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Tolerating Node Failures in WSN

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Abstract— In wireless sensor networks, nodes operates in a synergetic manner to deliver some tasks. In many practices, the network is set up in an uneven environments where nodes are influenced to damage due to which nodes may die because of energy exhaustion therefore, WSNs are expected to look for network's connectivity and consent to certain amount of node failures. Restoring overall network's connectivity is very crucial. This paper illustrates various topology management techniques for handling node failures in WSNs

***Keywords**— Topology Management, Node Failure Connectivity Restoration , Fault Tolerance, Multi-Path Routing*

I. INTRODUCTION

In WSN, sensor network includes sensor nodes referred as multiple detection stations in which group of nodes works in synergetic fashion to perform various actions such as monitoring environmental conditions, determining absence or presence of undeniable objects, speed direction, vehicular movement, performing disaster relief tasks, battlefield surveillance and many more[1]. In spite of its various applications, WSN suffers from many drawbacks. Fault occurrence is one of the major issues. Various fault tolerance techniques are proposed which helps in maintaining connectivity inside a network. Connectivity helps nodes to perform their action while achieving a task, and to forward the required useful information to base-station [2].
The sensor nodes may be failed by the following reasons [3]:

- Energy Depletion: sensor nodes may be broken easily and thus fails due to exhaustion of batteries.
- Link Availability: Because of partitioning of network and intense changes link failure may occur that can be either permanently or temporal failure.
- Packet Loss: Due to changeable topology and inaccurate communication, packet loss may occur.
- Network Congestion: Number of nodes continuously transmitting data to the base station leads to network conjection.
- Node Failure: A node failure may occur because of software failure or hardware failure.

Fault detection is designed to find out the feasible faults depending on various parameters, and fault recovery algorithm aims at treating fault facilely with less energy depletion. The cluster based detects fault while recovery algorithms detects node failure on the basis of energy consumption, failure of link and damaged node:
Two most common ways to recover a node from failure:

(i) Node repositioning
(ii) Deployment of extra nodes to reconstitute connectivity in case of failures.

Based on above approaches, number of schemes are proposed for establishing the network connectivity in case network gets partitioned.
Topology management techniques for WSNs can be categorised as follows [17]:

- Node Discovery: Detecting nodes and their positions is an essential not after the initial distribution but also for combining latterly added nodes.
- Sleep Cycle Management: For conserving energy and extending the network lifespan, few redundant nodes in a network can be turned off.
- Clustering: For achieving scalability, nodes can be collected together to form a hierarchical topology so that nodes can send their data to a cluster-head which in turn integrates and forwards the data to base station.
- Power Control: Transmission range reflects the maximum distance from a receiver to sender. Longer the range , the higher the power consumption. Many advanced radios allow lesser transmission power so a node can avoid excessive energy. Low transmission of power can also reduce intrusion and can increase the network throughput.
- Movement Control: Mobile relays with more capabilities as compared to sensors are used as data forwarders for prolonging the lifespan of a network of stationary sensors or to join disjoint groups of nodes.

This paper focuses upon various single node failure techniques in detail and fault tolerant routing techniques, which involves fault recovery process with fault detection scheme.

II. TYPES OF NODE FAILURE

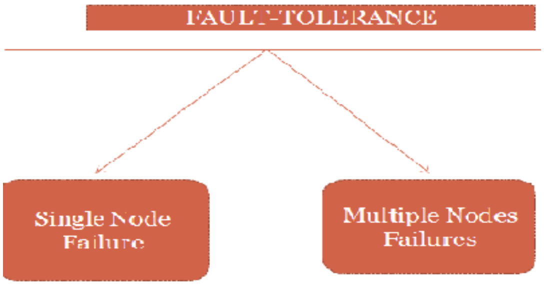

Fig.1 Types of node failure

In a single node failure, only one node in a networks fails.
PADRA(Partition Detection-Recovery Algorithm),RIM(Recovery By Inward Motion),Volunteer-instigated Connectivity Restoration (VCR), LeDir(Least-Disruptive Topology Repair Algorithm), Least-Movement Topology Repair (Le-MoToR), K-Connectivity are few techniques of single node failure. This paper illustrates all these techniques in detail.
In multi-node failure however, two or more than two nodes fails simultaneously leading to connectivity issues inside a network. An alternative of the multi-node failure is an arrangement of spatially-independent single-node failures. For example, multiple nodes may get damaged from various parts of the network simultaneously. However, these failures can be handled independently. These are more common as compared to single node failure. Autonomous repair (AuR), Cell-based Optimized Relay node Placement (CORP), etc. are multi-node fault tolerant techniques.

