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FDRRP - A Reliable Routing Protocol for Wireless Sensor Networks

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Abstract: An important challenge in Wireless Sensor Networks used in industrial applications is its reliability with respect to guaranteed delivery while maintaining minimum overhead. Although the traditional ad hoc routing protocols are designed for obtaining the maximum throughput, they cannot guarantee reliability. For process control applications, every information conveyed by every sensor is important. This paper proposes a reliable hybrid routing protocol called Fisheye State Routing (FSR) and Dynamic Source Routing (DSR) combined Reliable Routing Protocol (FDRRP) which combines the advantages of DSR and FSR to achieve better reliability in WSN. The performance of FDRRP is verified through simulation experiments and analysis. It is observed that the trade-off between end-to-end delay and routing overhead is well balanced in FDRRP when compared to DSR and FSR protocols without compromising much on the computational complexity.

Key words: Wireless Sensor Network · Reliability · Hybrid routing protocol

INTRODUCTION

In a process control environment, a WSN node gathers sensor data and passes information to the coordinator. Correspondingly, the coordinator performs appropriate control action as necessary. The sensor node transmits the data to the coordinator directly or via one or more routers. The challenge in a typical industrial environment is to ensure effective transfer of data from one place to another, in a reliable manner, within the allowable delay, with the least no of hops and minimum packet overhead amidst congestion, collision, link-failures, link-delays, etc. The two important methods of routing are source routing and graph routing. The former is on-demand while the latter is table-driven. While there are many pros and cons with both these methods, this paper presents the combination of two protocols for designing a hybrid routing protocol, namely, Fish-eye State Routing (FSR) protocol [1] which uses a table-driven routing mechanism and Dynamic Source Routing (DSR) protocol [2] which discovers routes on-demand. The proposed design is called FSR-DSR combined Reliable Routing Protocol (FDRRP) which offers the advantages of both FSR and DSR protocols and balances their trade-offs considerably. The rest of the paper is organized as follows. A brief overview of reliable routing protocols proposed in recent literature is given in Section II. Section III presents the design of the proposed FDRRP. The experimental results are illustrated in Section IV and finally in Section V, we draw the conclusion and present the scope for further work.

Related Work: A comprehensive analysis on the reliability problem in wireless sensor network based on the industrial environment demands such as energy efficiency, scalability, reliability and timeliness [3] illustrates that whenever a power management mechanism is employed, there is a considerable decrease in packet delivery ratio (PDR). To improve PDR, an adaptation module is introduced [4] which gets input from application layer, network layer and MAC layer in order to achieve reliability. Such a cross–layer design can increase the packet delivery ratio while reducing the power consumption [5]. Fault-tolerant routing protocol [6] combines multipath routing and security by load-balancing. By combining Dynamic Source Routing (DSR) protocol and Adhoc On demand Distance Vector (AODV) protocol, a lightweight hierarchical routing model has been proposed [7] where the whole path is divided into segments using waypoints. By this method, during node failure, only the waypoint nodes re-discover routes. A detailed survey about the available routing protocols

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[8] presents the different classifications of routing protocols. DSR protocol is modified with state flow mechanism to suit Ipv4 [9] and IPv6 [10] to realize route-load balancing while inserting the path details in the packet header. A two-zone routing protocol has been proposed [11] which is an enhancement to the zone routing protocol for balancing the control overheads. The two prominent routing protocols, namely, DSR protocol and AODV protocol are compared and analyzed in [12].

WirelessHART protocol [13] is an efficient and reliable routing protocol used in industrial environment. It employs two distinct routing protocols namely source routing protocol and graph routing protocol. Mostly the source routing protocol is used since it can take mobility into account. In the source routing protocol the entire path from the source to the destination is contained in the data packets to ensure reliable packet delivery. However, the flip side is that the packet length increases with hop count, resulting in large packet overhead. Also, in case of node failure, path rediscovery involves considerable time latency. In graph routing protocol, the complete network topology is maintained by each node and the data packet is transmitted along the shortest path as calculated from the graph. Since the network topology is updated by periodic exchange of topology information, this method involves large and frequent control information exchange. This leads to increased routing table overhead and control packet transmission overhead. Table 1 gives the comparison of these two routing protocols.

