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Research Article

PRS-LD: priority-based rank selection load distribution protocol for routing in MANETs

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Abstract
Internet of things (IoT) and fifth generation (5G) both are rapidly flourishing the demand for the development of ad hoc networks to meet the communication requirement of wireless communication. Mobile ad hoc multipath routing protocols offer the facility to build multiple paths for communication between a source node (SN) and the destination node (DN). As the number of paths has been maintained between the two nodes of the network, multipath routing protocols add the reliability feature to the network. Initially, multipath routing protocols make use of a single path for data transfer at a particular point of time. Switching to the next alternate path happens only when the previous one fails. Multipath variant of ad hoc routing protocols is gaining importance nowadays due to the reliability and consistent wireless communication offer by them. It is a difficult task to efficiently distribute the data traffic along multiple available paths with the parallel transmission of packets and is an open research problem that has been addressed by the paper. Load balancing or load distribution feature allows exploitation of the multipath routing in an efficient way. It allows the transfer of data traffics simultaneously along multiple available paths. This not only reduces the energy of nodes along a specific path, but also helps in reducing the end-to-end delay caused by the failure of nodes or paths. In this paper, a priority-based rank selection load distribution (PRS-LD) protocol for performing load-balanced routing has been proposed. It makes use of an optimized priority-based ad hoc on-demand multipath distance vector energy efficient (OPAOMDV-EE) routing protocol for the route discovery phase and rank based selection technique for distributing load or data traffics along the multiple obtained routes. The protocol has been simulated on a network simulator (NS)-2.35 and the analysis of the result proves the effectiveness of the protocol in high-load scenarios by reducing the value of route discovery frequency, routing overhead, the average end-to-end delay, and the number of energy exhausted nodes.

Keywords
AOMDV, Energy efficient, Load distribution, MANETs, Multi-path, Priority, Probability, Rank selection, Data traffic.

1.Introduction
Mobile ad hoc networks (MANETs) are complex distributed network systems where nodes are self-organized & self-configured, move freely and dynamically forming temporary or arbitrary ad hoc network topologies. It has wide applications for communication in military and rescue operations. These networks behave like a supplementary form of network for the internet of things (IoT) and fifth-generation (5G) networks. Routing is a major functionality of the network that generates paths for traveling data packets across the network. The characteristics and nature of MANETs make traditional routing protocols impractical for ad hoc networks [1].

Single path routing protocols have been introduced in the literature [2, 3] under two main categories named proactive and reactive routing protocols. Proactive routing such as destination sequenced distance vector (DSDV) [4] routing protocol consumes more energy because of large routing overhead caused due to maintenance of up-to-date information in routing tables of the node in advance, whereas reactive routing protocols such as ad hoc on-demand distance vector (AODV) and dynamic source routing (DSR) suffer from route discovery latencies arising due to the execution of route discovery phase whenever route request (RREQ) is initiated. In a view of resolving the above issues, multipath routing protocols [5] were introduced. Multipath variants of on-demand MANETs routing protocols such as ad hoc on-demand multipath distance vector (AOMDV)

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[6] and multi-path dynamic source routing (MP-DSR) [7] allow the transfer of data through multiple disjoint paths. In AOMDV, intermediate nodes maintain multiple various alternate loop-free reverse-paths using routing information from RREQ packets. Based on the routing metric, the best loop-free path is selected for forwarding data packets to the destined node. Multipath routing indeed offers reliability to the network, as in case of failure of one path next alternative path can be utilized for carrying out further communication. Even the performance of the network can be degraded if a single specific path is used for communication for a longer time. All the above-discussed multipath variants make use of a single path at a time for transmission, which further adds latency and overhead to the network. This problem demands the need for the discovery of the next category of multipath path routing protocols named as load balancing or load distributed multipath routing protocol.

Transfer of packets among communicating nodes in an unbalanced way can lead to power depletion of heavy load traffic nodes and enhance the drop rate, which leads to an increase in end-to-end delay and packet loss rate. The effect of all this will lead to a decrease in network performance and lifetime.

The solution to the above problem has been achieved by introducing the load balancing concept in multipath routing protocols. Load balancing maximizes the throughput, minimizes the response time, and avoids the overhead by distributing the packets in a balanced manner among multiple available paths. As a result of optimal resource utilization, the lifetime of the network increases by incorporating a balanced load mechanism in the multipath routing concept.

Suppose there exist two paths P1 & P2 between source node (SN) and destination node (DN) P1 requires a smaller number of hops to reach the DN. P2 demands more hops in comparison to P1. But P1 may require at more routing time due to congestion or insufficient energy level of nodes. In this way, rather than getting stuck in an inefficient path, optimal choice based on energy constraints should be given priority. Therefore, a multipath priority-based route discovery mechanism (MPRDM) [1] is used which exploits the priority factor over the various computed energy along the path to decide the order of preference among the multiple generated routes. Priority is a computed metric that has been assigned by the SN based on the values of the cumulative energy CE), maximum energy (Max_E), and minimum energy (Min_E) fields of the route reply (RREP) packets along a path. There can be several criteria for the election of a path among multiple available choices. The protocol aims in gaining information about the energy states of the nodes in advance. The target of the protocol lies in finding an optimal path that is necessarily not the shortest path. A path having sufficient energy to cope with the future energy requirement of the nodes can be designated as an optimal path. In this paper, to make use of available paths in an efficient balanced manner, a load balancing scheme has been presented under the proposed priority-based rank selection load distribution (PRS-LD) protocol. This work exploits the prominent concept from literature i.e., the rank selection technique from genetic algorithms that focuses on the exploration of population. The protocol successfully distributes the packets along the multiple generated paths in a proportionate manner based on calculated rank probability (RP).

Following is the contribution of the proposed work:

1) To present a mechanism that can support the parallel transmission of data packets along with the generated available paths in an efficient manner.
2) Prioritized routes based on calculated CE, Max_E and Min_Eoffers stable routes for communication that reduce route discovery frequency and routing overhead of the network.
3) Rank techniques applied over prioritized routes help in the proportionate distribution of packets along the available paths for parallel transmission of data packets over the paths. This reduces the load on a specific path and further reduces the chances of link or path breakage.
4) Simulation of the PRS-LD on a network simulator (NS) -2 produces efficient results in terms of end-to-end delay, route discovery frequency, the number of exhausted nodes, and routing overhead in terms of high load conditions.

This paper has been organized as follows: Section 2 briefly discussed the related work in the literature. In section 3, the PRS-LD protocol has been proposed and illustrated using an example. In section 4, the simulation setup of the experiment has been presented and results produced by the NS-2 have been investigated and explored. A discussion has been added in section 5 and finally section 6 concluded with future work.