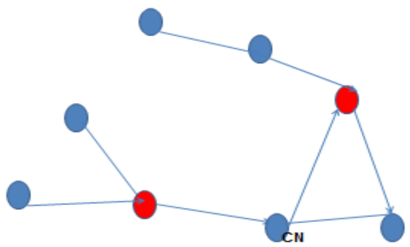

Fig.2 Scenario of multi node failure as failure of two nodes(red nodes) introduces a conflict for node CN since in many single node failure recovery schemes it has to be engaged in the recovery process for both of them

There are various steps that are involved in recovery of node failure:
- Generating originating message
- Store information and forwards it to all other nodes
- Transmit data
- Check for reply
- Generate new testing message to a single node
- Check for failure of node
- Send information to BS
- Reposition the neighbour node in case failure is confirmed.

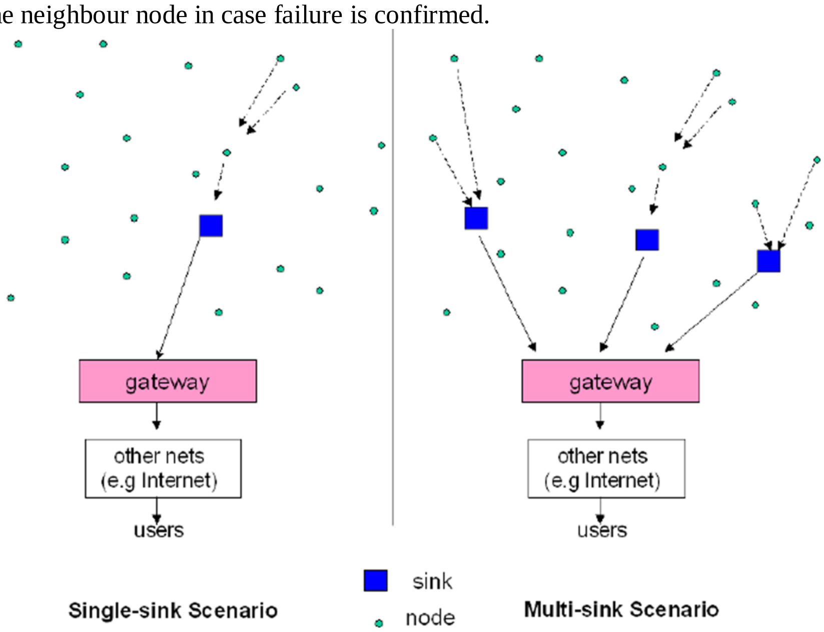

Fig.3 Single sink and Multi sink scenario

III. TECHNIQUES OF SINGLE NODE FAILURE

A. Partition Detection-Recovery Algorithm (PADRA)

This technique spots a connected dominating set (CDS) for the network. PADRA assigns for each cut-vertex Ai which acts as a failure handler which starts the process of recovery if Ai fails[10]. The ideal handler will act as dominatee neighbour for Ai which can easily substitute Ai. If a dominatee is unavailable, the dominator which is closet is picked as the failure handler of Ai. Re-substituting the failure handler at the location of Ai will then cause cascaded repositioning until and unless a dominatee is detected. No set of rules are followed for finding closest dominatee to the failure handler as a way of underrating the total covered distance for all convoluted nodes. Instead, a greedy heuristic is adopted in which a closest dominator is selected if a dominatee is unavailable.

In the example below, circle nodes( )are 'Dominators' and rectangular nodes are 'Dominates( ).When node A2 Fails, A3 acts as a failure handler and begins the recovery process. A3 substitutes A2, A5 substitute A3, and finally A8, a dominate, substitute A5 and connectivity is maintained.

