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Original Article

Path Indexed Energy Efficient MANET Routing Protocol (PiEER)

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Abstract - *Mobile ad hoc networks are a promising branch of network technology. The modern world is highly dependent on ad hoc networks for their flexibility, extensibility, and adaptability, and thus MANET is used in almost all modern devices. Much research is being carried out worldwide to maximize the performance of MANET in terms of routing, energy utilization, bandwidth utilization, mobility management, and so on. Researchers are trying to remodel the MANET by adjusting the above factors to an ideal nature. One major challenge MANET faces is managing power and saving it through optimization. In this paper, an energy-efficient routing protocol is used for data transfer. This method uses Path Indexed Energy Conserving Routing in MANET (PiEER). During the routing process, PiEER analyses the individual node energy, the outstanding energy of the path, distance, and recovery chances and ranks the different paths based on the statistics. Packets are transmitted over these paths based on the ranking. Since PiEER routing has energy balance data, more data is routed over healthy routes, and less data is routed over weaker paths to balance the overall data transmission.*

Keywords - *Energy management, Energy optimization, MANET, Packet routing, Route recovery.*

1. Introduction

The scope of computer networks is expanding day by day. The growth of network technology has enabled and opened up many advanced fields of science. There are a variety of networks, of which MANETs are considered the most flexible and scalable. We cannot imagine any modern device without wireless access. Society today demands enormous networking capabilities, so researchers are trying to add more services.

The growth of MANET is not a flash in the pan. Much research has been done in this area to maximize performance. The various constraining factors of MANET are mobility, routing, joining and retreating on demand, self-powered energy [1], and bandwidth [2]. Therefore, researchers have focused on these areas to improve the current situation. Mobility is such an unpredictable factor in MANET, as it depends solely on the situation of the node.

Mobility can adversely affect node and path energy as well as routing. Therefore, researchers keep trying to develop routing algorithms with predictions to improve the performance of MANET[3, 4]. The additional factors are more manageable with improved optimizations. We present a new energy-conserving routing protocol (PiEER) that generates a network energy plan by analyzing the node energy, the outstanding energy of the path, and the number of hopes. The collected information forms a hierarchy of data transmission paths. Data is transmitted over the ranked paths, and since the ranking is based on several parameters, the overall state of a path is maintained by sending more traffic over the best path and loading the remaining paths with the remaining data.

2. Related Works

This segment will discuss the recent research on optimizations on MANET based on power usage. Firstly, we will discuss Power Efficient Reliable Routing Protocol (PERRA) [5]. This algorithm aims to find the energy required to send, receive, and process a packet. It also identifies the path stability of the network, and the route selection is made accordingly. The second algorithm on the focus is c, which is called link-stability and energy-aware routing protocol (LAER)[6], which determines two factors such as link steadiness and least energy gutter rate. The link steadiness metrics are valued using the historical links and the prediction based on whether the links are alive. The routing path is selected based on the lowest energy gutter rate and link steadiness metrics. The third algorithm is grounded on energy thresholds and coefficients, known as Adhoc on-demand multipath routing with lifetime maximization (AOMR-LM) [7]. This algorithm optimizes energy usage using the parameters mentioned above. The energy-conserving OLSR routing protocol (EE-OLSR) [8] is a routing system dependent on the energy readiness function. Each node will publish its readiness to act as a relay station based on its outstanding energy and from which the data paths are formulated.

Another approach is Minimum Total Transmission Power Routing (MTPR) [9], which estimates the energy required to send a packet. In this approach, a node's outstanding energy is not considered. Minimum Battery Cost Routing (MBCR) determines the battery-cost function, which assumes that, at minimum, the BCF is better for data transmission. Min-Max Battery Cost Routing (MMBCR) [10] algorithm will focus on the weakest node in a path. Conditional MMBCR (CMMBCR) is a mixed tactic where a threshold is set, and it assumes that if all devices in a route have energy more significant than the threshold, it is an excellent path to transfer the data. Collision-constrained minimum energy node disjoints multipath routing algorithm for ad hoc networks (ECCA) [11] is built on the principle that it is always better to avoid collisions to maintain good network health. The multipath routing protocol (MEER) [12] is also based on collision avoidance.

