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Delay Aware Efficient Mobile Sink Path with Distributed Fault Detection and Recovery in Wireless Sensor Networks.

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Abstract: In Wireless Sensor Networks mobile sinks help in balancing the network and reduce energy consumption in addition to solving hotspot issues. These benefits of a mobile sink depend on the path of the mobile sink. Specifically, in critical applications such as fire detection data needs to be collected with minimum delay. In such systems, the number of Rendezvous Points are minimized to satisfy the shortest path criteria, which in turn burdens the selected Rendezvous Points and depletes their energy. An efficient mobile sink path with minimum delay is proposed considering node densities. An additional set of Rendezvous Points are formed by selecting nodes with minimum distance without increasing the path length of the mobile sink. Further, an effective method for the detection and recovery of uncovered nodes due to the failure of Rendezvous Points is proposed. Simulations are performed and the results are compared with existing methods in terms of energy consumption, network lifetime, fault tolerance, etc. The results imply the effectiveness of the proposed method.

Keywords: Wireless Sensor Network, Energy Efficiency, Mobile Sink, Routing, Mobile Sink Path

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1. INTRODUCTION

Wireless sensor networks(WSN) are used in many areas such as habitat monitoring, emergency areas like fire detection/gas leakage/ floods, military, health monitoring, etc. WSNs consist of tiny sensors with limited battery and sensing capabilities. The sensor nodes sense the environmental data and send it to a sink node periodically [2].

Energy saving in WSNs is the most challenging issue as the sensors have fixed batteries and cannot be replaced. Energy preservation has been researched extensively. Many algorithms have been proposed to reduce the energy of sensors for maximizing network lifetime. Multi-hop communication is used to reduce energy usage during the data transmission. In multi-hop communication, the sink is stationary. However, data transmission with a static sink depletes the energy of nodes near the sink causing a hot spot or sinkhole problem [3].

Recently Mobile sinks (MS) have become popular. The MS move in the network region and collect data directly from sensor nodes. But collecting the data from individual sensor nodes is time-consuming hence Rendezvous points(RPs) were introduced [4]. The sensor nodes send the data to the nearest RP instead of visiting each node the MS stops at the RPs and collects data. Therefore, the selection of RPs plays an important role in maximizing the network lifetime. Specifically, in critical applications such as fire detection data needs to be collected with minimum delay. In such systems, the number of RPs is minimized to satisfy the shortest path criteria, which will burden the selected RPs with more node coverage and deplete their residual energy.

In this paper, Cluster heads(CHs) or RPs are called as gathering points (GP). the proposed method delay aware efficient MS path with distributed fault detection and recovery in WSNs(DAMS) consists of three algorithms delay aware MS trajectory (DAMST), forming additional GPs (AGP), fault detection and recovery (FDR). First, an algorithm for finding the optimal number of GPs for an efficient MS path with minimum delay for critical applications is proposed. The first algorithm is based on [5]. But selecting fewer GPs to satisfy delay bound criteria will increase the load of the GPs, hence an algorithm for finding the additional set of GPs is formed without increasing the path length of the MS. The third algorithm FDR is used for recovering the nodes which are uncovered due to the failure of their corresponding GP.

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Nodes are susceptible to failure in harsh environments due to energy exhaustion or crash of on board electronics [6]. The failure of nodes GPs can cause network breakage by disconnecting the nodes covered by it. We propose an algorithm for the detection of GP failure and recovery of the sensor members which were covered by the failed GP.

The remaining paper is structured as follows, in Section **??** the existing works using both mobile and stationary base station for data routing, different mobility's of the MS, techniques considering the delay in the construction of MS path are briefly explained. Section **??** describes the network model, the terminologies used in the algorithms, and the notations. The proposed algorithms DAMST, AGP and FDR are explained with pseudo-codes in section D. Section E the simulation setup and results after comparing with existing techniques are presented. The last Section 6 is the conclusion.

