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Research Article

Delay-Driven Opportunistic Routing with Multichannel Cooperative Neighbor Discovery for Industry 4.0 Wireless Networks Based on Power and Load Awareness

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During data transmission, a decentralised Mobile Ad Hoc Network (MANET) might result in high Energy Consumption (EC) and a short Network Lifetime (NLife). To address these difficulties, an on-demand Power and Load-Aware multipath node-disjoint source routing is presented based on the Enhanced Opportunistic Routing (PLAEOR) protocol. This unique protocol aims at using power, load, and latency to manage routing costs depending on control packet flooding from the destination node. However, the exchange of control packets from the target to all nodes may impact network efficiency. As a result, the PLAEOR is designed with a Multichannel Cooperative Neighbor Discovery (MCND) protocol to locate the nearby cooperative nodes for each node in the routing path during control packet transmission. Furthermore, when the packet rate of CBR is 20 packets/sec, the simulated results show that the PLAEOR-MCND achieves 120 sec of NLife and 20 J of EC than the state-of-the-art protocols.

1. Introduction

MANETs are one of the wireless networks and have numerous mobile nodes for wireless communication. All mobile nodes are routers as well as hosts. It also uses peer-to-peer information exchange via multiple hops. Bandwidth and energy constraints and cooperation and complex topology are the key features of these networks. These networks can be used for various applications, including tactical communication, defense, and disaster management. However, because of their dynamic behavior, these networks are more vulnerable to different attacks [1].

Nodes are generally limited to their energy resources, which are absorbed by the transmission of the intermediate nodes during a multihop transmission. Every node will rely on each node to send the data packets through routing protocols. Different ad hoc protocols have been suggested in recent decades to select routes with a reduced hop number or the optimal shortest route between the source and destination [2]. Such routing protocols are based on various concepts, such as reliability, scalability, facility of execution, sensitivity to failures, and complex topology control. In MANETs, all nodes can link dynamically to more routes from the origin to the target nodes in an arbitrary way.

Multipath routing is the term used to describe this technique. A backup option is often chosen when the primary link becomes disrupted during data transfer. This process leads to improved fault tolerance and path recovery. It can also balance the packet flow between the collections of disjointed routes.

Generally, the most aggregated resources and the highest level of fault tolerance are provided by disjoint routes, since there are no connections between nodes. Likewise, a multipath performs better than a unipath. Therefore, it is important to use an independent method for selecting routes depending on the nodes and routes' practical conditions. On the other hand, the overloaded node batteries trigger node or path collapses, which can decrease the node's lifespan. To increase network life, energy- and power-conscious, multipath routing strategies [3] have been developed with the help of Ad hoc On-demand Distance Vector (AODV) and DSR protocols which handle the routes among nodes. Most of the routing strategies are based on DSR as a small-size network routing approach compared to the AODV protocol, because DSR operates more efficiently than AODV, so DSR is better suited [4].

Restricted Boltzmann Machine (RBM) is an Artificial Neural Network (ANN) with particle swarm optimization technique, which can learn the distribution of the probability across a number of inputs. The distribution utilized is the conditional distribution of probability given (i) the inputs on the visible layer and the likelihood of a hidden layer and (ii) the probability of a visible 55 layer in hidden layer. The ANN is extensively used in fields such as reduction of dimensionality, characteristic education, classification, collaborative filtering, and topic modelling. RBM restricts intralayer connections and results in efficient training and quicker learning compared to other algorithms. RBM is composed of two components, the unit visible and the unit concealed. The input features are taught for further processing in the visible layer and buried layer procedures. For connections between biased-weight units, RBM has binary-valued visible and hidden units with a weight matrix. The weight matrix depends on the network's dynamic behavior. The hidden layer is a softmax classifier, which classifies network traffic according to the target class. RBM supports discrete as well as continuously valued target classes.

Zhen and Juan [5] proposed an energy and delay-aware routing approach depending on the DSR (DSR-ED) protocol. In the DSR-ED, the path was decided by the remaining power and the overall transfer energy usage. The residue power was split into three categories: the ordinary, the heated, and the dangerous. During the path discovery process, the source node checked the residual energy of the available routes to ensure that they were still viable. The route from the point of origin to the point of destination was picked based on the residual power. The node's lifespan, on the other hand, was significantly reduced. So, Ali et al. [6] proposed an on-demand PLA-DSR protocol to decrease the node's power dissipation and the number of route discovery processes. In this protocol, a new cost factor was introduced to obtain multiple node-disjoint optimum routes based on the power and load of each node. Conversely, the DSR was the deterministic routing technique that impacted the reliable unicast transmission and control overhead under dynamic MANET circumstances.

Therefore, in this article, the PLAEOR protocol is proposed which utilizes the gradient forwarding strategy. In this newly proposed protocol, the source only forwards the data and the target chooses the best route for routing. The major goal of this PLAEOR protocol is to consider the power, load, and delay for measuring and managing the routing cost according to the flooding of control packets from the target node. As well, it establishes reliable communication and less control overhead under dynamic MANET configurations. In contrast, the node's energy can also be wasted by transferring the control packets from the target to each node in the network. Hence, the PLAEOR-MCND protocol is designed to discover the cooperative adjacent nodes for all nodes in the routing path during the transmission of control packets from the destination to the source. As a result, the power usage of each node during routing is reduced, thus increasing the node's lifespan.

The remaining sections of the article are structured as follows: Section 2 provides the previous research associated with the PLA-based multipath routing in MANET. Section 3 explains the methodology of the PLAEOR and PLAEOR-MCND protocols briefly. Section 4 displays the efficiency of these protocols. Section 5 summarizes the entire paper and gives the future scope.

2. Literature Survey

The Maximal Spatial Disjoint Multipath (MSDM) routing strategy [7] was introduced to determine spatially separated and maximally disjointed paths. In order to avoid collisions, distinct packets were sent through spatially fragmented routes. However, the cost of discovery is relatively expensive. The Fibonacci Multipath Load Balancing (FMLB) protocol was developed [8] which selects routes with small hops and allocates a Fibonacci weight for packet exchange according to the number of hops for each selected route. But it depends only on the number of adjacent nodes.

Barbudhe et al. [9] suggested the node-disjoint multipath routing scheme to define the primary path between source and destination for data transmission. In this NDMP, when the route was compromised, information at intermediate nodes was discarded before the backup paths were chosen to avoid fraudulent activities. But, the Routing Overhead (RO) was high. To solve the challenge of k-disjoint path discovery in WSN, a dispersed method to discover disjoint routes was suggested [10]. Each node can communicate dumpy packets through 1-hop adjacent nodes, but no predefined message structures were available. Nonetheless, this protocol has a high average EC.

