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Multipath Routing Protocol Using Basic Reconstruction Routing (BRR) Algorithm in Wireless Sensor Network

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***Abstract*—**A sensory network consists of multiple detection locations called sensor nodes, each of which is tiny, featherweight and portable. A single path routing protocols in wireless sensor network can lead to holes in the network, since only the nodes present in the single path is used for the data transmission. Apart from the advantages like reduced computation, complexity and resource utilization, there are some drawbacks like throughput, increased traffic load and delay in data delivery. Therefore, multipath routing protocols are preferred for WSN. Distributing the traffic among multiple paths increases the network lifetime. We propose a scheme, for the data to be transmitted through a dominant path to save energy. In order to obtain a high delivery ratio, a basic route reconstruction protocol is utilized to reconstruct the path whenever a failure is detected. A basic reconstruction routing (BRR) algorithm is proposed, in which a node can leap over path failure by using the already existing routing information from its neighbourhood while the composed data is transmitted from the source to the sink. In order to save the energy and attain high data delivery ratio, data is transmitted along a multiple path, which is achieved by BRR algorithm whenever a failure is detected. Further, the analysis of how the proposed protocol overcomes the drawback of the existing protocols is presented. The performance of our protocol is compared to AOMDV and energy efficient node-disjoint multipath routing protocol (EENDMRP). The system is implemented using NS-2.34. The simulation results show that the proposed protocol has high delivery ratio with low energy consumption.

***Keywords*—**Multipath routing, WSN, energy efficient routing, alternate route, assured data delivery.

I. Introduction

ROUTING in WSN is regarded as a significant area in research over the past decade. Wireless Sensor Networks consists of featherweight, low power, tiny sensor nodes. The single path routing is considered noneffectual to fit the efficiency of numerous applications like area monitoring, healthcare monitoring, environmental sensing and industrial monitoring. Sensor nodes can be utilized in two different ways namely, as an arbitrary fashion and pre-engineered way. As the nodes are economical, more number of nodes can be utilized. The main objective of the sensor nodes is to detect the target area and pass on the gathered data to the sink node.

Various performance demands of applications in combination with the resource limitations of the sensor node and unreliability of low-power wireless links [1] inflict many challenges in designing well organized communication protocols for wireless sensor networks [2].

The single path routing strategies are utilized in most of the existing routing protocols without considering the effects of traffic load strength. In single path routing, algorithm traffic towards the sink node is performed by the source node. Single path route discovery routing can be realized with minimum computational complication and resource consumption. Feasible network throughput is highly condensed due to the minimal capacity of a single path routing. In crucial circumstances, the performance of the network reduces substantially due to the low adaptability, node failures occurs. Dense utilization of the sensor nodes enable a multipath routing approach by constructing various paths between source and sink nodes [3]. The multiple paths discovered are utilized simultaneously to provide sufficient network resources in exhaustive traffic conditions. To overcome the performance issues and to deal with the limitations of the single path routing strategy multi-path routing strategy came into existence. Depending upon routing strategies some routing algorithms employ the best route, apart from the primary route, all other nodes in the alternate routes are put into sleep mode. Alternate routes are used only if there is a disturbance in the primary route. Some employ all their routes concurrently to send data.

Efficient data transmission in WSN is not possible due to the minimal capacity of a multipath and the high dynamics of wireless links. Therefore, the multipath routing approach is considered as one of the conceivable solutions to deal with this restraint. Reliable data transmission in wireless networks is a demanding task based on the time-varying characteristics of low-power wireless links, and wireless interference. The major factor in using multipath routing approach in WSN was to afford path resilience and reliable data transmission. Whenever a sensor node cannot transfer its data packets towards the sink, it can be benefitted from the availability of alternative paths to retrieve its data packets from the node or link failures. Even in the case of path failure, due to the availability of alternative path data transmission can be continued without any interference. Multiple paths also can be used concurrently to enhance data transmission reliability.

