Connectivity Restoration in Wireless Sensor Networks

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Abstract

Wireless sensor networks (WSNs) and services, especially those under hostile environments such as battlefield, are at greater risk because of failure of nodes. In Wireless Sensor Network (WSN), node failure is of significant concern. The node failure creates breakup in a network and leads to problems relating to the isolation of the affected node. It is important that the nodes are always live and communicate with uninterrupted network connectivity. The rapid detection of failure of node in the network is essential for inter-node communication. Recently, a number of methods for the restoration of inter nodes connections have been proposed. Replacing the node is one of the sustainable solution to address the issue. Another way is that a gateway node can take control of the functionalities of the affected node. Similarly, the residual energy available at each node can also be used to detect the faulty node in the wireless sensor network.

In addition to this, the performance of the network should not degrade in case of any such failures for which right mechanisms have to be put in place as outlined in this research work. The usefulness of the proposed solution is authenticated by the results of the simulation. The performance was validated using experimental analysis and better performance was achieved. This research study fills the gap existing in this domain. A novel method to address this issue is suggested in this work.

Keywords: Networking, Wireless Sensor Networks (WSN), Network Restoration

Background

1.1. Background

Wireless Sensor Networks (WSNs) have received a lot of focus in recent years. Majority of WSNs applications have opened up varied areas of research and is considered to be the most advanced technology in present day communications. Extensive research is being done on various WSN sites. The Wireless Sensor Network is a new communication technology that has shown major impact on the latest wireless sensor technology. Sensors have less power and energy resources and are responsible for transferring important information from the area of interest (node) & transmitting it to base station. Fig below shows the basic structure of a WSAN connection, where the sensors hear the data from the surroundings and send it to the subsequent nodes.

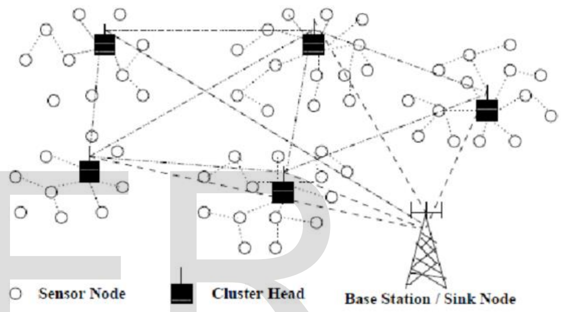

Fig 1.1: Typical WSN

The sensor nodes may fail because of battery failure, hardware issues, or some external intervention. Because of which, network is divided into various segments, leading to reduced performance. Therefore, the reconnection process has to be performed. Human contact is very limited in such applications and no one is watching or looking at the network all the time and making a timely decision. It is a difficult task to install the nodes at affected locations, especially in a difficult area such as a battlefield. It is therefore necessary to have a comprehensive approach that replaces a failed node with any of its neighbors. Interaction between healthy nodes is needed to restore communication to initial level. Node monitoring/navigation can improve overall network performance such as connectivity, coverage and network health. These recovery processes also create more text messages. Usually, these algorithms deal with the failure of a single node, and do not take into account resource efficiency and lack emphasis during recovery.

The use of WSNs has become very common in real life in recent years due to major advances in its wireless technology. Applications such as field intelligence, border protection, space exploration, etc. applies to the most difficult areas, where sensor nodes reduce the risk to human life. The sensor node however is restricted to its power consumption and connection issues as a large amount of sensor nodes are involved to ensure the availability of a network at a sensitive area therefore reliability of the data collected is important. Due to power limitations, the sensor is at high risk for failure. In case of hostile environments where the network sometimes encounters serious damage to the serving nodes thus leading to network fragmentation. Some node sensors may be damaged under snow or sand after a storm or battlefield or part of the transmission area may be attacked by enemy explosives and, thus, a collection of sensors node in the surrounding area will be destroyed. Some of the applications of the WSNs in today's world around us ae shown in the Fig below.

