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Robust Link Failure Recovery Mechanism Using Self-Reconfiguration in Wireless Sensor Networks

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Abstract: In wireless sensor networks, frequent link failures between nodes caused due to environmental conditions, wireless infrastructure, energy drain, obstacles, etc. To address this problem a Robust Self-Reconfiguration Link Failure and Recovery (RSRLFR) mechanism is proposed here. This technique enables sensor nodes to autonomously recover from the frequent link failures and to improve the network performance. The nodes with temporary faults can be recovered by using the proposed mechanism autonomous network reconfiguration system. This mechanism produces optimal path and to prevent the network from local link failures. The channel re-allocation algorithm is used to restore the connectivity of sensor nodes. The message loss and energy loss are greatly reduced and packet delivery ratio improved wisely and shown in the simulation results.

Key words: Link failure detection, self-reconfiguration, route recovery, WSN, packet delivery, connectivity

INTRODUCTION

Wireless sensor networks are used in variety of applications from simple data collection to critical monitoring systems. The collected data is passed to the sink via. multiple nodes if the sink node is out of transmission range from the source node. Mostly sensor nodes are designed with low computational power, limited memory capacity and low resource availability characterization.

Network failure under critical applications such as nuclear systems, health monitoring, military operations, etc., cause more harmful effect to the environment due to missing of timing constraints. Due to the limited energy supply of sensors, energy is a very scarce source and directly affects the network lifetime. Therefore, the energy efficiency is the most important issue which is to be considered during link formation between the nodes.

The routing protocols can be categorized based on the nodes participation, functioning mode and network structure. The challenges in routing include energy consumption, node deployment, scalability, connectivity, coverage, security. Generally, on-demand routing protocols find out routes only when the source desires to send the packets to the destination. Here, route maintenance overhead is approximately low whereas discovery of route before data transmission increases the delay. However, if the link failure occurs, nodes should inform the sources to change the existing route and lost packets that were lost due to link failure should be transmitted. This on-demand routing protocols increase delay and decrease the successful packet arrival ratio. To overcome this issue a new protocol is implemented in the proposed work to increase the data delivery rate and to improve the network performance.

Literature review: To improve the Quality of Service (QoS) and to reduce the network latency several reconfiguration techniques are presented. Generally, the routing protocol consumes high energy and leads to decrease network lifetime. Various routing protocols had developed to minimize the energy consumption and to maximize the network lifetime. In order to manage the WSN effectively, more number of schemes had developed.

Group based algorithm using self-organizing strategy had proposed to handle the variations on both transmission power and transmission periods to control energy utilization, so that, network performance is improved (Lai *et al*., 2003). The nodes are connected by the bidirectional links and the transmission power is assigned according to the node's role. Even the node is kept idle to preserve energy the link for the node is activated if node radio senses the important information. Management Information Base (MIB) is used to store the information which monitored by the network monitor

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(Akyildiz *et al*., 2005). The nodes need to report the server by continuously monitoring the network performance. Data processing algorithms are used to analyze the statistical data and the potential abnormality is determined, the server takes responsibility for the abnormal action caused by the node. Effective data processing algorithms is required to monitor the network effectively. A centralized approach for articulation node failure recovery and channel re-allocation had designed (Chouikhi *et al*., 2015). Here, the sink is responsibility for whole recovery process from failure detection to channel reallocation once the connectivity restored between the failure nodes. Some nodes rotated in such a way the information is passed about the failure node to all the segments. Graph theory heuristics and steiner points are used to channel reallocation and rearrangement of nodes around the failed node.