The main objective in the design of multipath routing protocols is QoS in terms of network throughput, end-to-end delay and data delivery rate. Alternate paths are utilized to assign network traffic. Critical data packets are transmitted

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through ideal paths with minimum delay whereas non-critical data packets can be transmitted through non-ideal paths with higher end-to-end delay. Multipath routing approaches preserve QoS demands of the destined application in the case of path failures by forwarding network traffic to the nearest active path.

Major routing protocols that exist for WSN includes LEACH [4], Directed Diffusion [5], Energy Aware Routing [6], Rumor [7], Braided [8], and MESH [9]. Among the mentioned multi-hop protocols, the only obviously asserted multi-paths for a data delivery are built by Braided. But only one of them is used. Remaining paths are considered as backup paths. Directed Diffusion routing can be single path or multi-path depending on the number of paths reinforced by sink node. The single path includes Energy-aware and Rumor routing. Single-path routing in comparison with multi-path routing is simple and consumes less energy. But failure in single-path causes a transmission failure that completely destroys the delivery. So, Researchers are turning to multi-path routing for a successful delivery. For example, sending the same data packet along 2 fully node-disjointed paths doubles the delivery ratio. The use of n-fully node-disjointed paths, for n>2, can approximately increase the delivery ratio in proportion to ‘n’. If the requirement for disjointedness is relaxed or partial, multi-path routing schemes shows higher resilience to single-path failure tentatively and analytically [10].Determining the width of multi-path routing before transmission is not an easy task as sensor network topologies are often changing uncertainly, due to abrupt node failures, ecological, and impetuous stable external interventions.

Large ‘n’ values ensure successful delivery, but may cause unnecessary energy loss. Conversely, a tiny ‘n’ value saves energy but may not assure the eminent claim delivery rate. The larger the value of ‘n’, the more is the traffic generated for a data packet delivery, which leads to network congestion. This is the major disadvantage for large ‘n’ values. Given that the simplest CSMA scheme is used at the MAC layer, more traffic causes a longer backoff delay waiting for transmission and more collisions triggered in wireless channel. If the source nodes are certified of path quality, it is possible to adjust the optional ‘k’ value dynamically to adapt to the uncertain network topology changes.

The rest of the paper is organized as follows: The related works are discussed in Section 2. Problem Statement is discussed in Section 3. Proposed Multipath Routing Protocol Using Basic Reconstruction Routing (BRR) Algorithm is briefly illustrated in Section. 4. Simulation results and Performance analysis are presented in Section. 5. Section 6 concludes the paper along with References.

II. Related Works

Query based multi-path routing protocol is used in Directed Diffusion Protocol [11], in which the sink initializes the routing process. The sink loads the concerned data through the network path which contains information concerning the task which will be performed by the sensors. During the data overload all the intermediate nodes store the concerned data obtained from their neighbours. The receiver node creates an incline [12] towards the nodes from which the data has been received. Multiple routes can be identified between each source and sink. In the next step, when the source discovers an event matched with the casual data in the concerned table, it forwards the data through all the constructed routes. The sink node selects a route based on the performance of the packet reception over each route. The selected route is used to transmit the data between the sources and sink node. In order to maintain the discovered routes the sink node constantly sends low-rate concerned data over the surviving routes. The data can be transmitted through the other surviving route if there is a fault in dominant route providing fault-tolerant routing.

In Braided Multipath Routing Protocol [13] similar to Directed Diffusion, several partially disjoint routes are constructed to provide fault-tolerant routing. Using two route reinforcement messages, partially disjoint routes are constructed in this protocol. They are dominant route reinforcement message and alternative route reinforcement message. The route construction is initialized by the sink by sending a dominant route reinforcement message towards its best next-hop neighbor towards the sink, and this process continues until the dominant reinforcement message reaches the source node. An intermediate node that is not a member of the dominant route will select the best next-hop neighbour towards the sink, and this process continues until the message reaches a node along with the dominant route which results in the formation of backup routes from all the intermediate nodes which are in the dominant route. Whenever a dominant route fails all the data can be transferred through to the alternate route.

