IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received July 1, 2021, accepted July 26, 2021, date of publication August 2, 2021, date of current version August 13, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3101850

Design of Novel Mobility and Obstacle-Aware Algorithm for Optimal MANET Routing

PRASANT KUMAR PATTNAIK[1], (Senior Member, IEEE), BANOJ KUMAR PANDA[2], AND MANGAL SAIN[3]

[1]School of Computer Engineering, Kalinga Institute of Industrial Technology, Bhubaneswar 751024, India
[2]Department of Electronics and Telecommunication Engineering, Utkal University, Bhubaneswar 751004, India
[3]Division of Computer Engineering, Dongseo University, Busan 47011, Republic of Korea

Corresponding author: Mangal Sain (mangalsain1@gmail.com)

This work was supported by the "Dongseo Cluster Project" Research Fund of 2021 through Dongseo University under Grant DSU-20210004.

ABSTRACT Existence obstacles in terrain area and the mobility of the nodes in the network are the vital constrains that degrade the performance in Mobile Adhoc Network (MANET). To diminish the effect of such obstacles and mobility on the performance of MANET, the protocol used for routing must be efficient enough to handle both the factors. In the present work, we have considered the issues of Mobility and obstacle aware multipath communication in MANET. For avoiding obstacles, DeCasteljau Algorithm with Bezier curve concept has been applied. To the minimize impact of mobility, a speed based mobility prediction concept is used. Here optimal routing path across the obstacle is selected depending on its mobility prediction indicator, link duration, network connectivity and path availability. The performance of the suggested protocol is evaluated with Network Simulator-2. Simulation results confirm that the suggested protocol minimizes average energy consumption, network overhead, average delay and improves data deliverance in MANET.

INDEX TERMS Obstacle, mobility, path availability, link time duration, DeCasteljau algorithm, Bezier curve.

I. INTRODUCTION

MANET is established with the help of a number of mobile communicating devices without having a centralized infrastructure. MANET has no centralized server, so here the mobile nodes are connected using wireless radio links. The devices in the MANET move freely in any random direction and random speed, hence its network topology changes frequently. Here each node is having its own transmission range, they communicate with each other through the radio frequencies. One of the main problems in the technology of MANET is the node's mobility that affects its network efficiency [1]. For improving the efficiency and performance of network further, many routing protocols are suggested [2]–[4]. But in these papers, the authors assume the plain terrain for simulation and they do not consider realistic terrain characteristics and the presence obstacles in their simulation. The existence obstacles affect the strength of the received signal at the destination node and that reduces the efficiency of the network. Formerly, many researchers have taken the geographic characteristics and the presence obstacles in their work, but nobody has suggested a protocol that addresses both obstacle and mobility issues in simulation terrain with the existence of irregular shape obstructing objects. In this part of work, we have proposed and analyzed a Mobility and Obstacle-aware Algorithm for optimal MANET Routing (MOAR).

In the proposed work, MOAR, our contribution as listed below.

- We have developed a simple and effective algorithm to overcome the presence of seven real world polygonal obstacles. Here due to presence of a fixed polygonal obstacle, link breaks to the destination, the route can be recovered locally without initiating a new route search process. A set of nodes, called 'Special node list' are selected along a Bezier path across the obstacle, which guide the data to the destination during failure of route to destination.
- Here, to make the algorithm Mobility-aware, we have developed a novel technique where optimal route selection is done based on the value of Mobility Indicator, link reliability, network connectivity and path availability

The associate editor coordinating the review of this manuscript and approving it for publication was Chuan Heng Foh.

concept so that a set of suitable nodes can be selected for routing data to destination avoiding obstacles.

II. RELATED WORKS

For efficient routing in MANETs, there is a set of mobility patterns and routing schemes accessible in the MANET literature. The section explains the available similar works suggested by different researchers as models for Mobility and protocols for routing in plain and realistic terrain.

The Environment-Aware Mobility model [5] suggested by the authors is suitable for various MANET environments. The existence of the obstacles in MANET causes the link failure. The Route model and the Hotspot model are used in this scheme to examine the node movement in a given environments. But, it lacks the mobility awareness of pathway in the network.

In paper [6] author discussed some obstacles avoiding routing schemes given by several researchers. Here several research works have been re-examined and analyzed. This paper summarizes pros and cons of every technique to obtain the scope of research in real terrain MANET with obstacles.

The paper [7] discusses the several issues like presence of obstacles, mobility and battery-powered node of MANET. The paper summarizes pros and cons of every technique to obtain the scope of research in real terrain MANET with obstacles.

In this paper [8], an energy efficient routing protocol for wireless network i.e. MWSN is suggested, which enhances data delivery and guarantee reliability. MWSN is able to choose the best multi-hop path amongst existing paths for the transmitting node and safely hops the data-packets to the sink nodes throughout network nodes.

QoS-assured Mobility-Aware Routing protocol (QMAR-AODV) [9] is an improved AODV protocol. It utilizes stability as well as quality metrics of the network like Mobility Ratio among nodes in a path, Energy consumption and load-congestion to select the most reliable and quality guaranteed routes.

Link availability-dependant Routing scheme [10] takes into account unfixed topology changes and frequent failure of the link. This technique assumes that the nodes are moving in an arbitrary mobility pattern and certainly guess the accessibility of links within a restricted time period. However, this scheme cannot precede the any process regarding awareness of obstacle and prediction of mobility in the network.

Mobility forecast scheme [11] is used for enhancing the stability of network, link status interruptions and QoS. Here, the mobility prediction is calculated by genetic algorithm is utilized to make a database for mobility prediction. Moreover, this scheme does not address the impact of presence of obstacles and energy consumption in the network.

Adaptive trained automata based mobility prediction scheme [12] is used for Gauss–Markov random process also continuous-valued reinforcement method discovers predict the potential mobility based on previous records of the node's mobility in plain unobstructed terrain. The Residual Lifetime of link [13] stands for the interdependence among neighbouring links and joint probability is derived for two neighbouring links in plain terrain. Mobility prediction [14] estimates the stability of paths, recognizing stable routes, thus help to enhance routing performance by minimizing the routing overhead and the count of link interruptions. It contains multiple layer and neural network with back propagation through time based algorithm for learning in plain MANET terrain. The multipath route technique [15] uses deviation of vibrant network conditions, thus it increases the MANET efficiency.

This technique detects automatically obstacles using the modified cartographically optimized link state based routing technique [16]. The scheme exactly shows the obstacle region with higher coverage and more efficient precision ratios. It delivers a sufficient precision fraction efficiently, avoiding busted links caused by the terrain obstacle absent analytical information about the obstacle plan.

Link-state based QoS routing scheme [17] establishes strong and sustainable paths between all MANET nodes. A stability function is specified for every node that chooses the path from the source node to sink node, depending on the degree of mobility of the node. But, it does not include the obstacle-avoidance concept during its design.

Path planning techniques [18] uses Ant Colony based Optimization technique to find out the most suitable path in MANET. Here, a Rational Bezier curve is used to find out the presence of obstacles. But, it is not a mobility- aware protocol. In [19], AODV tolerate from lowest data delivery, Mean Delay. It is majorly due to the reality that obstacle stages are not thanked about by Two-Ray Ground model.