2. Literature Survey

The MS has gained popularity in recent years because of its varying advantages. The mobility of the sink can be divided into random, fixed, and controllable [7]. In random mobility [8], [9] the MS moves casually in the target area. In fixed [10]–[12] the MS moves in a fixed path periodically. In controllable [13]–[15] the movement of MS is controllable and is dependent on network performance and quality of service [16]. Papers [17], [18] use both MS and stationary sink for data aggregation.

A dual sink-based network is proposed in [17]. The MS broadcasts its location to a portion of sensors in the area. The nodes which don't know their location send data directly to the stationary base station. Authors claim that network lifetime is improved by using a dual sink.

In [18] two methods are proposed and the nodes are arranged in 8 regions. In both methods, the inner circle nodes send data directly to BS. In the first method CHs are formed considering the highest energy and nodes in the outer circle send data through CH's which reduces the energy consumption but throughput is less. So, in the second method for collecting data from the outer circle two MS are used. One MS moves in clockwise and the other moves in the anticlockwise direction. Both methods improve the stability period and network life.

In [19] a tree grid-based structure for mobile targets is proposed with multiple sinks. The upper line of the grid is used for traffic allocation and trees at bottom grids are utilized for target and sink information collection. Even though energy consumption is reduced and traffic is balanced, delays may occur because of the grid structure. In [20] a flying sink is used. The nodes request a collector when data needs to be delivered. The sink moves to the location of the sensor and collects data. But buffer overflow can be caused.

In [21] MS path is formed based on the deadlines of the nodes. The sink needs to visit the nodes before their buffer overflows. But this method is not suitable for networks where deadlines are not very strict as the MS are moving continuously and result in unnecessary wastage of resources.

The above methods [17]–[20] don't consider delay which is important for critical applications. To reduce delay Rendezvous Based methods were introduced. RPs were used to reduce the path of MS. Member nodes forward data to the RPs and the MS visits the RPs and collect data [22]. Papers [16][22-24] form delay bounded paths.

In [23] an RP-based constrained path for MS is proposed. A routing tree is constructed starting from the sink node. Weights are assigned to the edges and the highest weighted edges are selected till the length of edges satisfies the packet delivery time. The MS visits the edges only. But as MS has to travel rooting tree it visits each edge twice so an improvement for this algorithm was proposed. Here the edges of the tree are divided into many short ones denoted as L0. RPs have been selected such that the distance between nodes and RP is reduced and tour between two RPs is minimized. To form a path travelling salesman problem (TSP) is used. But this method doesn't balance the energy consumption and the short L0 value increases RPs.

A fixed-path, uncontrollable MS path considering delivery delay and energy is proposed in [16]. Location calibration method which can be integrated with sink movement is presented which gives low overhead. Greedily advanced, discreetly steep back method is used for track routing of MS which gives reliable and on-time delivery. An RP-based delay-aware path is formed.

Weight-based RP selection is done in [24] to form a path that doesn't overreach the deadlines of nodes. Nodes with a high degree are considered as these nodes generate more packets. Considering them reduces congestion and energy holes. RPs with lesser hops to nodes are taken to reduce energy consumption. Virtual RPs are used in the final tour to enhance performance.

The authors in [25] form a combined structure of MS mobility, aggregation of data, and delay strategies. They also address the problems caused by using the combined structure and form an optimal algorithm for the same. The advantages of MS in increasing the network lifetime are explained. Different paths of the MS are studied and insights are provided after simulations.

FTEP [26] is distributed CH selection algorithm. It uses two-level clustering for fault detection. Level 1 CH collect data from nodes and send them to level 2 CH which sends them to the base station. Level 2 CH keeps updating about their state to back-up CH. when CH fails the back-up cluster takes the role of CH or starts re-election. Energy is wasted in re-election and single point detection through the backup node may be damageable.

