Fault Tolerance in Dynamic Cluster-Based Wireless Sensor Networks

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***Abstract*—Researches on Wireless Sensor Networks (WSNs) have been increased tremendously in the recent years. Cluster-based Wireless Sensor Network out performs flat network in terms of data routing, energy dissipation, data load balancing, etc. A self organized cluster-based sensor network that has the cluster management mechanisms for new nodes joining and existing nodes leaving, is defined as Dynamic Cluster-Based Wireless Sensor Network (DCWSN). Moreover, DCWSN can be categorized into two types such as, one hop neighbor information and partial one hop neighbor information. This article presents two novel algorithms that pertain multi-node leaving for DCWSN, where one of the proposed algorithm considers one hop neighbor information while the other one considers partial one hop neighbor information for multi-node leaving. Moreover, to evaluate the performance of the proposed algorithms, simulation is performed and compared.**

Keywords— *Wireless Sensor Network; cluster-based network; node joining; node leaving, Fault Tolerance.*

I. INTRODUCTION

Wireless Sensor Network (WSN) is highly resource constraint with limited power, bandwidth, processing capabilities, storage and computational capabilities. Therefore, sensor nodes are mostly inoperable and irreplaceable when failure occurs due to energy depletion. Increasing network sustainability and lifetime are the key issues for contemporary studies in sensor domain. Normally, energy depletion is highly dominated by radio transmission. The energy depletion of radio communication is directly related to any transmissions in the network. Clustering technique reduces number of radio transmissions and increases sensor network lifetime [1]. Thus, clustering technique can efficiently increase lifetime of various sensor applications such as, robot control, environmental control, offices, smart home, manufacturing environments, health monitoring, etc.

When sensor nodes are randomly deployed on the sensing zone, they establish a network to transmit the gathered data to the destination node. Wireless Sensor Networks are of two types, flat network and cluster-based network. Flat network can be deployed easily, however, network performance degrades with increasing network size. To overcome the problems associated with flat network, cluster-based network is introduced. Cluster-based network divides the network into logical groups to enhance network operations [2]. Cluster-based WSN has various advantages over flat sensor network in terms of efficient routing, prolonged network lifetime and energy dissipation.

In cluster-based network, cluster formation and cluster maintenance are performed. Cluster-based network is developed in cluster formation phase, while cluster maintenance handles network management activities. The network needs to be reformed from scratch when cluster maintenance is not present in the network. Thus in the absence of maintenance algorithms, performance of the network highly suffers [3-4]. Different algorithms have been investigated to address cluster maintenance issues, where Dynamic Cluster based Wireless Sensor Network (DCWSN) gives an efficient cluster maintenance mechanism.

DCWSN is a self-organize network when new nodes can join or existing nodes can leave the network. A node may retain its status in one of the three types such as, cluster head (CH), gateway (GW), or member node (MN) where root node *r* is also *CH* (Figure 3) [4]. Member nodes are the leaf nodes that transmit data to CHs, where CHs gather data and send to the base station (BS) via intermediate nodes (GWs and CHs) [4]. The DCWSN can be organized as one hop neighbor information or partial one hop neighbor information. In one hop neighbor information; a node may retain information of all neighboring nodes, which are within the range. In partial one hop, a node may retain only its parent and child node(s) information.

Sensor node(s) may be faulty due to node malfunctioning or the energy goes down from a certain threshold. Such faults may cause high data loss, transmissions delays or even network disconnection, hence the normal operations of the network suffers. In this article, two network management protocols are proposed to handle multi-nodes leaving in DCSWN. The first algorithm is proposed for DCWSN having one hop neighbor's information, while the second algorithm is proposed for DCWSN having partial one hop neighbor information.

This paper is organized as follows. In section 2, a review on fault tolerance schemes for wireless sensor network is discussed. Proposed nodes leaving algorithms are presented in section 3. In section 4, Simulation results are presented. Conclusion and future work is discussed in section 5.

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II. LITERATURE REVIEW

The cluster-based approach forms a backbone, where faults may split the entire network into various groups. Fault diagnosis and tolerance is normally distributed in every group or control in centralized manner.

