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Resilient routing in ad hoc wireless sensor networks

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K E Y W O R D S

QoS in WMSN

WMSN at the socket level,

Priority model in WMSN

Decision Based Routing

Energy Efficiency

A B S T R A C T

Ad hoc Wireless Sensor Networks (WSNs) are specialized networks comprising a collection of sensor nodes that communicate to perform a specific task or record data in a decentralized manner. A considerable amount of work has been done regarding security, power saving, and other issues related to ad hoc wireless sensor networks, but there have been fewer efforts to improve performance, optimal utilization, and minimize packet loss. This paper has devised an algorithm for identifying reliable routes for efficient and intelligent packet transmission in wireless network topology. A decision-based tree mechanism for routing has been developed, capable of establishing routes in an ad-hoc sensor network that can be transformed into a logical dual ring. The system also proposes embedding resilience and reliability features from the Resilient Packet Ring (RPR) and Quality of Service (QoS) mechanisms. The proposed scheme is also applicable to Fog/Edge Networks (FENs). It aims to create an easily deployable and adaptable routing protocol that leverages all devices to support seamless mobile-to-mobile communications and wireless interfaces. Besides, it performs effectively across a wide range of connectivity scenarios in uncertain FEN environments.

1. Introduction

Due to the limitations in resources, the development of an efficient and reliable routing strategy has become a critical issue in Mobile Ad Hoc Networks (MANETs).To address the issue, an intelligent routing mechanism is vital, one that is capable of using bandwidth efficiently alongside being feasible and optimal and can accurately and quickly acclimate to a variety of network environments such as router queue size, network delay, and network bandwidth. There have been various routing protocols devised to address these issues in Link State Algorithms and Distance Vector Algorithms used in mobile ad hoc networks which are classified as Proactive Routing Protocols, Reactive Routing Protocols, and Hybrid Routing Protocols.

The Destination Sequence Distance Vector Routing Protocol is a Proactive Routing protocol that, due to periodic update messages, generates a large amount of overhead for the network [1]. The mentioned protocol due to the utilization of a major portion of network bandwidth because of the updating procedure does not scale well. The Wireless Routing Protocol (WRP) is a proactive routing protocol that requires each node to manage four distinct tables: the routing table, the distance table, the message retransmission list table (MRL), and the link cost table. The MRL records information such as the sequence number of message updates, the retransmission count, and the list of updates included in the message updates. As the network expands, the memory overhead at each node substantially increases. Nevertheless, WRP has a drawback in that nodes become aware of their neighbour's existence through acknowledgments and other messages from different nodes. To ensure connectivity, nodes periodically send hello messages within specific timer intervals, especially when there is no recent packet transmission. These hello messages are exchanged between neighbouring nodes. The phenomenon consumes a major amount of power and bandwidth as it is mandatory for each node to stay active at all times in this scenario [2]. Global State Routing (GSR) shares similarities with the DSDV (Destination-Sequenced Distance Vector) protocol. A link state table is maintained in GSR, based on updated information received from neighbouring nodes. Unlike global flooding, GSR periodically exchanges this information only with its neighbour nodes. This approach helps keep the overhead of control messages low. However, it is worth noting that the dimensions of updated messages in GSR can be relatively huge. As the set of connections expands, this size will eventually increase, leading to a considerable amount of bandwidth being occupied by these updated messages. The routing of Cluster Head Gateway protocol is a heuristic routing scheme applied to ad hoc sensor networks, the issue with this protocol is that a significant amount of cluster overhead information is maintained at the cluster head. However, in this protocol, each node maintains only route information to its cluster head, which in turn results in lower overheads of flooding routing information through the network [3].

Routing tables do not exist in Reactive Routing Protocols and each user or service demands updating. The routes are maintained and determined only for those nodes that intend to send data to a specific destination. The routes are valid in either conditions in which the destination is either reachable or the route becomes invalid. The discovery of the route is carried out in the network by loading the routed request packet.

