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An Efficient Node Failure Discovery Mechanism in the Wireless Sensor Network

Manikandan K.B* and N. Sasirekha**

Abstract : Node failures are the most dangerous causing threat in the wireless sensor network where there is no fixed path is available. Node failure would lead to failure during data transmission by causing the data's to fall or corrupt before reaching its destination. Thus node failure detection is most considerable research focused by various researchers to reach the successful data transmission. In the existing research work probability detection scheme is introduced which can find the node failures by using the information gathered from the neighbors. However this approach may not find the node failures when there is direct path available between the nodes that are present in different regions. This is resolved in the proposed research work by introducing the novel mechanism namely Node Failure Detection and recovery Mechanisms depends on the Clustering Technique (NFDM-CT). The proposed research work will group the nodes that are fall in different regions based on their hop count. The higher priority for falling in the cluster is given based on nodes with no neighbor. The proposed research work can perform node failure detection with the increased decreased detection rate which evaluated and proved in the matlab simulation environment. The total number of nodes, N, is varied from 30 to 90 and based on the different performance metrics it is proved that the proposed NFDM-CT scheme provides better performance than the existing scheme.

Keywords : Node failure detection, Probabilistic approach, node importance level, transmission range, limited resources.

1. INTRODUCTION

A Mobile Wireless Sensor Network (MWSN) [1] can fundamentally be defined as a Wireless Sensor Network (WSN) in which the sensor nodes are mobile. MWSNs are extremely smaller, emerging field of research in contradiction of their well-established ancestor. MWSNs offer more versatility compared to static sensor networks since they can be implemented in any environment and can handle rapid topology variations. But, several of their applications are identical, like environment monitoring or surveillance. Generally, the nodes comprise of a radio transceiver along with a microcontroller driven by a battery, in addition to some type of sensor for the detection of light, heat, humidity, temperature, etc.

In case of MWSNs, there are two sets of challenges that must be taken with keen interest; hardware and environment. The major hardware constraints are inadequate battery power and low cost prerequisites. The restricted power indicates that it's vital for the nodes to possess energy efficiency. Limitations in price frequently ask for algorithms that are less complex for simpler microcontrollers and use only just a simplex radio. The foremost environmental aspects are the shared medium and varying topology. The shared medium dictates that channel access must be regulated by some means. This is regularly done with the assistance of a Medium Access Control (MAC) scheme, like Carrier Sense Multiple Access (CSMA), Frequency Division Multiple Access (FDMA) or Code Division Multiple Access (CDMA). The varying topology of the network comes from the mobility of nodes, which indicates that multihop paths from the sensors to the sink are not constant.

* Research Scholar (PhD), Rathinam College of Arts and Science, Coimbatore.

** Associate Professor, PG Department of Computer Applications, Vidyasagar College of Arts and Science Udumalpet

Meanwhile, there is no fixed topology in these kinds of network; one of the ultimate challenges is routing data effectively from its source to the destination. Usually, these routing protocols are inspired from two areas; WSNs and mobile ad hoc networks (MANETs). WSN routing protocols is responsible for the required functionality however cannot effectively manage the high frequency of topology transformations, While, MANET routing protocols can cope with network mobility, they are evolved for two way communications, not often required in sensor networks [2].

The target is to cooperatively sense, gather and process the information regarding objects in the coverage area, and subsequently sends it to the observer for the purpose of processing and analyzing. It is a system with multi-functional and low energy consumption [3]. Failed nodes possibly will reduce the Quality of Service (QoS) of the complete WSN. It is crucial and also important to examine the fault detection techniques for nodes in WSNs for the reasons below [4].

1. Bulky low-expense sensor nodes are frequently employed in unmanageable and aggressive situations. Hence, sensor nodes failure can happen more easily compared to other systems;
2. The applications of WSNs are being extended. WSNs are also employed in few situations like monitoring of nuclear reactor in which large security is needed. Fault detection for sensor nodes in this particular application holds huge significance;
3. It is burdensome and impractical to make manual examination if the nodes are working normally;
4. Right information cannot be provided by the control center since the failed nodes would generate data that is erroneous. In addition, it may lead to a damage of the entire network in critical scenarios;
5. Nodes are generally battery-driven and the energy is less, hence faults usually happen because of battery exhaustion.

