

Original Research Paper

Fault Node Detection and Connectivity Restoration with Mobile Relay Node in Wireless Sensor Networks

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Abstract: In Wireless Sensor Network (WSN), node failure is an imperative concern in a hostile environment. These node failures create disjoints in the network and leads to a network partitioning problem. It is important for the nodes to be alive and communicate with each other to check the network connectivity. Replacement of Mobile Relay Nodes (MRN) in the location of faulty nodes is the best solutions to reestablish the network connectivity. In this paper, a diverse mechanism is proposed to restore the network connectivity, in the first approach the gateway node takes the responsibility of identifying the faulty node and corresponding communication is to be given to MRN. In the second approach, the residual energy of each node will play a major role in determining the faulty node. Further, performance analysis was performed using a hardware setup with Node MCU and Raspberry Pi3, which proves that this work is mainly suitable for resource constrained devices and provides better results in restoring network connectivity. The performance was validated using experimental analysis and better performance was achieved.

Keywords: Wireless Sensor Networks, Mobile Relay Node, Gateway

Introduction

WSN includes geographically deployed end nodes which comprises of low-powered tiny sensors which consists of the microcontroller, transceiver, with power source, that measures the environmental parameters like temperature, humidity, pressure etc., After deployment, the end nodes are organized to form a connected network so that they can send and receive messages from the base station. The measured data collected at multiple end nodes are transmitted to the central control or the base station of the network using wireless transceivers. To ensure such effective communication among the nodes in the network, the network connectivity is the significant requirement.

WSN generally comprises processing node, Mobile Relay Nodes (MRNs) and gateway. Processing node is used for data acquisition model. MRN is mobile processing node and also a resource rich device in terms of computation power, data storage and energy. The gateway will act as master node that has full control over all the nodes in the network and also on the MRNs. The gateway is connected to all the nodes in the network with

single or multi-hops. Threshold energy (Zhang *et al.*, 2018) is the minimum energy that every individual node in the network must have for effective communication with other nodes or gateway in the network.

The coordination among the nodes of the network is essential to provide the best performance. The energy required for data transmission increases related with the amount of data processed. The network failure occurs due to factors like dislocation of nodes (i.e., out of communication range of the whole network), radio interference, battery drain, deployment in harsh environment. Due to physical fault and failure in network connectivity, most of the end nodes loses its node to node connectivity with the sink node and consequently interrupting the data delivery. Thus, nodes are considered as faulty nodes if they lose membership with the gateway or the base station. The failure of nodes can cause the network to break into partitions which in turn breaks the network connectivity goal, this decreases the Quality of Services (QoS) of the entire WSN (Kaur and Kumar, 2019). The MRNs are located in the predefined region to address the faulty node and takes the functions of the fault node till it recovers.

The possible solution to restore the connectivity (Essam *et al.*, 2018; Jahanshahi and Maddah, 2018; Feng *et al.*, 2019; Joshi and Younis, 2016) can be through node relocation by cascaded node movement as mentioned in (Mahmood *et al.*, 2018). But in this method, the leaf node replaces the failed node and hence there is a coverage hole at the place of the leaf node and also only a single node failure (Singh and Jinila, 2016) can be recovered by cascaded movement. Thus, this solution can address only single node failure and also needs reconstruction of the topology by node movement.

In this paper, the gateway node collects and utilizes the information of each node in the environment in monitoring the network connectivity. When there are node failures in the network, based on the local information from the gateway and without reconstruction of the topology the MRNs will replace the failure nodes to connect the disjoint partitions and restore the network connectivity. Additionally, this scheme avoids unnecessary node movement and rehabilitation of the topology in order to ensure the efficient multi node failure recovery.

