Journal of Zhejiang University-SCIENCE C (Computers & Electronics)
ISSN 1869-1951 (Print); ISSN 1869-196X (Online)
www.zju.edu.cn/jzus; www.springerlink.com
E-mail: jzus@zju.edu.cn

Planning VANET infrastructures to improve safety awareness in curved roads*

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Received Mar. 26, 2012; Revision accepted Aug. 20, 2012; Crosschecked Oct. 12, 2012

Abstract: We analyze the effect of using a vehicular ad-hoc network (VANET) on accident avoidance. As shown in our analysis, a higher frequency of safety packets can prevent accidents, even for high speed vehicles and dense roads. To overcome connectivity problems in blind crossing situations, a genetic algorithm (GA) based method is presented for VANET infrastructure planning. The proposed approach tries to remove coverage sight holes in low sight distance cases in a traveling path in the road. In such places, drivers might not have enough sight for proper action and also environmental obstacles prevent direct communication between vehicles. Furthermore, curved roads affect mobility. Simulation results show that the density of vehicles is increased right before a curve and is decreased after that. Therefore, in this kind of road, a high frequency of packet generation may not act well in accident avoidance. The method proposed in this paper tries to cover such places considering the lowest safety distances according to traffic theory. For this, the road must be covered directly by infrastructure. Therefore, the problem is to find the best number and also positions of road side units. Using GA, the algorithm minimizes the summation of total uncovered and overlapped points in the roads which are covered by more than one antenna. Simulation on a real road map confirmed the capabilities of the proposed approach.

Key words: VANET, Infrastructure, Traffic theory, Minimum safety requirement, Genetic algorithm
doi:10.1631/jzus.C1200082 **Document code:** A **CLC number:** TP393

1 Introduction

The Institute of Transportation Engineers of USA defines traffic engineering as "the application of technology and scientific principles to the planning, functional design, operation, and management of facilities for any mode of transportation in order to provide for the safe, rapid, comfortable, convenient, economic, and environmentally compatible movement of people and goods" (Pline, 1999). As mentioned in this definition and other similar definitions, the primary objective of traffic engineering is safety. Studies by the U.S. Department of Transportation (1999) showed that the three largest crash types, i.e., rear-end, intersection, and road departure, account for nearly 75% of all crashes. These studies showed that driver inattention plays a key role in accidents. Based on an AHSRA report, 65.1% of accidents happen just because of inattention to the forward view (AHSRA Japan, 2001). As reported in Adler (2006), different studies show that in 69% of cases, crashes happen because of the absence of critical and necessary information for drivers in appropriate time. Former active safety systems like camera vision and radars cannot provide information about situations beyond other vehicles. Vehicular ad-hoc network (VANET), as a radio communication system, solves this problem. Vehicles which are not in the sight distance of each other could communicate using communication capabilities of intermediate vehicles.

The fundamental goal of VANET is improving safety in roads. For this, VANET nodes (vehicles) can communicate with each other without any need for

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* Project supported by Iranian Research Institute for ICT

extra infrastructure like road side units (RSUs) or any type of base station. For example, Kato *et al*. (2002) presented a vehicle control algorithm which works according to the cooperation between the following vehicles based on VANET. Their proposed approach enables groups of vehicles to be merged together or separated from each other. Taleb *et al.* (2010) proposed a collaborative collision avoidance system based on VANET. Yousefi and Fathy (2008) enumerated effective range and beaconing rate as key metrics for performance evaluation of safety applications in VANET.

The main drawback of VANET is the huge deployment cost. It is necessary to have an acceptable number of well equipped vehicles with VANET tools. Equipping VANET with infrastructure, as a new aspect, vehicles communicate across an RSU with outside nodes on the Internet. Therefore, value-added services, e.g., entertainment, online games, advertisements, and file sharing, become available by using VANET. New services can add more attraction for data service providers toward VANET. The main issue in this case is vehicle localization across the road to deliver data from the best RSU. Saleet *et al.* (2010) proposed a region based location service management protocol for VANETs which has a limited query and response overhead on the network. Cruces *et al.* (2009) proposed some planning roadside infrastructure strategies for information dissemination. The proposed approaches try to maximize the overall service time usage by planning for k RSUs in a region or city. Their conclusion is that planning for RSUs in intersections provides the best answer. On average, vehicles spend more time in intersections than other parts of roads. Although these new services can make VANET infrastructure planning more economical, they should not bend attention from safety to other areas. Therefore, RSUs can be used to improve safety as well.

In this paper, first we analyze the efficiency of VANET to avoid accidents. For this, we focus on the IEEE 802.11p standard and rate of generating safety packets. In VANET equipped vehicles, an engine control unit can request the activation of the break as soon as it detects dangerous situations based on received data. We extend our analysis to a wide range of speeds, vehicle density in the road, and different packet generation rates. Furthermore, we propose a new genetic algorithm (GA) based approach to cover blind crossing areas, e.g., curved roads and even intersections. Simulation results show that in curved roads, traffic density is affected by the curve. In case of sparse traffic densities, the connectivity probability of nodes is decreased. Therefore, in blind crossing cases like curved roads and intersections, non-line-of-sight communication using infrastructure is necessary for safety. Our proposed approach focuses on indirect message propagation using infrastructure. We have implemented our approach in MATLAB and used it to cover a real curved road.

