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OPBRP - obstacle prediction based routing protocol in VANETs

M. Khalid Diaa [a], I. Samer Mohamed [b,*], M. Ayman Hassan [a]

[a] Benha Faculty of Engineering, Benha University, Egypt
[b] Faculty of Engineering, October University for Modern Sciences and Arts (MSA), Egypt

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Vehicular Ad-hoc Networks (VANETs) are recently getting high attention from different researchers due to increasing traffic problems, especially in densely populated countries. Increasing rates of accidents call for an Intelligent Transportation System (ITS) with efficient performance to reduce and mitigate this trend. The required enhancement of the ITS can be more focused on traffic performance, integrity, and reduction of the vehicles' CO_2 emissions. Existing routing protocols for VANETs consider different situations and methods to establish reliable communication between the vehicles and infrastructures. However other situations have not been addressed carefully like the link stability between vehicles during packet exchange. This paper develops an Obstacle Prediction Based Routing Protocol (OPBRP) for vehicle detection, packets transmission to Roadside Units (RSU) and choosing a better route in terms of reliability via using vehicle's Kinematics and Mobility prediction in VANET. Two fundamental contributions are included in this paper: (1) Upgrading prediction routing protocol to transfer packets using a reliable path, and (2) Adding new logic in choosing the intermediate nodes to the destination to achieve a higher Packet delivery ratio (PDR). The OPBRP uses the predictive greedy as forwarding algorithm and the predictive perimeter forwarding as recovery algorithm after introducing enhancements to both algorithms to meet the requirements of VANETs environment. To materialize the value achieved from the mentioned contributions we tested the newly developed OPBRP against the existing routing protocols using Vehicle in Network Simulation (Veins) which shows that our proposed protocol outperformed current existing routing protocols in terms of PDR by achieving 18.46% improvement, end-to-end delay (E2E-Delay) by achieving 10.51% improvement, and total power consumption used in transmission by achieving 23.80% improvement.

1. Introduction

Mobile Ad hoc NETworks (MANETs) is one kind of decentralized networks, which consists of various wireless nodes with no fixed infrastructure and pre-defined topology [1]. Each node is considered as an end node or router and is free to move without any restrictions. Also, the network must be dynamic and self-configured with multi-hop communications. VANETs on the other hand, is considered as a subclass of MANETs, where VANETs are the promising protocol for future ITS to improve the traffic efficiency and safety. In VANETs, each vehicle is considered as a node, and its movement can be predictable because the vehicles are restricted to the existing roads. Furthermore, each vehicle will become one part of the network and it may manage and control the communication at the network consistent with its specified requirements [2,3]. The kinematic data for vehicle such as its position, velocity and acceleration can be transmitted to another vehicle if it is within its radio range and therefore enables detecting nearby vehicles and establishing the temporary network's topology [4,5].

VANETs are based on short-range wireless communications between vehicles. Typical range of radio signal in VANETs is typically-three hundred meters. However, in a few implementations this range could extend to one thousand meters. The accomplishments of VANET features completely depend on the routing scenarios that are used for communication among the Vehicle-to-

* Corresponding author.
E-mail addresses: khaled.diaaeldeen@bhit.bu.edu.eg (M. Khalid Diaa), saibrahim@msa.eun.eg (I. Samer Mohamed), ayman.mohamed@bhit.bu.edu.eg (M. Ayman Hassan).

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Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) modes [4]. The information collected from GPS devices helps in routing and selecting optimum routing paths to destination nodes. With the assistance of GPS, every node has its very own location as well as the destination node's location [6–8].

VANET services can be classified as follows: (i) services that enhance safety, including risk-avoidance and automatic driving functions, and (ii) services that aim to enhance comfort, including services that notify surrounding road situations and others which include information exchange and sharing among users. Although a number of those services have already been found through a centrally controlled system, autonomous distributed systems based on VANET can endure inexpensively and adapt to a wide range of services [9–13]. The performance of VANET routing protocols is so crucial to the performance of both types of services.

The routing protocols for VANETs can be classified into main categories as shown in Fig. 1. The position-based routing protocol, known as geographic routing protocol, has been recognized as most promising for VANETs because of its stability in dealing with the fast topology changes and variable vehicles' velocities. Current protocols utilize beacon messages to detect neighbors periodically and find the best route for destination. Furthermore, existing protocols consider the velocity of neighbors at the beginning of transmission, but they don't consider the link stability of these neighbors throughout the duration of packet exchange, as during transmission time the relay nodes may experience halfway obstacles, which may lead to high packet loss due to low signal-to-noise ratio or because destination went out-of-range altogether [2,4,14–16]. The link stability can't be ignored in this situation and needs to be considered while choosing the optimum route for destination [15]. Existing routing protocols lack flexibility in dealing with the highly dynamic environment and changeable vehicle speeds in VANETs, frequent link failure, non-line of sight (NLOS) communication, and connectivity disconnection in the sparse regions.

Substantial number of studies have proposed routing protocols that use the side information of vehicles' three-dimensional movement. For example, an unmanned aerial vehicle (UAV), also known as drones, could be used to provide mobility information in a broadcast mode. Mobility information can improve the performance for routing in VANETs by decreasing frequent link failure due to NLOS communication, and connectivity loss in the sparse regions [17–20], However, this approach has two key challenges: First, risks coupled with the usage of drones at dense areas as they can interfere with the flight patterns of other aircraft and pose potential safety threats and could harm pedestrians if not controlled with a high safety protocol. Second protocols involving drones should consider the amount of residual energy and the lifetime of the UAV to make a practical solution [20].

A class of MANET's where a group of UAVs are connected in ad-hoc manner are called Flying Ad hoc Network (FANET). Significant number of routing protocols were proposed for FANETs that introduce different mechanisms including.

- Update information about adjacent routers only to limit the propagation of control messages which was introduced in Temporarily Ordered Routing Algorithm (TORA) [21].
- Utilize the benefits of both proactive routing that uses large bandwidth to maintain routing information and reactive routing which uses long-route request delays in The Zone Routing Protocol (ZRP). ZRP uses concept of zones, where inside a zone proactive routing is used, while communication outside the zone uses reactive routing [21,22].
- Choose multipoint relay (MPR) nodes which was introduced at Optimized Link State Routing Protocol (OLSR), where the source node chooses a set of MPR nodes so that the MPR nodes can cover two-hop neighbors [21].
- The store-carry-and-forward strategy in hybrid packet forwarding algorithm (HY BD^{fwd})which lets the sender use a node as ferry to store source's message and carry it directly to the destination node [23].