Obstacle-avoidance link re-establishment strategy [20] utilizes mobility method, avoiding any approaching shaped curved obstacle. A back-support selection scheme proactively decides the presence of cut-vertex sensing device in the MANET and allocates a standby sensor to each cut-vertex related node. Then, a chosen standby sensor, bypassing obstacles uses a gyroscopic based force controller restores the disrupted connectivity. The forecast based routing using the Markov model [21] employs the constancy of motor vehicle movement pattern to enhance the transmission efficiency. But it does not consider realistic terrain.

In the paper [22], the authors initially suggested a distributed autonomic method to find obstacles (ALOE) among a MANET utilizing the fundamental signalling of the cartography enhanced OLSR (CE-OLSR) protocol. They also suggest ALOE-CE-OLSR that is the combination of ALOE among CE-OLSR, and demonstrate the ensuing enhancement in performance of routing in comparing thereto of each CE-OLSR having and without having information of the obstructing object location in advance. However, they have done analysis considering OLSR routing protocol not AODV.

In [23], authors have proposed an M-Lion Whale optimization technique which considers various Quality of Service (QoS) parameters, namely node energy, distance, interlink lifetime, average delay, and trust value. By help of multi-objective QoS parameters, a network fitness function is taken for selection of best paths. However, they have done analysis taking obstacles in its terrain.

In [24] suggests link dependability based clustering scheme to deliver effective as well as robust data communication in Vehicular network. To get suitable routing decisions, they allot exceptional nodes at every terrain intersection to estimate the network situation by giving weights to every road segment. Paths having least weights are chosen as the best possible data forwarding routes. Moreover, they have not considered obstacles in their simulation.

In paper [25] authors proposed a DSR-based scheme where the solidity of the network link is calculated with the help of the Continuous Hopfield Neural Network (CHNN) to get the path having maximum stability of the path connecting transmitting end to receiving end node to enhance the results of the DSR protocol. The simulation output comes indicates that in comparison with DSR, CHNN-DSR is having improved performance. However, they have not considered real terrain conditions in their simulation.

In Paper [26] discusses a new Energy-yielding Routing scheme that is improved by combining further a novel "energy back-off" network parameter. Integrating with various energy yielding schemes, the suggested scheme enhances the node-life period and the MANET performance under various traffic condition and energy states. However, they have not considered real terrain conditions in their simulation.

In paper [27], author suggested a fresh Obstacle-aware and Mobility-aware Routing (OMAR) scheme. In this scheme, for avoiding obstacles, DeCasteljau technique with Bezier curve has been used. To decrease the impacts of mobility and energy consumption of a mobile node, an Energy dependant Mobility Index routing technique has been used. The path having higher value of EMI is chosen as the path to the destination. However, they have done analysis taking some rectangular obstacles.

In this paper [28], the authors have presented a neuron-based active queue management scheme for internet congestion control. However, this is very helpful for reducing congestion in wired networks.

In [29], author suggested a more stable route choice scheme depending on the mobility of nodes in the network. As per the scheme, a route is selected for data transmission depending on value point of the speed of the node, direction of movement and pause duration. A mobility_factor is calculated taking these points for a node. But here the authors have considered plain terrain.

In paper [30], author suggested an Energy proficient and Obstacle-aware Routing scheme for the network. To avoid obstacles, the idea of Bezier curve with DeCasteljau algorithm is applied. This technique improves the accessibility of paths and decreases energy consumption participating node. However, they have done analysis taking some rectangular obstacles.

The availability of node link [31] represents the chance that a link constantly presented for a specified epoch of time. In this scheme, uses Semi-Markov based Smooth mobility models to enhance the efficiency of the network. The link availability factor is used for route selection process to intend a consistent routing in the network. Moreover, here the authors are silent on presence of obstacles in the network.

A Realistic Mobility pattern with irregular sized obstacle constraints using Bezier curves [32] that characterize the practical movement rule and calculates a smooth path between the obstructing entities. But it is not a mobility-aware technique.

III. MOBILITY AND OBSTACLE-AWARE ROUTING PROTOCOL IN MANET (MOAR)

A. OBSTACLE-AWARE ROUTING

MOAR uses the concept of 'Realistic Mobility pattern with Bezier Curve' (RMRC) that uses Bezier curve path notion to overcome the obstacle coming across its path [32]. For simulation, seven number of irregular shape obstructing objects are considered which represent the real world obstacles present in urban area. To bypass the obstacles, present on the route, the mobility pattern is required must have a smooth curve line. The RMBC technique used here is based on Bezier curves described by a set of waypoints. The benefit of utilizing the set of curves indicates that RMBC deals with not only the locations of the start and finishing points, but also all the waypoints exist in between. The RMBC technique is the initial technique to describe a comprehensive curve movement model and can adjust well to a wide scenario.

Here a 'special node list' is created that includes those nodes which are neighbours to Bezier curve that passes through several nodes-waypoints constitute the entire route to sink node bypassing obstacles [32]. The figure. 1 shows the 'Special Node list' which connected along Bezier curve path. The Optimal parameter (OP) of all alternative paths is calculated depending on parameter values like mobile prediction, Link Duration Time, network connectivity and path availability. Out of all available alternative paths, the path having highest optimal parameter is selected for routing.

B. MOBILITY-AWARE OPTIMAL ROUTING

Mobility-aware routing uses a novel concept of 'Mobility prediction Indicator' along with link reliability, network connectivity and path availability concept to find the value of 'Optimal factor' for all alternative paths available in '*Special node list*'.

1) MOBILITY PREDICTION

Mobility Prediction uses an arbitrary mobility pattern for calculation of Mobility Indicator (MI) for each and every node present in '*Special node list*'. Probability mass function is applied to obtain the mobile node relative speed status in the MANET. As per the mobility of nodes, the speed of the node is categorized in four different states as: higher speed status $\boldsymbol{H_\alpha}$ (Ranges from 60% of maximum speed to the maximum value of speed), medium speed status $\boldsymbol{I_\beta}$(Ranges from 30% of maximum speed to 59% of maximum speed value), lower

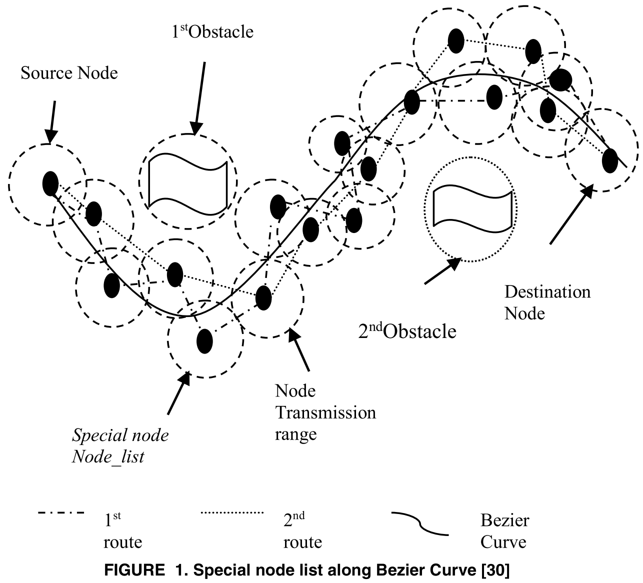

FIGURE 1. **Special node list along Bezier curve [30].**

speed status $\boldsymbol{L_\sigma}$ (ranges from 0 to 29% maximum value) and the pause status $\boldsymbol{P_\varphi}$. The entire Mobility discourse of the nodes is represented as 'Node Mobility State' i.e. X = $\{H_\alpha, I_\beta, L_\sigma, P_\varphi\}$. The mobile parameters of a node are differentiated by some notations i.e $\{T_0, D_x, a_x, \lambda_x\}$. Where, T_0 signifies the initial time of the movement of the node, λ_x signifies the time duration of movement, D_x denotes the direction of node movement, and a_x denotes the rate of increment of the node's speed.

