An Emergency Information Broadcast Routing in VANET

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Abstract. Aiming at the problem that the low efficiency of information transmission caused by the high speed of vehicle and the unstable network topology in the vehicle ad hoc network (VANET), an emergency information broadcast (EIBR) routing in VANET was proposed in this paper. The routing scheme decreases the number of nodes to broadcast packets. A connected dominating set (CDS) is created for the certain road section. Then the CDS is optimized with the approximation method to obtain the minimum connected dominating set (MCDS). The next hop relay node will be selected from the MCDS. In addition, these nodes broadcast the packets by a dynamic probabilistic broadcast strategy. It can enormously lessen the number of broadcast nodes and the transmission collisions, it also can reduce the end-to-end delay consequently. Simulation results have shown the effectiveness of our broadcast routing as compared to the two traditional broadcast protocols NCPR and DMB in the two aspects of the average transmission delay and packet delivery ratio.

Keywords: VANET · Emergency information · MCDS · Probabilistic broadcast · Routing

1 Introduction

In the process of incubating intelligent transportation system (ITS) into reality, vehicular ad hoc network play an indispensable role, moreover, the intelligent networked vehicles, which combine the technologies of VANET and autonomous driving, are the core elements of ITS. The vehicles sever as the nodes collecting traffic information around themselves and broadcasting safety, road conditions and other information by communicating with other vehicles in VANET. It can effectively improve traffic conditions and enhance road safety to reduce the impact of traffic on the environment [1]. VANET is known as a kind of MANET, in which vehicles are not only the nodes receiving information meant for it but also relaying information intended for others in the network, thus information can be transmitted to distant vehicles in a multi-hop method through the relay nodes. Vehicles can establish or join other established VANETs at any time with their movement and without the restriction of fixed facilities. In VANET, vehicles can communicate not only with other vehicles but also with road side units (RSU). It

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accesses the backbone network through roadside units to provide richer services for members in the vehicle.

However, the transmission of information in this network has numerous challenges. The network topology changes extremely quickly owing to the nodes at a high velocity, which results in shorter link duration between nodes. Besides, the mobility of nodes is constrained by the road, which makes the uneven distribution of nodes in the network, it accordingly causes serious network segmentation in VANET. In hot road areas such as intersections, the density of nodes is incredibly high. If all nodes are allowed to broadcast information freely without restriction, it will lead to fierce competition for channel resources and even paralyze wireless transmission in the region. These factors lead to the unreliable transmission of information in VANET. Therefore, it is a considerable significance to search for an efficient broadcast transmission path in VANET.

The main contributions of this work are summarized as follows.

(1) This paper described the importance of routing in VANET and illustrated the challenges of data transmission in the network.
(2) In order to reduce the data broadcast conflict, we design a minimum connected dominant sets construction algorithm and the nodes in the minimum connected dominating set broadcast the packets. Furthermore, these nodes broadcast the packets by a dynamic probabilistic broadcast strategy.
(3) In terms of the average transmission end-to-end delay and packet delivery rate, we evaluate the proposed protocol and compared the results with other schemes.

The remainder of this paper is organized as follows. A brief overview of related work is provided in Section II. The minimum connected dominant sets construction algorithm and the dynamic probabilistic broadcast strategy are presented in Section III. The performance evaluation is given in Section IV. The last Section is conclusion.

2 Related Work

Broadcasting is a basic method of wireless communication in networks. The process is that the node transmits the information packet to the whole network. It acts a significant role in network maintenance and management. In the design of the broadcasting protocol, it possesses many issues remained to solve, such as intense transmission conflict, broadcast storm and hidden terminal.

In [2], vehicles located in a specific road segment employed the slot map broadcast to perform distributed access. All nodes broadcast Hello messages periodically to establish local topology. Each vehicle node utilizes a marker variable to determine whether a packet is redundant or not. However, due to the rapid vehicle nodes and the network topology comparison, the redundancy of data packets is extremely large. It consequently reduces the delivery rate of packets and produces large broadcast latency. Singh et al. proposed a masqueraded probabilistic flooding routing [3]. In the mapping process from node ID to packet, the authors introduced a confusion that is capable of masquerade packets sent by a node to any other nodes as its own packets. In [4], the authors proposed a new probability-based multi-hop broadcast routing to guarantee reliability and low latency. The probability of a node forwarding a packet depends on the distance between the current node and the relay one. But in sparse VANET, there may be insufficient vehicles near the source node to transmit information, which can lead to a sharp drop in the delivery rate of packets.

