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An Efficient Decentralized Routing Framework for Wireless Sensor Networks

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Abstract

Objectives: Wireless Sensor Networks consists of a large number of battery-powered sensor nodes. Each sensor node collects data and forwards them to the sink. If the intermediate node is selected based on its minimal number of hops to the sink, then it will be used more frequently in routing which will lead to its quick expiration. If this happens, few nodes are disconnected from the sink. The energy and data of those nodes will thus be wasted since they have no means to route data. **Methods/Statistical Analysis:** The proposed method defines the energy definitions for the various categories of a sensor node based on its working and an energy-aware routing scheme named optimal node reliance (ONR) to select intermediate nodes for routing. It calculates the value to which nodes are participating in routing. By calculating the cost of nodes that are involved in routing helps to reduce the usage of a particular intermediate node repeatedly, thus avoiding the faster expiration of such nodes and thus maximizing the lifetime of the network. The optimal routing path and the common node is selected based on the residual energy calculated for each node. Then the packets from different sources are buffered at the common node and send them as a single packet to the sink. This will reduce the number of packets been sent through the same intermediate nodes to reach the sink. **Findings:** We then analyze the tradeoffs among communication delay, the energy requirement for route calculation, time taken for route calculation of the proposed method and few existing methods. It is observed that the proposed scheme holds good for the above-measured parameters. **Application/Improvement:** This ensures the selection of optimal routing path between any sensor node and its destination, avoiding the usage a particular intermediate node, thus preserving its energy and data. This eventually maximizes the lifetime of the Wireless sensor network.

Keywords: Common Node, Optimal Node Reliance (ONR), Wireless Sensor Networks

1. Introduction

Wireless Sensor Networks (WSN) consists of a large amount of sensor nodes each with sensing, computation and communication capabilities. These features of the sensor network pave the way of developing more applications that include but not limited to Environment Monitoring, Habitat Monitoring, Industrial process monitoring and control, Military Applications, and National Asset Protection. Each node in a WSN participates in decentralized routing to forward data by network connectivity. The sensor nodes sense the environment, generate data and then route it to a sink.

1.1 Limitations of Existing Techniques

Some of the existing routing schemes include the hop based routing, energy based routing, load balancing based routing.

1.2.1 Hop Based Routing

The hop based routing protocols selects a routing path based on the minimum number of hops necessary to reach the destination node. Few of the minimum hop based routing protocols are DSDV (Destination Sequenced Distance Vector), AODV (Adhoc On-demand Distance Vector), DSR (Dynamic Source Routing). While aiming

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to select the minimum hop path, the protocol may choose nodes that are geographically distant, and the nodes present in the minimum hop path are used frequently which leads to faster expiration. These are the drawbacks of the minimum hop based routing protocols.

1.2.2 Energy Based Routing

The energy based routing concept is contrast to that of the minimum hop routing. It allows to select a lengthy sequence of small hops which may require less energy when compared to a small sequence of long hops. The MLRP (MuLti stage data Routing Protocol) focuses on integrating layered Voronoi scoping and dynamic anchor selection. The protocol is designed exclusively for large scale wireless sensor networks having mobile sinks. The protocol MLRP returns the minimum hop path of least energy. The drawback is that it does not focus on the usage of particular nodes frequently for routing which may lead to faster energy depletion in them.

1.2.3 Load Balancing Based Routing

Load balancing routing distributes the routing workload across as many nodes as possible. The MREP routing protocol selects the path with node having the greatest residual energy. This is the key feature of this protocol. The packet forwarding is done through multihops, if the destination is not reachable. In MREP, the cost of a node and the remaining energy are inversely proportional to each other. The demerits of this concept are it is difficult to calculate the residual energy on each node and nodes need additional energy to distribute the workload among the nodes after analyzing its capability.

1.2 Issue to be Addressed

In a Wireless Sensor Network, every sensor node spends some energy to sense, transmit and receive data. When a node transmit data, the data traverse through several intermediate nodes to reach the sink (destination node). If the nodes use a particular intermediate node frequently for routing, then it will lose its energy quickly. This leads to two issues. One issue is, few nodes may have only that intermediate node to forward their data. Expiration of that intermediate node will lead to stagnation of data in those source nodes since they do not have any other node nearby to route their data. Another issue is the sink will not receive any data if there is only one intermediate node of optimal route that connects the sink with the other nodes of the network. These issues are the motivation for this paper.

To illustrate the issue with an example consider the following network.