2 Literature review on minimum safety distance requirements in traffic theory

Before talking about the effect of VANET on safety, it is necessary to have a primary understanding about the safety conditions in roads. Therefore, in this part, we review the main formulas and challenges in safety in traffic engineering (Roess *et al.*, 2004).

2.1 Road users

There are several characteristics that affect road users. Among them, field of vision and perception-reaction time (PRT) are the most important ones. Field of vision is related to the area in which drivers can see and detect objects. The Institute of Transportation Engineering of USA has defined three distinct fields for stationary persons (Dewar, 1999). As speed increases, however, these fields become narrow. Therefore, risk of accidents increases. PRT is the time in which a driver detects an unexpected object or condition in his/her field of vision, tries to identify it, makes a decision, and finally reacts to it. Based on studies of the American Association of State Highway and Transportation Officials (AASHTO), in 90% of cases, drivers react in less than 2.5 s (AASHTO, 2001). Nevertheless, there are other measured domains for PRT; e.g., 0.75–1.5 s was used in Yang *et al.* (2004) and Taleb *et al.* (2010). Using kinematic theory, reaction distance, i.e., the distance in which a vehicle travels during PRT, can be calculated by $d_{PRT}=vt$, where d_{PRT} is the reaction distance (m), v is the initial speed of the vehicle (m/s), and t is the reaction time (s). According to the AASHTO recommendation, this formula is summarized as $d_{PRT}=2.5v$.

Pedestrian behavior, drug impacts, and vehicle characteristics have important effects on driving. They need social investigations and more complicated research. We ignore them in this paper.

2.2 Acceleration and deceleration

Acceleration and deceleration have great impacts on safety. Acceleration is related to vehicle type and the weight-to-horsepower ratio, and deceleration is related to the braking system characteristics. The acceleration/deceleration distance can be computed as follows:

$$d_{\mathrm{a/d}}=(v_{\mathrm{i}}^2-v_{\mathrm{f}}^2)/(2a), \tag{1}$$

where $d_{\mathrm{a/d}}$ is the acceleration/deceleration distance (m), v_{i} is the initial speed (m/s), v_{f} is the final speed (m/s), and a is the acceleration rate (m/s^2). In breaking cases, to express Eq. (1) in terms of the coefficient of forward rolling or skidding friction F, where $F=a/g$ and g is the acceleration due to gravity, g=9.8 m/s^2, the deceleration distance can be addressed as

$$d_{\mathrm{d}}=(v_{\mathrm{i}}^2-v_{\mathrm{f}}^2)/[30(F\pm 0.01G)], \tag{2}$$

where d_{d} is the deceleration distance (m), F is the coefficient of forward rolling or skidding friction, and G is the grade (%). The standard deceleration rate, which covers 90% of cases, is 3.4 m/s^2 (Roess *et al.*, 2004). Therefore, Eq. (2) can be summarized as

$$d_{\mathrm{d}}=(v_{\mathrm{i}}^2-v_{\mathrm{f}}^2)/[30(0.348\pm 0.01G)]. \tag{3}$$

The total stopping distance, which is critical in safety applications, can be calculated as

$$d_{\mathrm{total}}=d_{\mathrm{PRT}}+d_{\mathrm{d}}=2.5v_{\mathrm{i}}+\frac{v_{\mathrm{i}}^2-v_{\mathrm{f}}^2}{30(0.348\pm 0.01G)}. \tag{4}$$

Eq. (4) is the base of the safe stopping sight distance, decision sight distance calculations, and other related distance intervals, especially in intersections and traffic lights. Another criterion is the safe stopping sight distance between two moving vehicles. While the vehicle in front (C_i) decelerates, the minimum required distance for safe stopping of the vehicle in behind (C_{i-1}) can be calculated as follows:

$$d_{\mathrm{total}}=d_{\mathrm{PRT}_{i-1}}+d_{i-1}-d_i, \tag{5}$$

where $d_{\mathrm{PRT}_{i-1}}$ is the PRT time of the driver in vehicle $i-1$ and d_x is the distance traveled by vehicle x before stopping.

2.3 Low sight distance in horizontal curves

Horizontal curves are common in different roads, especially in highways, sub-urban and rural roads. The severity of these curves is related to the design degree of curvature. As mentioned, the minimum sight distance has a great impact on safety. Road designers must be aware of this important issue in road design. Because of roadside objects, the sight distance is limited on horizontal curves. According to Fig. 1, the middle ordinate of the horizontal curve must be enough to provide the least required sight distances as (Roess *et al.*, 2004)

$$M=R[1-\cos(d_{\mathrm{total}}D/200)], \tag{6}$$

where M is the minimum required middle ordinate (m), R is the radius of the curvature (m), d_{total} is the total stopping distance, and D is the degree of the curvature.