Related Works

This section throws light on the works that are related to the restoration of multi-node failure as mentioned by (Shriwastav and Ghose Ghose, 2018). A number of schemes have recently been proposed for restoring network connectivity in WSNs. Some schemes replace nodes with additional relay nodes whereas other schemes carefully reposition the failure node to maintain the network connectivity. Younis *et al.* (2008) proposed a cascaded approach, Recovery through Inward Motion (RIM) for the relocation of nodes to restore the connectivity through inward motion. This method handles the single node failure with the movement of the one-hop neighbor node. In this work, the total distance travelled and the movement of nodes during replacement process are comparatively higher than other schemes. (Imran *et al.*, 2010) proposed a connectivity restoration schemes to handle the node failures, PCR scheme elects the suitable backup nodes. A backup actor used to detect the failure node and send a command to the recovery process. In multi-node failure restoration schemes, (Younis *et al.*, 2008) addressed the multiple-node failure problem for scenarios where the distance between each pair of segments is more than twice the communication range of a node. It is also required that some inter-segment QoS indicators be satisfied it uses a restoration algorithm called QoS aware Relay node Placement (QRP). Their proposed approach operates in two phases. The first phase ensures inter segment connectivity by specifying the positions to place the fewest number of RNs. In the

second phase, QRP deploys RNs in the selected positions to meet the corresponding QoS value. The drawback of QRP is that critical paths may be created during connectivity restoration. Mahmood *et al.* (2018; Sharma and Sharma, 2016) in Sharma which the failure of an RN can cause a new partition in the network. The algorithm restores the inter-segment connectivity by creating strengthening paths to attain the following three objectives: Failure tolerance, latency reduction and energy consumption minimization. A strengthening path allows the network to have a longer connectivity lifetime for different segments, but it requires more redundant nodes.

Boudries *et al.* (2016) proposed a Novel Approach for Replacement of a Failure node in wireless sensor network (NARF) which involves searching of redundant nodes in all the clusters in the network by the cluster heads and replacement of the failure node with the redundant node by cascading movement. This approach initially presents selection of cluster heads based on the energy of the node, its distance from the other nodes, throughput, trust and mobility. These cluster heads are responsible for monitoring the routing and also maintains the list of Redundant Sensor node List (RSL) in the cluster. If there is no redundant sensor node neighboring to the cluster head, then the cluster head of the neighboring cluster will be responsible to replace the failure node. It also addresses the issue of cluster head and gateway node failure. But the process of searching redundant node and detection of node failure causes additional overhead to the approach and also it generates more messages when the communication range is small.

Singh and Jinila (2016) explains another approach for fault node replacement using check point recovery algorithm for node failure detection. In this approach the fault node is detected by sending heartbeat messages to the node, if no response is received from the node then it is considered that the energy of the node is low and it is about to fail and it is replaced by dynamic sensor node with high energy. Tseng *et al.* (2018) presents a Resource Constrained Recovery (RCR) approach in which the network partitioned due to failure of the node is recovered by using a limited number of relay nodes. Each segment in the network has only a minimum number of relay nodes available for the recovery process. After the failure of the nodes in the network, the network is partitioned into numerous disjoint segments and nodes in the segments are not aware of each other's position in the network. Based on the pre-determined position of the node before failure the relay nodes are deployed. Bouyahia and Benchaïba (2016) developed a connectivity repairing protocol called CRVR9. The algorithm restores the inter-segment connectivity by creating strengthening paths to attain the

following three objectives: Failure toleration, latency reduction and energy consumption minimization.

It can be concluded from this review that different, mostly conflicting; objectives have been considered for connectivity restoration in the existing work including the restoration cost (in terms of the number of deployed relays) versus the restoration time and reliability. This proposed work focuses on the multi-node failure restoration by the deployment of additional relay nodes called Mobile Relay Nodes (MRNs) without changing the topology of the network.

Proposed System Model

Initially, the problem is defined as follows: A connected network with n nodes is given such that for all node _{i} is accessible by node _{j} for all $i = \{1, 2, \dots, n\}$ and $j = \{1, 2, \dots, n\}$ either directly or through other nodes by multi-hop information are deployed in an even terrain. All these nodes are in turn connected to the corresponding gateway or the local server where all the information about each node is sent. For our convenience, the total network area is divided into multiple regions. In a fully functional network, the regular nodes may not be adequate to reestablish network connectivity. Hence a new MRNs can be deployed in the (Modieginyane *et al.*, 2018) WSN field to maintain the network connectivity and coverage. An MRN is considered as a resource-rich node with other features such as mobility. Initially, the MRNs are assigned to the predefined regions. The number of MRNs assigned to the region depends on the area covered by the region. If the area of the region is small then only a few MRNs are deployed to that region, on the other hand, if the area of the region is comparatively large then the number of MRNs deployed will be more. The primary goal of this work is determining the node failure and deploying the MRN to that faulty node region, so that the connectivity is maintained in the network.