Connectivity Restoration after a node failure through Rearrangement (CRR) had proposed for recovering connectivity loss caused due to failure of nodes (Younis and Waknis, 2010). The network topology is rearranged and the node repositioned to ensure strong connectivity. The Steiner tree formation mechanism is used to restore the connections in which the number of steiner points is constrained. The dynamic energy efficient routing scheme had proposed dynamic reconfiguration approach to provide network adaptability (Kim and Kim, 2010). Clustering in WSN reduces energy consumption. Sensor nodes monitor the environment and forward the status to the cluster node. The function such as distance and remaining energy of each node dynamically estimates the degree of communication adaptability for each link. Based on clustering and re-configuration techniques efficient route was discovered among the nodes.

Minimum Connected Dominating Set (MCDS) using dominating set had proposed to design algorithms that able to operate in distributed manner (Rai *et al*., 2009). The dominating nodes are set using maximum degree of nodes. By using steiner tree the nodes present in the dominating set are connected and pruned MCDS. If any failure occurs in the MCDS, rule-k is used to recover the node from failure. A cluster based self organizing strategy had proposed for building a backbone among mobile devices, detecting segmentation and recovery (Chang *et al*., 2006). Based on local interactions each mobile device had controlled by multi role agent. A role is assigned for the node when it enters into the network if leader node exist already then new agent becomes a role of group member else the node become leader. The leader agents need more energy to execute tasks, keep on routing table updated and to communicate with member agents and gateway agents.

A new hybrid routing metric using enhanced AODV with autonomous network reconfiguration system was proposed to recover the network from local link failures (Gayathiri, 2015). The more optimal path is selected from source to destination using optimized routing scheme. If failure occurs ARS is called through network monitor for localized reconfiguration. The gateway sends the reconfiguration plan for the leader node and the group members. A distributed adaptive optimization beacon exchange selection model considers the distributed network load for energy efficient monitoring with proactive reconfiguration of the network (Iqbal *et al*., 2005). The network monitors the parent node and the information is registered and this profile is updated periodically by using network state beacons. The nodes assigned for cluster head is fully optimized to increase the lifetime of the network. Reliable Reactive Routing Enhancement (R3E) increases the resilience to link dynamics for WSNs/IWSNs (Niu *et al*., 2014). R3E is designed to provide reliable and energy-efficient packet delivery against the unreliable wireless links by utilizing the local path diversity. A biased back off scheme was introduced during the route-discovery phase to find a robust guide path it provide cooperative forwarding opportunities. Along this guide path, data packets are greedily progressed toward the destination through node's cooperation without utilizing the location information.

Hierarchical routing in sensor networks is considered to be energy efficient and cluster based. Each cluster in the network consists of one Cluster Head (CH) node, two Deputy CH (DCH) nodes and some ordinary sensor nodes (Sarma *et al*., 2010). The DCH nodes are used for mobility monitoring, collection of location information and this is also called as cluster management nodes. The concept of CH panel was introduced in order to minimize the re-clustering time and energy requirements. At the initial stage of the protocol, the BS selects a set of probable CH nodes and forms the CH panel. If the current CH losses connectivity or its energy drained below its threshold level, the charge of headship was transferred to either one of the DCH or a node within the CH panel. Energy Power Aware Routing (EPAR) protocol comes under reactive routing protocol and it uses the Min-max formulation cost function approach to calculate the energy cost of the available link in network (Shah and Rabaey, 2002). This protocol selects the path based on minimum number of hops and available energy in that corresponding hops. Autonomous network Self Reconfiguration System (ASRS) was developed to recover the link failures autonomously in order to preserve the performance of the network that enables a multi radio WMN. Here, the system co-operatively reconfigures the network setting but the route discovery is prolonged and overlapping.

However, the novelty of the self-reconfiguration system can be improved by reducing the average delay of the network. Without changing the routing topology of the network route failures can be handled by implementing self healing techniques. Hence, in the proposed method an efficient self reconfiguration system with optimal path is discovered to the dynamically changing network environment.