In this research work, a novel node failure detection scheme is introduced for the purpose of improving the network performance in terms of increased network lifetime and the optimal packet forwarding. This is carried out by considering the facts regarding nodes like being autonomous and not falling within transmission range of the rest of the nodes. These issues are managed in the proposed research technique through the clustering of the mobile sensor nodes that are present in various locations on the basis of their node importance. The node importance is computed with regard to the number of neighbors of that respective mobile node and its range of transmission. Once the clustering of mobile nodes is done, packets will be passed through them and thereafter the node failure detection is carried out making use of probabilistic detection technique if the heart beacon messages are not received for the specific time period.

The entire research work is organized as below: In the next subsequent section, a description regarding the different research strategies that have been performed are given in detail. In section 3, elaborate discussion of the research methodology proposed in addition to appropriate examples and diagrams is provided. Section 4 provides the description regarding the experimental evaluation with regard tovarious performance measure along with several otheravailable research methodologies is discussed. At last in section 5, the conclusion of the overall research work is given on the basis of their performance results.

2. RELATED WORKS

This section provides detailed explanationsaboutseveral research techniques, which have been introduced earlier by various researchers. In this section, a precise picture concerned with the multipleavailable research methods and their functionalities in the elaborated in detail.

In [5], all the nodes in the cluster are completely classified as boundary, pre-boundary, internal nodes and cluster head. Failure of boundary nodes does not ensure much influence in the functioning and does not need any recovery. When the energy of a particular node falls under the threshold value, at that time it transmits a fail-report-msg to subsequent nodes. In case there is a failure in the cluster head, then it makes its children to have their residual energy information exchanged. The node with higher residual energy turns out to be the Cluster Head (CH) and the node with second maximum residual energy turns into secondary CH. Then the children get attached to this new cluster head. This technique consumes energy since it interchanges their energy information as it is also time taking.

The disadvantage of [5] is got over by deploying a backup secondary cluster head [6]. The node having greater residual energy then becomes the cluster head and then the node having the second maximum residual energy is made the secondary cluster head. In this scheme, when the energy of the CH comes below the threshold value, the secondary CH becomes the main CH [6]. At this point, there is no requirement of any messages regarding the residual energy to be transmitted between the nodes. Therefore, this scheme is more time and energy efficient.

In[7], the sensor node failure detection is completely depends on the RTD (Round Trip Delay) time of different Round Trip Paths (RTP). RTD denotes the time essential for a data to be transmitted from the source node and return to the same source node. RTP is created by making a group of three sensor nodes. Accuracy of this technique can be maximized through the reduction of the RTD time. With all the nodes working properly, the RTD computed provides the threshold RTD value. This value is utilized for comparison purposes for the detection of the failed node. The existence of a failure node modifies the RTD values. The new RTD value could be either bigger compared to the threshold value (when node is malfunctioning) or infinity (if the node is dead).

In [8] the design of a distributed fault-tolerant decision fusion in the existence of sensor faults when the local sensors consecutively transmit their decisions to a fusion center is addressed. CollaborativeSensor Fault Detection (CSFD) scheme is formulated for the purpose of eliminating the untrustworthy local decisions while performing distributed decision fusion. On the basis of the pre-determined fusion rule, presuming similar local decision rules and fault-free scenarios, an upper bound is decided over the fusion error probability. In accordance with this error boundary, a criterion is introduced for searching the faulty nodes. When the fusion center detects the faulty nodes, all therespective local decisions are eliminated from the calculated of the likelihood ratios which are followed for making the final decision.

In [9] a distributed solution is formulated for a canonical task in WSNs—the binary detection of interesting environmental incidents. They explicitly allow for the possibility of sensor measurement faults and developed a distributed Bayesian scheme for the purpose of detecting and correcting such faults.