The work described in this paper is focusing on developing a routing protocol assuming the absence of the UAV. We propose an Obstacle Prediction Based Routing Protocol (OPBRP) that has the following features:

- Uses mobility prediction while considering the link stability during transmission time.
- Considers the link stability through analyzing the speed and position information collected from neighbors.
- The mentioned analysis is used to predict the neighbor's location during the duration of packet exchange.

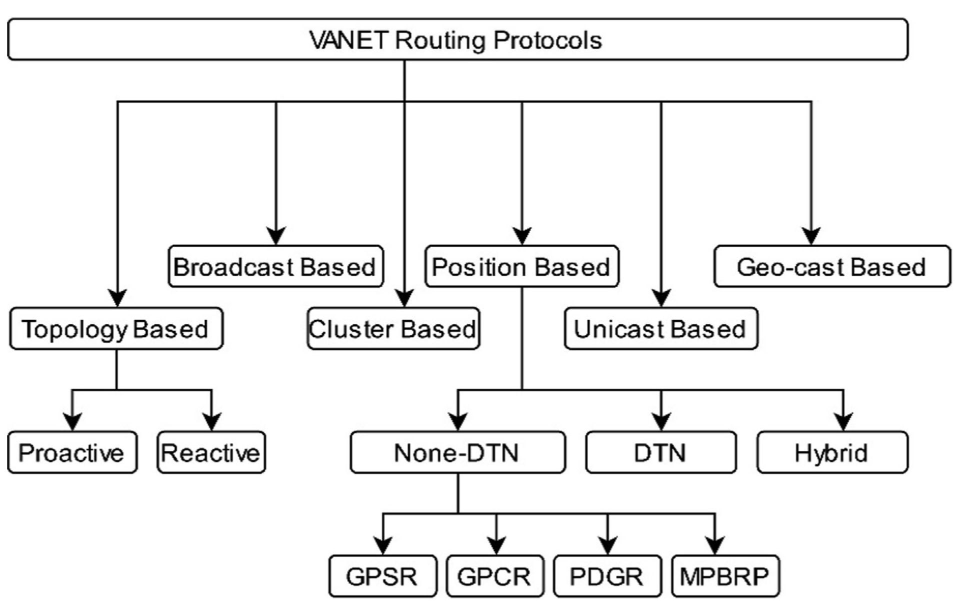

Fig. 1. Routing protocols in VANET.

- Predicts the neighbors' stability by drawing a trajectory map from each sender to surrounding neighbors, while estimating the probability of presence of radio obstacles in the trajectory.
- Uses the map to avoid the paths with radio obstacles, which leads to decreasing the probability of packet loss.

Via simulation, we show the effectiveness of the proposed protocol by comparing PDR, average hops count, and total power consumption used in transmission. The results show that the proposed protocol achieves higher PDR as it avoids ping pong cases, and better E2E-delay by avoiding the radio obstacles that affect the link quality during packet transmission time. It also achieves better average hop count by using prediction to avoid undesired hops, as well as better power consumption by detecting the packets that will be most probably blocked by a radio obstacle and consume power to recover.

2. Background and Related Work

Over the last few years, large efforts were made by researchers around the world to develop and analyze the routing protocols that can suit VANETs challenging requirements [24–27]. The major challenges for these routing protocols can be summarized as: (i) High dynamic topology: the duration of direct communication between any two vehicles could be too short to establish a stable communication link. (ii) Delay constraints: VANETs high data rates may not be needed, despite minimum end-to-end delay is required, especially for messages that could be helpful to prevent an accident [28,29]. (iii) Frequent network disconnection: The vehicles are always in a moving state; the connection between vehicles can be lost because of radio obstacles that can lead to high loss of packets. (iv) Battery power and storage capacity: In current vehicles battery power and storage are unlimited. Thus, it has enough computing power that is unavailable in MANETs that can be useful for powerful communication and making routing decisions. (v) Communication environment: Unlike MANETs, the node movement in VANETs are restricted to intersecting roads that can be used to enhance the performance of routing, so the routing protocols need to consider those challenges by design [26,27,30–32].

A class of MANEs with increasing interest is the FANETs, where routing algorithms are developed to efficiently connect flying UAV's. Among those algorithms is the stochastic packet forwarding algorithm (SPA). SPA is a recent routing protocol for FANETs. SPA uses a stochastic forwarding drone selection based on the combination of multiple real-time network metrics as forwarding algorithm. SPA computes the forwarding availability of each forwarding candidate drone to take the forwarding decision. The author used OMNeT++ and random waypoint mobility model to evaluate SPA performance. The SPA showed better performance than Geographic Delay Tolerant (DTN_{geo}) in terms of PDR and the average throughput, indicating a good approach in FANETs [33].

However, significant differences between FANETs and VANETs could be realized. First, FANET network contains significantly lower number of nodes compared to VANETs (e.g. 15 nodes in [33] vs 100–700 nodes at VANETs model used in this research). Second, channel propagation model for FANETs has major differences compared to the propagation model in dense areas, where the effect of high buildings and definite routes is evident. This calls for independent study of routing algorithm optimization taking into consideration these aspects.

Enormous number of routing protocols has been proposed to address VANET's challenges, including the position-based routing protocols, which proved to have the potential to satisfy the needs for VANETs constraints.

2.1. Evaluation for VANETs routing protocols

Researchers used different Key Performance Indicators (KPIs) to evaluate the routing protocols performance, among these KPIs are: Packet delivery ratio (PDR), communication distance (CD), routing protocol overhead, end-to-end delay (E2E-Delay), average hops (Hop Count), the path length and number of nodes the protocol can handle the communication efficiently with [4]. Most used KPIs are: (1) PDR, which measures the ratio of packets that can be delivered successfully from source node to destination node. (2) E2E-Delay, which measures the average time the packet takes to be delivered from source to destination, (3) Average Hop Count, which reflects the average number of intermediate nodes that the packet passes-by to reach the destination. Moreover, a valuable KPI that affects fuel consumption is (4) the power consumed in transmission of packets which measures the total power consumed in transmission of packets during the simulation scenarios [5,34–37].

2.2. Position based routing protocols in VANETs.

This section reviews the latest existing position-based routing protocols [3,10,11,24].