The above methods provide fantastic energy savings based on many criteria, such as remaining energy transmission power, path energy, connection constancy, battery coefficient, etc. However, most failed to produce improved results because they did not consider identifying steady paths based on energy and distance. The suggested strategy, which maps the traffic following the networks' overall energy equilibrium, is an alternative to the current approaches.

3. Energy Metrics

3.1. Node Energy

Let us assume a graph that is represented as Ĝ=(Ų, Ɛ) where Ų contains the nodes, and Ɛ is the total edges in the graph. Every node can transfer, accept, and process data packets. A node's routing table is updated with the presence of its neighbouring nodes during the route detection process. During routing, when a node receives a packet, it will be processed if it is destined for that node, else the packet will be sent according to the routing table. To do all this work, nodes need to consume their energy. Each node must log the energy consumption and remaining energy [13] during the routing process.

Let the amperage (Amp) be α, voltage be ν, and T be the time required to transfer or accept a packet. Then the energy ȄTR needed to send or receive a packet is

$$ȄTR = \alpha * \nu * T \quad (1)$$

The energy essential to transfer a packet from the origin s to a target d is the sum of the total energy required for transmission and the total energy needed for receiving the packet at d.

Let Ȅtran(p) be the energy mandatory to transfer a packet from the origin s, ERec(p) is the energy needed to receive packet p at destination d, and ȄProc(p) is the energy compulsory to process a packet at a node, then the whole energy used for packet transmission is

$$ȄCons(p) = Ȅ Trans(p) + Ȅ Rec(p) + Ȅ Proc(p) \quad (2)$$

Let ȄToT represent the entire node energy. The outstanding energy of a node after the packet exchange is estimated as

$$Ȅ RES = Ȅ ToT - Ȅ Cons(p)\ Joules \quad (3)$$

With each transmission, the ȄToT decreases by the summation of the energy needed to transmit all the data. Thus, the remaining energy of a node can be signified as follows.

$$Ȅ Resi = Ȅ ToT - \sum_{j=1}^{n} Ȅ Cons(Pj) \quad (4)$$

Where j varies from 1 to n, which is the packet count.

3.2. Energy of a Path

This sector refers to the mathematical design of the entire energy, depletion, and outstanding path energy from an origin s and terminating at a target d.

Let (Pn) be the overall energy of all nodes on a path from s to d, and let EPCons be the entire energy consumed by nodes in transferring a packet along the same route. The outstanding energy of this path is as follows.

$$Ȅ PRES = (Pn) - Ȅ PCons \quad (5)$$

Which can be split as

$$Ȅ P_{RES} = (P_n) - \sum_{k=1}^{n} ȄPCons \quad (6)$$

This shows that the outstanding path energy is contingent on the quantity of energy spent to transfer, accept, and process packets.

4. Path Metrics

Let us assume that the shortest path from s to d can be represented as $Psp(s,d)$, and the set of all paths from the origin to the terminus node[14] is $\rho sp\{s,d\}$ where $Psp(s,d)€ \rho sp\{s,d\}$, and packet flow from s to d is $f(s,d)$,

Then the summation of all streams from s to d through the set of shortest paths can be given as

$$fToT = \sum_{i=1}^{n} Fi \tag{7}$$

Where n is the shortest path in $\{s,\}$.

The flow intensity across a path is the most critical parameter to consider when evaluating the energy consumption of a node. As the flow rate increases, the energy consumption also increases. Thus, the remaining energy is directly related to the flow rate across the path.

$$EPRES = ((Pi)=i*fi\ ) \tag{8}$$

To optimize energy consumption [15], the flow of packets across the different paths must be regulated so that there is no node exhaustion due to energy exhaustion in a normal path.