In [14], authors proposed an energy efficient node-disjoint multipath routing protocol (EENDMRP) for WSN. During the route construction phase, the author proposes distributed multipath search algorithm that is capable to discover multiple-node disjoint paths. Also, a load balancing algorithm is proposed that allows the sink node to distribute traffic over multiple paths based on path cost, which depends on energy level and hop distance of nodes along each path. However, the route construction and maintenance is costly in terms of energy due to high overhead.

To attain energy efficient and low-latency communication in WSNs, AOMDV (Inspired Multi-path Routing Protocol) [15] is designed by using cross layer information. The technique introduced in this protocol for route construction is similar to the technique introduced in AOMDV with few amendments. AOMDV-Inspired Multipath Routing Protocol uses hop-count optimal paths towards the sink node whereas AOMDV recognizes all link-disjoint routes between each pair of source and sinks nodes. Here the sink node confirms a new route only if the first node is different from the previously discovered routes provided if the hop count is similar to the previous one. When the sink node obtains a route-request with lower hop count then all the previously discovered routes is replaced with the newly discovered route.

In Energy Efficient and Collision Aware Multipath Routing Protocol [16], location information of the nodes is used to create two collision-free routes on both sides of the direct line between the source node and sink node. Interference is limited by keeping the distance between the two routes more than that of the interference range of the sensor nodes. During this stage the source node discovers two distinct set of nodes on both sides of the direct line between the source node and sink node. After discovering the neighbouring set, the source node broadcasts a Route Request packet towards these nodes to discover two node disjoint routes. To select their next hop the intermediate nodes follows the same technique used by the source node. Based on their distance to the sink and residual battery level the intermediate nodes set a back-off timer before broadcasting the received route request message. After receiving the route request message the intermediate node will set a back-off timer to restrict the route discovery flooding.

The neighbouring nodes with high battery level and shorter distance to the sink will set shorter back-off time. Due to this only a single node, at each stage will transmit the obtained route-request packet towards the sink node. The sink node sends a route response in the reverse route towards the source on receiving the route request. The source initiates the data transmission through the established route when it receives the route reply. Data transmitted over minimum hop routes will reduce the delay and resource utilization but leads to packet loss and overhead of packet re-transmission.

III. Proposed Mechanism

A. Problem Definition

The proposed method forwards the data along a multi-path route to acquire a high delivery ratio, for small values of 'n' with low energy consumption. The table for multi-path routing is constructed by comparing the energy levels of the intermediate nodes with their threshold energy levels. If the node has energy more than its threshold value, it is selected for data transmission. Data will be forwarded along this path and whenever a path failure occurs, it will reconstruct the path. Path reconstruction is incorporated through many wireless routing protocols [17], [18]. Depending on the nature of establishment of the original path and the reason for path failure, the reconstruction approaches are discrete. In [17], [18], whenever a path failure occurs, an alert is directed to the source node, which is responsible to find an alternative path and re-send the data. This kind of source initiated path reconstructing approach is uneconomical.

B. System Model and Fault Model

The wireless sensor network consists of 'n' number of sensory nodes which includes a sink node. The nodes are considered as stationary after the deployment. Consider a static sink node in the middle of the network having unlimited computation, memory, and battery power. Every node knows their position in the network. Each node is provided with information like ID and it has the address of the nodes which comes under its range in the network. All sensory nodes are equivalent and massively organized. Communication range for every node is equivalent and predefined.

C. Basic Reconstruction Routing (BRR) Algorithm with Assured Data Delivery

This paper proposes a local path reconstructing approach, whereby the node, located at the immediate upstream of a failure, is liable for exploring alternative paths by conducting a local review. If alternative paths are available, data forwarding will advance without restarting from the source node. The selected alternative path may not be ideal from the viewpoint of the source node, but the energy is preserved by the prevention of the previous transmission effort from being exhausted, evading long distance failure alert, and restriction of the range of alternative path exploring into a small local area. Such energy savings should override the additional energy utilized by using a non- ideal path. If alternative paths do not exist, data forwarding will advance by finding the less loaded path among the remaining multi-path routes.