Examples of Reactive Routing Protocols are AODV Routing Dynamic Source Routing (DSR), Location Aided Routing (LAR), Ad-hoc on-demand Distance Vector, and Light-Weight Mobile Routing (LMR). The significance of AODV is that it is adjustable to dynamic networks. However, large delays may be experienced by nodes during route-deriving reconstructions. As the network size increases, bandwidth utilization also increases. Dynamic Source Routing (DSR) is an on-demand routing protocol based on the source routing concept. Node maintains route caches containing source routes they are aware of. When new routes are learned by the node, these entries are updated continuously in the route cache. The significance of Direct Source Routing is that multiple routes are maintained by the node in its route cache and when a node intends to send packet/data it will first check its route cache before initiating route discovery. In case a valid route is found, the node will not require a route discovery. Besides this, it also does not need periodic transmitting of data consequently the nodes can enter into a sleep mode that will have the same bandwidth and energy as the node. However, the complete address from source to destination is carried by each packet and these in turn make it inefficient for large networks because the overhead with each packet will increase with the increase in size of the network. Location Aided Routing(LAR) is another proactive routing protocol that reduces routing overhead in existing flooding algorithms by leveraging location data. Both LAR algorithms conserve bandwidth by limiting the control overhead transferred via the network. As routed request packets move from the source toward the destination, they determine the shortest path to reach the destination. [4].

Zone-Based Hierarchical Link State Routing (ZHLS) and Zone Routing Protocol (ZRP) are Hybrid routing protocols and are developed by combining both reactive and proactive routing. The aforementioned routing protocols follow partial formulation and partial updating on the demand of routing tables. The protocols aim to enhance scalability by enabling nodes to collaborate as a backbone within proximity. This approach reduces route discovery overhead. Proactive maintenance of nearby node routes is employed, and a route discovery mechanism determines routes to distant nodes. Zone Routing Protocol is a pioneer hybrid routing protocol containing reactive and proactive routing components. ZRP is based on the zone concept. IARP(Intra-zone routing protocol) is based on proactive routing however, IERP(Inter-zone Routing Protocol) is reactive routing and is used for communication between zones. Information nodes that are in the routing zone are maintained by IARP which in turn enhances route maintenance and route discovery which is based on local connectivity [5]. The Zone-based Hierarchical Link State Protocol is a hybrid routing protocol that follows a hierarchical structure. Its reactive component maintains information about the network, resulting in reduced latency. However, one disadvantage of this protocol is its reliance on a pre-programmed static zone map, which all nodes must have to function. Unfortunately, this requirement might not be practical within a dynamic geographical boundary. When a node needs to find a route beyond its routing zone, it only needs to reach a node situated on the boundaries of the target destination. For larger routing zone sizes, the protocol functions similarly to a purely proactive routing protocol. Conversely, for smaller routing zone sizes, it behaves more like a reactive protocol [6]. The proposed resilient routing protocol has broad applications in domains requiring efficient and reliable data transmission under dynamic conditions. It is ideal for IoT sensor networks in agriculture and smart cities, fog and edge networks for healthcare and manufacturing, and disaster response systems, ensuring robust communication in infrastructure-limited areas. Its adaptability also makes it suitable for military communications, where reliable routing is critical. The simulation with 500 packets demonstrates the protocol's scalability and effectiveness in real-world scenarios.

