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Reliability and Connectivity Analysis of Vehicular Ad Hoc Networks Under Various Protocols Using a Simple Heuristic Approach

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ABSTRACT Vehicular ad hoc networks (VANETs) provide alternative technology solutions to various transportation problems, and they provide a communication solution in intelligent transportation systems. However, the reliability and connectivity of VANET networks are subjects of concern. In building any routing protocol, a minimum level of network reliability must be ensured, which requires conducting a reliability analysis in order to investigate the different factors that affect reliability. Conducting a real-world reliability analysis is very expensive, and it requires significant preparation. Simulations are computationally costly due to the high number of available paths between the source node and the destination. In this article, a simplified approach is conducted that is mainly based on a simulation model of a road-type environment for a VANET network. A heuristic approach is developed for calculating the reliability based on the highest probability paths using the Dijkstra algorithm and the inclusion–exclusion approach for calculating the reliability of a given path. For vehicle-to-vehicle (V2V) communication, short-range protocols were considered—ZigBee (802.15.4), WiFi (IEEE 802.11), and Bluetooth (802.15.1)—as well as their standards for data rates, association time, and transmission range. On the other hand, the IEEE 802.11b was used for vehicle-to-roadside (V2R) communications. Another parameter that was considered was the speed limit of the road environment, and three types of road environments were evaluated: highway, urban, and mixed. Other factors that were considered were the number of vehicles, the number of roadside units, and the type of message that was transmitted. The effects of all of these elements on the connectivity of the network were studied.

INDEX TERMS VANET, reliability, connectivity, inclusion–exclusion, heuristic approach.

I. INTRODUCTION

Vehicular ad hoc networks (VANETs) provide alternative technology solutions to various transportation problems, and they also provide a communication solution in intelligent transportation systems [1], [2]. Many challenges are emerging in VANETs [3]. The reliability and connectivity of VANET networks are subjects of concern. In developing any routing protocol, a minimum level of network reliability must be ensured. Assuring adequate network reliability requires conducting an analysis of all the factors that affect reliability [4]. Conducting a real-world reliability analysis is very expensive, and it requires significant preparation. Simulations are based on mathematical models and graph algorithms developed to describe the network and routing; however, directly applying such mathematical models and graph algorithms imposes additional computational costs. This is because of the high number of available paths between the source node and the destination.

In this article, a simplified approach is conducted to calculate network reliability. The approach considers a VANET network located in a road-type environment. The simplified approach uses heuristics to calculate reliability. Instead of considering all the possible paths between the source and the destination, only the paths with the highest probabilities are considered. For Vehicle-to-vehicle (V2V) communications,

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short-range protocols were considered, including ZigBee, WiFi, and Bluetooth, and their standards for data rates, association time, and transmission range were applied. On the other hand, the IEEE 802.11b was used for Vehicle-to-roadside (V2R) communications. Three types of road environments were considered: highway, urban, and mixed. The speed limit of the road environment, the number of vehicles, the number of roadside units, and the type of message that was transmitted were also taken into consideration. The ultimate goal was to study the effects of these parameters on the network connectivity.

The remainder of the article is organized as follows. Section 2 provides a background and definitions of terms used in the article. Section 3 provides a review of the relevant literature. Section 4 presents the formulation of the problem. The methodology is described in Section 5. Section 6 provides a discussion of the experimental results, and the paper is concluded in Section 7.

II. BACKGROUND

This section provides some needed definitions and background about the terms that are used in the article.

1. Reliability: is defined as the probability of the successful delivery of a message to its meant destination before the expiry of the life time of the message [5].
2. Connectivity: is defined as the constraint of having any node in the network connected to any other node [6].
3. V2V communication: it refers to the transmission of messages in the VANET network through the vehicles themselves without the assistance of any road infrastructure. Usually, V2V communication is performed through on-board units (OBUs), which are often found with on-board equipment that facilitates such communication [7].
4. RSUs: The infrastructure located beside the road to facilitate the communications between vehicles are named as road side units or RSUs [7].
5. V2R communication: it refers to the communication between vehicles with the assistance of RSUs. This is done using IEEE 802.11b [7].
6. Hybrid communication: is a VANET network that supports both V2V and V2R [8].

III. LITERATURE REVIEW

The exponential growth of wireless devices and the demand for wireless communication call for the enhancement of the efficiency of the network infrastructure, as well as its protocols, using different technology. To address these issues, various topologies have been proposed with different access technologies for efficient roadside wireless communications. Among them, vehicular ad hoc networks (VANETs) have been implemented, which have mainly been inherited from mobile ad hoc networks. VANETs are sophisticated technology, which ensure the establishment of a communication link between wireless devices on vehicles on the road. To accomplish such communication with higher efficiency, dedicated base stations and routing protocols are used. However, over time, it has been observed that the efficiency of such routing protocol can be problematic when there is an issue with the connection establishment between the source node and the destination node. This issue has inspired researchers and wireless industries to conduct research for solutions. Researchers have suggested improving transmission reliability in order to ensure the reliability of the network performance [9]. This work has mainly adopted bio-inspired genetic algorithms and considers the impact of the interface on transmission consistency. Other research has modeled an orthogonal street system using a Poison distribution model for a one-dimensional (1D) and two-dimensional (2D) network for vehicles on the road [10]. Researchers have expressed the system analytically with the selected parameter being the general user, as well as typical intersection users. In such models, the upper limits of the success probability of the distinctive intersection user in the suggested orthogonal system are limited by the minimum success probabilities. Researchers have modeled the consistency of short-range communication control channels in order to ensure application reliability, determining receiving status and safety messages probabilities from onboard wireless devices in vehicles [11]. The main parameters of such studies are the range of the transmitter in the vehicles, the density of the vehicles, and the speed of the vehicles. The speed, density, impact of mobility in a dense vehicle scenario, reliability of the vehicle speed that is correlated with the transmission and reception with base stations (BTS), channel fading conditions, and hidden terminal collusion problems have all been considered in designing a network mobility model. A reliability analysis has also been developed VANETs to address crucial issues in terms of reliability support [12].