MATERIALS AND METHODS

Network self-reconfiguration is required for planning algorithms that keeps a track of the local network variations. This planning algorithm monitors the network variations to sort out the network failure problems and to improve the QoS. Robust Self-Reconfiguration Link Failure and Recovery (RSRLFR) mechanism is proposed to avoid frequent link failures between the sensor nodes and the base station and to manage temporary node faults. The proposed mechanism consists of Autonomous Network Reconfiguration System (ANRS). This ANRS provides route failure detection and route recovery. The Base Station (BS) in the network continuously monitors the route availability of source to destination. The availability paths are frequently updated in the route table. If the first path between source and destination get fail, then alternative path is considered. But this timing delay leads to create harmful effect to the critical applications and it consumes more energy. Hence, the network monitor possesses route maintenance continuously by monitoring the link quality and energy availability in the desired path. The Residual Energy (RE) is computed for all the nodes once the path is determined from source to destination.

Link quality estimation between nodes: The link quality estimation is done by using Required Number of Packet retransmissions (RNP) method to determine available bandwidth. It includes Expected Transmission Time (ETT) and minimum number of Hop Counts (Hc). The ETT can be evaluated by using Eq. 1:

$$ETT = ETX(ps/bw) \quad (1)$$

Where:

ETX = Expected Transmission count
ps = Packet size
bw = Bandwidth

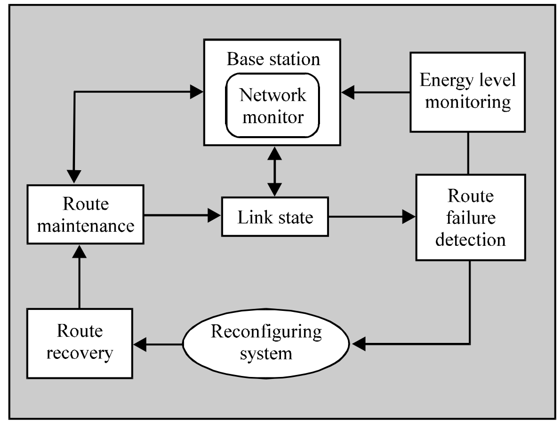

Fig. 1: Network self-reconfiguration system

The minimum Hc is chosen with the average expected transmission count in order to select the robust path or optimal path from source to destination. The optimal path is estimated by using Eq. 2:

$$\text{Optimal path} = \min(Hc) \times \sum_{n=0}^{i} ETT \quad (2)$$

Delivering the data over high quality links improves the network throughput by limiting packet loss and minimizing the number of retransmissions and avoids route reselection provoke by link failure. Link quality estimation plays a crucial role for topology control mechanisms to maintain the stability of the network. High-quality links are long-lived and rely on the aggregation of high-quality links to maintain robust network connectivity for long periods.

Network self-reconfiguration system: The NSR system consists of BS with network monitor, route maintenance, link state, route failure detection, reconfiguring system and route recovery are explained in Fig. 1. The network is deployed with several nodes. The node is in need of information is said to be destination and the node have resources to send is said to be source. The source sends RREQ and the available nodes send RREP. Several possible paths are identified in parallel and the most optimal path is determined among them so that the nodes with permanent fault can be isolated from the path.

Once, the optimal path is discovered from source to destination then the route is monitored by the network monitor for every time period. The operation-time is partitioned into equal intervals of length unit time. Every unit time, the current remaining energy level for each node

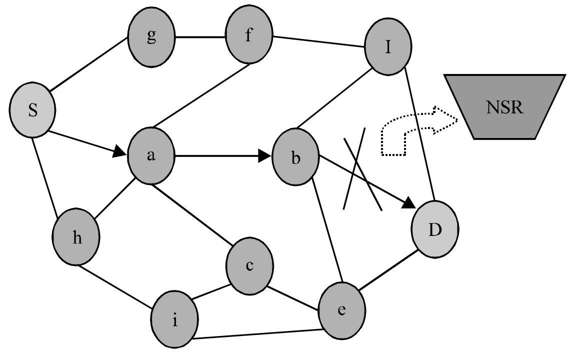

Fig. 2: Route failure detection

is examined periodically. The threshold for the link quality is effectively monitored by using Network Interface Card (NIC) and the settings are reconfigured according to the network.