2. Related Work

An energy-efficient self-organized algorithm is proposed [7], wherein the Author has proposed a backbone structure to control network traffic flow. The proposed structure reduces the energy consumption in discovering and updating the route table. However, an efficient route discovery mechanism along with reliable connections with the neighbouring nodes will be more efficient as proposed in this paper rather than implementing a backbone structure that will increase the network load. A hop-by-hop congestion control system is proposed for Ad hoc Networks [8], the authors have argued that the hop-by-hop mechanism can reduce the congestion and there will be no packet loss with the proposed scheme. The scheme can minimize the bandwidth requirement and maximize buffer utilization for nodes in the routing path, however, packet loss due to time-out periods is not considered in this research work. There are also chances of more energy required for more computations. Caching and multipath routing protocol is proposed [9]; to reduce packet loss and avoid frequent route breakouts, the proposed protocol shows significant improvement in packet delivery and is 30% more efficient than AODV and DSR. It will be interesting to implement the aforementioned algorithm with the one opted for in this research. The Caching Technique used in [10], investigates spatial locality in the context of node mobility, and researchers observed that the node cannot move far too fast Query localization techniques use this property to lower routing overhead while discovering routes and repairing. This can reduce the computations required which will eventually reduce the power consumption. It is assumed that since the node cannot move too far too fast therefore it is probable that the destination node is nearby. In [11] an optimization scheme is used that searches for route cache as an alternative due to route failure. The scheme increased packet losses as there may be more messages floated in search of a new node to establish a reliable route for packet delivery. In [12], a Cross-Layer Adaptive Fuzzy-based ad hoc On-Demand Distance Vector (OLSR) Routing Protocol is proposed to reduce routing broadcast traffic. The protocol achieves this by considering Quality-of-Service (QoS) metrics such as throughput, delay, and packet loss. It employs a two-level fuzzy logic approach and cross-layer design. By evaluating parameters from the first three layers of the OSI model, the protocol selects appropriate nodes with a higher probability of participating in broadcasting. The goal is to enhance QoS, adaptability, and stability. Broadcasting redundancy is reduced in [13] by ExDP (Extended Neighbourhood Knowledge-based Dominant Pruning. The mechanism keeps three or more hops of information to reduce the retransmission of packets for broadcasting of packets. The information is kept on the node to avoid redundant re-transmissions.

3. Proposed Model

3.1 Model Structure

Various techniques are used for routing and the objective is to effectively connect randomly distributed wireless nodes into a logical ring formation. Identification of the next hops is based on the routing signal strength and physical distance in the DBR algorithm, to form a ring topology. In a sophisticated network’s real location, GPS could be used and in the normal network, this could be achieved based on signal strength.

DBR algorithm is the technique that allows in a wireless environment, the use of Packet Ring Architecture. The algorithm has two portions i.e.

- Formation of Decision Tree
- Routing based on Decision Tree

3.2 Decision Tree Formation

Tree formation is made based on the distance of nodes in the network. Firstly, a tree is formed based on the distance of nodes from each other and the connection graph identifies loops. After the first iteration, the nodes that are not part of the ring are made part of the ring by a further process. In this algorithm, each parent node connects to two descendants: the nearest node is the left descendant, and the second closest is the right. Starting from the first node, it measures distances to all others in the network, then assigns the left and right descendants, accordingly, structuring the network based on proximity.