A grid-based structure is formed in [27] and nodes are grouped into cells. Each cell has a manager. The managers form an upper layer and the remaining nodes form lower. The manager and secondary manager are formed based on residual energy. A group manager is also selected whose task is to collect data from its cell and manage a group of cells. If a manager's energy falls below the threshold it notifies its members and a new one is formed. But only failures caused by energy are considered.

Delay aware path of MS sink is necessary for critical applications, but considering energy balancing and minimizing the energy consumption of the nodes is equally important. For forming delay aware short path the RPs are reduced in the many existing works, which will increase the load on the selected RPs and will cause a buffer overflow. Hence in the proposed method, additional RPs are formed for load balancing without increasing the path length. None of the existing works renews the path of the MS based on the present densities of nodes as designed in the proposed. Many of the existing works with MS have not implemented fault tolerance and Recovery. Faulty RPs can cause the disconnection of nodes covered by them. A method for recovering the nodes is put up. The recovery method doesn't disturb the functioning of other RPs and is carried out in a distributed way. No energy is wasted in forming backup RP and reforming new RPs. The uncovered nodes directly join current neighboring RPs or nodes.

3. System Model

A. Network Model

Homogeneous sensor nodes are deployed in the target region. CHs or RPs called GP are formed. The sensors send their data to corresponding GPs. The MS moves in the network and collects data from GPs. GPs are formed by considering a cost function that considers distance, residual energy, nodes covered, and impact of residual energies of nodes covered. The GPs are further added by using another algorithm without increasing the length of the MS path. Following assumptions are made

- The sensors are steady and don't move once deployed.
- Communication between any two sensors is wireless and can be done if and only if they both are in the communication range (CR) of each other.
- All sensors generate one packet per interval.
- All the packets generated during an interval have the same deadline.
- The MS has unlimited energy or can be recharged at the base station. There are no obstacles in the MS path.

B. Terminologies Used

- Residual Energy (RE): Let IE be the initial energy of a sensor node n_i and CE be the consumed energy of the sensor after a certain period of time then the residual energy after R rounds will be

$$RE(n_i) = IE(n_i) - CE(n_i) \tag{1}$$

- Distance between two nodes($dist(n_1,n_2)$: The space in between two nodes n_1 and n_2 can be calculated by using *(X, Y)* euclidian distance,

$$dist(n_1, n_2) = \sqrt{|X_1 - X_2|^2 + |Y_1 - Y_2|^2} \tag{2}$$

- Energy Influence (EI): The energy influence on sensor node n_i by its neighboring node n_j can be calculated as the correlation of the remaining RE of n_j and the distance between n_i and n_j .

$$EI(n_i) = \frac{RE(n_j)}{dist(n_i, n_j)} \tag{3}$$

- Overall Energy Influence (OEI): Overall Energy Influence on a sensor node n_i by all its neighboring nodes in its CR can be calculated as,

$$OEI(n_i) = \sum_{j=1}^{CR_i} EI_j \tag{4}$$

- Energy Density (Ed): Energy Density can be calculated as follows,

$$Ed(n_i) = \frac{OEI_i + RE(n_i)}{CR(n_i) + 1} \tag{5}$$

- Average Ed of GP(AE_d): Average energy density of all the GPs (g) can be calculated as

$$AE_d = \frac{\sum_{i=1}^{g} E_d(n_i)}{g} \tag{6}$$

- Threshold (TH): The TH can be calculated as γ percentage [5] of the AE_d of constructed MS path,

$$TH = AE_d \frac{\gamma}{100} \tag{7}$$

- Additional GP (AGP *criteria*): AGP of a node n_i considers its distance to its GP and number of neighbors in its CR and can be calculated as,

$$AGP(n_i) = \frac{dist(n_i, GP(n_i))}{CR(n_i)} \tag{8}$$

- Weight: The weight of sensor node or GP n_j is computed by considering residual energy j and its distance from the uncovered sensor s_i and is calculated as follows,

$$weight_j = \frac{RE_j}{dist(s_i, s_j)} \tag{9}$$

C. Notations

The notations used in the paper are listed in table I with a description.