The proposed work is concerned with the connectivity (Wang and Chen, 2018) among all the nodes in the network for perfect coordination and also on the internal architecture of the nodes in the network. As a recovery plan mentioned in (Tseng *et al.*, 2018) it is assumed that the MRN (Wang and Chen, 2018) are deployed to the application area in order to connect the partitions. It is assumed that the total coverage area of the network is divided into multiple regions. The MRNs are deployed to the region based on the coverage area of the region. If the area is more, then a greater number of MRNs are assigned to that region. Suppose if the region is small, then only a few MRNs are assigned to the region. Hence the number of MRNs

deployed to the region depends on the area covered by the region. MRNs are deployed to a node only after the node sends an ALERT message to all its neighbors and the gateway. This approach can work for both the cases in which the node broadcasts the ALERT message and also when it is not able to broadcast the message. The overall pictorial design of end nodes and gateways and MRN deployment is depicted in Fig. 1.

Algorithm-Fault Node Detection

Algorithm-1: Faulty Node Detection using Periodic ALERT Message

In the first approach the problem of determining the node failure can be carried out by sending a periodic ALERT message to all the nodes in the network. i.e., the nodes in the network send an ACK message to the Gateway and MRN also gets proper response from Gateway. The ACK message contains the residual energy of the nodes and also many other fields like timestamp, sense and services. If the response is received then the node is alive or else the node may be faulty or the message may not be received even if there is network traffic, so to confirm that the node is totally faulty, the MRN waits till the response from the gateway for other ALERT message which is sent at a periodic interval after the first message. If there is no reply even to this message then it is confirmed that the node is a failure node. After confirming the nodes that are faulty, the MRN takes the position of the faulty node.

Algorithm-2: Faulty Node Detection using Residual Energy

In this approach, the residual energy is calculated and the node is declared as faulty or not depending on the residual energy of the node. So, first the threshold energy of the network i.e., the minimum energy required for the node to be alive and also the residual energy of the nodes is calculated. If the residual energy of the node is less than the threshold energy required for the node to function then the node is declared as the faulty node. Even though the node may not fail abruptly when the energy is equal to the threshold energy, it is considered as the faulty node and proceed the recovery process in order to prevent the node from failing and also to avoid loss of coverage and connectivity (Joshi and Younis, 2016) even for some period of time. Then the nodes broadcast the ALERT message to all its neighbors as well as the gateway. The ALERT message includes the nodeID of the failure node, the regionID, the MRN_ID of the MRN deployed to the region and also the type of sensor. After this ALERT message, gateway directs the MRN with the ID referred in the ALERT message to the faulty nodes by

specifying the location of the node. For better understanding the scenario, an abstract view of faulty node detection using periodic ALERT message and faulty node detection using residual energy are shown in Fig. 2 and 3 respectively. It is first checked if the MRN of that ID in the region is idle or not. If the MRN in the region is idle then the gateway directs that MRN

to the faulty node or else the gateway passes the responsibility to the other MRN deployed to the region to take the position of the faulty node. The MRN continues functioning as the normal node until the faulty node recovers and is ready to function. The MRN is removed from that place when the node is ready to recover for that action.