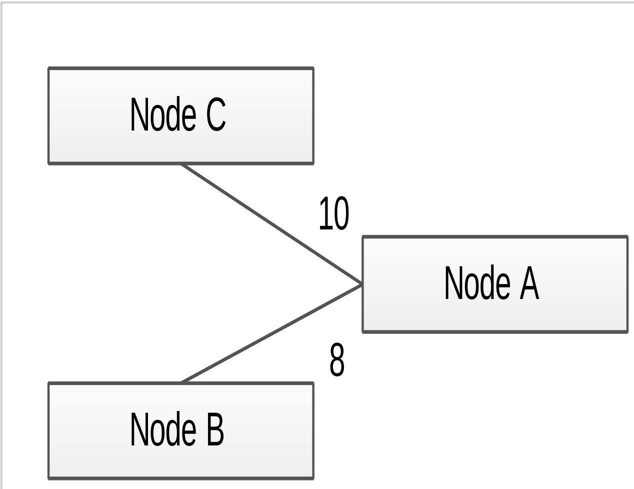

Fig. 1. Decision Tree Based On The Distance Of Each Node From A Parent Node

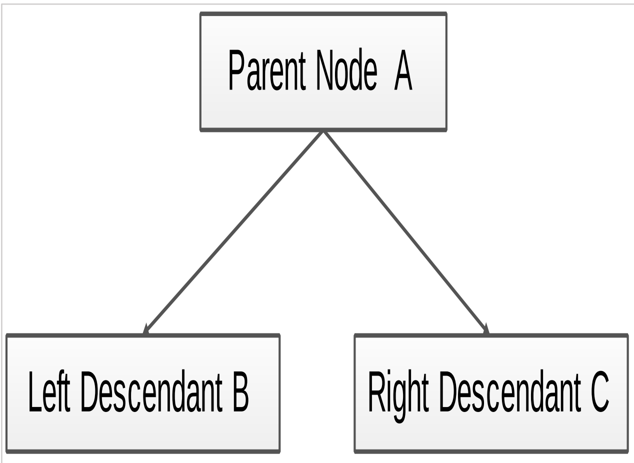

Fig. 2. Decision Tree Organized On The Basis Of Units.

In a network with three nodes, as depicted in Fig. 1, the decision tree is formed based on the distance of each node from a parent node. For instance, if Node A is taken as the parent, and it's determined that Node B is 8 units away and Node C is 10 units away, Node B would be designated as the left descendant due to its closer proximity, and Node C would be the right descendant, as illustrated in Fig. 2.

3.3 Tree Completion (Addition of Missed Nodes)

The first run of tree formation is to allow the algorithm to calculate the distance of all descendants to establish a ring and to ensure that all nodes are reachable. When the ring is formed, the algorithms ensure that all the nodes in the networks are descendent of at least one node. In a situation where a node is not a descendant of any node, the distance of such node is obtained and is made a right descendant of the node that is closest to this specific node.

The phenomena are applied to add nodes in the network. Furthermore, parent nodes are marked by the algorithm to avoid the situation where nodes that are not part of the network, replace the parent nodes. In case there is more than one node that was not initially part of the network then these nodes will be added to the network in the same fashion as proposed above but, in a situation, where the shortest node is marked then an additional node will be made as right descendent and will be added as 2nd closest node. Packet delivery and tree formation are majorly based on the left node as the algorithm is left descendent. As an example, whenever a node is added during tree formation it will be added as left descendent. In case the destination node is not found in the descendent nodes then the packets will be directed to the left descendant, so adding a right descendant should not impact routing, and the node will remain accessible.

3.4 Prevention of Multiple Loop Formation

Given that the algorithm relies on distances, a node can have the same parent and descendant node. This situation can lead to small loops, potentially causing the system to halt or enter an infinite state. To avoid such a situation, it is ensured that the descendent/s of a node is not its parent node, and if such a situation is found then the node is made right or left descendent to its second nearest node.

3.5 Routing Based on Decision Tree

Every packet has an origination and destination address in the network and has the address of each node visited by that packet. Since the node knows its left and right descendent in the network therefore the packet after a few checks is either routed to its left or right descendent. A packet on arrival to a node is placed in a queue and gets processed when it reaches the top. First, in First out technique is used for processing packets. On arrival at the top, the node checks for its destination address, and if the node address and destination address are the same the packet is processed accordingly in another case the node checks for left and right descendent nodes, and in case the destination address matches either of the address it is transferred to left or right descendent accordingly. If in case the above conditions are not valid the node then checks for all the nodes visited by the packet and for any node that is not in the list, the packet is forwarded to that node, for any case except that the packet is transferred to the left descendent node by default.

To prevent loop creation, hop count is used. Each packet sent by a node contains a hop counter and is incremented by 1 on each visit to a node. When a node sends a packet, it includes a hop counter that gets incremented by each visited node along the route. There is a threshold value set for hop count and when the value reaches its threshold the packet will be discarded and the "Message Discarded" packet is set to the originating node.

3.6 Routing Based on Decision Tree

A seven-node network is considered for simulation as a basic unit and can be extended to any number as mentioned in Fig. 3.