2.Literature review

Efficient use of network resources is a key issue of concern, specifically in resource-scarce networks like MANETs. Flooding of RREQs and RREPs packets by the routing algorithm in the MANET always affects the performance of the network. Thus, it is very important to avoid network flooding for preventing inefficient use of network resources. A new metric node cardinality (NC) has been proposed by Glam et al. [8] that reduces the use of relay packets and provides improved network efficiency. Achieving quality of service (QoS) in MANETs is again a critical problem, due to the random nature of mobile nodes. In [9] AODV has been analyzed based on the QoS metrics such as packet drop rate, delay, memory capacity, network load, and bandwidth. QoS-based dynamic secured broker system has been proposed and simulated on NS 2 that can provide secure path selection, higher scalability, and reduced network load based on the QoS metrics. Energy is one of the important requirements of these types of networks. The continuous use of batteries and restricted battery capacity can result in broken links. Trust-based efficient energy balanced less loss routing (TER) protocol [10] for MANETs has been proposed to improve the network performance by working on the selection mechanism of the intermediate forwarding node. This helps in building trust in the selected node. The main focus of TER is to reduce the chances of data loss. This further results in the improvement of the throughput and packet delivery ratio (PDR) of the network. Another multipath variant for reliable communication has been developed by Benatia et al. [11] to select a better link quality path that provides stable and reliable data transmission. The protocol has considered characteristics such as energy, transmission range, and mobility of MANETs that put critical challenges for maintaining network performance. Further, network performance can also be enhanced by utilizing the true benefits of multipath routing. Among the multiple available paths in multipath routing protocols, balanced traffic distribution plays a critical role in determining network performance. Meta heuristic-based algorithm such as artificial bee colony optimization algorithm [12] has been proposed for the same purpose in distributed computer networks. The path reservation multipath routing (PRMR) [13] protocol has provided a path discovery mechanism along with a packet scheduling algorithm for every available traffic depending upon the service requirements. PRMR tries to solve the problem of unbalanced load among reserved paths caused by different kinds of traffic. For unmanned aerial vehicles (UAV) networks, load-balanced optimized predictive and adaptive routing (LB-OPAR) [14] has been proposed. It works on optimizing the performance of the network in terms of flow completion time, throughput, and success rate. Recurrent networks from artificial neural networks have been used for developing multipath load-balanced routing protocols. Here, Elman recurrent neural network model has been used for predicting the future load of obtained routes during the route discovery model. At the time of route searching the proposed protocol is used to calculate the traverse time taken by every packet. This information is being used for load distribution as the number of packets sent on a particular path is inversely proportional to the traversing time of the path. The work proposed by the Pal et al. [15] produces a more stable and congestion-free network but the same has not been proved with any simulation results. Load-balanced ad hoc routing (LBAR) [16] has used the concept of setup messages for finding the best-balanced route for communication purposes between the SN and DN. The destination is used to filter the route based on the calculated cost metric that is calculated by using the nodal activity of the node. It produces less PDR and end-to-end delay in comparison to the DSR and AODV. The concept can be extended for providing a multipath solution to the network. In the load balancing ad hoc on demand multipath distance vector routing (LB-AOMDV) [17]current node focuses on maintaining the neighbor list and then analyzing it under different parameters such as delay, loss rate, and communication rate and giving priorities from low to high based on the analysis. This priority will help to distribute the load among the nodes. Load balancing parallel routing [18] tried to solve the problem generated from the execution of the traditional multipath mechanisms and proposed a mechanism that manages to send data on all the multiple paths simultaneously. Node centric load balancing routing (NCLBR) [19] aims at reducing the overall overhead of the network and balancing the load among the node of the network simultaneously. The protocol stops sending RREQ messages when congestion in the network arises. The work in [20] focuses on controlling congestion and applying a load balancing mechanism adaptively to adapt to the requirement of the network at the same time. The concept of path vacant ratio is used to find several link disjoint paths among all the available paths. An algorithm is further developed to split the messages or data packets into multiple segments that travel through multiple paths according to the path vacant ratio to reach the destination. Traditional multipath routing is unable to produce completely disjoint paths and shifts to the second available path only when the first one breaks. In [21] efficient load-balancing routing techniques have been proposed that focus on the improvement of QoS parameters such as routing overhead and PDR and increasing the overall lifetime of the network. The work presented in [22] proposed a load-balancing mechanism that considered the centrality of nodes as a prominent factor for identifying the congested nodes. It further tried to move or push the traffic farther from the central congested nodes and distributes the nodes evenly in the neighborhood of the central nodes. In multipath load balancing (MLB) [23] routing authors presented a load-balancing mechanism for IoT networks. Firstly, nodes have been assigned to different layers based on the position of IoT gateway from the nodes. All the nodes in the neighbor on a particular layer communicate information regarding the current load and balance it among them. The various other works related to load balancing protocols studied in the literature covering the work proposed by the authors, their limitations along with the further scope of improvements that can be considered to propose an efficient routing protocol have been summarized in *Table 1*.

Table 1 Related work

S.N.	Routing protocol	Authors	A problem discussed	The solution proposed	Performance analysis	Limitation	Further scope
1.	Traffic - aware load balancing in AOMDV (TA-LAOMDV) For mobile Ad-hoc networks	Pathak and Kumar[24]	Traditional AOMDV uses a single path for transmission and keeps rest as a backup which increases the burden and overutilisation of a single path.	The proposed TA-LAOMDV generates and uses multiple paths which help in load distribution.	Simulation and performance analysis on NS-2 performed well in terms of E2E delay, throughput, and PDR.	Lack of a dynamic decision-making mechanism regarding the selection of better routes.	The use of the energy factor for the selection of path can be used for further improvement in the network performance of the routing protocol.
2.	Load balancing maximal, minimal nodal residual energy ad hoc on-demand multipath distance vector (LBMMRE-AOMDV)	Alghamdi [25]	To conserve the energy of nodes by distributing load in multipath routing.	The protocol first, sorts the path according to available residual nodal energy in descending order And then selects the path that is having the maximal Value of nodal residual energy.	Performance evaluation on NS-2 outperforms in terms of PDR, consumption of energy, decreasing routing overhead, and the number of dead nodes.	Suffers from high end-to-end delay to transfer the maximum amount of data.	Protocol end-to-end delay can be decreased by applying some scheduling mechanism for packet distribution.
3.	Channel busyness based multipath load balancing (CBMLB)	Aouiz et al.[26]	To reduce the load on the centrally placed intermediate node of the network in multipath routing.	The protocol computes the channel busyness ratio and selects routes with the least computed ratio that	It was simulated on NS-2 and performed well in terms of PDR, end-to-end ratio, and overhead as compared	The concept of energy consumption by nodes of the network has been left	To work on a multi-criteria approach for congestion detection.

S.N.	Routing protocol	Authors	A problem discussed	The solution proposed	Performance analysis	Limitation	Further scope
				detects the network's congested nodes.	to AOMDV.	untouched by the protocol.	
4.	Improved routing protocol	Li et al.[27]	To find a reliable transmission path considering the node's randomness and dynamic topology of the network, which overload some nodes, while the under-loaded nodes fail to use resources	The proposed protocol applies a load-balancing mechanism by forwarding data packets by selecting nodes with higher residual energy and lower queue capacity.	The protocol shows improved results in terms Of routing discovery frequency, end-to-end delay, and the number of energy-exhausted nodes.	The protocol makes use of single primary standby path for transmission of data packets at a time.	Work can be carried out in the future to replace single primary standby path with parallel transmission.
5.	Prediction-based multipath routing protocol.	Pal et al.[28]	To work on finding stable routes by discovering a stable neighbor and further balance the load on multiple available paths so that total packet time can be reduced.	A recurrent neural network is used for the selection of stable neighbors. Based on path length, a mechanism has been developed for packet distribution across multiple available paths.	The proposed algorithm results in higher PDR and reduced route recovery time.	The proposed model claims for reducing the energy requirement of the network, but nothing has been proved using simulation.	In the future, the proposed work can be extended by increasing the throughput of the network by including delay parameters for the link and propagation.
6.	Conditional max, min battery capacity routing (CMMBCR)	Rungtaveesak et al.[29]	To propose a load distribution mechanism based on the remaining energy of nodes. The protocol aims at increasing the lifetime of the network by preventing link breakage due to low-energy modes.	It applies two approaches i.e., MTPR and MMBCR. The mechanism uses the available residual energy of nodes both at the routing and data transmission phases to maintain the most effective	Simulation results in an increase in network lifetime and the number of remaining nodes.	There is no improvement in the PDR and there is an increase in End-to-End delay.	The load distribution mechanism can be further improved by considering the dynamic nature of the network.