IV. Proposed Model

The proposed protocol consists of five stages namely Neighbourhood Discovery, Multipath Construction, Data Forwarding along the Ideal Path, Detecting the Broken Link and basic route reconstructing protocol.

A. Neighbourhood Discovery

In neighbourhood discovery, every node while transmitting a control packet, stores the following information in its routing table: node ID, hop number, residual energy, energy consumption, delay, remaining energy, etc to all the other nodes. It waits for the control packets from them. After receiving the control packets, each node discovers its neighbouring nodes. Now every node has the partial view of the network which is displayed in Fig. 1.

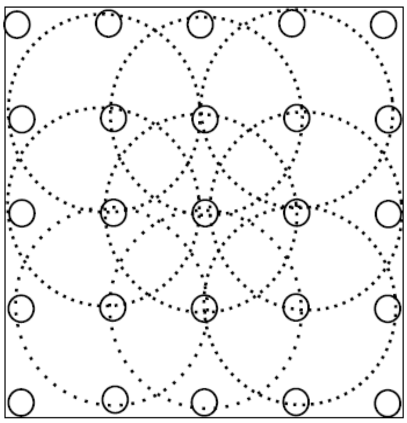

Fig. 1 Neighbourhood Discovery

B. Multipath Construction

Multipath Construction phase starts after the discovery of Neighbouring node in which every node holds their neighbour information. Assume that the source node knows the location of the sink node and based on its location, the source node proceeds with the route request process. Thus multiple paths are constructed from the source node to the sink node. The path used is called as dominant path while other paths are considered as alternate routes. The dominant path is constructed with the best feasible neighbour with the minimum Location Factor (LF) and the alternate route is constructed with the next best feasible neighbour with the next minimum Location Factor (LF). Location factor describes the minimal distance between the source and neighbour node.

C. Data Forwarding along the Ideal Path

Data transmission takes place between source and sink nodes after the multipath construction phase. Although both the dominant and alternate routes are available, data is transmitted over the dominant route only. The remaining nodes which are not in the active route will go to sleep mode in order to save energy. When the data is transmitted to a sink node, based on the stored information in the routing tables of the source node and all its successors the data packet will be automatically directed to drift down from the source node along its dominant path to the sink node. Each data packet holds the source_id, sender_id, sender_hop number and direction in its header. After receiving a forwarded data packet, the node registers the values of source_id and sender_id into its data cache and loads its own id into the sender_id domain. The updated data packet is forwarded to its next hop, indicated by the node ID in its routing table.

D. Detecting the Broken Link

The data packet is forwarded through the dominant path. Any node failure along the dominant path causes an interruption in transmission. Each node is responsible for assuring that its beneficiary has successfully received the packet. The sender node sets a bit in its data packet header to request precise end-to-end acknowledgment from the next hop. The transmitted data packet must be stored in the buffer before its beneficiary was confirmed.

Data failures are caused due to node failure or transmission errors. Transmission error indicates the temporary path failure caused due to a collision, snooping or barrier in the wireless channel. Conversely, the failure nodes indicate the permanent path failure due to energy depletion, malfunction or physical damage of sensor nodes. Channel error is resolved through ARQ or FEC mechanism at the data link layer which is explained in [4] and transport layer in [15]. In the worse case, in order to evaluate the performance of the proposed scheme, we assume that there is no longer a function of defense against channel errors in the other layers.

E. BRR Algorithm

The basic function of each intermediate node is to confirm that its successor has successfully received the data packet. When the transmitter detects a failure report, it concludes that its successor node has been "broken" and looks for an alternative path that bypasses the "broken" node in its neighborhood. In this section, we propose a BRR algorithm to seek the best alternative node among the available path.

F. Alternate Path Selection Rule

Exploring an alternative path starts from the immediate proceeding node of the broken link to broadcast a Help Request (HREQ) message, which bears the helped node ID (helped_node), the broken node's ID (broken _node), the broken node's hop H (broken_node), the detection of the functioned data packet (source_id) and sender_id to its neighborhood.