In article [10] an agreement-based fault detection mechanism is formulated for the purpose of detecting cluster-head failures in clustered Underwater Sensor Networks (UWSNs). Every cluster member is permitted to independently detect the fault status of its CH and simultaneously a distributed agreement protocol is employed to attain an agreement on the fault status of the CH among multiple cluster members. The detection methodology is dependent a TDMA MAC protocol which is utilized in the network and executes in concurrence with the normal network operation by conducting a distributed detection process periodically at every cluster member. It uses the data that is sent periodically by a cluster head in the form of the heartbeats for the purpose of fault detection. A number of forward and backward TDM frames are specifically created for facilitating the multiple cluster members to attain a consensus within the two frames in every detection process. Also, a schedule generation method is also presented for a cluster head to have the schedule of transmission of the forward and backward frames generated.

3. EFFICIENT NODE FAILURE DISCOVERY MECHANISM

A mobile wireless sensor network is a widely known domain in the practical world environment, employed by several applications for finding and sharing the information concerned with the environment. The mobile node failure that may happen owing to technical problems or resource constraint issue would result in degradation in the network performance. In the available research work, the probabilistic based detection approach, which is based over location estimation information, is brought into use for the detection of the node failures that might not be appropriate for all types of network conditions. This technique cannot do node failures detect if the nodes are present away from the range of transmission and the nodes have only one neighbor node. In such a case, location estimation information might not be received with accuracy, resulting in degradation in the network performance.

In the proposed scheme, node failure detection and recovery mechanisms depends on the clustering technique (NFDM-CT) is introduced which would effectively cluster the nodes in accordance with the nodes importance level. In this work, node importance is computed based on neighbor's information and the transmission range level. Subsequently, the CH is selected for the clusters, in which the CH will be present under transmission range of the entire mobile sensor nodes existing in the cluster. Therefore, the location estimation information regarding the nodes that are assumed to be failed/moved beyond the transmission range can be found effectively. The steps that are to be adhered to, for the effective and optimized node failure detection and recovery strategy are listed below:

- Clustering of mobile wireless sensor nodes with respect to energy, network life span and the contribution of relaying messages.
- Electing the cluster heads on an optimal basis of maximized network life span and packet forwarding
- Discovering the node failure making use of the probabilistic based detection technique
- Node recovery on the basis of the level of failure cause.

The steps mentioned above are followed in order to detect the node failures with accuracy, and therefore the necessary actions can be carried out for recovering the nodes. The research work proposed surpasses the challenges of the available research by adopting these steps for the node failure detection and recovery.

The complete flow chart of node failure detection and recovery process is illustrated in the below figure.