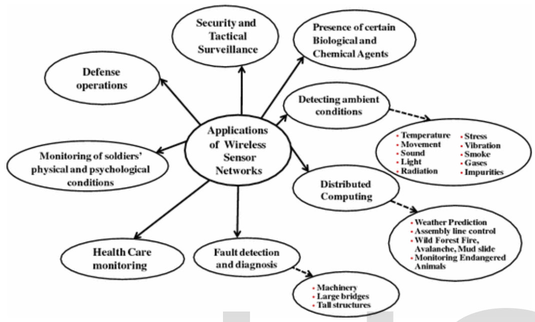

Fig 1.2: WSN Applications

1.2. WSN Network Restoration

WSN is still widely distributed in difficult areas such as the battlefield, dense forest or large areas. These networks are usually installed in remote areas, so the restoration of an effective connection is a very difficult process. The process of restoring communication should be disseminated, treated and localized. Additionally, the process should be so fast that it minimizes the impact of node failure. If the node is too slow to reconnect, then it will consume a lot of power and may also affect other network disconnections. Therefore, restoring connectivity is a daunting task in a distributed, localized, and effective way. Effective recovery strategies work tirelessly and begin when node failure occurs.

Nodes can only communicate with each other if S/N (Signal-to-Noise Ratio) is not below the threshold. Signal strength decreases as we increase transmission. Some algorithms used for recovering a single failed node use a collaborative communication method to restore the connection. Many techniques are available to determine whether a node is cut and uses the information of the hop neighbors. When a fault occurs, the neighbors of the error node will select the most suitable backup node. It will look at node, distance and inform its sibling locations. Improved algorithms provide details of specific location in advance of whether a split has occurred. Nearby neighbor decides whether it is out of service or not. Distributed distribution detection algorithms detects sensitive information in advance on the basis of local knowledge and places the neighbor as backup. When a node failure occurs, the backup initiates a process of immediate recovery.

Recovery algorithms for multi-node failure handles the failure of two nearby nodes at the same time. It is thus called a hybrid delivery system. Detailed comparisons of various strategies for the connectivity restoration are shown in the table below:

Sr	Name of Technique	Year	Objective	Centralized/ Distributed	Movement Type	Node Type	Node Mobility	Node Failure Type
1	C^2AP	2007	Connectivity	Distributed	Cascade	Any node	Mobile Sensor/ Actor	Single node
2	DARA	2007	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Sensor	Single node
3	NN	2008	Connectivity	Distributed	Direct move	Any node	Mobile Sensor	Single node
4	C^2AM	2009	Connectivity	Distributed	Cascade	Any node	Mobile Sensor	Single node
5	RIM	2010	Connectivity	Distributed	Cascade	Anyone	Mobile Sensor	Single node
6	C^3R	2010	Connectivity and Coverage	Distributed	To and fro movement	Any node	Mobile Sensor	Single node
7	NORAS	2010	Connectivity and Coverage	Distributed	Cascade	Cut-Vertex	Mobile Sensor	Single node
8	DORMS	2010	Connectivity with partial coverage	Distributed	Cascade	Any node	Mobile Sensor	Multi nodes
9	PADRA	2010	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Node/ Robot	Single node
10	MPADRA	2010	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Node/ Robot	Multi nodes
11	LeMoToR	2011	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Sensor/ Actor	Single node
12	DCRA	2011	Connectivity	Distributed	Block movement	Cut-Vertex	Mobile Sensor	Two nodes
13	DCR	2012	Connectivity	Distributed	Cascade	Cut Vertex	Mobile Sensor/ Actor	Single node
14	PCR	2012	Connectivity	Distributed	Cascaded or shifted	Cut Vertex	Mobile Sensor/ Actor	Single node
15	RAM	2012	Connectivity	Distributed	Cascaded or shifted	Cut Vertex	Mobile Sensor/ Actor	Two nodes
16	AuR	2012	Connectivity with partial coverage	Distributed	Cascade	Any node	Mobile Sensor	Multi nodes
17	LeDIR	2013	Connectivity	Distributed	Block movement	Cut-Vertex	Mobile Sensor/ Actor	Single Node
18	NNN	2013	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Sensor/ Actor	Single Node
19	DPCRA	2014	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Sensor/ Actor	Single Node
20	CC-IC	2016	Connectivity and Coverage	Distributed	Cascade	Any node	Mobile Sensor	-
21	CSFR-M	2016	Connectivity	Distributed	Cascade	Any node	Mobile Sensor	Single node
22	CCRA	2016	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Sensor	Multiple nodes
23	SFR-RNR	2017	Connectivity with partial coverage	Distributed	-	-	Mobile Sensor	-
24	HCR	2017	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Sensor/ Actor	Single node
25	EAR	2017	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Sensor/ Actor	Single node
26	DEENR[22]	2018	Connectivity with partial coverage	Distributed	Cascade	Any node	-	Single node
27	DCRMF	2018	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Sensor/ Actor	Single/ multi nodes
28	PRACAR	2018	Connectivity and Coverage	Distributed	Cascade	Any node	Mobile Sensor/ Actor	Single node