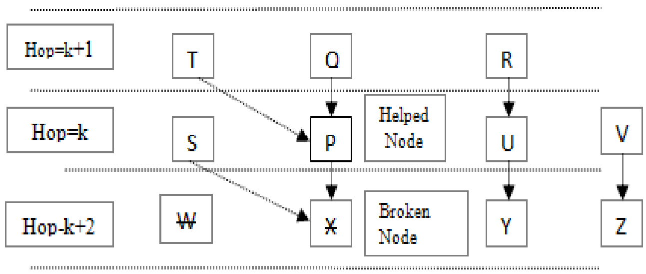

Fig. 2 Alternate Successor Node Selection

After acquiring this message, each active neighbour node performs the following assessment chronologically based on the previously stored information and does the correlation process according to the compared result.

If the successor node of the receiver is the helped node or the broken node, the message is dumped, because the purpose of alternative path exploring is to evade the broken node.

If the data packet recognized by HREQ. (source_id) has been received by the current node before the message is dumped, knowing the previous receipt indicates that the same packet had crisscrossed the current node.

If the results of the above comparison are not the two previous cases, the current node analyzes its hop with that of the broken node. If its hop is equal to or smaller than HREQ. H (broken_node) then the current node concludes that the ideal path to the sink node will not go through the broken node. Therefore, it generates a Help Response (HREP) message and sends it back to the helped node along the nearest path traveled by the Help Request message. Else the current node transfers the Help Request message on to its successor node.

Apart from source_id, a Help Response message also bears two fields in its header: transmitter Id (sender_id) and its hop (sender_hop). Each HREP message gathered by the helped node, point towards the eligible alternative node from the helped node to the sink node, which in turn evade the broken node. The hop of the alternative path is denoted as HREP (sender_hop +1) and the next immediate hop as HREP (sender_id). Thus, the helped node selects the node with minimum hop as the alternative pathway and by updating its routing table, it sends the data to its latest successor node.

The above procedure is illustrated with an example in Fig. 2. Node P receives data from its preceding node Q and transmits it to its successor node X. Consider a broken path between nodes P and X. After the transmission break is detected, node P broadcasts a Help Request message to its neighbours. The successor node is stored in its routing table. After the HREQ message is received from Node P, node S (neighborhood) dumps it, as its successor node is the broken node X. Nodes T and Q also dump the message as their successor is the helped node P.

The message is forwarded to node U by the node R as the hop of node R is greater than that of the broken node X. After the HRWQ message is received from node R, the message is passed on to its successor node by node U.

The process stops at node Y whose hop is equal to that of node X. Then, node Y issues a corresponding HRES message and forwards it back to node P through the path Y - U – R - P. From this HRES message, node P is conscious of an alternative node P – R - U - Y, whose hop sequence is k+2. Similarly node P also receives HRES messages from node U, Y and V respectively. Among the entire alternative node, the path P – R - U – Y has the lowest hop (=k). So node P updates its routing table by changing its successor node Id to Y and its successor node hop to k-1 and the hop of itself to k. Finally, the data forwarding is done from node P along the latest path.

V. Simulation Results

A. Performance Evaluation

Through analysis, the efficiency of the proposed scheme is assessed. 'N' numbers of sensor nodes are chosen for detection and one destination node is considered as Sink node for which all the other sensor nodes send the gathered data.