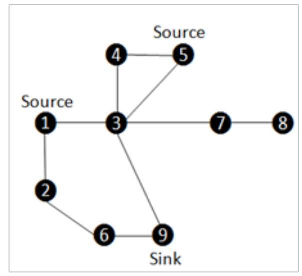

Figure 1. A Network of Sensor Nodes.

Figure 1 shows a Wireless Sensor Network consisting of nine sensor nodes. For an example, the nodes 1 and 5 are transmitting data (Sources), node 9 is collecting and processing the data (Sink). The line between the nodes means that the nodes can participate in bidirectional communication. The source nodes calculate the optimal routing path to reach the sink. For the source node 1, the shortest path to the sink (9) based on the minimum hop routing schemeis1-3-9 and for the source node 5, the shortest path is 5-3-9. In both the routing paths, intermediate node 3 plays a vital role. The node 3 is frequently used in routing, hence it will lose its energy faster.

Section 2 projects the related work done so far. Section 3 describes the sensor network model and Energy definitions of sensor node operations. Section 4 states the proposed Optimal Node Reliance scheme. Section 5 shows the performance evaluation parameters and analysis of the transmission delay and power consumption of the nodes, and time taken for route evaluation. The above mentioned parameters are measured, compared among the proposed and the existing routing schemes (DSDV, DSR).

2. Existing Schemes

Several schemes have been proposed regarding wireless sensor routing. They have some problems in attaining efficiency while routing.

In the paper[1], Clustering and Routing algorithm are performed at the same stage to decrease control packets. Initially, Cluster head (CH) is selected based on Residual energy, Distance to Base station, and proximity to its neighbors. In first level competition, CH is selected based on the previously mentioned factors and the maximum result value among its neighbors. In lower level competition, Candidate CHs check the residual energy, the low value of the distance to upper-level CH to the BS. At each level, the sensor nodes need to check few parameters of itself, its neighbors and previous level CHs. This leads to more energy consumption. This is the problem identified in this paper.

A load-balancing algorithm is proposed in paper[2]. The packet to be routed is split up into multiple segments which are sent through multipaths to the destination. From all the available paths between source and sink, a list of link-disjoint paths are found by calculating path-vacant ratio. The proposed scheme suggests an adaptive congestion control scheme, that will be useful in case of a node or link failure. It also improves the reliability, by including a secret sharing scheme at the source.

In the paper[3], a highly dynamic DSDV protocol is proposed. The routing path is chosen based on the minimum number of hops needed to reach a sink. Also, it aims to consider every mobile node as a speciallized router. The working of this specialized router is advertise the interconnection topology with other mobile hosts of the network. Some of the traditional minimum hop routing protocols are DSDV[3] (Destination Sequenced Distance Vector), AODV[4] (Adhoc On-demand Distance Vector), DSR[5] (Dynamic Source Routing). They have the two main demerits. One of the drawback is they select routing path with minimum number of hops to the sink. So, they may use nodes that are geographically distant. The Second drawback is that they select few nodes more frequently, thus they will expire more quickly.

A collaborative routing algorithm is proposed in paper[6]. A score is assigned to each node based on how much that node is relied upon for routing. Initially, the algorithm selects nodes that are least relied on routing. By that it uses nodes which causes minimal effect on network if it expires. Thus the protocol avoids quicker expiration of important intermediate nodes whose expiration may isolate some parts of network from connectivity.

In paper[7], energy efficiency and service discovery functionality based protocol-Efficient Protocol for Intelligent Spaces (EPIS) is proposed. The idea is devised particularly for smart home environments. The protocol is designed based on the idea of using a longer sequence of small hops may require less energy than a short sequence of long hops. The idea is achieved by low power listening schemes along with lesser number of data transmissions. The advantage of EPIS protocol is that it will support all the network activities such as topology discovery, service discovery etc with the help of service interfaces.

The authors of paper[8], framed a design to calculate energy efficient routes and to reduce the overhead in route calculation. The proposed method selects nodes to perform route-searching process in an adaptive manner. It considers every node's residual energy and the link transmission power for route calculation. Thus it could reduce overhead in calculating energy efficient routes.

PMPR[9] (Potential Management based Proactive Routing) protocol suggests to perform routing recovery based on a request. Every node is assigned a value (Potential) for each of its destination. If a node gets request for route recovery, it lowers its potential value and provides a new route. Then the success rate of local route recovery and route optimality are calculated. Thus it performs well in heavy traffic conditions on mobile adhoc networks.

