



# Energy Aware Efficient Data Aggregation (EAEDAR) with Re-scheduling Mechanism Using Clustering Techniques in Wireless Sensor Networks

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## Abstract

In present scenario of wireless sensor networks and communications, efficient sensed data transmission among nodes is being a great confrontation because of the impulsive and volatile nature of sensors in the network. For providing that and enhancing network lifetime, there are several approaches are developed, specifically using clustering techniques. Still, there are requirements for energy based efficient routing in WSN. With that note, this paper develops an Energy Aware Efficient Data Aggregation (EAEDAR) and Data Re-Scheduling with the incorporation of clustering techniques. Moreover, the model used energy based cluster formation and cluster head selection for increasing the network stability and data delivery rate. The model comprises four main phases, namely, Energy factor based cluster formation, Aggregator\_SN (Sensor Node) Selection, Efficient Data Aggregation (EDA) and Data Re-Scheduling based on delay and processing time. Furthermore, the model is updated with respect to the status of the nodes and links, for providing consistent network with improved reliable data transmissions. The simulation results portrays the effectiveness of the proposed model over other compared works in terms of the performance factors such as, throughput, packet delivery ratio, network lifetime, transmission delay and packet drop.

**Keywords** Energy aware efficient data aggregation (EAEDA) · Data re-scheduling · Clustering · Aggregator node · Data aggregation · Transmission delay

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## 1 Introduction

Wireless Sensor Network (WSN) is commonly defined as the collection of closely distributed sensor nodes for the accumulation and propagation of sensed data about the environment. There are several applications of WSN in environmental sensing such as Pollution Monitoring, Military Applications, Industrial Monitoring, Fire Detection, etc. [1]. Moreover, the sensor networks observe and controls their surrounding area using remote locations also. However, the sensor nodes that are used in the network for environmental sensing are with some limitations on storage, computational ability, power and energy. Hence, required models are to be designed that provides efficient resource utilization in WSN [2]. The General Mode of Wireless Sensor Network is showed in the Fig. 1.

In WSN, data aggregation process is incorporated for enhancing the network lifetime by collecting and aggregating the sensed data from various distributed sensors with efficient energy utilization and also by minimizing the conflicts over medium access layer. Further, the aggregated sensed data are forwarded to the sink node through some routes [3]. That is, the real sensed data are transmitted from the source to sink are performed with multi-hop transmissions through the neighbour sensors. Moreover, the data transmission should be established with the consideration of energy efficiency with reduced power consumption. In general, the data aggregation in WSN can be categorized into two as Lossless and Lossy Data Aggregation [4, 5]. Lossless Aggregation is performed when the payload is not exceeding the threshold, whereas, the Lossy aggregation is done, when the data crosses its threshold rate that are fixed based on the system capacity.

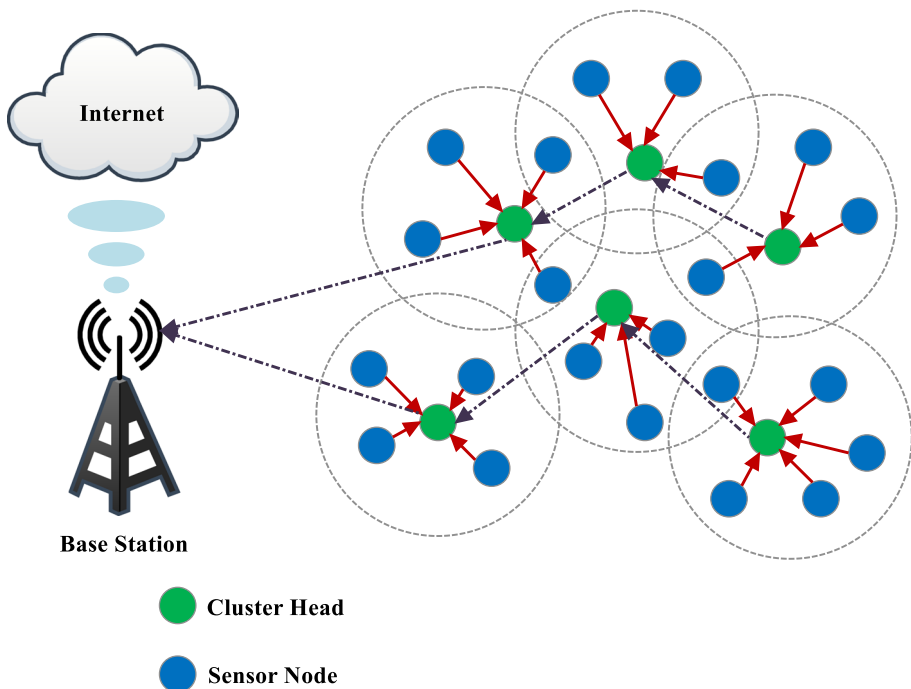


Fig. 1 Wireless sensor network model

In the WSN model, sensor nodes are combined into groups and termed as clusters and having a leader called Cluster Heads (CHs), as in Fig. 1. The distributed sensors are used to identify the local environmental data and the data are forwarded to their corresponding heads. Further, the data aggregation process is carried out at the cluster head and forwarded to the base station. Clustering in WSN is performed for the following reasons,

1. It permits data collection at head nodes towards eliminating the repeated data and also the unrelated data.
2. The network stability is managed, since the routing is established with the cluster heads.
3. The communication bandwidth is similar between the sensors that are connected with their corresponding heads and hence, reduces the redundant data exchange.