Table 1.1: Strategies for the Connectivity Restoration

It covers the strategies presented and their objectives, type of nodes, type of movement, and type of node failure. It also indicates whether the techniques are split or distributed and what is the most powerful process to restore normal node connections. This table also shows the movement of nodes and which processes have the potential to restore a single or multiple connection. The framework adopted in line with the above table is shown below for taking the right approach towards the recovery.

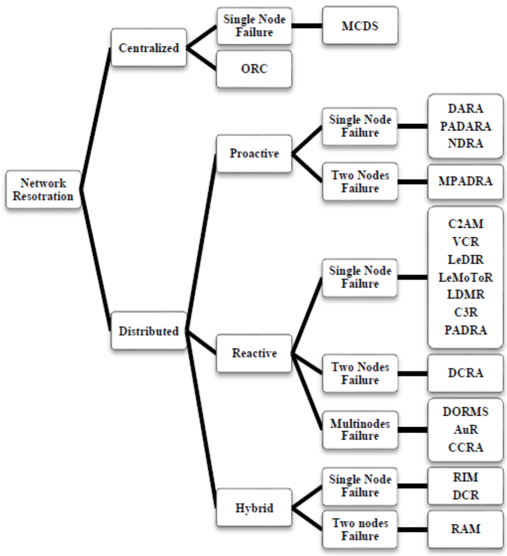

Fig 1.3: Restoration Framework

Advanced network recovery models are designed having 2 main objectives in mind. The first goal is to increase utilization of network resources, and the second to protect the network from failure. In recognizing the purpose of increasing resource utilization, a distinct feature of WSNs is exploited, i.e., their ability to remain active even if one or more of the active (sensor nodes and / or connecting links) fail. For advanced recovery models, researchers adopt processes that collectively look at the minimum lengths, sustainable topologies, and the energy requirements to achieve new energy recovery solutions.

1.3. The Research Problem

The problem associated with wireless sensor networks is the sensors nodes connection failures during deployment or low power issues leading to breakup of communications. Restoration costs, restoration time and reliability of the networks are compromised in case of node failures.

1.4. Objectives

The research contribution is focused on the following points:

- Restoring inter-node connectivity in WSNs.
- Designing a diverse mechanism for restoration of connectivity.
- Performance analysis during WSNs deployments.
- Performance validation

1.5. Simulator

Simulation is a cost-effective way to develop, deploy and manage network systems. Users can test basic network performance and test a lot of network features. Simulator, NS2 in this case, provides a complete environment for creating and highlighting network conditions, and analyzing performance. Thus, NS2 simulator is used which gives the best results. It is an open source simulation tool that works on Linux. It focuses on network parameters and provides valuable simulation support.