Researchers have modeled VANETs using graph theory to plot network topology and routing reliability [13]. The improved distributed channel access technique was also used to emphasize the performance of a broadcast in which an IEEE 802.11p MAC layer was utilized to characterize the hidden terminal as well as the priorities of the messages. The delay was also assessed using the M/M/1 queuing model [14].

Several studies have been conducted to examine the reliability of networks in terms of connectivity according to the network topology. These approaches have been categorized into two general classes: inclusion–exclusion (IE), and sum of disjoint products (SDP) [15], [16]. Considering the precision of the network, a GPS receiver has also been used [17].

Another factor that affects reliability is traffic jam and congestion. In order to eliminate the congestion, testing has been conducted [18]. For instance, a beacon was sounded on an interval basis to test traffic flow, as well as to serve as a warning to other vehicles. This was to avoid unwanted situations/accidents during roadside communication. However, in special cases, priorities need to be considered. To overcome the risk of accidents and congestion issues, a solution was proposed to identify and analyze messages received by vehicles to determine the authenticity of the received message [19].

One study conducted a simulation of VANETs for roadway paths on a highway [20]. The evaluation of the simulation study demonstrated the potential communication capability, with the average number of communications being four in a one-second span, which covered almost 90% of the communications tested, and the maximum limit was five per second.

To diminish traffic jams, a routing selection-based technique relying on shared traffic visual information was used to determine the routing path [21]. The authors of [22] developed an estimation method that considers congestion control for VANET communications. The estimation method disposes of similar types of messages by separating them. Nevertheless, on a practical level, diverse responses from vehicles may create numerous messages that lead to overhead. The authors of [7] highlighted VANET reliability issues under various topologies for both V2V and V2R communications. The authors of [23] performed a connectivity analysis of a VANET by considering the entrances and exits on the highway with and without an RSU installed. A highway toll plaza connectivity analysis was performed by the authors in [24].

The study of connectivity developed into a new field of research with the introduction of VANETs. Studying the network of VANETs has become increasingly popular and attracted the attention of many research groups [25]–[28].

Two vehicles on a highway are said to be connected if they are in transmission range of each other. In order to obtain the optimal distribution of real-time data, a reliable and strongly connected network is required [29].

In [30], the authors analyzed vehicle-to-vehicle wireless connectivity by using mathematical models of mobility and studying its relation with time. The effect of headway distance, acceleration, association time (i.e., connection setup time), the relative speed of the vehicles, transmission range, and message/data size in short-range-based V2V communications were analyzed in the models. However, the model they developed was based only on vehicle-to-vehicle direct communication. Routing messages through other vehicles and/or roadside units was ignored. Moreover, no analysis of the relationship between the distribution of the velocity ranges within the network and the reliability, as well as the number of roadside units located inside the environment, was conducted. The goal of this article is to generalize the model of [30] to include multi-vehicle routing, with and without roadside units, with different configurations, such as the total number of vehicles, statistical distribution of velocities, number of roadside units, type of message, and applied protocol. To do so, we develop graph representation of the network and use the Dijkstra algorithm to select the available routes to calculate an approximation of the probability of successful data exchange from one vehicle to another.

This work is based on the model of traffic and communication given in [30]. However, this study builds on the work of [30] by offering several novel contributions. The main contributions of this paper are as follows:

TABLE 1. List of symbols.

Symbol	Meaning
$\boldsymbol{v_i, i = 1, 2 \ldots N_v}$	The vehicle
$\boldsymbol{N_v}$	The number of vehicles
$\boldsymbol{N_R}$	The number of roadside units
$\boldsymbol{V_i}$	Velocity of vehicle $\boldsymbol{v_i}$
$\boldsymbol{a_i}$	Acceleration of vehicle $\boldsymbol{v_i}$
$\boldsymbol{G(V, E)}$	Graph of VANETs
$\boldsymbol{T_R}$	Transmission range of the protocol
$\boldsymbol{D_r}$	The data rate of the protocol
$\boldsymbol{A}$	Association time of the protocol

1. A heuristic approach is developed for calculating reliability based on the highest probability paths using the Dijkstra algorithm to calculate the reliability of a given path, as well as the selection of the available routes, to develop a rough calculation of the successfully exchanged messages.
2. A mobility model for a VANET is developed, which considers additional multi-vehicle routing with and without roadside units.
3. Reliability is analyzed in V2V-only and hybrid V2V+V2R scenarios with varying numbers of RSUs and different expected speeds, considering reliability for information messages and emergency messages and reliability with varying number of vehicles.