An adaptive emergency broadcast strategy for VANETs (AVED) is proposed by Chou et al. in [5]. When a traffic accident happens, the current node transmits the emergency messages to all nodes in a certain range. While in AVED, vehicle nodes maintain a routing table through periodical cooperative awareness message, which increases the redundancy of packets. Presented in [6], a recursive broadcast routing is based on the cluster to transmit emergency information in VANET. The algorithm selects a vehicle node as cluster head to broadcast packets. But if some cluster members cannot receive the packet, the cluster head will broadcast the packet repeatedly. It is not suitable for sparse VANET consequently. Virdaus et al. analyzed the influence of broadcast storming for emergency delivery in VANETs [7]. Some scholars proposed many schemes to solve the broadcast storm problems [8, 9, 10, 11]. Yet there are still some unresolved problems in these patterns, such as the redundancy of packets, transmission collision, and transmission delay.

The strategies in [12, 13] and [14], utilize a distance-based broadcast algorithm frequently to appoint the nodes farther away from broadcast ones as the relay node. It lessens the transmission delay of broadcasting data packets through decreasing the value of the hops in the data broadcast transmission process. Moreover, it can further control the amount of redundant broadcast information in the network and improve the utilization efficiency of network resources. While if the reliability of data transmission is not guaranteed, some nodes may not receive data packets. The authors of [15] presented a novel sender-based broadcast protocol in VANET. They designed a control structure based on an index to define control messages. The size of the control messages is determined by a segment-based partition algorithm to adapt the distribution of the relay node. On the other hand, this fashion will add additional overhead in transmission, which affects the transmission efficiency.

To solve the problem of packet collisions and medium contentions along with broadcast storm in VANETs, and inspired by the above-mentioned schemes, we propose an emergency information broadcast routing in this paper, which is based on the idea of reducing the number of nodes to broadcast packets. In our proposed method, a connected dominating set (CDS) is created for the current node, and then optimized to approximate the MCDS. The scheme as presented in our paper greatly lessen the number of broadcast nodes and the transmission collisions, moreover, it also can reduce the end-to-end delay.

3 Routing

3.1 Problem Description

When transmitting emergency data packets, it is demanded that the end-to-end delay of information be severely within a certain given threshold. For example, when congestion occurs in road, the road section near the congestion point will be a local hotspot area, which results in a high local traffic density. If the packets are transmitted according to flooding broadcasting, the problem of broadcast storm mentioned above will arise, which will increase the transmission delay and packet loss rate. This paper researches the routing that can reduce the number of packets transmitted by nodes.

The traditional data transmission is broadcast in VANET. There is no definite destination node for this transmission. The relay node broadcasts the received data to all neighbor nodes, which easily leads to channel congestion, high packet loss rate and so on. The results in [16] show that when data is transmitted by broadcast, the network delivery rate is less than 20%. In order to improve the data transmission efficiency in VANET, this paper divides the highway into cells from the physical level.

In urban environment, roads are generally long rectangular with a length of several kilometers and a width of tens of meters. R represents the maximum distance between two nodes that can transmit packets. The roads are divided into short rectangular cells with 2R, and each cell is assigned an ID. Mark the location of the cell with two points on the diagonal of the short rectangle, as shown in Fig. 1.

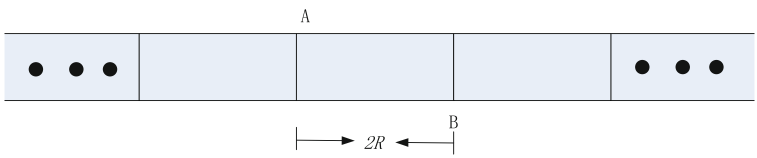

Fig. 1. Cell.