Table 1: Comparison of existing routing protocols in WirelessHART

Description	Source Routing	Graph Routing
Implementation	Simple	Complex
Node failure / congestion	Takes time to overcome	Reroutes quickly
Network overhead	Less	More
Packet overhead	More	Less

In DSR protocol, during the route discovery phase, a route request packet having the destination node ID and a sequence number is flooded. Any node receiving node will rebroadcast the packet under three conditions: (i) if it is not the destination node (ii) if it has not forwarded same packet and (iii) if the time to live (TTL) is non-zero. If the receiving node is the destination node, it will generate the route reply packet with the route traversed by the route request packet embedded in the packet and sends back to the source node. The advantage of DSR protocol is that the routes are reliable. The disadvantage is that in large networks, the number of hops in the path increases, resulting in large packet headers. Hence, the overall packet size increases.

In FSR protocol, the nodes maintain accurate information about the nodes in its local topology and not-so-accurate information about the nodes beyond its fish-eye zone. The accuracy of the network information decreases with increasing distance. The exchange of topology information takes place periodically rather than being driven by an event. The advantage of FSR is that the routing overhead reduces significantly by adopting low update rates for nodes belonging to far-away zones. The link state information for the nodes belonging to the nearest zones is exchanged at the highest frequency. The frequency of exchange decreases with an increase in scope. The disadvantage with the FSR is that the performance of the whole network will degrade with increase in the zone length of the FSR.

The proposed FDRRP combines the advantages of DSR and FSR and alleviates their disadvantages.

FDRRP Design: Consider the scenario shown in Fig. 2 where 25 nodes are placed randomly each having 3-tier information of other nodes. We use Carrier Sense Multiple Access (CSMA) mechanism for packet transmissions.

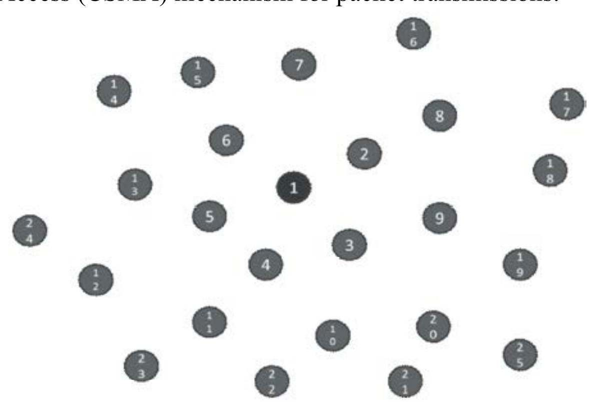

Fig. 3: WSN scenario chosen for testing the proposed FDRRP

Fig. 4 shows the flowchart for the implementation of FDRRP. The initialization phase starts with the transmission of beacon packets by the coordinator, followed by the association phase where the nodes are added to the network. After successful completion of association phase, the nodes move into maintenance phase during which the data exchange takes place smoothly until any errors are encountered. In the initialization phase of the transmitter and receiver nodes, upon successful exchange of beacon and acknowledgement packets, the node ID's and their corresponding time stamps are appended into the routing table.

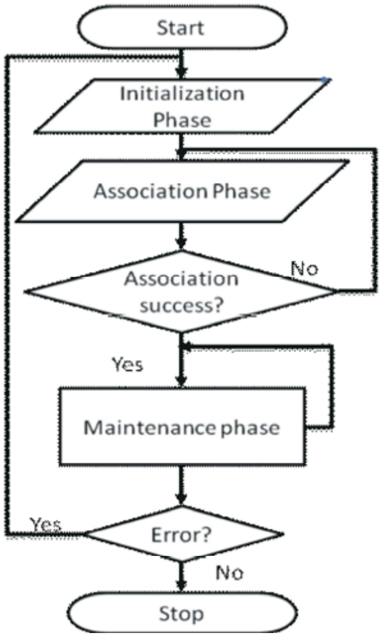

Fig. 4. Flow chart for node initialization procedure

Fig. 5 shows the transmission of beacon packet generated at node 0 and its relay upto 3-tier level.