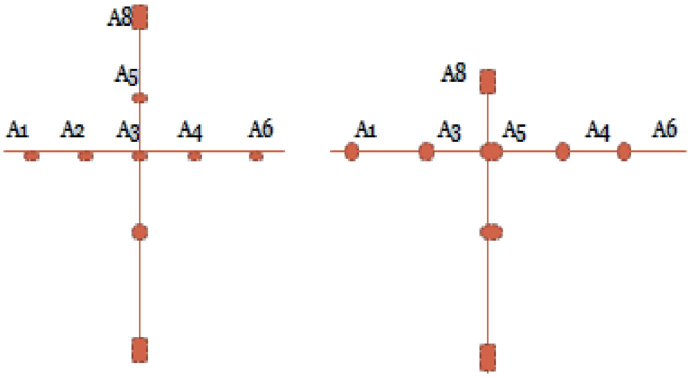

Fig.4 Partition Detection-Recovery Algorithm(PADRA)

B. Recovery By Inward Motion(RIM)

This techniques needs just 1-hop information and is a localized arrangement that restricts the extent of the recovery process and functions in a distributed manner. The basic idea is to shift the neighbours of a failed node Af inwards towards the place of Af to be able to reach each other[11].

The figure illustrates RIM (a) A1 fails, then its neighbours A2, A8, and A9 applies RIM.

(b) A2, A8, and A9, move inward towards A1. The motion triggers repositioning of A3 to maintain connectivity with A2, and then repositioning of A10, A11, and A12, to maintain their links with node A9.

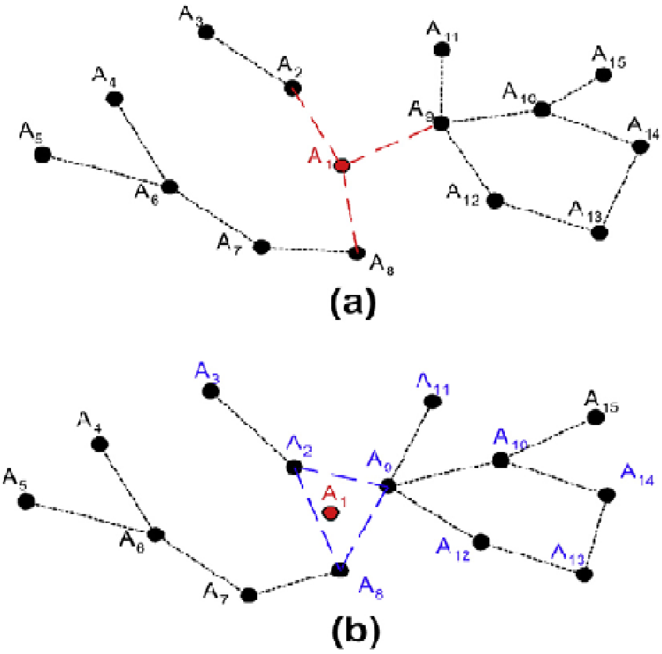

Fig.5 Recovery by Inward Motion (RIM)

The major advantages of this technique is its simplicity and effectiveness. RIM follows a simple process that recovers serious as well as non-serious breaks in connectivity of the network without determining whether the failed node is a cut vertex or not. Although, nodes with higher densities RIM tends to reposition many nodes and increases the overall travelling overhead on the network, but the overhead per node can still make RIM a best approach as it balances the load among various nodes.

C. Volunteer-instigated Connectivity Restoration(VCR)

In VCR, the acquaintance of the failed node volunteer to fix connectivity by imposing their partially utilized communication range and by switching adjoining to the failed node. These neighbours volunteer by muliplying their communication power and impelling towards the failed node Af. To avoid increased medium access collision in the proximity of Af, VCR applies a dispersal force between volunteer nodes based on their carrying range so that they extent while maintaining connectivity[9]. The recovery process involves two phases. Firstly, volunteer actors are identified Volunteer declaration takes place on the basis of various parameters such as proximity, legibility factor. Secondly, topology repair is carried through uncoordinated repositioning of volunteer actors while manipulating partially used communication range and actor diffusion.