When a road is divided into short rectangles as shown in the above figure, the communication network between vehicle nodes in the road can be designed into a structure composed of physical layer and logical layer, as shown in Fig. 2. The real vehicle nodes are nodes in the physical layer, and each short rectangle is regarded as a virtual node. At the logical level, the broadcast of packets in VANET can build a broadcast tree, and the nodes in the tree are virtual nodes referred to above. Therefore, packets transmission on the road can be regarded as point-to-point transmission.

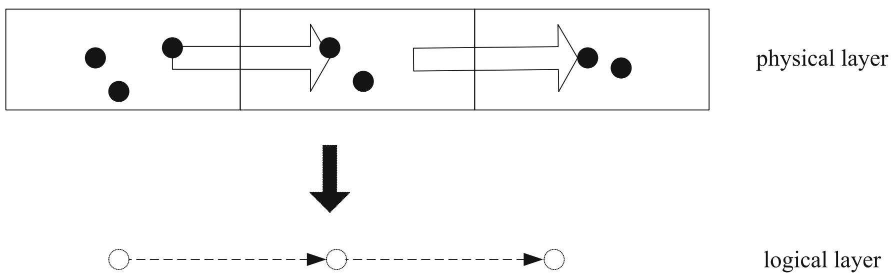

Fig. 2. Two layers structure.

To reduce the number of nodes transmitting packets, a MCDS is constructed for the network composed of physical nodes in above cells. Only the nodes exist in the MCDS can broadcast packets. The construction algorithm of connected dominating set is shown in Sect. 3.4.

3.2 Relevant Definitions

The wireless transmission mode discussed in this paper adopts the omnidirectional transmission mode. In the omnidirectional transmission mode, the wireless coverage area is disc-shaped. In this paper, the transmission range of nodes is represented by the unit disk graph (UDG)[17], that is, all nodes within the disk can communicate with the center node. Let G = (V, E), the V represents the nodes in the graph and the E represents the edges in the graph.

Definition 3–1: Assume that all nodes have the same transmission distance. The nodes relaying packets is considered as the center of the disk and the maximum transmission distance R is considered as the radius. Supposing the distance between two nodes is less than R, they can communicate with each other accordingly.

In VANET, each vehicle has a unique identification. V represents the node of VANET. |V| represents the number of vehicles in VANET. While E represents a connected edge in G, and formula $(v_i, v_j) \in E(G)$ denotes that node v_i and v_j are adjacent.

Definition 3–2: The node set $D \subseteq V(G)$ is the Connected Dominant Set in G, and it indicates for any v, if either v ∈ D or v is the neighbor node of the nodes existed in D.

Definition 3–3: V represents a node in G. let $Neighbor(v)$ be the neighbor node set of v.

Definition 3–4: $\mathrm{d}(\mathrm{v}_1, \mathrm{v}_2)$ Denotes the distance between v_1 and v_2. Let R be the maximum transmission distance of nodes, thus v_1 and v_2 are connected, provided $\mathrm{d}(\mathrm{v}_1, \mathrm{v}_2) < \mathrm{R}$.

3.3 Broadcast Routing Description

This broadcast routing consists of two steps: the first step is that Connected Dominating Set (CDS) is constructed for vehicle nodes of a hot area in VANET; the second one is that the nodes in CDS are selected as the relay nodes to transmit the packets.

3.4 Connected Dominant Sets Construction

The construction of Minimum Connected Dominating Set (MCDS) is an NP-hard problem [18], and that signifies no solution in polynomial time. Hence this paper researches the approximate solution of this problem, and proposes an approximate algorithm to construct MCDS.

Algorithm Description. Initial Connected Graph G with the center of the current node S is constructed. In this paper, an initial connected dominant set is constructed according to the minimum spanning tree method as presented in [19]. Obviously, the greater the degree of a node means the more neighbor nodes of the node, so the connected dominating set construction algorithm should give priority to choose this node. Therefore, the degree of the node can be used as an important parameter to determine the relay node in CDS. Consequently the nodes with greater degrees have higher weights.