2) HIGHER SPEED STATUS (H_α)

In higher speed status, the node's motion ranges from 60% of maximum speed ($N_{s\alpha min}$) to the maximum speed value ($N_{s\alpha max}$) and $N_{s\alpha}$ represents the state speed. The rate of increment of the node's speed is given by a_α, the calculation is given below.

$$a_\alpha = N_{s\alpha}/\lambda_\alpha$$

Here T_α represents $T_0 + \lambda_\alpha$, the time margin for the mobile node, i.e. $\{T_0, T_\alpha\}$. The node's motion time λ_α, node direction D_α and speed a_α, are uniformly distributed as given the equation below.

$$\lambda_\alpha \sim U(\lambda_{\alpha min}, \lambda_{\alpha max}), N_{s\alpha} \sim U(N_{s\alpha min}, N_{s\alpha max}),$$
$$D_\alpha \sim U(0, 2*\pi)$$

where, $\{N_{s\alpha min}, N_{s\alpha max}\} \rightarrow$ Speed margin $\{0, 2*\text{pi}\} \rightarrow$ Direction margin and $\{\lambda_{\alpha\,\min}, \lambda_{\alpha\,\max}\} \rightarrow$ Duration margin

In higher speed status $\boldsymbol{H_\alpha}$, the initial value of node speed is 0 and consistently accelerated to N_{smin}, the probability of speed margin is between $N_{s\alpha min}$ and $\{N_{s\alpha min} + \Delta N_s\}$ is given by $\{N_{s\alpha min} + \Delta N_s\}$. The expression $\left\{\frac{1-\Delta N_s}{N_{s\alpha max}-N_{s\alpha min}}\right\}$ represents the value of $\{N_{smin} + \Delta N_s\}$.

The 'Probability Mass Function' (PMF) of the node speed for a discrete speed domain can be modified as given below [31].

$$r_v^\alpha(N_s) = \begin{cases} \dfrac{2}{(N_{s\alpha min} + N_{s\alpha max})} & when\ \ 0 \le N_s \le N_{s\alpha min} \\ \left(\dfrac{2}{(N_{s\alpha min} + N_{s\alpha max})}\right) * \left(\dfrac{(N_{smax} - N_s)}{(N_{s\alpha max} - N_{s\alpha min})}\right) & when\ \ N_{s\alpha min} \le N_s \le N_{s\alpha max} \end{cases} \tag{1}$$

3) MEDIUM SPEED STATUS (I_β)

In Medium Speed Status, the nodes move with medium speed which ranges from 30% of maximum speed ($N_{s\beta min}$) to 59% of maximum speed value ($N_{s\beta max}$). The direction and speed of the node are denoted as $D_{\beta E}$ and $N_{s\beta}$ respectively, with a permitted small deviation from the value $D_{\beta E}$ at any instant of time. For realizing any node's gradual transition from status H_α to status I_β, the direction gap among $D_{\beta E}$ and D_α must be limited to D_d^β and $D_d^\beta > 0$. Here ψ represents movement degree ψ and i.e. $\psi \epsilon$ (0,1) that exists among $N_{s\beta}$ and $N_{s\alpha}$.

During the node's transition from the status T_α to the status T_β, the interval of time is given by

$$T_\beta = T_\alpha + \lambda_\beta.$$

where, $\lambda_\beta \sim U(\lambda_{\beta min}, \lambda_{\beta max}), D_{\beta E} \sim U(N_{s\alpha} + D_d^\beta, D_\alpha - D_d^\beta)$

V_0 is the Gaussian random variable which relates to the node 'N' takes the value (0, 1). The initial value of speed the node is $\mathbf{I_\beta}$ (Ns_0^β) given as $N_{s\alpha}$ and $N_{s\beta}$ that is defined as given below.

$$I_\beta = \psi N s_0^\beta + (1-\psi) * N_{s\alpha} + \sqrt{(1-\psi^2 V_0)}$$

The equation given above can be simplified as equation given below because value of Ψ is very less.

$$I_\beta = N_{s\alpha} + \sqrt{(1-\psi^2 V_0)}$$

Hence medium speed PMF can be derived as a reference to the equation (1) for a discrete speed domain is given as below [31].

$$r_v^\beta(N_s) = G\left(\frac{(N_s - N_{s\beta min})}{\sqrt{(1-\psi^2)}}\right) - G\left(\frac{(N_s - N_{s\beta max})}{\sqrt{(1-\psi^2)}}\right) \Big/ (N_{s\beta max} - N_{s\beta min}) \tag{2}$$

where $G(x)$ is the cumulative density function

4) LOWER SPEED STATUS (L_σ)

In Lower speed status, the node's speed ranges from 0 ($N_{s\sigma min}$) to 29% maximum value of speed ($N_{s\sigma max}$). The changeover of node from T_β to T_σ, takes place. Where $T_\sigma = T_\beta + \lambda_\sigma$ and the time duration is $\lambda_\sigma \sim U(\lambda_{\sigma\,\min}, \lambda_{\sigma\,\max})$. Ns_0^σ shows the initial state of L_σ which is the final state for I_β.

So here, $Ns_0^{\sigma} = N_{s\beta}$. The rate of increment of the node's speed a_{σ} calculation is given below.

$$a_{\sigma} = Ns_0^{\sigma}/\lambda_{\sigma}$$
$$D_{\sigma} \sim U(D_{\beta E} + D_d^{\sigma}, D_{\beta E} - D_d^{\sigma})$$

where D_d^{σ} can deviate range from D_{σ} and $D_{\beta E}$.

Let $V_0 = \sqrt{(1-\psi^2 V_0)}$ then $Vo \sim N\left(0, 1-\psi^2\right)$ Where, V_0^{σ} is mostly determinate through $N_{s\alpha}$ (1). Here the V_0^{σ} is as well consistently distributed as $N_{s\alpha}$.