(1) Greedy Perimeter Stateless Routing (GPSR): it uses the positions of nodes and packet's destination to make the forwarding decisions. Yet, its algorithm doesn't consider any prediction that can't be ignored for highly dynamic environment and highway [38]. GPSR has been tested by the Network Simulator (NS2). The tester used PDR, overhead for routing and path length as KPIs to prove GPSR performance. However, it lacks for the prediction of the vehicular nodes and is therefore not suitable for urban areas that encounter frequent disconnections from the radio obstacles [39].
(2) Greedy Perimeter Coordinate Routing (GPCR): This Protocol benefits from the structure of the urban streets from a natural planar graph and uses greedy algorithms as forwarding strategy and right-hand rule as a recovery strategy without using algorithms. GPCR was tested by NS2 simulator and used PDR, CD, and hops count as KPIs to evaluate the GPCR. The disadvantage of GPCR is that it only uses a natural planar graph consisting of streets and junctions without using any global or external information that are essential to have a more reliable forwarding strategy [40].
(3) Predictive Directional Greedy Routing (PDGR): it depends on position, speed, and direction of each neighbor and the predictable mobility of vehicles to make the forwarding decision. The author used NS2 simulator to test PDGR in an open environment. PDR, E2E delay, and average hops KPIs were used to test it. However, PDGR is only suitable for an open environment as it doesn't consider the radio obstacles in the urban environment [41].
(4) Mobility Prediction Based Routing Protocol (MPBRP): This protocol uses both predictive greedy forwarding and perimeter forwarding strategies to forward the packets, which improves the performance by considering the high dynamic mobility and predictive nature of vehicles. The Veins platform combining SUMO and OMNET++ has been used to test the MPBRP using PDR, E2E delay and average hops as KPIs. The protocol showed better performance than GPSR, GPCR and PDGR on the chosen KPIs. However, MPBRP is not considering the radio obstacles at transmission time, which could lead to loss of packets and high E2E-Delay [4].

2.3. Discussion

Most routing protocols assume that the vehicles are in the same location at transmission time at beacon exchange phase. This approach doesn't consider the new positions of the vehicles and the new state of radio obstacles resulting from the high speed and variable direction of vehicles. For example, when a source needs to send a packet to a destination outside its radio range, it sends beacons to detect the neighbors around. Then it chooses the neighbor that is closest to the destination with the greedy forwarding strategy. Alternatively, in prediction-based protocols the source chooses the node that will probably be the closest to the destination at transmission time. However, predictive greedy forwarding strategy doesn't consider the fact that the chosen node may have radio obstacles that prevent the reception of the packet. This will drive the protocols to use a recovery strategy, which in turn leads to lower PDR and higher E2E-Delay. Therefore, considering the effect of instability in radio conditions due to obstacles is crucial while designing efficient VANET protocols.

This paper proposes a version of position-based routing protocol which considers the effect of obstacles on VANET radio signals in urban environment through mobility prediction. The protocol is tested on a unified simulation platform. The results show good improvements compared to existing routing protocols mentioned above.

3. OPBRP: Obstacle Prediction Based Routing Protocol

This section introduces the Obstacle Prediction Based Routing Protocol (OPBRP) and shows how it can be a viable candidate for VANETs to handle the dynamic changeable topology of the network and deal with the variable velocities of vehicles and packet's loss due to radio obstacles. The OPBRP collects the vehicle's position and velocity vector collected from the global positioning system (GPS) and gets the same data for neighboring vehicles through V2V communication. These data are then used to calculate the predicted distances and angles between source, neighbors, and destination. Based on those results, each node gets a weight that guides the packet forwarding decisions.

Like any position-based routing protocol, OPBRP needs to deal with two key issues, namely the forwarding strategy and the recovery strategy. Forward strategy governs how packets are routed through nodes till it reaches its destination. Recovery strategy is engaged when the packet reaches a dead end and needs to find alternate route, so that it can overcome the problem of current local maximum. We addressed those key issues with a new technique discussed in detail in the following paragraphs. In OPBRP we use the predictive greedy as forwarding algorithm and the predictive perimeter forwarding as recovery algorithm after introducing enhancements on both to meet the requirements of VANETs environment [35,41–43].

The basic predictive greedy forwarding uses the predicted node position in the near future to choose the nearest node to destination and forward the packet to it. As shown in Fig. 2, if node S needs to send a message to Roadside Unit (RSU) it will start neighbor discovery to collect the kinematic information and predict the vehicle's positions at the transmission time and forward the packet along the route S → A → G → I → J → D → M → RSU to the destination [4].

If the greedy strategy couldn't find a node closer to the destination, like the example in Fig. 3, it switches to recovery mode and uses the basic predictive perimeter forwarding that checks if the neighbors on the perimeter can find a better candidate to forward the packet using Relative Neighborhood Graph (RNG) and Right Hand Rule. Therefore, for the current example the strategy will use the route S → B → E → A → F → H → J → RSU to forward the packet.

These strategies work fine in an open environment without radio obstacles. In urban scenarios, the link chosen to carry the packet to destination could be blocked by:

(1). Radio obstacles: if we consider the scenario at Fig. 1 and the existing radio obstacle, the message will not be delivered, as when node J tries to send the message to node D it will be blocked by radio obstacle as illustrated in Fig. 4.

(2). Transmitting to a Vehicle out of sender transmission range: as at transmission time it is evident that the message to be sent to the next neighbor is lost because the neighbor became out of source transmission range, as depicted in Fig. 5. On the other hand, if the message is sent according to the predictive greedy forwarding based on the predicted positions for vehicles, the packet will follow the route S → A → F → H → J → RSU, even if H is expected to go out of F transmission range, according to its speed vector.

OPBRP addresses the mentioned problems as follows: (1) The radio obstacles problem can be reduced through predicting the vehicles that may be blocked by radio obstacles, and hence avoid using them as intermediate nodes. The protocol utilizes the speed vector and vehicle position to calculate potential routes and calculate the probability of the presence of radio obstacles for each route. Applying this strategy to the case in Fig. 4, OPBRP would choose the route: S → A → G → I → J → L → M → RSU.

(2) The out-of-transmission problem is solved by predicting the vehicle's new location, calculating the associated free-space transmission range, and therefore avoiding those vehicles expected to go out of transmission range from the planned route. So, for the example in Fig. 5 the protocol will decide the route S → A → F → G → H → J → RSU.

OPBRP implementation is described through eight equations that calculate the link weight for different neighbors. Therefore, the forwarding decision and the route between source and destination nodes are obtained. This can be shown in a simple flowchart in Figs. 6a, 6b, which describe the steps for the proposed OPBRP.

As shown in Fig. 6a to forward the packet to destination with location (X_d, Y_d), some calculations are done on the speed vector $v_s \rightarrow$, and position (X_s, Y_s) for the source node, and neighbors speed vector and positions, $v_n \rightarrow$ and (X_n, Y_n) respectively.