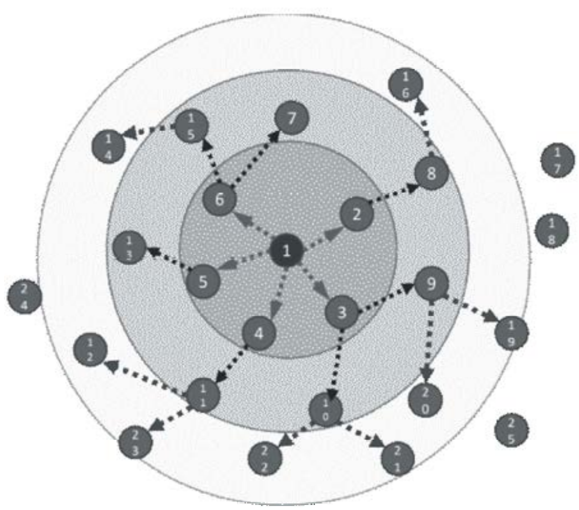

Fig. 5: Beacon packet from node 0 forwarded upto 3-tier level.

Fig. 6 shows the Beacon packet format. The number of hops will be used to restrict the Fish-eye zone and the recent node id will help in identifying the route within the zone using DSR protocol.

Beacon ID	No of Hops	Recent node ID	Time to live (TTL)

Fig. 6: Beacon packet format

The destination node upon receiving the beacon packet will append the node ID and timestamp and then initiate a route reply procedure. Fig. 7 shows the format of the route reply packet.

Node ID	Neighbour Node	Next node	No of hops

Fig. 7. Routing table format

In the maintenance phase, the transmitting node constantly checks for acknowledgements for the sent data. If the acknowledgement is not received for any packet within twice the Round Trip Time (2*RTT), path error is asserted and hence the node looks up the routing table for a new path. Fig. 8 shows how the nodes other than the coordinator respond on receiving a beacon / data packet.

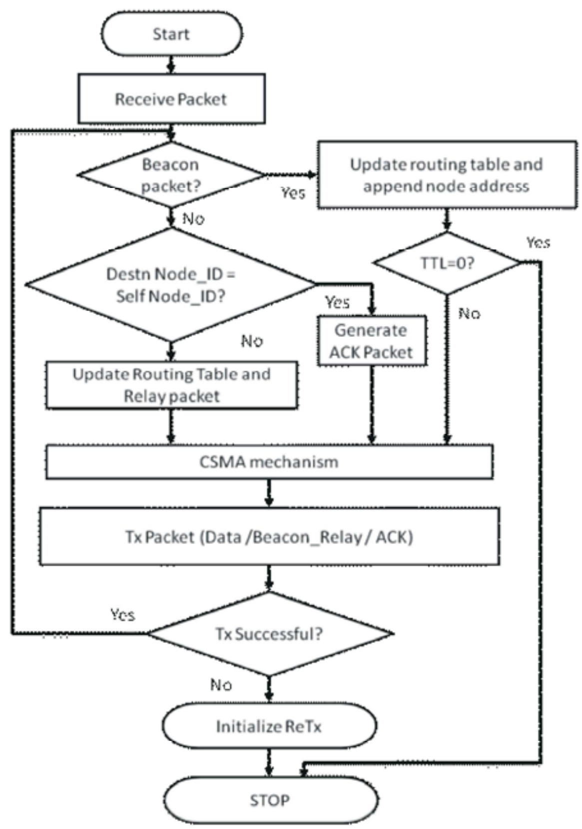

Fig. 8: Response of the nodes to the beacon packet sent by the coordinator

Experimental Results: Consider the case of link failure between Node 2 and Node 9 as shown in Fig 9. The rerouting has to be done via Node 3 and Node 1 as illustrated in Fig. 9.

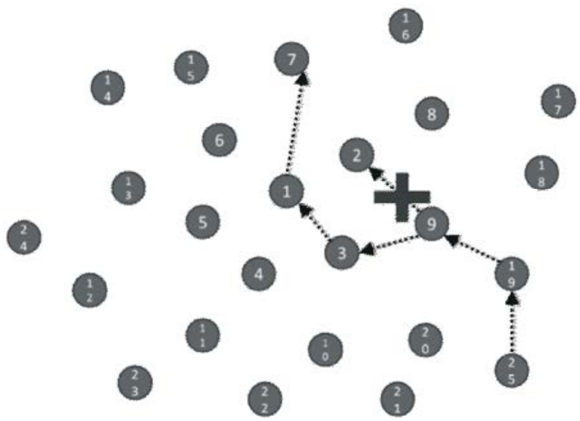

Fig. 9: Rerouting of data packet

The new path is found using the routing table maintained at Node 9 as shown in Table 2. The highlighted rows show the two paths from Node 9 to Node 7 from which the alternate path is chosen. It may be noted that, for single hop destinations, redundant routes are not applicable.