IV. PROBLEM FORMULATION

In this study, a road environment (highway or urban) that contains N_v vehicles v_i and N_R roadside units rsu_j was assumed. Each of the vehicles was equipped with a communication device that supported one of three protocols: ZigBee, Bluetooth, or WiFi. Additionally, the device contained a gateway interface between the supported protocol and the roadside unit protocol (IEEE 802.11b). Each of the vehicles $v_i, i = 1, 2 \ldots N_v$ reached certain velocity V_i and acceleration a_i. The protocol had the following specifications: transmission range T_R, data rate D_r, and association time A. We assumed a VANET network was established among the vehicles and the roadside units, and that VANET network was represented by a graph $G(V, E)$, where $V = \{v_i, rsu_j\}$. Two types of messages were transmitted within this network: the first type was an information message with a size of 5 KB, and the second type was an emergency message with a size of 64 B. The main goal was to calculate reliability by weighting the edges of the graph with the probability of successful data exchange P_s and to study the factors that affect reliability positively and negatively during various scenarios. The symbols used in this study are presented in Table 1.

V. METHODOLOGY

In this study, the reliability of the connection between a source and a destination was analyzed, and hybrid architecture was used. This was because this scenario empowered long-distance connection with vehicles that were far away. A graphical illustration is provided below:

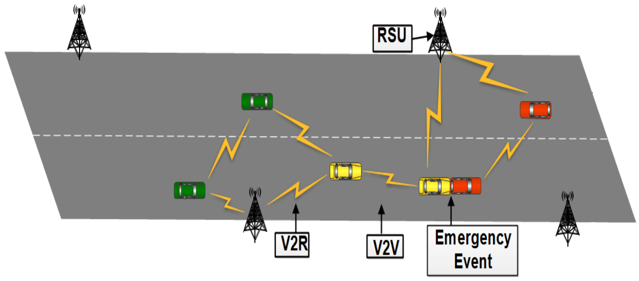


FIGURE 1. VANET communication infrastructure.

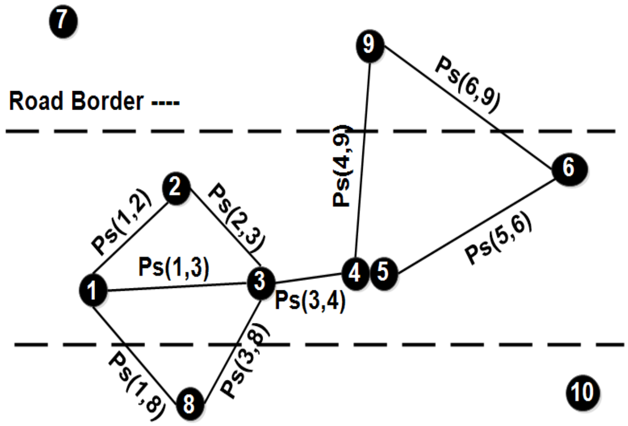


FIGURE 2. Graph representation of nodes in Figure 1.

4.1. Graph Representation

Vehicles and roadside units are nodes in the graph representation, and the weight of each edge connecting two nodes is the probability of successful data exchange P_s between these two nodes. An example of a real-life network is given in Figure 1, and it was transformed into the graph representation shown in Figure 2. The calculation of P_s is described below.

4.2. Reliability Analysis

This section describes the reliability analysis, which is based on a simplified model that calculates reliability based on the best n paths of the available paths between any source S and destination D. The analysis is assessed using the simulation model, which is discussed below.

4.2.1 Simulation Model

The simulation model focused on the road environment. Selected parameters that were used to model the simulation are presented in Table 2.

Once the simulation model is enriched with the proper infrastructure, reliability must be estimated. The reliability estimation is discussed below.

The highway mobility model [31], [32] is a combination of a number of lanes using discrete equations based on an integration of the acceleration with time step of Δt. The equations can be written as follows:

$$v_i(t+\Delta t) = \begin{cases} min(v_i(t) + a_i(t)\,\Delta t, Vmax) & if\ a_i(t) \geq 0 \\ max(v_i(t) + a_i(t)\,\Delta t, Vmin) & if\ a_i(t) < 0 \end{cases} \tag{1}$$

TABLE 2. List of symbols.

Parameters	Meaning
Width	Highway width along x-axis [m]
Length	Highway length along y-axis [m]
Number of vehicles	Number of mobile vehicles in the highway
Speed limit	The speed limit in the road
Maximum acceleration	The maximum possible acceleration
Minimum acceleration	The minimum possible acceleration
Number lane	The number of lanes in the road environment
AGG	Parameter to control the aggressive behavior of drivers
pr	Parameter that controls the inclination of vehicles to change speed