D. Least-Disruptive-Topology-Repair Algorithm(LeDir)

The aim of LeDiR is to restore network's connectivity without extending the distance of the shortest path among nodes distinguished to the pre-failure topology. This algorithm overcomes the deficiencies of high node re-motion overhead and distension of inter-actor data paths comparative to its pre-failure status. This method relocates the smallest count of nodes and there is no extension of data paths. This algorithm recognizes the faulty one and find out if it is a cut vertex or not by applying the moderately populated Shortest-path Routing Table and invoking the recovery process then block with lowest count of nodes are found for repositioning which restricts the recovery overhead. Faulty node is replaced by the neighbouring node of the failed node which are a part of the smallest block [13]. After that offspring nodes which are directly linked to the super node are also repositioned thereby recovering the connectivity. The figure illustrates LeDiR, restoring the network connectivity ones the failure of a cut vertex occurs.

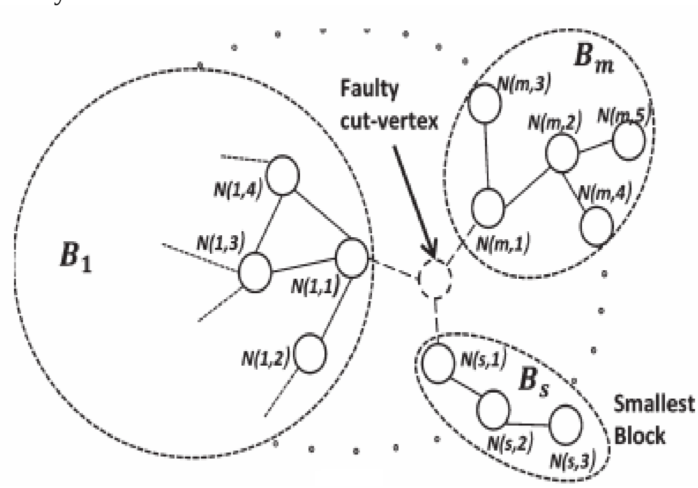

Fig.6 (a) WSAN before a cut vertex fails

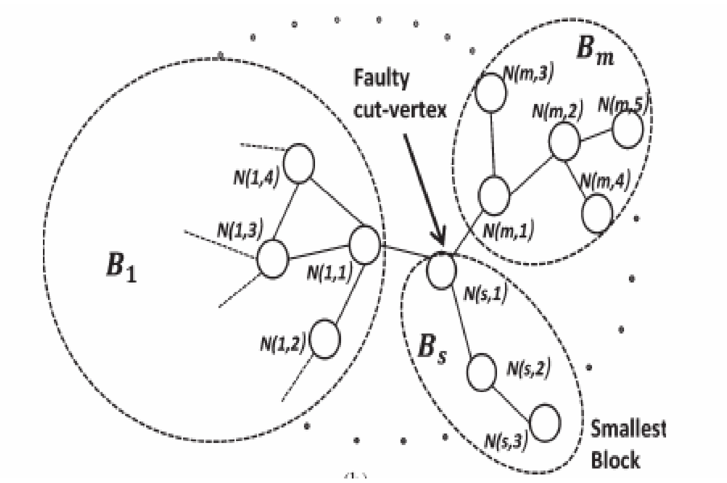

Fig.6(b) WSAN topology after applying LeDiR

E. Least-Movement Topology Repair (Le-MoToR)

It repositions a node Aj in a segment on a different distance path by moving parallel to the line AiAf. This amendment reduces the count of moved nodes and maintains the coverage gained by the node in the smallest segment by not shifting the topology towards Ai after it replaces Af [8].

Fig 6 illustrates the working of Le-MoToR algorithm. Only 3 nodes are indulged in the recovery process. Fig(a) shows node A10 fails. (b) node A14 substitute node A10. (c) Node A15 substitute node A14 and node A18 initiates replacement of A15. (d) For the same condition, more nodes (indicated as gray nodes) are involved in the recovery process when RIM is applied. This is the major benefit of Le-MotoR over RIM. Fig.7 shows the working of Le-MoToR.