4.1. Path Assortment Metrics

After the energy investigation is finished, it is crucial to consider choosing and categorizing the best method for data exchange. The path with the highest energy in most earlier efforts founded on energy-conserving routing is overloaded with the most data transmission. However, this results in an issue with network segmentation and uneven energy use in MANET. Other studies concentrate on categorizing pathways according to energy coefficients [16]. The data is transmitted based on the various classes. There are several classes for the pathways, but the coefficients selected are constrained. However, this results in an issue with network segmentation and uneven energy use in MANET. Other studies concentrate on categorizing pathways according to energy coefficients. The data is transmitted based on the various classes. There are several classes for the pathways, but the coefficients selected are constrained.

The suggested method uses a different technique for classifying and choosing a path based on energy-based path coagulation. Calculating the total node energy, the remaining node energy, the total energy of the path, the recovery paths accessible in the event of a route failure, and the outstanding energy of the path forms the basis of this method. During route discovery, the origin node gathers the data mentioned above. The source conducts indexing for each path based on the number of hopes, the path's feeblest node, the amount of energy still available, the amount of energy needed to send the packet, and the number of alternative routing paths. This is how the indexing is carried out.

Consider the below MANET scenario in Figure 1. Data is transferred from Source S to Terminus D. Eight paths are identified in the route detection procedure. In Table 1, Source S has the information mentioned above after the route-finding process. With this knowledge, the source starts indexing each path at various levels according to criteria.

- Energy
- Fast Recovery
- Distance

4.2. First Level: Indexing Based on Energy Metrics

This level of indexing has excellent significance because node energy is the parameter to be evaluated. Each path in a routing process from origin S to terminus D is evaluated based on the presence of nodes with the weakest energy. If a path contains more than one weakest node, then there is a high chance that network partitioning [17] can occur. So the first level of indexing is based on the principle of 'Survival of the Fittest'. So in the above table, path P3, P4, P7, and P8 will be eliminated from the routing process. After the first level of indexing, the path table (Table 2) is as follows.

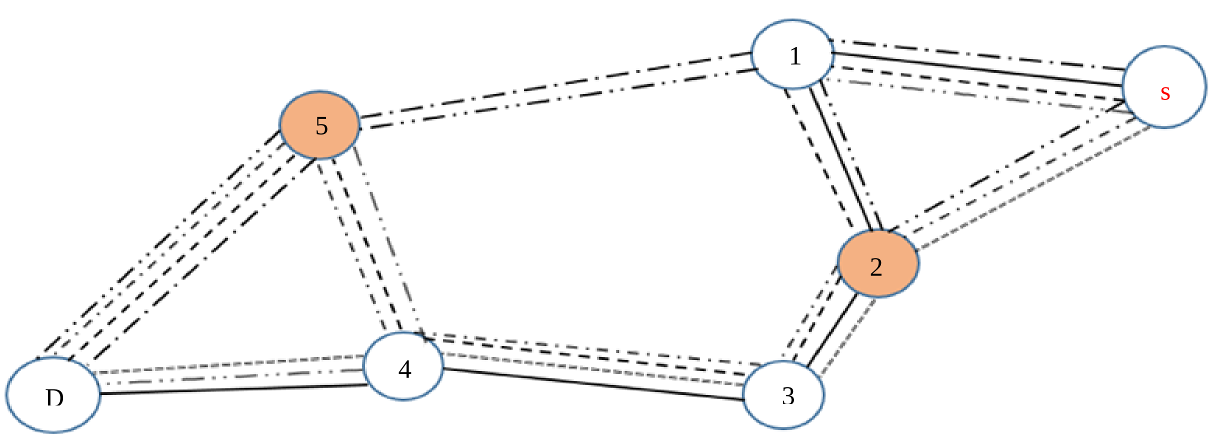

Fig. 1 MANET topology has seven nodes where S is the source, D is the destination, and nodes 2 and 5 have the weakest energy