S.N.	Routing protocol	Authors	A problem discussed	The solution proposed	Performance analysis	Limitation	Further scope
				path.			
7.	Lightweight load balancing and route minimizing Solution for RPL (L2RMR)	Seyfollahi and Ghaffari[30]	To prevent packet loss in lossy networks that occurs due to the overloading of a small number of nodes, because of an imbalance in packet distribution.	A new algorithm and objective function to solve the load balancing has been proposed.	Results obtained on the Cooja simulator show improvement in the packet loss ratio, end-to-end delay, and energy consumption of the network.	The performance of the method on throughput and weights of paths has been evaluated.	The proposed method can be further extended to deal with heterogeneous traffic on IoT networks.
8.	Dynamic Hop selection static routing protocol (DHSSRP)	Adil [31]	To propose a routing protocol for IoT networks that can consume minimal resources in communication and achieve load balancing among heterogeneous devices without affecting network performance metrics.	Based on the priority information, congestion-free communication has been established, while based on the acknowledgment (ACK_ of the sensor nodes traffic priority is decided, and the alternate routes are assigned to neighboring nodes.	Simulation results show significant improvement in communication cost, computational cost, traffic congestion, throughput, PLR, and network lifetime.	The effect of the proposed work on the energy consumption of networks and devices is untouched.	The proposed scheme can be implemented and studied in the real IoT communication Infrastructure.
9.	Least common multiple-based routing for load-balanced multipath routing in MANETs.	Bhattacharya and Sinha [32]	To decrease the routing time in existing AOMDV by introducing load distribution among routes.	The method finds multiple paths along with time to send data packets between source and destination nodes. Thus, the packets distributed along a path are inversely proportional to the routing time along that path.	The proposed least common multiple based load distribution technique successfully reduced the overall routing time of data packets along all the paths.	The proposed scheme mainly concentrates on the routing time, whereas, there are many other factors such as energy, overhead, and delay which affect the overall performance of the network.	To further optimize the protocol so that it can dynamically decide 5G enabled IoT networks.

S.N.	Routing protocol	Authors	A problem discussed	The solution proposed	Performance analysis	Limitation	Further scope
10.	Multipath battery and mobility-aware routing scheme (MBMA)	Jabbar et al. [33]	To present a routing scheme for MANETs that can cope with the two most incurred challenges i.e. Energy failure and mobility.	Here multi-criteria node metric has been exploited to rank the paths based on stability using a link assessment function. An energy and mobility aware multi-point relay (EMA-MPR) selection mechanism has been introduced.	Simulation results proved that the scheme is effective in mobility and high-traffic load scenarios.	More quality-of-service parameters should have been evaluated to justify the protocol for the high mobility environment.	For WSNs (wireless sensor networks), WMNs (wireless mobile networks), and large-scale networks, this scheme can be further extended and improved.

The literature so far studied proved the effectiveness of multipath routing in comparison to single path routing as it comes with the concept of reliability by offering multiple paths for communicating data packets from the SN to the DN. In view to exploiting the actual benefits of multi-path routing packets two points required immediate action. Firstly, rather than using one path at a time for sending information, simultaneous transmission of packets should be promoted for fast execution, and secondly, in case of parallel transmission data packets required some sort of mechanism for balanced distribution otherwise one path may get overloaded in comparison to others. Various load balancing and load distribution mechanisms have been studied above, but some limitations have been observed and inferred. In the next section, our proposed protocol tries to overcome the limitations by considering the concept of energy and priority along the generated routes and then applying the concept of rank selection on the prioritized routes for the proper distribution of data packets along the generated paths.

3.Method

Multipath routing certainly helps in adding reliability to the network in the form of a number of different available paths at a time. However, in order to have an optimum utilization of multipath routing, a proper load balancing mechanism is certainly required. This section presents in detail the need as well as the mechanism that can be used to introduce the load balancing in PRS-LD routing protocol.

3.1Problem formulation

In a multipath routing protocol, multiple routes are generated by the route discovery phase. As earlier proposed, MPRDM generates multiple routes between SN and DN. These routes are used for sending data packets among the selected nodes, selecting one route at a time. In the case of parallel sending of data packets along every generated route, a new mechanism has to be added to the existing MPRDM, which can properly distribute the packets along every available route so that no path gets over-utilized. This is the problem addressed by the current paper. To solve the problem, a novel mechanism has been proposed named PRS-LD that consists of two phases. The first phase is the route discovery phase, which uses the existing MPRDM for generating multiple prioritized routes between the SN and DN. The second phase is the load balancing phase. This phase makes use of the existing concept from the literature i.e., Rank based selection technique. Firstly, based on the priority value (PV) of routes, rank (RI) every route from 1 to n, n ∊ # Routes. Rank 1 belongs to the least priority route and rank n belongs to the highest priority route, then RP is calculated for every route as per the following Equation1:

$$rp_i = r_i / \sum_{i=1}^{n} ri \quad (1)$$

Based on the value of RP, packets are distributed or scheduled along multiple available paths.

3.2PRS-LD routing protocol

PRS-LD routing protocol utilizes the concept of prioritized route for obtaining knowledge about the energy states of the routes in advance. On the prioritized route load distribution mechanism has been applied by using the concept of rank selection. The detailed design and concept of PRS-LD has been divided and explained under following three phases.

3.2.1Route discovery phase

PRS-LD is a multipath reactive routing protocol that has included a load distribution mechanism in view to enhance the capability of multipath routing. Multipath routing allows more than one path to exist among SN and DN. As a reactive routing strategy has been followed for discovering routes, so whenever demand is raised for communicating to a specific DN, the route discovery phase of PRS-LD is initiated. PRS-LD is an extension of OPAOMDV-EE routing protocol. The route discovery phase is initiated by broadcasting RREQ packets consisting of three additional fields, namely CE, Max_E and Min_E with one hop limit in the neighborhood. All intermediate nodes (IN) after receiving the RREQ packets keep on updating the value of the fields as per Equation 2, 3 and 4 and store the information in their routing table. RREQ packets will be broadcasted until they reach the DN. The DNwill generate RREP packets corresponding to every received RREQ packet and send them on the reverse path. On the reverse path, CE, Max_E and Min_Efields will be updated again by every IN. The SN on receiving the RREP packet prioritizes them according to CE, Max_E and Min_Eindividually and then calculates the total PV for every RREP packet as per Equation 5. Based on the total priority metric value, the SN will have multiple prioritized routes for maintaining communication among SN and DN. In algorithm 1, phase 1 gives the step-by-step execution of the route discovery phase.

3.2.2Load distribution phase

Multiple paths generated by phase 1 of an algorithm will be utilized for further transmission of data packets from the SN to the DN. To make efficient use of these routes, packets should be sent on multiple routes in a balanced manner. Unbalanced transmission of the packet may overload the nodes of specific paths which results in the overutilization of resources along a particular path. With a view to avoid congestion over certain paths and to increase the lifetime of the network by implementing an energy-efficient balanced packet distribution strategy, a load distribution phase is required.

Phase 2 of algorithm 1 describes the execution of the load balancing phase of the PRS-LD routing protocol for MANETs. The load distribution phase has been designed by making use of the rank selection technique from the genetic algorithm.

Rank selection [34] sorts the population based on the fitness value of chromosomes and then ranks them accordingly. Every chromosome is assigned a selection probability concerning rank. Individuals are selected based on the allocated selection probability. The same concept has been used by the SN of the network over the multiple generated paths. Firstly, the source route will assign a rank based on the value of the total priority metric to every route generated by the route discovery phase from 1 to n, n ∊ total number of available routes. Rank 1 will be assigned to the route having the least value of the total priority metric, whereas the route having the highest PV will be designated as rank n. For the selection of a particular route, RP is calculated as per Equation (6). The proposed algorithm will distribute the packets based on the calculated RP of the route in a proportionate manner. This process will be continued till all the packets have been transmitted to the DN.

3.2.3Route recovery phase

During the communication process between a particular source and destination pair, there may come a situation where some intermediate nodes exit from the transmission range and organize and configure themselves with some neighbor network. There can be many other reasons such as energy depletion or sleep conditions due to which link failure can occur. A reliable protocol considers these situations so that communication should not get halted. In the route recovery phase of PRS-LD, if any node is not under the working condition, then it will send a route error (RERR) message to the SN. The SN will check all the path sequences for that particular node and remove those paths from the path list. The source will work with the remaining available paths. If still no path is left for carrying out further communication, then the route discovery phase will be initiated again.