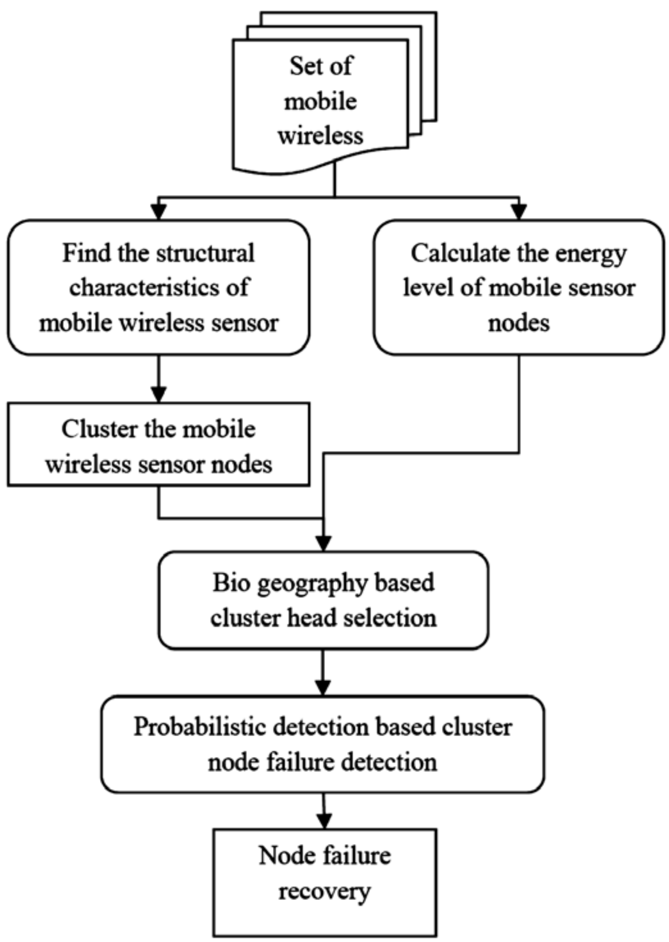

Figure 1. Overall flow of node failure detection and recovery mechanism based on clustering technique

Figure 1 shows the view of the newly introduced research methodology on an overall. This figure indicates the processes that have to be followed step by step to attain the optimal finding and recovery of the faulty sensor nodes existing in the environment of mobile wireless sensor. The elaborate discussion of the research methodology proposed is provided in the next sub section clearly.

3.1. Clustering Mobile Wireless Sensor Network based on Node Importance Level

It must be noted that all schemes to-date make use of the node id or the node's degree in prioritizing the node for insertion in the dominating set, *e.g.*,[11, 12]. Few schemes initially consider the node(s) which serves as the only neighbor of a node in $N_{12}(\cdot)$ and subsequently examine the node(s) with the maximum degree with respect to nodes not covered yet, however other schemes simply consider the node(s) with the maximum degree. None of these schemes is suitable since: a) the former schemes treat nodes in a heterogeneous manner, and b)later schemes, even though they are conscious of the 2-hop neighborhood, do not make completetreatment of the availableinformation. Hence, a newdefinition of node's significance is presented that completely avoids both weaknesses.

Consider $\sigma_{uw} = \sigma_{wu}$ represent the number of shortest pathsfrom $u \in V$ to $w \in V$(by definition, $\sigma_{uu} = 0$). Consider $\sigma_{uw}(v)$ represent the number of shortest paths from utowthat some vertex $v \in V$ lies on. Subsequently, the node importance index NI(v) of a vertex v is given as:

$$\mathrm{NI}\,(v) = \sum_{u \neq v \neq w \in V} \frac{\sigma_{uw}(v)}{\sigma_{uw}}$$

Large values for the NI index of a node v represent that this node v can reach others on comparatively shortpaths, or that the node v lies on extensive fractions of shortest paths connecting remaining nodes. It is observed that the NI index computed over the entire graph acquires the structural features of the graph in a better manner than done by the node degree. In addition, it enforces a ranking of the nodes based on their contribution in surrounding the entire network. Factually, the NI value does the identification of what is called the geodesic nodes of the network, *i.e.*, nodes playing the role ofarticulation points, or nodes havinga great degree corresponding to their neighbors. This way, it can be proven that NI does the concept generalization of node degree, since this has been utilized for the purposes of clustering till now.

The NI index would be extremely advantageous in designing clustering protocols in sensor networks only if it capturesstructural features of small graphs, for instance, the 2-hopneighborhood of a node and only if it can be calculatedreally fast. When these conditions hold, subsequently it can be utilizedin designing localized algorithms. Certainly, they bothhold. The reader can simplyvalidate that, for any nodev, the NI indexes of the nodes in $N_{12}(v)$ computedonly for the subgraph LNvdisclose the relative significance of the nodes in covering the subgraph N_{12} (fromv's point of view). In case for a node u, which belongs to the 2-hopneighborhood of a node v(or if $u \equiv v$), the NI indexof u(computed over LN_v) will be indicated as $NI_v(u)$.

The individual practices for the formation of the clusters are not radically dissimilar from those developed for other clustering protocols. Therefore, it is assumed that the reader is well-known with them. Assume a sensor network, where the nodes do the exchange of "Hello" messages (beacon signals) with their neighbors in a periodic manner, containing the list of their one hop neighbors. (It is to be recalled that the protocol operate sun modified also in case that the nodes just inform regarding for their presence, without notifying regarding their neighbors). Therefore, each node is capable of forming a graph that corresponds to its 2-hop neighborhood (or its 1-hop neighborhood). Furthermore, each node, when it receives a packet, is capable of figuring out from which 1-hop neighbor this packet was transmitted.