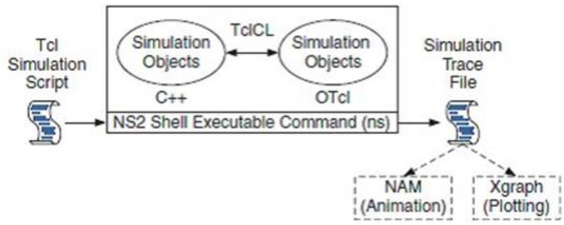

Fig 1.4: Basic Architecture of NS2 Simulator

Literature Review

2.1. Literature

In research, RCR (Relative Citation Ratio) algorithm has been suggested for the reconnection of WSNs based on the locations of the transmitted character [1]. In CBMAR (Connected and Balanced Mobile Actor Relocation), the authors proposed to solve the problem of load balance and connectivity [2]. The NSCRA (Node Stability aware Connectivity Restoration Algorithm) process is proposed to address the problem of network fragmentation using an efficient power method and the node is selected for migration based on the storage capacity of the survival nodes [3]. A practical process is proposed to handle connection recovery on WSNs based on the configuration method algorithm [4]. The novel process is suggested to improve the performance of WSNs based on linking of locations [5].

Node Recovery is a method used to detect the failures of the most widely used sites in WSN, where it has become increasingly important to fix these nodes from failures and from a situation where another part is uncontrollable. The flow of information is greatly affected by node failure. To solve this problem, we learn the LEDIR (least-disruptive topology repair algorithm) and how it comes in comparison to RIM. Researchers compare the two algorithms on the basis of three parameters: no of nodes delivered, total distance traveled and complete exchanged [6]. C3R (coverage conscious connectivity restoration) includes one or more neighbors of a node that failed to recover from a failure.

Internal motion retrieval (RIM) [7], is a distributed algorithm to effectively restore network connectivity after node failure. Instead of performing a comprehensive network analysis to assess the impact of node failure and set the course of action, RIM triggers a local retrieval process by relocating lost node neighbors. RIM (Recovery trough Inward Motion) reduces over-sending and reduces the distance traveled by individual nodes during recovery [8].

Number of schemes have been proposed for the network connections relating to WSN. Some schemes change the nodes having additional transmission areas and other some schemes reset the failure node to save network connection. Younis et al. (2008) suggested a way of restoration by internal movement (RIM) redirecting nodes for retrieval of communication. This way it handles the failure of a single node through neighbor's node which is adjacent or one-hop away. In this work, the total distance traveled and movement of nodes over time is relatively higher than other schemes [9]. (Imran et al., 2010) suggested connection recovery schemes to manage a node failure. The PCR system selects the appropriate backup nodes. The backup is used to find the failure node and the initiation of the recovery process [10]. In multi-node recovery schemes, (Younis et al., 2008) explored multiple-node failure issues for situations where the distance between each pair of sections is more than double the range of node [11].

Mahmood et al. (2018; Sharma and Sharma, 2016) explains that the RN failure can cause a new split in the network. The algorithm returns to communication by building reinforcement mechanisms that can achieve the following three objectives: Tolerance, delay reducing and reducing energy consumption. The verification method allows the network to last longer having more connection time for various components [12].

Boudries et al. (2016) suggested a novel approach by switching a failed node in the wireless network. This method reveals the selection based on node strength, its distance from other nodes, login, trust and navigation. These clusters maintain the redundant list of sensor nodes (RSL). However, node search and detection process generates multiple messages when the communication distance is small [13].

Singh and Jinila (2016) describe an alternative to node modification error using test point recovery algorithm for detecting node failure. This way error is detected by sending messages to the location. If no response was received from the node, it is considered that the strength of the node is low and it will fail and will replace the sensor node with the node having high power [14].

Tseng et al. (2018) introduces Resource Constrained Recovery (RCR) method in which the network disconnects due to node failure using a limited number of relay nodes. Each component in the network has only a minimum number of referral nodes available for access
Process [15].

Buyahia and Benchaïba (2016) developed a communication correction process which was named as CRVR9. It restores the communication by building constructive paths to tolerance to failure, delay reduction and reduced energy consumption [16].