Algorithm Implementation. Table 1 describes the algorithm of constructing initial connected graph. Table 2 describes the algorithm of constructing a MCDS. A MCDS is constructed in a cell.

Table 1. Algorithm of constructing initial connected graph

Input: Initial Vertex u_0, The length d Output: $G(V, E)$
1. Initialize set $V = \Phi, E = \Phi$
2. U is the vehicle set that exist in the road section within length a certain d (e.g. $2R$), For any $u \in U$, the $d(u, u_0)$ is computed according to their coordinates
3. If $d(u, u_0) < d/2$, then add u to V
4. Delete u from U 5. If U is not empty, go to step 2. Else go to step 6 6. Traverse each node in set V from vertex u and calculate the distance $d(u, u_x)$ between u and u_x in V 7. If $d(u, u_x) < R$, then add (u, u_x) to E. Until all nodes have been traversed 8. Determine that (u, u_x) or (u_x, u) are the same edge. Traverse set E and delete duplicate edges
9. Return $G(V, E)$

Table 2. MCDS Constructing Algorithm

Input: $G(V, E)$ Output: $MCDS$
1. $U = \{u_0\}$, u_0 is the source node
2. $MCDS = \{\Phi\}$, $CDS_{initial} = \{\Phi\}$
3. Weight each edge in the graph based on the degree of nodes on both sides of the edge
4. Choose one edge (u, v) existed in E and have current maximum weight. Add u or v that is not in U to U 5. Repeat, until $U = V$ 6. U is the $CDS_{initial}$, and $u \in U$ and D(u) > 1 7. For $\forall u_1, u_2, u_1 \in CDS_{initial}, u_2 \in CDS_{initial}$, If $Neighbor(u_2) \subseteq Neighbor(u_1)$, then $MCDS = CDS_{initial} - u_2$. Else $MCDS = CDS_{initial}$ 8. (u, u_x) and (u_x, u) are judged to be the same. Delete duplicate edges in E
9. Return $MCDS$

Algorithm Analysis. We analyze the time complexity of the above two algorithms. Table 1 are c the classic construction graph algorithm, the time complexity is $O(n^3)$. Let's analyze another.

The algorithm in Table 2 mainly consists of four linear steps.

(1) The first step that weights to the edges of graph G. The time complexity of is $O(n)$.
(2) The time complexity of the Prim algorithm is $O(n^2)$.
(3) The time complexity of selecting non-leaf node steps is $O(n)$.
(4) Step to delete redundant nodes. It requires pairs comparing the neighbor nodes number of nodes classified to the initial CDS. For a set with n nodes, the number of this comparison is $O(n^2)$. Let m_1 and m_2 represent the number of neighbor nodes for two nodes. $Max\{m_1, m_2\}$ represents the number of steps to determine whether the neighborhood set of two nodes has a inclusion relationship. The opinion proposed in [20], is that a network is fully connected if each node possesses more than $5.1774 \log n$ neighbors in the network. As a result, m_1 and m_2 are less than $5.1774 \log n$. Therefore, the time complexity of this step is $O(n^2 \log n)$.

Since the above four steps are linear, the time complexity of constructing a MCDS is $O(n^2 \log n)$.

3.5 The Probabilistic Broadcast Strategy

The MCDS is constructed for the network composed of vehicle nodes in the cell. When a packet is transmitted to the cell, only the nodes in CDS can broadcast the packet. In order to further reduce the data transmission conflict, the nodes in the MCDS adopt a Dynamic Probabilistic broadcast strategy to broadcast the packet. The probability of the packet being broadcast by the node is determined by two parameters. One is the average density of the node in VANET. Another is the neighbor coverage set (NCS) of a node for certain packet.

Computing for Average Number of Neighbors of Nodes. In VANET, nodes maintain and update their neighbor sets by periodically sending hello packet. When node x receives the hello packet of node y, it queries whether node y exists in its neighbor table. If it does, it updates the information of node y in its neighbor table. Otherwise, it stores node y in its neighbor table. This paper sets a threshold for the time interval between two nodes sending hello packet. If two nodes do not receive hello packet sent to each other within the given time threshold, they will delete this node in the neighbor table.