To improve network reliability and robustness, a twin node-disjoint path routing strategy [11] has been suggested which creates all available node-disjoint routes. But, the normalized routing load was high due to increasing node mobility. Arora [12] proposed a dynamic communication energy-aware multipath routing strategy to obtain node-disjoint routes. An adaptive choice of sufficient transfer power has been employed to avoid the maximum intrusion and unnecessary data produced by the control messages. However, the average End-to-End Delay (E2E-D) was high.

DDoS Assault Mitigation Mechanism begins with two stages of attack detection identification. SDN controls self-learn application plane cognitive metrics, and the user provides traffic flux functionality for detecting and mitigating traffic flow of DDoS attacks.

A residual power-based, trustworthy multicast routing method [13] has been designed which builds the multicast backbone to increase network strength depending on the node awareness and honest round. The trustworthy route measure was also determined to elect the most excellent route for data transfer. But it does not analyze the network efficiency under varying mobility. The power-aware on-demand multipath routing protocol [14] has been developed to select an optimal energy-aware node-disjoint multipath based on route selection, discovery, and maintenance. But the packet loss rate was high while increasing the node's mobility.

A Path Efficient AOMDV (PE-AOMDV) protocol [15] was designed which applies a novel threshold to constrain the number of communication paths passing through the node. For each new request, the threshold has been analyzed to check whether the highest number of links has been met or not. Conversely, the packet loss rate was not reduced. The power-effective load-aware routing scheme [16] has been designed to balance the load and power simultaneously. In this scheme, link estimation and training of load balancing were executed. But performance efficiency was not effective for increasing the number of nodes.

Das et al. [17] analyzed link and node-disjoint multipath routing for MANET. However, this analysis only considered the random waypoint mobility model, whereas other node mobility models were required to analyze the multipath AOMDV protocol. An Energy-Efficient Node-Disjoint Multipath Routing Protocol (E2NDjMRP) [18] was developed that uses the minimum hop count with an adaptive transfer rate to elect the major and minor routes. Also, the gap has been determined from the origin and target for modifying the node's transmitting energy. However, the power usage was still high. The energy-aware load balancing multipath routing scheme [19] has been designed to provide optimum power-effective route choice and powerful traffic sharing schemes. Also, load balancing was performed based on the nodes having the least residual energy for data transfer. But the RO was not analyzed.

A multipath power and mobility-aware routing method [20] has been developed which uses a multicriteria node rank measure to rank the link stability and decide the most effective and robust routes between source and target. Also, a power and mobility-aware multipoint relay choice has been applied to detect the node's compliance with flooding topological information. But the number of packets dropped was still high. A less ordinary multiple-based routing [21] has been designed, which finds multiple paths from the origin to the target. Also, the traffic among all the routes was maintained to reduce the route time. However, the average route time was still high [22].

Temporary connections between mobile nodes are not supported by infrastructure. Ad hoc routing protocols may be broadly classified into three types: table-driven protocols, on-demand protocols, and hybrid protocols [23]. Table-driven protocols are the most common kind. Table-driven protocols are fundamentally proactive in nature since each node keeps its routing table up to date by communicating periodic routing information with the others [24]. As a result, the time necessary to calculate a route is small since the path is already known before data packets are delivered, but a significant amount of network resources are required to keep the most up-to-date routing information [25]. Table-driven protocols include the destination-sequenced distance vector, the optimal link state routing, and the wireless routing protocol. On the other hand, because they are reactive in nature, on-demand methods are essentially reactive. When a route is discovered, nodes start the route discovery process. It is necessary [26]. As a result, the wait may become somewhat longer until a solution is found. The path has been determined and the source routing changes on the fly.

3. Proposed Methodology

This part describes the PLAEOR and PLAEOR-MCND protocols in brief. In particular, the earlier PLA-DSR was a deterministic routing scheme that frequently failed to obtain suitable paths under dynamic MANETs with high mobility of nodes. So, the PLAEOR protocol is presented using gradient forwarding to reduce the control overhead and achieve reliable transmission [27]. It employs power, load, and delay as the cost metrics for deciding the routing path. In this protocol, the source node only forwards the data, whereas the target node decides the best route for routing data. Furthermore, the MCND protocol is added in PLAEOR in order to locate the nearest cooperative node among all nodes in the routing path for the purpose of transmitting control messages from the destination to the source [28]. Figure 1 illustrates the process flow of the presented protocol.

3.1. Overview of PLA-DSR Protocol and Opportunistic Routing. When using the receiver-based auto-rate (RBAR), the carrier-sensing threshold is the same at all nodes, and a modulation scheme is automatically chosen on the basis of the received signal intensity by the receiver [29]. Due to the fact that onehop distance reduces when a route is set with numerous short-distance hops, the received signal strength at each node along the route grows stronger as the route lengthens. As a result, intermediate nodes along the path will be able to pick the modulation scheme that will support the greater data rates, and the total number of time slots utilized (a time slot is the smallest time period allotted to a node) throughout the whole network may be lowered [30].

As previously stated, the proposed routing algorithm is intended to minimize the number of time slots consumed across the entire network while simultaneously satisfying the time slots requirements at all pairs of adjacent nodes along the route as well as their contention neighbors in order

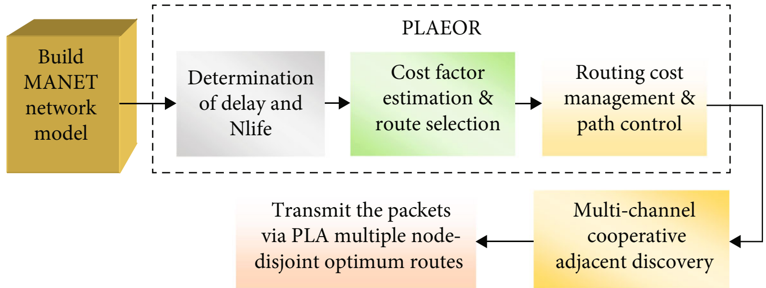

Figure 1: The process flow of presented multichannel multipath node-disjoint routing protocol in MANET.

to support the route [31]. The suggested routing method, instead of using hop count, latency, or transmission power as routing metrics, measures the ratio of the spent time slots to the total time slots as an indicator of performance. It is required to make an educated guess as to how many time slots will be available at each node during a predetermined monitoring period [32]. In order to establish a reliable route, which may need a significant quantity of control packet transmission on the network.

Instead of sending control packets, we regularly monitor the wireless channel and identify the busy time interval in which the received carrier signal strength is greater than the carrier-sensing threshold, therefore reducing the routing overhead and increasing the efficiency.

In the PLA-DSR protocol, a cost factor was measured depending on the node's expected lifetime for every node which contributes to the path-finding tasks. Based on this factor, the optimum routes are chosen [33]. This PLA-DSR depends on choosing many optimum paths from the origin to the target that ensure the trustworthiness of the paths and maximize the error acceptance. Origin often contains alternate routes to their targets, which minimizes the occurrence of commencing path-finding tasks, so power usage in path-finding tasks is decreased [34]. In the on-demand routing mechanism, the beginning of the path-finding task is taken if the origin requires transmitting data to a certain target and does not contain a cached path to it. So, power is reduced and the number of path-finding tasks is decreased by the multipath routing protocol with on-demand routing since, in many situations, the origin contains another optimum route to the required target [35].