Middle-ware implementation for heartbeat-style is presented in [5] to detect heart beat failure. Three types of message are exchanged to diagnose faults namely, Heart message, Health status, and Digest message. In heartbeat exchange phase each node sends a Health-status-update message in first phase. Between. Cluster head also broadcast the arrived messages of heartbeat. Meanwhile, cluster-head also sends its own status to each member. In the last third round, cluster head detects the faulty nodes by analyzing the heartbeat information collected in last two rounds. A node is detected as fail node if the cluster head does not received the heartbeat message nor the digest message.

In [6] propses cluster head failure detection scheme. In this scheme, cluster head periodically transmits it health status to member nodes about its live status. If the heartbeat message is not received to member nodes, a member node detects that the cluster head is faulty. However, in a network if member nodes go through a duty cycle, they cannot listen the periodic heartbeats. This approach addresses this issue where a member sensor node can solicit a heartbeat from its cluster head after sending a certain number of messages. Cluster heads detect neighboring cluster head failures using routing updates. This approach studies crash, timing faults, and omission.

[7] proposes an agreement-based fault detection mechanism for detecting cluster-head failures in clustered underwater sensor networks. Periodically, every node is performed distributed detection process at every cluster member. This requires each cluster member in a cluster to maintain a status vector in which each bit corresponds to a cluster member and is initialized to zero. A bit in the vector is set to one, once its corresponding cluster member detects that the cluster head has failed. If the elements of the vector of cluster member become one, an agreement is come to reach where cluster member takes their own decision. This approach is considered crash faults.

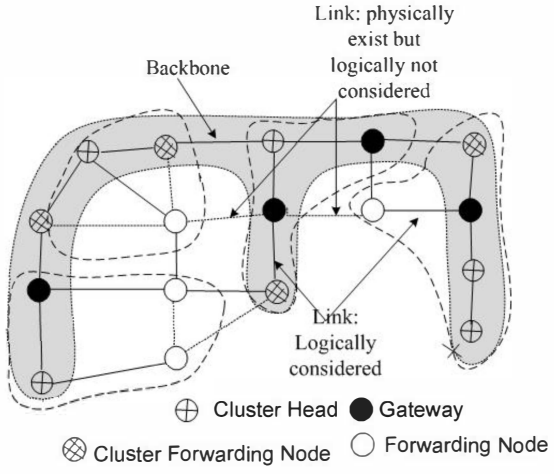

Figure1: CBNet (G) algorithm

[8] describes CBNet(G) algorithm where nodes are capable of performing two atomic operations: node-move-in and node-move-out. Three types of nodes are consider such as, cluster head, gateway, cluster forwarding node, and forwarding node in the architecture [8].

In another work propose DCWSN (Figure 3) where the author describe two algorithms for network robustness such as, node move-in and node move out [4]. However both algorithms is based upon single node maintenance scheme.

Thus, multi nodes leaving are still missing from the current literature.

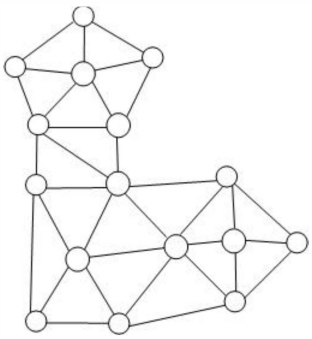

Figure 2: Flat Wireless Sensor Network

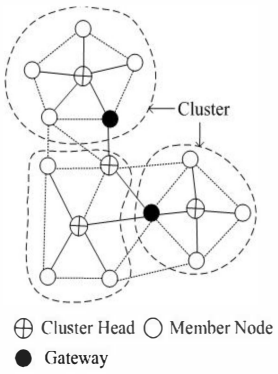

Figure 3: Dynamic Cluster Based Wireless Sensor Network form from flat graph network

To handle faults when multi nodes leave the network, Dynamic Cluster-based WSN is used as a base to introduce multi nodes leaving.