Energy Aware Reliable Routing (EARR)[10] algorithm defines that only nodes with adequate residual energy alone can participate in transmitting data. Thus it generates a valid transmission path all the time. Thus it prevents the frequent usage of hotspots and reduces route reconstructions due to energy shortage.

The aim of a Wireless Integrated Network Sensors (WINS)[11] is to support huge number of sensors in a local area having shorter range along with lesser bit-rate transmission. It expects a protocol to power off radios if not involved in transmission. The result of those rules could be gaining the advantage of heterogeneous processing in dense networks.

After several experiments, the authors of paper[12] concluded that the essential factors for achieving reliability in wireless sensor networks are calculating the link quality, managing neighbor nodes and reliable cost metrics. The paper analyzed those three parameters with the help of a new estimator called Window Mean with Exponentially Weighted Moving Average (EWMA).

The paper[13] analyses the optimal routing policy for maximizing the lifetime of Wireless Sensor Network. For any fixed topology, the routing possibilities are achieved by solving non linear programming (NLP) problems. The paper arrives at a policy that could give solution to the energy depletion of all nodes by solving them as NLP problems.

The paper[14] classified the mobile Wireless Sensor

Network routing protocols into delay-sensitive and delay-tolerant protocols. They analyzed the protocols based on two factors-signalling overhead and packet delivery ratio. Finally they concluded that machine to machine communication concept can be integrated with Wireless Sensor Network for achieving betterment in the above mentioned parameters.

CASER[15] (Cost-Aware Secure Routing) protocol proposed a strategy to maximize network lifetime and security solutions. The solution is based on the two parameters-energy balance control and probabilistic based random walking. The advantages of this protocol are achieving high data delivery ratio, preventing trace back attacks and also maximizing the network lifetime.

The paper[16] mainly focuses on utilizing the sensor node energy in an efficient way. The scheme aims to have five cluster head. In each cycle, the cluster head is selected based on the proposed Cluster Arrangement Energy Efficient Routing Protocol (CAERP). It mainly includes efficient way of node clustering and distributed multi-hop routing. CAERP eliminates the initial dead node problem. The proposed scheme showed significant improvement in energy consumption and network survival rate.

In paper[17], it was decided to improve the lifetime of a node. This is achieved by the adaptive sleep scheduling algorithm and also by considering the residual energy of the sensing node, its distance towards the base station. It is proposed to solve the mobility issues by finding the probability of node's contact to each other and weighted moving average concept.

3. Network Model

We consider a moderately dense wireless sensor network. We describe the network model with which we will be working as follows.

- Sensor network has n sensor nodes denoted by $sn_1, sn_2, sn_3 \ldots\ldots sn_n$
- The sensor nodes are deployed uniformly at random in an area XY
- There exists a base station which serves as a gateway for extracting data from the sensor network.
- *sn* denotes the *n*-th node from the sink. *N* is a set of all nodes.

Energy Definitions

To evaluate the actual performance of the proposed scheme, the following definitions are considered. For the existing as well as the routingprotocol, calculate the energy required for routing in each of the schemes by using the given formula[9].

Source: E = 1.9* packet size+ 266 (μJ) (1)

Sink: E = 0.5*packetsize+56 (μJ) (2)

Intermediate node: E =2.4*packet size +322 (μJ) (3)

4. Proposed Model

A. Optimum Node Reliance

Many of the existing routing schemes aim to reduce the energy expenditure of sensor nodes. To improve the routing path selection and also to avoid the issues mentioned in Section 1.2, the proposed model is framed. The proposed scheme known as Optimal Node Reliance (ONR) focuses on giving weightage for sensor nodes. The residual energy of every node is also calculated using the mentioned energy definitions. The weightage of a node means that how much the node depends on the routing path and the entire network also. If a node is present in a lot of routing paths, then its usage should be avoided wherever possible. If a node is present rarely in the routing paths, then it can be used without any hesitation. The proposed model makes use of the two definitions relative reliance and absolute reliance to frame the optimal routing path for a node. These two definitions differentiate between how much the node is relied upon the entire network and to a specific node.

For the example network in Figure1., the relative reliance[5] of a node 2 to a (source, sink) pair (1, 9) is the degree to which node 2 is relied upon in routing data from node 1 to 9 and the absolute reliance[5] of a node 2 is the degree to which node 2 is relied upon in the entire network.

