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Reliable and Efficient Self Reconfiguration WSN design (RESR) to Mitigate Link Failures

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ABSTRACT

The wireless medium is one of the most prominent reason for the success or failure of any wireless network. Wireless Sensor Network (WSN) experiences frequent link failures caused by interference, obstacles, node energy drained and Time to Live (TTL) expired. In WSN, reduction in the quality of communication between the sensor nodes or from the sensor nodes to the sink nodes causes the failure of links, which in turn disrupts the entire communication. Therefore, we propose a Reliable and Efficient Self-reconfiguration of WSN (RESR) to mitigate link failures. RESR scheme automatically reforms the route to conserve the network performance. The simulation results of RESR improves throughput, reduces the transmission delay and energy consumption in the network.

Keywords: Self-Configurable, Reliable routing, Throughput, WSN.

1. INTRODUCTION

Present improvements in Wireless Communications have enabled the growth of least cost, little power, multifunctional sensor nodes that are tiny in size and intercommunicate in short distance [1]. WSN are used in variety of fields which includes military, commercial, healthcare, biological, environmental and home applications. The following Fig.1 shows the example of WSN. With the highest growth in the field of embedded computer and sensor technology, WSN, which is composed of several thousands of sensor nodes capable of sensing, actuating and relaying the aggregated statistics, have made remarkable impact everywhere [2].

However, the wireless sensor nodes forming the network do not guarantee reliability and data link speed: radio packets can lost during the transmissions, and the employed transceivers generally have limited bandwidth and power. The resources of the nodes are also limited in terms of computational power of the Micro Controller Unit (MCU), power source and memory space. All these facts make the implementation of a WSN a challenging task[3].

In this paper, we design Reliable and Efficient Self Re-configuration WSN (RESR) to mitigate link failures. This paper focuses on the link failure detection and helps nodes recover from the link failures using the link quality estimation technique proposed. The rest of this paper is organized as follows: Section II describes the analysis of the existing scheme; Section III explains proposed scheme; Section IV describes the proposed strategy reinforced and the corresponding results are presented; and Section V concludes the design of RESR.

2. RELATED WORKS

In WSNs [4], a single link or a group of links in the same region could fail due to different causes such as radio fading caused by nature of the wireless medium, signal attenuation, radio interference due to the

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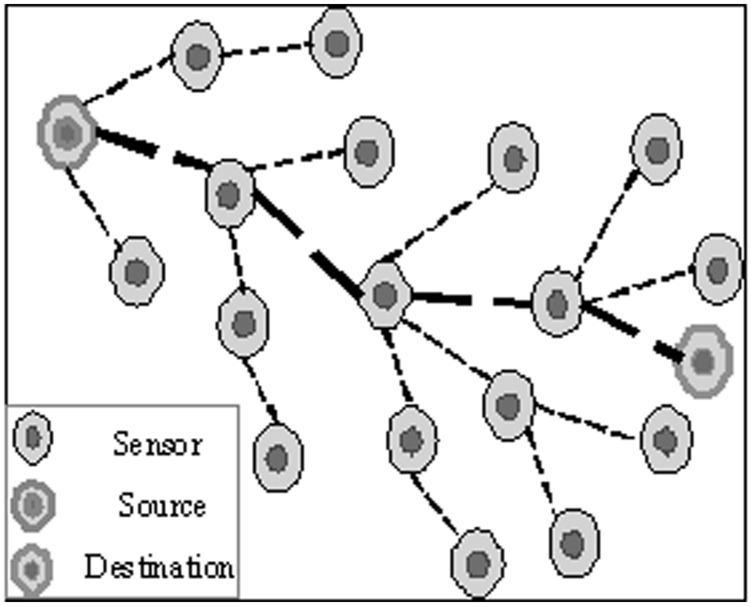

Figure 1: Examples of Wireless Sensor Network

presence of other signals, background noise [like Additive White Gaussian Noise (AWG) etc.], or failure of one of the sensor nodes that are connected to the link. The most commonly used radio model for link failures in wireless networks is based on the path loss model, in which the received signal level decreases as the transmitter and the receiver move farther apart. Time-dependent link failure model incorporates the battery discharge model with sensor power consumption in different modes and wireless channel conditions. This model investigates the reliability of WSN and energy consumption of transmitting sensed data.

Dynamic link quality aware routing protocol [5] described the problem of link failure detection while congestion. Ad hoc On-demand Distance Vector routing protocol with Multi-Radio (AODV-MR) detects the link failure in congested environment. In this scheme, difference between the quality of the current link and the available bandwidth is calculated. The threshold value is predefined between 10 kbit/s to 300 kbit/s. If it exceeds this predefined value then the path is recovered proactively. The threshold value is decided by considering the network status. Self-link Breakage Announcement [6] scheme quickly detects the link breakages in order to minimize the delay and power consumption. In this scheme, a node recognizes the upcoming link breakages in the aforementioned link breakage cases by implementing inner detectors inside of the node to detect that cause before the link breakage actually occurs. Therefore, the neighbour nodes can immediately initiate the route recovery process. This scheme also eliminates the routing overhead caused in the network. Failure detection using counter approach [7], discusses the failure situation of communication. This approach is used to recoup from the communication failure at the circumference node and the radius node.