Since the direct data transmission between nodes make some transmission delay and also increases the energy consumption of nodes in the network. And also, the multi-hop data transmission between nodes is not energy efficient, since, the node energy utilization is directly proportional to the hop-distance travelled by the data [6, 7]. For reducing energy utilization of nodes, clustering model is incorporated in WSN. Hence, Energy Aware Efficient Data Aggregation (EAEDAR) with Data Re-Scheduling model is proposed in this paper. The contribution of the proposed model is given as follows,

1. In (EAEDA- DR), Energy factor based cluster formation is performed for reducing the node energy utilization.
2. Aggregator\_SN (Sensor Node) Selection model is computed for aggregating the collected sensed data from various sensor nodes.
3. Efficient Data Aggregation model is defined using the A\_SNs.
4. Based on the processing time and transmission delay, transmissionRe-Scheduling model is provided and which also minimizes the time-bloated state problem.
5. An analytical model is derived for evaluating the proposed work and the results are compared with the existing models.

The remainder of this work is arranged as follows: Sect. 2 narrates about the various data aggregation and routing models in WSN. The work process of the proposed Energy Aware Efficient Data Aggregation (EAEDA- DR) with Data Re-Scheduling model is described elaborately in Sect. 3. The results and discussions with comparative analysis are presented in Sect. 4. The conclusion and future work is written in the final part Sect. 5.

## 2 Related Works

The authors of [8] developed a model called Low Energy Adaptive Clustering Hierarchy (LEACH) for establishing dynamic clustering in WSN. The model used random energy balancing technique between sensors. In a different manner, the work presented in [9] developed a random cluster head rotation model for ensuring efficient resource utilization in all sensor nodes in the defined network. In [10], delay aware data aggregation model has been developed based on clustering. The results showed that the model was moderately fusible and could be enhanced with delay and energy efficiency. Energy Delay Index for Trade-Off (EDIT) was the model developed in [11] for enforcing energy efficient routing in

WSN. Moreover, the distance travelled by the sensed data was estimated using Hop counts and Euclidean Distance.

A model for balanced energy utilization in WSN has been derived in [12]. Queuing theory based data aggregation has been used for data aggregation and energy efficiency has been effectively achieved in that model. In order to provide better Quality of Service (QoS) in Mobile Wireless Sensor Networks (MWSNs), real time routing model has been proposed in [13]. Geographic routing has been enforced for deriving the present location of the sensors. The transmission delay was reduced in this model by computing the hop count of the node that is adjacent to the destination. Based on the integrated touring strategy and data aggregation using clustering, a model has been proposed and presented in [14]. Using the integrated work, the data latency has been reduced significantly without conceding the benefits of Mobile Data Collector (MDC) model.

An Energy-efficient Delay Aware and Lifetime Balancing (EDAL) model has been developed in [15] for addressing the issues on energy utilization in packet forwarding in WSN. Load balancing has been carried out in each sensor of the network for increasing the network longevity. Different models have been proposed in papers [16–20] for clustering with uneven cluster sizes for handling energy hole problem. In [21], Ring Zone based Routing Algorithm (RARZ) has been proposed for enhanced energy utilization in the sensing area. And, tree based data aggregation model was presented in [22] for improved resource utilization in WSN. In the same manner, Tree based Clustering (TBC) model has been developed in [23] using the distance parameter, but the model resulted in higher delay. Enhanced Threshold Sensitive Stable Election Protocol (ETSSEP) for cluster head selection in sensor networks has been given in [24]. In another work, weight probability factors were used to define a new work called Energy Efficient Heterogeneous Clustering Scheme [25].

In a different manner, the clusters were further divided into squares for sensing the environmental data and given as Fault Tolerant Energy-Efficient Clustering (FT-EEC) [26]. The model involved in enhancing a number of links by detecting the faulty nodes. Link aware Clustering Model (LCM) [27–32] developed for increasing network longevity. The Link aware routing model is performed based on status of the node, links and clustering factors and so on. Re-clustering was performed periodically, that increased the additional energy consumption and overheads.