III. PROPOSED MULTI-NODES LEAVING ALGORITHMS

This section presents proposed multi-nodes leaving algorithms for dynamic wireless sensor networks. It is assumed that when the threshold value of a node reaches certain limit, the node wants to exit from the network. Moreover, root node (node number 0) of the DCWSN is a cluster head node that has complete information of the network. The network consists of n number of immobile sensors placed randomly in the environment.

To efficiently handle data communication and nodes leaving process in DCWSN, Steady State Phase and Setup Phase are proposed. In steady state phase all the nodes send their data to the root node, while, in setup phase, nodes leaving is happened. In setup phase, root node sends an “inquire message” to the network to gather information about the nodes that want to leave from the network. When a node receives the “inquire message” from the root node, it calculates its threshold value. If the remaining energy is equal to the minimum threshold, node(s) sends “leave me” to withdraw itself from the network. When the root node receives “leave me” messages from the network, it informs the leaving node(s) one by one via DFS algorithm. Therefore, a leaving node that is in the depth will leave first compare to the node that is in lower depth.

Since the DCWSN considerations two types of neighbor information such as, one hop information and

partial one hop information. Therefore, two algorithms are proposed for DCWSN, where first algorithm considerations one hop DCWSN while second algorithm considerations partial one hop neighbor information.

A. Multi Nodes Leaving where nodes have one-hop neighbor information

Since in one-hop neighbour information, nodes retain all its neighbour information. The leaving node be a non-leaf node or leaf node where the leaf node has no child node. The leaving node waits for the "inquire message" in setup phase. Upon receiving an "inquire message" the leaving node initiates withdrawal procedure. If the leaving node is a leaf node(s), it sends the "leave-Me" message to its parent node and neighbor node(s). Upon receiving the "leave-Me" message, neighbor(s) removes the leaving node's information from its routing table. The parent node of the leaving node informs the root node about the leaving node. The root node also removes the leaf node information from its routing table.

If the leaving node is non-leaf node then it informs the root node about its leaving upon receiving "inquire message". Next, the leaving node waits to get intimation from root to execute node withdrawal procedure. If root node receives, withdrawal request from multiple nodes then root node allows each node to quit one by one. For this purpose, root node calls DFS algorithm to allow node withdrawal. Hence, root node sends an acknowledge message to allow each leaving node one by one. The same process repeats for all leaving node to withdraw from the network.

Now we define, how a leaving node quits from the network. The leaving node divides the network into two portions. One tree is indicated by tree T and another tree is indicated by sub tree T whose root node is the leaving node (Figure 4). The tree T is the effected tree once the root node leaves the network. Re-joining the subtree nodes with the network efficiently solves this problem. Therefore, to re-join the subtree, the root node of the leaving node calls Eulerian algorithm to inform T about it is leaving. In Eulerian tour the "Leave-Me" message is traversed in such a way that the message starts from the source (root node of the leaving node) and return to the source node. Since each node has its one hop neighbor information, therefore, when a node receives the message it disconnects from the current parent and establish a new join request by sending "Add Me" request. The same process repeats in all nodes via Eulerian tour until the sender node receives the message. Once the source node (leaving node) receives the message, it confirms that subtree is connected with network. Afterwards, the leaving node informs the root node about subtree connection. Root node removes the leaving node information and sends a message to leaving node to quit from the network.

Root node again informs another leaving node to withdraw from the network. Periodically, all the leaving nodes repeat the same process.

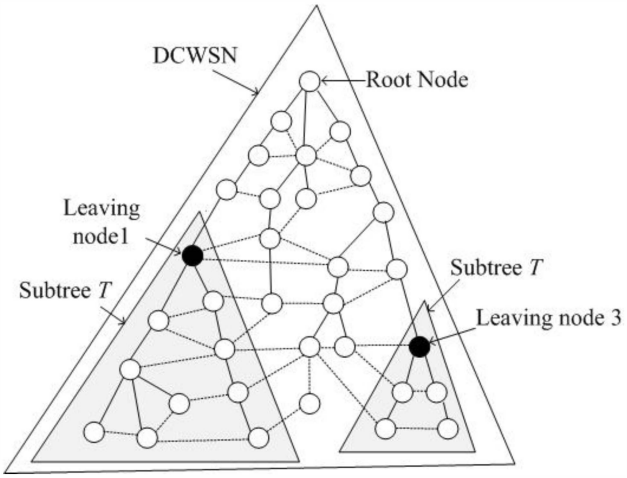

Figure 4: Multiple Nodes Leaving

After all leaving nodes withdrawal, root node sends a request message to the network for data sending. This changes the network in the steady state phase where each node sends their data to the root node. When each node sends their data to root node it sends an "inquire message" to inform the leaving node to send their information. Now the network coverts to setup phase where node's leaving procedure will be called.