Route maintenance: The route established between source and destination is maintained by the Route maintenance. The route maintenance consists of two parts namely route failure detection and route recovery.

Route failure detection: The outgoing link of every node in the network is monitored passively by the network monitor at every period of time (e.g., 5 sec) and reports the result to the gateway. At every unit time the node information is passed to the reconfiguration system. If the energy is reduced below the threshold level (E_{Thresh}) then the link failure occurs. Due to the link failure, the packets dropped during the transfer of packets.

The route failure detection is shown in Fig. 2. The optimal path is selected S-a-b-D. However, node 'b' may get compromised due to fall of energy threshold level or low memory capacity, therefore the link get disconnected from b-D. This information or alert message is passed to NSR for reconfiguration.

Route recovery mechanism: The route failure or disconnected link from b-D is recovered by using reconfiguration system. The failed link sends the request message via. NIC to the leader node or BS. The gateway synchronizes the planning request and generates reconfiguration plan through stabilizing the energy level of the node according to the request. The NRS sends the planning request to the gateway. The setting for the failure link is reconfigured according to the reconfiguration plan using the energy equilibrium process only if the remaining energy level falls below the threshold value whose details are explained in Fig. 3.

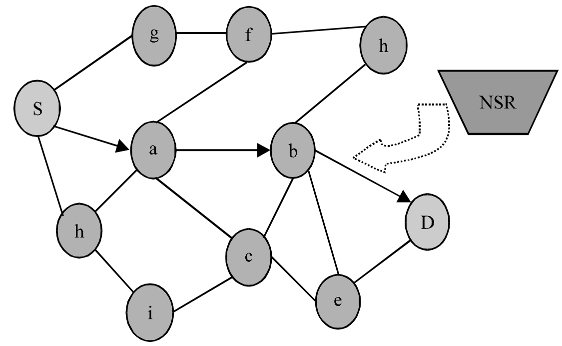

Fig. 3: Route recovery by using NSR

Hence, the failure node is rectified by automatic reconfiguration then the packets are transferred efficiently and it is termed as self stabilization technique.

This automatic reconfiguration includes local repair algorithm and this algorithm is able to hold the minor changes like temporary Link Failure (LF) occur in the network topology due to deactivation of intermediate node present in the routing path. Each and every node deployed in the network has some self-stabilization characteristics which possess local repair algorithm by monitoring the network. This avoids the deep discharge of the battery and allows it to rejuvenate itself.

Network Self Reconfiguration System (NSRS)-algorithm:

```
Initialize   source broadcasts → RREQ
             receive RREP → Destination
Multiple path discovered from Src → Dest
Compute RE(n)
Set E_thresh
for all n nodes in optimal path do {
   Compute ETT=ETX*(ps/bw)
   Dest node receives multiple RREQ's
   Compute path cost
   Choose Min Hc with avg ETT value of n
   Select optimal path Src → Dest
   Send data to Dest
      If (any link failure occurs) {
       Call NSR system
       Detect link failure node
       Check E_Thresh & E(n)
       Apply Self-Stabilization
       Energy equilibrium
       Route recovered by NSR
       Now send data from current LF node to Dest
     else
       Send data from src to Dest
     }          break
        end if
     end for
}
```

RESULTS AND DISCUSSION

The performance of RSRLFR is analyzed by using the Network Simulator Version-2 (NS2). NS2 is an open source