Though creating many routes from source to target nodes, multiple routes can traverse certain or many ordinary nodes. Even if the data flow is partitioned among such routes, those ordinary nodes can run down rapidly since the data load on those nodes can be greater than other nodes on the routes. So, many path-finding tasks can be begun and additional resources can be used [36]. There is an increased risk of route collapse due to the increasing network dynamics, and these ordinary nodes may leave their 1-hop transfer area at any time. The node disjointness between two optimal routes may be determined for preventing this issue, i.e., 2 optimal routes with no shared nodes, omitting the source and target. It prevents the system from splitting the challenge and preserves additional energy [37].

This PLA-DSR protocol applies the reactive routing scheme depending on the DSR protocol. In DSR, if a source requests to transmit a packet to the target, it searches for its cached optimum PLA node-disjoint multiple routes to this target. The optimum routes are chosen at the target node to minimize the overhead [38]. When there is no accumulated route to its target, a path-finding task is begun via forwarding a Route Request (RREQ) message to its 1-hop adjacent. Then, transitional nodes retransmit the RREQ message awaiting the target to accept it. The target transmits a Route Reply (RREP) message via the reverse route of the RREQ message. Once transitional nodes accept the RREP message, all nodes generate a novel admission in their routing cache for this target. If the origin accepts the RREP message, the path-finding task is ended and data is transmitted [39].

On the other hand, the DSR protocol is a deterministic routing protocol where packets are transmitted via a fixed route towards their target. If the path is not collapsed, it can offer reliable and effective data delivery. But, the path quality in MANET is not static and frequently varies across periods, which reduces the routing efficiency [40]. Also, it may be affected by high control overhead when the path updates become recurrent because of high node mobility in MANET. It requires sophisticated methods to build and update many paths that incorporate considerable processing complexity in the MANET scenario [45].

3.2. Power and Load-Aware Enhanced Opportunistic Routing (PLAEOR) Protocol. To avoid the challenges of deterministic routing, i.e., PLA-DSR, this paper introduces PLA depending on opportunistic routing with gradient forwarding protocol which also adopts destination-side routing decision, i.e., the routing decision is determined by the target nodes. This opportunistic routing does not utilize a predetermined route for the E2E packet transfer. In this new PLAEOR protocol, a source simply transmits the data and the destination determines whether to transmit the data or not [45]. In order to maximize the reliability of data transport, nodes are designed to use several pathways. In this respect, a better routing cost factor is needed for a gradient broadcasting opportunistic routing which takes into account the route efficiency and is managed with a low RO.

3.2.1. Computation of Delay and Network Lifetime. Typically, the number of source nodes influences the trade-off between delay and transfer failure [41]. So, it is vital to choose source nodes to maximize the probability of opportunistic early packets. If there are many source nodes, then the delay is less in which the node could wait to accept the packet from the source [42]. However, considering multiple source nodes may increase the probability of transfer failure because paths among nodes are unreliable [43]. As a result, the nodes must have a specified path quality between them so that a transfer has a high chance of being observed by all other nodes within the network [44].

For this purpose, a path quality threshold is applied to determine whether a path is good or not. The node having the high path quality has the maximum chance to initiate the transfer with no failure. Choosing the optimum path indicates the minimum number of transfers is anticipated so that both the predicted packet delay and energy cost are the minimum. The flooding data latency of all nodes is an arbitrary parameter because of untrustworthy paths. The distribution of the delay is computed to direct the decision-making task of adjacent nodes. i^{th} busy period of a j^{th} node is $t_j(i)$, data latency (D_p) is signified by the collection of tuples $\{t_j(i), p_j(i)\}$, where $p_j(i)$ denotes the chance of accepting the data at duration $t_j(i)$. At first, the origin is constantly active and the chance that it accepts the data with latency is 100%. After that, $j+1^{th}$ node computes its D_p based on its j^{th} node's D_p.

For a given D_p of this j^{th} node, its $j+1^{th}$ node with busy periods $t_{j+1}(k)$ for k, the chance is calculated that it accepts the flooding data at its k^{th} busy period by

$$p_{j+1}(k) = \sum_{i:t_j(i)<t_{j+1}(k)} p_j(i)q(1-q)^{n_{ik}}. \tag{1}$$

In Equation (1), q denotes the corresponding path quality satisfying and $q \in (0, 1]$, n_{ik} denotes the amount of the $j+1^{th}$ node's busy period amid $t_j(i)$ and $t_{j+1}(k)$. The term $p_j(i)q(1-q)^{n_{ik}}$ represents the chance that the data that enters the j^{th} node at its i^{th} busy period is initially received at the $j+1^{th}$ node at its k^{th} time. Based on this, a node can find its D_p as its threshold latency and distributes it with their prior hop nodes.

Assume j^{th} node X receives a packet at its i^{th} busy period with latency $t_j(i)$ and aims at deciding broadcasting towards one of its $j+1^{th}$ adjacent Y in the busy period $t_{j+1}(k)$. If the transmission from X to Y be initiated, Y's Expected Packet Delay (EPD) from X is calculated as follows:

$$EPD = p_{j+1}(k) = \sum_{k:t_{j+1}(k)>t_j(i)} t_{j+1}(k)q(1-q)^{n_{ik}}. \tag{2}$$

In Equation (2), n_{ik} denotes the number of Y's busy period amid $t_j(i)$ and $t_{j+1}(k)$. Once the EPD is determined, X analyzes it with Y's D_p to make a decision when this broadcasting is opportunistically essential than delivery through the power and load-aware optimal nodes.

If $EPD \le D_p$, then the chance defines that Y has previously accepted this flooding data through the power and load-aware optimal node is no larger than p. So, this packet is crucial. If $EPD > D_p$, then the chance defines that Y has previously accepted this data. So, this data is termed superfluous and will not be transmitted to the next hop Y. Observe that p denotes a control variable for balancing the delay and power usage. But, since p becomes greater, a source is probable to label a packet as essential.

So, many packets are transmitted opportunistically, maximizing the probability of quick reception when failure is managed properly. The number of transfers to high-power use is also maximized as a result. On the contrary, since p becomes lesser, a minimum amount of packets are transmitted opportunistically through power-suboptimal routes which maximize the energy efficiency and delay.