B. Multi Nodes Leaving where Nodes have Partial one-Hop Neighbor Information

Since in partial one hop neighbor information, nodes retain its parent and child nodes information only. Therefore in this section, the root node of the leaving subtree calls Eulerian two times. At first, Eulerian is called to inform the subtree nodes to gather information from the neighboring nodes. While in the second Eulerian is used to inform the subtree nodes to join with the other subtree nodes.

In first Eulerian message, the subtree of the leaving node sends a message to subtree to inform the nodes about the leaving. When nodes receive the message for very first time it sends "inquire message" to neighbor node(s). The neighbor nodes send their status upon receiving "inquire message". The node also forwards the Eulerian message to other nodes until the initiator node (root node of the subtree) receives the message. In this traverse all the nodes gather their neighboring nodes' information. When the root node receives the Eulerian message, root node again initiates "Leave Me" message using Eulerian algorithm. Upon receiving the Eulerian message in the subtree T, the node withdraws itself from the network and re-joins based on the information gathered in its previous round. The rest of the procedure is same as defined in section A.

IV. SIMULATION RESULTS

In this section, simulation results for multi nodes leaving algorithms are discussed. The simulation is developed using Matlab. The results conducted using randomly dispersed nodes. For the purpose of simulation we randomly scattered nodes in 500m x 500 m. The transmission range of each sensor node is set to be 70 m.

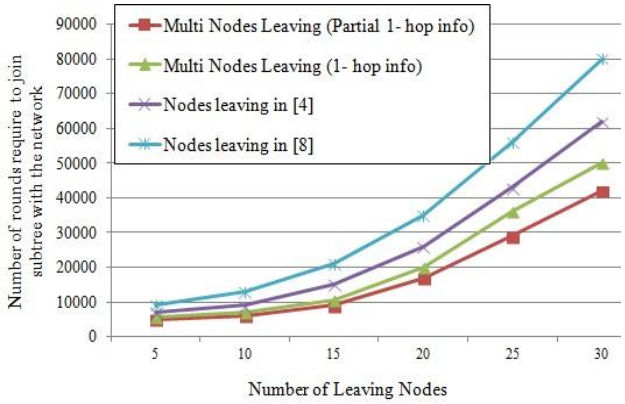

Figure 5: Computation complexity of Multi Nodes Leaving Algorithm

Figure 5 describes the number of rounds require to leave n nodes. Round is the number of messages require during node leaving and re-joining the subtree with the network. When nodes leave from the network, the sub-tree nodes re-join the network. Figure 5 shows that when five nodes leave the network, multi nodes leaving for partial 1-hop algorithm and multi node leaving for 1-hop neighbor provide less difference where partial 1-hop perform efficient. When nodes leaving are exceeded to thirty nodes, the multi nodes leaving for partial 1-hop information outperforms other algorithm with lesser number of rounds.

V. CONCLUSION AND FUTURE WORK

Fault tolerance techniques are widely used in wireless sensor networks. Dynamic Cluster Based WSN is a robust network to handle new nodes joining and existing nodes leaving. This paper efficiently handles multiple nodes leaving in DCWSN. Since the Dynamic Cluster Based WSN is categorized into two types such as, one-hop neighbor information and partial one-hop neighbor information, two algorithms are proposed. The simulation result shows that multi node leaving considering 1-hop neighbor information out performs multi nodes leaving considering partial one-hop neighbor information. In future, the research can be concentrated on the security, QoS and load balancing for DCWSN is also investigated.

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