Vehicles were assigned to the slow lane or fast lane randomly. The acceleration for each vehicle i at time t, i.e., $a_i(t)$, was calculated using Equation (2). R_1, R_2, R_3, and R_4 are uniformly distributed random variables between 0 and 1. Each vehicle has a range of acceleration A_{max} and deceleration D_{max}:

$$a_i(t) = \begin{cases} R_2 A_{max}, & if\ R_1 < acc_i + pr \\ R_2(-1)\,D_{max}, & if\ acc_i + pr < R_1 < acc_i \\ & + dacc_i + 2pr \\ 0, & otherwise \end{cases} \tag{2}$$

where R_1, R_2 are random variables uniformly distributed between 0 and 1, A_{max} is the maximum possible acceleration, D_{max} is the maximum possible deceleration, pr is a parameter that controls the inclination of vehicles to change speed, and acc_i $dacc_i$ are parameters of the model used to describe the behavior of each driver with respect to acceleration or deceleration. acc_i $dacc_i$ are given by the equation:

$$acc_i = \begin{cases} R_4\,(1-2pr)\,, & if\ R_3 < 3\frac{AGG}{4} \\ 0, & otherwise \end{cases} \tag{3}$$

$$dacc_i = \begin{cases} R_4\,(1-2pr)\,, & if\ 3\frac{AGG}{4} < R_3 < AGG \\ 0, & otherwise \end{cases} \tag{4}$$

where R_3, R_4 are random variables uniformly distributed between 0 and 1 and AGG controls the aggressive behavior of drivers by giving them higher probability to accelerate than deceleration based on statistical studies about driving behaviors [31], [32].

A. RELIABILITY ESTIMATION

In order to calculate the reliability of the network, we calculated the probability of successful transmission from any node to any other node. Inside a given graph that represents a VANET network, there is a huge number of possible paths between two defined nodes. Therefore, the calculation of reliability becomes an exhausting process. In order to simplify the process, we calculated reliability based only on the highest probability paths using a heuristic block to identify

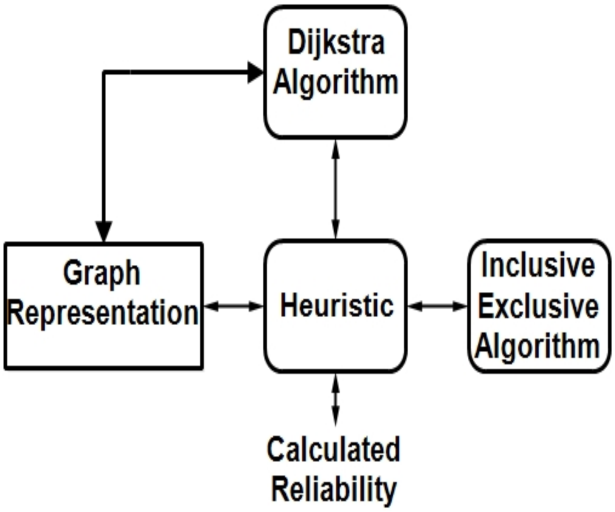


FIGURE 3. Diagram of the general reliability calculation process.

the probability. The general process is shown in Figure 3. The Dijkstra algorithm was applied to the given graph, which represented the network. Then, once the path with the highest probability was determined, the heuristic method was used to re-weight the links of the path to exclude it and find the second highest probability path (and so on). This process is called until nPaths. Then, the paths were plugged into the inclusive–exclusive algorithm to calculate the reliability.

Let us assume that the VANET network is represented by a graph G, and let us assume that we want to calculate the probability of successful transmission between two nodes: source S and destination D. The probability of successful data exchange is calculated using the model [30]. The Dijkstra algorithm must be used for the number of times equal to the number of paths that have to be generated between the two nodes S and D. Every time a path is generated, the graph G is changed to decrease the probability of the path by a multiplying factor—decrement factor α.

Thus, the next time the Dijkstra algorithm is used, a path with a lower probability than the last one is selected. After obtaining the number of paths equal to nPath, the inclusion–exclusion algorithm is used to calculate the reliability between S and D. A pseudo code of the calculation of reliability between two nodes S and D is provided in Table 3. A pseudo code of the Dijkstra algorithm is provided in Table 4. The general algorithm selects two random nodes from the graph for a certain number of times, considers them to be the source and destination, and selects one of the two message types—information or emergency—to be transmitted based on one of the protocols.

VI. EXPERIMENTAL RESULT ANALYSIS

A. VALIDATION OF THE TRAFFIC AND COMMUNICATION MODEL

In order to validate our traffic and communication model, we re-generated the results that were presented in [30]. Figure 4 shows the total communication time with respect to the relative speed, which ranged from 0 to 150 mph. Figure 4 was generated for various communication ranges. Communication time decreases with an increasing relative speed or a decreasing communication range. We selected three protocols for our analysis, similar to the work of [30]. Thus, we re-constructed the time used for data exchange for each of the three protocols—Bluetooth, WiFi, and ZigBee—as shown in Figure 5. The results show that ZigBee did not require as much time for association as WiFi and Bluetooth, which required the most time. These results are similar to the results presented in [30], which indicates the validity of our communication and traffic model. Additionally, we generated the maximum data packet size that can be transmitted by each of the three protocols—ZigBee, WiFi, and Bluetooth—as shown in Figure 6. The similarity of results with [30] shows that our traffic and communication model is suitable for conducting a reliability evaluation.

TABLE 3. A pseudo code of the calculation of reliability between two nodes S and D.

```
Calc Reliability
INPUT:
G : graph adjacency matrix, G[i][j] contains the probability of connectivity between node i and node j; S : source node, D : destination node, $\alpha$: edge probability decrement factor (better to be between 0.9 and 1.0), nPath : number of paths to generate
OUTPUT:
Reliability
ALGORITHM:
Original Graph = G // save a copy of the graph
paths = {} // generated set of paths
FOR i = 1 to nPath
  path = Dijkstra(G,S,D) // get a path with the highest probability using Dijkstra
  IF length(path) == 0
    break
  END IF
  paths{i} = path // add this path to the set of paths
  FOR j=2 to length(path) // multiply all edges of this path by alpha
    G(path(j-1),path(j)) = G (path(j-1),path(j)) * $\alpha$;
  END FOR
END FOR
Reliability = Inclusion Exclusion(original Graph, paths) // calc reliability using inclusion exclusion
```

B. EVALUATION OF RELIABILITY

This study aimed to evaluate the reliability of various protocols with different numbers of vehicles, message sizes, numbers of roadside units, and expected road speeds.