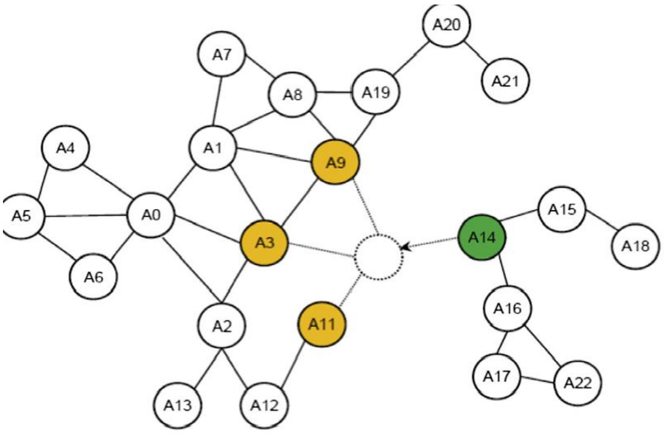

Fig.7(a)

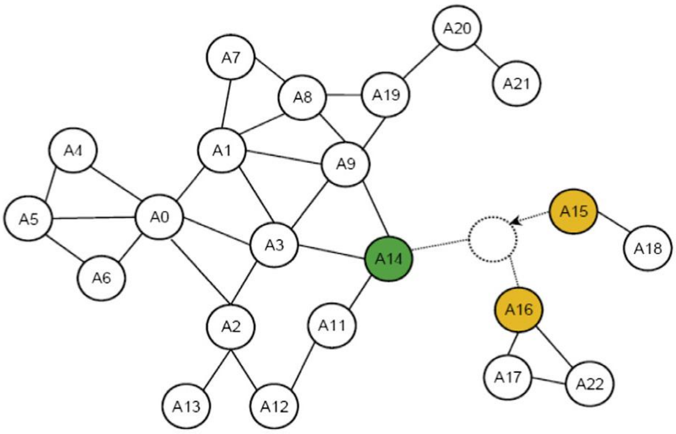

Fig.7(b)

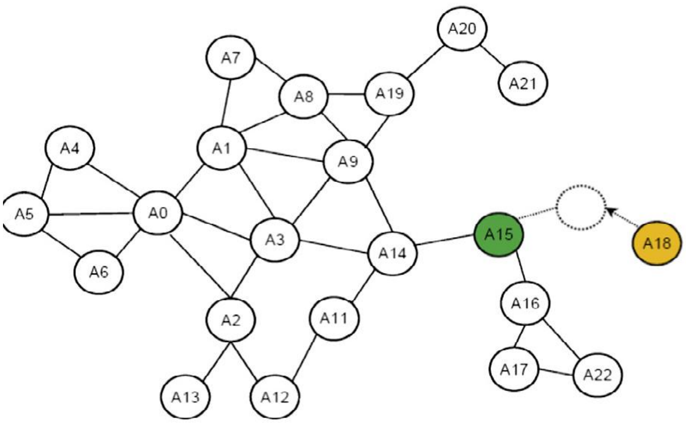

Fig.7(c)

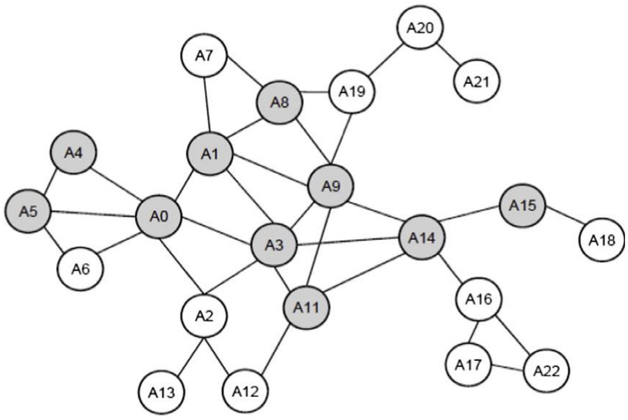

Fig.7(d)