First, we calculate the current distance to destination in (1).

$$D_{s,d} = \sqrt{(X_s - X_d)^2 + (Y_s - Y_d)^2} \tag{1}$$

Then if $D_{s,d}$ is within the sender transmission range, the packet is directly forwarded to the destination. Otherwise, to the protocol calculates the source angle to destination $\theta_{s,d}$ as in (2).

$$\theta_{s,d} = cos^{-1}\left(\frac{v_s \rightarrow .\ sd \rightarrow}{|\ v_s \rightarrow || \ sd \rightarrow |}\right) \tag{2}$$

where $sd \rightarrow$ is the direction vector from source to destination. The predicted position for the source at sending time can be easily calculated in (3) and (4).

$$X_s^{'} = X_s + (vt + \frac{a}{2} \times t^2) \times cos\theta_{s,d} \tag{3}$$

$$Y_s^{'} = Y_s + (vt + \frac{a}{2} \times t^2) \times sin\theta_{s,d} \tag{4}$$

where v and a are the velocity and the acceleration for the source vehicle, respectively, while $X_s^{'}$ and $Y_s^{'}$ are the predicted coordinates for the source at transmission time, and t is the time differ-

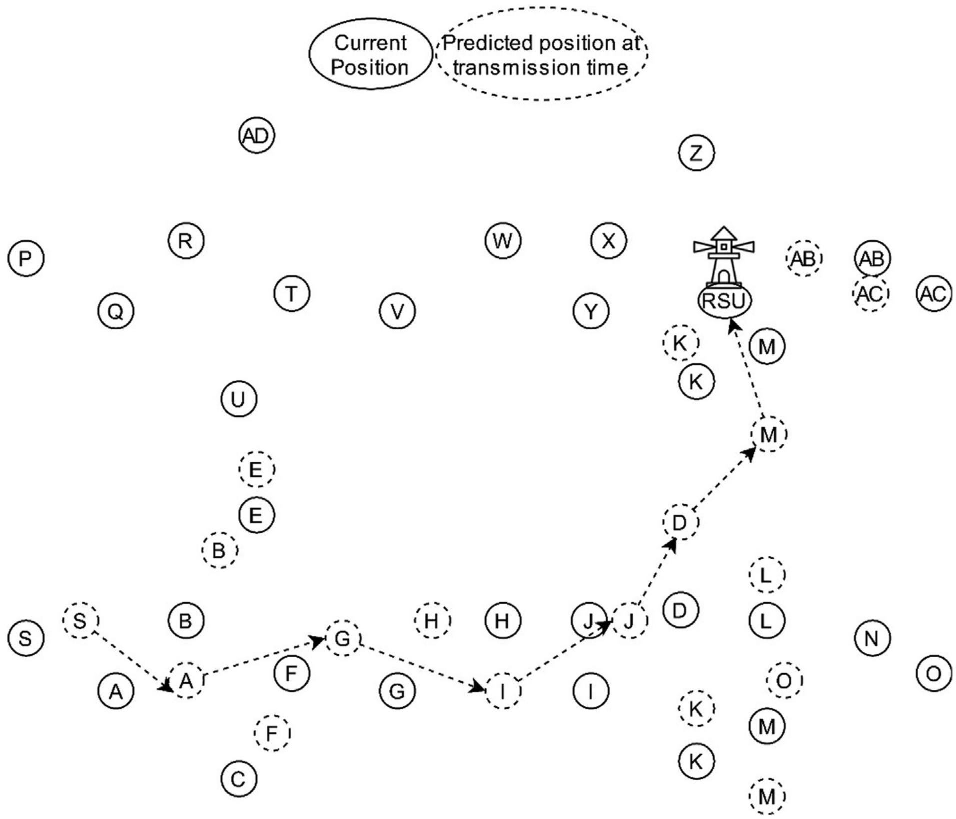

Fig. 2. The Basic Predictive Greedy Forwarding.

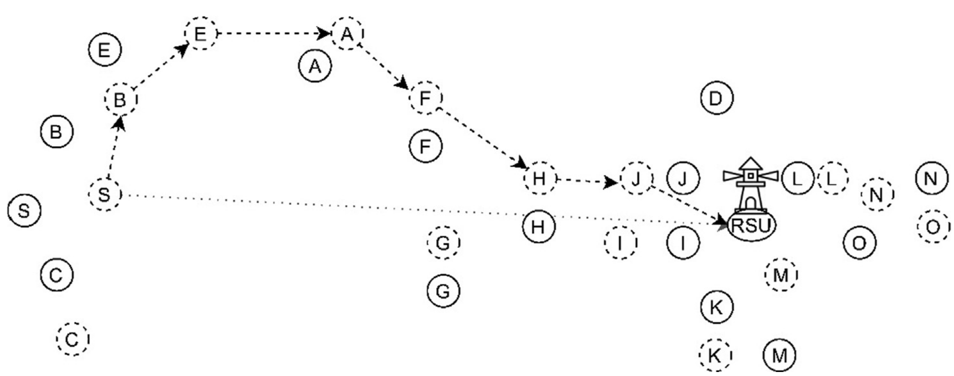

Fig. 3. The Basic Predictive Perimeter Forwarding.

ence between the current time and the time at the end of transmitting the packet. The predicted distance to destination can then be calculated in (5).

$$D'_{s,d} = \sqrt{(X'_s - X_d)^2 + (Y'_s - Y_d)^2} \tag{5}$$

Similarly, the protocol calculates for each neighbor the current distance to destination $D_{n,d}$, angle with destination $\theta_{n,d}$, predicted position for neighbor (X'_n, Y'_n) and predicted distance of the neighbor to destination $D'_{n,d}$ using formulas (1) – (5) after just replacing source subscript with the neighbor subscript. In addition, for each neighbor the predicted angle with source $\theta'_{s,n}$ is calculated in (6).

$$\theta'_{s,n} = cos^{-1}\left(\frac{v_s \rightarrow . \ sn' \rightarrow}{| \ v_s \rightarrow || \ sn' \rightarrow |}\right) \tag{6}$$

where $sn' \rightarrow$ is the direction vector for the source towards the predicted location for the neighbor at transmission time. Then, knowing $\theta'_{s,n}$, the road relation between the source and neighbor can be estimated as follows: (i) Source and neighbor on the same lane if the angle between them is approaching 0°. (ii) Source and neighbor on parallel lanes if angle is approaching 180°. (iii) Crossing lanes if approaching (90° or 270°). Otherwise, if the angle is approaching (45°, 135°, 225° or 315°), the source and neighbor will most probably have radio obstacles between them at transmission time due to obstructing buildings. The previous situations can be used to formulate an equation to give a factor J_n that indicates the link stability between the source and the neighbor according to the road relation and can be formulated in (7). Also Fig. 7 plots the relation between J_n and $\theta'_{s,n}$ from 0° to 90°, and the same graph is obtained for (90° to 180°), (180° to 270°)and (270° to 360°).