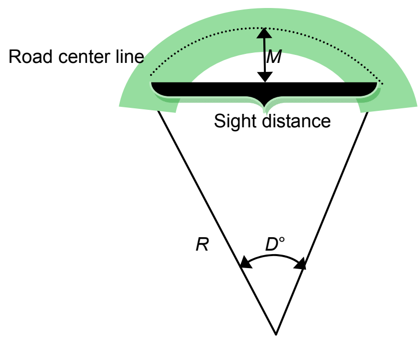

Fig. 1 Sight restriction on horizontal curves

In some places like mountains and valleys, reaching the minimum M and sight of distance is difficult and costly. In such places, roads are designed in a spiral while low sight of distance and safety recommendations may be ignored. Another special case of dangerous positions is intersections. While drivers move straight, the minimum sight distances for crossing vehicles are not met because of buildings, trees, and other environmental obstacles. Such points are great potential points for accidents. Although designers try to inform drivers about intersections and possible dangers using traffic signs and marks, these are not enough. It seems that VANET infrastructure provides more information about road crossings that drivers approach blindly.

3 Effect of VANET on safety

In this section, we analyze the effect of VANET on accident avoidance. Busson *et al.* (2011) analyzed the possibility of an accident for consecutive vehicles. They focused on multi-hop message propagation to avoid an accident; however, safety information has local worthiness. In this paper, we analyze the effect of VANET on safety, using single hop message propagation.

To deal with safety issues in the roads, IEEE has proposed IEEE 1609 series of standards (IEEE Std. 1609.1-2006; IEEE Std. 1609.2-2006; IEEE Std. 1609.3-2006; IEEE Std. 1609.4-2006) for Wireless Access in Vehicular Environments (WAVE) compromised with IEEE 802.11p (IEEE Std. P802.11p/D3.0, 2007). The IEEE 802.11p standard is based on IEEE 802.11e (Alcaraz *et al.*, 2009). The media access control (MAC) layer of IEEE 802.11p has two modes: contention-based mode and contention-free mode. The former is related to the situation in which sender nodes contend with each other to get a chance for transmission. In the latter, a polling mechanism is used. Because of the delay overhead of polling and the need for an external coordinator, the second method is unsuitable for use in emergency data propagation. In IEEE 802.11p, the channel is divided into 100 ms time intervals. Each time interval is divided into two 50 ms sub-intervals: the Control CHannel (CCH) and six Service CHannels (SCH) (Mišić *et al.*, 2011). Safety messages can be transmitted only in CCH intervals with a default frequency of 10 Hz. However, during congestion in the channel, this rate is decreased.

Before continuing the analysis, we make the following assumptions:

1. A group of tandem vehicles with the same specifications and VANET equipment move on a road.

2. All of the tandem vehicles have localization capability, e.g., GPS, to detect their current positions.

3. The network channel is perfect. There is no packet corruption or packet loss in the network. However, adding effect of channel fading and loss models (Nakagami, 1960) in experiments is straightforward.

4. d_{total} in Eq. (5) is discretized into sections with 1 cm length.

5. The vehicles in the road satisfy a Poisson distribution with an inter-vehicle distance of λ m (λ=1000/(number of vehicles per kilometers)).

6. According to Yousefi *et al.* (2008), lane width with respect to the communication range of vehicles is negligible. Therefore, we can simply replace a multi-lane road with a single-lane road.

According to Section 2, an accident could happen if the distance between two tandem vehicles is less than d_{total} in Eq. (5). In such a situation, the driver has little chance to have sufficient reaction time to avoid upcoming accidents. For a given λ and d_{total}, the cumulative distribution function (CDF) of the Poisson distribution (Eq. (7)) returns the possibility that the distance between two tandem vehicles with specified speeds, in the road, and with a specific density, is less than or equal to d_{total}. This possibility can be interpreted as the possibility of occurrence of an accident in the road.

$$F(d_{\text{total}},\lambda)=P(d_{\text{total}}\le\lambda)=\mathrm{e}^{-\lambda}\sum_{i=0}^{d_{\text{total}}}\frac{\lambda^i}{i!}. \qquad (7)$$

Using this method, we can divide a chain of n vehicles into $n-1$ different groups of tandem vehicles to find the possibility of an accident in the chain.

To reduce the possibility of an accident, we need to restrict d_{total} in Eq. (5). Although d_i and d_{i-1} are related to the velocity of the vehicles, d_{PRT} is reducible. In VANET enabled vehicles, automatic breaking in case of detecting a hazard can reduce PRT. A higher packet rate means lower interval time between two consecutive packets and therefore shorter PRT.