Table 2: Routing table of node 9

Node ID	T1 neighbour ID	T2 neighbour ID	Hops
9	1	1	1
	8	8	1
	19	19	1
	18	18	1
	7	2	2
	16	2	2
	21	20	2
	7	3	3
	16	8	2

To demonstrate the effectiveness of FDRRP algorithm, for the network topology of Fig. 9, data transmission from node 23 to node 16 is considered. The DSR data packet will have the entire path in its packet header leading to heavy overhead as shown in Fig. 11.

Source ID	Destination ID	Path				
23	16	11	4	1	2	8

Fig. 10: DSR data packet

In FSR, the routing table is updated at different intervals for different tiers. The first tier update is done most frequently and it reduces as the order of tier goes higher with respect to the source node. The nodes use Dijkstra's algorithm to calculate the shortest path. However, the accuracy of the route is not reliable in a mobile environment due to infrequent routing updates for far-away nodes. The typical FSR data packet is as shown in Fig. 11, which is very similar to Adhoc On-Demand Distance Vector (AODV) routing protocol. The only difference is that, the periodic updates in AODV offer dependable paths, whereas, in FSR, the likelihood of path failure is higher.

Source ID	Destination ID	Neighbour
23	16	11

Fig. 11: FSR data packet

In FDRRP of level 2, only alternate Node ID's are placed in the path field as shown in Fig. 12 and rest of the node's ID are taken care by the routing table maintained at each node.

Source ID	Destination ID	Neighbour	FDRRP Path	
23	16	11	1	8

Fig. 12: FDRRP Data packet

The packet reaches the intermediate nodes in a table-driven manner. The path for each packet is defined sufficiently, although not completely, thus reducing the packet overhead and also bringing about reliability in the routes. It has to be noted that if we increase the level in FDRRP, the size of each packet reduces. However, the routing table has to be updated for that level resulting in higher network overhead. Also, small additional overhead is introduced for maintaining the intermediate-node information.

Fig. 13 explains how the packet size differs over different network sizes in DSR, FSR and in different versions of FDRRP. From the graph it is clear that FSR produces the least overhead while DSR produces the highest overhead. And also by increasing the tier level in FDRRP it is shown that less packet overhead can be achieved which is close to FSR.

Fig. 14 shows the end-to-end delay among the protocols. It is observed that FSR produces the highest delay and DSR produces the least. The reason is that FSR requires calculation of path to the destination at each node while DSR does not, since it has the path embedded in its packet. In FDRRP each node calculates the shortest path only for its tier-level (2 in our case). If the tier-level of the FDRRP is increased the delay is gradually decreased as shown in Fig. 14.

Fig 15 shows the computational complexity in terms of routing table look-ups for the three routing protocols under consideration.

Table 3 gives an overview of the performance of FDRRP as compared with DSR and FSR protocols.