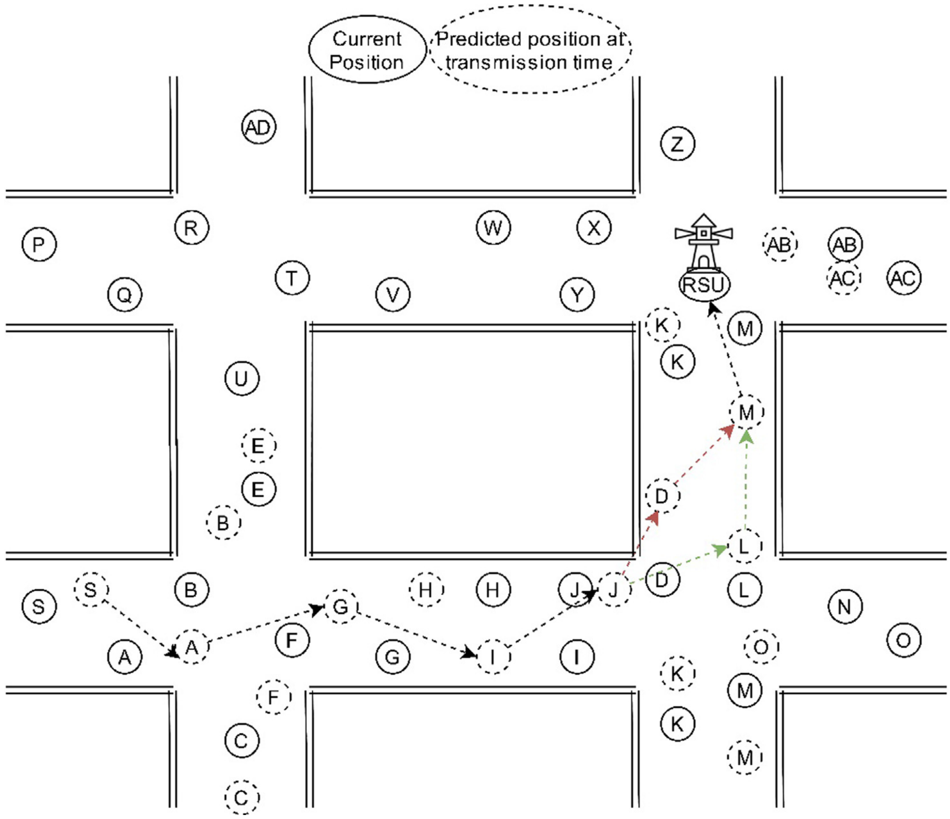

Fig. 4. The Basic Predictive Greedy Forwarding vs proposed OPBRP to overcome radio obstacles problem.

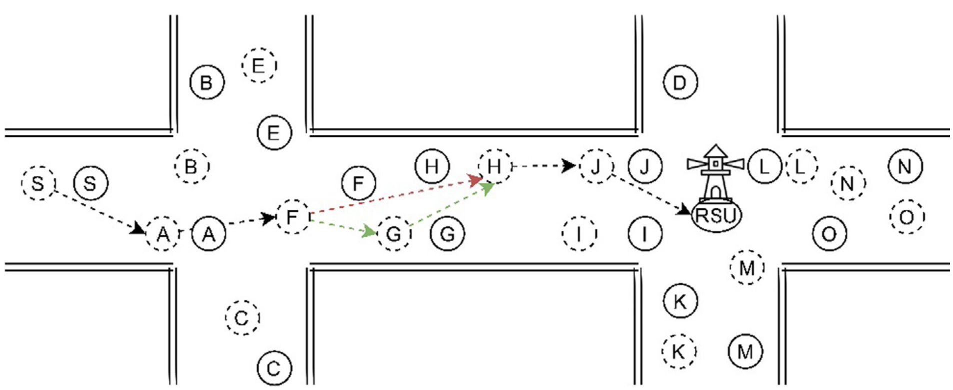

Fig. 5. The Basic Predictive Greedy Forwarding vs proposed OPBRP to overcome the transmission problem.

$$J_n = (tan(45^o - (\theta'_{s,n} mod 90^o))^2 \quad (7)$$

Finally, the weight for the source P_s and each neighbor P_n is calculated using (8) and (9), respectively.

$$P_s = W_{q1} cos\theta_{s,d} + W_{q2} \quad (8)$$

$$P_n = W_p\left(\frac{D'_{n,d} - D'_{s,d}}{D'_{s,d}}\right) + W_{q1} cos\theta_{n,d} + W_{q2} J_n \quad (9)$$

where W_p, W_{q1} and W_{q2} represent scaling factors for the three parameters that affect the node weight and are selected to obtain maximum PDR and minimum E2E delay, under the constraint shown in (10).

$$W_p + W_{q1} + W_{q2} = \quad (10)$$

To summarize the use for the OPBRP equations we could also use the below Pseudocode:

- • Sending message start.
- o Calculate $D_{s,d}$ using formula in (1).
- o If $D_{s,d}$ < Transmission range:
- ■ Forward the message directly to destination.
- o Else:
- ■ Calculate P_s using formulas in (2) - (6) and (8).
- ■ Set $P_{n,max} = 0$.
- ■ For i in Surrounding neighbors:
- • Calculate $P_{n,i}$ using formulas in (2) - (7) and (9).
- • If $P_{n,i} > P_{n,max}$:
- o Set $P_{n,max} = P_{n,i}$.