Latest software based systems and applications increase in two characteristics at large, resourcefulness and functionality. Handling incompatible resources and service disparate user requirements become increasingly imperative. The system increases complexity, rectification of fault and reclaim from malicious attack become difficult. These factors dealt with self-healing systems.

Hello-based failure detection [8] is one of the predominant failure detection mechanisms that provide a lower bound on the packet delivery ratio. It captures the competing requirements of link failures, false detections, and missed detections on the beaconing parameters. Disadvantages of this method are route repair and queuing losses, when route discovery is prolonged and overlapped. Autonomous Reconfiguration System (ARS) [9] autonomously alleviates the local link failure to preserve the network performance.

Hardware reconfigurable node with novel scheduling [11] enabled the utilization of environmental energy with harvesting awareness. The task allocation can be scheduled according to the availability of energy. In this approach, energy can be saved because only the most frequently used tasks are executed using the hardware. The novel scheduling strategy was used to identify the most valuable application for the reconfigurable hardware. The reconfigurable hardware based heterogeneous system is an effective method of increasing the processing ability of systems at lower energy costs. However, this scheme provides computing complexity.

Dynamically reconfigurable routing protocol [12] was designed for under water sensor network. The sensor nodes must be able to re-route their packets even if the configuration of the network changes. It is a multi-hop datagram routing scheme which will offer reliable underwater wireless transmission by dynamically re-routing data, when there is a change in the network configuration. This protocol provides the optimal path for successful communication of data without any interruption and allows reliable communication within limited resources. The failure of nodes may leave some areas uncovered and degrade the fidelity of the collected data. Losing network connectivity has a very negative effect on the applications. Topology management techniques for tolerating node failures in WSN [10] focus on the network topology management for tolerating/handling node failures in WSNs. A faulty sensor node is detected by calculating the Round Trip Delay (RTD) time of discrete round trip paths and thereby comparing them with threshold value [13].

As the advancement in technology increases, the interference and other causes for failing communication increase consequently. A Steadfast Routing scheme for Increasing Reliability (SRIR) [14] makes use of the Packet Received Ratio to indicate the reliability. The formula for Steadfast Routing Factor (SRF) uses energy, distance and packet received ratio assists in selecting a node as the next forwarding node. The SRIR scheme provides efficient results pertaining to reliability, quality of service and energy.

The quality of the link instantaneously decreases during the movement of the robot and the interrupt in communication due to link failure. Therefore, timely detection of the link failure is vital for a dependable communication service. The Cross layer accelerated link failure detection [15] is a faster detection technique for the link failures, achieved by a cross layer approach. By evaluating information about communication errors as well as delivery failures within the Media Access Control (MAC) Layer, a link failure can be detected in the routing layer. Routing layer is the layer at which route is constructed. Link failure detection avoids the communication failure and minimizes the packet loss in the network.

Reliable Reactive Routing Enhancement (R3E) [16] was designed to enhance the reactive routing protocols to provide reliable and energy efficient packet delivery against the unreliable wireless links by utilizing the local path diversity. R3E can effectively serve to progress robustness, end-to-end energy efficiency and latency. However, this scheme causes the occurrence of unwanted delay and extra energy consumption. Wireless channel conditions and sensor node failures may cause network topology and connectivity changes over time. In Industrial WSNs, transmission failures can result in the missing or delaying of communication tasks.

Quality of Service (QoS) aware Distributed Adaptive Cooperative Routing system (DACR) [17] to reach both consistency and delay definite delivery of packet in WSN, disseminate the energy utilization load between many nodes and thus improve the lifetime of network. The DACR's decision on communication mode selection and sensible option of relay nodes was based on the link-consistency values and link-delay values obtained at intermediary hops permit it to proficiently handle different network environments.

3. PROPOSED WORK

Maintaining the performance of WSN in the face of dynamic link failures remains to be a difficult task. The quality of wireless links in WSN degrades due to node energy drained, TTL expired, obstacles or other interference. To resolve this problem, we propose Reliable and Efficient Self Re-configuration (RESR) WSN design.

Initially, every sensor node monitors the quality of its link based on Route Reply (RREP) message it receives via the wireless medium. This ensures the connectivity between all nodes in the network. These nodes send the connectivity information to the source. Then the source transmits the data to destination.

The failed links are detected using information about the inactivity of the wireless links between nodes. Then the system made the self-reconfiguration plan to recover from a link failure on a channel.

3.1. Self-Reconfiguration Plan

The Self-reconfiguration plan effectively searches all genuine changes in link configurations around the area where link failure occurs. RESR discovers possible exchanges that avoid a local link failure but keep up the existing network connectivity. In generating such plans RESR has to address the following challenges.