4. Proposed Method

The proposed system consists of three algorithms Delay aware MS trajectory , forming additional GPs , fault detection and recovery . The first algorithm DAMST is used to form the initial GPs set and form the MS path through them considering delay using the TSP algorithm. The second algorithm forms additional GP sets without increasing the MS path. AGP uses distance and coverage factors in selecting the additional GPs. The third algorithm FDR is used for recovering the nodes which are uncovered due to the failure of their corresponding GP. Figure 1 displays the flow of the proposed technique. The following subsections explain these algorithms in detail.

A. Delay aware mobile sink trajectory (DAMST)

The sensor nodes discover the neighbor nodes in their CR and send their ID, residual energy, and neighbor information to the MS. MS computes the energy density of the sensor nodes using this information. MS path is constructed depending on the Ed of sensors. The threshold is computed using equation 7 and MS travels through this path. The sensors send data and residual energy to the MS during each round. After completion of each round the MS checks if the path criteria is satisfied i.e., *(AEd<Th)*, if it falls below *Th* then MS computes the current densities of the sensors calculates the threshold and forms new path. The path calculation and GP formation are done using Algorithm 1.The densities of sensor nodes are calculated by using equation 5. The energy densities are arranged in ascending order by using quicksort. Sensors with less energy density are selected as GP one by one and added to the initial GP set and nodes covered by them are removed. The GP sends a join message to the nodes covered by it. The nodes join the GP.TSP is used to form the MS path. The path length formed by the initial GP set is *tourL1*.

B. Forming Additional GPs (AGP)

Initially, Algorithm 2 DAMST computes the MS tour(*tourL1*) by using the initial set of GPs. But selecting fewer GPs to satisfy the delay will increase the load on the GPs this could exhaust GPs energy. Hence here we propose an algorithm AGP to add more GPs. The additional GPs can share the load of the initial GP set by dividing the nodes covered between the initial GP and added GP. GPs are added without increasing the path length of MS.

Algorithm 2 shows the working of algorithm for AGP. To add a GP, the sensors that are near the path are considered. AGP criteria are calculated for the sensors near GP using equation 8. After adding a new GP, the new path length *L2* is calculated by applying a TSP solver. If the inclusion of such a node in GP list satisfies the constraint *L2≤tourL1*, then the node is included in GPset. *tourL1* is updated with *tourL2*. Finally, the nodes covered are split between the previous GP and the new GP.

Algorithm 1 DAMST

```
Inputs: Senor nodes n, the CR of sensors CR, delay D.
Output: Set of GPs and MS path.
Begin
Step 1:
for $i = 1 to n$ do
  $energy = 0$
  $cover = 0$
  for $j = 1 to n$ do
    if $dist(ni, nj) \leq CR$ then
      $E = \frac{totalenergy+RE(n_i)}{dist(n_i,n_j)}$
      cover = cover + 1
    end if
  end for
  Calculate energy density Using Equation 5
end for
Step 2:
$Ed = Quicksort(Ed, ascend)$
Step 3:
while $tourL1 < Delay$ do
  Sensor with lowest Ed is selected as GP and remove
  sensors covered by it
  if $GPset > 1$ then
    $path, tourL1 = TSP$
  end if
end while
stop
```

Algorithm 2 AGP

```
Inputs: Initial GP set IGP, sensor nodes with minimum
distance to GP, tourL1.
Output: New Added GP, tourL2.
Begin
Find sensors with minimum distance to IGP
Using Equation 8 to find additional GPs
$IGP = n_i + IGP$
$PathofMS = L2(TSP)$
if $L2 \leq tourL1$ then
  $GP = IGP \cup n_i$, divide nodes between previous GP and
  new GP.
else
  $GP = IGP$
end if
if $GP = IGP \cup n_i$ then
  $L2 = tourL2$
  $path = tourL2$
end if
stop
```