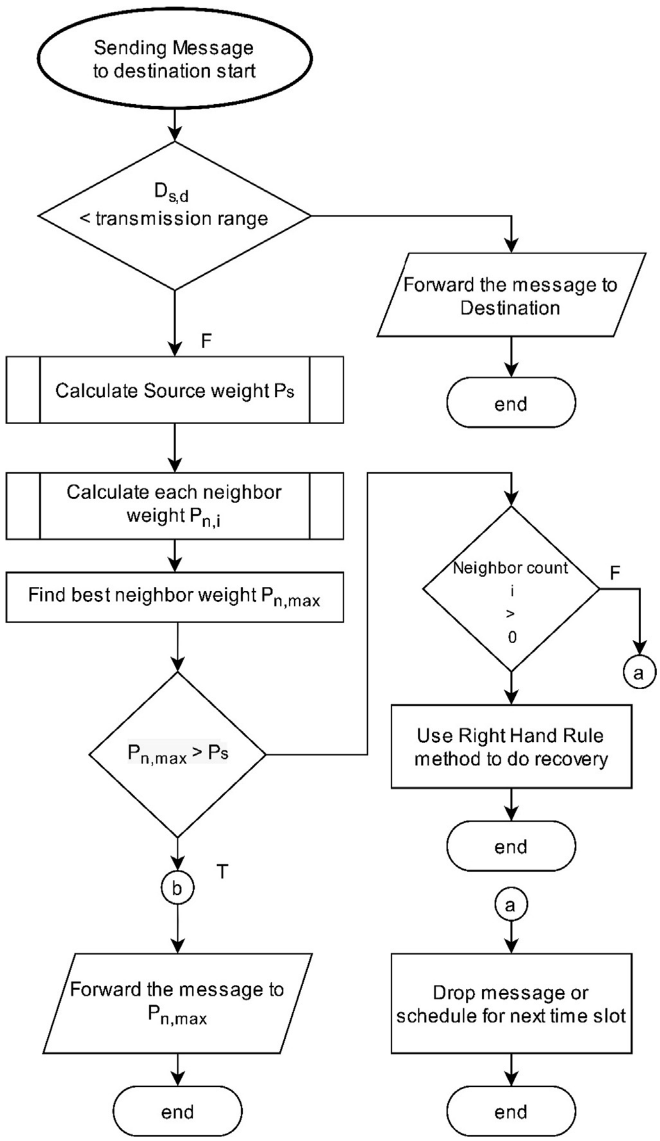

Fig. 6a. The OPBRP steps flow chart.

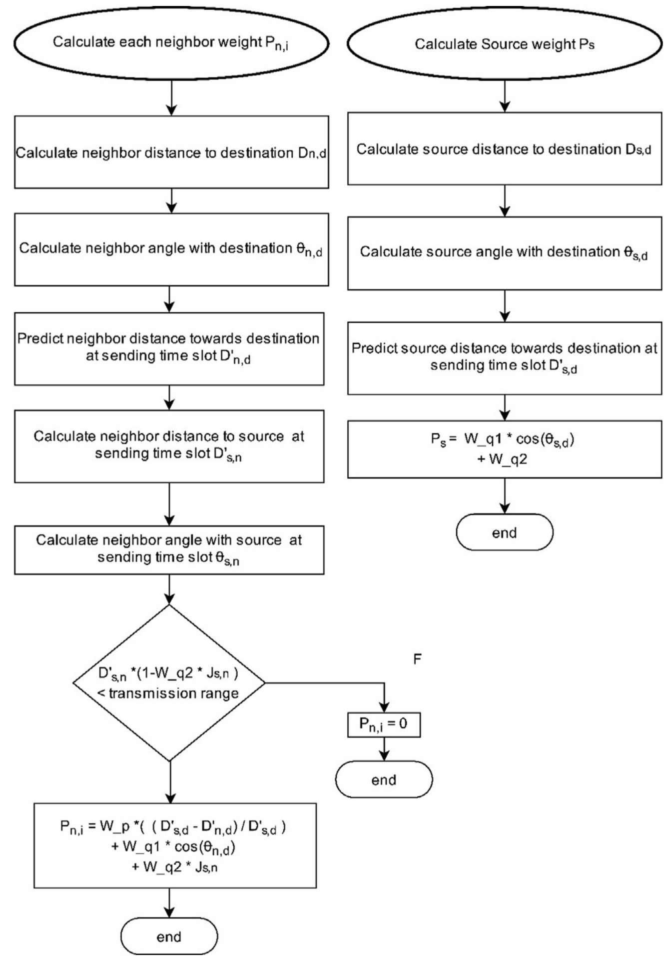

Fig. 6b. The OPBRP calculations steps flow chart.

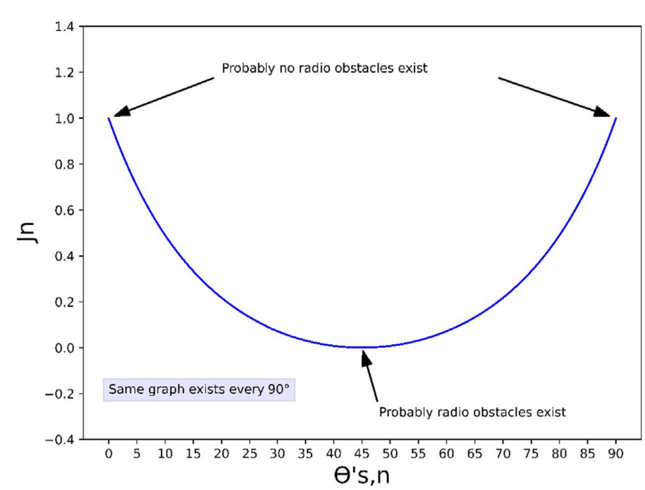

Fig. 7. Plot J_n versus $\theta'_{s,n}$.

- ■ If $P_{n,max} > P_s$:
- • Forward the packet to $P_{n,max}$.
- ■ Else if $P_{n,max} > P_s - 0.1$ And message was not received from $P_{n,max}$:
- • Forward the packet to $P_{n,max}$.
- ■ Else:
- • Drop the message or schedule for next time slot.
- • Sending message end.

The decision for forwarding the packet is then based on better weight while excluding neighbors that will be predicted to be out of transmission range for the sender, as illustrated in the flowchart of Fig. 6a.

4. Simulation experiment

Recent publications show that Veins is the best platform to test VANET protocols as it simulates most of the resources needed for testing VANETs in real life like hardware capabilities, delays and noise [24,44,45]. This platform uses an open-source framework to run vehicular network simulations. Veins is based on (1) OMNeT++: Event-based network simulator, [46–48], (2) SUMO: Road traffic simulator. [49–51]. So, Veins was used to test the proposed OPBRP to measure its performance using PDR, E2E, Average Hop Count and Transmission Power benchmarks described in section 2.1 [52].

The experiment uses a map extracted from OpenStreetMap for a section of the city of Erlangen, Germany as shown in Fig. 8 [53].

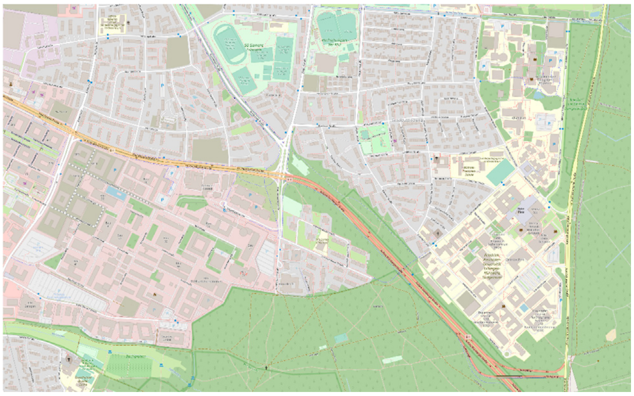

Fig. 8. Section of the city of Erlangen, Germany.