F. k-Connected Hybrid Relay Node Placement(CHRNP)

This approach helps in maintaining the federation problem either by placing of relay nodes (RN's) or relocating the existing node for establishing the connections again. For each portion, one stationary relay nodes are positioned on the line connecting to CoM. Thus these nodes forms the ring .Mobile data collectors are positioned to connect the segments in the network. Convex hull algorithm is used to find the evocative node from each segment. Thus the ring topology is created around the centre of mass. Here every node is k-connected, so traffic load is distributed evenly and it therefore ensures robustness, Average end to end delays, Packet Delivery Ratio, Throughput (Bits/sec) are optimized while maintaining connectivity within the network. .

```
// Checking 3 points are right turn [7]
int orientation (Point a, Point b, Point c)
{
double value = (b.y – a.y) * (c.x – b.x) - (b.x – a.x) * (c.y – b.y);
if (value == 0) return 0;
return (value > 0)? 1: 2;
}
//Looping for orientation
int a = 1, b;
do
{
b = (a+1) % n;
for (int i = 0; i < n; i++)
if (orientation (points[a], points[i], points[b]) ==2)
b = i;
next [a] = b;
a = b;
} while (a != 1);
```

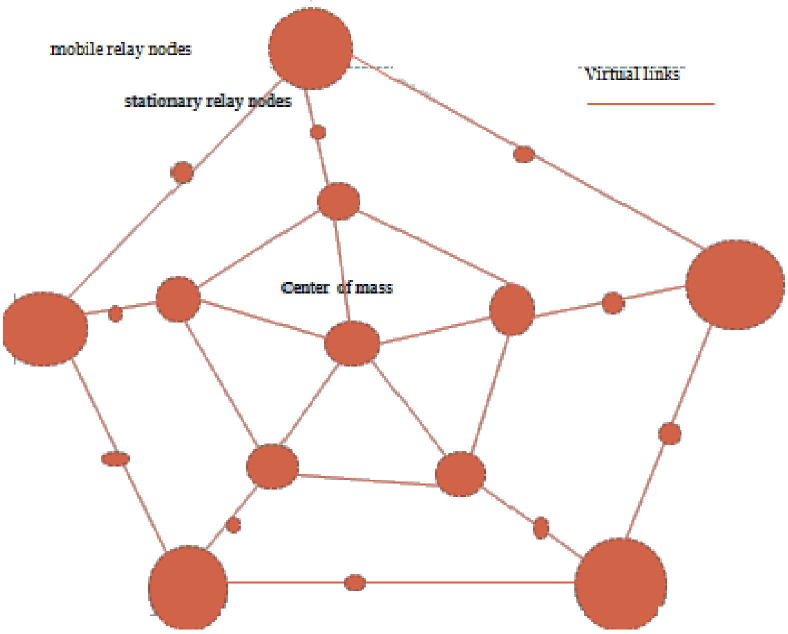

Fig.8 k-connected topology

G. Fault Tolerant Multipath Routing scheme (FTMRS)

For node fault identification and recovery in WSN, scheme of multipath routing is proposed .Only one shortest path is used for routing the data and other two backup paths are treated as an unusual track for faulty network and for handling overburdened traffic at main channel. This Shortest path data routing guarantees energy effectiveness data routing.

In this technique, each and every cluster member node delivers data to CH. Cluster head aggregates all cluster member data and transmits it to base station[16].

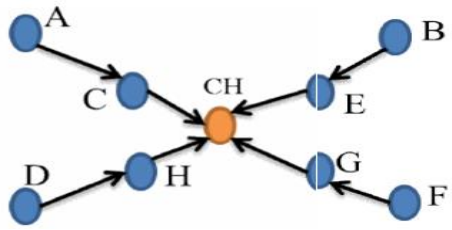

Fig.9(a)

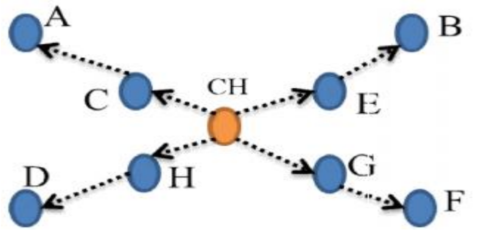

Fig.9(b) Data transmission policy in FTMRS technique

In Figure 9(a) Nodes A, B, D, F sends their data to cluster head's that is nearest to nodes C, E, H, and G respectively. If any node failure or communication fault does not occurs, then after data received by the cluster head's nearest nodes C, E, H, and G sends an acknowledgement (Fig (b)). Similarly, cluster head nearest nodes C, E, H and G send their data to cluster head CH.