### 3 Proposed Model

In the proposed Energy Aware Efficient Data Aggregation (EAEDAR) with Re-Scheduling model, the distributed sensor nodes in the sensing area are divided into clusters. In each cluster, an aggregator node is presented for data fusion from other nodes in the corresponding cluster. It is eminent the sensor nodes are static and the defined location coordinates remains unchanged throughout the complete process. In a multi-hop data transmission process, the data that are sensed are transmitted to the sink through the neighbour nodes. It is to be stated that all neighbour sensor are deployed at same communication range and the distance between SNs are same. For attaining efficient data collection from the sensors, the proposed EAEDA- DR functions in four phases, as follows,

1. Energy Factor based Cluster Formation.
2. Aggregator\_SN Selection.

3. Efficient Data Aggregation.
4. Re-Scheduling process.

Figure 2 presents the pictorial representation of the complete work process and the operations performed in the proposed model and the detailed process is explained below.

### 3.1 Energy Factor Based Cluster Formation

Through proper clustering formation, the network longevity can be increased and data loss can be reduced effectively. In each cluster  $A\_SN$  is selected for data accumulation from sensors and transmitting that to sink node. Here, the sensor nodes in the defined WSN is mentioned as  $SN_i$ . All sensors are embedded with a battery for energy source and proper

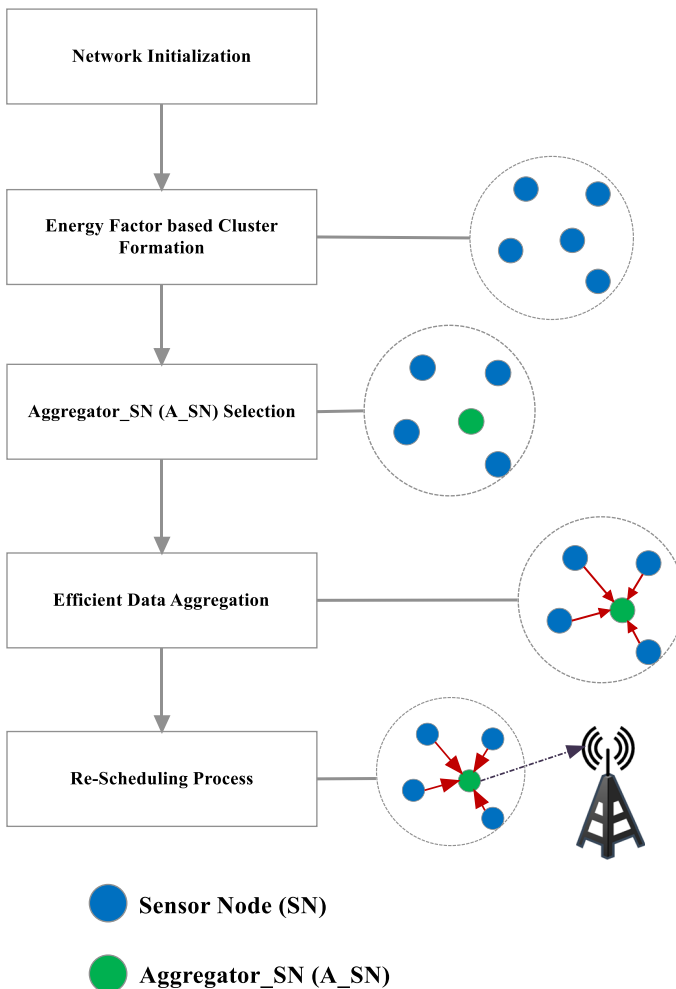


Fig. 2 Operations involved in EAEDAR

utilization of energy is a significant confrontation in WSN. Energy consumption of ( $SN_i$ ) can be computed as follows,

$$E_{cons}(SN_i) = \begin{cases} (E_{ee} \times PR_i + E_{pe} \times by_i \times \|SN_i - A_{SN}\|^4), & \text{if } \|SN_i - A_{SN}\| \geq dist_a \\ (E_{ee} \times PR_i + E_{fe} \times by_i \times \|SN_i - A_{SN}\|^2), & \text{if } \|SN_i - A_{SN}\| < dist_a \end{cases} \quad (1)$$

where ' $E_{ee}$ ' denotes the electronic energy, ' $PR_i$ ' power range at each node, ' $by_i$ ' is the bytes that are transmitted by the sensors, ' $E_{pe}$ ' is the power amplifier energy, ' $E_{fe}$ ' is the free space energy and ' $dist_a$ ' is the distance between the sensor node and aggregator node. And, the electronic energy is calculated as,

$$E_{ee} = E_{trans} + E_{AGG} \quad (2)$$

where ' $E_{trans}$ ' is the energy consumed for data transmission, ' $E_{AGG}$ ' energy used for data accumulation. ' $\|SN_i - A_{SN_j}\|$ ' is the distance between the 'i'th SN and 'j'th A\_SN node. When ' $SN_i$ ' node links with 'A\_SN' at jth position, there is an energy loss, which is computed as,

$$E_D(A_{SN_j}) = E_{ee} \times by_i \quad (3)$$

The information about the aggregator nodes and the SNs are updated based on the energy consumed for data transmission and reception. The formula for updating SNs and A\_SNs are presented below in (4) and (5).

$$EY_{T+1}(SN_i) = E_T(SN_i) + E_D(SN_i) \quad (4)$$

$$EY_{T+1}(A_{SN_j}) = E_T(A_{SN_j}) + E_D(A_{SN_j}) \quad (5)$$

where 'T' is the time factor. The process of updating information loops till the energy level of an SN becomes 0 or can be mentioned that the node become dead. Based on these energy factor evaluations, the clustering process is carried out, that is, the sensor nodes that are with same characteristics are combined here to form clusters. Initially, the cluster formation is decided at the first node. The characteristics of each SN are observed and the nodes with similar features are combined to form clusters.