3.2. Bio geography based cluster head selection

Grouping sensor nodes into the cluster can effectively decrease the size of the routing table of the all individual nodes and preserve communication bandwidth. Sensors in these kinds of environments are energy constrained and moreover their batteries cannot be recharged. Consequently, designing energy-aware algorithms turns out to be an important factor for the purpose of extending the lifetime of sensors. Cluster formation and CH selection schemes are employed for the purpose of achieving better operation and effectively extend network lifetime by means of minimizing energy consumption.

In case of bio-geography based optimization scheme, the selection conditions of the objective function completely depends on theresidual energy, minimum average distance from themember nodes and head count of the probable CH nodes.The foremost concept in the proposed Bio-Geography based Optimization (BGO) scheme is theselection of a CH that can effectively reduce the intracluster distance between itself and the cluster member, andthe optimization of energy management of the network.

BGO [13] is a new evolution algorithm formulated by Dan Simon for the global optimization.It is motivated by the immigration and emigration of species amongislands in search of more friendly habitats.Every solution is known as a "habitat" having a habitat suitability index (HSI) and indicated by an -dimension real vector. The variables of the individual whichfeature the habitability are known as suitability index variables (SIVs). An initial individual of the habitat vectors is generatedrandomly. Those solutions, which are good are regarded as habitats having a big HSI. And those, which are poor are regardedto be habitats having a low HSI. The highHSI attempts to have their features shared with low HSI. Low HSI solutions acknowledge several new features from high HSI solutions.In case of BGO, a habitatHis a vector (SIV*s*) which completely follows migration and mutation step in order to reach the optimal solution. The new candidate habitat is producedfrom all of the solution in population through the process of using the migrationand mutation operators.

In BGO, the migration strategy extremely resembles the evolutionarystrategy in which several parents can contribute to a single offspring. The migration model is utilized for the purpose of changing existing solutionand to transform the existing island. Migration is a probabilisticoperator that fine-tunes a habitat H. The probability Hiis modified in accordance to its immigration rate λ_i, and the source ofthe modified probability comes from H_j is in accordance to theemigration rate μ_i. In BGO, every individual has its individual immigrationrate λ and emigration rate. The immigration rate andemigration rate are functions of the number of species in thehabitat.

$$\lambda_k = 1\left(1-\frac{k}{n}\right)$$

$$\mu_k = E\left(\frac{k}{n}\right)$$

Where I represents the maximum possible immigration rate, E indicates themaximum possible emigration rate, *k* denotes the number of species of the *k*th individual, and nindicates the maximum number of species. It must be noted that this model is a linear migration model. Migrationcan be described as given below:

```
Procedure Habitat migration
Begin
        For i = 1 to NP
        Select X_i with probability based on λi
        If rand (0, 1) < λ_i then
        For j = 1 to NP
        Select H_j with probability based on μ_j
        If rand (0,1) < μ_j then
        Hi (SIV) ← H_j (SIV)
End if
```

End for

End if

End for

End

Once the clustering and cluster head election is done optimally, transfer of packetswill be carried out. Simultaneously, hello message would be transmittedin addition to the control packets routing. If there is no response from the nodes for the specifictimeperiod, then there would be an analysis if the node is failed or if it has moved away from itsrangeof transmission. It would be performed by collecting the location estimation information from the neighboring nodes and also the cluster head, therefore the accurate prediction regarding the node failure detection can be carried outmaking use of the probabilistic detection approach. The operation of the probabilistic detection approach is explained in the next section that follows.