Reliability performance was assessed during a simulation of a connection. It was equivalent to the probability for successful communication between a source and a destination. The parameters of the simulation are presented in Table 5. Three different communication standards were used for V2V communication (Bluetooth, ZigBee, and WiFi). Table 6 compares these standards.

The environment used in the simulation was a 10-km stretch of road. This road was two-way with two lanes for each way. The nodes were generated at the two ends

TABLE 4. Pseudo code of Dijkstra algorithm.

```
Dijkstra Algorithm
INPUT:
G : graph adjacency matrix, G[i][j] contains the probability of connectivity
between node i and node j
S : source node; D : destination node
OUTPUT:
Path
N = number of nodes
q : Priority Queue
q.insert(1,[S -1])  // insert S with probability 1.0
visited = zeros(N)  // visited and parent array
WHILE q.is Empty() == 0
   [probability data] = q.pop()
   node = data(1)
   parent = data(2)
   IF visited(node) != 0
      continue
   END IF
   visited(node)=parent // save parent of this node
     IF node == D // destination reached
      best = p
      break
   END IF
   FOR i = 1 to N  // push all not visited children into priority queue
      IF G(node,i) != 0 and visited(i) == 0
         q.insert(probability * G(node,i) , [ i node]);
      END IF
   END FOR
END WHILE
path = [] // output path
IF visited(D) == 0
    return  % no path found
END
WHILE D > 0
    path = [D path] // append node D to the path
    D = visited(D) // move from D to the parent of D
END
```

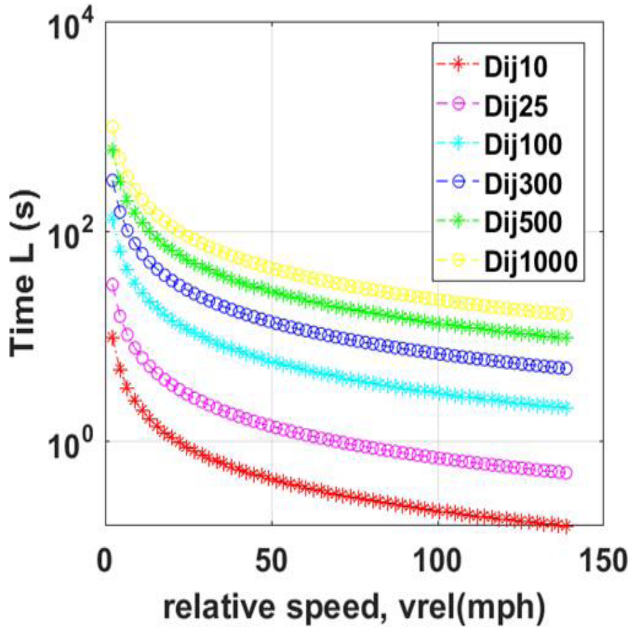


FIGURE 4. Relationship between communication time, relative speed, and communication range.

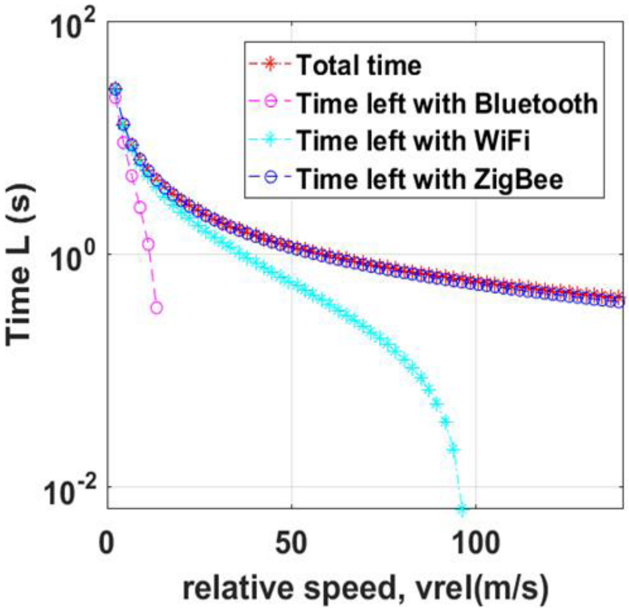


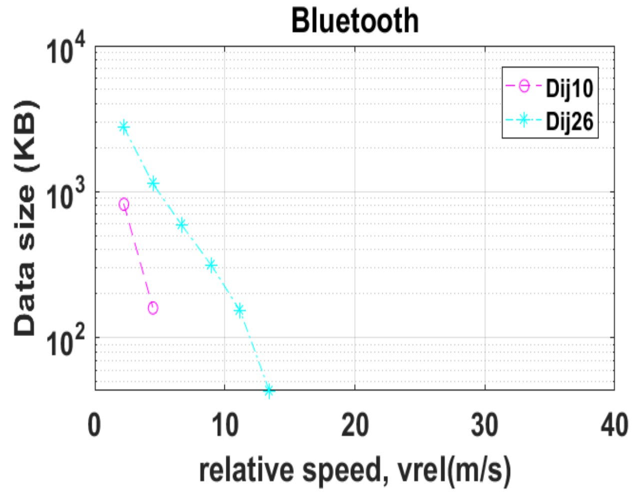
FIGURE 5. Time left for data exchange after successful association for the three protocols: Bluetooth, WiFi, and ZigBee.

of the road. Figure 7 shows the environment plotted in MATLAB (the red squares are the vehicles, and the blue squares are the roadside units).