### 3.2 Aggregator\_SN Selection for Efficient Data Aggregation (EDA)

In this model, the data transmission is performed in multi-hop levels, in which, each SN forwards the data packets to their corresponding neighbours. Moreover, the sensor nodes that are very closer may obtain similar data and removing repeated data may cause a great impact on increasing the network lifetime in WSN. For that, in the proposed work, the data that are collected in each cluster with their SNs will be transmitted to their respective head nodes and aggregation is performed there. That process also utilizes energy at its level; therefore, the head node may lose its energy earlier and become dead. Hence, Aggregator sensor nodes are selected in this proposed model to conserve energy resources of sensor nodes.

The A\_SN selection is employed at different levels of node selection. In the process of data aggregation at each level, time intervals are allotted. Based on that, the nodes can transmit their observed data to their parent nodes. In order to avoid the data latency

and intrusion, the nodes at each level is further separated into ‘n’ number of parts. It is assumed that the data packets are forwarded from  $SN_i$  to  $SN_{i+1}$  and can be mentioned as,  $\{P_1, P_2, \dots, P_n\}$ . It is observed that the sensed data from part  $P_i$  can be allotted to transmit data from  $i$ th time interval. The main intention of this process of to divided sensors at different levels from their parallel parts. When all the SNs of certain level are allotted at a particular time interval for forwarding sensed data to their parents, process scheduling is performed, in which, the SNs that are not on level sectors are considered as in aggregation sets. Moreover, the node selection process performed from the bottom level, in which, the principal SNs are considered as to be in even levels, whereas, the linked SNs are assumed to be in odd levels. The principal node in the level sector  $LS_d$  is divided into ‘n’ number of sub parts, when ‘ $LS_d$ ’ is even. Likewise, the  $LS_c$  is divided into ‘m’ number of sub-parts, when the level is odd. Here, the node  $SN \in LS$  is generally allotted to  $j$ th part in  $i$ th level, where the scheduling time based on the time interval of node  $SN_i$  is derived as,

$$T_{shed} = \begin{cases} k + j + \sum_{d=H}^{i=2} n_{LS_d} + \sum_{c=H}^{i=1} m_{LS_c}, & \text{if } i = \text{even} \\ k + j + \sum_{d=H}^{i=2} m_{LS_c} + \sum_{c=H}^{i=1} n_{LS_d}, & \text{if } i = \text{odd} \end{cases} \tag{6}$$

where ‘k’ latency of A\_SN and ‘H’ denotes the depth of aggregation. Based on the above equation, the level sector that is having the principal node is located and the principal node is taken as the aggregator sensor node. Hence, the data aggregation process is performed with that node is each cluster.

### 3.3 Transmission Re-scheduling Based on Processing Delay

#### 3.3.1 Network and SNs Setup

In this proposed model, the network is modelled with level sectors, which assumes that the complete sector having ‘A’ number of sensors. Each LS contains a node collection, which is denoted as ‘C’ and the communication links are denoted by ‘L’. Moreover, the level sectors are further divided into concurrent parts that are given as  $\{P_1, P_2, \dots, P_n\}$ . Each Part contains node clusters that are framed as explained in Sect. 3.1. And, each cluster has an Aggregator\_SensorNode A\_SN for data accumulation from other nodes. The respective base station will receive the aggregator data from the aggregator nodes. In the process of data aggregation, the certainty rate of each A\_SN is considered, which is computed based on the following factors.

- Sensor Node\_Energy:

The Energy utilized by the entire WSN network can be calculated as,

$$mE(j) = \sum_{i=1, i \in j}^M (1 - E(SN_i) * E(SN_j)), 1 \leq j \leq N \tag{7}$$

$$CE(CompleteEnergy)(m) = N * \sum_{i=1}^M E(SN_i) * E(SN_j) \tag{8}$$

where  $E(SN_i)$  denotes the energy consumed by the 'i'th node and  $E(SN_j)$  is the energy utilized by node at 'j'. 'm' is the number of nodes and 'n' is the number of nodes in the cluster.