Simulation Design

3.1. Model Design

A network of "n" nodes is designed whereas all the nodes are accessible to each other through single or through multiple hops. These nodes are designated as end nodes. These nodes are deployed in an area which can be vulnerable to any hostile environment. All these nodes in turn have a connectivity with a gateway. We can call this gateway as a server where all the information relating to each node is transferred or sent. It is a good idea to divide the network into different regions for clarity and as a design aspect of having a distributed network design. The network consisting of these nodes is fully up and running with all its functionalities. However, the end nodes may not be capable of reestablishing a connection in case any fault occurs. In order to resolve the issue of node failures and their restoration, a mobile relay node is introduced. These are low powered nodes which provide enhanced coverage. These are basically used for the enhancement of the coverage areas.

The researcher has deployed one such relay node in the wireless sensor network area or field in order to provide seamless connectivity and network coverage. The established node has rich features including the option of mobility in the WSN area or coverage. The mobile relay nodes can be multiple and can be assigned to a particular region the researcher defined. It can be any area of interest. In case the area is small, only very few relay nodes can be placed. In case of larger areas, many more relay nodes can be installed.

The main focus for this network design is that in case of failure of any node, these mobile relay nodes can be deployed in that particular region with the aim to maintaining the required connectivity for the restoration of the services. It is a must that connectivity between the nodes is maintained at all the nodes and the internal designed network architecture works in harmony and coordination systematically. The deployment in the application area is based on multiple regions deployments.

The mobile relay node is only deployed in case of failure of any node. When a node fails, it

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communicates a message for neighboring nodes including the gateway node/server. Status of the affected node is conveyed to the neighboring nodes and the gateway node in case of its failure hence even when the alert message is not sent and the node becomes dead or out of service, the status of that node is recorded in the network. The designed network architecture is shown in the Fig below:

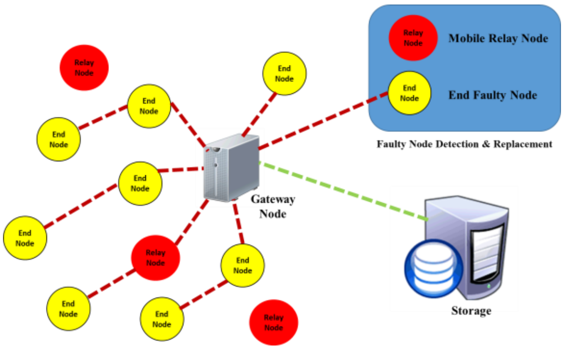

Fig 3.1: Designed Network Architecture

3.2. Faulty Node Detection

There are two ways to detect the faulty node.

- Through Alert Message
- Through Residual Energy

3.2.1. Alert Message

The issue of determining if a node is down or otherwise can be done by sending an alert message to all the nodes in the wireless sensor network. In response to this alert message, nodes in network send an acknowledgement message to the gateway which subsequently informs the mobile relay node in the network. The acknowledgement message sent by nodes to the gateway contains the following information.

- Residual Energy of the node
- Time Stamp (Date/Time)
- Services

When this acknowledgement message is received by the gateway, it means that the node is working properly. Otherwise, the node is faulty. However, the node can be alive and working at times but the acknowledgement message somehow failed to get delivered because of the network congestion. To avoid this, multiple alert messages are sent periodically by the gateway and in case of any response, the relay node is informed accordingly. If the acknowledgement message is still not received after sending repeated alert messages, then the node is considered to be out of service. Fig below shows the requisite messaging:

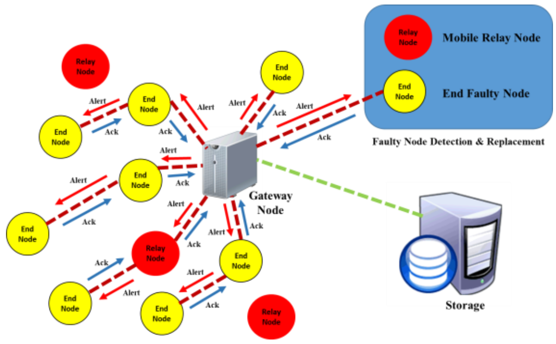

Fig 3.2: Alert/Acknowledgement Messaging

The sequence of commands is shown below:

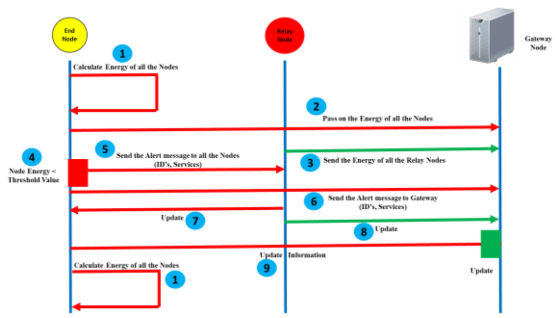

Fig 3.3: Alert/Acknowledgement Messaging Fault Detection Sequence

3.2.2. Energy (Residual)

Using this method, the residual energy of the node is analyzed. Depending on defined threshold value, a node is declared faulty or otherwise. The following two factors are of importance.

- Minimum value of the energy needed for the node to be considered alive.
- Residual energy of the node.

If,

Residual Energy ≤ Threshold Energy = Faulty Node

Once a node is declared faulty, the next step involves starting the recovery process so that the network connectivity can be ensured. This leads to the initiation of the alert messages to all the neighboring nodes in addition to the gateway node. The alert message carries with it the details about the node and region identification in addition to the relay node identification deployed in that particular region. This triggers the gateway to inform the relay node with faulty node parameters. The sequence of events is shown in the Fig below:

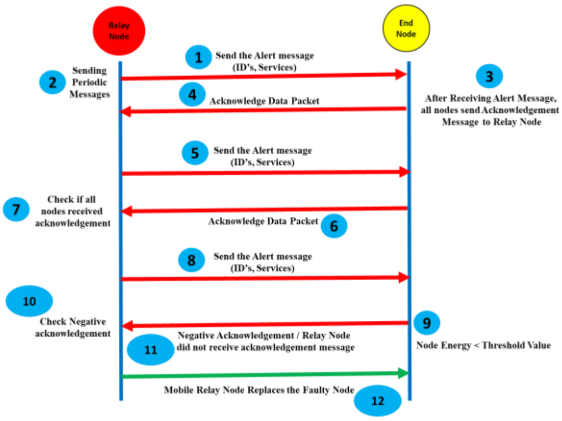

Fig 3.4: Residual Energy Fault Detection Sequence

As seen in the above sequence, the gateway checks if the relay node in the region is idle or not. If it is not idle, this information from the gateway is passed to other relay node which is idle. Gateway directs the relay node deployed in the region to work in place of the faulty node and continues to work at its place till the time the faulty node becomes active again. Once the faulty node is active, the relay node goes back to its idle state.

The Fig below shows the taking over of the relay node of the faulty node in the researchers designed model.

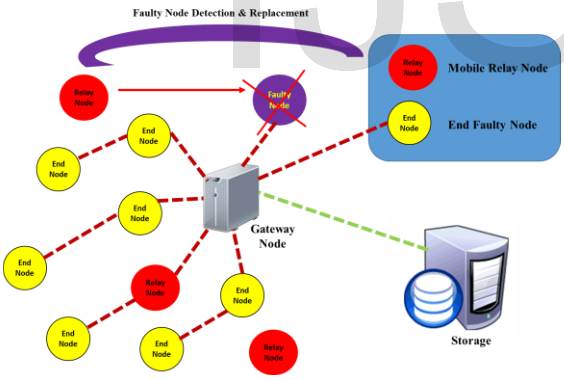

Fig 3.5: Faulty Node Detection and Replacement

3.3. Simulation

The simulation was done using NS2 for analyzing the performance, energy and packet network communications.

Simulation Analysis

This section looks at the design of the network and analyzes the performance of the network in terms of system overheads, data or messages communicated between the nodes inside the designed network, relocation of the failed notes and the recovery processes.