Similarly, the Expected Lifetime (EL) of j at t is determined as

$$Lt_j(t) = \frac{E_j(t)}{\mathrm{ETR}_j(t) \times P_{j,i}(t)}, \tag{3}$$

$$\mathrm{ETR}_j(t) = \left(1 - e^{\frac{\mathrm{timeGap}}{k}}\right)\left(\frac{\mathrm{pktSize}}{\mathrm{timeGap}}\right) + \left(e^{\frac{\mathrm{timeGap}}{k}} * \mathrm{estRate}\right). \tag{4}$$

In Equations (3) and (4), $Lt_j(t)$ is the estimated lifetime of j at t, $E_j(t)$ denotes the battery capacity of j at t, $\mathrm{ETR}_j(t)$ indicates the expected arrival traffic rate of j at t, $P_{j,i}(t)$ is the transfer energy of j to transmit a data through route i at t, timeGap is the variance of the present period to the period of final data entrance, k is the mean time (in seconds) to measure the rate, pktSize is the length of the packet and estRate is the current flow's estimated rate.

3.2.2. Path Selection and Cost Factor Estimation. By considering both EPD and EL, the cost factor $(F(C_j(t)))$ is represented by

$$F(C_j(t)) = \frac{1}{Lt_j(t)} + \mathrm{EPD}_j(t). \tag{5}$$

This cost factor is determined to elect the optimum routes from a collection of accessible routes which will link a certain origin to its required target. Since the cost of a particular route decreases, the optimality improves.

This cost factor considers the remaining power, transfer energy, EPD, and EL of a certain node. The optimality of the route is measured by using the highest cost of the bottlenecked transitional node and the total cost of all intermediate nodes which are controlled by gradient forwarding.

Consider P_i is the route that links the origin (S) to its required target (D) via transitional nodes $(n_1 - n_2 - \cdots - n_{m-1} - n_m)$ at t. Such that

$$P_i = S - n_1 - n_2 - \cdots - n_{m-1} - n_m - D. \tag{6}$$

Category	*Dst*	*Src*	Hop-from-Src	EPD-from-Src	PUM-SN

(i) Path update message (PUM)

Category	TTL	*Dst*	Cost-from-Dst	PIM-SN

(ii) Path information message (PIM)

Category	*Dst*	*Src*

(iii) Replace broadcast ending message (RBEM)

Category	*Dst*	*Src*	Unreachable path-from-Src	PIM-SN

(iv) Path failure message (PFM)

Figure 2: Format of control messages in PLAEOR protocol.

The highest cost of the bottlenecked transitional node on the route P_i is by

$$C(p_i) = \max_{j=1} F\left(C_j(t)\right). \quad (7)$$

The total cost of every transitional node on P_i is by

$$C(p_i) = \sum_{j=1}^{m} F\left(C_j(t)\right). \quad (8)$$

3.2.3. Path-Quality-Based Backoff. If a node aims at initiating a transfer, it backs off for a period. The interval of the backoff relies on the path efficiency from the source to the destination. If the path quality is high, then the backoff time will be less.

Consider the backoff period is T_{backoff}, the highest amount of source group is W and T_{backoff} is split into W slots for various backoff intervals. A source can compute its t_{backoff} as follows:

$$t_{\text{backoff}} = \left(\lfloor W(1-q) \rfloor\right) \frac{T_{\text{backoff}}}{W} + R. \quad (9)$$

In Equation (9), R denotes the arbitrary interval created from $[-T_{\text{backoff}}/W, +(T_{\text{backoff}}/W)]$ when $1 \le \lfloor W(1-q) \rfloor \le W-1$ and from $[0, +(T_{backoff}/W)]$ when $\lfloor W(1-q) \rfloor = 0$. It guarantees that t_{backoff} is nonnegative and within the backoff limit. By using this factor, the probability of failures is reduced while two or more nodes have identical path quality. Thus, the packets are transmitted opportunistically through the PLA optimal collision-free paths that increase the energy efficiency and reduce the flooding delay.

3.2.4. Path Discovery and Routing Cost Management. By merging the gradient forwarding with this new routing cost $F(C_j(t))$, the PLAEOR is designed. Normally, this protocol handles the cost data via periodic flooding of control packets from the target. This cost managing protocol consists of different major aspects: (i) A particular flooding packet from the target is applied for many origins. (ii) The packet flooding region is limited to the hop gap from an origin to the target. (iii) Every node preserves the cost of the optimal path that supports regularizing the cost range.

The PLAEOR's cost management process comprises 4 kinds of control packets such as Path Update Message (PUM), Path Information Message (PIM), Replace Broadcast Ending Message (RBEM), and Path Failure Message (PFM). Their message structures are portrayed in Figure 2, correspondingly.

A PUM is created by the origin while it does not contain the cost data to the target. It comprises the origin ID (Src), the target ID (Dst), the arbitrary sequence number (PUM – SN), EPD from the source (EPD – from – Src), and the hop count from the source (Hop – from – Src) that is primarily assigned to null.

The PUM-SN is utilized for identifying the occurrence of PUM. If the origin transmits a PUM, a clock is initiated and a PIM from the target awaits. If the origin is not received by a PIM prior to the deadline, a fresh PUM-SN will flood the other PUM. If a PUM is sent to the node, the PUM-SN is initially checked. If it is an ancient one, then the PUM will be thrown away. Otherwise, the PUM-SN is accumulated by the recipient and the data is updated via assigning the Hop – from – Src as 1. When the PUM is not for the recipient, the PUM is forwarded following t_{backoff}.

When the recipient is at the PUM target, the recipient creates an Active Source List (ASL), which records the collection of active traffic origins and their EPDs. The ASL has Src, Hop – from – Src and EPD – from – Src. According to this list, the target analyzes various routes to elect many node-disjoint optimum routes and transmits PIM messages to the origin. The determination to choose the optimum routes initiates only after t_{backoff} terminates, the similarity among the accepted routes is depending on their hop count and EPD values. Path with the least hop count and EPD is

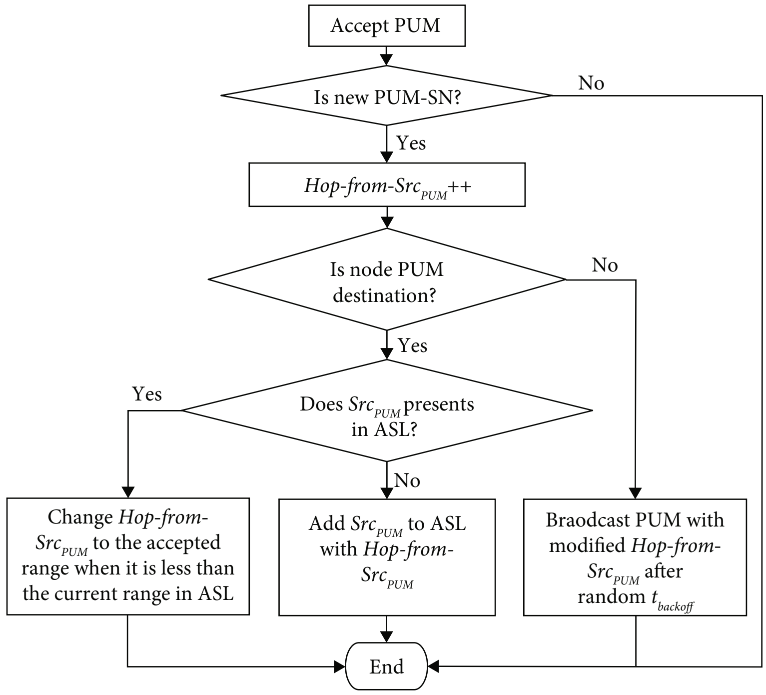

Figure 3: Procedure for accepting the PUM.

considered the major route and the PIM packet is transmitted back to the source involving this major optimum route.