TABLE I. Notations

Notation	Description
n	sensor node
g	GP
$CR(n_i)$	Sensors in CR of sensor node n_i
$dist(n_i,n_j)$	Distance between nodes n_i and n_j
IGP	Initial GPs
s	Total sensor nodes
$tourL1$	The initial tour formed by IGP
$tourL2$	The final path formed after adding AGP

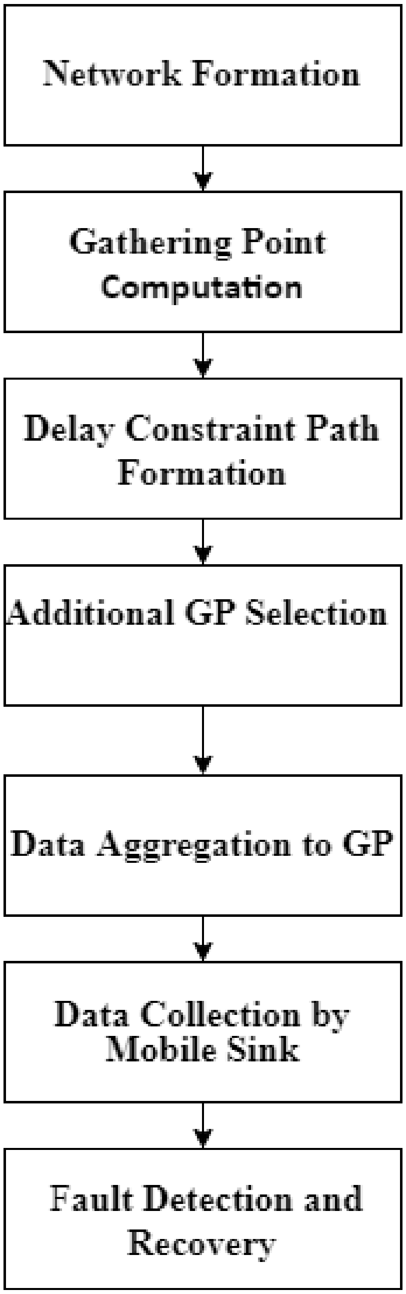

Figure 1. The flowchart of Proposed Technique DAMS

C. Fault Detection and Recovery (FDR)

Nodes fail due to various reasons. But the failure of nodes GPs can cause network breakage by disconnecting the nodes covered by it. We propose an algorithm for the detection of GP failure and recovery of the sensor members which were covered by the failed GP. The failure of GP can be identified by the nodes covered by it during message exchange. The pseudo-code for recovery algorithm is displayed in algorithm 3.

When a node identifies the failure of its GP it broadcasts a help message to all the sensor and GPs in its CR. The nodes which receive the help message reply with their residual energy. The sensors join a GP that is close to it. If more than one GP replies, in that case, the weight function is calculated for the GPs using equation 9. The weight function considers high residual energy and minimum distance. The GP with maximum weight is selected. If there is no GP in its communication range and any sensor replies then it joins the sensor. If more than one sensor replies then join the sensor with maximum weight. Note that the entire fault tolerance phase is carried out in a distributed way. The failure of one GP doesn't affect other nodes, the remaining GP function as usual and the network will function as usual.