Sumo is used to generate a realistic traffic flow on the map as shown in Figs. 9a, 9b, while OMNeT++ is used to generate roadside units on the map and generate network events as shown in Figs. 10a, 10b, respectively [54]. The scenario for the experiment is as follows: When vehicle receives a packet with a destination information (RSU location), it collects the kinematic information for surrounding vehicles (position, direction vector and acceleration) and uses this information to calculate the forwarding or recovery decision, then the packet is forwarded to the next hop, this process continue until packet reaches destination or dropped when no valid path is found.

GPSR, MPBRP and proposed OPBRP are implemented in OMNET ++ using C++ language to test each of them with the same scenario and parameters.

The Experiment tests the GPSR, MPBRP and proposed OPBRP using the parameters shown in Table 1, where the simulation area is chosen to be big enough to be able to handle various vehicle mobility scenarios. The dedicated short-range communication (DSRC) media access control (MAC protocol) IEEE802.11p is used as it has been defined to be the standard for VANETs with maximum transmission distance of 300 m and 20mw transmission power [55–58]. Each protocol is tested for 200 s with vehicle count from 100 to 700 to verify the performance with different traffic situations [24]. Effects of shadowing and obstacles propagation models are accounted for at the simulator to obtain realistic road structure [59]. Finally, W_p, W_{q1} and W_{q2} values are set to 0.6, 0.1 and 0.3 according to each parameter criticality in the forwarding decision.

Fig. 9a. Map of the Scenario in SUMO.

Fig. 9b. Generated Road traffic in SUMO.

Fig. 10a. Generated RSUs in OMNeT++.

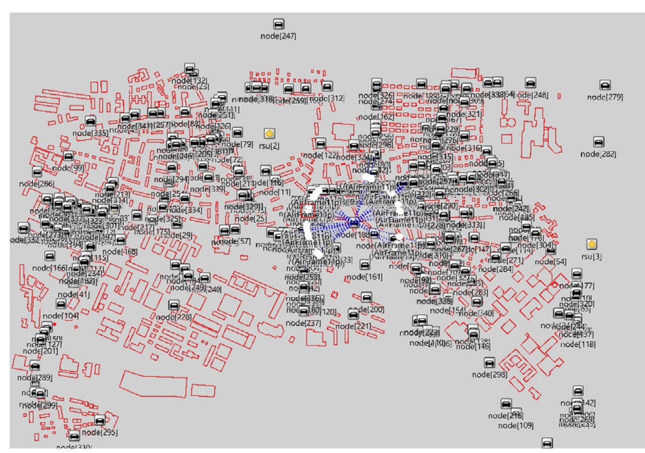

Fig. 10b. Packet transmission in OMNeT++.

Table 1
Veins parameters.

Parameter name	Value
Simulation area	3400 m × 3400 *m*
Number of vehicles	100,200,300. 700
Beacon interval	1.5sec
Packet size	1024 Bytes
Simulation time	200sec
Mac protocol	IEEE802.11p
Propagation model	Shadowing and Obstacles
Maximum transmission range	300 *m*
Minimum signal reception threshold	−89dBm
Antenna transmission power	20mW

Graphs reflecting simulation results for PDR, E2E-Delay, Average Hop count and Power consumption in transmission are plotted using OMNET++'s scatter charts for the data generated from the experiment [56].

5. Results and Discussion

The results for PDR, E2E-Delay, Average Hop count and Power consumption in transmission are shown in Figs. 11-14, respectively.

As shown, PDR for the proposed OPBRP achieves 18.46 % better than MPBRP and 20.83 % better than GPSR. It can be noticed that at vehicle density of 100, GPSR achieves higher PDR compared to OPBRP and MPBRP due to the fact that both OPBRP and MPBRP avoid ping pong cases that may lead to dropping packets in case message is being sent in a closed loop (due to recovery strategy) until path is found, e.g. (path S → A → B → S → A → B → S →.. S → A → B → C → D).

Fig. 12 indicates the E2E delay for the three protocols. It can be noticed that OPBRP achieved better performance compared to MPBR by more than 10 %) and better than GPSR by more than 20 %. This reduction of E2E delay is justified by the unique feature of OPBRP which avoids the radio obstacles that affect link quality during packet transmission time, which in turn avoids delaying of packet delivery to the destination. On the other hand, GPSR has high E2E delay as it doesn't have this predictive assessment of link state.

Average Hop Counts for the three protocols are illustrated in Fig. 13. It can be noticed that both the proposed OPBRP and MPBRP achieves nearly the same Average Hop Count as they both use similar approach in transmission while they achieved better performance than GPSR as it has no prediction to avoid undesired hops.

Finally, when analyzing the power consumed in the transmission according to Fig. 14, it can be noticed that the proposed OPBRP achieved 23.80 % better than MPBRP and a minimum of 48 % better than GPSR. The results are expected, as OPBRP can detect packets that will most probably be blocked by a radio obstacle and need a recovery strategy that consumes more transmission power, while MPBRP lack for this feature. On the other hand, GPSR has high power consumption as it consumes a large amount of power in the ping pong scenarios until it finds the next link near the destination.

In practical realization, the proposed protocol could be implemented on an embedded device onboard the vehicle which runs

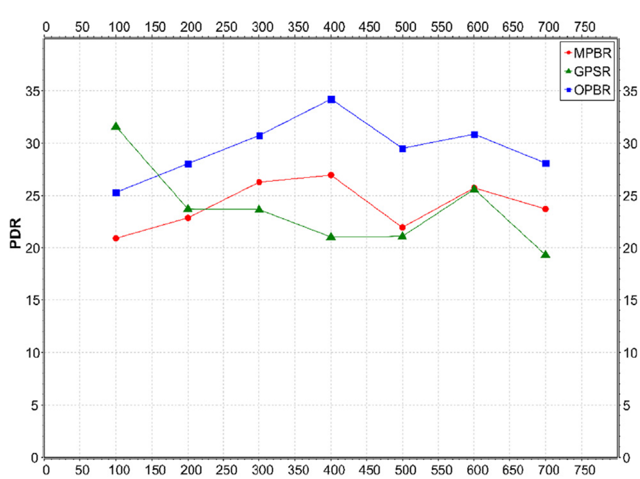

Fig. 11. Packet Delivery Ratio (PDR) simulation results showing OPBRP achievement.