3.1.1. Avoiding a faulty channel

RESR first ensure that the faulty link needs to be fixed as in the proposed method via reconfiguration. To this end, RESR considers two primitives to fix a faulty link(s). RESR use: 1) a channel-switch where both end-radios of link AB can simultaneously change their tuned channel; and 2) a route-switch where all traffic over the faulty link can use a detour path (alternate path) instead of the faulty link.

3.1.2. Maintaining network connectivity and utilization

RESR needs to maintain connectivity with the full uses of resources. RESR maintains its own connectivity and it maximizes the usage of network resources by making each node associate itself with at least one link and by avoiding the use of redundant channel (only one at a time).

3.1.3. Controlling the scope of reconfiguration changes

RESR uses a hop reconfiguration parameter. Starting from a faulty link(s), RESR considers link changes within the first hops and generates possible plans. If RESR cannot find a local solution, it increases the number of hops so that it may explore a broad range of link changes. Thus, the total numbers of reconfiguration changes are determined on the basis of existing configurations around the faulty area.

3.1.4. Avoiding cascaded link failures

RESR needs to check whether neighbouring links are affected by local changes by monitoring the requests and replies. To identify such adverse effect from a plan, RESR also estimates the QoS satisfiability of links one hop away from member nodes whose links' capacity can be affected by the plan. If these one-hop-away links still meet the QoS requirement, the effects of the changes do not propagate thanks to spatial reuse of channels. Otherwise, the effects of local changes will propagate, causing cascaded QoS failures.

3.1.5. Link Bandwidth Estimation

RESR has to check whether each link's configuration change satisfies its bandwidth requirement. To estimate link bandwidth, RESR measures link capacity.

In order to satisfy all these conditions mentioned above, we use the following optimized metrics. In order to reduce the complexity of computation, we select the most apt metrics that impact all the above requirements.

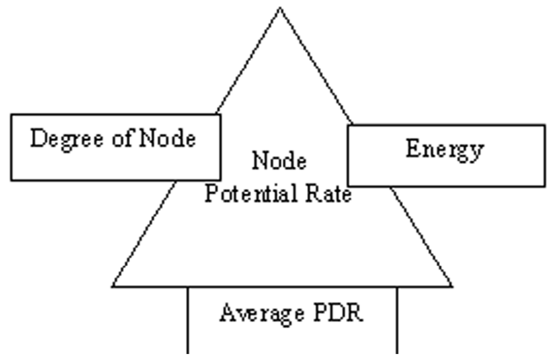

Figure 2: NPR estimation

Node Potential Rate (NPR) is used to estimate the node link quality and the highest NPR node is selected as a forwarding node. Link Quality Estimation module estimates the link quality by NPR shown in Fig. 2.

The Node potential Rate (NPR) equation is given below

$$NPR(n) = D(n) * E(n) * AvgPDR(n) \tag{1}$$

where

$D(n) \rightarrow$ Degree of Node (number of neighbours)

$E(n) \rightarrow$ Energy of Node in Joule

$AvgPDR(n) \rightarrow$ Average PDR

The degree of node represents the number of neighbour nodes present in the particular node. The energy represents the energy level of nodes in the network. In WSN, a node loses a particular amount of energy for every packet transmitted and every packet received. Packet Delivery Rate (PDR) is the ratio of the total number of packets successfully delivered to the total packets sent. Average PDR represents the average PDR value of the node.

However, this highest NPR node does not send the data directly to the destination. This node adds the self-reconfiguration plan along with the data to the node whose link failed previously. Apart from forwarding the data to the destination, it also reconfigures its broken link and then sends back repairing messages until its link is completely recovered by using the suggestions in the self re-configuration plan it receives. Therefore, this broken link is recovered and is ready for use for all further communications.

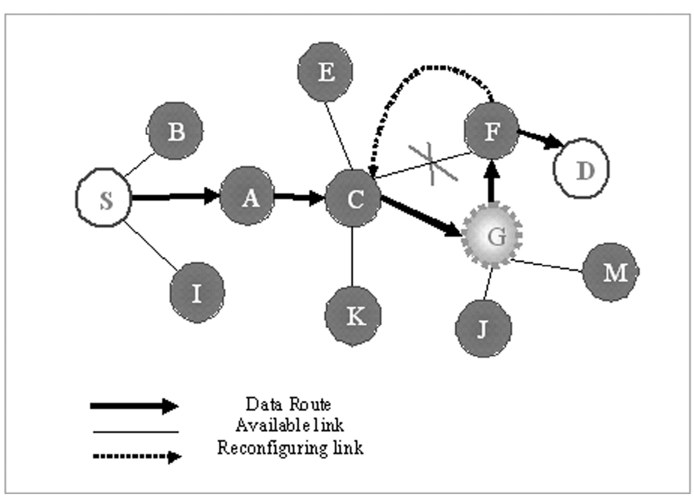

Figure 3: Illustration of RESR strategy

In order to get a clear understanding of the proposing method, Fig. 3 shows the illustration pictorially representing a real WSN scenario.