Algorithm 1: PRS-LD Algorithm for routing data packets

Input: SN has to send data packets to DN
Output: Data Packets reached DN traversing multiple paths.
Begin
Phase 1: Route Discovery Phase
SN broadcasts RREQs in the neighborhood with three additional fields in every RREP packet, namely CE,

Max_E and Min_Ewith initial values CE = 0, Max_E = 0 %, Min_E = 100%.

If *(RREQ at IN)* then
{
Update CE, Max_E and Min_E as follows:
CE after Node (i) = (CE before Node (i) + Energy of Node (i)) (2)
Min_E after Node (i) = Minimum (Min_E before Node (i), Energy of Node (i)) (3)

Max_E after Node (i) = Maximum (Max_E before Node (i), Energy of Node (i)) (4)
}
Else if (*RREQ at DN*) then
DN generates RREPs and sends them back to the Reverse path
If (*RREP at IN*) then
{
Update CE, Max_E, and Min_E as per Equation 2, 3 &4.
Collect information in their stack and further forward It on the reverse path
}
Else if *(RREP at SN)* then
{
Φ=Rx E + Tx E + IE

Where Φ is the threshold, Rx E is Energy required for receiving a packet, TX E is for Energy required for transmitting a packet & IE is Energy spent in idle mode.

If (Min_E<Φ) // Min_E parameter of every received RREP will be checked
Then
{
RREP is discarded
}
Else
{
SN assigns PV to CE, Max_E, and Min_E fields individually
SN calculates the Total PV for RREPs as follows:
Total PV RREP (Ai) = [(PV for CE per Node) + (PV for Max Energy) + (PV for Min Energy)] (5)
Add the Total PV to the RREP packets
}
}

SN has multiple prioritized routes for sending data packets

Phase 2: Load Balancing Phase

If*(Current Node (CN) = SN)*then
{
Based on the PV of routes rank (ri) every route from 1 to n, n ∈ # Routes
Rank 1 belongs to the least priority route and rank n belongs to the highest priority route
Calculate rep for every route
$rp_i = r_i / \sum_{i=1}^{n} ri$ (6)
Take rp on a scale of 100.
Based on the value of rp send the proportionate number of packets along the respective path
Else
{
Start route discovery phase
}
End

3.2.4Working example

For analyzing the working of PRS-LD, some nodes have been taken that form a network as shown in *Figure 1*. In *Figure 2* and *Figure 3*, the route discovery phase has been initiated, where RREQ packets have been forwarded in the neighborhood and the DN replies with the RREP packets on the reverse path for every received RREQ packet. In *Figure 4*, SN calculate the value of the total PV field using an MPRDM *Figure 5*, and *Figure 6* makes use of a PRS-LD algorithm in the load distribution phase.

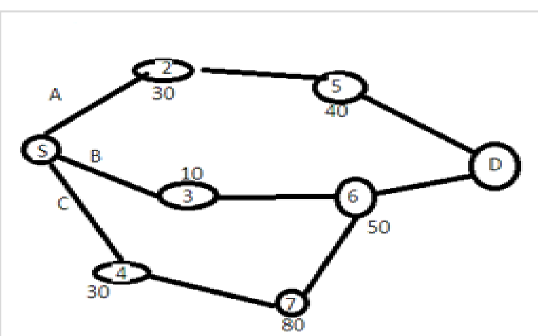

Figure 1 Network of nodes

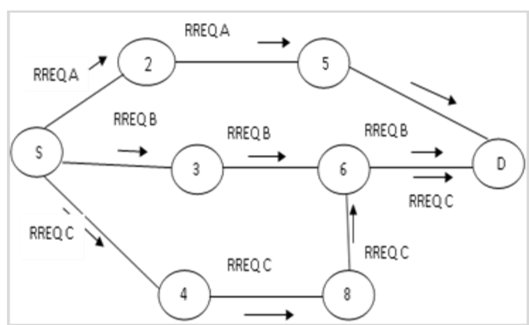

Figure 2 S Forwarding RREQs towards D

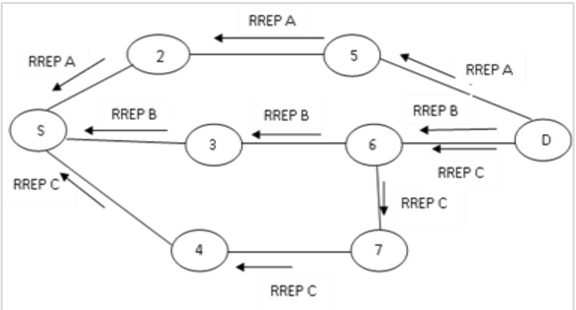

Figure 3 D sending RREPs for every RREQ's

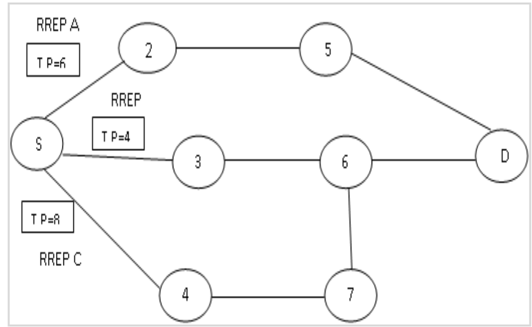

Figure 4 S calculating the total PV

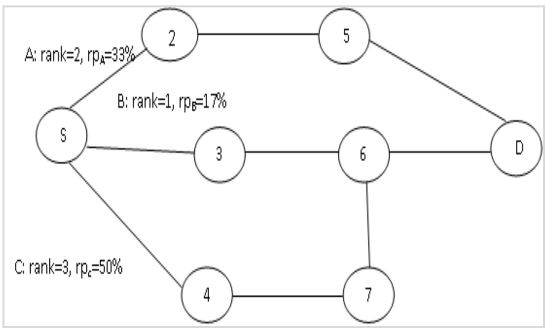

Figure 5 S assigns rank based on rank selection

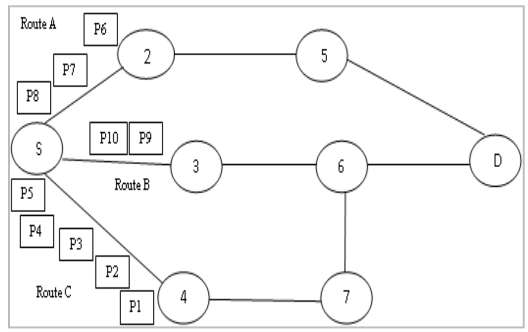

Figure 6 S sends proportionate packets based on RP

Table 2 calculates the RP for individual routes and specifies the number of packets that have been assigned to each route by applying the PRS-LD protocol. Suppose 10 packets are traveling between S and D then 5 will be traversing through C, 3 follow path A, and 2 will reach through path B. All the packets will be distributed along the paths as shown in *Figure 7*. The complete pictorial representation and flow of the mechanism have been demonstrated with the help of a flowchart in *Figure 8*. Here SN initiates route discovery by flooding the RREQ packet with added CE, Max_E, and Min_E fields. When RREQ reaches the next neighbor node, all three fields will be updated as per Equation 2, 3, and 4 and RREQ packets will be broadcasted further in the network. This process will continue till the RREQ reaches the DN. On receiving each RREQ packet, the DN is supposed to generate the corresponding RREP packet. These RREP packets will be directed toward the SN along the reverse path. The value of CE, Max_E, and Min_E will be updated and stored at every node on the reverse path as per Equation 2, 3, and 4. SN will assign PV to every received RREP packet, and calculate the total PV for every generated route. These routes will be ranked based on PV from 1 to n, where n represents the number of routes discovered. Further, RP is calculated for every route by applying the concept of rank selection. The number of data packets to be directed along different paths is decided based on RP.