3.3. Node Failure Detection using Probabilistic Detection Approach

In this work, a probabilistic scheme is adapted and formulated non binary feedback in accordance with node failure detection scheme thatsystematically integrate localized monitoring, location estimationand node collaboration.The non-binary feedbackscheme diverges from the binary version in that Ainitially gathersnon-binary information from its neighbors and subsequently computes the conditional probability that B has failed using all theinformation jointly. Consider the scenario in which none of A's neighbors has heard regarding B (otherwise, the case is insignificant as discussed below). Exactly, consider A receives responses from n – 1 neighbors regarding B. Without any loss of generality, represent these nnodes (*i.e.*, A and its n-1 neighbors) as 1,…., n. For time t + 1, consider $C_{i,j}$ represent the event that the i-th node does notreceive the j-th heartbeat packet from B; consider $P^{(i)}_{c,K}$ indicate theprobability that all the K heartbeat packets from B to node Iare lost (K ≥ 1); consider Rirepresent the event that the i-th node is in the transmission range of B. Recall that D indicates theevent that B fails at time t + 1. Subsequently, A calculates the followingprobability:

$$P(D \mid \overline{C}_{1,1,\dots}\ \overline{C}_{n,1,\dots}\ \overline{C}_{n,k}) = \frac{}{P(\overline{C}_{1,1,\dots}\ \overline{C}_{1,K,\dots}\ \overline{C}_{n,1,\dots}\ \overline{C}_{n,K})}$$

It is summarized as, in case of the non-binary scheme, A'sneighbor, i, responds the following information to A. When it hasheard from B at time t + 1, subsequently it transmits a single bit to A (same as that in the binary feedback scheme). Then,it transmits $P^{(i)}_{c,K}$ and $P(R_i)$ to A. When A receives a bit fromone of its neighbors, at that point it knows that B is alive. Then,it obtains the probability that B has failed. When theprobability is greater than threshold θ, at that point A generates analarm that B has failed and transmits it to the manager node. Algorithm 1 summarizes the actions associated with sending aquery message and the actions following hearing responses on the query. Algorithm 2 summarizes how a node reacts toa query message. Hence, for thebinary scheme, this scheme is unresponsive to the choice ofthe detection threshold, θ, and utilizes the same mechanism forforwarding the alarm to the manager node.

Algorithm 1

Non-binary feedback scheme (sending query)

Suppose A hears from B at t but not t + 1

A calculates p, probability that B fails

If ($p \geq \theta$) then

A starts a timer with a random timeout value

If A has not heard a query about B when the timer times out then

A broadcasts an inquiry about B

If A receives at least one response of 0 then

A does nothing (B is alive)

Else

A upates p based on feedbacks

If ($p \geq \theta$) then

A sends a failure alarm about B to the manager node

End if

End if

End if

End if

Algorithm 2

Non-binary feedback scheme (receiving query)

Suppose C receives a query message about B

If C has just heard from B then

C responds with 0

Else

C responds with the probability that all k messages from B to C are lost and the probability that C is in B's transmission range

End if

By employing these algorithms, the node failure detection can be carried out optimally. Then the clustering and cluster head elections make the processing of the node failure detection approaches easy. This newly introduced research methodology is deployed in the matlab simulation environment thatassessedwith respect to different performance measures.

4. EXPERIMENTAL RESULTS

In this subsection, a quantitative performance study is presented.In all the simulations, the nodes move in a 500*m* *500m square area. The total number of nodes, N, is varied ranging from 30 to 90. From these nodes, a total of ten percentage of the nodes will be nodes that failed *i.e* is 9 nodes. The initial locations of the nodes follow a 2D Poissondistribution. The transmission range of a node is circular withthe radius, *r*, varied from 30*m* to 130*m* (the schemes canbe applied to irregular transmission ranges; evaluation underthose settings is left as future work). The above combinationof parameters lead to a wide range of neighborhood densityfor evaluating our approach The performance measures that are considered in this work evaluating its performance improvement over existing methodology, probabilistic detection approaches are listed as follows: "Detection rate, False positive rate, Communication overhead".

4.1. Detection Rate comparison

Detection rate is defined as how well the proposed research scenario can find the number of nodes failed in the network environment for the varying number of nodes. The detection rate is calculated as like as follows:

$$\text{Detection rate} = \frac{\text{True Negative}}{\text{Total attacks}} \times 100$$

Figure 2 illustrates the comparison analysis made between the newly introduced and the already available research technique with respect to getting the node failures. The greater detection rate indicates the improved performance of research approach proposedwhile this figure 2 reveals clearly that the proposed research methodologyresults ina higher detection rate compared to the other available research methodologies.