Algorithm 3 Fault Detection and Recovery

```
Input: Failed GP and nodes covered by it
Output: New GP assigned to the nodes covered by failed GP
Begin
For each sensor $s_i \in GPfail$
send Help message
Nodes and GP in their CR reply by sending their residual energy
For each sensor $s_i \in GPfail$
if any GP replies it joins it then
    while $GP < 1 replies$ do
        calculate weight using equation 9
        Join GP with maximum weight
    end while
else
    Any Sensor node replies join it
    while $sensor < 1 replies$ do
        calculate weight
        Join sensor with maximum weight
    end while
end if
Stop
```

5. SIMULATION RESULTS/ PERFORMANCE EVALUATION

For analysis 500 × 500 m2 network is considered in the NS-2 version 2.34 network simulator. Homogeneous nodes are taken and nodes once deployed are stationary. Network scenario with the different number of nodes, different CR are simulated. The proposed method DAMS is compared with previous algorithms DAEDT [5],(EEDR) [24], and GAECH [28]. The simulation parameters are listed in table II.

A. Analysis with Standard Deviation

To determine the load balancing amid the sensor nodes in the network the standard deviation (SD) of the remaining energies of nodes is calculated. The SD should be low. SD is inversely proportional to load balancing. Low SD gives high balancing. Fig. 2 shows a graph with different sensor nodes plotted against the SD of remaining energy.The proposed DAMS outperforms other algorithms in terms of SD this is due to the consideration of residual energies of nodes in the calculation of density used in the selection of GP and reforming of the path. The standard deviation of the remaining energy of EEDR is 12%, GEACH is 74% but DAMS has only 5% SD.

B. Analysis with Network lifetime

Here we compare the algorithms using network lifetime. The network lifetime graph with varying nodes and varying CR is shown in Fig. 3 and 4. In varying CR it can be seen that there is a slight decrease in the lifetime as the CR increases. The proposed method enhances the Network lifetime when compared to EEDR and with GEACH because of the selection of GPs that reduces the energy consumption and enhances the network lifetime. For the selection of GPs two algorithms are proposed in this work. The GP is selected by using density equation 5 and further added by using equation 8 without increasing the path length because of which the entire network is balanced and in turn increases the lifetime. Performs better by 10% when compared to EEDR and 23% when compared with GEACH when plotted against CR. Performs better by 8% when compared to EEDR and 10% when compared with GEACH when plotted against varying nodes.

C. Analysis with Packet Delivery Ratio

Comparison using packet delivery ratio (PDR) with varying number of nodes. packet delivery ratio (PDR) is the rate at which packets are delivered at the Base station. Can be calculated as,

$$PDR = \frac{Packetrecieved * 100}{\sum_1^n packetsent} \tag{10}$$

Packetrecieved are the number of packets received by the Base station and packetsent are the number of packets sent by the source nodes and n is the number of nodes. The graph for PDR with varying nodes is displayed in Fig. 5. DAMS has a 10% high packet delivery ratio when compared to the other algorithms. The performance of DAMS owes to the delay-aware path of the MS, which is achieved by efficient selection of GPs.

D. Analysis with average Delay

The time between the packet sent and the packets received is called delay time and can be calculated as,

$$Delay = PRtime - PStime \tag{11}$$

TABLE II. SIMULATION PARAMETERS

Parameters	Values
Network Size	500 m *500 m
MAC	802.11
Number of sensors	50,100,150,200,250
Communication Range	100,125,150,175,200
Packet length	512 bytes
γ	95%
Radio propagation model	Two Ray Ground
Transmission power	0.02J
Receiving power	0.01J

