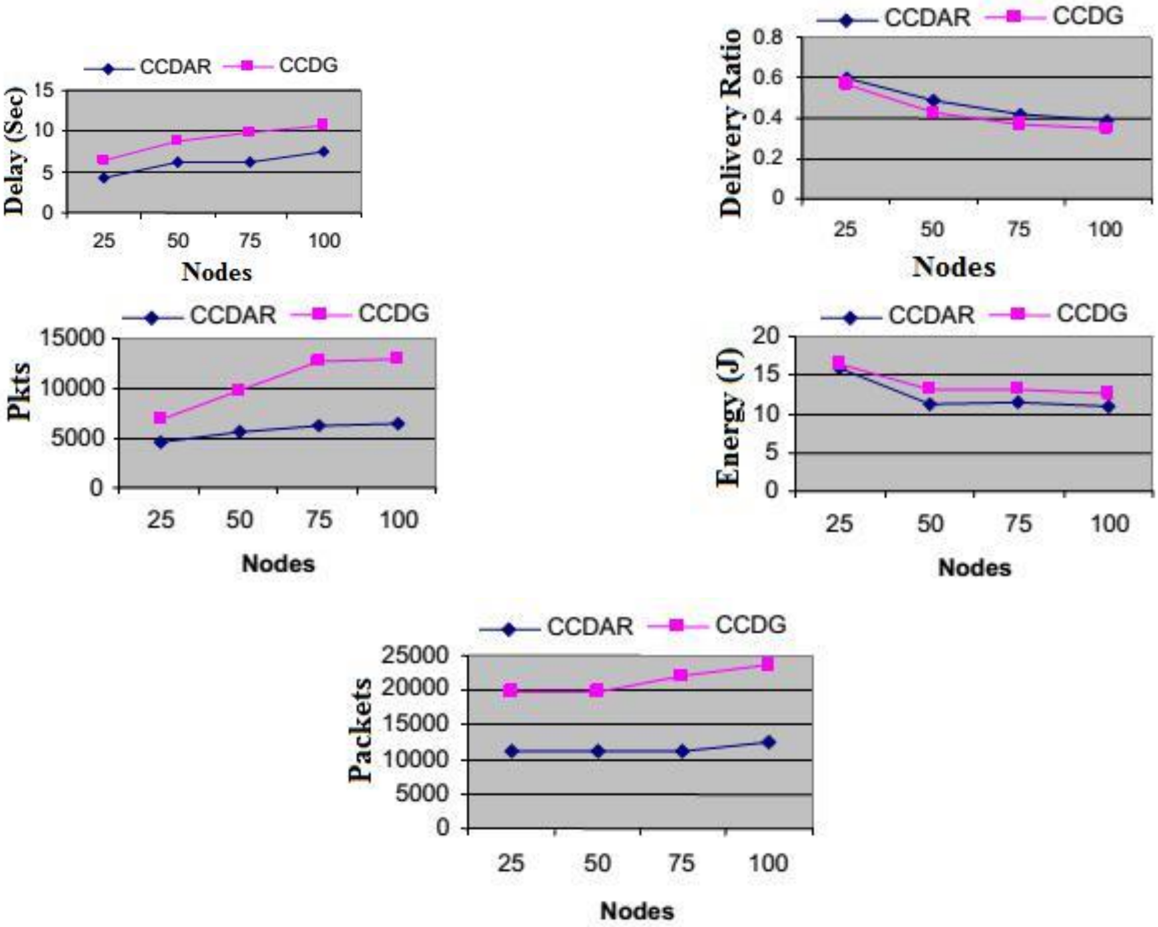

Figure 5-9: Nodes vs Delay, Delivery Ratio, Drop, Energy Consumption, and Overheaad

5. Conclusion

In this paper we have proposed an efficient data aggregation tree for communication and routing based on the previous clustering architecture. Here data correlation and data compression method is used as an energy saving method. Next a routing tree is constructed using the cluster based routing algorithm. This cluster-based routing algorithm balances the energy consumption among the cluster heads by adjusting intra-cluster energy consumption and inter-cluster energy consumption. By simulation results, we have shown that the proposed technique enhances the network lifetime with increased delivery ratio and decreased energy consumption. In future work for optimal clustering we planned to propose an fuzzy as well as optimization algorithm, so that we can improve the clustering efficiency and that results in improving the system performance.

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