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Hybrid Connectivity Restoration Approach for WSANs

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Abstract: Wireless Sensor and Actor Networks (WSAN) have been very popular from the research community because of their suitability for real time systems. To maintain inter-actor connectivity is crucial in real time situations where actors have to quickly take corrective actions to detected events. Failure of actor and sensors partitions the inter-actor network into disjoint segments, and thus disrupt the network connectivity. Various approaches have been proposed to restore the connectivity of the network. This paper proposes the node failure recovery scheme known as hybrid connectivity restoration approach that works in a distributed manner for detecting partitions in a network and restore the connectivity. This approach may involve relocation of multiple sensors and actor nodes on the path and also analyze the energy consumption of each node before selecting them as a backup node. Thus, reducing the message overhead, less data backup energy consumption, and improves network connectivity. The effectiveness of this hybridization is validated through various simulation experiments.

Keywords: Node failure, Remains Energy, Topology change, connectivity restoration, shortest path.

I. INTRODUCTION

Wireless sensor network (WSN) refer to the collection of homogeneous elements such as collection of sensors in a network but today's popular approach called wireless sensor and actor network (WSANs) refer to the collection of heterogeneous elements linked by wireless medium to perform distributed sensing and acting tasks. These heterogeneous elements are known as sensor nodes and actor nodes. In WSANs, sensors gather information about the physical world, sends the information to the actors that are able to take decisions and then perform appropriate actions. WSAN can reduce cost and human risk in various areas such as space exploration, coastal and border protection, search and rescue etc. Nodes in a network are deployed gradually and then form a network in order to share data and taking corrective actions in the execution of particular task. The nodes need to be stay reachable to each other, thus connectivity should be maintained at any cost.

It is clear that for the connectivity, the only requirement is the location of any node should be within the communication range. The failure of a node could disrupt the network connectivity. The best case of a network is that the failure is recovered with the limited energy as well as with the less distance. But the worst case is that, due to the failure, the network gets partitioned into different segments and the connectivity of a network is lost.

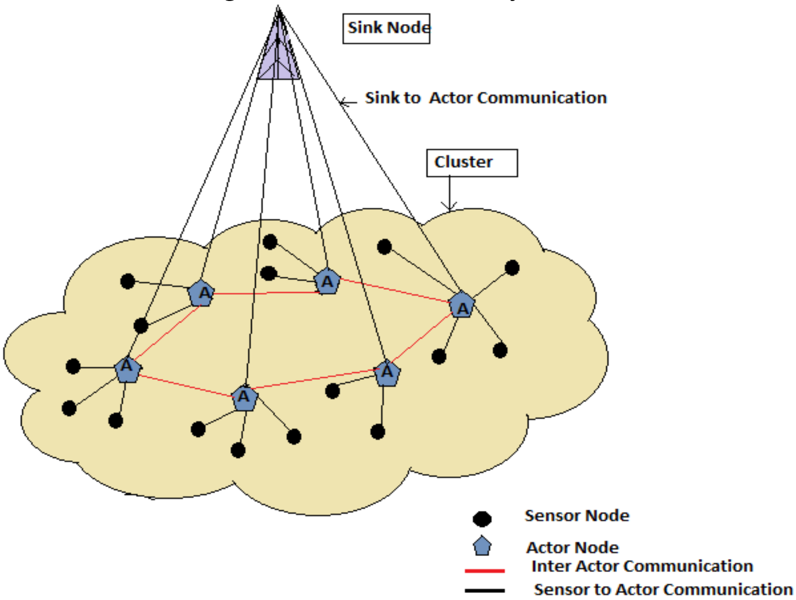


Fig 1: A Model of WSANs

The fig 1 demonstrates the wireless network with number of actor nodes are connected with sensors. All connected actor nodes reports directly to the situated sink node.

Among all the problems of wireless sensor and actor networks, the major one is network partitioning due to the failure of nodes that are critical to network. The network gets partitioned into disjoint segments. For the recovery of network, additional nodes can be used that are mobile such as unmanned aerial vehicles (UAVs) or robots [3]. These nodes are expensive to deploy but to reduce the cost of network the implicit actors are used to replace the failure nodes. To enable such tasks, actor nodes need to be stay reachable within a range and energy conscious for replacement.