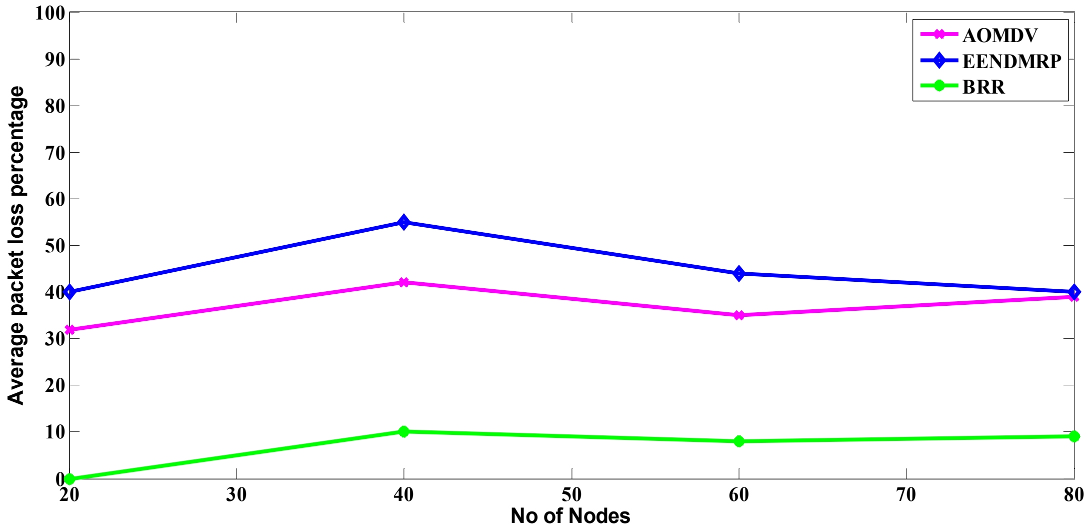

Fig. 3 Average Packet Loss Percentage vs. Number of Nodes

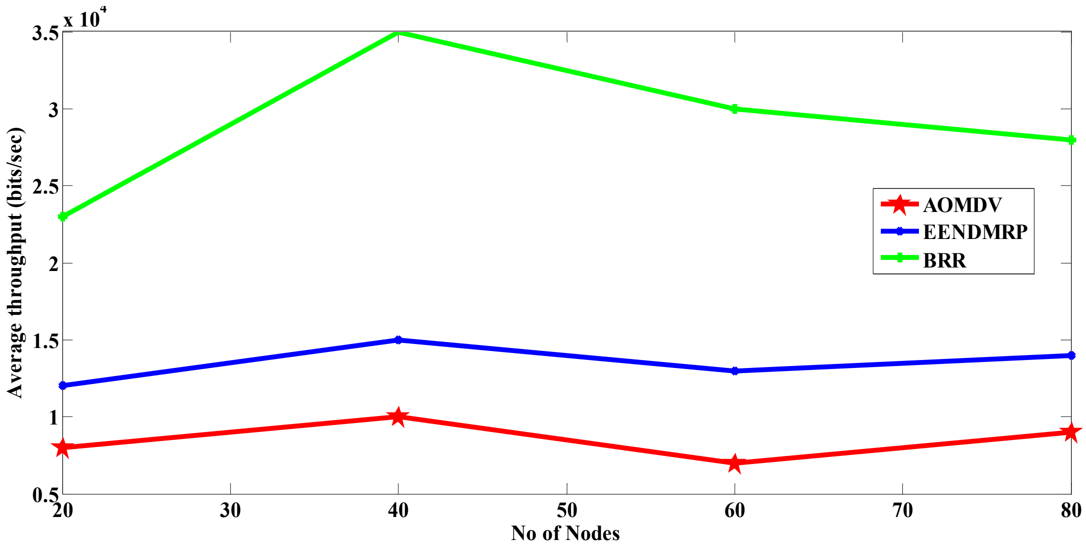

Fig. 4 Average Throughput vs. Number of Nodes

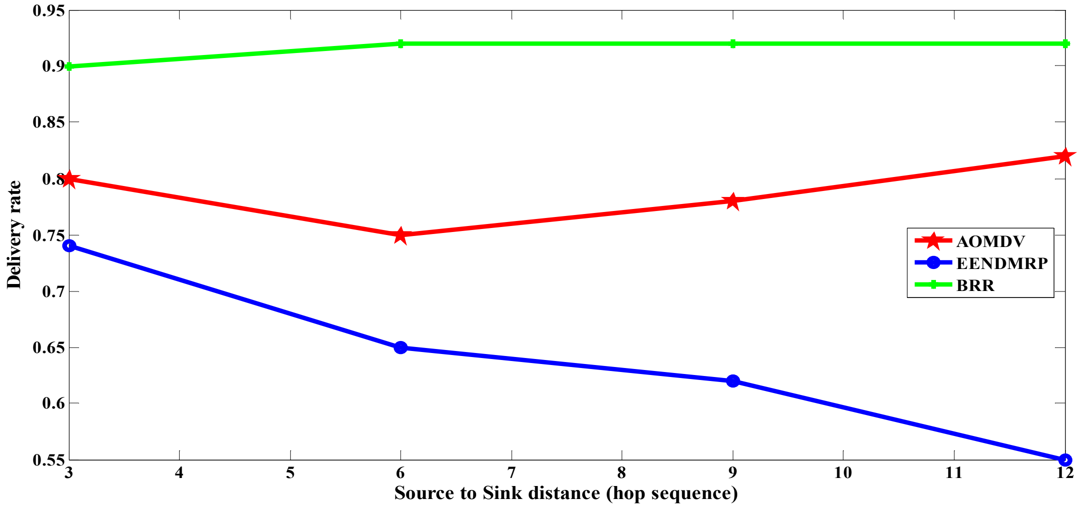

Fig. 5 Delivery Ratio vs. Path

The nodes that are present in the path set are called intermediate nodes. Multiple sources to Single Sink communication model have been considered and the performance parameters are analyzed. The following metrics are measured from the simulation of WSN using NS 2.34. Parameters like Average packet loss, Throughput (sec), node failure ratio and channel error rate are monitored at various time intervals. The results are described in the next section.

Throughput: The ratio of number of bits received at the sink during the lifetime to the ratio of network lifetime in seconds.

Packet loss percentage: The percentage of the packets lost from all the packets sent by all sources during the network lifetime, taking into account that the same packet may be received at the sink through more than one path to the count of packets sent by all the sources during the lifetime.

It is evident from Fig. 3, that the usage of BRR algorithm reduces the loss percentage by a huge margin. It specifies the point of the problem and makes the local path repair better and faster. It also takes accurate repair decisions and thus makes the best use of all the healthy possible positive paths.

As mentioned earlier the smaller lifetime is exploited in sending data, but not in sending control packets for path repairs with incorrect decision until a healthy complete path is established. Thus BRR throughput is increased as shown in Fig. 4.

Fig. 5 plots the change of delivery ratio Vs different source-sink paths. Delivery ratios in BRR and AOMDV schemes have no distinct changes as the path increases. AOMDV maintains high success ratio even when the path has 15 hops. The delivery ratio of BRR is the highest among the compared schemes. The proposed scheme Basic Repair Reconstruction (BRR) Algorithm is compared with AOMDV and EENDMRP.Our algorithm outperforms the compared algorithms in terms of high packet delivery ratio.