- Transmission Delay (TD):

The transmission delay of each SN is more significant factor in computing the certainty rate of nodes and the value ranges from 0 to 1. When the network clusters are less, the TD will also be small. And, the complete delay is determined here as,

$$C_{delay} = \frac{\sum_{i=1}^N E(SN_i)}{M} \tag{9}$$

In all aggregator sensors, the data sensed by other nodes are aggregated and forwarded to the base station, which is at the next time interval. After accomplishing the first time interval, the data from different SNs may collide and energy loss and TD occurs. Moreover, the process of data transmission is looped for each time interval till the base station obtains the final aggregated data. Because of energy loss and TD, data loss may also occur in transmitting the data to the next level. That can be solved by planning to retransmit the data, when high rate of end to end delay and waiting time is observed. The process for calculating the Waiting time for the data packet to be transmitted based on delay is computed as below,

$$WT = \frac{Max_{limit} - EED}{1 + \left(\frac{SN_M - 1}{SN_M}\right)^\alpha} \tag{10}$$

where ' $Max_{limit}$ ' is the deadline time for the data packet to reach its target node, ' $EED$ ' is the end to end delay that is required for transmitting the data from one node to sink, ' $SN_M$ ' is the intermediate sensor and ' $\alpha$ ' is the constant factor.

The priority provision is given based on the data aggregation effectiveness and the receivers may cause random time delay in receiving packets to reduce collision. Selection of data packets with minimal delay can be given as more priority. Furthermore, for reducing Clear To Send collision, the target node executes random delay process. The higher node priority as node fitness rate is calculated as follows,

$$PR = WG \times \left(1 - \frac{X}{Y(C, i)}\right) + (1 - WG) \left(\frac{E_{res}(i)}{E_{init}(i)}\right) \tag{11}$$

where

$$X = \frac{d(C, sink)}{Max_{limit}} \tag{12}$$

$$Y = \frac{d(C, sink) - d(N, sink)}{E_{fr}} \tag{13}$$

where 'd' denotes the distance between nodes, ' $E_{fr}$ ' energy consumed for data forwarding from a sensor to the next relay node. And,  $E_{res}$  and  $E_{init}$  is the remaining energy at SNs and initial energy at each node, and 'WG' is given as the node weight. Based on



these computations, the fitness value for node priority is obtained. The sensed data by the deployed SNs are induced to transmit data based on this prioritization for avoiding data collision. The algorithm for the entire work process of the proposed Energy Aware Efficient Data Aggregation (EAEDAR) with Re-Scheduling model is presented in the following Table 1.

## 4 Results and Discussion

Since the deployed SNs are homogeneous in nature, the implementation is carried out in NS-2 simulation tool with Omni-directional antenna setup with equal communication range. Moreover, the network is designed with 300 sensor nodes with the sensing area  $100\text{m} \times 100\text{m}$ . The results are evaluated based on the performance evaluation factors of WSN such as, Energy Efficiency, Transmission delay, Network lifetime, Throughput, Packet Delivery Ration and Packet loss. For evidencing the efficiency of the proposed work, the obtained results are compared with existing models such as Energy-efficient Delay Aware and Lifetime Balancing (EDAL) and Fault Tolerant Energy-Efficient Clustering (FT-EEC). And, the parameter initialization for simulation and domain values are provided in Table 2.

For performance evaluation of the model, the analysis is employed with two factors such as SN density and payload with respect to the aforementioned evaluation parameters such as Energy Efficiency, Transmission delay, Network lifetime, Throughput, Packet Delivery Ration and Packet loss.

### 4.1 Node Based Evaluation

This section provides the evaluation results of the above mentioned parameters based on number of deployed sensors. Figure 3 presents the energy consumed by the models with respect to the number of sensor nodes. It is explicit from the figure that the proposed EAEDAR model utilizes minimal energy than other compared works. Further, the graph displayed in Fig. 4 gives the energy evaluation based on simulation time. That shows, the energy consumed by the proposed model lesser than others. Hence, it can be stated that the adduced model provided efficient energy consumption of energy with respect to node density and simulation time.

Figure 5 displays the results of analysis for network lifetime based on the node density. The network lifetime in the proposed model is effectively increased with the incorporation of efficient clustering and aggregation model. The proposed model increases the network lifetime for about 36% in average than the compared models. Another evaluation parameter called throughput is evaluated with respect to the number of sensors and the results are presented in Fig. 6. And, the graph shows that the proposed work achieves better throughput than others. For all efficient network models, the transmission delay should be minimal and that is analyzed in this work based on sensor node density. Hence, the Fig. 7 portrays the results on evaluating transmission delay in the proposed and compared models. It can be observed from the graph that the model attained minimal delay than others.

**Table 1** Pseudo code for proposed model

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```

//Energy Factor based Cluster Formation
Input:  $SN_i, EY_{T+1}(SN_i), EY_{T+1}(A_{SN_j})$ 
Output: Clusters
Begin
Initialize sensor nodes
Calculate node's initial position
Compute  $EY_{T+1}(SN_i)$  and  $EY_{T+1}(A_{SN_j})$ 
Calculate the distance between  $SN_i$  and  $A_{SN_j}$ 
Update neighbour nodes with similar characters
Frame clusters
End
Return Clusters