Fig. 2 shows the possibility of an accident for different packet rates. This figure is drawn based on Eqs. (5) and (7). The speed difference between two-tandem vehicles ranges from 15 to 40 m/s. Also, the density of vehicles in the road is between 8 and 13 vehicles/km. These density rates can satisfy the minimum safe distance between two tandem vehicles with a maximum deceleration rate of -10 m/s^2. As we can see, lower data rates, higher speeds, and higher densities have direct relation with the increasing possibility of an accident. Comparison of Figs. 2a and

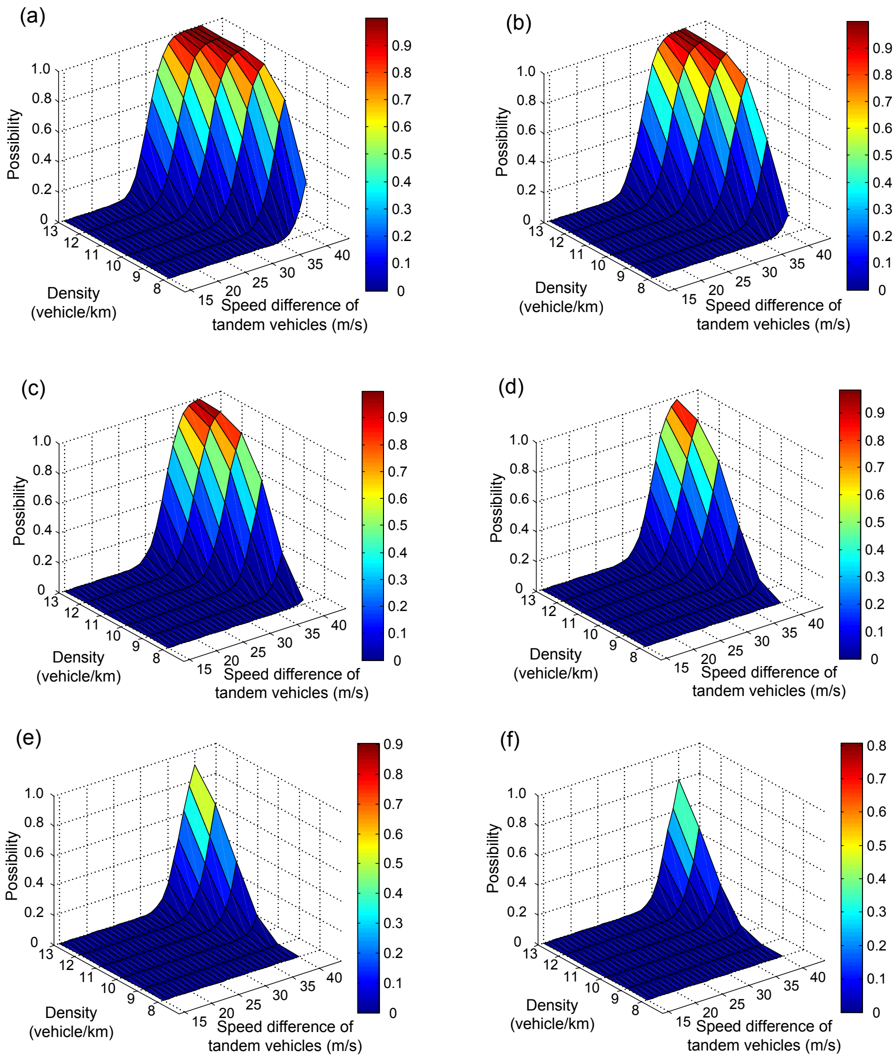

Fig. 2 Possibility of an accident using a data rate of one packet per 1000 ms (a), one packet per 800 ms (b), one packet per 600 ms (c), one packet per 400 ms (d), one packet per 200 ms (e), or one packet per 100 ms (f) for safety messages

2b with Figs. 2e and 2f shows the direct effect of the number of packets generated, especially in congested situations. These results show the efficiency of VANET in safety. Even if we assume that the PRT of human being is 1 s, then the possibility of an accident for a vehicle under human control, by such a PRT value, is equal to the case of sending one packet per second in VANET.

4 Investigating the effect of curved roads on density of vehicles

To study the effect of curved roads on the density of vehicles, we have set up a simulation using MATLAB software. The simulated area consists of a curved road with two lanes along the same direction and 2 km length. Speed limitations in the road, $v_{\min}$, v_{avg}, and $v_{\max}$, are equal to 60, 75, and 90 km/h, respectively. If the distance between two following vehicles becomes less than half of the safety distance, the follower must reduce its speed. Otherwise, each vehicle can accelerate or decelerate freely with an acceleration/deceleration in the range of [−10, 10] m/s^2 (the probability of acceleration is 0.15, the probability of deceleration is 0.15, and in 70% of situations vehicles do not change their velocities). Also, PRT is 2.5 s.