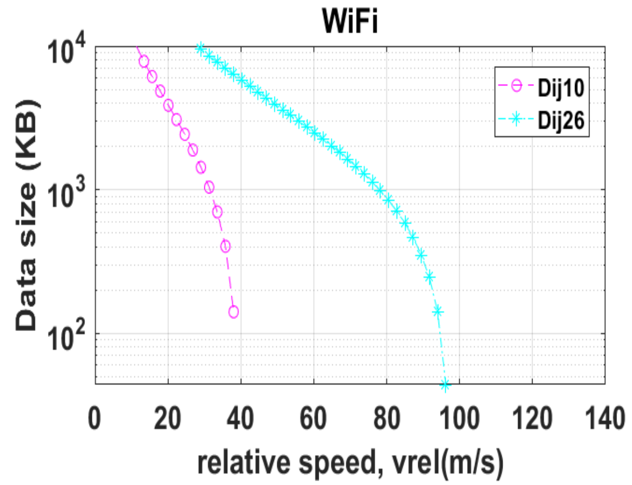
Below, we will show the mean of connection reliability with different numbers of vehicles, different speeds, different numbers of roadside units, and different types of messages. Table 7 presents the parameters used in each experiment.

In Figure 8, it can be seen that increasing the number of vehicles from 200 to 800 in the proposed environment led to better reliability, and that is because more paths to choose from and the distance between vehicles is now smaller. Without roadside units, Bluetooth could not transfer any messages because of its small range, ZigBee was ranging between 5% and 38%, and WiFi ranged from 30% to 90%. When 2 roadside units were added to the environment, all three standards gave better numbers, Bluetooth is now between 16% and 21%, ZigBee reached 50%, and WiFi reached 97.5%.

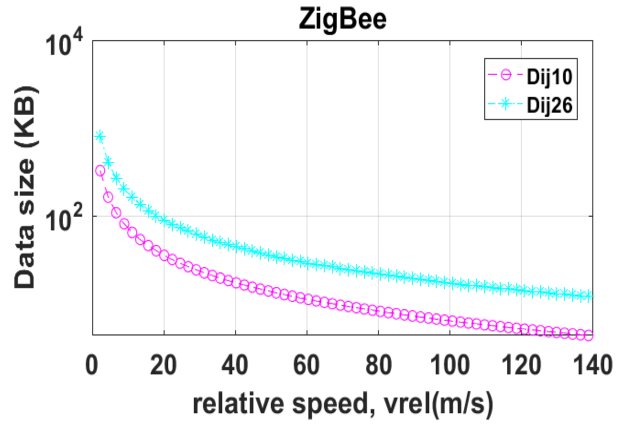
The given message size for the previous experiment was 5KB (typical size of one-page message of 568 words) and this message is called information message, the kind of message used to solve traffic jams, pollutant emissions, and fuel consumption problems. Another type of messages is an emergency message, it has the size of 64B the type of message used to avoid accidents.



(a). Maximum data packet size that can be transmitted by Bluetooth.



(b). Maximum data packet size that can be transmitted by WiFi.



(c). Maximum data packet size that can be transmitted by ZigBee.

FIGURE 6. **Maximum data packet size that can be transmitted for various values of relative velocities and two cases of transmission range: 10 m and 26 m for the three selected protocols.**

TABLE 5. **Simulation parameters and values.**

Parameter name	Value	Unit
Width	20	m
Length	10,000	m
Speed limit	30	m/sec
Maximum acceleration	10	m/sec^2
Minimum acceleration	−10	m/sec^2
Time period of update	0.01	Sec
Time unit	0.01	Sec
Number of vehicles	800	

TABLE 6. **Communication standards used in the simulation.**

Standard	Bluetooth	ZigBee	WiFi	RSU standard
IEEE spec.	802.15.1	802.15.4	802.11a/b/g	802.11b
Max signal rate	1 Mb/s	250 Kb/s	54 Mb/s	1 Mb/s
Nominal range	10 m	10–100 m	150 m	1500 m
Approx. assoc. time	4 s	30 ms	600 ms	0

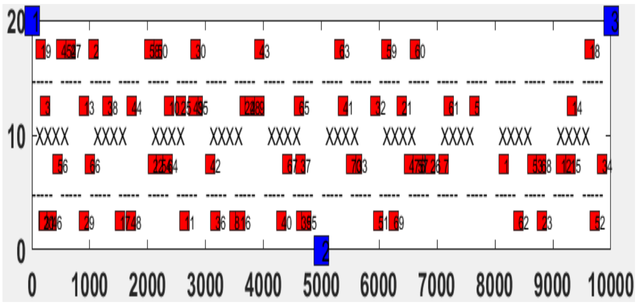


FIGURE 7. **Simulation environment.**

TABLE 7. **Environment parameters in each experiment, simulation time is 50 s.**

	No. of vehicles	No. of RSUs	Expected speed	Size of msg
Experiment 1	200–800	2	70 miles/h	5 KB
Experiment 2	500	2	70 miles/h	64 B, 5 KB
Experiment 3	500	0–3	70 miles/h	5 KB
Experiment 4	500	2	30, 50, 70 miles/h	5 KB

In the second experiment, we are calculating reliability with the two different kinds of messages. The same environment is used, with 500 vehicles and with or without the addition of 2 roadside units. Figure 9 shows the best reliability was for an emergency message with WiFi standard and with 2 roadside units where it reached 96%, while it was 91% for the information message with the same conditions.