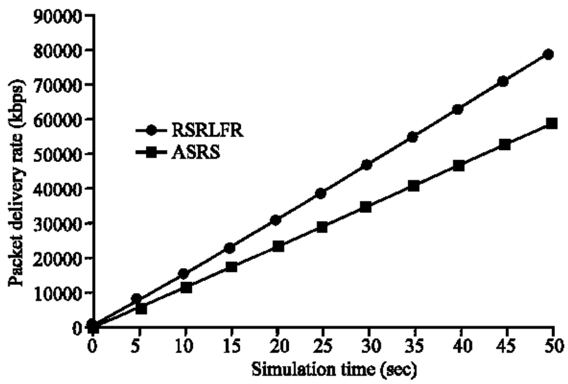

Fig. 4: Packet delivery rate

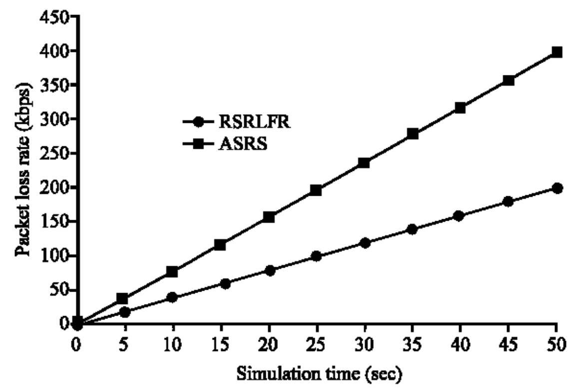

Fig. 5: Packet loss ratio

Table 1: Simulation parameter

Parameters	Values
Channel type	Wireless channel
Simulation time	50 sec
Number of nodes	50
MAC type	802.11
Traffic model	CBR
Simulation area	1000×1000
Transmission range	250m
Network interface type	WirelessPhy
Mobility model	Random way point

programming language written both in C++ which is used in back end and Object oriented Tool Command Language (OTCL) used in front end. NS2 is a discrete event time driven simulator which is used to mainly model the network protocols and simulation analysis. The nodes are distributed in the simulation environment in the communication network. The parameters used for the simulation of RSRLFR are shown in Table 1. The simulation of the proposed RSRLFR has 50 nodes deployed in the simulation area 1000×1000 m.

Packet delivery: Ratio between packet sent to the destination and packet received by the destination is considered as Packet Delivery Rate (PDR). The PDR calculation is done by using Eq. 3:

$$\text{PDR} = \frac{\text{Total packets received}}{\text{Total packets sent}} \quad (3)$$

The proposed scheme is compared with the existing one and the result shows that the proposed scheme gives better result. Figure 4 shows the PDR of proposed RSRLFR It includes packet received rate with respect to the simulation time and it is measured in bits per second. The proposed method achieves better delivery rate with respect to the time taken and the efficiency is calculated as 33% better than the existing ASRS mechanism.

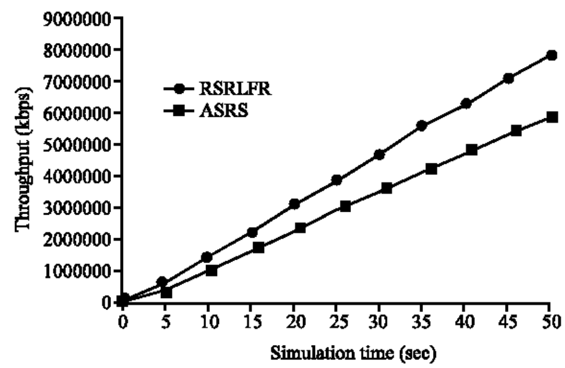

Fig. 6: Throughput

Packet loss: The Packet Loss Rate (PLR) is the ratio of total amount of packet dropped by the receiver to the total amount of packet sent to the receiver. The PLR is calculated using Eq. 4:

$$\text{PLR} = \frac{\text{Total packets dropped}}{\text{Total packets send}} \quad (4)$$

The PLR for the proposed and existing scheme is shown Fig. 5. The loss rate obtained for the proposed RSRLFR is lesser compared to the existing scheme. The loss rate or dropped packets are measured in bits per second.