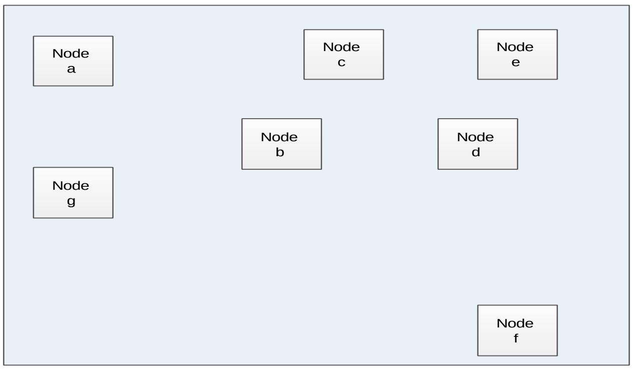

Fig. 3. Node Positions

3.6.1 Distance calculation

A tree is formed by calculating the distance of each note from all the other nodes in the network. We have considered a 07-node structure for our research work and can be extended to any number as below in Table 1.

Table 1

Calculated distance from decision tree

Node	Distance to Node a	Distance to Node b	Distance to Node c	Distance to Node d	Distance to Node e	Distance to Node f	Distance to Node g
a	0	10130	160	10240	270	90265	22500
b	10130	0	10030	110	10140	40135	2630
c	160	10030	0	10080	110	90105	22660
d	10240	110	10080	0	10030	40025	2740
e	270	10140	110	10030	0	40005	22770
f	90265	40135	90105	40025	40005	0	22765
g	22500	2630	22660	2740	22770	22765	0

3.6.2. Decide left descendants and right descendants

As assumed the left descendent and right descended assignment is done by calculating the distance for the nodes as shown in below Fig. 4. The green lines represent the shortest or most efficient paths between nodes. The red lines indicate longer or less efficient connections. These colours differentiate favourable and less favourable paths in the network.

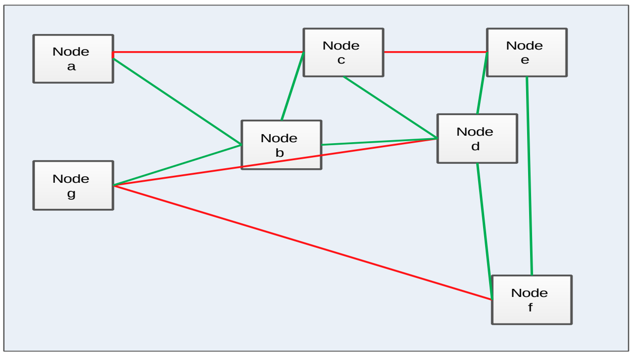

Fig. 4. Calculations for Left and Right Nodes

Tree formation with unreachable nodes and endless loops is shown in Fig 5 where all nodes in the network define left and right descendants as per the designed algorithm.

In Fig 4, the nodes a, c, and e have created an endless loop. As a result, when a packet is sent by node a to node b, it may get caught in an infinite loop between nodes a, c, and e.

Moreover, Node **f** is in an unreachable state due to the reason that it is not defined as a descendant of any node. As per the algorithm to prevent the formation of a loop, the calculation is carried out again for those nodes whose descendants and parent node are the same, excluding the previously assigned left and right descendants from the distance list. Fig 5 shows the resultant tree formed after applying the check.

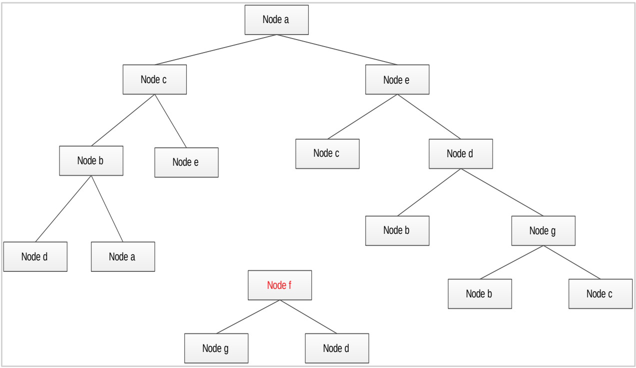

Fig. 5. Tree Without The Endless Loops

To address the issue of unreachable nodes, as per the algorithm if a node is unreachable then the node will be added as the right descendent to its nearest node and the resultant tree formation.