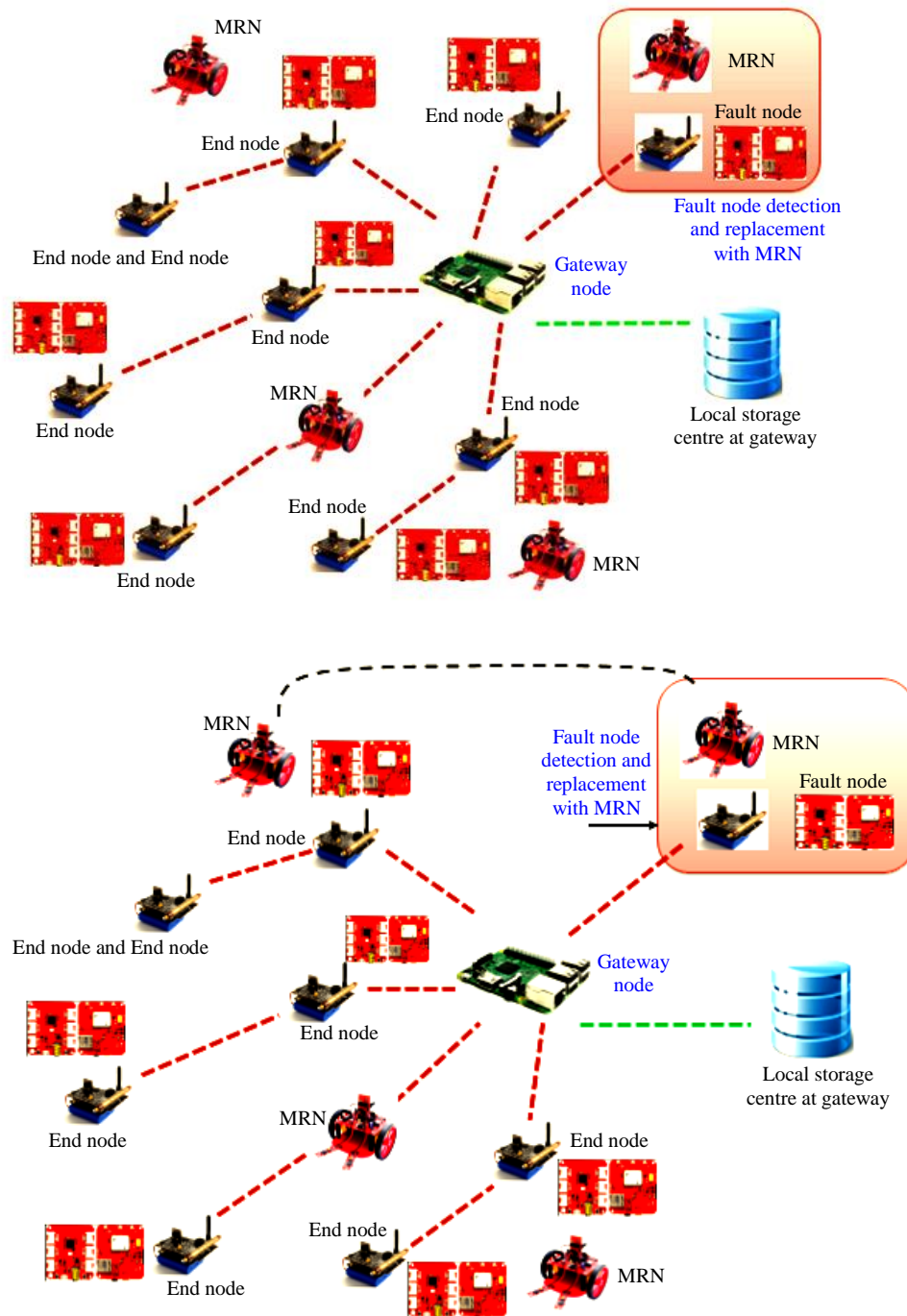


Fig. 1: Illustration of end nodes and gateways and fault node replacement by MRN

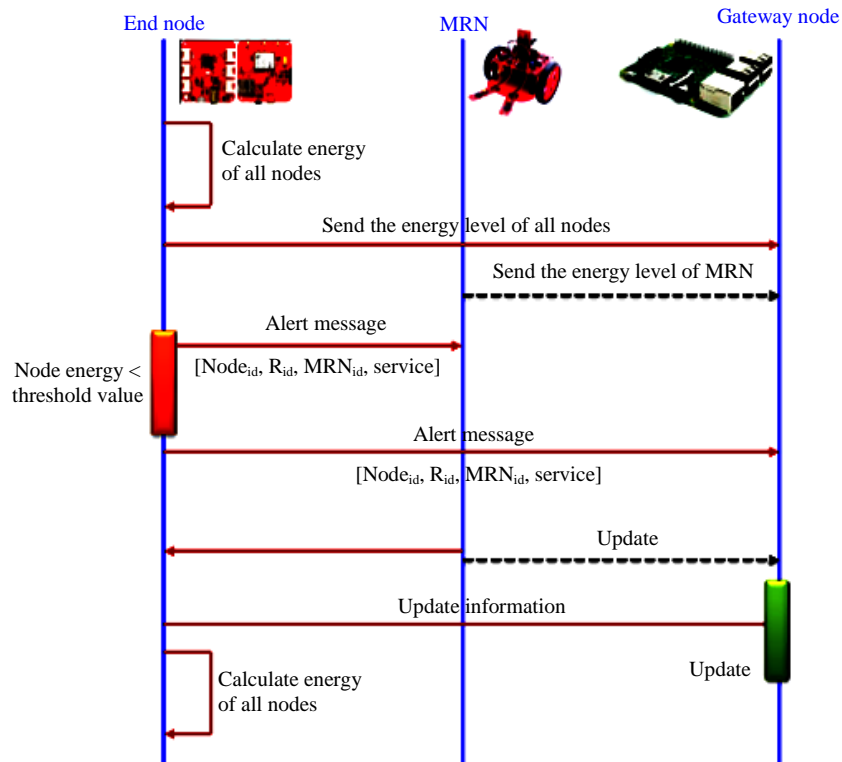


Fig. 2: Faulty node detection using Periodic ALERT message

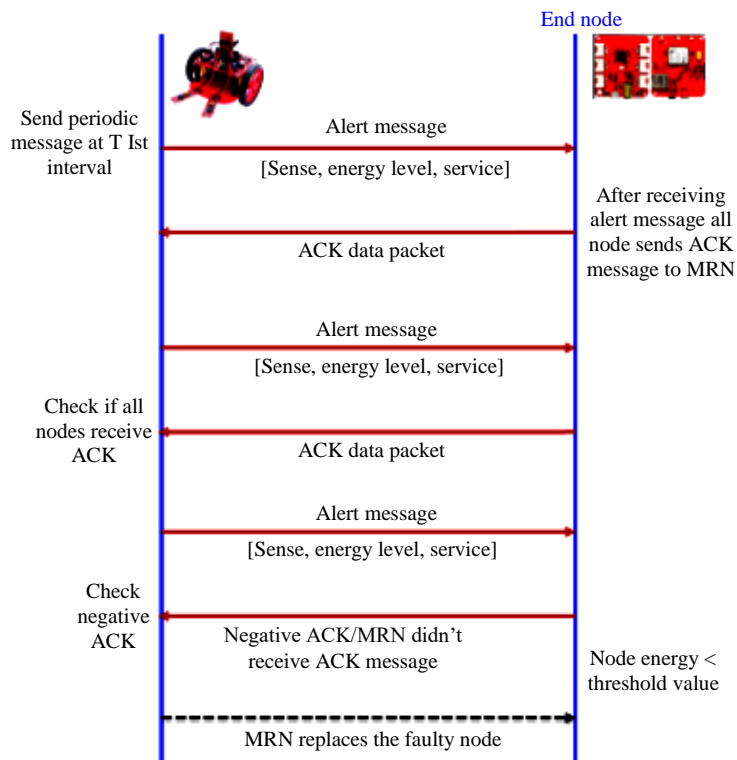


Fig. 3: Faulty node detection using Residual energy

In this paper, MQTT uses a publish/subscribe communication pattern to establish the asynchronous message communication between the nodes and the gateway. MQTT uses the following control packets for the effective machine-to-machine communication: Connect, Connack, Publish, Puback, Pubcomp, Subscribe, Suback, Unsubscribe, Unsuback, PinReq, Pingresp and Disconnect. The protocol enables messages to be delivered efficiently in milliseconds. And also, it provides fast transaction rates and supports lower latency and scalability.