Source (S) sends the data to destination (D) through the intermediate hops A-C-F-D. However, the link C-F is failed, the NPR value is estimated for all the neighbouring nodes. From this group the node G is chosen as the highest NPR node, which forwards data back to the node F whose link with C failed previously. In this process, highest NPR node adds the self-reconfiguration plan (either by plan 1: changing channel or by plan 2: changing route) for F and sends the data to F. The node F now is free to send data to the destination D. Apart from this, F also uses its self-reconfiguration plan to recover its link back to the node C. Thus for further communications the node C can send data to the node F.

Fig.4. shows the architecture of the proposed scheme. In this architecture the link state is obtained by monitoring the node energy drained, Time to live Expired, obstacles and other interference that are the reasons for link failure occur in the Network. Failure detection module detects the failure by an absence of a reply.

During *Local Recovery*, RESR uses a Self Re-configuration plan only when changes occur in the neighbourhood where link failure occurs. During *Route Recovery*, RESR construct a re-routing plan that interacts with the link layer re-configuration. Fig. 5 shows that flowchart of the RESR scheme.

3.2. Procedure

Step 1: The source send Route Request (RREQ) message to all adjacent nodes. These adjacent nodes in turn reply with a message. It ensures the node connectivity.

Step 2: Transmit the data from source to destination.

Step 3: If data reach the destination, finish the process otherwise occurrence of the link failure detected.