Several approaches are used to recover the network from partitioning, that are further classified into three flavors [11, 12]:

a. Pre-Failure Approach: Several recovery approaches are followed to maintain inter-connected topology. During these approaches, network bears large message overhead between actor nodes.
b. Post-Failure Approach: When the failure occurs, the respective backup nodes initiate the recovery until the connectivity is restored. These approaches are suffered from high energy consumption during recovery.
c. Hybrid Approach: Each critical actor identifies its backup node to handle its failure, when the failure arises in the future. The hybrid approach reduces recovery time, message overhead as well as low energy consumption as each actor has a capability to identify their backup in advance.

In this paper, I present a hybrid approach for connectivity restoration in WSAN which examines the network proactively for determining the failure actor nodes and then perform assignment of backup nodes reactively based upon the battery life of the actor node. A criterion is followed for the calculation of remains energy of actor before the selection as a backup. When the remains energy falls below the threshold energy the actor turns green and notifies its neighbors' for providing the backup of its data and once the remains energy goes down it changes into dead mode and declared as a failure node. However, recovery of such failure is followed by the nodes on the way. The nodes with large distance are not selected for the backup. The concept of hybridization is that the connectivity is restored with minimum overhead of actors for backup, the lower energy consumption of data backup by failed actors.

This paper is structured as follows: section 2, presents the related study of existing approaches. Section 3, represents detailed description of proposed algorithm. In Section 4, pseudo code of approach is discussed. In Section 5, the performance of HCR is evaluated through simulation and section 6, presents the conclusion of the approach.

II. CASE STUDY

In the previous work related to WSAN, the crucial problem detected by researchers is to maintain the continuous connectivity of network in case of failure. However, various fault-tolerant models are proposed in context of maintaining inter-actor connectivity. The connectivity range of actors has two radios for sensor to actor and actor to actor communication. The proposed approach is followed for maintaining actor to actor connectivity.

Jinglin Du.et.al [8] focused upon the movement of backup nodes to an optimal position through which the backup node can communicate with surrounding sensors as many as possible. But the coverage of all sensors is not possible if the radius of a cluster is large and the energy consumption using this approach is high for all sensors as well as actors.

Abbasi et al. [4[presents a distributed approach like DARA which requires each actor to maintain two-hop neighbors which requires extra memory and increases message overhead while transmitting the status of network to all neighbors. The neighbor is selected for the failed node to initiate the recovery process to minimize the movement overhead. DARA selects the node for recovery that has least node degree. If all the least degree nodes are failed then the network suffers from the starvation problem.

Akkaya et al. [5] suggests an algorithm called PADRA which uses CDS approach to determine a dominatee node to detect cut vertices or critical nodes of network. The backup node does not directly move to the location of the failed node. PADRA requires 2-hop information of network which increases message overhead.

Younis M et al.[6] states a algorithm that called RIM that follows a simple procedure to recover from both critical and non-critical failures in network without considering if the failed node is cut vertex. This is the main disadvantage of this algorithm which doesn't recover the network efficiently.

Imran M et al. [10] designed an approach to handle multi-node failures occurs in a network. This algorithm follows the Centralized scheme and considers the presence of central node which is responsible for processing data and making the appropriate decision. In this approach, central node consider as a single point of failure.

Abdullah et al. [7] presents a distributed algorithm called LDMR uses mobility of nodes and availability of backup nodes for the network recovery during the recovery process. It requires the searching of non critical backup nodes, which increases communication overhead, consumes more backup energy as well as decreases the network life time.

Several schemes are existed for the recovery of nodes are completely reactive and can be divided into two flavors such as block movement which requires high pre failure connectivity of nodes and cascaded movement that needs network state information of nodes for maintenance after failure of nodes.

The present scenario states that the real environment faces several problems while recovering the failed nodes because all the nodes are not capable of participating in the recovery process. The main constraints are loss of battery power, the status of node in the network and congestion in network. Therefore, a hybrid connectivity restoration approach that works in a distributed manner for recovery that elects the node for a backup on the basis of battery backup.

This approach is similar to DCR, PCR and EDCR as it follows cascaded node movement technique to distribute the load of nodes.