Other available routes are organized depending on their hop count and EPD values. The process of a node, while it accepts the PUM, is illustrated in Figure 3.

PIMs for their origins and transitional nodes are often flooded by a target that has greater than a single legitimate origin in its ASL to determine the legitimate cost of transporting it. The PIM contains time to live (TTL), which is set to the highest number of hops and the lowest number of EPDs on the ASL. The original TTL, reduced by 1 per PIM, is higher than the utmost hop count in ASL. It prevents unwanted PIM floods over the most remote origin. Finally, each origin's hop distance and EPD in ASL may be upgraded by allowing the origin and transitional nodes when transferring data to the target. The process of a node, while it accepts the PIM, is shown in Figure 4.

Depending on accepting a PIM, a node upgrades its cost towards the target (i.e., the origin of PIM). If X accepts a PIM from Y commenced from Z and the accepted flooding delay for the PIM is $d(s)$. Using the cost C_Y^Z in the PIM, X computes the temporary cost $\bar{C}_X^Z$ to Z by

$$\bar{C}_X^Z = \begin{cases} C_Y^Z + 1, & \text{if } d > d_{th} \\ C_Y^Z + \lceil d_{th} + 1 - d \rceil, & \text{Otherwise} \end{cases}. \quad (10)$$

In Equation (10), $\lceil a \rceil$ refers to the value not higher than a and d_{th} is the highest delay. Once $\bar{C}_X^Z$ is computed, the receiver updates its cost $C_X^Z \longleftarrow \bar{C}_X^Z$ either if the PIM is new or when the cost is reduced. The objective of this technique is to increase the chance that data is sent to a node with fewer latency connections to the target.

The routing cost measure is increased by 1 according to (10) because the hop count for a less delay path is greater. Also, when many PIMs with comparable sequence numbers are given, nodes can keep the optimal costs. An intermediate node with less delay can thus sustain its routing costs far less than other nearby nodes, resulting in a greater probability of data transfer from this node during gradient transmission. When the TTL in the PIM exceeds 1, X will amend the PIM and will broadcast it after t_{backoff}. Or X will not retransmit PIM. Moreover, the traffic source uses RBEM to inform the target that the origin node contains the packet. When an RBEM is received, the associated origin is removed from its ASL. When the ASL gets null, the flooding of PIMs is terminated. This PLAEOR cost control method can only be activated when active end-to-end packet intervals are being used.

3.2.5. Path Maintenance. Additionally, path maintenance is achieved because of the dynamic characteristics of MANET. The path between the origin and target may fail at any interval, so a PFM packet will be broadcast. Then, the origin searches its cache for backup paths. If every backup route fails, then the other path-finding task has to be commenced.

3.3. PLAEOR with Multichannel Cooperative Neighbor Discovery (PLAEOR-MCND) Protocol. Though PLAEOR achieves reliable data transmission, the exchange of control packets, i.e., PIM from target to all nodes, may affect the efficiency of the node's lifetime. To avoid this problem, the PLAEOR is further combined with the MCND protocol, which finds the cooperative adjacent nodes for each node in the routing path during control packet exchange from the destination to the source node. This is achieved by using the finding probability, which reflects the chance of an

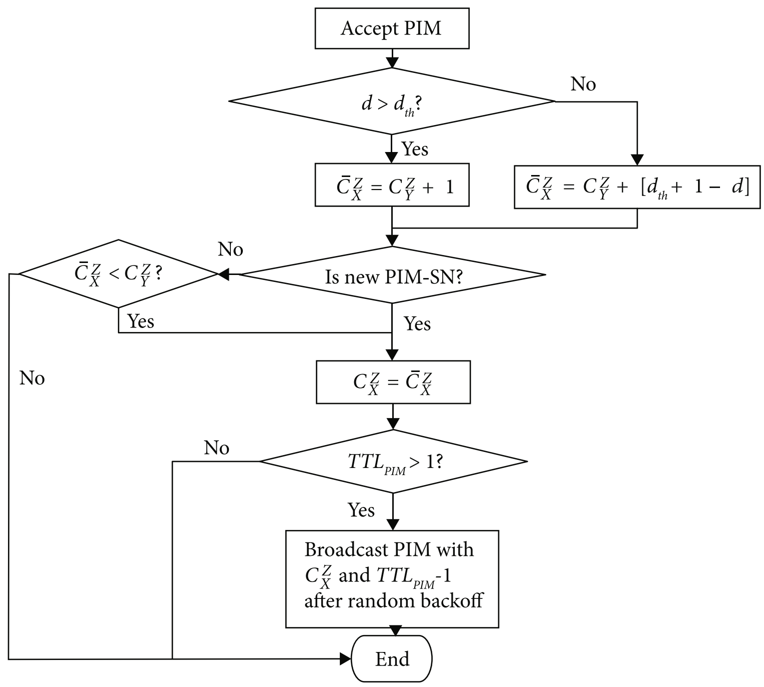

FIGURE 4: Procedure for accepting the PIM.

effective finding of cooperative adjacent nodes during a random interval in the transmission area.

In this protocol, a hypothesis is considered that during a random interval, the node has p_h probability in the active mode and $1 - p_h$ in the inactive mode. So, the cooperative adjacent nodes are discovered while they are in the active mode. Additionally, the finding probability is considered across the multiple detection channels.

Let there are n_i active nodes (among N number of nodes) in the transfer area for an interval i. Then, the finding probability during a random interval i and channel k is

$$P_s = \binom{n_i}{k} p_h^k (1 - p_h)^{n_i - k}. \tag{11}$$

After determining the finding probability, the nodes having a higher probability are labelled as cooperative adjacent nodes; or else, the nodes are labelled as noncooperative adjacent. This cooperative adjacent node list is updated in the target nodes along with the ASL to transmit the PIM packets via the decided PLA multiple node-disjoint optimum routes. Thus, the frequent transmission and reception of PIM packets to all nodes are prevented to reduce the overhead and power depletion of nodes so that the NLife is significantly increased.

4. Simulation Results

This part simulates the PLAEOR and PLAEOR-MCND protocols in Network Simulator version 2.35 (NS2.35) to analyze their efficacy. Networks that use PLAEOR as a routing mechanism spend less energy with fewer control packets, according to this study, because each node's neighboring cooperative nodes are found in the optimal pathways. The major aim of this analysis is to verify the effectiveness of PLAEOR and PLAEOR-MCND against various existing protocols: DSR, E2NDjMRP [18], and PLA-DSR [6]. For this reason, the control packets are generated at CBR to transfer between source and target nodes. The analysis is conducted regarding E2E-D, NLife, EC, and RO. The simulation parameters are listed in Table 1.