Fig. 6 shows the change of delivery ratio as a function of node failure ratios. The BRR algorithm takes an active strategy against broken paths and always tries to repair them, which are at the cost of energy consequentially. Even with the higher node failure, BRR maintains the highest delivery ratio. The proposed scheme Basic Repair Reconstruction (BRR) Algorithm is compared with AOMDV and EENDMRP. Our algorithm outperforms the compared algorithms in terms of high packet delivery ratio.

Fig. 7 shows the change of delivery ratio as a function of channel error rate. As shown in Fig. 7, the delivery ratios of all the schemes decrease as the channel error rate increases. The reason is there is no mechanism in AOMDV to prevent loss of a returned data packet, which terminates the whole data delivery and its possibility increases with channel error rate. Improving the delivery ratio of BRR at a high channel error rate is one part of the future work.

VI. Conclusion and Future Work

Reliable data delivery schemes in wireless sensor networks are studied in this paper. It is proven that a multiple-path routing with repair is an efficient solution, which can concurrently assure delivery as well as avoid wastage of energy. A basic reconstruction routing algorithm is proposed, in which a node can leap over path failure by using the already existing routing information in its neighbourhood. The proposed scheme BRR is implemented and compared with AOMDV and EENDMRP schemes. The simulation results show that BRR can provide the highest success rate among all the compared schemes in a wide range of average packet loss, throughput, node density, path length, node failure ratio. It also assures the highest success rate at both low and medium channel error rate. In future, the impact of different parameter setting will be evaluated to the comparative results. The delivery ratio of the proposed scheme will be improved at a high channel error rate. So far, most of the protocols work, which is been done in the field of WSN's is for non-mobile sensor nodes. The proposed work can be enhanced to handle mobile nodes by continuously updating the routing table. This extension would not be sophisticated, as already, it updates the routing table after the power loss and death of some sensor nodes.