As per "3-σ" theory, if h$\sim$ N(μ, σ^2), possibility of h going outer of ($\mu - 3\sigma$, $\mu + 3\sigma$) is always less than 3 %. Hence, we presume

$$V_0 \in \left\{-3 * \sqrt{(1-\psi^2)}, 3 * \sqrt{(1-\psi^2)}\right\}$$

We can put the above value in equation (1) we get

$$V0^{\sigma} \sim U\left[N_{s\sigma min} - 3 * \sqrt{(1-\psi^2)}, \times N_{s\sigma max} + 3 * \sqrt{(1-\psi^2)}\right]$$

and

$$P\left(V0^{\sigma} \geq Ns\right) = \frac{\left(N_{s\sigma max} + 3 * \sqrt{(1-\psi^2)} - Ns\right)}{\left(N_{s\sigma max} - N_{s\sigma min} + 6 * \sqrt{(1-\psi^2)}\right)}$$

Since L_{σ} is having symmetrical property as H_{α} so we may write r_v^{σ} (Ns) as in given equation (3) [32].

$$r_v^{\sigma}(Ns) = \begin{cases} \dfrac{2}{(N_{s\sigma min} + N_{s\sigma max})} & if\ 0 \leq Ns \leq N_{s\sigma min} \\ \dfrac{2}{(N_{s\sigma min} + N_{s\sigma max})} * P\left(V_0^{\sigma} \geq N_s\right) & if\ N_{s\sigma min} \leq N_s \leq N_{s\sigma max} \end{cases} \quad (3)$$

5) PAUSE STATUS P_{φ}

In pause status $P_{\varphi,}$ node halts for a random period of time $[t_{\sigma}, t_{\varphi}]$ where $t_{\sigma} \sim U(t_{\sigma\ min}, t_{\sigma\ max})$, $t_{\varphi} = t_{\beta} + t_{\sigma}$ previous to start a new mobility cycle. The PMF value during pause status is taken as zero. PMF of a node Ns i.e. $r_v^{\beta}(Ns)$ is utilized to obtain Mobility Indicator (MI) of the node i.e. MI = 1- PMF. A node with lower value of MI gives a more stable path.

6) LINK DURATION

Link Duration Time (LDT) represents the time duration for which the dynamic link exists between a pair of nodes in the '*Special node list*'. Two mobile nodes must have a lively link when they are neighbours to each other and in the *Special node list*. The signal propagation here is not blocked by obstacles. Keeping originality of concept, the duration of existence of a link between two nodes is having time boundary [t, t∗] while the node link represents l_{ij}. Mathematically, Link Duration Time represents $T_{LD}(i, j, t)$ = [t∗-t]. The average of link time duration (T_{LDA}) of a particular path can be measured the equation is given below [32]. Where, 'N' is the total number of nodes and 'L'' is the number of link durations.

$$TLDA = \frac{\sum_{t=0}^{T}\sum_{i=1}^{N}\sum_{i=i+1}^{N} TLD(\text{i,j,t})}{L} \quad (4)$$

7) AVAILABILITY OF PATH

The accessibility of a definite path via the network among two nodes in the *'Special node list'* is known as path availability. Path failure induced by node mobility creates to route reconstruction and degrade the network performance. Path availability metric-based route selection is used for selecting a reliable route. The availability is referred as the duration of time during which a path available among two Node N_i and N_j((i,j) ϵ N). The path availability among pairs of nodes computation is given below [32].

$$APn(\text{i,j}) = \begin{cases} \dfrac{\sum_{t=tcstart(i,j)}^{T_E} I(\text{i,j,t})}{(T_E - t\,c\,\text{start(i,j)})} & if\ T_E - tcstart\ (\text{i,j}) > 0 \\ 0 & Otherwise \end{cases} \quad (5)$$

I(i,j,t) represents the Indicator Random variable that value denoted by path availability from node N_i to N_j at time t. The notation *tcstart(i,j)* refers to the starting time of communication link among N_i to N_j. The variable *APn(i,j)* denoted by determining the feasibility of communication among two mobile nodes N_i to N_j.

To examine the feasibility of communication for a path established taking *Special node list*, we calculate average path availability *APn(i,j)* averaged on node pairs calculation is given below [32].

$$AP = \left(\sum_{i=1}^{N}\sum_{j=i+1}^{N} APn(\text{i,j})\right) \div Ncpair \quad (6)$$

where *Ncpair* is the number of pairs (i,j) in the *Special node list* along Bezire curve the MANET.

8) CONNECTIVITY OF NETWORK

Connectivity metric is the essential characteristics of MANETs application, because it decides the node capacity to support link reliability level and communication. Let two nodes from '*Special node list' i.e.* N_i and N_j have the same communication range 'r' while two nodes are connected based on three conditions such as:

- Instantly connected by a link $l_{ij,}$ the node distance $d_{ij} \leq r$.
- Indirectly linked with a node path way P_{ij} having a set of links.
- Jointly linked by l_{ij} and P_{ij}.

To examine the connectivity of the network in the '*Special node list*', assign C_Y^+ and C_Y^- correspondingly refer the connectivity situation and non connectivity situation among

TABLE 1. Simulation parameters.

Parameter	Value
Simulation time	500s
Number of nodes used	50
Pairs of Sources	5,10,1520,25
Max. Node Speed	30 m/s
MAC protocol	802.11
Protocol used for Routing	AODV
Type of Traffic	CBR
Initial Energy of Node	100 Joules
Packet's Size	512 Bytes
Area of Simulation	1000m×1000m
Range of Transmission	250m
Mobility Model used	Random Way Point

node i and j, where $C^{\pm}_{Y} = \{l_{ij} \cup P_{ij}\}$.Then the connectivity of a network can be showed as the random process $\{C^{\pm}_{Y}(t)\}_{(I,j)\epsilon(1,2,\ldots,\infty,N)}$

Let the total number of active links exist in $C_Y{}^{\pm}(t)$ be $N_{L(t)}$. So, we can define

$$NL(t) = \sum_{i=1}^{N}\sum_{j=1}^{N}\frac{N_{ij}(t)}{2} \tag{7}$$

where $N_{ij}(t) \rightarrow$ Neighbor Count of node 'i' in $\{C_Y{}^{\pm}(t)\}$. The network connectivity rate $\eta(t)$ in the *Special node list* is calculated using the equation is given below [32].

$$\eta(t) = \frac{2NL(t)}{N(N-1)} \tag{8}$$

If $\eta(t) = 0$, then it is considered that no connection exists in network. When $\eta(t) = 1$, it is considered that network is completely connected. The optimal path selection algorithm is given in Figure. 2.

Based on the value of parameter like Mobility Indicator, Path availability, Link duration and network connectivity, the optimal path parameter 'OP_I' are calculated for each alternative path. The path having maximum Optimal route parameter is considered for data transmission from source node to sink node in MANET.

IV. SIMULATION AND ANALYSIS OF RESULTS

A. SIMULATION SETUP

The simulation of the novel MOAR is done using NS2. The simulator uses the front end Object Oriented Tool Command Language (OTCL) and C++ programming as the back end tool. The outcomes of MOAR in term of parameters like Routing Overhead, Packets Received Ratio, Average Delay, Throughput and Average Energy Consumption are analyzed and compared with the existing AODV protocol with plain terrain (AODV), AODV with obstacles in (AODV-RT) and EEOARA [30]. The parameters used for the simulation are shown below in Table 1 [33]. Five seeds of simulation have been made for each parameter and the seeds average are considered to draw different plots.