4.1. E2E-D. The interval required to transfer the information between origin and target is called E2E-D.

$$\text{End} - \text{to} - \text{end delay} = \frac{\text{Total time for packets received by the destination}}{\text{Total Number of packets received by the destination}}. \tag{12}$$

Figure 5 presents the E2E-D (in sec) for DSR, E2NDjMRP, PLA-DSR, PLAEOR, and PLAEOR-MCND protocols under varying traffic loads (in packets/sec). According to this, it is proven that PLAEOR-MCND reduces the E2E-D compared to other protocols. For instance, if the packet rate of CBR is taken as 20packets/sec, then the E2E-D

Table 1: Simulation parameters.

Simulator tool	NS2.35
Network dimension	$1600 \times 1600\ m^2$
No. of nodes	100
Network structure	Flat-grid
MAC layer	IEEE 802.11
Queue category	DropTail
Queue size	50
Antenna	Omni-directional
Propagation method	2-ray ground
Physical and channel category	Wireless
Transfer energy	0.2818 W
Communication scope	250 m
Primary power	100 J
Transfer energy	1.4 W
Receiver energy	1 W
Mobility method	Random waypoint
Node mobility	0-10 m/s
Simulation period	120 s
Traffic category	Constant bit rate (CBR)
Packet length	512bytes

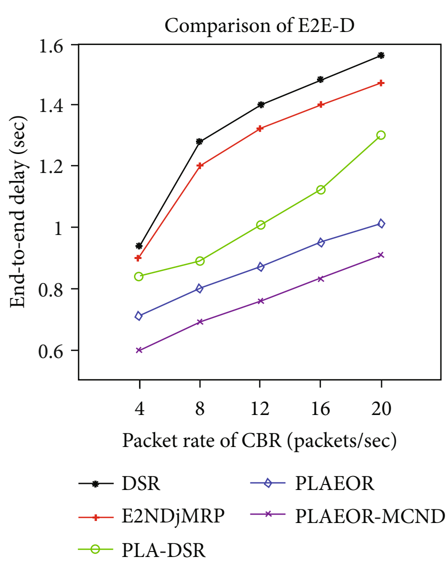

Figure 5: E2E-D vs. packet rate of CBR.

of PLAEOR-MCND is 41.7% lower than DSR, 38.1% less than E2NDjMRP, 30% less than PLA-DSR, and 9.9% less than PLAEOR protocols. This is because of finding both cooperative adjacent nodes and multiple node-disjoint optimum routes for data transfer.

4.2. EC. It is the amount of power depleted during communication.

Figure 6 illustrates the EC (in Joules (J)) for DSR, E2NDjMRP, PLA-DSR, PLAEOR, and PLAEOR-MCND under varying traffic loads (in packets/sec). This analysis

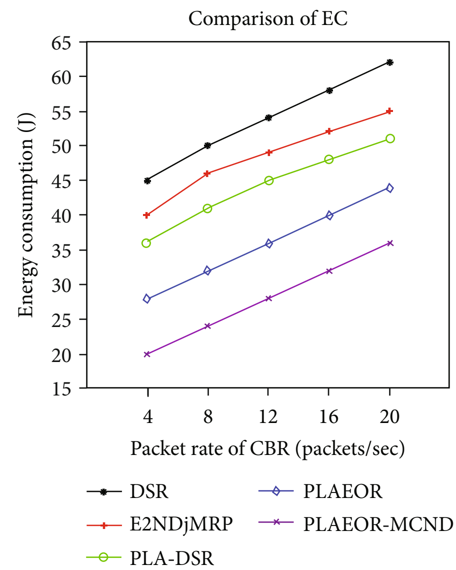

Figure 6: EC vs. packet rate of CBR.

indicates that the PLAEOR-MCND protocol decreases EC compared to all other protocols. If the packet rate of CBR is 20packets/sec, the EC of PLAEOR-MCND is 41.9% lower than DSR, 34.5% less than E2NDjMRP, 29.4% less than PLA-DSR, and 18.2% less than PLAEOR protocols. This is due to the discovery of cooperative adjacent nodes as well as power and load-aware multiple node-disjoint optimum paths to transmit the data between origin and target.

4.3. RO. It is the fraction of the overall amount of RREQ and RREP broadcast per data packet.

$$\text{Routing Overhead} = \frac{\text{Total number of routing packets transmitted}}{\text{Total number of data packets received}} \quad (13)$$

Figure 7 shows the RO for DSR, E2NDjMRP, PLA-DSR, PLAEOR, and PLAEOR-MCND under varying traffic loads (in packets/sec). This scrutiny observes that the PLAEOR-MCND protocol minimizes the RO among all other protocols. In the case of 20 packets/sec traffic load, the RO of PLAEOR-MCND is 50% less than DSR, 46.9% less than E2NDjMRP, 45.2% less than PLA-DSR, and 19% less than PLAEOR protocols. This is achieved due to the prevention of frequent transmission of control messages from the target to the source.

4.4. NLife. The time required to transfer the data between origin and target is called an NLife.

Figure 8 depicts the NLife (sec) for DSR, E2NDjMRP, PLA-DSR, PLAEOR, and PLAEOR-MCND under varying traffic loads (in packets/sec). This analysis addresses that the PLAEOR-MCND protocol improves the NLife better than all other protocols. For the case of 20 packets/sec traffic load, the NLife of PLAEOR-MCND is 91 sec, whereas the NLife of DSR, E2NDjMRP, PLA-DSR, and PLAEOR is 22 sec, 35 sec, 62 sec, and 79 sec, correspondingly. Thus, this

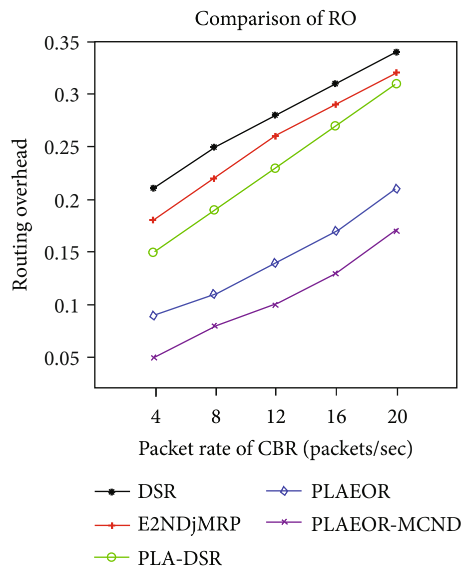

Figure 7: RO vs. packet rate of CBR.