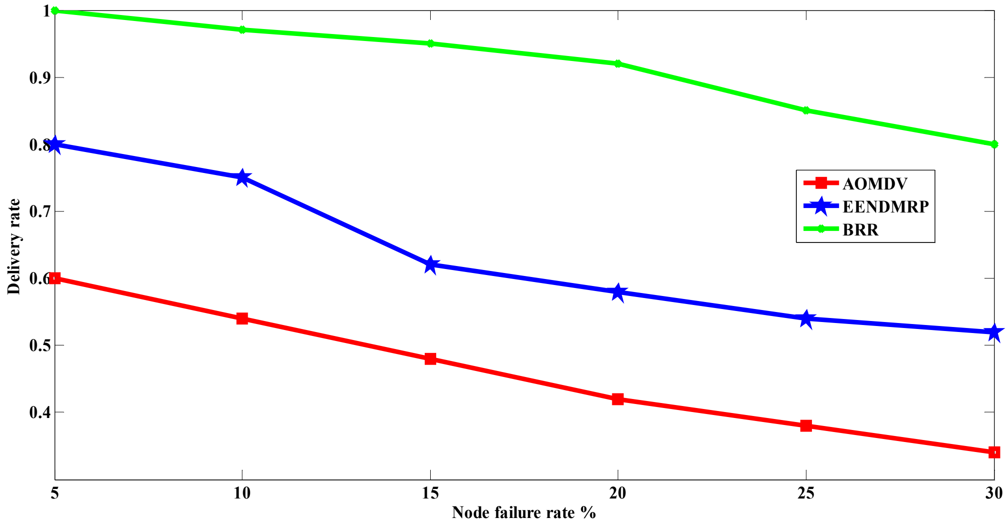

Fig. 6 Delivery Ratio vs. Node Failure Ratio Length

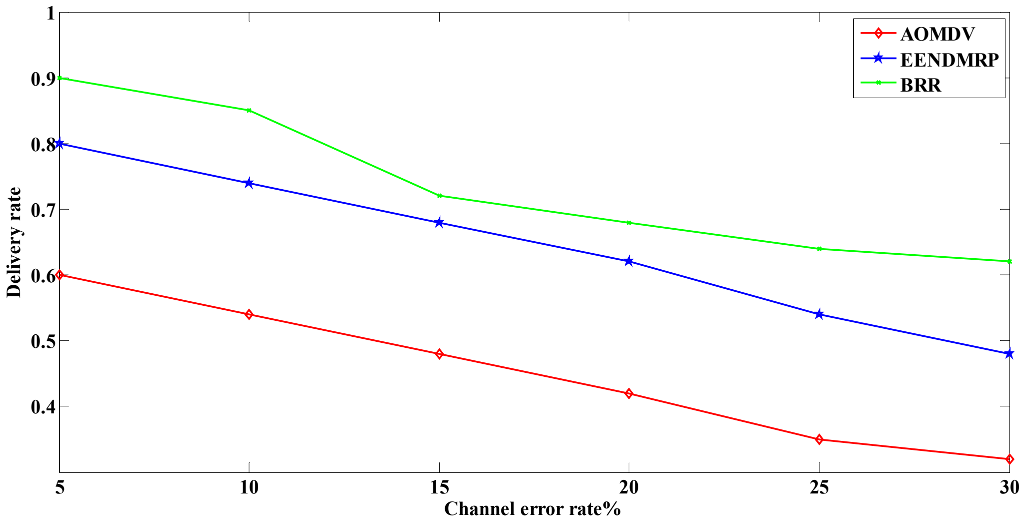

Fig. 7 Delivery Ratio vs. Channel Error Rate

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