Table 2 Proportionate rank-based packet distribution

Routes	Total PV	Rank	Rank probability (RP)	RP on a scale of 100	Proportionate rank based packet distribution
A	6	2	2/6 =0. 33	33%	3
B	4	1	1/6 = 0.16 ~ 0.17	17%	2
C	8	3	3/6 = 0.50	50%	5

P1: P5	P6:P8	P9:P10
Path C	Path A	Path B

Figure 7 Priority-based rank selection load distribution among path A, B, and C

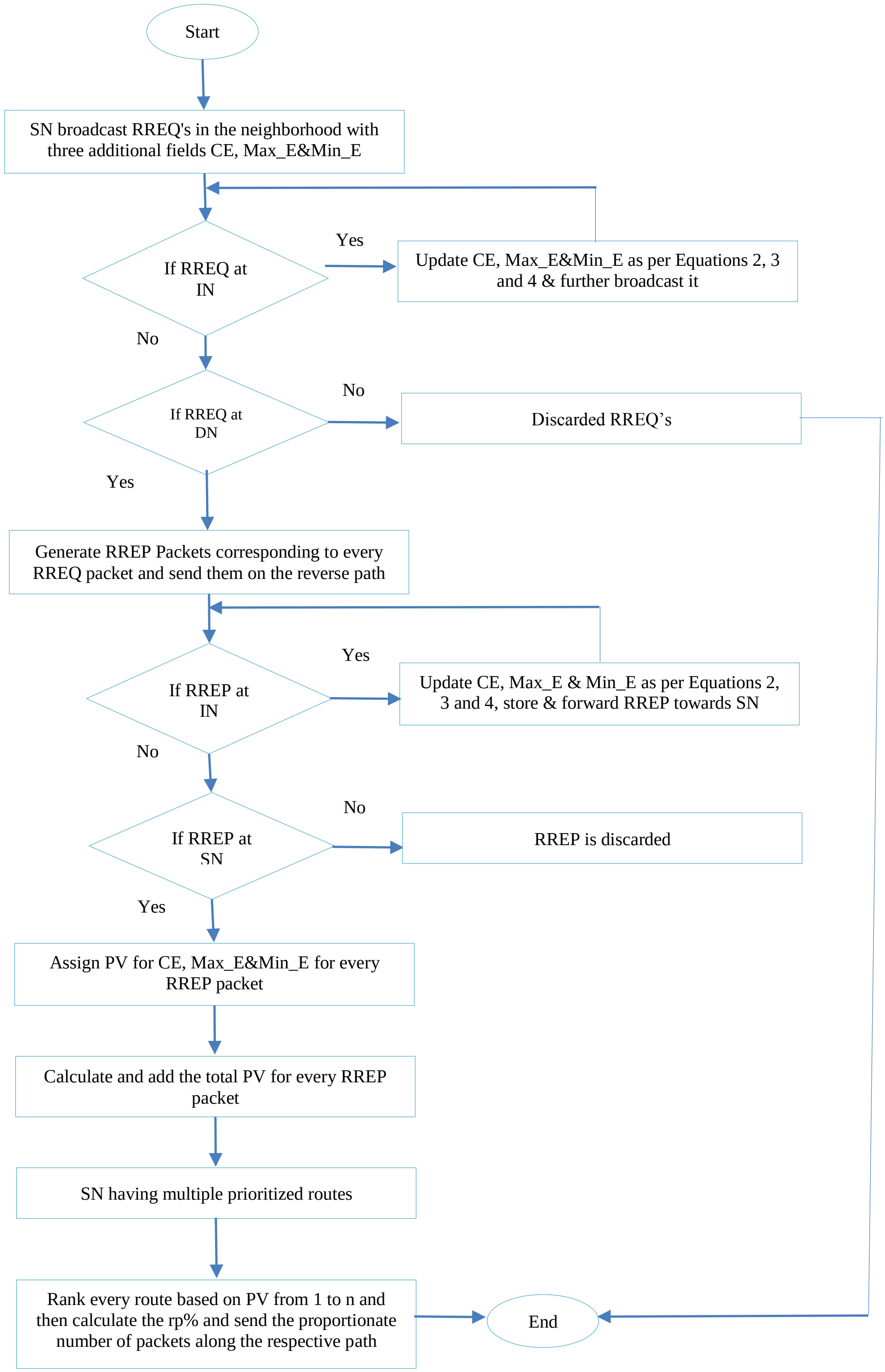

Figure 8 The Flowchart of the PRS-LD routing protocol

4.Results

Evaluating the performance of designed protocol is an essential activity. Evaluation not only provide a proof to the logic used in the protocol, but also provides the directions for the work that can be carried out in the future. Li et al. [27] Analysed and compared the performance of improved routing protocol on the basis of four performance metrics such as the average end-to-end delay, route discovery frequency, routing overhead, and number of exhausted nodes. To overcome the limitation of improved routing protocol, the PRS-LD worked by utilization the true benefit of multipath by distributing the load along the prioritized routes by applying a rank selection technique. This has been verified by using the simulation over NS-2. This section presents the various simulation parameters used as well the results obtained over the NS-2 simulator.

4.1Simulation Environment and set-up

PRS-LD performance has been simulated on NS-2.35. *Table 3* summarizes the simulation setting performed on NS 2.35. All the simulation scenarios have been discussed after studying the results obtained for the four metrics as follows:

Table 3 Simulation set up

Compared routing protocols	**AOMDV, Ad hoc on-demand multipath distance vector load balanced (AOMDV-LB), improved routing protocol and PRS-LD routing protocols**
Maximum number of case-based reasoning (CBR) connections	10, 20
Nodes	50, 100
Maximum Nodes Speed (m/s)	20 m/s
Size of Packet (Bytes)	512 bytes
Pause Time (s)	0 s
Initial Nodes Energy (J)	50 J
Simulation Area (m2)	1000 m×1000 m

4.2Average end-to-end delay

Average end-to-end delay is referred to as the average time taken by a data packet from the source internet protocol (IP) layer to the DN IP layer. This cover all types of delays such as route discovery delay, queue delay, transmission delay, propagation delay, and retransmit delay.

Figure 9 and *Figure 10* show the average end-to-end delay with 100 nodes & 10 connections and 100 nodes &20 connections, respectively. The average end-to-end delay is less for low load scenario (i.e. 10 connections) when compared with a high load scenario (i.e. 20 connections). With the increase in simulation time, the value of delay decreases for all the compared routing protocols. The reason for the decrease lies in the fact that with time, routes have been always built & stored and known in advance for transmission of packets due to which, they are available instantly for the sending message packet with no additional wait.

It can be deduced from *Figure 9* and *Figure10* that the AOMDV-LB routing protocol produces a lower average end-to-end delay than that of traditional AOMDV because there is no inbuilt load balancing mechanism performed by AOMDV. It only switches to the next alternate path in case of failure of the primary path. AOMDV-LB avoids the use of heavy load nodes to become part of the selected path. This process lowers the packet waiting times in queues. Additionally, the improved routing protocol focuses on selecting the light load nodes along with nodes having high residual energy to carry out the transmission for a longer time. This helps in reducing congestion and transmission delay to a great extent.

On the other hand, PRS-LD performed better than all three routing protocols, because the routes are ranked by using PV which is calculated based on the CE, Max_E, and Min_E of nodes. PRS-LD presents more stable routes and further, it applies rank selection for calculating rank probabilities which avoid overloading of routes. Simultaneously, all the generated paths actively participate in the transmission of data packets which results in lesser end-to-end delay in comparison to other cases. PRS-LD is producing better results only when no. of connection was less (i.e.,10). In high load scenario improved routing performs quite well in terms of end to end delay.