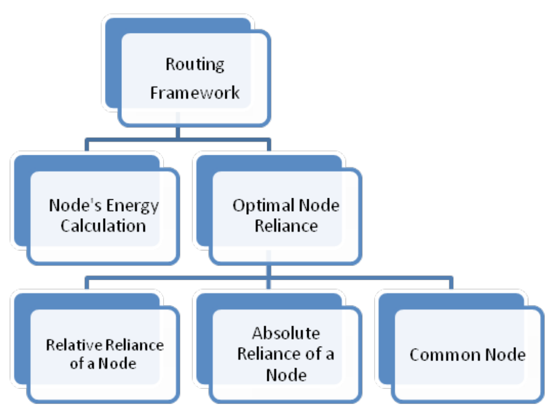

Figure 2. ONR (Optimal Node Reliance) Routing Framework.

The proposed scheme is explained in Figure 2. It considers the minimum hop routing scheme initially. Then, for each source node find out all possible optimal paths to the sink using the DSR (Dynamic Source Routing) protocol.

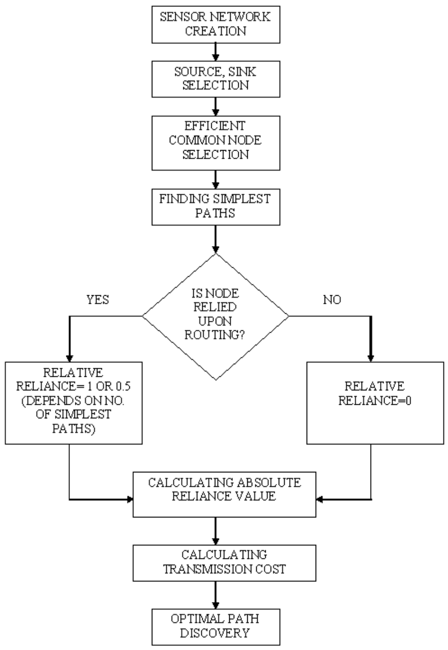

Figure 3. Optimal Node Reliance routing algorithm.

The step by step explanation of optimal node Reliance algorithm is depicted in Figure 3. In network shown as figure 1, to find the relative reliance value of node 2 (e.g.) to a (source, sink) pair (1, 9) derive all possible minimum hop paths between 1 and 9. The number of path which includes node 2 divided by the total number of paths gives the relative reliance value. If node 2 lies on all paths between 1 and 9, then its relative reliance value is 1. If node 2 does not lie on any paths, its relative node reliance value is 0. The absolute reliance value of a node is the average of relative reliance across all pairs. Thus the weightage value is calculated for all the nodes in the network. Now for all the possible paths of any (source, sink) pair, calculate the sum of weight of all nodes in the path. The optimum routing path is the one that has the least sum value. The simulation results indicate that the proposed scheme avoids the overuse of particular nodes in the network. The nodes that are less relied upon the routing can be overused. Thus the scheme protects the highly relied nodes of the network.

B. Collective Communication

Once the routing paths are identified using the proposed scheme, there is a chance of occurrence of common nodes in the paths created for routing. The sequential transmission of packets in the common paths leads to inefficiency in terms of time required for packet transmission time. We propose a scheme called the collective communication to solve this problem. In collective communication (ONR-CC), the common nodes are identified once the routing paths for the different source nodes are found. The packets from different sources are collected in a buffer and are then transmitted to the destination. This concept avoids the packet transmission from different sources to happen at a different time thus minimizing the total packet transmission time. Also the intermediate nodes need not spend too much energy in sending smaller packets again and again. If more than one common nodes are available in the optimal paths chosen for all the sources, then the common node which has the minimum hop to the sink is selected for transmission.

Then the time taken for route evaluation and packet transmission are calculated for the DSDV[3], DSR[5] and the proposed routing scheme.

5. Test Setup

The experiment is simulated using Java JDK1.5. The experiment is repeated several times using random sources and sinks to evaluate the performance of optimal node reliance (ONR-CC), DSDV and DSR routing schemes. The source nodes generate a randomly sized piece of data every five seconds which should be routed to a sink. The experiment is done for a different set of nodes such as 5, 10, 15 and 20 for each algorithm. For an example, In a network with 20 nodes, Nodes 1 and 2 are selected as Source nodes, Nodes 11 and 14 are fixed as Sink.