Let $\overline{n}$ represent the average number of neighbors for all nodes. The total number of nodes in VANET is represented by N, and the neighbor number of node i is U_i, so $\overline{n}$ can be computed by the following formula.

$$\overline{n} = \frac{1}{N} \sum_{i=1}^{N} U_i \tag{1}$$

The NCS of a Node for Certain Packet. Each node for certain packet has its NCS. It is the set of nodes that coincide in the neighbor table of two nodes. As shown in Fig. 3, vehicle S transmits a packet to A, B, C, H. Both C and H are in the neighbor table of D, and they have received this packet. Therefore, for this packet, the neighbor coverage set of D is C and H.

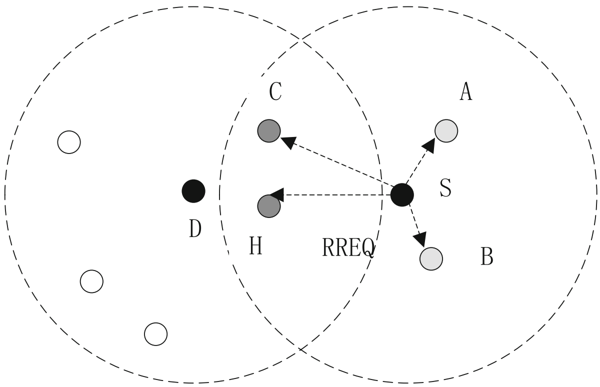

Fig. 3. Packet neighbor coverage set of node.

The Probability Formulation for Broadcasting Packet of Node. The probability of a packet being broadcast by a node is determined by the average density of nodes and the neighbor coverage set of the packet to the node. When a node receives a packet, it first determines the neighbor coverage set of the packet for the node. Obviously, the larger the set of covered neighbor nodes is, the smaller the probability of the packet being broadcast is. Because the larger the node set is, the more number of neighbor nodes that the packet has been transmitted to the node. Therefore, for this node, broadcasting this packet is a repeated broadcast, which will reduce the transmission efficiency.

When the minimum connected dominating set is constructed, this section sets the broadcast probability function formula for the packet P_c in the current node based on the results of above. The average number $\overline{n}$ of neighbors of nodes, is computed in formula (1). The node neighbor coverage set of packet P_c is the number $\tilde{n}$ of nodes that P_c existed in the neighbor table for the current node. The neighbor node number is n for the current node.

The probability Pr that the current node u broadcast a packet is calculated as follows [21].

$$P_r = \begin{cases} \dfrac{n - \tilde{n}}{\overline{n}}; n \le \overline{n} \\ \dfrac{n - \tilde{n}}{n}; n > \overline{n} \end{cases} \tag{2}$$

4 Simulation and Analysis

In the section, this paper computes the end-to-end delay and delivery rate of packets. The experimental parameters are set in Table 3.

Table 3. Parameters.

Parameters	Value
Simulation Size	40 m*10000 m
Number of vehicles	From 5 to 30
Max transmission Distance	250 m
Bandwidth	10Mbps
Type	CBR
Minimum speed	10 m/s
Maximum speed	30 m/s
Packet generation rate	10 per second

This paper compare the emergency information broadcast routing (EIBR) with RBM as presented in [22] and SB adopted by [23] in terms of packet delivery ratio and transmission delay. In SB, the network is divided into adjacent cells. Each cell is assigned a special waiting time. Thus the waiting time of a vehicle that belongs to different cells is not the same. The minimum waiting time allocated to the cell is farthest from the current node, the farthest node consequently can be selected as the relay node first. It guarantees that the distance of each hop about transmitting information is the longest. In the RBM method, the predefined equations are used to allocate the waiting time of each vehicle, and similarly, minimum waiting time allocated to the cell is farthest from the current node for fast transmission.