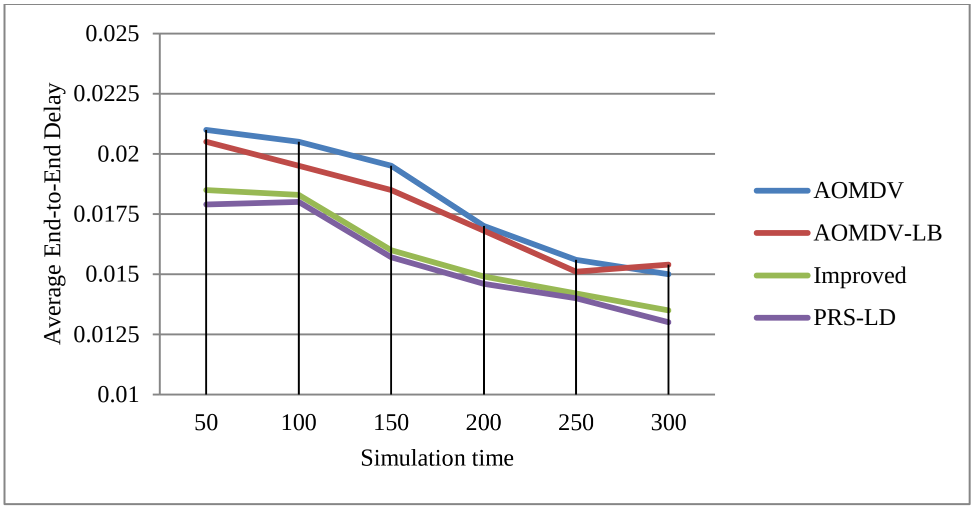

Figure 9 Average end-to-end delay with 100 nodes and 10 connections

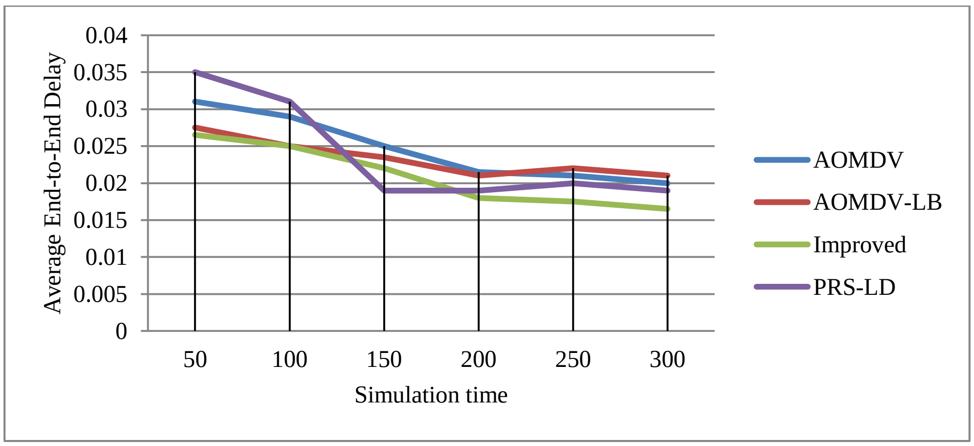

Figure10 Average end-to-end delay with 100 nodes and 20 connections

4.3Route discovery frequency

Route discovery frequency is calculated by the total number of route discovery requests initiated by the nodes of the network per unit time. As it can be seen from *Figures 11* and *Figure12*, the route discovery frequency of all three compared protocols, and PRS-LD is showing a consistent decrease in simulation time. This is because, with time, the route learning capacity of the network increases, and more stable routes are stored at intermediate nodes of the network. This will result in a decrease in demand for finding new routes and hence there will be a lesser number of initiated RREQs that decrease in the route discovery frequency for the routing protocol.

AOMDV-LB selects routes based on the load conditions of nodes and hence it results in lesser breakage of routes with time in comparison to AOMDV. Since there is a lesser number of route discoveries carried by AOMDV-LB when compared with AOMDV. The improved routing protocol used the concept of energy of nodes for route selection, hence producing less route discovery in comparison to AOMDV-LB, but PRS-LD outperforms all three protocols because more stable and longer sustained paths are calculated by using the priority technique over the calculated CE, Max_E and Min_Evalue of paths. Route breakage is ensured by using a rank-based selection mechanism, which applies proportionate distribution of packets along the generated path. This process does not overload any specific path as already available paths fulfilled the demand of the network transmission that results in a lesser requirement for new route discovery. PRS-LD performing 47% better than improved routing protocol in terms of route discovery frequency in high load scenarios. Although, both in high and low load scenario, PRS-LD performed well as compared to other, but when no of connections were 10 and with an increase in simulation time, PRS-LD has nearly the same performance as compared to improved routing protocol in terms of route discovery frequency.

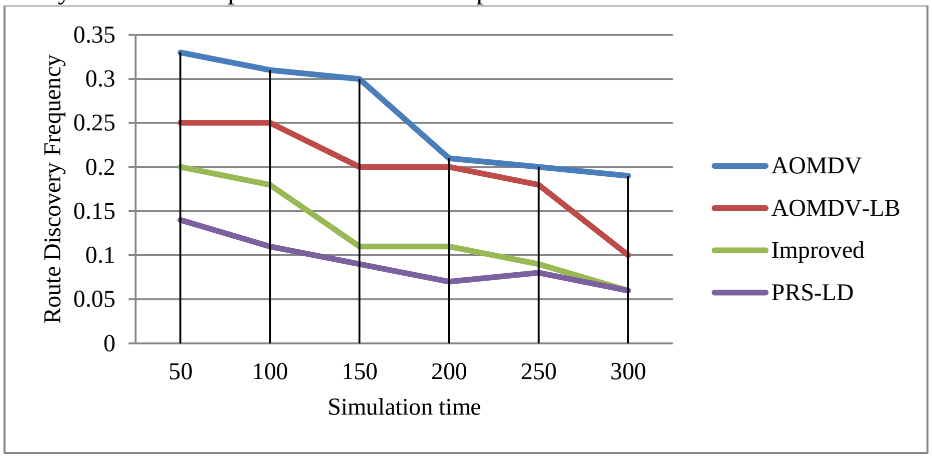

Figure 11 Route discovery frequency for 100 nodes and 10 connections

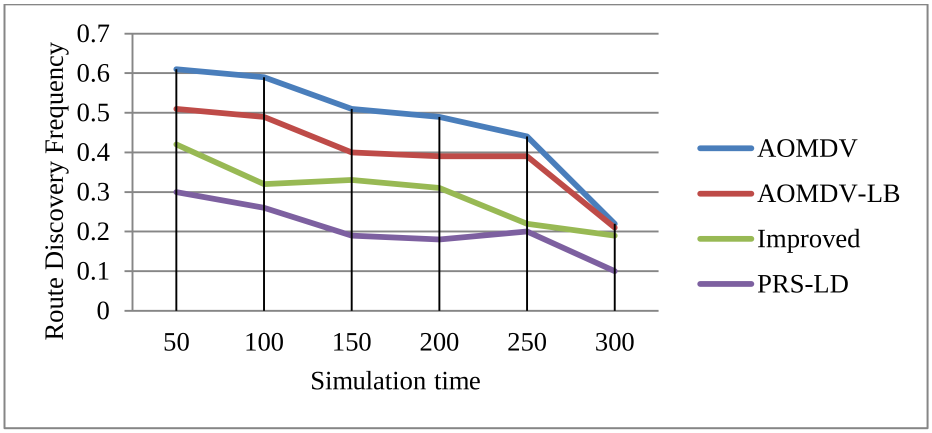

Figure12 Route discovery frequency for 100 nodes and 20 connections

4.4Routing overhead

Routing overhead represents the congestion estimate of the network. It is generally calculated based on the number of control messages exchanged among the nodes of the network for each data packet transmission. A certain level of overhead is also added by the route maintenance phase, but it is comparably less as compared to the route discovery phase.

The value of routing overhead has been calculated and analyzed by simulating the PRS-LD for two scenarios (50 nodes & 20 connections and 100 nodes & 20 connections). AOMDV certainly produces less overhead for the network, as it doesn't involve any kind of load distribution mechanism in comparison to the AOMDV-LB and improved routing protocols. AOMDV-LB makes use of a lower load node for forwarding packets that require real-time updating of information in the network using control packets, whereas improved routing protocol exploits residual energy factor of the nodes for forwarding RREQ, adding stability to the links and reduces the routing overhead of the network.