Performance Evaluation

In this section, the performance of the proposed scheme is compared and evaluated with other baseline approaches in terms of average system overhead, a total number of messages communicated among the nodes in

the network and the average number of relocated nodes during failure recovery process. All the nodes deployed in this network has the same communication range. Figure 4 depicts average number of messages used for communication within the nodes during the recovery process. It is observed from this figure, that only a moderate number of messages are required during the recovery process compared to the other single node failure approaches like Least-Disruptive Topology Repair Algorithm (LeDIR), Distributed Connectivity Restoration (DCR). And also, it is depicted that the number of nodes that are relocated is also minimum compared to the DCR approach. The performance of the proposed work is verified both logically and by the simulation model. The results for measurements of node energy level for lower and normal case are shown in Fig. 5 and 6 respectively.

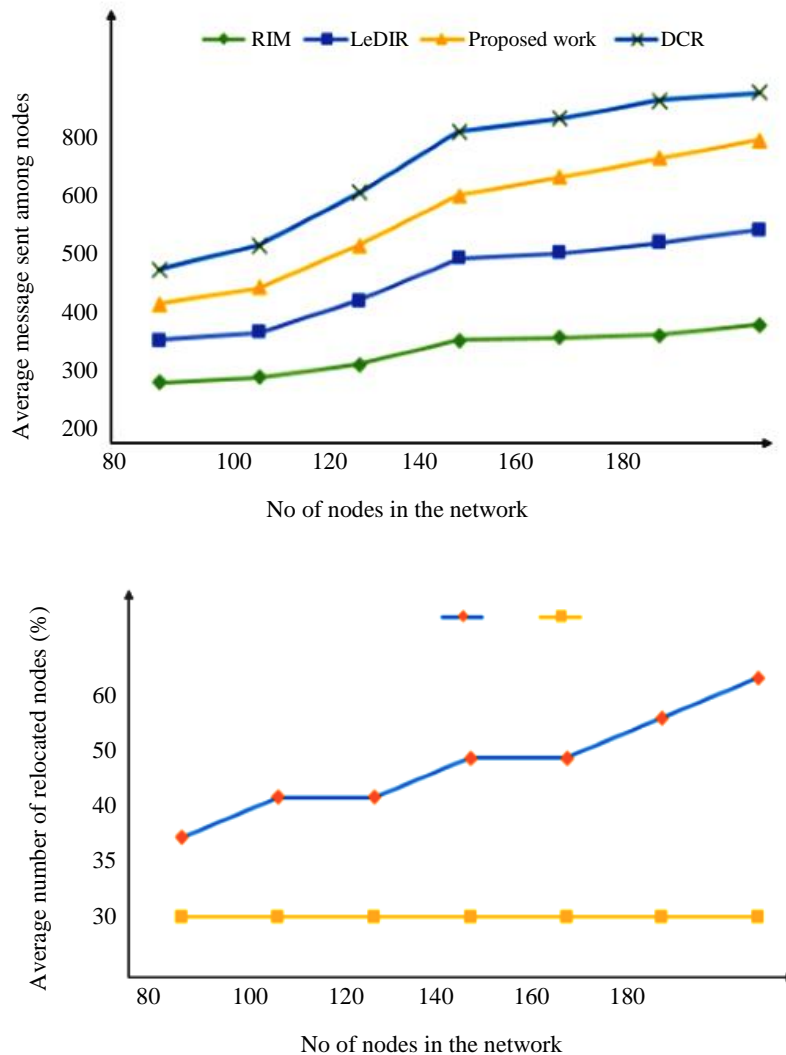


Fig. 4: Average message sent, average number of relocated nodes vs. number of nodes in the network