Throughput: Throughput is defined as overall network performance or the total amount of successfully delivered packets in a given period of time. Throughput can be calculated by using Eq. 5:

$$\text{Throughput} = \text{Packets received}(n) \times \text{Packets size} \times 100 \quad (5)$$

Figure 6 shows the throughput analysis for the existing and the proposed scheme. The proposed scheme

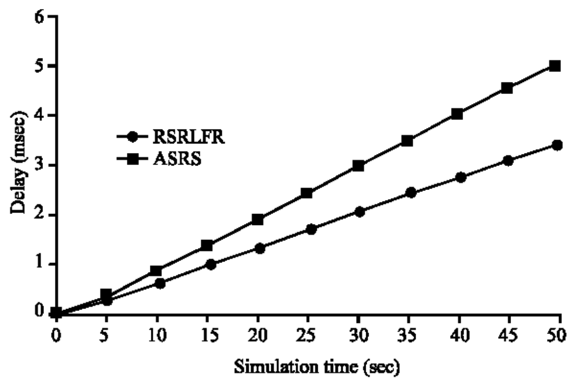

Fig. 7: Delay

has better throughput. The maximum rate of packets received successfully from the sender node to the receiver node in a given time period gives the overall throughput of the system. The proposed mechanism throughput (PRO_THPT) is better than the existing ASRS (EXI_THPT) system.

Delay: The time difference between the current packet received and the previous packet received is defined as the average delay of the network. Equation 6 is used to calculate delay:

$$\text{Delay} = \text{Current packet received time-} \\ \text{Prev packet rcd time} \quad (6)$$

The performance analysis of delay for the both existing and proposed system is shown in Fig. 7. The proposed system RSRLFR (PRO_DLY) has lower delay compared to the existing ASRS (EXI_DLY). The time taken for sending the packets is better than the time taken for sending packets in ASRS scheme. The y-axis represents the time taken for a set of data transmission for the given period of time represented in x-axis.

Residual energy: The remaining energy present in the node after the transmission of data is defined as residual energy. The proposed system consumes less energy for sensing and data transmission. Figure 8 shows the residual energy for both proposed RSRLFR (PRO_Energy) and existing ASRS (EXI_Energy) schemes.

The higher leftover energy indicates the higher network performance thus it maximizes the network lifetime better compared to the ASRS system. The y-axis represents the remaining energy available in the nodes after the set of data transmission and the x-axis denotes the time taken by the node for data transmission. The energy is measured in terms of joules.

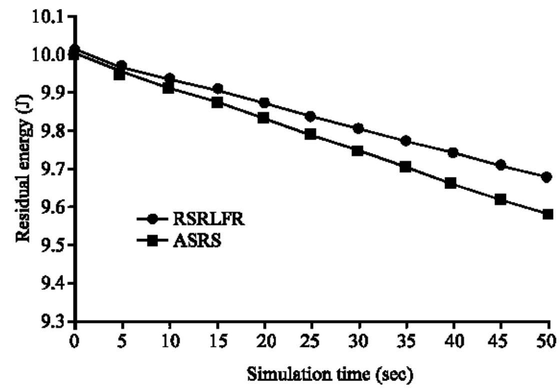

Fig. 8: Residual energy

CONCLUSION

The occurrence of frequent link failures between the nodes is prevented by using self-reconfiguration technique in the network. The robust self-reconfiguration link failure and recovery mechanism is proposed here to recover the nodes from frequent link failures and to improve the performance of the network. It is not necessary to create new routing topology if any link failure occurs in the network, since, the link quality is effectively monitored by using network interface card that restores the system connectivity. NSR is used to recover the node from failure mode in this proposed method. The performance analysis is done for the proposed RSRLFR method and the result shows that the system have good throughput as well as low energy consumption. The delivery rate is greatly increased in their efficiency by 33% comparing to the existing method.

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