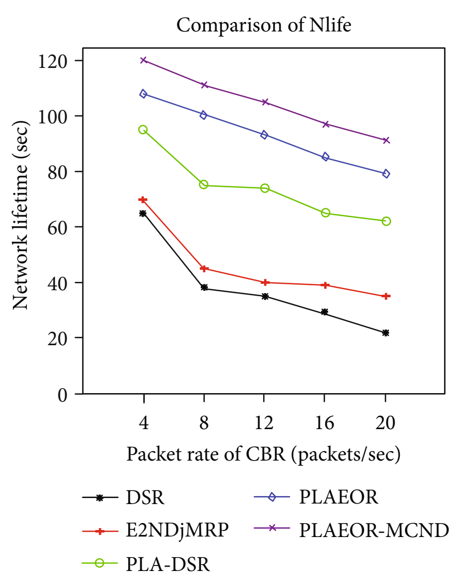

Figure 8: NLife vs. packet rate of CBR.

summarizes that the PLAEOR-MCND protocol will increase the node's lifespan by reducing the RO, latency, and EC during data transfer.

5. Conclusion

In this article, the PLAEOR protocol was designed based on the opportunistic gradient forwarding strategy where the source only transmits the packet and the destinations create the routing decision. The routing cost was determined according to the power, load, and delay of all nodes during the flooding of the control messages between the source and target nodes. Moreover, the PLAEOR-MCND protocol was introduced to avoid the transmission of control packets to all nodes by finding the collaborative neighboring nodes of each node in the route. Finally, the simulation findings realized that the PLAEOR-MCND increases the NLife and reduces the overhead, energy usage compared to the existing protocols. It indicates that the PLAEOR-MCND has 0.6 sec of E2E-D, 0.05 of RO, 120 sec of NLife, and 20 J of EC than all other protocols because of reducing the redundant flooding of control packets from the target nodes. On the other hand, recurrent collisions exist among nodes during MCND in dense scenarios. So, the future work will focus on reducing the collisions and improving the channel utilization by determining the negotiation cost among adjacent nodes.

Data Availability

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of Interest

The authors of this manuscript declared that they do not have any conflict of interest.

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References

[1] M. Kumar and R. Mishra, "An overview of MANET: history, challenges and applications," *Indian Journal of Computer Science and Engineering (IJCSE)*, vol. 1, pp. 121–125, 2012.

[2] D. S. Dhenakaran and A. Parvathavarthini, "An overview of routing protocols in mobile ad-hoc network," *International Journal of Advanced Research in Computer Science and Software Engineering*, vol. 3, pp. 251–259, 2013.

[3] B. Sharma, S. Chugh, and V. Jain, "Investigation of adaptive multipath routing for load balancing in MANET," *International Journel Of Engineering And Advanced Technology*, vol. 2, pp. 65–71, 2013.

[4] D. I. Elewely, M. F. Areed, and H. A. Ali, "A proposed routing scheme for power reduction in wireless networks," *International Journel Of Engineering And Advanced Technology*, vol. 3, no. 1, pp. 20–29, 2014.

[5] X. Zhen and X. Juan, "Energy-aware and delay-aware QoS routing in mobile ad-hoc networks," in *IEEE 2012 International Conference on Computational Problem-Solving*, pp. 511–515, Leshan, China, 2012.

[6] H. A. Ali, M. F. Areed, and D. I. Elewely, "An on-demand power and load-aware multi-path node-disjoint source routing scheme implementation using NS-2 for mobile ad-hoc networks," *Simulation Modelling Practice and Theory*, vol. 80, pp. 50–65, 2018.

[7] W. Almobaideen, R. Al-Soub, and A. Sleit, "MSDM: maximally spatial disjoint multipath routing protocol for MANET," *Communications and Network*, vol. 5, no. 4, pp. 316–322, 2013.

[8] Y. Tashtoush, O. Darwish, and M. Hayajneh, "Fibonacci sequence based multipath load balancing approach for mobile

ad hoc networks," *Ad Hoc Networks*, vol. 16, pp. 237–246, 2014.

[9] V. K. Barbudhe, A. Kumar, S. N. Sisat et al., "Node-disjoint multipath routing method based on AODV protocol," *International Journal of Research in Advent Technology*, vol. 2, 2014.

[10] K. Zhang, G. Yin, Q. Han, and J. Lin, "DFDP: a distributed algorithm for finding disjoint paths in wireless sensor networks with correctness guarantee," *International Journal of Distributed Sensor Networks*, vol. 10, no. 6, Article ID 258959, 2014.

[11] Y. Yu and M. Liang, "A node-disjoint multipath routing protocol in MANETs," in *IEEE 2015 International Conference on Computer Science and Mechanical Automation*, pp. 108–112, Hangzhou, China, 2015.

[12] B. Arora, "An adaptive transmission power aware multipath routing protocol for mobile ad hoc networks," *Procedia Computer Science*, vol. 57, pp. 1242–1248, 2015.

[13] S. Gopinath and N. Nagarajan, "Energy based reliable multicast routing protocol for packet forwarding in MANET," *Journal of applied research and technology*, vol. 13, no. 3, pp. 374–381, 2015.

[14] M. Bheemalingaiah, M. M. Naidu, D. S. Rao, P. Vishvapath, and J. N. T. Uniersity, "Energy aware on-demand multipath routing protocol in mobile ad hoc networks," *International journal of computer networks and wireless communications*, vol. 6, pp. 14–33, 2016.

[15] K. Mounagurusamy and K. Eswaramurthy, "A novel load balancing scheme for multipath routing protocol in MANET," *Journal of Computing and Information Technology*, vol. 24, no. 3, pp. 209–220, 2016.

[16] M. A. Salem and R. Yadav, "Efficient load balancing routing technique for mobile ad hoc networks," *International Journal of Advanced Computer Science and Applications*, vol. 7, pp. 249–254, 2016.

[17] I. Das, D. K. Lobiyal, and C. P. Katti, "An analysis of link disjoint and node disjoint multipath routing for mobile ad hoc network," *International Journal of Computer Network and Information Security*, vol. 8, pp. 52–57, 2016.

[18] S. M. Benakappa and M. Kiran, "An energy-aware node disjoint multipath routing protocol for MANETs with dynamic transmission range adjustment," in *2017 IEEE International Conference on Electrical, Electronics, Communication, Computer, and Optimization Techniques*, pp. 335–341, Mysuru, India, 2017.

[19] M. Shinde and S. Jain, "PALBMRP: power aware load balancing multipath routing protocol for MANET," *International Journal of Advanced Networking and Applications*, vol. 9, pp. 3329–3334, 2017.

[20] W. A. Jabbar, M. Ismail, and R. Nordin, "Energy and mobility conscious multipath routing scheme for route stability and load balancing in MANETs," *Simulation Modelling Practice and Theory*, vol. 77, pp. 245–271, 2017.