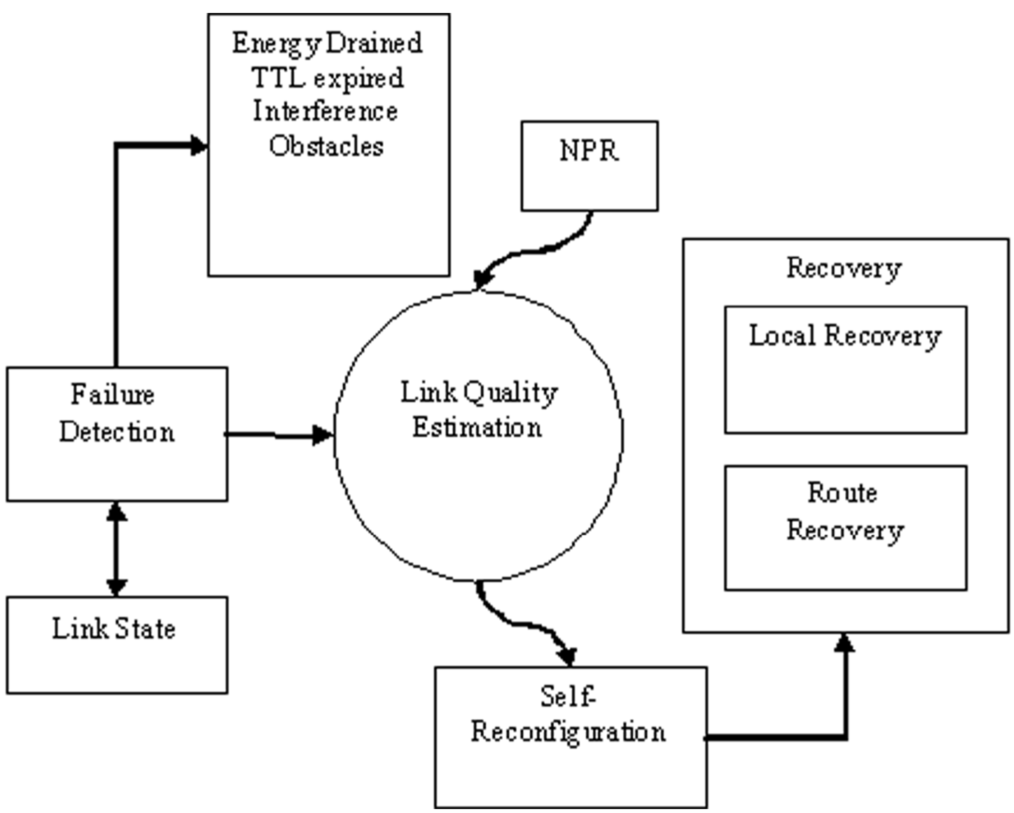

Figure 4: Architecture of the proposed scheme

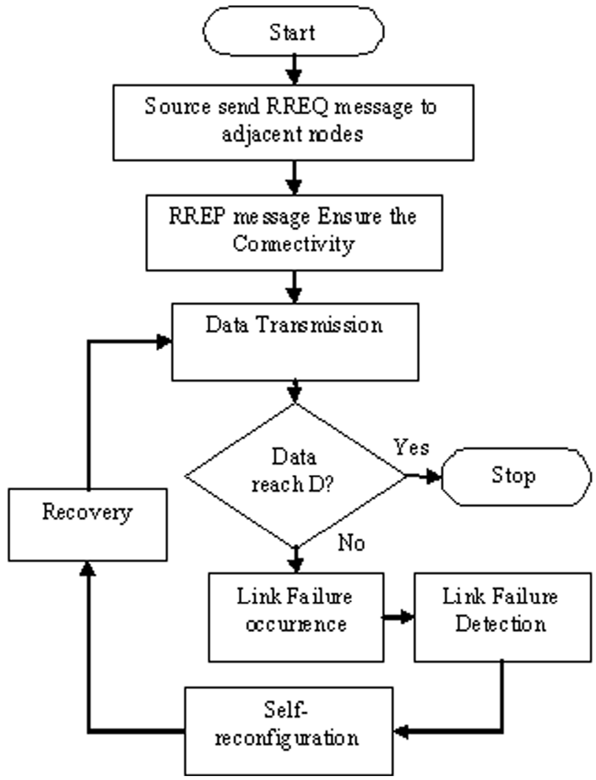

Figure 5: Flowchart of RESR scheme

Step 4: Identify the reason of link failure and make self-reconfiguration (by plans 1 or 2).

Step 5: Finally, route is reformed and continue the data transmission.

3.3. Mathematical Computation of NPR

We perform a mathematical computation of NPR using an example scenario in Fig. 6. The example shows the *node 2* checks NPR value for neighbor *node 3* and *node 5.*

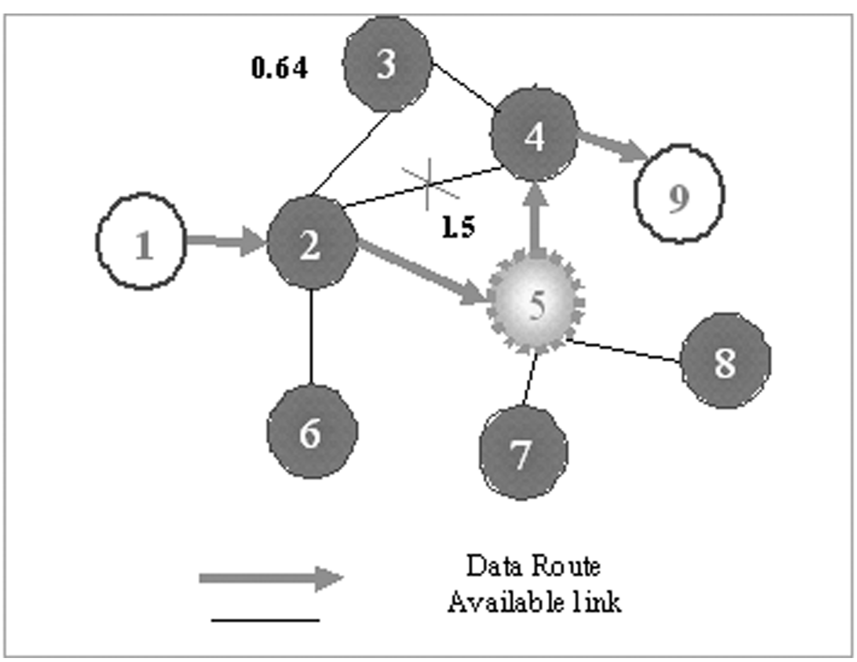

Figure 6: NPR illustration with an example Scenario

The NPR value computation is given below,

For *node 3:* E(3) = 0.41J and D(3) is 2

For *node 5*: E(5) = 0.45J and D(5) is 4

The PDR value is normalized to 1. For example, if *node 2* sends 1000 packets to *node 3*, packet delivered to node 3 is 786, then PDR value is 0.786.

If *node 2* sends 1000 packets to *node 5* ,packet delivered to node 5 is 856, then PDR value is 0.856.

The NPR estimation for *node 3* is $NPR(3) = 0.41 \times 2 \times 0.786 = 0.64$

The NPR estimation for *node 5* is $NPR(5) = 0.45 \times 4 \times 0.856 = 1.5$

Therefore the *node 5* is selected as the highest NPR node that can generate the self-reconfiguration plan for the *node 4*. The self reconfiguration of the failed links therefore help the next communicating nodes to perform effective communication. This increase the efficiency of the RESR protocol to a good extent, which is analysed in the simulation analysis that follows. .

4. SIMULATION ANALYSIS

The performance of Reliable and Efficient Self Reconfiguration scheme is analyzed by using the Network Simulator (NS2). The NS2 is an open source programming language written in C++ and OTCL (Object Oriented Tool Command Language). NS2 is a discrete event time driven simulator, which is used to mainly model the network protocols. The parameters used for the simulation of the proposed scheme are tabulated in table 1.

The simulation of the proposed scheme has 50 nodes deployed in the simulation area 800×800. The nodes communicate with each other by using the communication protocol User Datagram Protocol (UDP). The traffic is handled using the traffic model Constant Bit Rate (CBR). The radio waves are propagated by using the propagation model two-ray ground. All the nodes receive signals from all directions by using the Omni directional antenna. The performance of the proposed scheme is evaluated by the parameters packet delivery ratio, packet loss ratio, average delay and throughput.

4.1. Packet Delivery Rate

Packet Delivery Rate (PDR) is the ratio of number of packets delivered to all receivers to the number of data packets sent by the source node.