Suppose that there is a curve placed in the middle of the road with its center placed in the 1000th meter of the road, with a minimum sight distance of

50 m. Vehicles must reduce their speed to $v_{\min}$ within the 100 m before the center of the curve. They are free to accelerate within the 50 m after the center of the curve. In addition, takeover is forbidden along the road. The road grade G is 4. Simulation time is 4000 s. We omit the results of the first and last 200 s. In other words, we have analyzed the results of 3600 s or 1 h of the simulation. The simulation results have been updated and analyzed every 0.1 s during the simulation. The simulation is run 100 times.

Fig. 3 shows the average density along the road. To remove the side effects of the two ends of the road, the results of the first and the last 200 m of the road are not presented. Although the average density along the road is somewhat fixed, in the distance between 800 and 1300 m, there are two large fluctuations. The first one occurred because of the effect of the curve along the road on the mobility of vehicles. The vehicles have to reduce their speed before the curve. After passing the curve they are free to increase their speed. The second fluctuation occurred because of the effect of vehicles in front of the vehicles passing the curve. These speed changes cause backlogs before and after the curve.

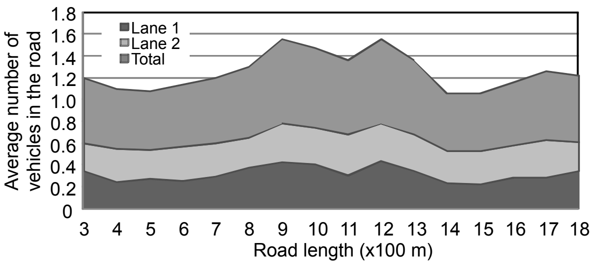

Fig. 3 Vehicle density analysis along the curved road

Fewer vehicles in the area near the curve mean less connectivity. In addition, in the curved roads, obstacles can prevent direct communication between tandem vehicles. Therefore, in case of low density, even higher data rates cannot solve the safety problem. To cover this problem, in curved roads, infrastructure can relay safety messages between vehicles.

5 Proposed GA-based planning algorithm

In this section, we introduce a GA-based planning strategy for minimum cost deployment of VANET infrastructure. GA is one of the well-known optimization tools. The proposed method is introduced to prepare the best coverage in the road positions which do not provide enough sight distances as safety applications require. Approaches like that proposed by Sepulcre *et al.* (2011) focus on reliability of 99.99% in accident avoidance. This reliability is achieved if and only if the follower vehicle receives at least one safety packet during a proper time period before the break. Therefore, planning strategies like that proposed by Abdrabou and Zhuang (2011) cannot react well in such cases. The method proposed by Abdrabou and Zhuang (2011) is based on satisfying the maximum tolerable delay bounds of applications, not safety considerations.

If there is not a minimum density in the road, as Mohimani *et al.* (2009) analyzed, the connectivity between vehicles is broken. Therefore, in the planning strategy, we follow the strategy of direct communications between vehicles and antennas in the curved roads. We propose a full coverage of such areas, using VANET infrastructure. Deploying infrastructure is costly; therefore, finding the least number of required antennas is important.

The proposed method has three steps (Fig. 4). The first step is preprocessing. The map of a road is injected into software or processed manually. This map contains only the area with minimum safety distance requirements. Based on the height of antennas, the map is divided into three regions and colored: road, roadsides with height lower than the antennas, and roadsides with height higher than the antennas. In the second step, the processed map is analyzed according to the communication range of the antennas and environmental obstacles in the direct path of signal propagation. The output of this step is the number of antennas with a minimum cost to cover safety requirements in the road. In the last step, the best positions for the selected number of antennas are chosen.

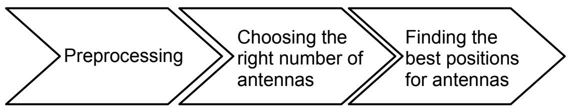

Fig. 4 Steps of the proposed genetic algorithm based planning algorithm

5.1 Preprocessing

In the first step, a map of the area is processed based on the chosen height of the antenna. The antenna height has important effect on signal propagation. Short antennas have problems in data dissemination with respect to environmental obstacles; in contrast, tall antennas need more transmission power. Furthermore, in some situations, e.g., intersections or mountainous roads, obstacles are long and elevated. For the given antenna height, the map is colored black for regions in which signals cannot propagate, gray for roadsides which do not disturb dissemination, and white for the road area that must be covered by direct signals of antennas.

5.2 Choosing the right number of antennas

Assume we deal with an optimization problem to minimize a cost function

$$f(x)=f(x_1,x_2,\ldots,x_n) \tag{8}$$

subject to some conditions. In the first step, we need to define x_1, x_2, …, x_n. As mentioned before, because of a low degree of connectivity, we are looking to cover the curved area such that vehicles could communicate with RSUs directly. We need at least two inputs: a map of the road and a detailed coverage area of each antenna. For simplicity and also minimizing the cost of antennas, in this study, we focus on omnidirectional antennas. Using this type of antenna, we need only to know the communication range of the antenna and its position to calculate the coverage.