III. HYBRID CONNECTIVITY RESTORATION APPROACH (HCRA)

3.1 System Design and Problem Definition

In WSAN, the sensor and actor nodes are deployed randomly in the environment. The location of the nodes is tracked by using global positioning system and by various localization techniques. The inter connected topology is represented by the un directed graph *G (N, E)*, where $N \in n1, \ldots, nz$ and $E \in e1, \ldots, ez$. An edge *(ez)* exists between *vi* and *v j* if there is sink link between the nodes *ni* and *n j*. The communication range or area of a sensor is determined by the maximum Euclidean distance. Each node maintains a 1-hop neighbors list.

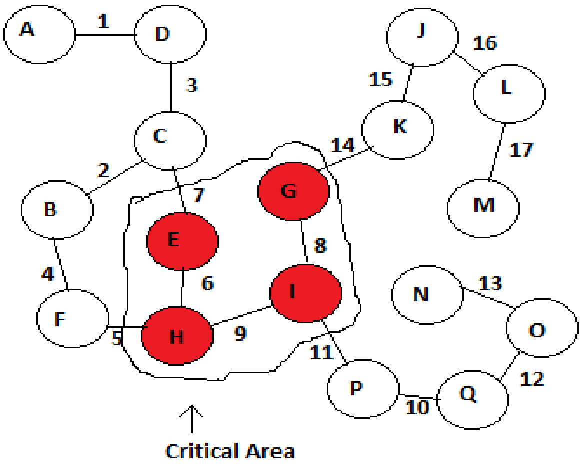


Fig 2: A Inter Actor Wireless Topology

The impact of a nodes failure on the network depends on the position of that node in the topology. Two types of nodes are situated in a network, such as cut vertex and non critical nodes. A node is said to be cut- vertex, if its removal partitions the network into different segments.

In figure 2, the white nodes are non critical of leaf nodes, whose removal doesn't partition the network. The red nodes are critical nodes; meanwhile, the failure of these node such as E, H, I, G partitions the network into disjoint partitions and collection of these critical nodes are called critical area.

Table1: Performance Evaluation and Analysis

Type	Parameter	Range
Network	Network Size	(0,0) to (100,100)m
	Nodes	10-50
	Initial Energy	2 joule
	Sink	(0.5) (0.5)
	Threshold Value	0.1
	Packet Size	128 bits
	Communication range	10-50 m
Radio Model	E_{elec}	50Nj/bit
	E_{mp}	0.004pJ/bit/m^4
	E_{fs}	10 pJ/ bit/ m^2

3.2 HCR Approach

The Hybrid Connectivity Restoration approach explores the DCR approach by maintaining 1-hop neighbor list as well as the EDCR approach by considering the energy constraint for the election of backup nodes.

The approach follows up two parts, the pre-failure knowledge of 1-hop neighbors after the deployment of nodes in a network. By using this information, the critical nodes are examined and select the appropriate backup node to handle the failure. In the post- failure part, the nodes, on board energy are calculated. If the remains energy is equal to threshold value then they send critical data to base station, before the depletion of energy. After the depletion of energy, the actor declares as a failure node and goes into sleep mode. The backup node replaces the failed node and informs the new neighbors of network.

3.2.1 Determining cut vertex and non-cut vertex actor nodes

The nodes in the hazardous environment are deployed randomly. A localized scheme is followed to determine the cut vertices in the graph. For determining the critical nodes, there are two types of schemes such as centralized and distributed [1, 2]. In centralized scheme, up to date network wide information is required to maintain in advance as well as increase in message overhead, so this scheme isn't reliable for large scale real time or dynamic networks. In distributed scheme, the nodes maintain a connection list based on k-hop information and employ the localized algorithm for determining critical/non critical nodes of network. During this scheme no critical node will be missed. The distance between nodes is calculated based upon their relevant positions. If the distance between two nodes is less than the communication range, the node is considered to be non-critical because removal of non- critical node would not harm the connectivity [9].

3.2.2 Election of Backup Actor

Before selection of suitable backup node, first the election procedure is conducted by the sink node on the basis of remaining energy and healthy node is selected.A node with the most remains energy is selected for backup. An energy model is used to calculate the consumption of energy [9].

$$(RE)= \begin{cases} b(E_{elec} + \varepsilon_{FS})\ d< d_o \\ b(E_{elec} + \varepsilon_{MP})\ d> d_o \end{cases}$$

RE= Energy dissipation of transmitting bits between two nodes situated apart by a distance d meters.