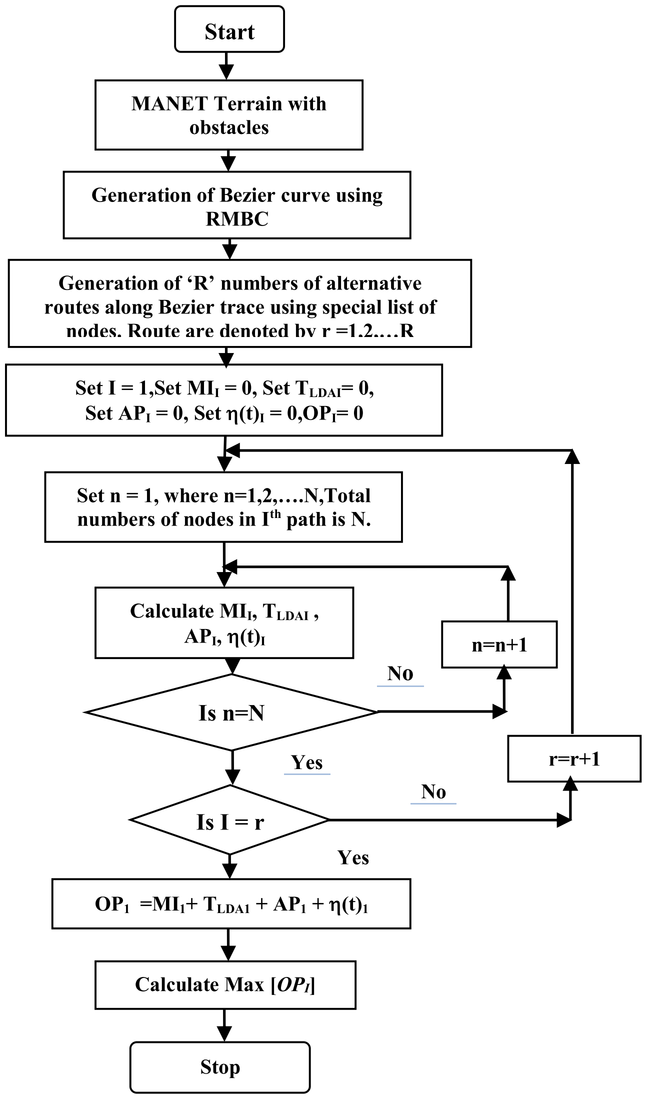

FIGURE 2. Selection of optimal path using MOAR.

B. PERFORMANCE EVALUATION METRICS

Five important metrics are considered for evaluation of performance of MOAR.

Packet delivery Ratio: It is the fraction of the total number of input data packets received at all the destinations to the total number of data packets transmitted by all sources.

Average delay: It is defined as the average of total end-to-end time delays incurred to all the data packets during its propagation from source to destination.

Routing Overhead: It is the fraction of the total number of routing packets broadcasted to network to deliver a single data packet to the destination.

Throughput: Throughput is defined as the product of the total number of packets received at the destination and the packet size. It is generally given in Kbps.

Energy Consumption: Average energy consumption defined as to the ratio of total energy consumed by all the nodes to the total number of nodes.

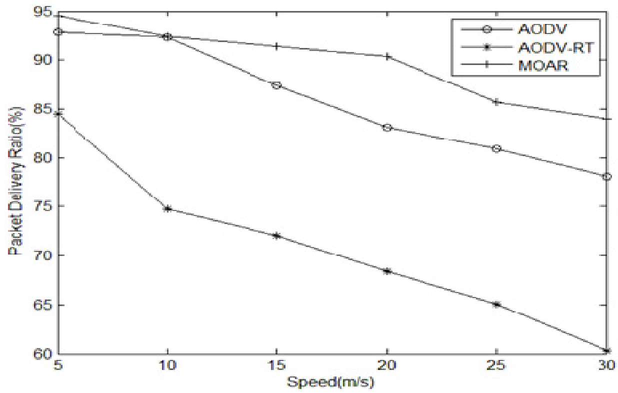

FIGURE 3. PDR for 50 nodes with 10 sources.

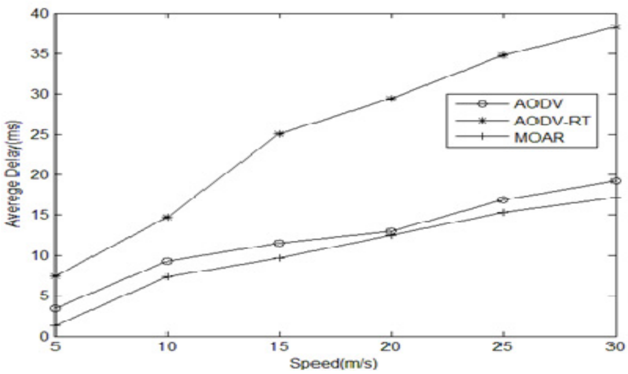

FIGURE 4. Average delay 50 nodes with 10 sources.

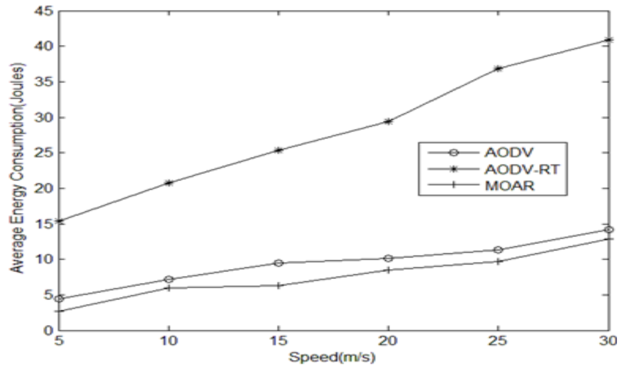

FIGURE 5. Average EC for 50 nodes with 10 sources.

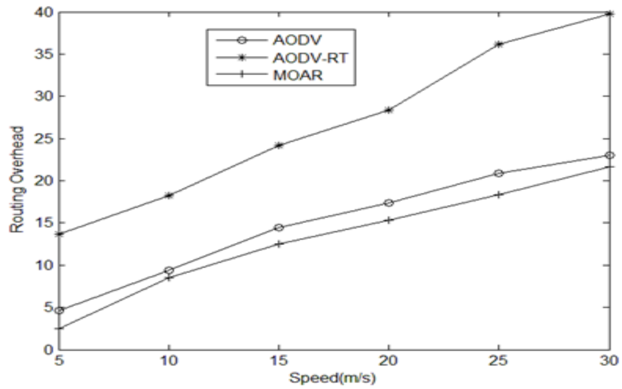

FIGURE 6. Routing overhead for 50 nodes with 10 sources.

C. PERFORMANCE ANALYSIS

1) VARYING MOBILITY (Varying Speed)

During simulation, the mobility of mobile nodes is varied by varying their speed. The duration of pause time is fixed at 10 sec. 10 sources are taken here, i.e. 10 nodes are transmitting data and 10 nodes are receiving data. Outcomes of MOAR are analyzed in comparison with AODV-TR and AODV.

From the Figure 3 it is clear that the Packet delivery fraction (PDR (%)) of AODV protocol is 92.85% on the speed value '5 m/s' and decreases gradually to 78.13% at speed value 30 m/s. At the speed value is '5 m/s', the node's mobility is less, hence the number of broken links is low and the value of PDR (%) is more. PDR (%) of AODV is more than AODV-TR i.e. 84.49% at speed '5 m/s'. The reduction in the PDR is due increase in link break in the presence of obstacles. A similar trend is monitored as the speed value increases. PDR (%) of MOAR is higher than AODV protocol and that is 94.56% at speed '5 m/s'. Link-breaks in MOAR are less due to use of obstacle avoidance technique. PDR (%) of MOAR is overly improved by 5% as compared to the AODV.

The Figure 4 shows the variation of Average Delay with the change in node's speed. 'Average Delay' of AODV is 3.49 ms at the speed value '5 m/s', it improves, as speed value increases due to increase in link-break. 'Average Delay' of AODV-RT is higher than the AODV protocol, i.e. 7.49 ms at speed value '5 m/s'. The value of Average Delay increases as there is an increase in link-break due to the existence of the obstacles. 'Average Delay' of MOAR is 1.34 ms at the speed value '5 m/s' that is lower than AODV.