For the cost function, we need to determine the elements that affect the cost. Our goal is to maximize the covered area using n antennas. Also, uncovered points by antennas mean indirect communication between RSUs and vehicles, which is against our coverage strategy. For success, we need to avoid overlapped covered points as much as possible. Based on these factors, we define the cost function C for minimization as

$$C=\min\left(\alpha\sum\vartheta+\beta\sum\psi\right), \tag{9}$$

where α and β (α, β>0) are weights of summation of uncovered points ϑ and summation of overlapped covered points ψ, respectively.

To choose the best number of antennas, GA is used. The area of a curved road is not convex. It consists of multiple consecutive curves in small areas. Mathematical optimization approaches like convex optimization or linear programming is not suitable for such conditions. In addition, the proposed liners programming approaches for sensor placement, like Chakrabarty *et al.* (2002), Sahni and Xu (2005), Xu and Sahni (2007), and Osais *et al.* (2008), have a time complexity problem. They fail to return the final answer in an acceptable length of time. For example, in a 20×20 grid field, the model proposed by Sahni and Xu (2005) returns the answer after 14 h (Osais *et al.*, 2008). GA is a powerful, robust, and flexible optimization tool. It can be easily modified for different problems and tolerate noisy functions (Sivanandam and Deepa, 2008). The main inputs of GA are genomes and a fitness function. As shown in Fig. 5, the structure of genomes contains position information of antennas. In this structure, (X_k, Y_k) is the position of antenna k. Here, we suppose that all antennas are similar. Therefore, for memory saving, we use the communication range as a global variable, not a local variable in the structure of the genome.

X_1	Y_1	X_2	Y_2	…	X_n	Y_n

Fig. 5 Common structure of the used genomes

The second important input is the fitness function. This function provides the fitness value for each offspring. We use the proposed cost function C in Eq. (9) as our selected fitness function. The best answer is the case with the minimum fitness value.

Based on the position information in the genome, antennas are placed on the processed map. Then, according to the colored map, the covered area of each antenna is determined. If a point in the road, presented by white color, remains uncovered, it implies a negative point. If two antennas become closer than twice the communication range, some inappropriate overlapped points appear. Therefore, the summation of uncovered points and overlapped covered points is a negative score for the genome.

To calculate these negative points, in each round two matrices of the same size as the original image are prepared. In the first matrix, the cells corresponding to road points in the map take value 1 and other cells take value 0. To fill this matrix, we prepare a black and white image using a threshold of 0.6. Any point not placed on the road takes value 0. If a cell is covered by an antenna and its value is not 0, its value is changed to 0.5. Cells in the second matrix have value

0 at first. If a point is covered by an antenna, its corresponding cell value is incremented to show the possible overlaps. To check the effects of the environment on data dissemination of each antenna, we create the second black and white copy of the map using a threshold of 0.2. Therefore, gray points are changed to white. The data is disseminated if and only if there are not any black points in the propagation path.

By running different iterations of GA, new offspring are generated by crossover and recombination of old genomes. Some offspring can be mutated and make new generations. Genomes with better fitness values have more chance to remain in the current generation for the next round of the algorithm. The selection algorithms do not select the best options because such a selection strategy can cause the algorithm to produce sub-optimal answers.

The GA-based algorithm must be run with the different numbers of antennas and communication ranges. Then, the best choice for the number of antennas required can be determined. It is recommended to choose the right number with respect to the backbone facilities. Although the case with a lower fitness value, a lower number of antennas, and higher communication ranges can be the best choice, this option causes difficulties for backbone connectivity between antennas.

5.3 Finding the best positions for antennas

The final step of the planning algorithm is to find the best places for antennas. For this, there are two approaches. First, in the second step, position information is gathered and after choosing the number of antennas, their positions are extracted. Second, after selecting the best values for the number of antennas and the communication range, the GA-based algorithm is run again to choose the best positions for deployment. The first approach can reduce the time for decision making.

5.4 Drawbacks of GA

Although GA can solve complicated optimization problems, it suffers from some unwanted problems. The main negative point is its running cost. GA consumes much memory and time to prepare responses. Selecting clearer and more restricted options can improve this but may consequently reduce the chance of finding better answers. Another drawback of GA is that there is not a well-defined way to choose the best algorithms for mutation, crossover, and selection functions (Sivanandam and Deepa, 2008). As presented in Eiben and Smith (2003), there is not a specific and exact approach for parameter control in GA. Testing different setups to establish a good algorithm design implies a semi-exponential number of runs.

6 Performance evaluation of the proposed method

In this part, we first present simulation parameters and then investigate the performance of the proposed approach via different simulations.

6.1 Simulation setup parameters

To test the abilities of the proposed GA-based covering algorithm, an image from the entrance road of Tuyserkan (Hamedan, Iran) is selected (Fig. 6a). This figure is extracted from Google's Maps website. This image has been preprocessed manually using geographical information and 2 m high antennas (Fig. 6b). The rest of the process is implemented in MATLAB. The selected GA parameters are shown in Table 1. We run simulations five times for each case with a maximum of 1000 iterations for each case, to avoid unwanted local minima in the final results. The best results in these simulations are selected as the final answer of the algorithm.