4.1. Performance Evaluation

Performance evaluation is what validates the design of the conceived network. The proposed scheme needs to be compared and analyzed in terms of the system load (average), amount of data or messages communicated between the nodes, overheads, node relocations, failed nodes and their recovery. As per the design of the conceived network, the communication range within the network is the same.

4.1.1. Messages Sent, Relocated Nodes

The graph shown below shows the Average no of message sent between the nodes against the no of nodes in the deployed network.

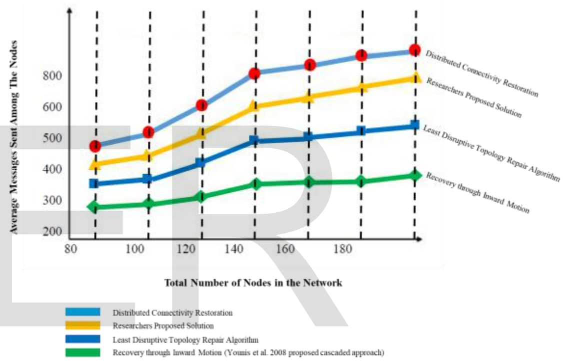

Fig 4.1: Average number of messages sent among the nodes

Fig above depicts number of messages (average) which were communicated or sent across the network between the nodes during the process of recovery. In case of Least Disruptive Topology Repair and Distributed Connectivity Restoration algorithms, the number of messages to be sent for the recovery are more as compared with researchers proposed scheme/model. Also the number of nodes deployed is less (298) as compared to that of Distributed Connectivity Restoration (498). The validity of the performance can be easily judged through the simulation model.

```
// EVERY NODE BUILDS ITS SHORTEST PATH ROUTING TABLE (SRT) BASED
// ON THE ROUTE DISCOVERY ACTIVITIES THAT IT INITIATES OR SERVE IN, I
// WHILE EXECUTING A DISTRIBUTED ROUTING PROTOCOL.

LeDiR(J)
IF node J detects a failure of its neighbor F
   IF neighbor F is a critical node
      IF IsBestCandidate(J)
          Notify_Children(J);
          J moves to the Position of neighbor F;
          Moved_Once ← TRUE;
          Broadcast(Msg('RECOVERED'));
          Exit;
      END IF
   END IF
ELSE IF J receives (a) notification message(s) from F
   IF Moved_Once || Received Msg('RECOVERED')
          Exit;
   END IF
   NewPosition ← Compute_newPosition(J);
   IF NewPosition != CurrentPosition(J)
       Notify_Children(J);
       J moves to NewPosition;
       Moved_Once ← TRUE;
   END IF
END IF

IsBestCandidate (J)
// Check whether J is the best candidate for tolerating the failure
NeighborList[]← GetNeighbors (F) by accessing column F in SRT;
SmallestBlockSize ← Number of nodes in the network;
BestCandidate ← J;
FOR each node i in the NeighborList[]
      //Use the SRT after excluding the failed node to find the set of
      //reachable nodes;
      Number of reachable nodes ← 0;
      FOR each node k in SRT excluding i and F
          Retrieve shortest path from i to k by using SRT;
          IF the retrieved shortest path does not include node F
             No. of reachable nodes ← No. of reachable nodes + 1;
          END IF
      END FOR
      IF Number of reachable nodes < SmallestBlockSize
          SmallestBlockSize ← Number of reachable nodes;
          BestCandidate ← i;
      END IF
END FOR
IF BestCandidate == J
   Return TRUE;
ELSE
   Return FALSE;
END IF
```