Table 1. Identified paths

Path No	Hope Count	Intermediate Node	Next Hope	Feeblest Node (Energy)
Path1	4	1-2-3-4	1	2
Path2	3	2-3-4	2	2
Path3	5	1-2-3-4-5	1	2,5
Path4	4	2-3-4-5	2	2,5
Path5	2	1-5	1	5
Path6	3	1-5-4	1	5
Path7	3	2-1-5	2	2,5
Path8	4	2-1-5-4	4	2,5

Table 2. First level-energy-based indexing result

Path No	Hope Count	Intermediate Node	Next Hope	Feeblest Node (Energy)
Path1	4	1-2-3-4	1	2
Path2	3	2-3-4	2	2
Path5	2	1-5	1	5
Path6	3	1-5-4	1	5

Table 3. First level-recovery-based indexing

Path No	Hope Count	Intermediate Node	Next Hope	Feeblest Node (Energy)
Path1	4	1-2-3-4	1	2
Path2	3	2-3-4	2	2
Path6	3	1-5-4	1	5
Path5	2	1-5	1	5

Table 4. Path Comparison between path 1 & path 2

Parameter	Path1	Path2	Optimum path
Feeblest node energy	Low	Low	Path2
Path outstanding energy	Medium	Medium	
Distance	High	Medium	
Recovery	High	Medium	

Table 5. Path comparison between path 1 & path 5

Parameter	Path1	Path5	Optimum path
Feeblest node energy	Low	Medium	Path1
Path outstanding energy	Medium	Medium	
Distance	High	Low	
Recovery	High	High	

5. First Level: Indexing Based on Recovery

This level of indexing is a failsafe classification, where paths with a high possibility of rerouting in case of route failure are iterated and ranked.

For example, Path Nos -Path1, Path2, Path5, Path5, Path6, the rerouting can be done quickly because many alternate paths are available. So after recovery-based indexing, the path table becomes. Table 3 shows the indexing result.

6. First Level: Indexing-Based Distance

This indexing will look for paths with minimum distance. So based on the criteria, the paths are ranked and shown in Table 4.

7. Second-Level Path Comparison and Ranking

This is the second level of indexing, where the paths are compared and ranked based on the merit of participating in routing. Table 4 to 9 shows the path comparison tables.

Table 6. Path comparison between path 1 & path 6

Parameter	Path1	Path6	Optimum path
Feeblest node energy	Low	Low	Path1
Path outstanding energy	Medium	Medium	
Distance	High	Medium	
Recovery	High	Medium	

Table 7. Path comparison between path 2 & path 5

Parameter	Path2	Path5	Optimum path
Feeblest node energy	Low	Medium	Path2
Path outstanding energy	Medium	Medium	
Distance	Medium	Low	
Recovery	Medium	High	

Table 8. Path comparison between path 2 & path 6

Parameter	Path2	Path6	Optimum path
Feeblest node energy	Low	Low	Path2 or Path6
Path outstanding energy	Medium	Medium	
Distance	Medium	Medium	
Recovery	Medium	Medium	

Table 9. Path comparison between path 5 & path 6

Parameter	Path5	Path6	Optimum path
Feeblest node energy	Medium	Low	Path5
Path outstanding energy	Medium	Medium	
Distance	Low	Medium	
Recovery	High	Medium	

8. Third level: Optimal Path Occurrence Count

Based on the calculations mentioned above, the third indexing stage begins. The optimal path is chosen in this stage by finding paths that have already been chosen as the optimal path [18] several times and ranking them from the first stage. The sequence of occurrence is as follows. Table 10 shows the third level indexing, and the final indexing table is as follows (Table 11).

Table 10. Third level indexing

Path	Occurrence Count
Path1	2
Path2	2
Path5	1
Path6	1

Table 11. Path rank

Rank	Path
1	Path1 or path2
2	Path5 or path6

9. Algorithm PiEER

1. All nodes should send a hello packet to their neighbours to inform them of their position, available energy, and rate of energy consumption.2.Every node should build its routing database based on distance after receiving such "hello" packets.
2. A Routereq packet initiates data routing from an origin to a terminus.
3. If a Routereq packet arrives at a node that is not the intended recipient, it forwards it to the next hopeful node.
4. The destination waits for all subsequent Routereq packets to arrive once it gets a Routereq packet.
5. The destination prepares a Routereply packet and transmits it in the opposite direction after all Routereq packets have arrived.
6. If a node is not the source and receives the Routereply packet, it will add its remaining energy and outflow rate and forward it in the reverse direction.
7. The source begins indexing the paths based on the energy of the feeblest node, recovery rerouting chance, the distance, and the energy needed for transmission once it has received all of the router-reply packets.