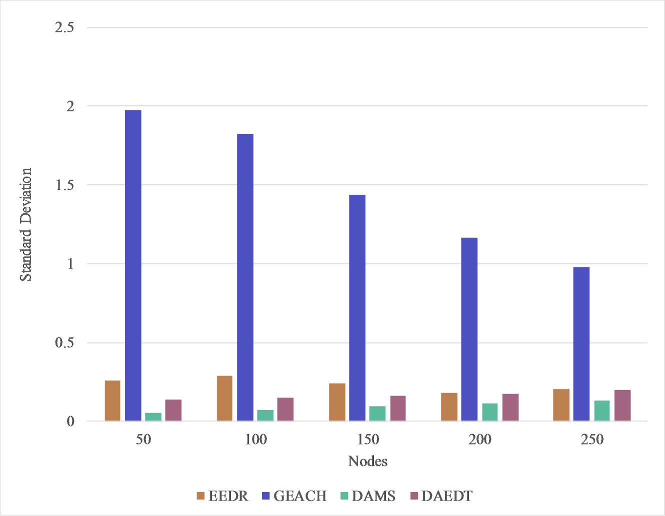

Figure 2. Standard Deviation with varying nodes

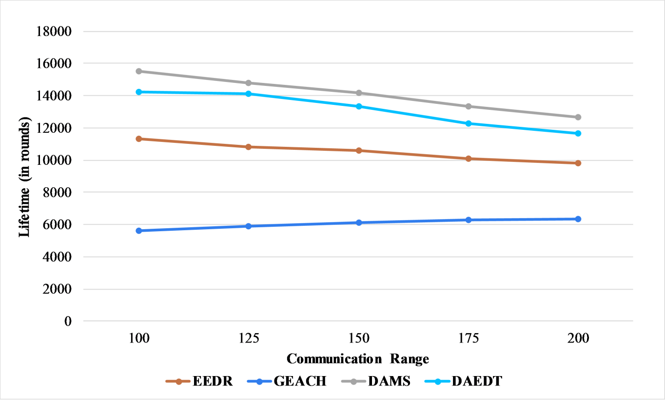

Figure 3. Network Lifetime with varying Communication Range

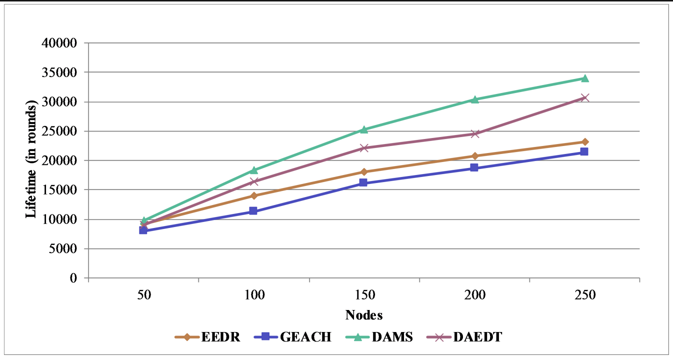

Figure 4. Network Lifetime with varying nodes

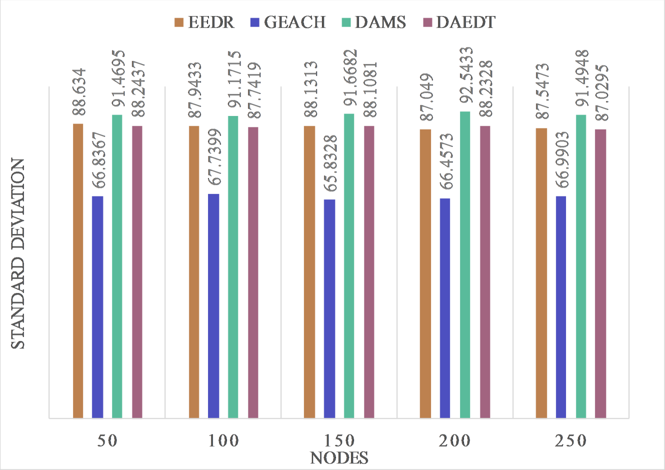

Figure 5. Packet Delivery Ratio with varying nodes

The average delay for all the packets can be calculated as,

$$AvgDelay = \frac{\sum_0^n PRtime - PS\,time}{time} \qquad (12)$$

PRtime is the time at which the packet is received by the Base station and PStime is the time the packet is sent. Fig. refFig:Delay shows the graph of average delay versus varying CR. For critical applications such as fire detection, intrusion detection the delay should be less. The delay of DAMS is less when compared to the other two algorithms. This is achieved due to the dynamic path of the MS in DAMS which is formed by considering the delay.