E_{elec}= Electronic Energy

ε_{FS}= Free space Energy

ε_{MP}= Transmit amplifier Energy

3.2.3 Selection of Backup Actor

The selections of backup actors is done by using pre-nomination approach so that it reacts instantaneously after the failure of critical node and stop the further possible partitioning of network. Each node maintains neighbor state information (NST) to avoid extra communication overhead. Since, the network gets partitioned when a critical actor fails, the non critical nodes are determined with high energy as a backup to handle the failure. The neighbor state information table has the following contents:

a) **Actor Critical Status (ACS)**: it determines, whether the neighbor actor is critical or non- critical. A non-critical actor is selected for the backup. This will reduce the message overhead, as well as improve the scope of recovery.
b) **Actor Degree (AD)**: A non-critical node such as leaf node with least degree is selected for backup. If the non critical node is not available then the critical node with highest degree is picked up because there is a probability to have non critical nodes in the neighborhood.
c) **Inter- Actor Distance (ID)**: the recovery of failure is followed by the nodes on the way to reduce the movement overhead. The actor nodes with larger distance are not selected for backup.

3.2.4 Detection of Failure

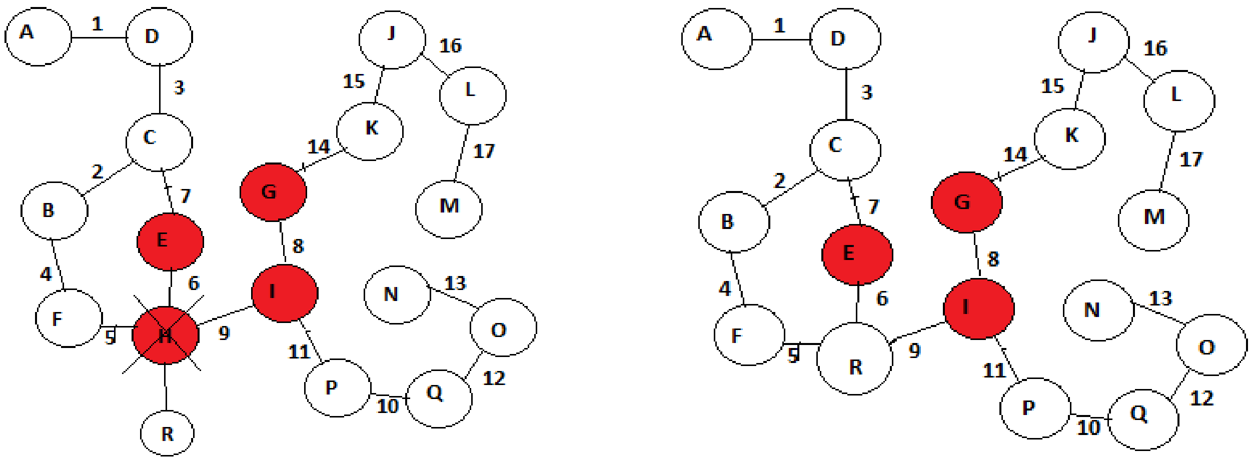
After the deployment, the node can be in three modes by varying the energy levels. When the energy level is high, the node is in active mode. After certain period, the energy goes at the level of threshold value, then the node is in normal mode and start buffering of his data and send to the base station. Once the energy level goes down to zero, then the node goes to the sleep mode and act as a failure. The backup nodes start monitoring their neighbors by detecting the HEARTBEAT messages.

3.2.5 Recovery Procedure

The recovery process of a network starts by determining the position of failure nodes in a network. The actors examined whether the faulty node is cut vertex or not. If the backup node is non-cut vertex then, it simply replaces with the failure node. If it is cut vertex then cascaded relocations are performed.

a) **Primary relocation**

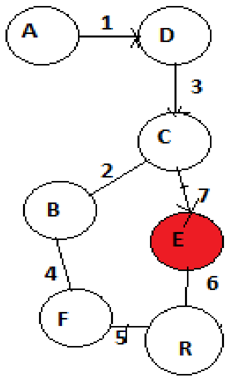
The recovery process is a reactive approach of HCR.



a) Node H represents Cut vertex b) Node R represents non- critical node

Fig 3: Recovery Procedure when Backup Node is Non-Cut vertex. a) Node H is cut vertex & its backup R is no-cut vertex. b) R simply replaces the failure node H.