For PRS-LD routing, overhead is certainly more when node density is high (*Figure 13*) since a greater number of routing control packets are exchanged among the nodes of the network, whereas in case of low node density (*Figure 14*), there is less requirement of control packets in route discovery and maintenance results in less overhead on the network. As observed from *Figure14*, the value of routing overhead is decreasing with the simulation time for all the protocols in a high-load scenario. The reason behind the decrease is certainly that with an increase in simulation time, the network attains a stability level, so a smaller number of route discoveries is required. Hence, a smaller amount of control information is exchanged which reduces the overhead on the network. In high load conditions, PRS-LD is producing 49% less overhead as compared to improved routing protocol but when number of nodes were less (i.e., 50) PRS-LD performed at least place as compared to all the three-routing protocol in terms of overhead.

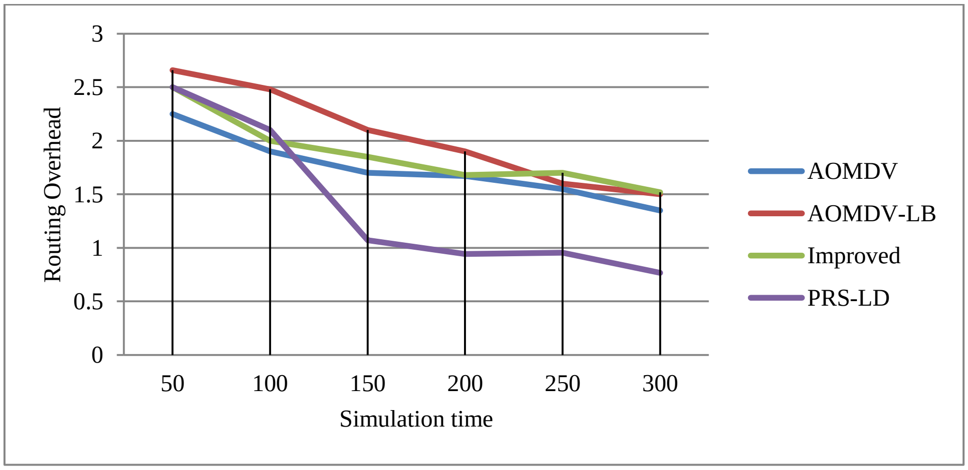

Figure 13 Routing overhead for 100 nodes and 20 connections

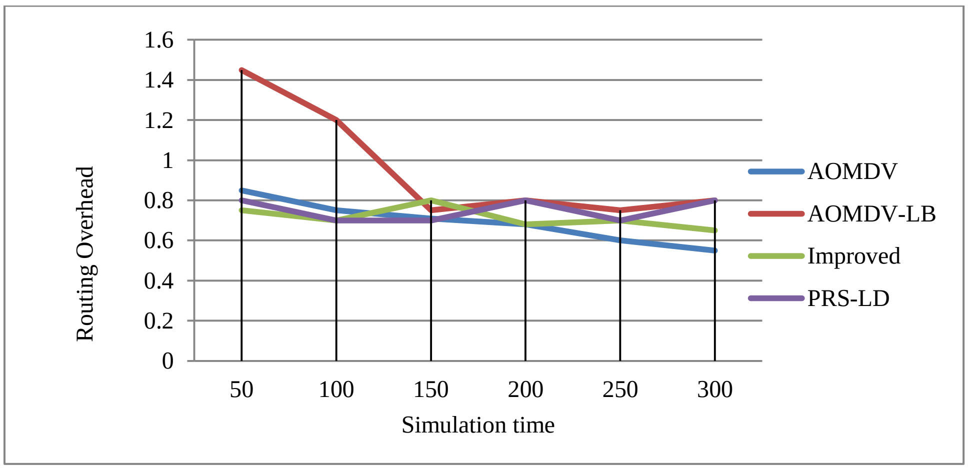

Figure 14 Routing overhead for 50 nodes and 20 connections

4.5Number of energy-exhausted nodes

For an efficient working protocol, the number of energy-exhausted nodes should be less while performing routing. Energy consumption of the network increases with simulation time since it increases the number of exhausted nodes of the network. It can be observed from *Figure15* and *Figure16* that there is an increase in the number of exhausted nodes with simulation time for 50 nodes & 20 connections and 100 nodes & 20 connections, respectively. Both AOMDV and AOMDV-LB perform nearly the same with little difference in the number of exhausted nodes, as AOMDV depends upon the least arrival time of RREPs for path selection and AOMDV-LB selects the lower load nodes for packet transmission. Improved routing protocol performs better than both (i.e., AOMDV and AOMDV-LB) as it makes use of the residual energy factor of nodes for path selection. PRS-LD outperforms all the compared routing protocols due to the reason that the protocol focuses on energy usage while deciding the priority of obtaining paths. This results in the selection of a path that is having higher stability in terms of energy. This will further help in reducing overhead and route discovery frequency, which can be caused due to route failure if a node gets exhausted in between the communication process. Here, in low and high-load scenarios PRS-

LD is producing a smaller number of exhausted nodes as compared to all the other routing protocols. The performance of PRS-LD is 33% more than improved routing protocol.