10. Simulation Results

In NS2, the PiEER routing protocol is simulated. The following criteria are used to evaluate how well the protocol performs. Table 12 shows the list of parameters.

Table 12. Parameters

#	Parameter	Value
A	Area	870 m^2
B	Number of nodes	90
C	Maximum Node Speed(meter/second)	20 meter/second
D	Total Simulation Time	550 seconds
E	Traffic Type	Constant Bit Rate (C B R)
F	Size of a Packet	512 bytes
G	Power of Transmission	1.4 W
H	Reception Power	1.2 W
I	Source/Origin Nodes	22,56,88,90
J	Traffic start time	9^{th} Second
K	Traffic end time	550^{th} Second
L	Mobility Type	Random

Trace data was analyzed, and the results were compared with the existing methods.

1. Packet Delivery Ratio (PDR) [19, 20]
2. Normalized Control overhead [21]
3. Average Energy Consumption
4. Average Node Residual Energy

Protocols such as LAER, PERRA, and EGPSR, MSPIEC are compared with PiEER routing protocol performance in several ways. The primary parameters utilized in the comparison are node movement [22], packet delivery ratio, normalized control overhead, energy usage, and gutter rate.

10.1. Average Node Residual Energy

If energy usage is optimized and kept to a minimum, MANET's outstanding energy would be high; otherwise, node power would quickly run out. Calculating and comparing the average outstanding energy of the nodes with the LAER, PERRA, MSPIEC, and EGPSR algorithms revealed that PiEER had the highest average node residual energy[23].

The path selection strategy used in the suggested method results in high energy optimization. The outstanding energy is usually kept and used to its full potential when the data traffic flow load is stable and spread among several pathways based on energy fitness. Figure 2 shows the performance comparison between PiEER and other existing algorithms based on average residual energy.