E. Analysis in terms of fault tolerance

In this section, we evaluate the proposed algorithm with and without the fault detection and recovery algorithm. The number of alive sensor nodes after 200-1000 rounds graph for with fault and without fault recovery algorithm is given in Fig. 7. It can be observed that the proposed algorithm with fault recovery has a greater number of active nodes when compared to without fault. Fig. 8 the network lifetime with varying nodes is evaluated. The proposed algorithm with fault recovery has an increased lifetime when compared to without fault recovery algorithm. This is achieved because the fault recovery algorithm keeps the network connected even after the failure of any GP. The orphan nodes are recovered without disturbing the functioning of other GPs.

6. Conclusions and Future Work

In this paper, a delay-aware MS path is formed. For the selection of GPs, the density of nodes is considered which includes the residual energy of nodes. Further to reduce the load of GPs in delay aware path additional set of GPs are selected by considering the shortest distance and nodes indegree. A method for the detection of faulty GP and recovery of nodes covered by the faulty GP is proposed. The recovery method is distributed and doesn't disturb the functioning of other GPs while the recovery is going on. The proposed method is compared with existing methods in terms of the standard deviation of remaining energy, delay, network lifetime, and packet delivery ratio with a varying number of nodes and varying CR. The proposed methods excel in all aspects. It balances the energy consumption and prolongs network lifetime. In the future improved MAC layer protocols can be added to avoid collision and congestion of packets.

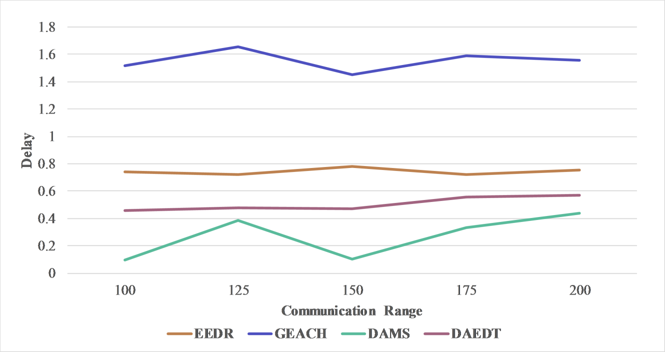

Figure 6. Delay

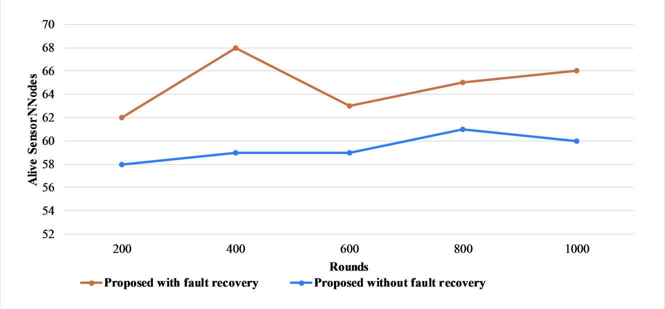

Figure 7. Enhancement in number of alive sensor nodes due to fault tolerance

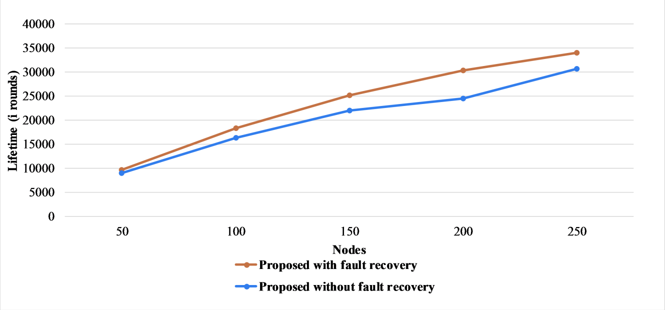

Figure 8. Enhancement of Network Lifetime due to fault tolerance

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