When the node of VANET is scarce, the packet delivery ratios are close to 100% for all schemes as shown in Fig. 4. While the delivery ratio of packets in RBM decreases significantly with the traffic density increasing, the SB algorithm performs better than the RBM algorithm. Nevertheless, the delivery rate of the proposed broadcast algorithm is still close to 1. In the sparse network, the average transmission delay of SB and RBM algorithm is less than that of the broadcast method proposed in this paper as shown in Fig. 5. The average transmission delay of SB broadcasting increases significantly with vehicle density increasing, while the RBM algorithm and the method proposed in this paper have better performance. Since there will be no transmission conflict to broadcast packets in the sparse network. By comparison, the proposed broadcast algorithm needs to construct CDS, which will cause some delay, meanwhile, the relative distance between nodes decreases with the vehicle density increasing. The SB algorithm promises that the farthest node relays the message first. Sometimes the selected relay node may be not the appropriate next hop, which leads to an increase in the number of repeat broadcasts. The relative distance between nodes decreases with the vehicle density increasing. The number of packets in RMB increases and the number of conflicts increases correspondingly, which cause a rise in the number of repeat broadcasts due to lack of a solution to the collision problem. The proposed broadcast method in this paper broadcasts packets via the nodes in the connected dominant set. The probability of broadcasting collision is extremely reduced. Therefore, the average end-to-end delay is low.

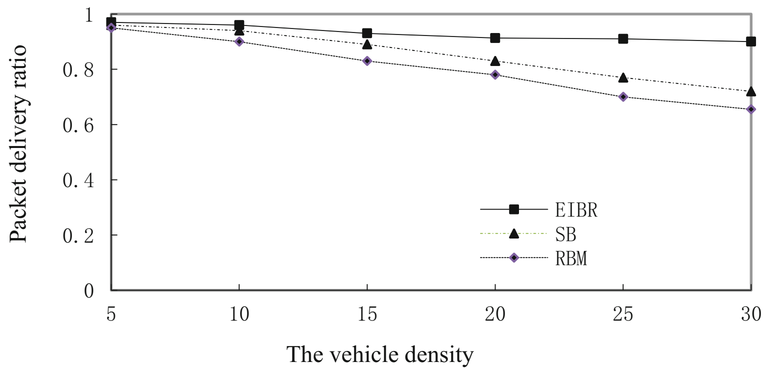

Fig. 4. The vehicle density vs Packet delivery ratios.

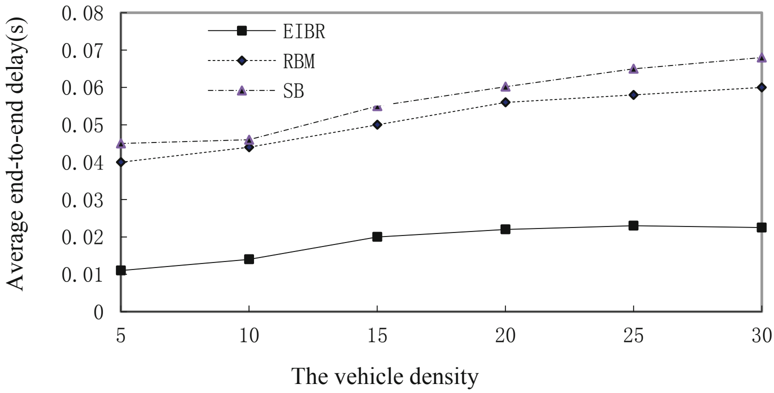

Fig. 5. The vehicle density vs Average end-to-end delay.

5 Conclusion

With the intense Channel competition between a large scale of communication nodes in VANET, it increases the network packet loss rate and decreases the communication efficiency. In case of emergency, the information must be transmitted to relevant vehicles with extremely low delay. This paper designs a broadcasting routing scheme based on a decrease in the number of nodes to broadcast packets. In this paper, an MCDS is constructed for the nodes in the current node communication range, and then the nodes in the MCDS are utilized to broadcast packets. Furthermore, these nodes broadcast the packets by a dynamic probabilistic broadcast strategy. Simulation results show that the proposed method can effectively reduce the transmission delay and improve the packet delivery rate.

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