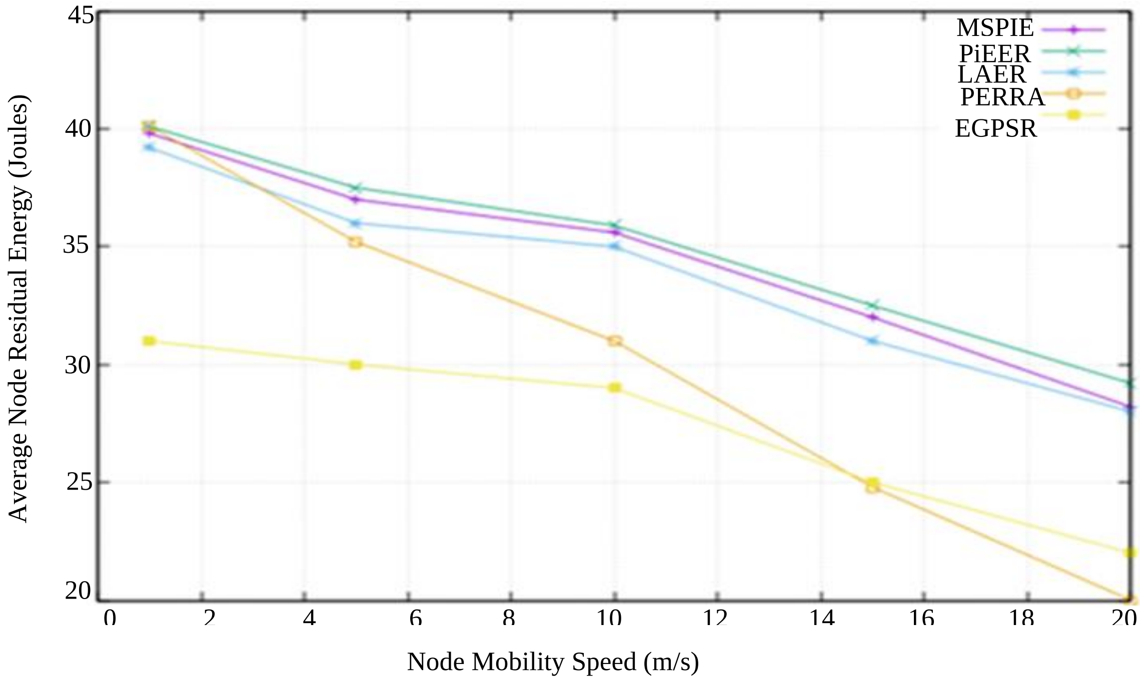

Fig. 2 Average residual energy vs Node mobility speed

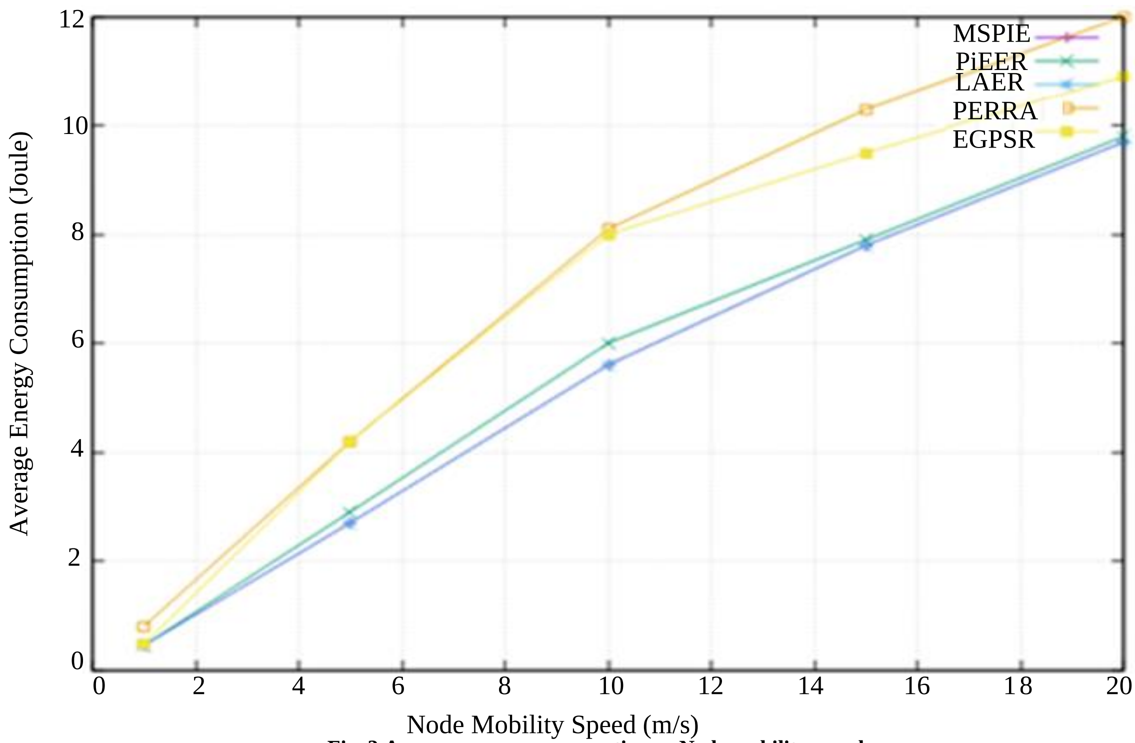

Fig. 3 Average energy consumption vs Node mobility speed

10.2. Average Energy Consumption

Data transfer, route maintenance, and route finding all consider energy usage. The investigation demonstrates that the PiEER routing protocol uses the least energy compared to the MSPIEC, EGPSR, LAER, and PERRA algorithms regarding average energy intake. This is a result of the multi-level indexing method used in path selection. As the route detection procedure is ongoing, there is significant traffic flows over healthy channels; average and slight traffic is spread over modest and low energy paths.