//Aggregator_SN Selection
Input: Level Sectors
Output: Aggregator_SN
Begin
Initialise level sectors
Divide the LS into parts  $\{P_1, P_2, \dots, P_n\}$ 
Calculate  $T_{shed} = \begin{cases} k + j + \sum_{d=H}^{i=2} n_{LS_d} + \sum_{c=H}^{i=1} m_{LS_c}, & \text{if } i = \text{even} \\ k + j + \sum_{d=H}^{i=2} m_{LS_c} + \sum_{c=H}^{i=1} n_{LS_d}, & \text{if } i = \text{odd} \end{cases}$ 
Determine the principal node and select
End
Return Aggregator_SN

// Re-Scheduling Process
Begin
Initialize node SN
Divide sectors into  $\{P_1, P_2, \dots, P_n\}$ 
Compute certainty rate
Compute X and Y
Calculate Node fitness rate
If ( $PR_i > PR_j$ )
 $PR_i$  has the higher fitness
Update the  $PR_i$  as  $PR_j$ 
End

```

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**Table 2** Values and parameters for simulation settings

Simulation parameters	Initial values
Sensing area	100m × 100 m
Number of sensor nodes	300
Transmission range	50 m
Size of packet	100 bytes
Initial energy	18,720 Joules
Simulation time	1000 s
Payload size	1024 bytes
Band width	2.4 GHz
Data rate	200 kbps

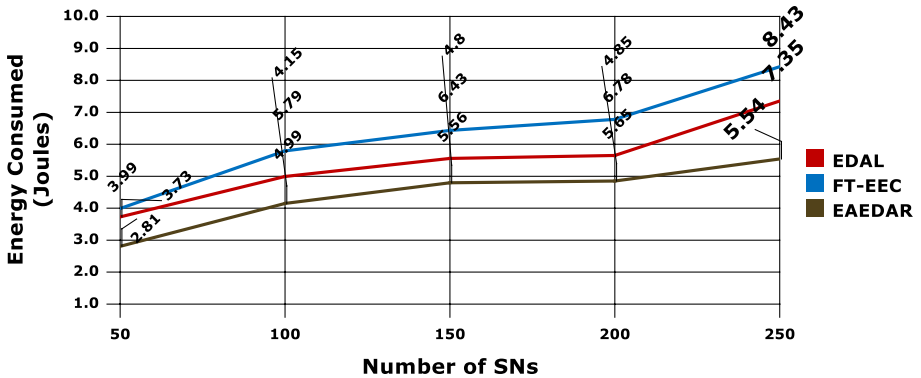


Fig. 3 Energy consumption with respect to number of nodes

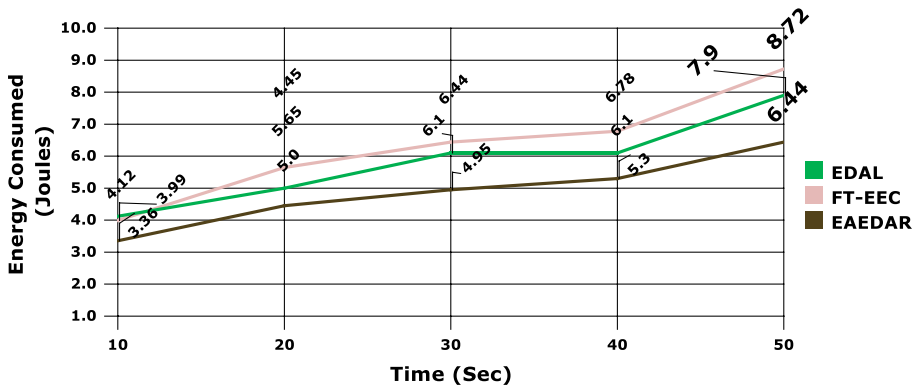


Fig. 4 Energy efficiency evaluation