(a) (b)

Fig. 6 The selected curved road for coverage and the entrance road of Tuyserkan, Hamedan, Iran
(a) Satellite map; (b) The map after preprocessing

Simulations are repeated in three different series. The selected values of α for these series are 1, 1, and 3 and the selected values of β are 1, 3, and 1. A larger α

Table 1 Running parameters of the genetic algorithm

Parameter	Value
α	1, 1, 3
β	1, 3, 1
Maximum number of simulations	5
Maximum population size	50
Maximum generation size	50
Maximum number of iterations	1000
Maximum number of iterations without any change in the best fitness value	5
Crossover probability	0.7
Mutation probability	0.03, Eq. (10)
Selection function	Roulette wheel
Crossover function	$0.2\text{Gen}_1+0.8\text{Gen}_2$

to β ratio means that the uncovered points have a greater impact than the overlapped covered points in the deployment, while a larger β to α ratio means that the impact of the overlapped covered points is greater than the impact of the uncovered points. The values selected in this study are arbitrary. Readers can choose other values based on interest. The maximum generation size and maximum population size are both limited to 50. Increasing these sizes can improve the probability of having better results; however, this leads to extra processing time and memory overhead. We have used a single point crossover function with a probability of 0.7. Further adding crossover points reduces the performance of GA (Sivanandam and Deepa, 2008). The selected crossover function is $0.2\text{Gen}_1+0.8\text{Gen}_2$. The selection function is a roulette wheel, one of the traditional and commonly used GA selection techniques (Sivanandam and Deepa, 2008).

One of the methods used for parameter control in GA is changing the mutation step size (Eiben and Smith, 2003). In this study, we use two approaches for this. In the first approach the mutation probability is fixed to 0.03. In the second approach, based on Eiben and Smith (2003), we use the following equation to calculate the mutation probability dynamically, during the runtime:

$$P_{\mathrm{m}} = \mathrm{init}\,P_{\mathrm{m}} + N(0, \sigma(t)), \tag{10}$$

where

$$\sigma(t) = 1 - 0.9t / T. \tag{11}$$

Herein P_{m} is the mutation probability, $\mathrm{init}P_{\mathrm{m}}$ is the initial mutation probability (equal to 0.03 in this paper), $N(0, \sigma(t))$ is the normal distribution function with mean zero and standard deviation σ, t is the current generation iteration number varying from 1 to T, and T is the maximum generation iteration number (1000 in this paper).

In the rest of this paper, we call the former approach (fixed mutation probability) the primary approach and the latter the adaptive approach.

6.2 Coverage of the curved road

For performance evaluation, we have changed the antennas' propagation radius from 100 m to 500 m with a step of 100 m. Fig. 7 depicts the results of calculating the antenna locations with minimum negative points. The trend of the presented results in the graph is not smooth or uniform. This happens since GA prepares only sub-optimal results. Furthermore, the two defined approaches follow a similar trend. However, in most of the time, the trend of the adaptive approach is smoother than that of the primary approach. This happens because there are more possibilities of mutation in the first rounds of the second approach.

Figs. 7c, 7d, and 7e show the effect of increasing the transmission range. There is little difference of the results between different cases with 300 m, 400 m, and 500 m transmission range antennas. Selecting antennas with a larger transmission range depends on the curved road. If the road has a lot of curves with short minimum sight distances, selecting a smaller transmission range is better; otherwise, a larger transmission radius is considered.

Readers can tune the cost function using α and β, based on their requirements. If they are looking for a full coverage, they can increase the value of α. If they are looking to use the minimum number of possible antennas, they can focus on β. The proposed cost function in Eq. (9) is a general function. Furthermore, the reader can select the transmission range based on the map of the road to examine the effects of curves and obstacles on the effective transmission range of antennas.

To show the efficiency of the proposed method, in Fig. 8, we show the selected positions for deployment using the primary approach with a 100 m or 200 m communication range of antennas. As mentioned before, our criterion for selecting the best number of antennas is Eq. (9). Based on Fig. 7, the results of deployment in the adaptive approach are similar to those of the primary approach; therefore, we do not show their selected points here.