Table 1
Simulation parameters of RESR

Parameter	*Value*
Channel Type	Wireless Channel
Simulation Time	50 ms
Number of nodes	50
MAC type	802.11
Network Interface Type	Wireless PHY
Traffic model	CBR
Communication Protocol	UDP
Simulation Area	800x800m
Transmission range	250m
Antenna Model	Omni Antenna

The PDR is calculated by the equation 2,

$$PDR = \frac{\sum_0^n Packets\ Received}{\sum_0^n Packets\ Sent} \tag{2}$$

The Fig. 7 shows the PDR of the proposed scheme RESR is higher than the PDR of the existing method R3E. The greater value of PDR means the better performance of the protocol.

4.2. Packet Loss Rate

The Packet Loss Rate (PLR) is the ratio of the number of packets dropped to the number of data packets sent. The formula used to calculate the PLR is given in equation 3.

$$PLR = \frac{\sum_0^n Packets\ Dropped}{\sum_0^n Packets\ Sent} \tag{3}$$

The Fig. 8 shows the packet loss rate for the existing and the proposed systems.

4.3. Average Delay

The average delay is defined as the time difference between the current packets received and the previous packet received. It is measured by the equation (4).

$$Average\ Delay = \frac{\sum_0^n Pkt\ Recvd\ Time - Pkt\ Sent\ Time}{n} \tag{4}$$