For node **a**, the left descendant is node **c**, and the right descendant is node **e**.

Node **b** has node **d** as its left descendant and node **a** as its right descendant.

Node's left descendant is node **b**, with node **e** as the right descendant.

Node **d** is linked with node **b** as the left descendant and node **g** as the right.

Node **e** pairs with node **c** as the left descendant and node **d** as the right.

For node **f**, node **e** is the left descendant, while node **d** is the right descendant.

Lastly, node **g** has node **b** as its left descendant and node **f** as its right descendant.

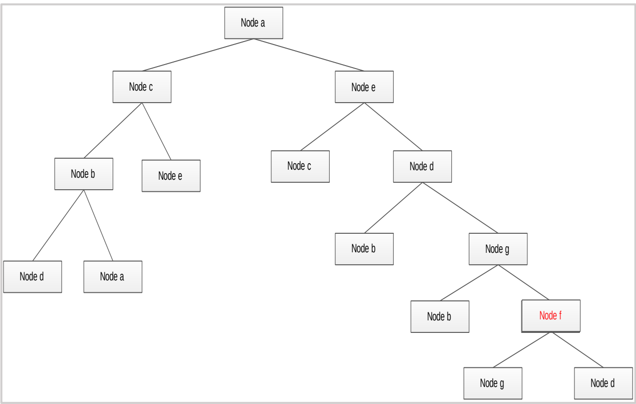

Fig. 6. Resultant Tree

3.7 Routing of Packet Follow Templating For Such Results

Source node = **a**

destination node=**g**

Total number of nodes = 7 (Fig 5).

I. Start from Initiating Node i.e., "node **a**."

II. Check both nodes, left descendent and the right descendent node for the end point i.e., "node **g**." (If neither of them is the destination node, then proceed to the left descendant node i.e., node **c**)

III. In the visited node array, add node **a**.

IV. Check both nodes i.e., node on left and node on right of node **c**.

V. In case the destination is not found then move to node **b** which is left descendent and is not in the visited node list.

VI. Check the left descendent and right descendant of node **b**, in case the destination is not found then find the left node i.e., node **d**. Also, in the visited node list add node d.

VII. At node **d** check the right descendent and left descendant, as the right descendent is the destination node we were looking for therefore move the message to this node.

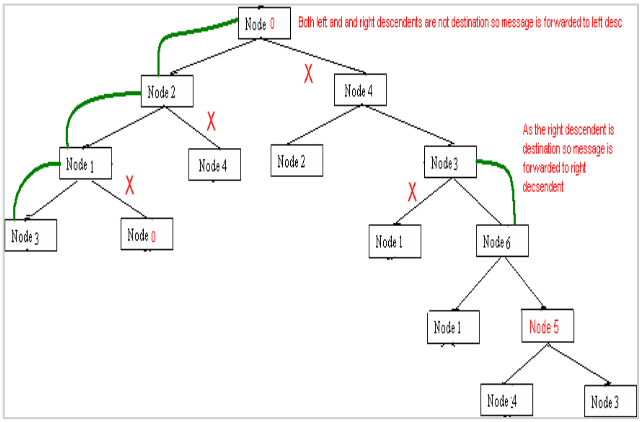

Fig. 7. Routing Decision 1

4. Simulation

As per standard performance evaluation practice, the proposed protocol is benchmarked against the existing algorithm i.e., LAR. The selection of the LAR algorithm as a benchmark is due to the following reasons.

- In this particular instance, the Location-Aided Routing (LAR) algorithm, typically employed for mobile nodes, is adapted for static nodes by setting the velocity parameter of each node to zero. This adaptation minimizes any overhead typically caused by node mobility in LAR, making it nearly negligible.
- Both LAR and Distance-Based Routing (DBR) are reactive algorithms that rely on the distance to the destination to function. Given their similar operational frameworks, using the LAR algorithm as a benchmark for evaluating the performance of DBR is appropriate. This comparison can help

highlight the efficiency and effectiveness of DBR under similar conditions.