When backup node is also cut vertex node and cause further partitions if it moves to another location. In this case, the backup critical node inform to its own backup node so that the network stays connected.



a) Node E is cut vertex

Fig 4: Cascaded Relocations when Backup Node is also Cut vertex. a) Node E is cut vertex & its backup C is also cut vertex. b) C replaces the failure node E and informs its neighbors D & A.

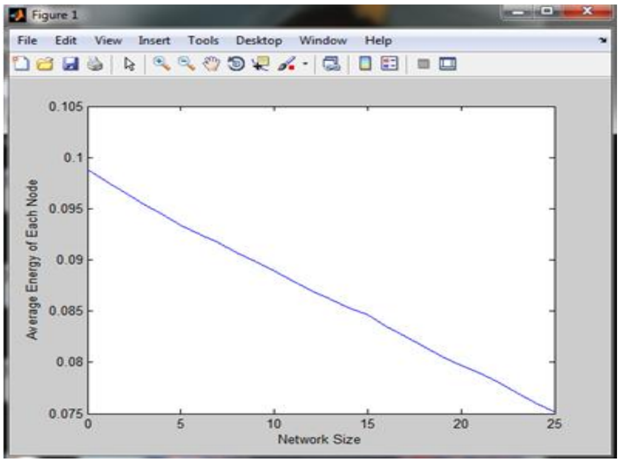
Third, when the failed node and backup node, both are critical nodes and simultaneously serving one another. Then, the solution of this problem is cascaded relocation of nodes. In cascaded movement, the non-critical backup actor nodes replace the critical primary node and connectivity is restored.

b) Cascaded Relocation

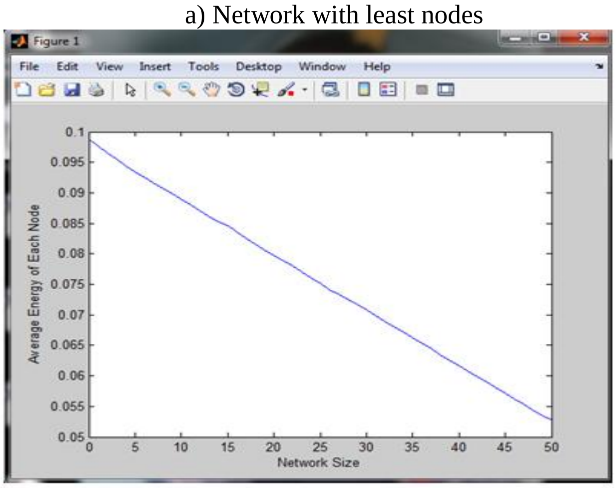
As discussed earlier, the scope of recovery is determined by the position of the backup node. The node is chosen as a backup by following three criteria in order: (1) Lowest node degree, (2) Least distance, and (3) Highest energy. The recovery process of second scenario is repeated with cascaded relocations until it founds the non critical backup node. The cascaded relocations involves more energy consumption, election of backup node is high.

IV. PERFORMANCE EVALUATION

The actor nodes are randomly deployed in an area of 100m × 100m consisting of number of actor nodes (10–50) with fixed communication range (R = 50m) and variable range between 10 and 50m. After examining the cut vertex and non-cut vertex nodes; the backup actors are elected on the basis of remaining energy and healthy node is selected as a backup node for recovery.