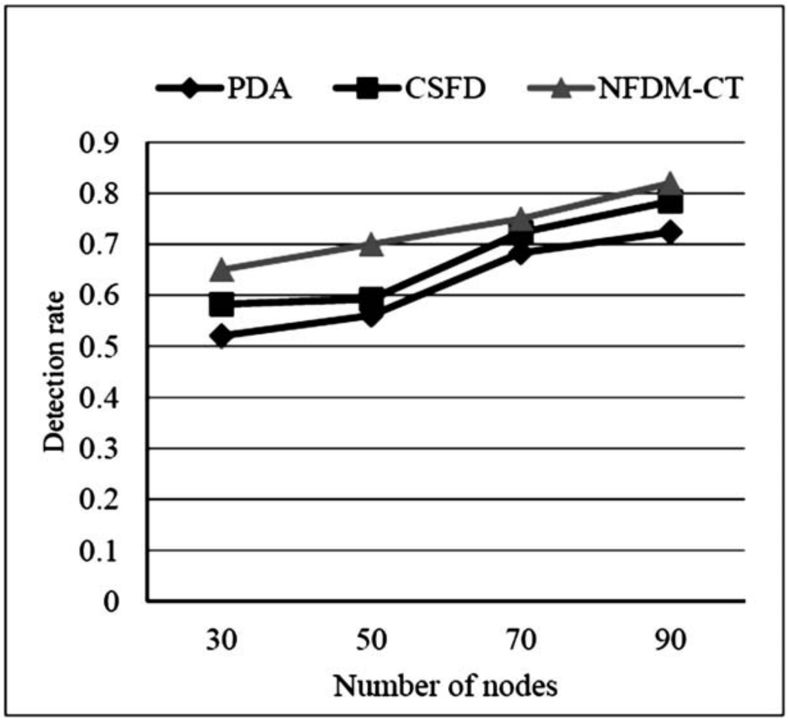

Figure 2: Detection rate comparison

4.2. False Positive Rate

When performing multiple comparisons in a statistical framework such as above, the false positive ratio (also known as the false alarm ratio, as opposed to false positive rate / false alarm rate) usually refers to the probability of falsely rejecting the null hypothesis for a particular test. False positive rate is calculated as like as follows:

False Positive Rate = N incorrectly classified as P / N

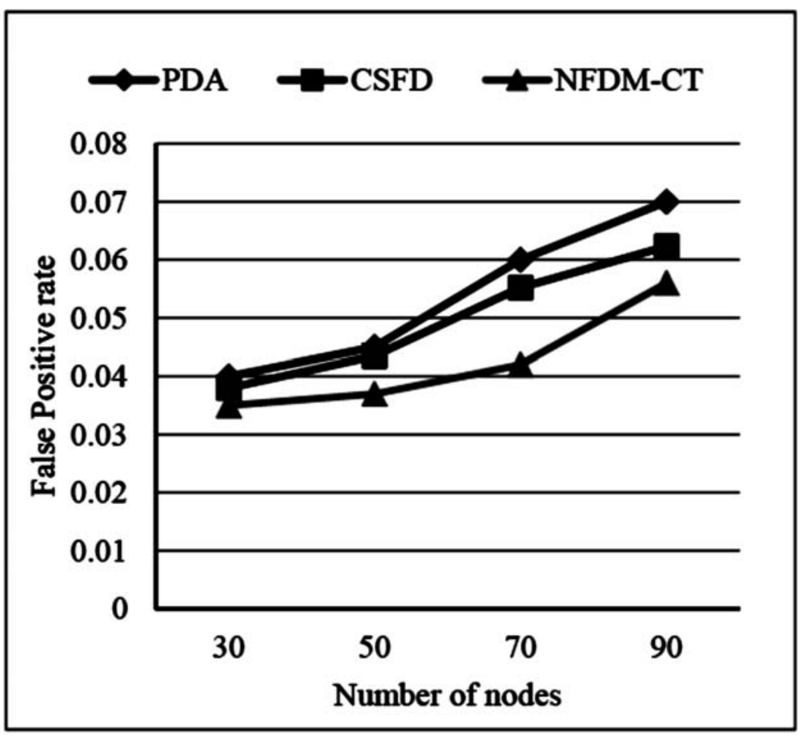

Figure 3: False positive rate

The much lesser false positive rate in this scheme is due to its capability of differentiating a node failure from the node that moves awayfrom therange of transmission, whereas the available schemes cannot distinguish between these two cases. The figure 3 shows that the research methodologyproposed offers much lesser false positive rate compared to the available research mechanisms, and this way, the performance is enhancedsignificantly on an overall.

4.3. Communication overhead

Let H denote the averagenumber of hops from a node to the manager node. The much lower false positive rate under our scheme isbecause of its ability to differentiate a node failure from thenode moving out of the transmission range, while the existing scheme cannot differentiate these two cases.Thecentralized scheme leads to an average of N*K*H messagesin each time unit, where N is the number of nodes and K isthe number of heartbeat messages per time unit. In our schemeand existing scheme, the number of heartbeat messages is N *K in each time unit, significantly lower than that of thecentralized scheme especially when H is large. The following figure 2, 3 and 4 depicts the comparison. The performance metrics results of the proposed schema is high for detection rate and false alarm rate detection rate since the NFDM-CTmechanism proposed is proposed, efficiently clustering the nodes based on the nodes' importance level, and the false alarm nodes are detected during the initial phase of the work itself.

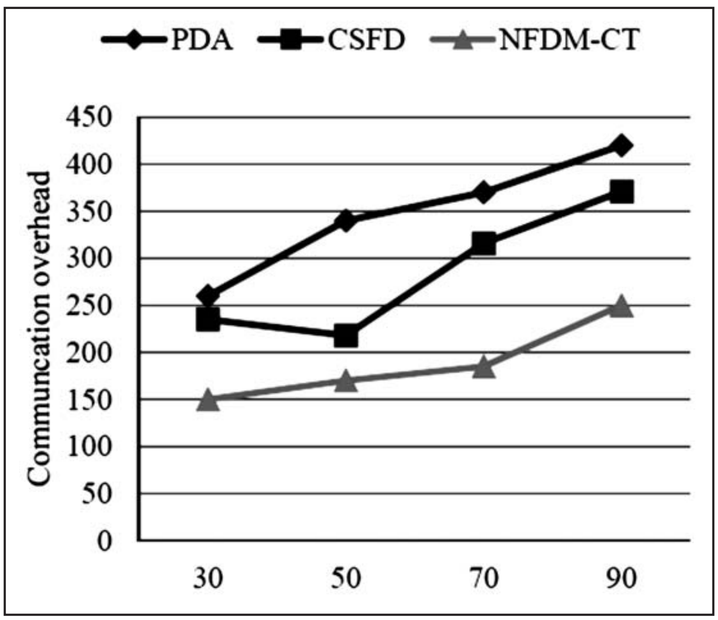

Figure 4: Communication overhead

The lower the communication overhead, the better is the performance. Figure 4 illustrates the comparison of the communication overhead which shows that the research methodology proposedgives better results compared to the available research strategy.

5. CONCLUSION

In this research, clustering based node failure detection scheme is formulated and it is intended for the non-binary feedback based node failure detection schemes that integrate localized monitoring, location estimation and node collaborationfor mobile wireless networks. Here, clustering is carried out in accordance with the node importance level and after clustering CH selection is done optimally by means of biogeography based optimization approach. Subsequent to clustering and CH selection, node failure detection is carried with the assistance of probabilistic approach using location estimation information. This scheme is evaluated in the Matlab simulation environment for the varying number of nodes. Simulation resultsexhibit that the proposed schemes achieve high failure detectionrates, low false positiverates, and low communication overhead than the existing research methodologies.

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