4.1 Simulation Environment

The simulation has been developed using the C#.NET platform, chosen for its advantages in rapid development. This environment is particularly effective because it allows for quick iterations and updates. If any issues arise, they can be addressed by modifying the algorithm code and conducting necessary tests. This setup ensures a flexible and responsive development process, ideal for handling the complexities of network simulation.

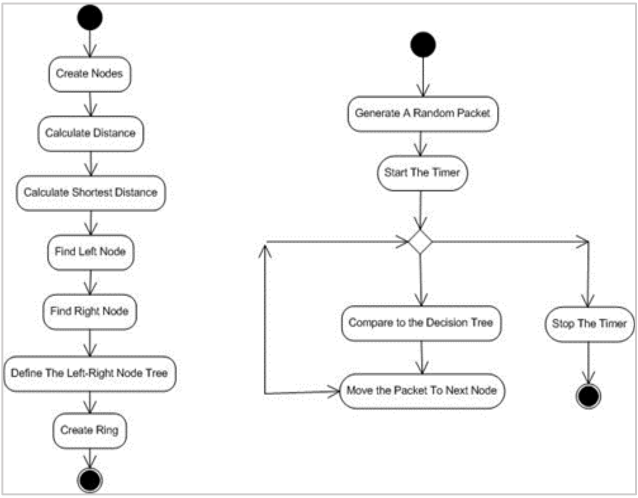

Fig. 8. Activity Flow

4.2 Simulation Limitations

The simulator is designed primarily for evaluating routing protocols and network topology construction. It efficiently manages the setup and testing of network routes, although it has some constraints, notably its inability to handle simultaneous multiple packet transmissions. This limitation hampers its capability to fully assess other critical aspects like congestion control and security, which may require further enhancements.

Key features integrated into the simulator to support its main functions include:

- Node Creation: Allows for the integration of the desired number of nodes within the simulation.
- Ring Generation: Establishes the network and defines routing paths for all nodes.
- Nodes Mobility: Facilitates the movement of nodes and assesses the impact of such changes on network performance.
- Performance Tracking: Measures and records the time required for various tasks within the simulation.
- Packet Delivery: The simulator selects a source node and a destination node randomly from the network to route a specific number of packets.

Upon completion, the simulator compiles and stores all data necessary for subsequent analysis. This setup ensures that while the focus remains on network formation and routing, there is scope for future upgrades to expand its analytical capabilities.

4.3 Simulation

The Simulation for the algorithm is developed in Microsoft Visual Studio.Net. The flow diagram of the simulation is given in Fig 8. The following procedure is followed for running the simulation.

- At first, a simulation is executed to create nodes as per the algorithm.
- After node creation, distances are calculated between nodes.
- Keeping distance as a criterion to decide left and right descendent, each node in the network is assigned left descendent and right descendent.
- A logical ring is established after left and right descendent assignment.

5. Results

The simulation was run for different numbers of nodes and results were calculated for mean delay, overhead, and throughput. The case when a node is disabled and blocking traffic from passing through the node is also analysed.

This type of routing simulation is crucial for understanding and optimizing packet delivery in network communication systems, particularly in scenarios where dynamic routing protocols like distance vector routing are employed. The simulation also helps identify potential pitfalls, such as routing loops, which can lead to inefficient use of bandwidth and network congestion. Furthermore, the number of packets used in the simulation plays a significant role in analysing the scalability and resilience of the network under various traffic loads, aiding in the development of strategies to minimize packet loss and latency.

In Table 2 simulation results are compiled. The number of packets is kept fixed to 500 and the number of nodes is varied i.e. 5,10,15,20,25,50.

Table 2 below shows the mean delay, throughput, and overhead results with different numbers of nodes and the number of packets constant at 500.