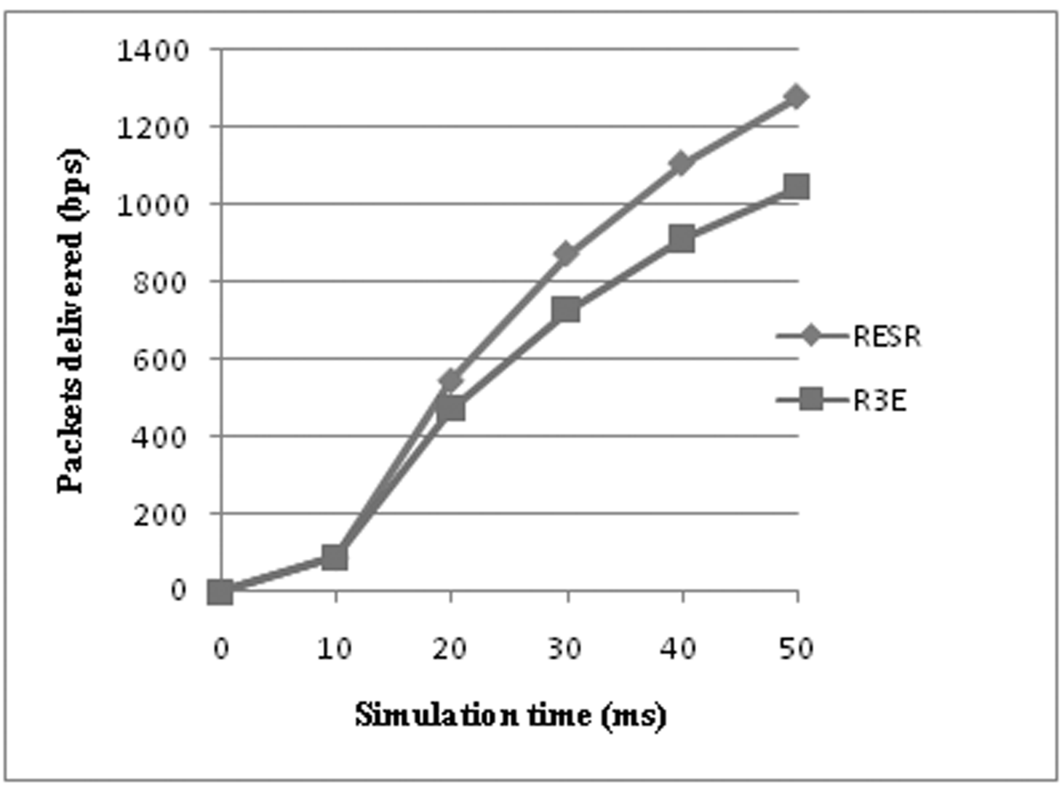

Figure 7: Packet Delivery Rate

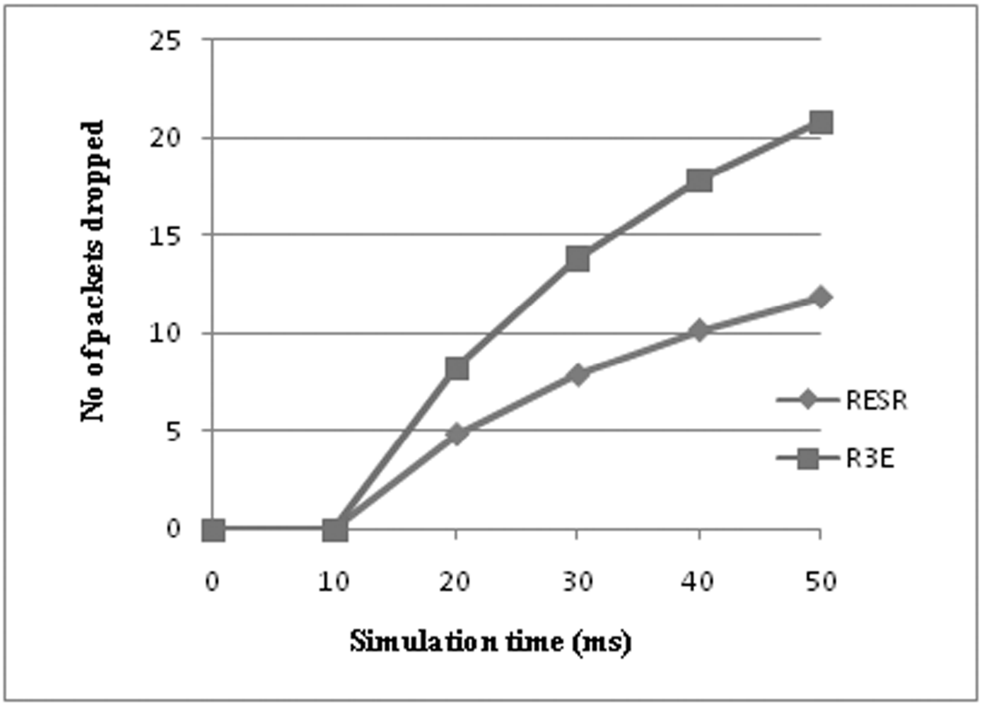

Figure 8: Packet Loss Rate

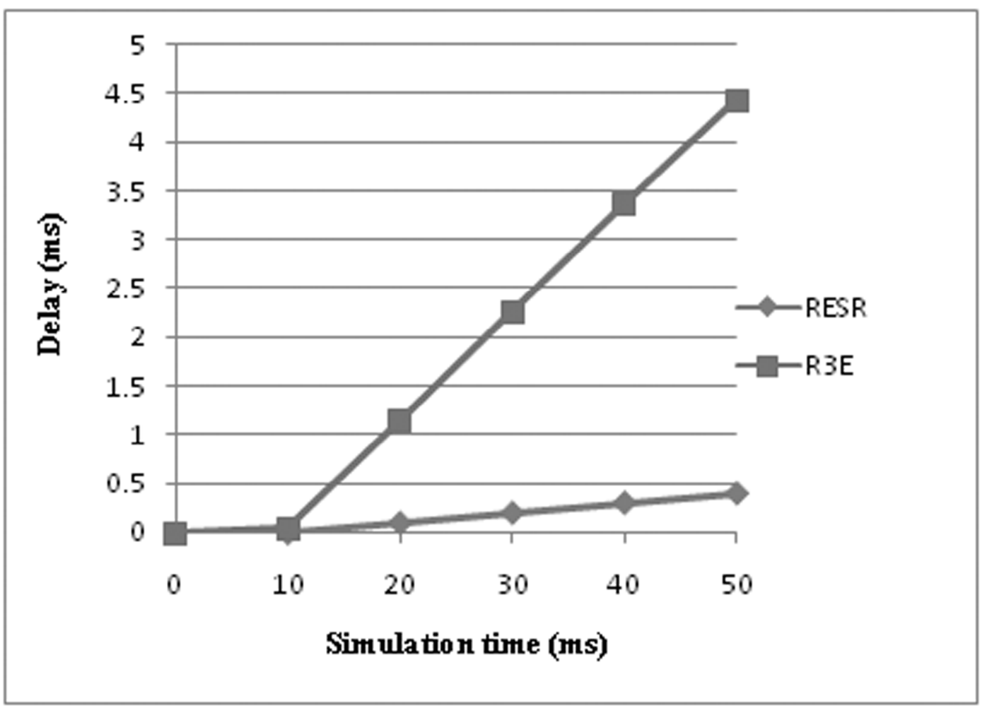

Figure 9: Average Delay

Fig. 9 shows that the delay value is low for the proposed scheme RESR than the existing scheme R3E. The minimum value of delay means that higher value of the throughput of the network.

4.4. Throughput

Throughput is the average of successful messages delivered to the destination. The average throughput is estimated using equation 5. Fig. 10 shows the throughput variations.

$$Throughput = \frac{\sum_{0}^{n} Pkts\ Received\,(n) * Pkt\ Size}{1000} \quad (5)$$

4.5. Residual Energy

The amount of energy remaining in a node at the current instance of time is called as residual energy. A measure of the residual energy gives the rate at which energy is consumed by the network operations.