### 4.2 Payload Based Evaluations

In this section, the simulations are performed based on the maximum payload in the network design. Figure 8 provides the energy efficiency evaluation results and the results show the EAEDAR model consumed lesser energy than other models. The

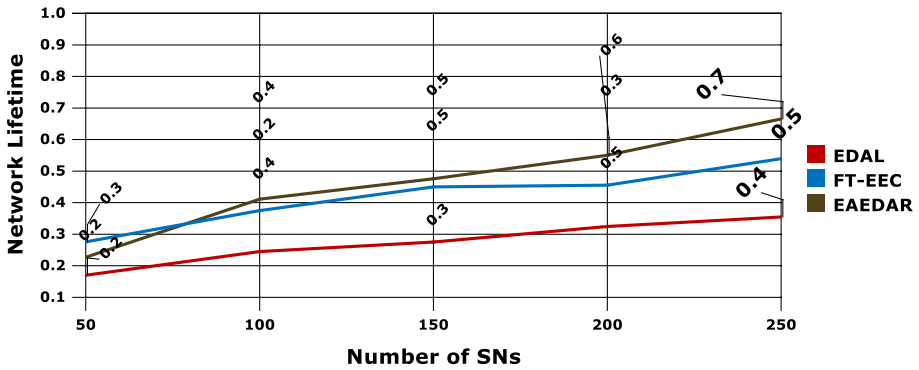


Fig. 5 Network lifetime versus no. of nodes

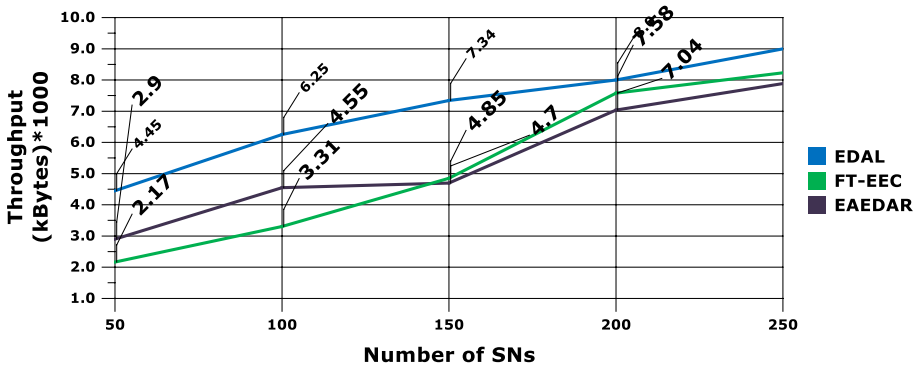


Fig. 6 Results of throughput evaluations

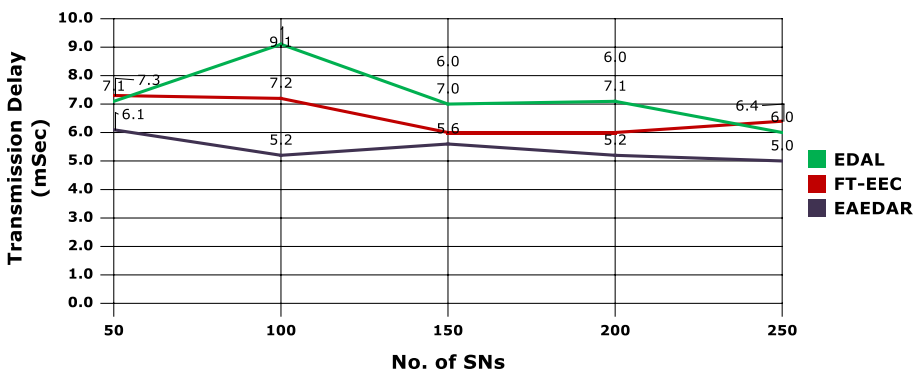


Fig. 7 Transmission delay versus node density

lifetime of sensor nodes determines the network lifetime. Here, it is evaluated based on the payload and the network lifetime is enhanced with this work. The results are displayed in Fig. 9. And, Fig. 10 displays the results of throughput analysis based on

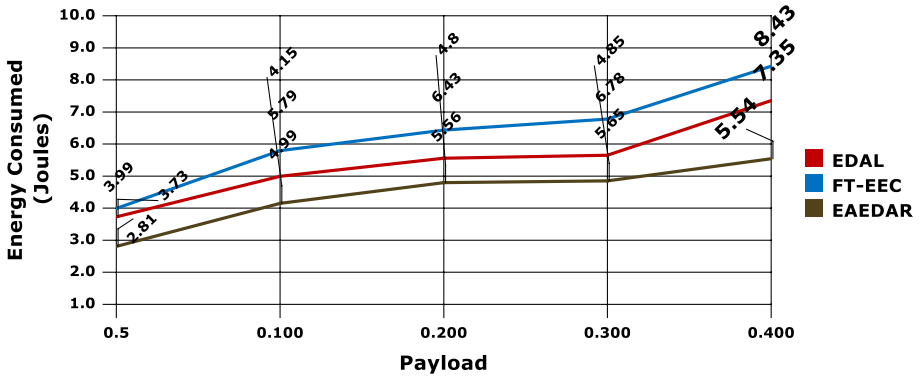


Fig. 8 Energy efficiency based on payload

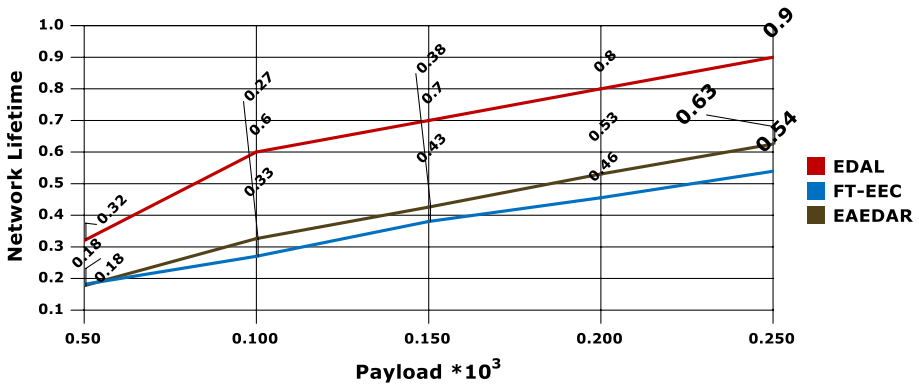


Fig. 9 Network lifetime versus payload

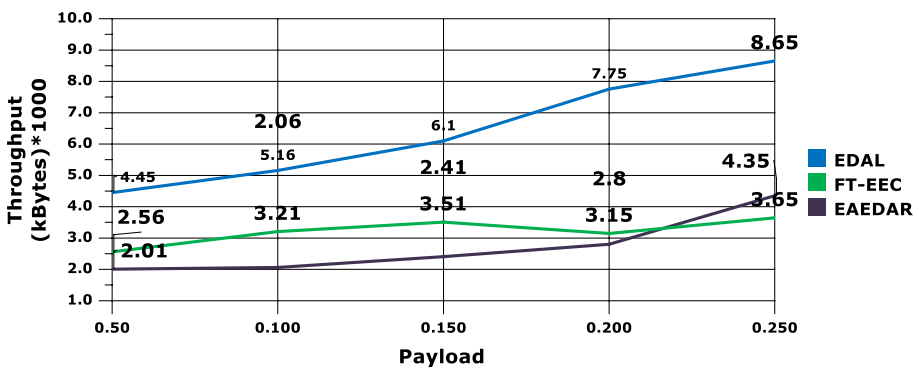


Fig. 10 Throughput analysis on payload

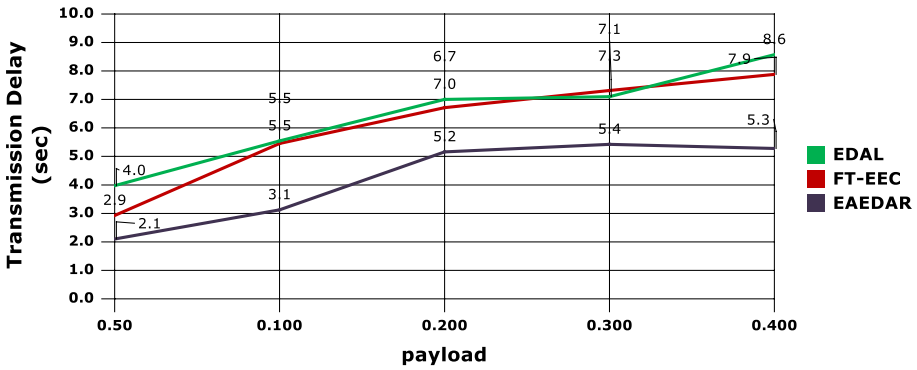


Fig. 11 Transmission delay versus payload

throughput. It is observed that the model produces higher throughput than other compared works.