This is because of implementation of mobility-aware technique. Average Delay of MOAR is overly reduced by 13.57 % than AODV.

The plot Figure 5 shows the variation of the value of the Average Energy Consumption (AEC) with change in node's speed. AEC of the AODV protocol at speed value '5 m/s' is 4.48J. Similarly, AEC of AODV-RT at speed value '5 m/s' is 15.34J. This raise in the AEC is because of the presence of obstructing entities which causes the link-failure. As a result of that, new path finding processes are again started and hence the consumption of energy increases. MOAR is having energy consumption 2.65J at the speed value '5 m/s'. The cause of decreases of energy consumption is due to decrease in number of link-break as MOAR implements of mobility-aware technique. The Average Energy Consumption of MOAR is overly decreased by 19.27% than AODV.

The plot Figure 6 shows the variation of Routing Overhead (Normalized Routing Overhead) with changes in value of speed. Routing Overhead of the AODV protocol at speed value '5 m/s' is 4.65. AODV-RT is having Routing Overhead 13.65 at speed value '5 m/s'. The increase in Routing Overhead is due to the presence of obstacles for which link-break increases. So that again the new path search process is started so extra routing and control packets are flooded

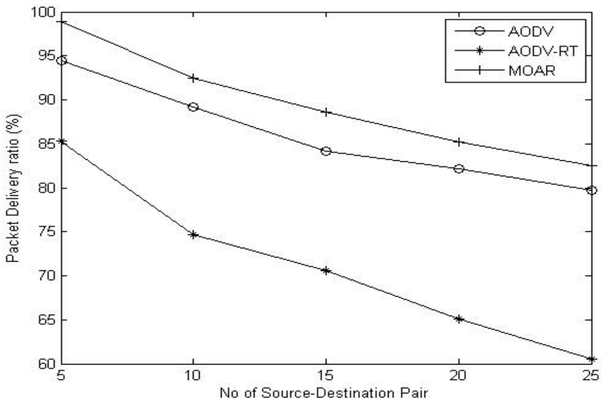

FIGURE 7. PDR for 50 nodes with 10 sec pause time.

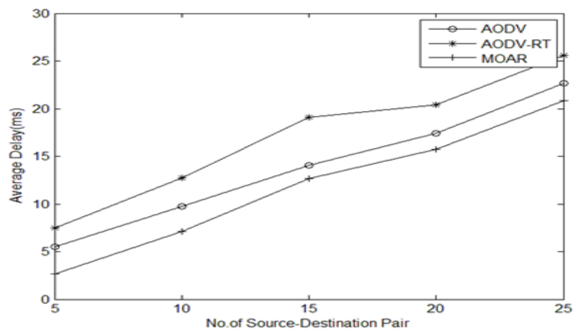

FIGURE 8. Average Delay for 50 nodes with 10 sec pause time.

into the network. Routing Overhead of MOAR at speed value '5 m/s' is 2.47. Here Routing Overhead decreases because due to decrease in link-break as MOAR uses obstacle-aware technique. Routing Overhead of MOAR is overly decreased by 12.13% than AODV.

2) CHANGING TRAFFIC OF THE NETWORK

Traffic volume is varied here by varying the number of pairs of source-destinations. Pause duration is set at 10 sec and simulation is done taking 50 mobile nodes. Performance of MOAR is analyzed in comparison with the AODV-RT and AODV.

The plot Figure 7 shows the change of PDR% with regard to the traffic of the network, i.e. Source-Destination Pairs (SD-Pair). It is found from the figure that PDR% of the AODV protocol is 94.49 at the SD-Pair value '5'and it decreases gradually to 79.75 at SD-Pair value 25. The reduction of PDR percentage is as a result of the increase of traffic on the network (i.e. SD-Pair) due to increase in congestion of the network. PDR (%) of the AODV-TR is lesser than the AODV and having value 85.29% at the SD-Pair value '5'.

This happens as in the existence of obstacles, the link-break increases. The same trend is monitored for all values of SD-Pairs. MOAR is having PDR value 98.91%, which higher than AODV at the SD-Pair value '5'. Link-break reduces as obstacle-aware technique is implemented in MOAR. PDR of the MOAR is overall increased by 4.15 % compared to AODV for all value of traffic on the network.

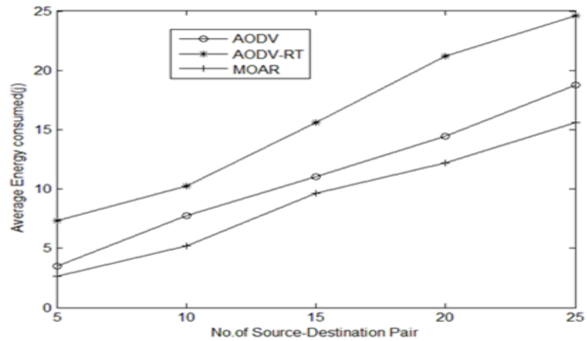

FIGURE 9. Average EC for 50 nodes with 10 sec pause time.

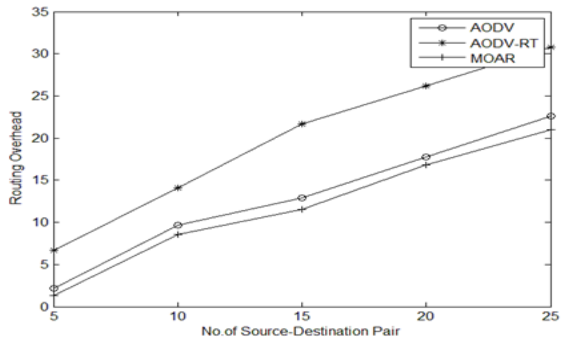

FIGURE 10. Routing overhead for 50 nodes with 10 sec pause time.

The plot Figure 8 shows the change in the Average Delay in regard to the change in the Destination Pairs (SD-Pair). From the figure it is examined that the value of Average Delay of the protocol AODV is 5.49 ms when SD-Pair value is 5. Gradually, it rises to 22.64 ms when the SD-Pair value is 25. Average Delay of MOAR is less than AODV and is 2.70ms. Average Delay of a network decreases when number of link-break reduces. Here the impact of the existence of obstacles is reduced due to use of obstacle-aware technique. The Average Delay of MOAR is overly decreased by 14.85 % in compared with the AODV.

Plot Fig 9 shows the change in Average Energy consumed in regard to the Destination Pairs (SD-Pair). From the Figure 9, it is examined that the Average value of Energy consumed by AODV is 3.49 j when SD-Pair value is 5 and it rises gradually to 18.75 j at SD-Pair value 25. When traffic of a network increases, the Energy consumption of the network also increases as the congestion of the network increases. The Average value of Energy consumption of the AODV-TR is greater than the AODV and is having value 7.34 j. The number of link-break increases in the network with the existence of obstacles in the terrain area. The same trend is marked for all values of SD-Pairs. Average Energy consumption of MOAR is less than the AODV and that is 2.65 j. This is due to decrease of link-break as this protocol uses obstacle-aware technique. The Average Energy consumption of MOAR is overall decreased by 19.72 % in comparison with the AODV for all traffic values.