Recovery Process In FTRMS takes place as follows:

In the FTMRS if transmission fault or node fault occurs , then source nodes A, B, D or F does not receive any acknowledgment message. Therefore, they sends their data through alternative path. In Fig 10(a) A to C node transmission fault occurs, hence 'A' transmits again sensing data to node D . Similarly, if node fails, node 'B' transmits its data to node 'F'. Although, node F does not get any acknowledgment message from G; therefore it retransmits its to D node (Fig 10.b). Similarly, cluster head transmits their data to the base station[6].

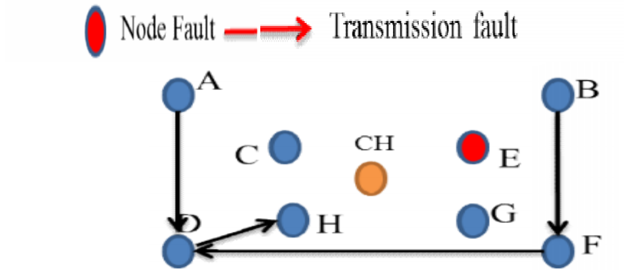

Fig.10(a)

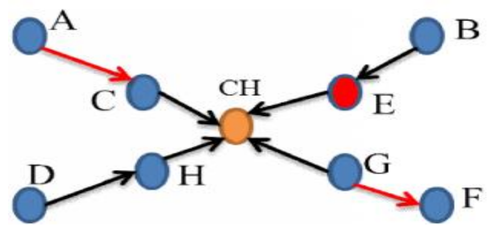

Fig.10(b) Fault recovery policy in FTMRS technique

In Fig 11(a) when node 'E' sends data to cluster head then transmission fault takes place. Due to which 'E' transmits data to node 'C'. When 'C' receives E's message then it sends data through available shortest path, as is shown in Fig(b), through node 'H'. Instead of initial multipath propagation of, it sends the data by a single shortest path[5]. However, if transmission fault occurs in that route then it sends the data through alternative backup routine. Therefore, energy dispersal for multipath data propagation is saved in FTMRS.

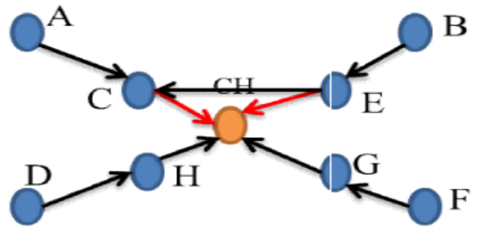

Fig.11(a) Data Traffic management in FTMRS technique

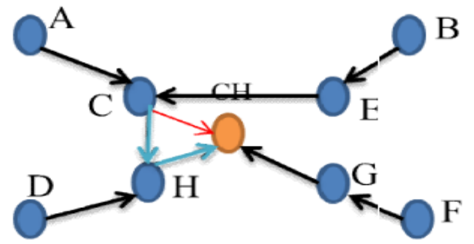

Fig.11(b) Data Traffic management in FTMRS technique

IV. CONCLUSION

In many operations, WSNs accomplish in unfavourable setups, e.g., battlefield, and the node becomes bounded to expand the risk of getting impaired. In addition, nodes are equipped with small batteries and their functions ceases upon exhausting their onboard energy supply[17]. The failure of nodes may not only lead to coverage and data fidelity but can also cause the network to be segmented into disjoint blocks of nodes. A convincing research has been done in this direction to restore connectivity in partitioned WSNs, though there are several directions that need further exploration. Based on these advantages and disadvantages of the recovery approaches have been presented. The paper incorporates number of open issues, unexplored ideas and variants of the recovery problem that warrant further investigation.

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