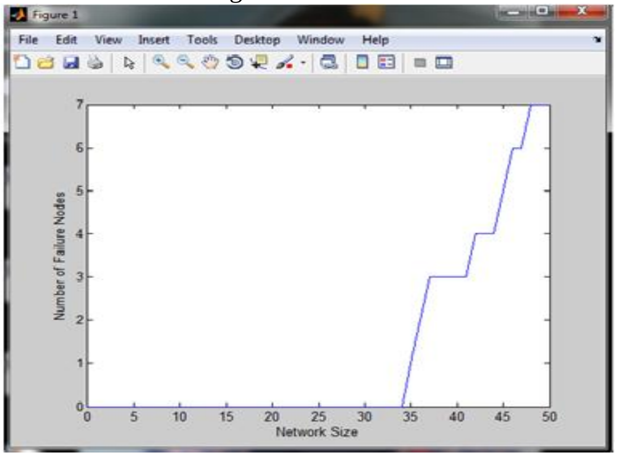
a) Network with least nodes



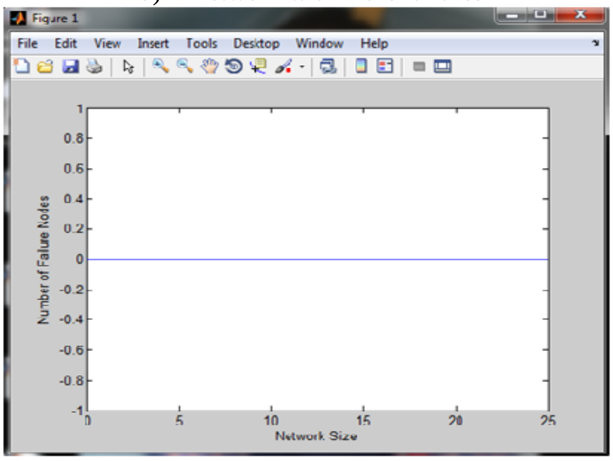
b) Network with more nodes

Fig 5: Average Energy of each node while network size is a) 25 and b) 50.

Average energy of Nodes: The fig 5 illustrates the average energy calculated for each node. After evaluating the hybrid connectivity restoration approach, the results shows that as the network size is small the average energy of each node consumes during communication does not go below the threshold value.



a) Network with more failures



b) Network with less failures

Fig 6: Number of failure nodes while network size is a) 50 and b) 25.

Number of Failure Nodes: The fig 6 illustrates the number of failures occurs in the network. Through this approach the number of failure nodes decreases and the loss of data are also less as network size varies.

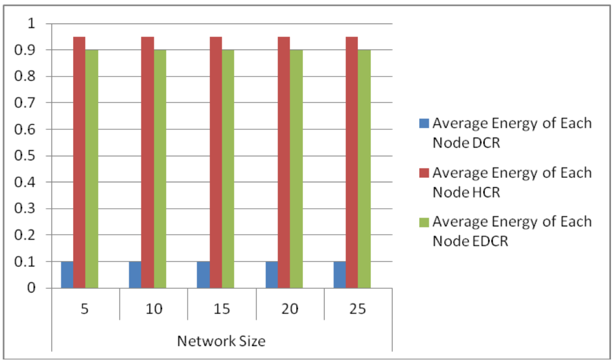


Fig 7: Energy Analysis between DCR, EDCR & HCR Approach

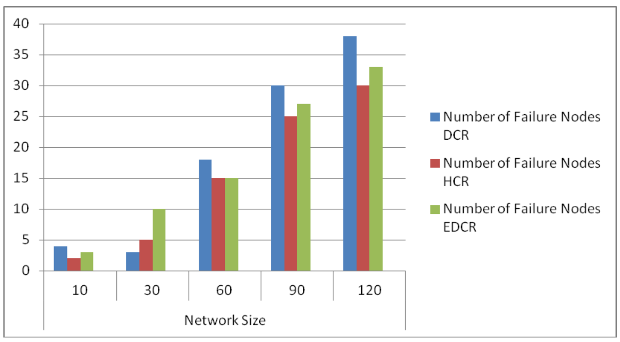


Fig 7: Failure Analysis between DCR, EDCR & HCR Approach

V. CONCLUSION

In hybrid approach, pre-failure detection is pursued in order to increase the efficiency of the network. The main strength of this approach is that the data backup energy is reduced as it also balances the energy consumption of network and increases the network lifetime. It also reduces the sink node overhead as the actor node before failure sends its data directly to sink node. Thus, the communication overhead of sink node to actor nodes also reduces. Existing approaches only identifies the single failure of actors at a time but this approach supports multiple failures at a time and restore the connectivity with less message overhead.

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