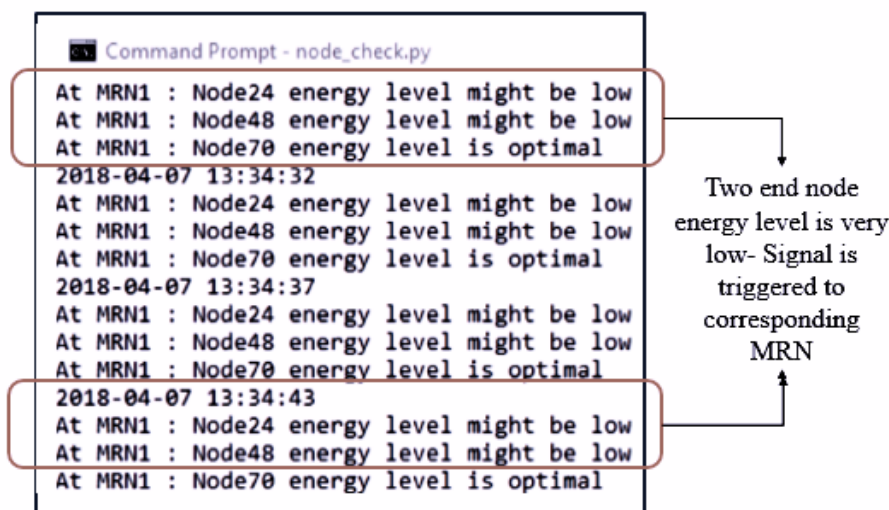


Fig. 5: Experimental results-low energy level case

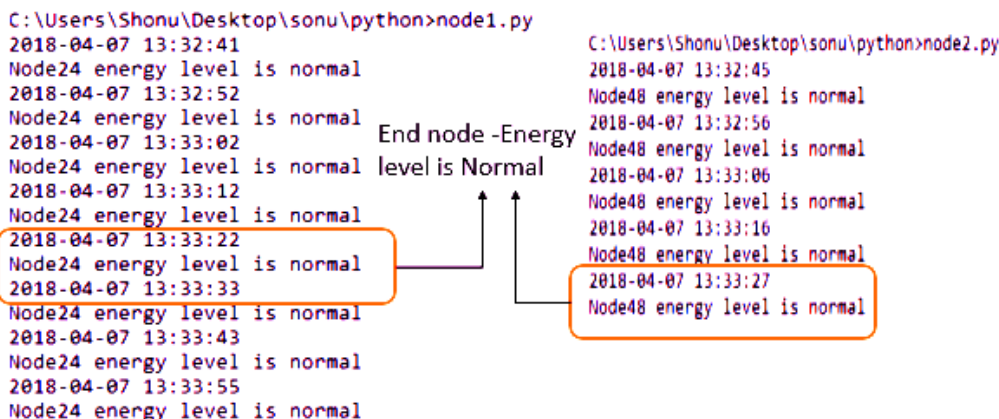


Fig. 6: Experimental results- normal energy level case

Conclusion

An effective fault node detection and connectivity restoration scheme in WSN is proposed and employed with Mobile Relay Node (MRN). In the first approach, the problem of determining the node failure can be carried out by sending a periodic ALERT message to all the nodes in the network it makes certain system overhead. In next methodology, the residual energy of the node in the network is measured and compared with the threshold energy of the node, if it is less than the threshold value, then the node is declared as the faulty node. The proposed algorithm has been confirmed through performance evaluation. The outcome of this work is, low cost, less resource, quick fault node restoration management system well suited for WSN application, which reduces the complexity and delivers effective network and power management. Further, the overall system

follows MQTT protocol which facilitates network connectivity and enhances the system flexibility for adapting in all embedded applications.

Author's Contributions

Anuradha, M.P.: Developed the theoretical concepts. Conceived the presented idea, performed the analytic calculations, develop the experimental model and the framework in real time environment.

Swetha, A.M.: Designed the model and the computational framework and analyzed the working model. Processed the experimental data, performed the analysis, drafted the manuscript and designed the figure.

Manivannan Doraipandian: Developed the theory and performed the computations. Designed the experimental model and the computational framework and analyzed the data. Carried out the implementation.

Conceived the experimental study and were in charge of overall direction and planning.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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