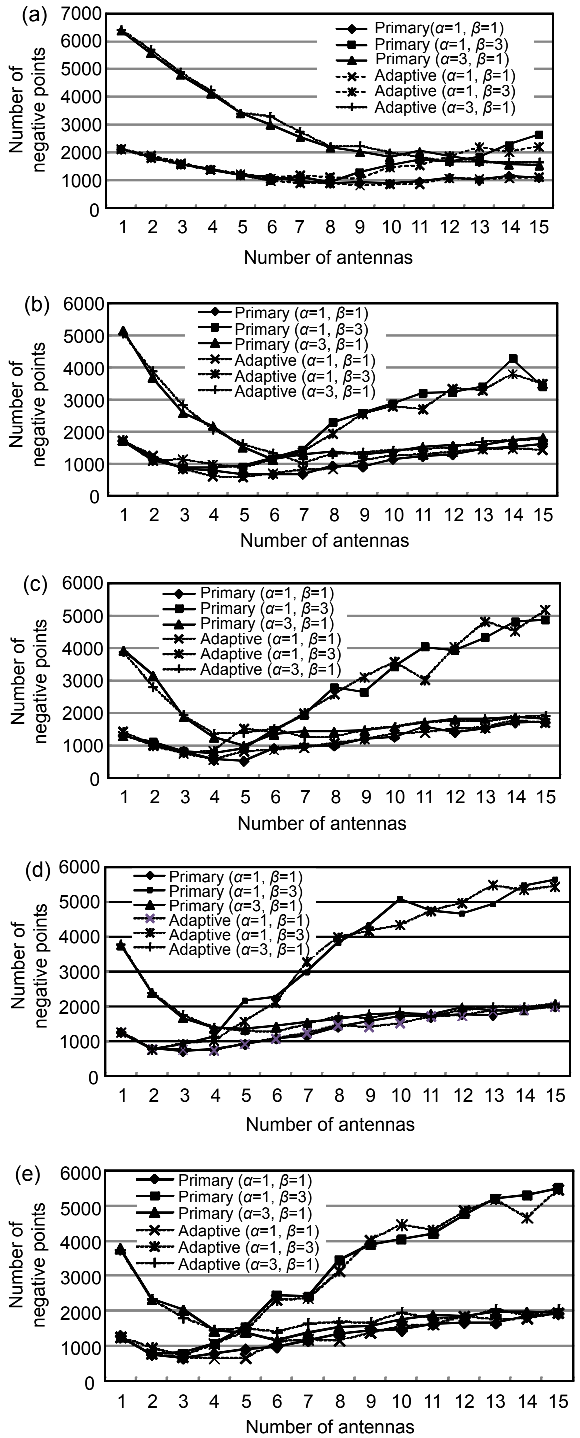

Fig. 7 Results of selecting the best places using antennas with a 100 m (a), 200 m (b), 300 m (c), 400 m (d), or 500 m (e) propagation radius

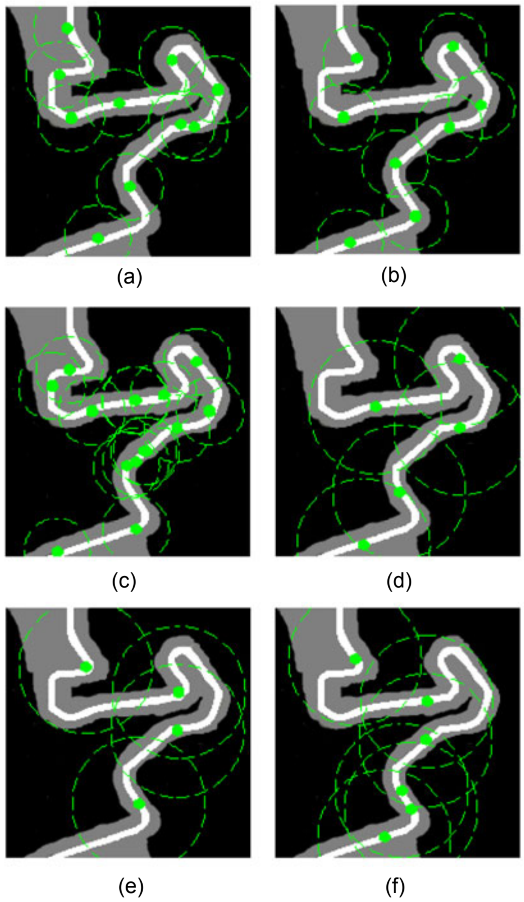

Fig. 8 Selected points for installing the antennas with a 100 m (a, b, c) or 200 m (d, e, f) transmission range
(a) 10 antennas, α=1, β=1; (b) 8 antennas, α=1, β=3; (c) 15 antennas, α=3, β=1; (d) 5 antennas, α=1, β=1; (e) 4 antennas, α=1, β=3; (f) 6 antennas, α=3, β=1

7 Conclusions

Safety is an important goal in ITS and VANET. In this paper, we have shown the effect of VANET in accident avoidance. It is shown that, using VANET with high rates of safety packets effectively reduces the possibility of accidents, even for high speeds and low inter-distance between tandem vehicles. A novel GA-based method was proposed to cover curved roads using VANET infrastructure. In curved roads, there is not enough sight distance for drivers. Furthermore, environmental obstacles prevent direct communication between vehicles. Therefore, the possibility of an accident at such points increases. To solve this problem, we plan and install VANET infrastructure in curved roads. The proposed algorithm tries to minimize the summation of uncovered areas and multi-covered areas. Simulation results show the abilities of the algorithm. Working on 3D map processing is scheduled as future work.

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