The module consists of three steps:

- Common Node reliance table creation:

Among all the intermediate nodes, one of the nodes is selected as a common node. Filter all the routing paths having that common node from the list of optimal routes obtained through DSR scheme. The node reliance values are put for the multiple sources corresponding to the selected sinks in the filtered routing paths.

COMMON NODE RELIANCE TABLE

	Relative reliance to 1	2	Absolute reliance
1	1.0	0.00	0.333
2	0.00	1.0	0.333
3	0.00	0.00	0.0
4	0.00	0.00	0.0
5	0.011	0.00	0.003
6	0.00	0.004	0.001
7	0.00	0.00	0.0
8	0.00	0.00	0.0
9	0.00	0.00	0.0
10	0.012	0.004	0.005
11	0.032	0.007	0.013
12	0.00	0.00	0.0
13	0.00	0.00	0.0
14	0.071	0.111	0.060
15	0.015	0.005	0.006
16	0.00	0.00	0.0

Figure 4. Node reliance table.

- Common Node Optimal Routing

With the help of the common node reliance table in Figure 4, the optimal route is found out. The optimal routes found using the existing as well as the proposed schemes is displayed for the analysis purpose. The following diagram in Figure 5 represents the optimal routing paths been generated by various algorithms.

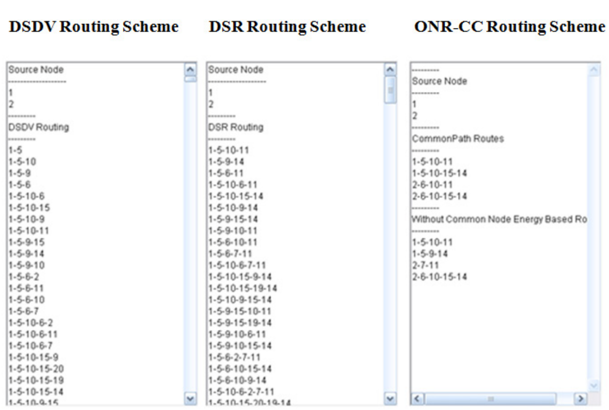

Figure 5. Optimal routes with common path for DSDV, DSR and the proposed ONR-CC Routing Schemes.

- Route Transmission

The optimal route found out using the collective communication for the selected sources and the sinks are displayed. In the Figure displayed below, the energy value of the nodes that are involved in the routing process are reduced and those that are not involved remain the same.

The parameters identified for Performance Analysis of the proposed routing framework is given in Table 1.

Table 1. Parameters for Test Cases

S.No	Test Case	Parameters
1	Energy Efficiency	• No of nodes in the simulation scenario • Energy Consumed
2	Delay	• Packet transmission rate
3	Route evaluation time	• Number of nodes • Time taken to calclate optimal path with common node

6. Analysis

The performance metrics used to analyze the three routing schemes are energy required, route evaluation time and packet transmission time (Delay). The values are tabulated, and the graph is drawn which are shown below.

A. Required Energy

The energy required for the nodes involved in the routing is calculated using the discussion in Section 3.

Table 2. Energy Requirements for Varied Number of Nodes

Number of Nodes	Required Energy(J) DSDV	DSR	ONR	ONR-CC
5	6.37	1.25	0.64	0.64
10	514.30	65.20	0.86	0.84
15	6853.09	802.68	1.11	1.10
20	10934.05	1880.50	2.57	2.49

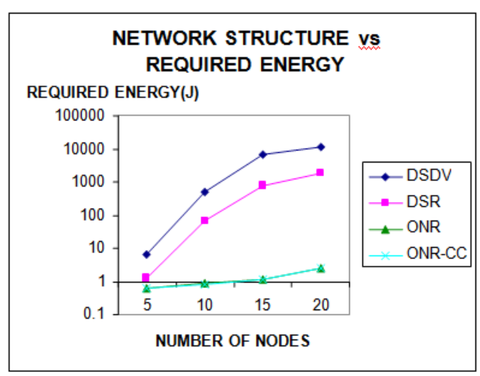

Figure 6. Number of Nodes vs. Required Energy.

The Table 2 and the graph in Figure 6 shows, that the proposed scheme consumes less energy for routing than the DSDV and DSR routing schemes. With 5 nodes in the network, the proposed scheme is 89% more efficient than DSDV, 48% efficient than DSR scheme regarding packet transmission time. On considering the network structure with a maximum of 20 nodes, the proposed scheme is 99% efficient with the DSDV and DSR schemes in terms of the packet transmission time.