In the previous experiments, it was proven that adding roadside units to the environment always results in an increase in reliability. Therefore, in the third experiment, we changed the number of roadside units to see how the reliability changed. The message type in the experiment was information message (5 KB), and the number of vehicles

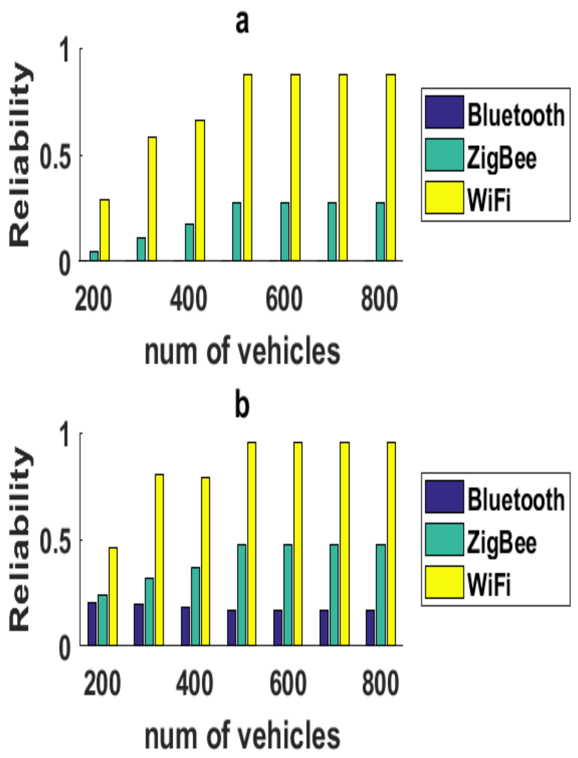


FIGURE 8. Reliability with ranging number of vehicles: (a) V2V only (b) Hybrid V2V+V2R.

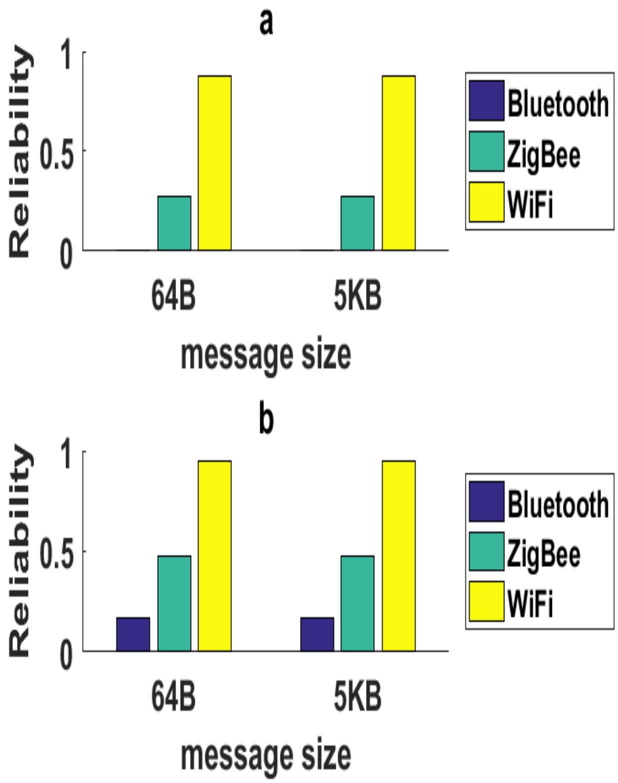


FIGURE 9. Reliability for information message and emergency message: (a) V2V only (b) Hybrid V2V+V2R.

was 500. Figure 10 shows that the reliability of all three types of communication standards increased with the number of roadside units. Three roadside units resulted in reliability of 19%, 47%, and 94% for Bluetooth, ZigBee, and WiFi, respectively, whereas the reliability was 0%, 23%, and 83% with no roadside units.

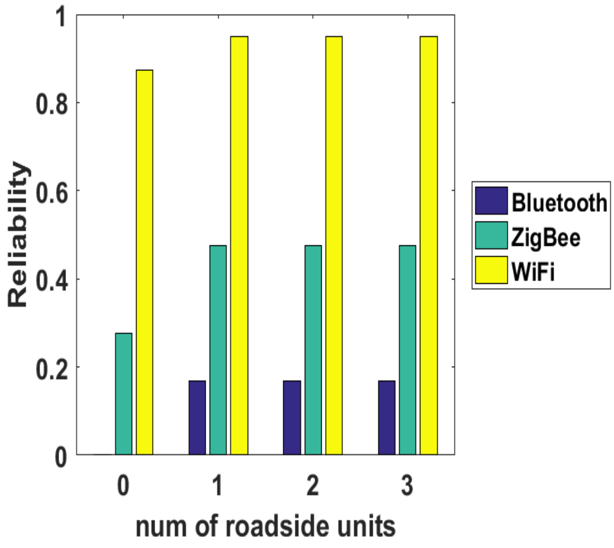


FIGURE 10. Reliability with increasing number of RSUs.