Fig 4.2: Least Disruptive Topology Repair Algorithm

```
Algorithm
 DCR(A)
1. if(Is-Critical(A)==True) Then
2. AssignBackup(A)
3. If(A energy goes under the critical-level) Then
4. Broadcast DistressMessage
5. End if
6. End if
7. If(A receive DistressMessage) Then
8. Failure Detection(A,F)
9. End if
10. If(A received Recovered Message) Then
11. Send Buffered Data

  Failure detection(A,F)
12. If(A detects missing Heartbeat Message from F) Then
13. If(A->BackupStatus()==Failed) Then
14. Buffer Data
15. Else
16. Recover(A,F)
17. End
18. End if

  Recover (A,F)
19. If(Is-Critical(A)==True) Then
20. If(A->BackupStatus()==Failed) Then
21. AssignBackup(A)
22. End if
23. NotifyBackup(A)
24. End if
25. Move to location (A,F)
26. Notify New Neighbors with send Recovered Message

  AssignBackup(A)
27. //Assign noncritical neighbor with highest degree and least distance node as Backup
```

Fig 4.3: Distributed Connectivity Restoration algorithm

The algorithms of Least Disruptive Topology Repair Algorithm and the Distributed Connectivity Restoration are shown in the above Figs. The graph shown below is between average number of relocated nodes and the total nodes in the designed network.

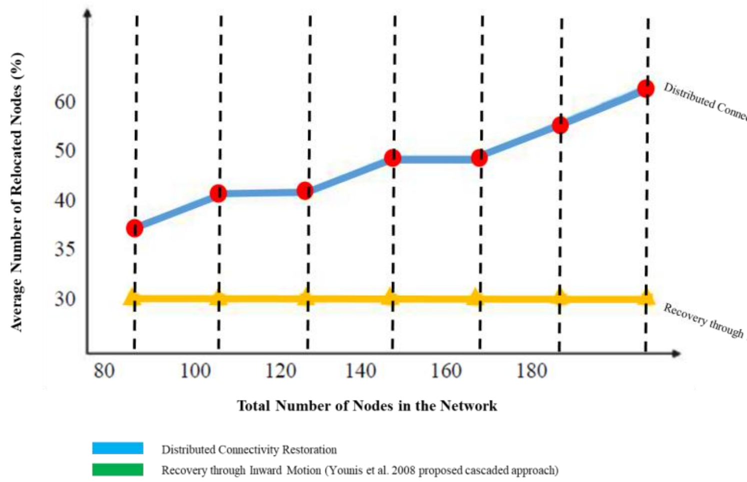

Fig 4.4: Ave No Relocated Nodes Vs. Total No of Nodes

As seen in the above simulation result, the relocated nodes minimum in case of researcher's analysis in comparison with that of Distributed Connectivity Restoration scheme.

4.1.2. Energy levels

The other performance analysis/measurement factor in the research is that of energy levels. Normal and Low energy levels are shown below.

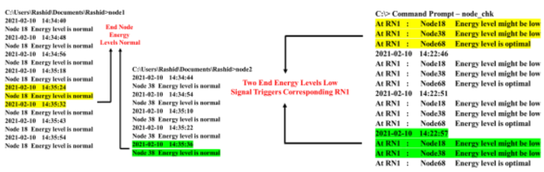

Fig 4.5: Normal-Low Experimental Energy Levels

Conclusions

5.1. Conclusion

Following are concluded from our simulation results.

- WSNs under hostile environments are at greater risk because of nodes failures.
- Detection of node's failure is must for seamless inter-node communication.

- Node replacement node is one of the sustainable solution.
- Residual energy management can detect node failures.
- Performance of the network degrades in case of node failures.
- Fault detection and connectivity restoration scheme is designed.
- Concept of mobile relay node introduced to restore the faulty node.
- Node failure can be detected by sending alert messages.
- Energy thresholds measurements lead to faulty node detections and its handing over to the active relay node.
- Proposed scheme validated through performance evaluation.
- Low cost, minimum resource, rapid node restoration management achieved.
- Complexity reduction achieved in WSNs.
- Effective power management achieved.

4.2. Contribution to Knowledge

The researcher looked at WSN architecture to address node failure issues. This work can be extended to incorporate mobile networks where the network nodes can be considered as sensor nodes and similar detection and restoration mechanisms can be used.

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