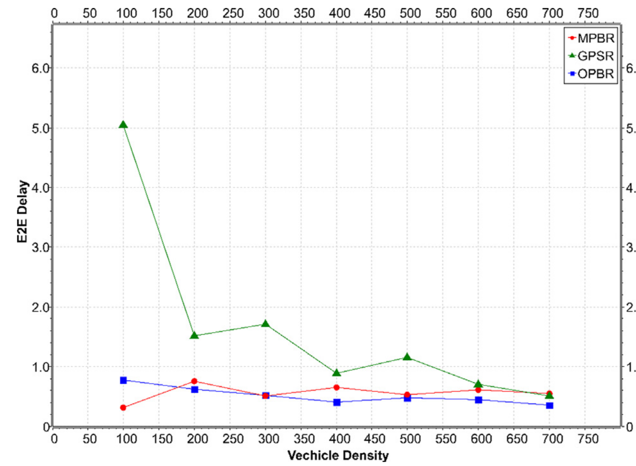

Fig. 12. E2E – Delay simulation results showing OPBRP achievement.

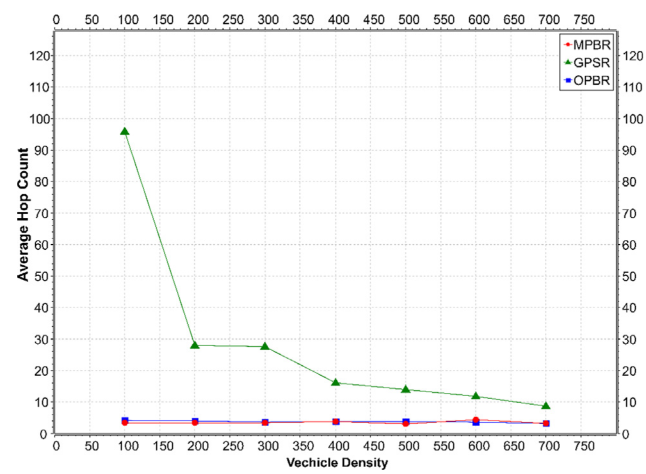

Fig. 13. Average Hop Count simulation results showing OPBRP achievement.

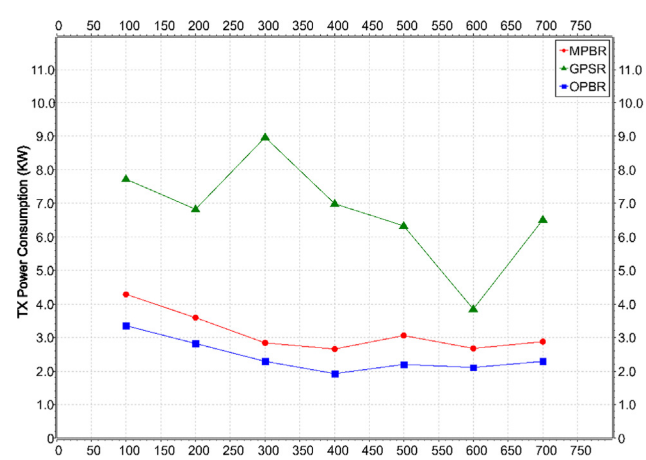

Fig. 14. Power consumption in transmission simulation results showing OPBRP achievement.

the logic depicted at the flowcharts in Fig. 6a and Fig. 6b, along with equations 1–9. The device is connected to the vehicle communication bus (e.g. Controller Area Network bus – CAN -bus) to get the required information from both the GPS module and the vehicle kinematics. Henceforth, this information is then communicated to neighboring vehicles and RSU through DSRC communications. At this point, the source vehicle identifies the next hop as per OPBRP protocol, as well as each neighboring vehicle. Consequently, the packet will follow the optimum route through distributed realizations of the OPBRP protocol on all related vehicles.

Quick complexity analysis of equations 1–9 indicates that the following operations are required to calculate the weight for each neighbor: 21 multiplications, 6 square root, 3 division, 2 "arc-cos", one "cos", one "sin" and one "tan" operations. modern embedded devices (e.g. RH850/F1K) would execute all the mentioned operations in less than 1 msec [60]. Assumed 5 km between each 2 RSUs, maximum distance between vehicle and nearest RSU is 2500 m. Furthermore, assuming the radio coverage range of DSRC is $\sim$ 300 m, the vehicle needs an average of 9 hops to reach nearest RSU. Given that each vehicle will be surrounded by average of 10 vehicles, total processing time will be given by: Execution time for 1 node $\times$ Number of neighbors around the vehicle $\times$ Number of hops to reach destination = $\sim$1msec $\times$10 neighbors $\times$ 9 hops = $\sim$90msec. Therefore, complexity is O(n), where n is the number of neighbors around the vehicle doing the calculations. With average vehicle speed of 60 KM/HR, vehicles will move 1.5 m during the whole time of calculations. Consequently, embedded devices with modern features are sufficient to let the protocol operate smoothly.

The proposed protocol would provide maximum performance in cities and highways, because it depends on choosing the best available node to carry the packet according to its prediction algorithms. It is flexible in dealing with the highly dynamic environment and changeable speed in VANETs because it assures to calculate the predicted locations of the vehicles and the obstacles around them including the time consumed to send and receive the control packets. This also helps to reduce the frequent link failures by avoiding the nodes that will lead to failures or sparse regions. Moreover, if side information from UAV is available, the proposed protocol could achieve even better performance for reducing NLOS communication, and connectivity disconnection in the sparse regions.

6. Conclusions

This paper introduces OPBRP that uses the vehicle's kinematics collected from neighbors to reach optimum forwarding decision. Higher Packet Delivery Ratio (PDR), lower average hops count, and lower power consumption are achieved compared to MPBRP and GPSR.

The proposed OPBRP achieves better results by utilizing more stable links between the source and the destination. OPBRP uses the neighbor vehicle's kinematics to predict the road situation in near future, while considering the radio obstacles in the prediction. Based on this information, the forwarding or recovery decision can be made.

Future work will include (1) Study and assessment of the applicability to apply the proposed protocol in a traffic management system and assess the implications compared to other existing benchmarks in this research domain. (2) Study the approaches to use the UAV with the OPBRP to get better performance. (3) Run field trials to validate results obtained from simulation.

Author Contributions

Under the supervision of Associate Prof. Samer Ibrahim and Dr. Ayman Mostafa, Khalid M. Diaa has conducted and written the paper; all authors had approved the final version.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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