The plot Figure 10 shows the change in Routing Overhead (Normalized Routing Overhead) in regard to the SD-Pair.

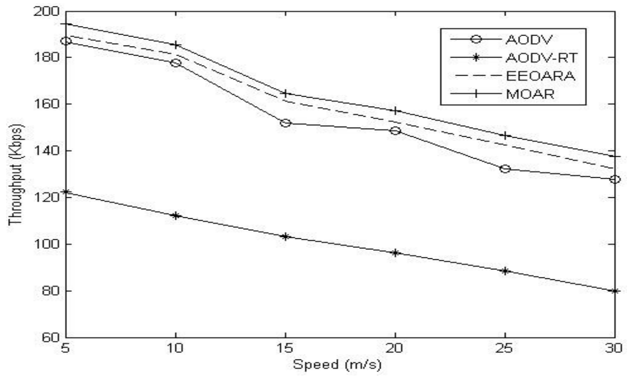

FIGURE 11. Throughput for 50 nodes with 10 sources.

From the Figure 10, it is examined that the Routing Overhead of the AODV protocol is 2.18 at SD-Pair value 5 and rises gradually to 22.59 at the SD-Pair value 25. The increase of Routing Overhead is because of an increase in the traffic on the network. As traffic of the network increases congestion of the network also rises. That increases link-breaks and therefore Routing Overhead of the network also increases. AODV-TR is having Routing Overhead higher than the AODV and its value is 6.65 at SD-Pair value 5. This is due to increases in link-break in the network as obstacles are present in terrain. The similar trend is marked for every SD-Pairs value. MOAR is having Routing Overhead lesser than the AODV and that is 1.34. The decrease in link-break is due to implementation of obstacle-aware technique. The Routing Overhead of MOAR is overall decreased by 9.09 % in comparison with the AODV at all traffic value of the network.

3) THROUGHOUT COMPARISON OF AODV, EEOARA AND MOAR

The plot Figure 11 shows the change in the average value of Throughput in regard to the variation of the node's speed. The duration of pause time is fixed at 10 sec. 10 sources are taken here. The figure shows that the Throughput of AODV is 186.91 kbps at speed 5 m/s. In the presence of obstacles, the Throughput of AODV-RT is at 5 m/s is reduced to 122.23 kbps. Throughput of EEOARA is at speed 5 m/s is 189.61 kbps [30]. Throughput of MOAR is higher than EEOARA at speed 5 m/s i.e. 194.61 kbps. As the speed of nodes increases, mobility of nodes increases, more the number of links break, hence average Throughput decreases. A similar trend is observed for all the protocols compared here. MOAR gives 3.23 % higher throughput that of the EEOARA and 5.06 % higher than that of AODV.

The plot Figure 12 shows the change in the average value of Throughput in regard to the variation of SD-Pairs. Pause duration is set at 10 sec and simulation is done taking 50 mobile nodes. The figure shows that the Throughput of AODV is 94.41 kbps at 5 SD-Pairs. In the presence of obstacles, the Throughput of AODV-RT is at 5 SD-Pair is reduced to 73.41 kbps. Throughput of EEOARA is at 5 SD-Pair is 98.11 kbps [30]. Throughput of MOAR is higher than EEOARA at 5 SD-Pairs i.e. 104.41 kbps. As the number of

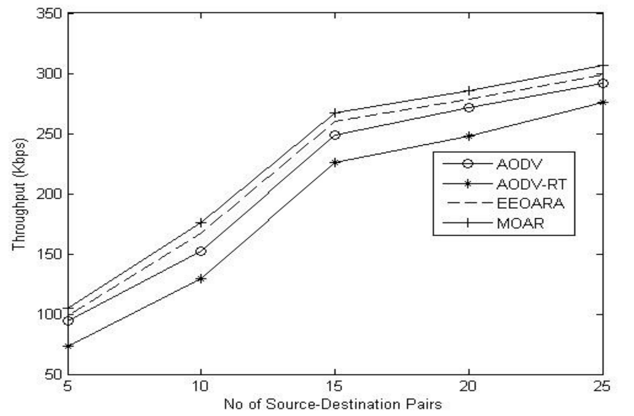

FIGURE 12. Throughput for 50 nodes with 10 sec pause time.

SD-Pairs increases, network traffic increases, more sources send data packet to different destinations, hence average Throughput also increases.

A similar trend is observed for all the protocols compared here. MOAR gives 3.35% higher throughput that of the EEOARA and 6.34 % higher than that of AODV.

V. CONCLUSION

The suggested MOAR protocol performs better than EEOARA and AODV with the existence of obstacles in the terrain area, thus enhancing the communication efficiency of the MANET. The outcomes of the MOAR have been evaluated and compared with AODV, AODV-RT and EEOARA. It is found that MOAR provides better enhancement in terms of Packet Received Ratio, Average Delay, Average Energy Consumption, Throughput and Routing Overhead in changing mobility and traffic condition.

REFERENCES

[1] D. B. Johnson and D. A. Maltz, "Dynamic source routing in ad hoc wireless networks," in *Mobile Computing* (The Kluwer International Series in Engineering and Computer Science), vol. 353, T. Imielinski, and H. F. Korth, Eds. Boston, MA, USA: Springer, 1996, doi: 10.1007/978-0-585-29603-6_5.

[2] E. M. Royer and C.-K. Toh, "A review of current routing protocols for ad hoc mobile wireless networks," *IEEE Personnel Commun.*, vol. 6, no. 2, pp. 46–55, Apr. 1999.

[3] E. M. Royer, P. M. Melliar-Smith, and L. E. Moser, "An analysis of the optimum node density for ad hoc mobile networks," in *Proc. IEEE Int. Conf. Commun. Conf. Rec.*, vol. 3, Jun. 2001, pp. 857–861.

[4] I. Chlamtac, M. Conti, and J. J.-N. Liu, "Mobile ad hoc networking: Imperatives and challenges," *Ad hoc Netw.*, vol. 1, no. 1, pp. 13–64, Jul. 2003.

[5] G. Lu, G. Manson, and D. Belis, "Mobility modeling in mobile ad hoc networks with environment-aware," *J. Netw.*, vol. 1, no. 1, pp. 54–63, May 2006.

[6] B. K. Panda, U. Bhanja, and P. K. Pattnaik, "Some routing schemes and mobility models for real terrain MANET," in *Machine Learning and Information Processing* (Advances in Intelligent Systems and Computing), vol. 1101, D. Swain, P. Pattnaik, and P. Gupta, Eds. Singapore: Springer, 2020, doi: 10.1007/978-981-15-1884-3_49.

[7] M. Jabirulla and A. Kumar, "Design and analysis of obstacle, mobility and power aware optimal MANET routing—A review," *Solid State Technol.*, vol. 63, no. 3, pp. 46–55, 2020.

[8] S. Mostafavi, V. Hakami, and F. Paydar, "A QoS-assured and mobility-aware routing protocol for MANETs," *Int. J. Informat. Visualizat.*, vol. 4, no. 1, pp. 1–9, Feb. 2020.

[9] O. Oladayo and A. Ashraf, "A secure and energy-aware routing protocol for optimal routing in mobile wireless sensor networks (MWSNs)," *Int. J. Sensors, Wireless Commun. Control*, vol. 9, no. 4, pp. 507–520, Sep. 2019.