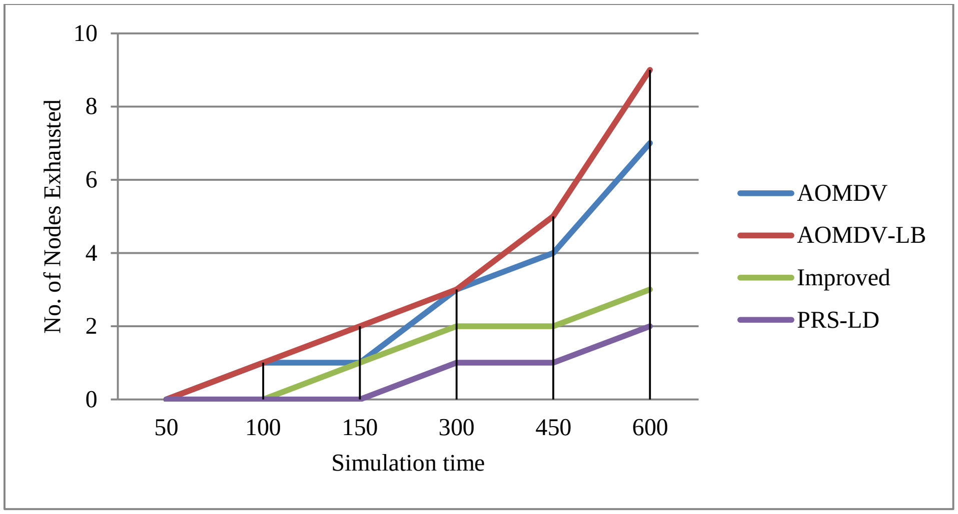

Figure 15 No. Of Nodes Exhausted for 50 nodes and 20 connections

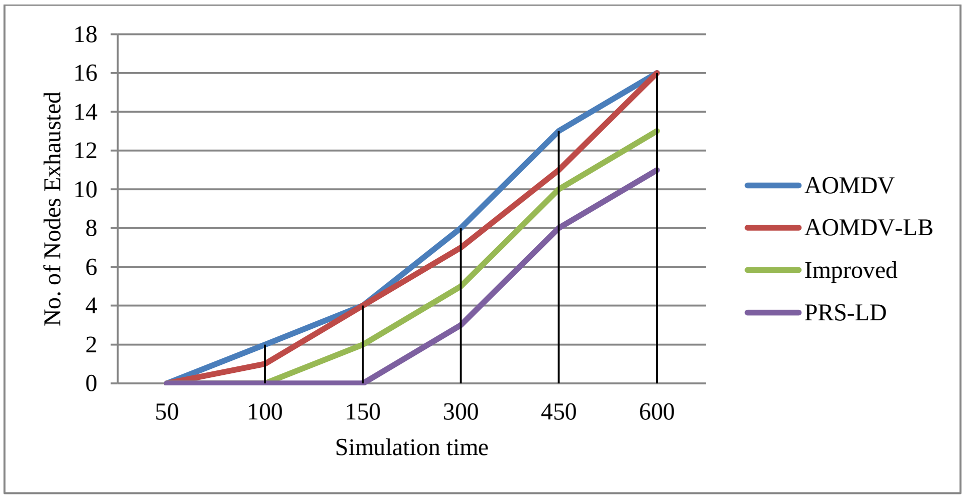

Figure 16 No. Of Nodes exhausted for 100 nodes and 20 connections

The concept of the PRS-LD protocol is mainly aimed at improving the energy state of the network. Thus, the nodes along discovered routes must have sufficient energy to cope with the future energy requirements for data transmission in the network. PRS-LD ranks the routes according to the value of PV, which is calculated using the CE, Max_E, and Min_E values of the nodes. The priorities of routes are decided dynamically according to the current energy state of the network. This helps in preventing the use of obsolete routes. This further result in improvement in packet dropping issues and also improves the throughput of networks. In this way, PRS-LD tries to predict the energy state of the network and routes the packet along different paths according to their current energy states. The Energy sufficient routes will reduce end-to-end delay, no. Of exhausted nodes, and packet drop rate caused due to link breakage or route failure. Further rank selection technique is being used for load distribution among different discovered paths. It helps in dealing with overloading and congestion along the selected routes. This also helps in reducing the total energy consumption of the network. The combined concept of priority and rank selection in PRS-LD successfully reduces delay and packet drop rate i.e., helpful in achieving high throughput with efficient energy utilization of nodes of the network. Thus, it employs load balancing by giving due consideration to the energy state of the network.

5.Discussions

The results of PRS-LD for end-to-end delay show a consistent reduction with an increase in simulation time. It can be seen from *Figure 9*, where 100 nodes with 10 connections have delays of 0.017s over the simulation period of 50 s, whereas for simulation time of 300 second the delays have reduced to 0.013 s. Similarly for 100 nodes and 20 connections, as can be seen from *Figure 10,* delay corresponding to simulation time of 50 s is 0.035 s and for simulation time of 300 s delay is 0.019 s.

From *Figure 11* and *Figure 12* it can be observed that to increase in simulation time, route discovery frequency is decreasing in case of PRS-LD, hence proving the effectiveness of protocol in controlling the need for route rediscoveries. For 100 nodes with 10 connections, at 50 s routes discovery frequency is 0.14 whereas for simulation time of300 s, it is 0.06 for PRS-LD. Similarly, for 100 nodes with 20 connections, for simulation time of 50 s route discovery frequencies is 0.30 for PRS-LD whereas for simulation time of 300 s, it is 0.1.

PRS-LD also succeeds in controlling the overhead of networks, which considerably remains constant with an increase in simulation time in case of small networks. However, with an increase in the size of the network the PRS-LD shows a much better control over the routing overhead. As can be seen from *Figure 13*, for 50 nodes with 20 connections, for simulation time of 50 s, 250 s and 300 s values of routing overhead are 0.8, 0.7, and 0.8 respectively for PRS-LD. Whereas, as can be seen from *Figure 14*, for 100 nodes with 20 connections, for simulation time of 50 s, 250 s and 300 s values of routing overhead are 2.5, 0.956 and 0.767 respectively for PRS-LD.

Figure 15 and *Figure 16* also prove the effectiveness of PRS-LD in terms of number of exhausted nodes. For 50 nodes with 20 connections, for simulation time of 50 s, 300 s and 600 s number of exhausted nodes are 0, 1and 2 respectively for PRS-LD. For 100 nodes with 20 connections, for simulation time of 50 s, 300 s and 600 s number of exhausted nodes are 0, 3 and 11 respectively for PRS-LD.

A complete list of abbreviations is shown in *Appendix I.*

6.Conclusion and future work

The MPRDM has been further extended by adding the concept of load balancing. The proposed PRS-LD protocol uses MPRDM in the first phase (the route discovery phase) of the algorithm, whereas in the second phase (the load distribution phase), it uses the rank-based selection approach for distributing the proportionate number of packets on the different available generated paths. The concept of prioritization based on CE, Max_E, and Min_E value obtained along the paths with the rank selection effectively distributes the data packets among the different obtained routes. Further, the proposed protocol has been implemented and simulated on NS-2.35 and its performance has been evaluated by considering various performance metrics such as average end-to-end delay, route discovery frequency, routing overhead, and several energy-exhausted nodes. Results analysis proved the effectiveness of PRS-LD in high load conditions, as the protocol reduces average end-to-end delay by simultaneously conserving a greater number of energy nodes in high load scenarios. Although alternate routes are available for the transmission of data packets, a novel route repair approach can be constructed to repair the failed route. With a view to extend the work in the future, rather than carrying out route discovery again, some mechanism should be developed so that the route can be repaired at the point of disconnection, which can further help in reducing the energy requirement of the network.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Author’s contribution statement

Swati Atri: Conceptualization, methodology, software, data curation, writing-original draft preparation, visualization, investigation, validation. **Sanjay Tyagi:** Supervision, validation, writing- reviewing and editing.

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Appendix I

S. No.	Abbreviations	Description
1	5G	Fifth Generation
2	ACK	Acknowledgment
3	AODV	Ad Hoc On-Demand Distance Vector
4	AOMDV	Ad Hoc On-Demand Multipath Distance Vector
5	AOMDV-LB	Ad Hoc On-Demand Multipath Distance Vector Load Balancing
6	CBMLB	Channel Busyness-Based Multipath Load Balancing
7	CBR	Case-Based Reasoning
8	CE	Cumulative Energy
9	CMMBCR	Conditional Max Min Battery Capacity Routing
10	DHSSRP	Dynamic Hop Selection Static Routing Protocol
11	DN	Destination Node
12	DSDV	Destination Sequenced Distance Vector
13	DSR	Dynamic Source Routing
14	EMA-MPR	Energy and Mobility Aware multi-Path Routing
15	IE	Idle Energy
16	IN	Intermediate Node
17	IoT	Internet of Things
18	IP	Internet Protocol
19	L2RMR	Lightweight Load Balancing And Route Minimizing Solution for RPL
20	LBAOMDV	Load Balanced Ad Hoc On-Demand Multipath Distance Vector
21	LBAR	Load-Balanced Ad Hoc Routing
22	LBMMRE-AOMDV	Load Balanced Maximal Minimal Residual Energy Ad Hoc On-Demand Multipath Distance Vector
23	LB-OPAR	Load-Balanced Optimized Predictive and Adaptive Routing
24	LCM	Least Common Multiple
25	MANETs	Mobile Ad Hoc Networks
26	MAX_E	Maximum Energy
27	MBMA	Multipath Battery and Mobility- Aware Routing Scheme
28	MIN_E	Minimum Energy
29	MLB	Multipath Load Balancing
30	MP-DSR	Multi-Path Dynamic Source Routing
31	MPRDM	Multipath Priority-Based Route Discovery Mechanism
32	NC	Node Cardinality
33	NCLBR	Node Centric Load Balancing Routing
34	NS	Network Simulator
35	OPAOMDV-EE	Optimized Priority based Ad Hoc On-Demand Multipath Distance Vector Energy Efficient
36	PDR	Packet Delivery Ratio
37	PRMR	Path Reservation Multipath Routing
38	PRS-LD	Priority-Based Rank Selection Load Distribution
39	PV	Priority Value
40	QoS	Quality of Service
41	RERR	Route Error
42	Rp	Rank Probability
43	RREP	Route Reply
44	RREQ	Route Request
45	RxE	Receiving Energy
46	SN	Source Node
47	TA-LAOMDV	Traffic -Aware Load Balancing in AOMDV for Mobile Ad-Hoc Networks
48	TER	Trust-based Efficient Energy Balanced Less Loss Routing
49	TxE	Transmission Energy
50	UAV	Unmanned Aerial Vehicles
51	WMNs	Wireless Mobile Networks
52	WSNs	Wireless Sensors Networks