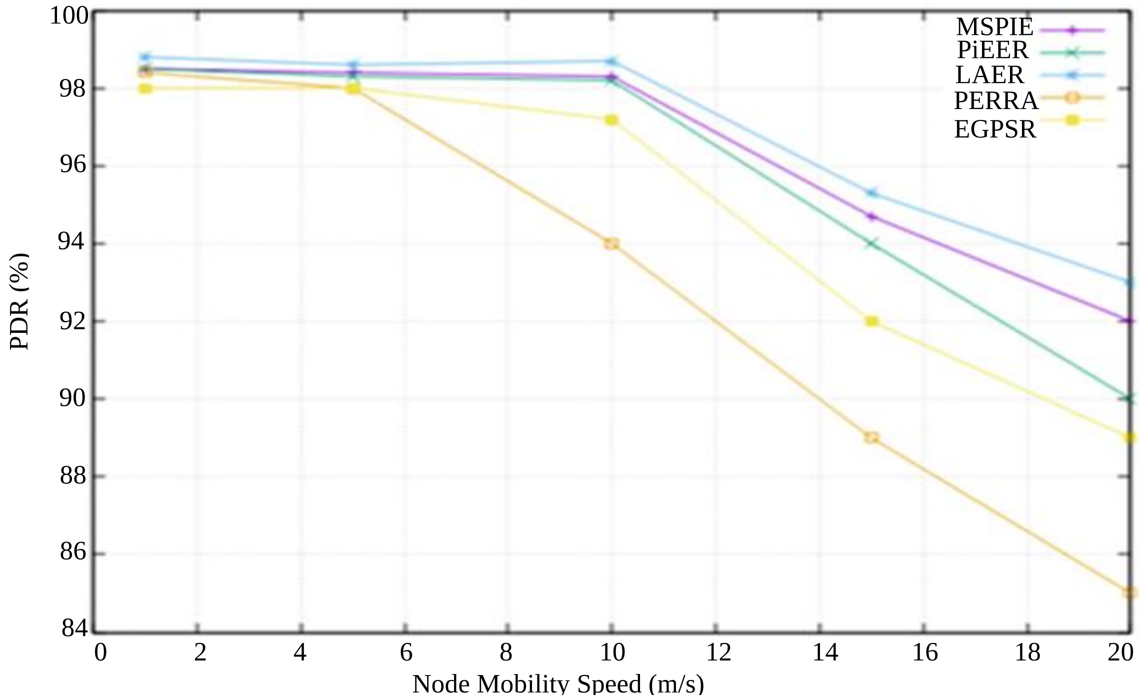

Fig. 4 Packet delivery ratio vs Node mobility speed

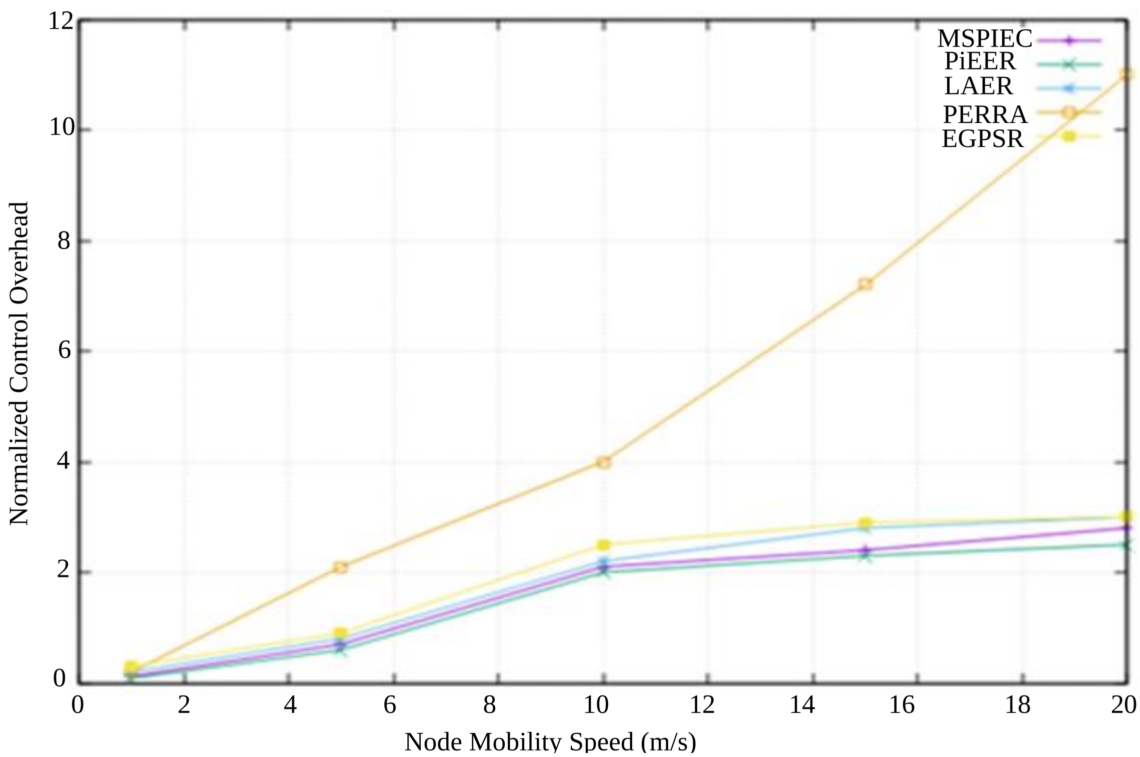

Fig. 5 Normalized control overhead vs Node mobility speed

Various detected paths are classed and indexed based on energy. As a result, the model's average energy consumption is low compared to other models. Figure 3 shows the performance comparison based on Average Energy Consumption between PiEER and other algorithms.

10.3. Packet Delivery Ratio

The PDR of protocols such as MSPIEC, EGPSR, LAER, PERRA, and PiEER are compared based on accelerating node movement speed. Node speeds range from 1 to 20 m/s. According to the research, the PDR is most significant while the node displacement speed is at its lowest and diminishes as the speed rises. Path breaks [24] may occur frequently as speed increases, which is one of the leading causes of this poor PDR. The suggested approach offers the best PDR at slower speeds than previous approaches. However, the PDR tends to be low along with the speed, but the approach still performs on par with others. Figure 4 shows the performance of PiEER and other algorithms based on PDR.

10.4. Normalized Control Overhead

The amount of control information [25] that must be formed, shared, and used by the nodes for route detection, route management, and data interchange [26] is referred to as control overhead. Due to mobility [27] and power outages, highly dynamic environments like MANET frequently experience path loss [28] and network partition. The excess grows as the data transfer progresses.

The emphasis in our method is on energy optimization, and node mobility is unpredictably distributed. The model makes an effort to maintain energy and hence link stability. Therefore, control overhead is significantly lower than current methods like EGPSR, LAER, and PERRA. Figure 5 shows the performance analysis of PiEER and other algorithms based on normalized control overhead.

11. Conclusion

Since MANET has numerous application domains in the real world, its performance must be enhanced to address numerous technological issues. The majority of routing algorithms just use distance as their primary routing metric. This makes it difficult to build solid pathways. The energy metric was only used as a routing parameter by a select few algorithms, and they were successful in executing routing via reliable routing paths. However, the mainstream algorithms failed to disseminate traffic across various routes. Using a different method, the Path Indexed Energy Efficient Routing algorithm adds indexing to the paths found based on the path's feeblest energy node, path outstanding energy, distance, and energy needed to carriage the data. Modest and mild data traffic will be allocated to the remaining paths, while the fit and robust paths will be employed to transfer the highest amount of data based on the hierarchy rank. Fewer path breakdowns due to power exhaustion will result from this strategy's superior energy consumption and preservation of residual energy.

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