[10] Q. Han, Y. Bai, L. Gong, and W. Wu, "Link availability prediction-based reliable routing for mobile ad hoc networks," *IET Commun.*, vol. 5, no. 16, pp. 2291–2300, Nov. 2011.

[11] R. Suraj, S. Tapaswi, S. Yousef, K. K. Pattanaik, and M. Cole, "Mobility prediction in mobile ad hoc networks using a lightweight genetic algorithm," *Wireless Netw.*, vol. 22, no. 6, pp. 1797–1806, Aug. 2016.

[12] J. A. Torkestani, "Mobility prediction in mobile wireless networks," *J. Netw. Comput. Appl.*, vol. 35, no. 5, pp. 1633–1645, Sep. 2012.

[13] C. Papageorgiou, K. Birkos, T. Dagiuklas, and S. Kotsopoulos, "An obstacle-aware human mobility model for ad hoc networks," in *Proc. IEEE Int. Symp. Modeling, Anal. Simulation Comput. Telecommun. Syst. (MASCOTS)*, Sep. 2009, pp. 1–9.

[14] S. Boschi, P. Crescenzi, M. Di, and P. Vocca, "A mobility model simulation environment for mobile wireless ad-hoc networks," in *Proc. 1st Int. conference Simul. Tools Techn. Commun., Netw. Syst. Workshops*, 2008, pp. 1–11.

[15] S. Kim, "Adaptive MANET multipath routing algorithm based on the simulated annealing approach," *Sci. World J.*, vol. 2014, 2014, Art. no. 872526, doi: 10.1155/2014/872526.

[16] A. Belghith, M. Belhassen, A. Dhraief, N. E. Dougui, and H. Mathkour, "Autonomic obstacle detection and avoidance in MANETs driven by cartography enhanced OLSR," *Mobile Inf. Syst.*, vol. 2015, pp. 1–18, 2015, Art. no. 820401, doi: 10.1155/2015/820401.

[17] A. Moussaoui, F. Semchedine, and A. Boukerram, "A link-state QoS routing protocol based on link stability for mobile ad hoc networks," *J. Netw. Comput. Appl.*, vol. 39, no. 1, pp. 117–125, Mar. 2014.

[18] J. M. M. Alves, "Path planning and collision avoidance algorithms for small RPAS," M.S. thesis, Dept. Aerosp. Eng., Tecnico LISBOA, Lisbon, Portugal, 2017.

[19] K. Amjad, M. Ali, S. Jabbar, M. Hussain, S. Rho, and M. Kim, "Impact of dynamic path loss models in an urban obstacle aware ad hoc network environment," *J. Sensors*, vol. 2015, pp. 1–8, Mar. 2015.

[20] Z. Mi, Y. Yang, and J. Y. Yang, "Restoring connectivity of mobile robotic sensor networks while avoiding obstacles," *IEEE Sensors J.*, vol. 15, no. 8, pp. 4640–4650, Aug. 2015.

[21] L. Yao, J. Wang, X. Wang, A. Chen, and Y. Wang, "V2X routing in a VANET based on the hidden Markov model," *IEEE Trans. Intell. Transp. Syst.*, vol. 19, no. 3, pp. 1–11, Jun. 2017.

[22] M. Belhassen, A. Dhraief, A. Belghith, and H. Mathkour, "ALOE: Autonomic locating of obstructing entities in MANETs," *J. Ambient Intell. Humanized Comput.*, vol. 9, no. 2, pp. 1–20, 2018.

[23] R. M. Chintalapalli and V. R. Ananthula, "M-LionWhale: Multi-objective optimisation model for secure routing in mobile ad-hoc network," *IET Commun.*, vol. 12, pp. 1406–1415, 2018.

[24] X. Ji, H. Yu, G. Fan, H. Sun, and L. Chen, "Efficient and reliable cluster-based data transmission for vehicular ad hoc networks," *Mobile Inf. Syst.*, vol. 2018, Jul. 2018, Art. no. 9826782.

[25] H. Yang, Z. Li, and Z. Liu, "A method of routing optimization using CHNN in MANET," *J. Ambient Intell. Humanized Comput.*, vol. 10, no. 5, pp. 1759–1768, May 2019.

[26] T. D. Nguyen, J. Y. Khan, and D. T. Ngo, "A distributed energy-harvesting-aware routing algorithm for heterogeneous IoT networks," *IEEE Trans. Green Commun. Netw.*, vol. 2, no. 4, pp. 1115–1127, Dec. 2018.

[27] B. K. Panda, U. Bhanja, and P. K. Pattnaik, "Obstacle and mobility aware optimal routing for MANET," *J. Intell. Fuzzy Syst.*, vol. 37, no. 1, pp. 1007–1017, Jul. 2019.

[28] S. K. Bisoyi and P. K. Pattnaik, "A neuron-based active queue management scheme for internet congestion control," *Int. J. Reasoning-Based Intell. Syst.*, vol. 12, no. 4, pp. 248–254, 2020.

[29] S. Sarkar and R. Datta, "Mobility-aware route selection technique for mobile ad hoc networks," *IET Wireless Sensor Syst.*, vol. 7, no. 3, pp. 55–64, Jun. 2017.

[30] B. K. Panda, U. Bhanja, and P. K. Pattnaik, "A novel energy efficient obstacle aware routing algorithm for MANET," *Int. J. Knowl.-Based Intell. Eng. Syst.*, vol. 24, no. 1, pp. 37–44, Apr. 2020.

[31] L. Lei, D. Wang, L. Zhou, X. Chen, and S. Cai, "Link availability estimation based reliable routing for aeronautical ad hoc networks," *Ad Hoc Netw.*, vol. 20, pp. 53–63, Sep. 2014.

[32] W. Wang, J. Wang, M. Wang, B. Wang, and W. Zhang, "A realistic mobility model with irregular obstacle constraints for mobile ad hoc networks," *Wireless Netw.*, vol. 25, no. 2, pp. 1–20, 2017.

[33] S. R. Das, C. E. Perkins, E. M. Royer, and M. K. Marina, "Performance comparison of two on-demand routing protocols for ad hoc networks," *IEEE Personnel Commun.*, vol. 8, no. 1, pp. 16–28, Feb. 2001.

PRASANT KUMAR PATTNAIK (Senior Member, IEEE) received the Ph.D. degree in computer science. He is currently working as a Professor with the School of Computer Engineering, KIIT University, Bhubaneswar, India. He has more than a decade of teaching and research experience. He has published numbers of research papers in peer-reviewed international journals and conferences. His research interests include mobile computing, cloud computing, brain–computer interface, and privacy preservation. He is a fellow of IETE.

BANOJ KUMAR PANDA graduate in electronics and telecommunication engineering from The Institution of Engineers (India), Kolkata. He received the M.Tech. degree in digital electronics from Visvesvaraya University, Karnataka. He is currently pursuing the Ph.D. degree with Utkal University, Odisha. His research interest includes mobile ad-hoc networks.

MANGAL SAIN received the M.Sc. degree in computer application from India, in 2003, and the Ph.D. degree in computer science, in 2011. Since 2012, he has been an Assistant Professor with the Division of Computer Engineering, Dongseo University, South Korea. He has authored over 70 international publications, including journals and international conferences. His research interests include wireless sensor networks, cloud computing, the Internet of Things, embedded systems, and middleware. He is a member of TIIS and a TPC member of more than ten international conferences.