B. Route Evaluation Time

The time taken to find out the routing path is calculated for the proposed scheme (ONR), DSDV and DSR using the system time.

Table 3. Route Evaluation Time for Varied Number of Nodes

Number of Nodes	Route Evaluation Time(s)			
	DSDV	DSR	ONR	ONR-CC
5	4.89	4.88	4.88	4.88
10	10.85	10.31	10.28	10.28
15	80.37	23.22	22.17	2.16
20	569.67	490.78	490.52	479.12

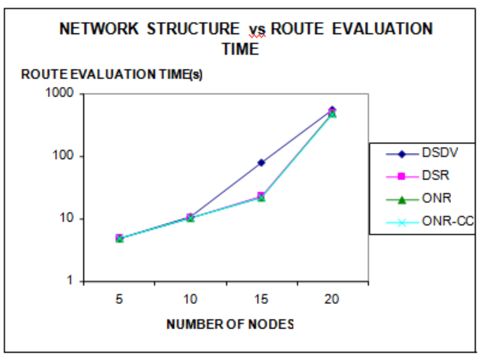

Figure 7. Number of Nodes vs. Route Evaluation Time.

The Table 3 and the graph drawn in Figure 7 show that the proposed scheme takes lesser time in finding the routing path than the DSDV but a bit lesser than the DSR routing scheme. On analyzing the route evaluation time metric, the proposed scheme is 14% more efficient than DSDV and 0.06% more efficient than DSR routing schemes.

C. Packet Transmission Time

The time required for transmitting packets from source to destination is calculated for the proposed scheme (ONR-CC), DSDV and DSR. It is assumed that an average time of 0.5ms is required for the packet to move from one node to another.

Table 4. Packet Transmission Time for Varied Number of Nodes

Number of Nodes	Packet Transmission Time(ms)			
	DSDV	DSR	ONR	ONR-CC
5	20.70	3.90	2.30	2.30
10	1847.80	234.30	3.10	3.00
15	24621.90	2883.90	4.00	3.71
20	32736.70	5456.71	5.20	4.50

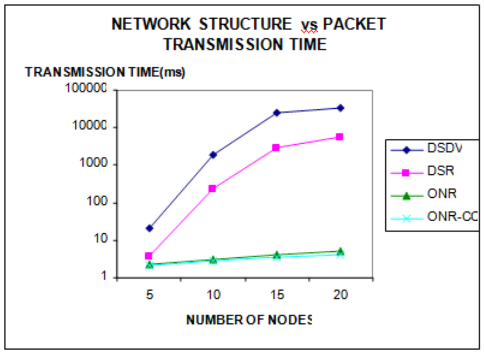

Figure 8. Number of Nodes vs. Packet Transmission Time.

The Table 4 and Figure 8 show that the proposed scheme takes lesser packet transmission time than the DSDV and DSR routing schemes.

With 5 nodes in the network, the proposed scheme is 88% more efficient than DSDV, 30% efficient than DSR scheme regarding packet transmission time. On considering the network structure with a maximum of 20 nodes, the proposed scheme is 99% efficient with the DSDV and DSR schemes in terms of the packet transmission time. Thus, the proposed energy-aware routing scheme is advantageous regarding energy required, packet transmission and route evaluation.

7. Conclusion

In this paper, an energy saving routing scheme known as Optimal Node Reliance (ONR) is proposed to solve the problem of energy wastage on source nodes in a WSN. The node reliance scheme assigns a score to each node based on the degree for which it is relied upon for routing. By calculating the cost of nodes that are involved in routing helps to reduce the usage of a particular intermediate node repeatedly, thus avoiding the faster expiration of such nodes and thus maximizing the lifetime of the network. The optimal routing path and the common node is selected based on the residual energy calculated for each node. Then the packets from different sources are buffered at the common node and send them as a single packet to the sink. This will reduce the number of packets been sent through the same intermediate nodes to reach the sink. By using the nodes that are least relied upon first, the source nodes will choose paths whose existence has the least effect on the network. Thus, the energy wastage of source nodes is reduced.

The proposed scheme includes the energy definition values for the source nodes, sink, and the intermediate nodes. On analyzing the proposed method along with the existing schemes such as DSR and DSDV, the proposed scheme is found to be much better than the other two. The performance metrics taken under consideration are the required energy, route evaluation time and the packet transmission time.

Future work includes improving the scalability of the routing scheme by enabling Software Defined Networking (SDN) management of wireless sensors.

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