[21] A. Bhattacharya and K. Sinha, "An efficient protocol for load-balanced multipath routing in mobile ad hoc networks," *Ad Hoc Networks*, vol. 63, pp. 104–114, 2017.

[22] M. Gupta, V. P. Singh, K. K. Gupta, and P. K. Shukla, "An efficient image encryption technique based on two-level security for internet of things," *Multimedia Tools and Applications*, 2022.

[23] N. K. Rathore, N. K. Jain, P. K. Shukla, U. S. Rawat, and R. Dubey, "Image forgery detection using singular value decomposition with some attacks," *National Academy Science Letters*, vol. 44, no. 4, pp. 331–338, 2021.

[24] G. Khambra and P. Shukla, "Novel machine learning applications on fly ash based concrete: an overview," *Materials Today Proceedings*, pp. 2214–7853, 2021, https://www.sciencedirect.com/science/article/pii/S221478532105121X?via%3Dihub.

[25] A. Kumar, M. Saini, N. Gupta et al., "Efficient stochastic model for operational availability optimization of cooling tower using metaheuristic algorithms," *IEEE Access*, vol. 10, pp. 24659–24677, 2022.

[26] D. Singh, V. Kumar, M. Kaur, M. Y. Jabarulla, and H.-N. Lee, "Screening of COVID-19 suspected subjects using multi-crossover genetic algorithm based dense convolutional neural network," *IEEE Access*, vol. 9, pp. 142566–142580, 2021.

[27] H. Kaushik, D. Singh, M. Kaur, H. Alshazly, A. Zaguia, and H. Hamam, "Diabetic retinopathy diagnosis from fundus images using stacked generalization of deep models," *IEEE Access*, vol. 9, pp. 108276–108292, 2021.

[28] P. Kumar Shukla, P. Kumar Shukla, P. Sharma et al., "Efficient prediction of drug–drug interaction using deep learning models," *IET Systems Biology*, vol. 14, no. 4, pp. 211–216, 2020.

[29] J. Amin, M. Sharif, A. Haldorai, M. Yasmin, and R. S. Nayak, "Brain tumor detection and classification using machine learning: a comprehensive survey," *Complex & Intelligent Systems*, 2021.

[30] M. Arif, F. Ajesh, S. Shamsudheen, O. Geman, D. Izdrui, and D. Vicoveanu, "Brain tumor detection and classification by MRI using biologically inspired orthogonal wavelet transform and deep learning techniques," *Journal of Healthcare Engineering*, vol. 2022, Article ID 2693621, 18 pages, 2022.

[31] R. R. Althar, D. Samanta, M. Kaur, A. A. Alnuaim, N. Aljaffan, and M. A. Ullah, "Software systems security vulnerabilities management by exploring the capabilities of language models using NLP," *Computational Intelligence and Neuroscience*, vol. 2021, Article ID 8522839, 19 pages, 2021.

[32] P. Bondada, D. Samanta, M. Kaur, and H.-N. Lee, "Data security-based routing in MANETs using key management mechanism," *Applied Sciences*, vol. 12, no. 3, p. 1041, 2022.

[33] A. Khare, R. Gupta, and P. K. Shukla, "Improving the protection of wireless sensor network using a black hole optimization algorithm (BHOA) on best feasible node capture attack," in *IoT and Analytics for Sensor Networks. Lecture Notes in Networks and Systems*, P. Nayak, S. Pal, and S. L. Peng, Eds., vol. 244, Springer, Singapore, 2022.

[34] R. Bhatt, P. Maheshwary, and P. Shukla, "Application of fruit fly optimization algorithm for single-path routing in wireless sensor network for node capture attack," in *Computing and Network Sustainability. Lecture Notes in Networks and Systems*, S. L. Peng, N. Dey, and M. Bundele, Eds., vol. 75, Springer, Singapore, 2019.

[35] R. K. Gupta, K. K. Almuzaini, R. K. Pateriya, K. Shah, P. K. Shukla, and R. Akwafo, "An Improved Secure Key Generation Using Enhanced Identity-Based Encryption for Cloud Computing in Large-Scale 5G," *Wireless Communications and Mobile Computing*, vol. 2022, Article ID 7291250, p. 14, 2022.

[36] R. Panigrahi, S. Borah, A. K. Bhoi et al., "A consolidated decision tree-based intrusion detection system for binary and multiclass imbalanced datasets," *Mathematics*, vol. 9, no. 7, p. 751, 2021.

[37] L. Xu, X. Zhou, X. Li, R. H. Jhaveri, T. R. Gadekallu, and Y. Ding, "Mobile collaborative secrecy performance prediction

for artificial IoT networks," *IEEE Transactions on Industrial Informatics*, p. 1, 2021.

[38] A. Revathi, R. Kaladevi, K. Ramana, R. H. Jhaveri, M. R. Kumar, and M. S. P. Kumar, "Early detection of cognitive decline using machine learning algorithm and cognitive ability test," *Security and Communication Networks*, vol. 2022, Article ID 4190023, 13 pages, 2022.

[39] S. Stalin, V. Roy, P. K. Shukla et al., "A machine learning-based big EEG data artifact detection and wavelet-based removal: an empirical approach," *Mathematical Problems in Engineering*, vol. 2021, Article ID 2942808, 11 pages, 2021.

[40] V. Bhandari, S. Tamrakar, P. Shukla, and A. Bhandari, "A new model of M-secure image via quantization," in *Data, Engineering and Applications*, R. K. Shukla, J. Agrawal, S. Sharma, and T. G. Singh, Eds., Springer, Singapore, 2019.

[41] S. Pandit, P. K. Shukla, A. Tiwari, P. K. Shukla, M. Maheshwari, and R. Dubey, "Review of video compression techniques based on fractal transform function and swarm intelligence," *International Journal of Modern Physics B*, vol. 34, no. 8, p. 2050061, 2020.

[42] E. M. Onyema, P. K. Shukla, S. Dalal, M. N. Mathur, M. Zakariah, and B. Tiwari, "Enhancement of patient facial recognition through deep learning algorithm: ConvNet," *Journal of Healthcare Engineering*, vol. 2021, Article ID 5196000, 8 pages, 2021.

[43] P. Pateriya, R. Singhai, and P. Shukla, "Design and implementation of optimum LSD coded signal processing algorithm in the multiple-antenna system for the 5G wireless technology," *Wireless Communications and Mobile Computing*, vol. 2022, Article ID 7628814, 12 pages, 2022.

[44] D. Jain, P. K. Shukla, and S. Varma, "Energy efficient architecture for mitigating the hot-spot problem in wireless sensor networks," *Journal of Ambient Intelligence and Humanized Computing*, 2022.

[45] S. Joshi, S. Stalin, P. K. Shukla et al., "Unified Authentication and Access Control for Future Mobile Communication-Based Lightweight IoT Systems Using Blockchain," *Wireless Communications and Mobile Computing*, vol. 2021, Article ID 8621230, p. 12, 2021.