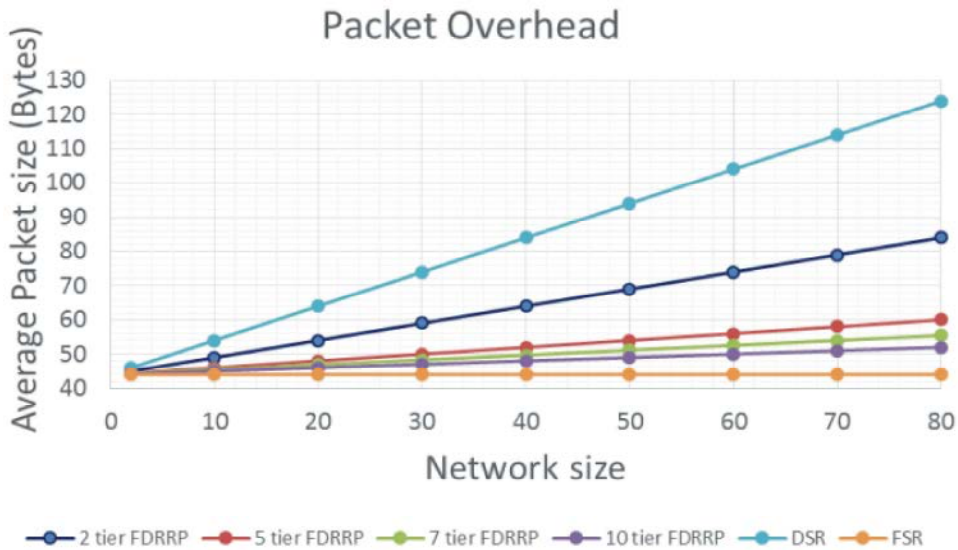

Fig. 13: Packet Overhead

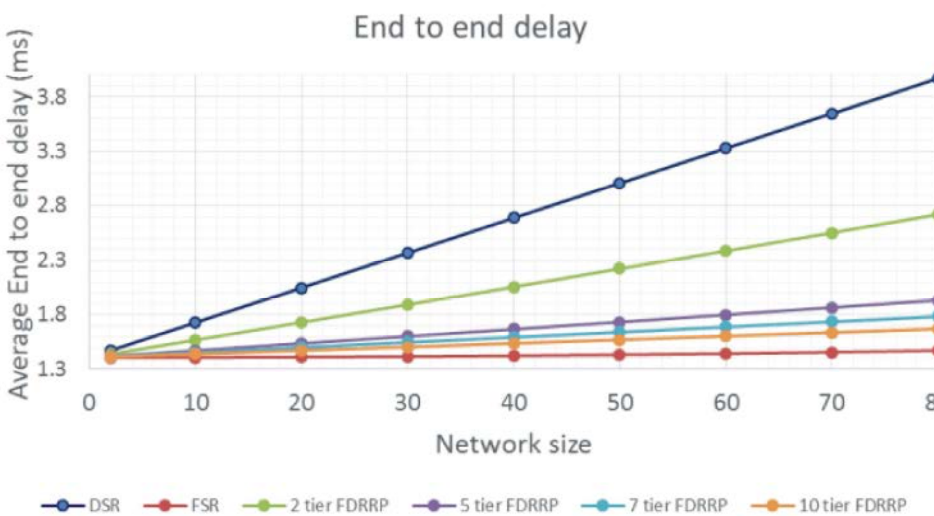

Fig. 14: End to end delay

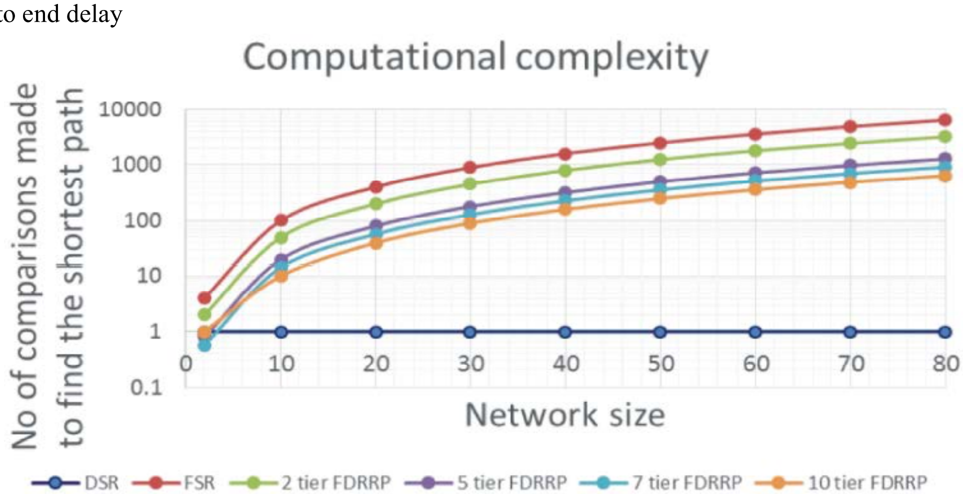

Fig. 15: Computational complexity

Table 3: Qualitative Performance analysis

Performance parameters	DSR	FSR	FDRRP
Packet overhead	High	Low	Medium
Network overhead	Low	High	Medium
Processing delay	Low	Medium	High
End-to-end delay	Low	High	Medium
Scalability	Low	Medium	High

CONCLUSION

A hybrid routing protocol called FSR and DSR combined Reliable Routing protocol (FDRRP) has been proposed which offers better performance when compared to DSR and FSR routing protocols in terms of reliable routing without inducing and reduced packet overhead. FDRRP combines the two separate routing methods, namely, graph routing and source routing, defined for WirelessHART protocol for achieving a balanced performance. FDRRP can be further improved for energy efficiency and security by appropriate cross layer design and encryption algorithm respectively.

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