Transmission delay is analyzed with payload is displayed in Fig. 11 and the EAEDAT produces lower delay than others and the delay rate increases when the size of payload increases. Further, packet delivery ratio of the proposed model is evaluated in accordance with the simulation time and the results are given in Fig. 12. It is shown than the EAEDAR model produces higher rate of packet delivery in data transmission of sensed data.

### 5 Conclusion and Future Work

In this work, Energy Aware Efficient Data Aggregation (EAEDAR) and Data Re-Scheduling for Wireless Sensor Networks is proposed. The model derives energy factor based cluster formation for reducing the transmission time and enhancing the efficiency of data aggregation. Appropriate Aggregator SN selection and EDA is processed for reducing the energy consumption rate of sensor nodes, thereby enhancing the network lifetime. Transmission Re-scheduling is for reducing data packet loss. The results are analyzed with respect to the payload size and the number of deployed nodes in NS-2. The results show

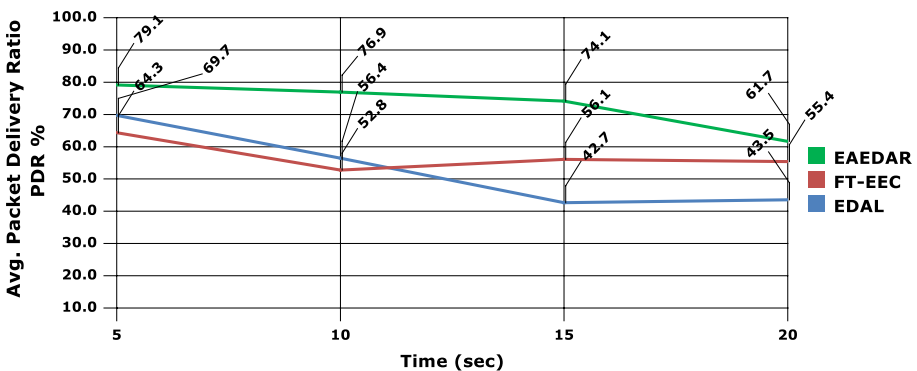


Fig. 12 Packet delivery ratio analysis

that the proposed model produces higher rate of throughput, packet delivery rate, energy efficiency, with reduced delay and enhanced network longevity. In future, the work can be further enhanced with Quality of Service based factors.

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