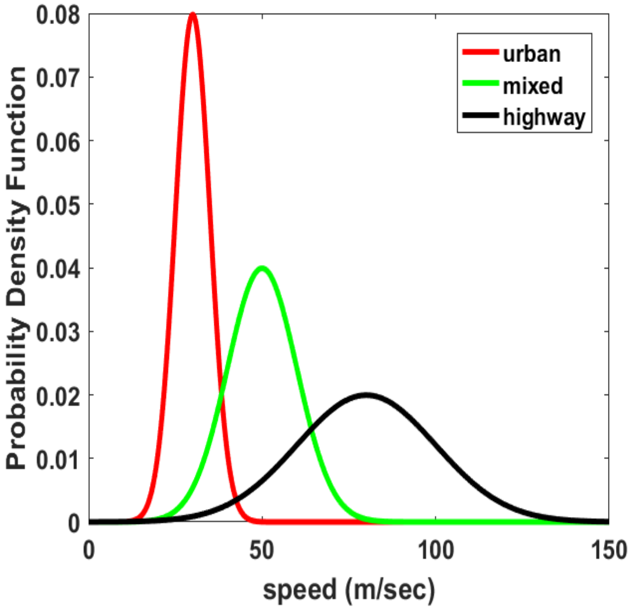


FIGURE 11. PDF of different expected speeds.

The final experiment intended to compare the reliability between urban roads and highway conditions. The previous experiments were held on a highway where the expected vehicle speed was 70 miles/h. In this experiment, the reliability was compared while changing the PDF function of the speed of the vehicles, as shown in Figure 11.

The results in Figure 12 show that with a lower expected speed, reliability increased. Therefore, slow vehicles in urban areas will create a successful connection more easily than vehicles on the highway traveling at high speeds.

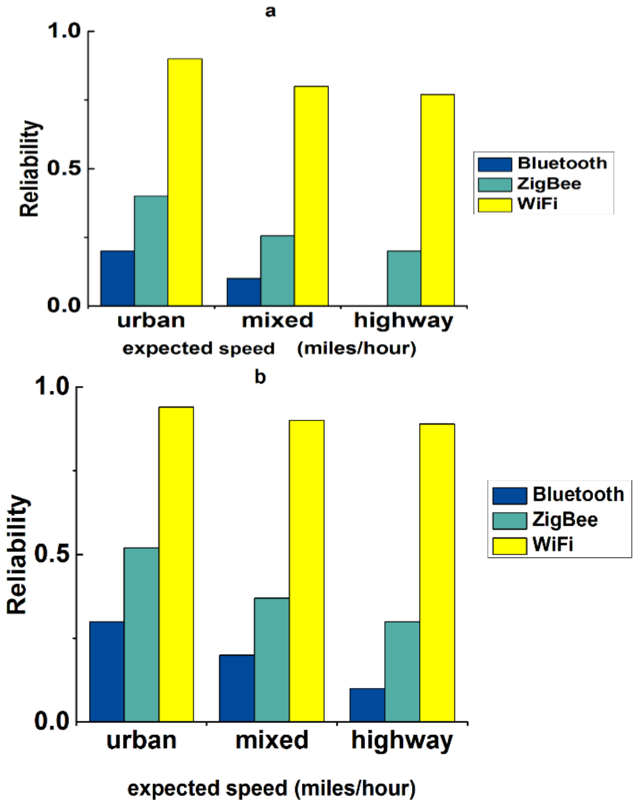


FIGURE 12. Reliability for different environments: (a) V2V only; (b) Hybrid V2V+V2R.

VII. CONCLUSION

In this article, the reliability of a VANET network with respect to V2V and V2R communications was analyzed using the heuristic approach that was based on the paths with the highest probability of successful transmission. Various parameters and factors were included in the analysis. For V2V communications, short-range protocols were considered: ZigBee, WiFi, and Bluetooth with their standards for data rates, association time, and transmission range. On the other hand, IEEE 802.11b was used for V2R communications. Other parameters included the speed limit of the road environment and three types of road environments: highway, urban roads, and mixed. Other factors considered were the number of vehicles, the number of roadside units, and the types of transmitted messages. The effects of all of these elements on the connectivity of the network were studied. The estimated reliability was calculated in several experiments. It turned out that, without roadside units, Bluetooth could not transfer any messages because of its small range, the reliability of ZigBee ranged between 5% and 38%, and the reliability of WiFi ranged between 30% and 90%. When two roadside units were added to the environment, the performance of all three standards improved: Bluetooth reached between 16% and 21%, ZigBee reached 50%, and WiFi reached 97.5%. Moreover, it was found that emergency messages achieved higher reliability than information messages. This was because of its small size. Furthermore, increasing the number of roadside units played an important factor in increasing reliability. Additionally, we found that with a lower expected speed, reliability increased. Therefore, slow vehicles in urban areas will create a successful connection more easily than vehicles on the highway traveling at high speeds.

In future work, the proposed reliability estimation method will be compared with other existing methods in terms of the computation time and accuracy based on real datasets.

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