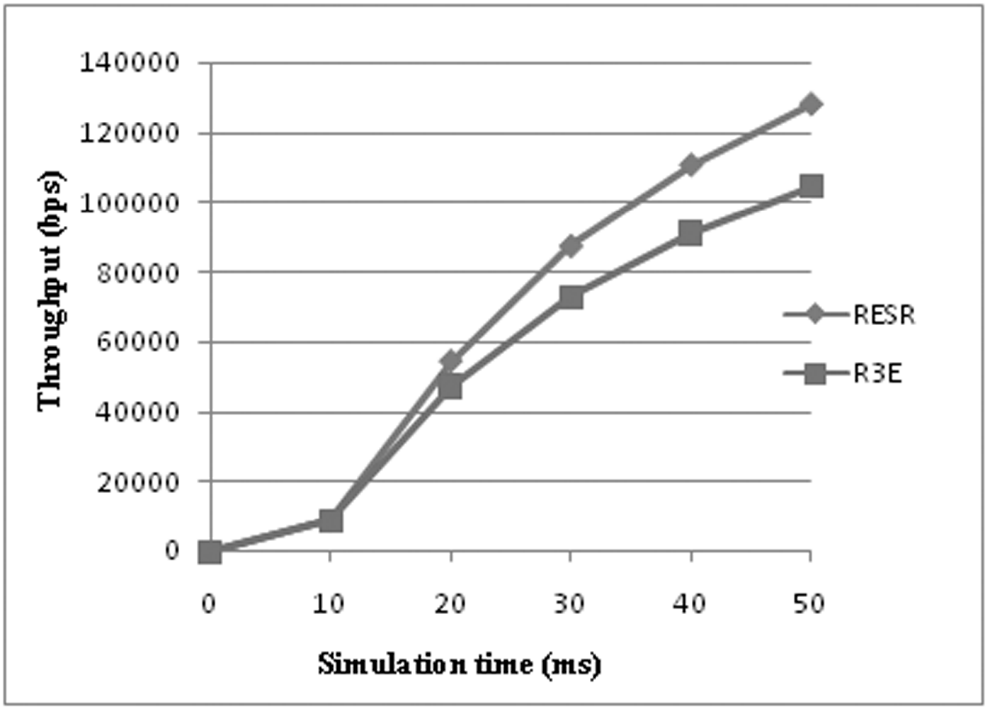

Figure 10: Throughput

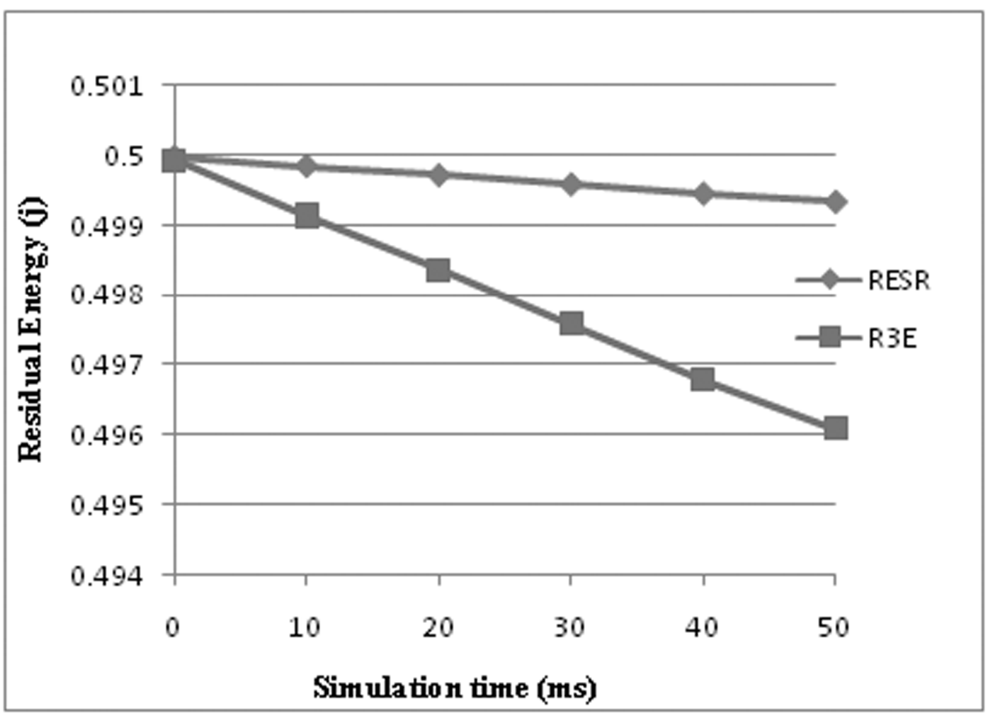

Figure 11: Residual Energy

Fig. 11 shows that the residual energy of the network is better for the proposed scheme RESR when compared with the existing scheme R3E.

5. CONCLUSION

This paper presents a Self-reconfiguration system that automatically recovers the link failure in WSN. RESR effectively generates the self-reconfiguration plans to both local recovery and the entire route recovery based on the self-reconfiguration plan. Node Potential Rate is used to estimate the node link quality. RESR increases the throughput and reduces both transmission delay and energy consumption, when compared to the existing protocol. Our experimental evaluation demonstrates the effectiveness of RESR in reestablishment of route and satisfies the QoS requirement in WSN. For future work, it is possible to avoid and reduce the faults occurring in a wireless sensor network due to energy drain.

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