Table 2

Results for Mean Delay Throughput and Overhead

Sent Packets	No Of Nodes	Lost Packets	Received Packets	Mean Delay DBR	Mean Delay LAR	Throughput t DBR	Throughput t LAR	Over Head LAR	Over Head DBR
500	5	0	500	20	26	2.484	6.784	750	161
500	10	0	500	32	40	6.8708	15.422	1200	695
500	15	0	500	35	48	11.5008	22.814	2000	1553
500	20	0	500	39	54	15.5896	25.745	4000	2880
500	25	0	500	41	62	21922	29.732	7000	4372
500	50	0	500	46	70	44.7182	51.2442	57000	17540

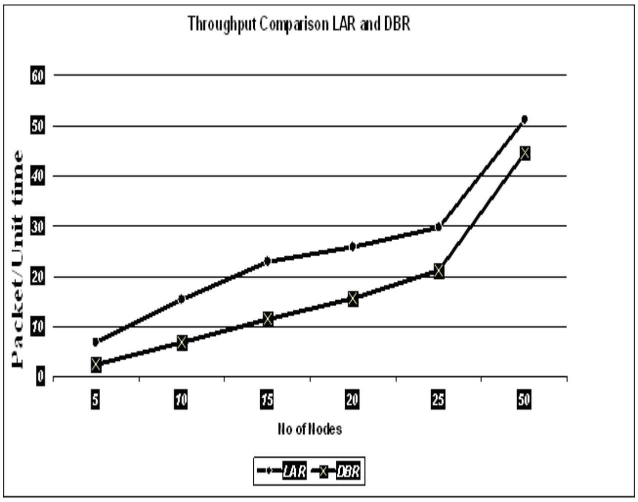

Fig. 9. Comparison Of Throughput Of Both Algorithms

Fig. 9 shows a comparison between LAR and DBR throughputs.

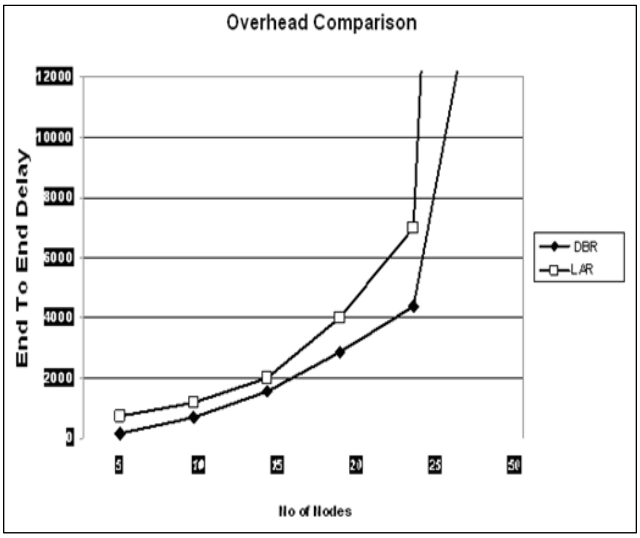

Fig. 10. Overhead Comparison LAR And DBR

In Fig. 10, the overhead for both algorithms are assessed based on node removals or positional changes within the network. Specifically for the Distance-Based Routing (DBR) algorithm, when a node exits the network or when the positions of descendants change, the algorithm recalculates the new descendants or parents for the nodes impacted by these changes. This ensures the network remains optimally configured despite dynamic changes.

6. Conclusion

The location Aided Algorithm gives a higher Mean delay as compared to the Distance Base Routing algorithm; however, throughput of Location Aided Routing is higher than the Distance Routing algorithm. After compiling the results, it is interesting to see that the DBR algorithm is more efficient in terms of processing packets as compared to LAR.

Overhead is calculated for both algorithms when a node is removed from the network or in the case when a node changes its location.

For the DBR algorithm when a descendant changes its position or a node leaves the network, the algorithm calculates new descendants/parents for the node/s affected by these changes in the network. The results indicate that the Overhead of LAR is higher than DBR and this will lead to saving energy for nodes in case the DBR algorithm is applied.

In the future, it will be interesting to simulate the algorithms for longer time intervals with larger network sizes to see the results. Another interesting scenario to work on is adding and deleting nodes at different times to see the effect of change on delay, overhead, and throughput.

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