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A Multicast Routing Scheme for Efficient Safety Message Dissemination in VANET

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Abstract—Vehicular ad hoc network (VANET) is a wireless ad hoc network that operates in a vehicular environment to provide communication between vehicles. VANET can be used by a diverse range of applications to improve road safety. Cooperative collision warning system (CCWS) is one of the safety applications that can provide situational awareness and warning to drivers by exchanging safety messages between cooperative vehicles. Currently, the routing strategies for safety message dissemination in CCWS are scoped broadcast. However, the broadcast schemes are not efficient as a warning message is sent to a large number of vehicles in the area, rather than only the endangered vehicles. They also cannot prioritize the receivers based on their critical time to avoid collision. This paper presents a more efficient multicast routing scheme that can reduce unnecessary transmissions and also use adaptive transmission range. The multicast scheme involves methods to identify an abnormal vehicle, the vehicles that may be endangered by the abnormal vehicle, and the latest time for each endangered vehicle to receive the warning message in order to avoid the danger. We transform this multicast routing problem into a delay-constrained minimum Steiner tree problem. Therefore, we can use existing algorithms to solve the problem. The advantages of our multicast routing scheme are mainly its potential to support various road traffic scenarios, to optimize the wireless channel utilization, and to prioritize the receivers.

Index Terms—multicast routing, optimization, cooperative collision warning, VANET, context-aware

I. INTRODUCTION

The *vehicular ad hoc network* (VANET) is a wireless ad hoc network that operates in a vehicular environment which involves vehicle to vehicle (V2V) and vehicle to roadside infrastructure (V2I) communications. The technology that can provide reliable V2V and V2I communications has been proposed and is being standardized as the IEEE 802.11p and *Wireless Access in Vehicular Environments* (WAVE) [1]. VANET can be used by a diverse range of applications to improve road safety. One of such applications is *cooperative collision warning system* (CCWS). CCWS can provide situational awareness and warning to the drivers by exchanging safety messages between a group of cooperative vehicles. Many CCWS concepts have been proposed and several prototypes have been developed in prior research [2], [3].

There are two types of safety messages that can be utilized in a CCWS: *routine* safety messages and *event* safety messages [4]. Routine safety messages, also called *beacon* messages, are status update messages regularly sent by vehicles containing information such as position and speed. The beacon messages enable a vehicle to realize the state of surrounding vehicles and provide advance warning to the driver of any possible collision. Event safety messages are *warning* messages triggered by any drastic change in the vehicle state that may cause an accident (for example, hard braking, sudden maneuver, or mechanical failures). A vehicle that may endanger other vehicles is called an *abnormal* vehicle. An abnormal vehicle must send warning messages to all endangered vehicles to prevent collisions. The warning messages may need to be propagated along a roadway beyond the coverage area of the original sender. This implies the use of a multi-hop scheme in which warning messages are relayed by other vehicles. Timely dissemination of warning messages can prevent multi-vehicle chain collision because warning messages can propagate faster than visual indicators such as the tail brake light [5]. Figure 1 illustrates the multi-hop message forwarding in which vehicles b and e relay the warning message that is sent by vehicle a to vehicle c.

In this paper we focus on the dissemination scheme for warning messages. Technical details and research on beacon messages are outside the scope of this paper. Performance evaluation of the preliminary IEEE 802.11p WAVE standard indicates that the technology cannot ensure time critical message dissemination in a dense traffic environment or high channel-load scenarios [6]. Therefore, it is necessary to employ efficient safety communication protocols that can reduce channel-load. This can be achieved particularly by proper design of repetition or multi-hop retransmission strategies.

Several broadcast strategies to disseminate warning messages have been proposed in literature [5], [7], [8], [9]. These strategies aim to reduce the number of retransmissions by limiting message dissemination to a specific area and direction. Most of those strategies do not consider the use of beacon messages; therefore, they assume no prior knowledge on the receivers and their states. The basic principle is to let the sender broadcast a message to all vehicles within its radio coverage, and let the receivers decide whether to rebroadcast the message based on some rules. Generally, priority is given to the farthest possible vehicle within the sender's transmission range. A delay is introduced before rebroadcasting a safety

message, which allows a vehicle to detect if other vehicles have already rebroadcasted the same message. If a vehicle detects that same message, then it will abort the rebroadcast attempt. However, the broadcast schemes are not efficient as they may still send a warning message to vehicles that are not endangered and cannot prioritize the receivers based on their critical time to avoid collision. Also, they only consider simple scenarios, mainly straight road segment such as a highway, in which only two directions are considered: forward or backward.

Unlike the scoped broadcast schemes used in related protocols, this paper proposes a multicast routing scheme to disseminate warning messages. The objective of the multicast scheme is not to deliver warning messages as fast and far as possible, but to deliver warning messages only to relevant vehicles with delay not exceeding a specific time, while minimizing channel utilization. We will show that this problem can be formulated into a well-known delay-constrained minimum Steiner tree (D-CMST) problem in graph theory. This means that we can solve the multicast routing problem using any of the existing D-CMST algorithms. We also present the methods to obtain the required context information such as the global network topology, a sender node which is an abnormal vehicle, the receiver nodes which are the vehicles that may be endangered by the abnormal vehicle, and the latest time for each endangered vehicle to receive the warning message in order to avoid the danger. Such information can be obtained because a CCWS also exchanges beacon messages to realize the state of surrounding vehicles. To the best of our knowledge, this concept of multicast routing for CCWS has never been proposed in literature.

The rest of this paper is organized as follows: Section II introduces the related works in the field of CCWS and Steiner tree optimization. Section III presents the multicast routing problem and the formal definition. The methods to obtain the input values from context information are elaborated in section IV. Section V discusses the proposed multicast scheme and its advantages. Finally, Section VI concludes this work and proposes future research direction.
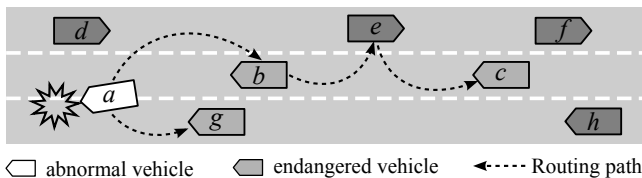

Figure 1. Illustration of multi-hop routing for warning messages

II. RELATED WORK

A. Cooperative collision warning system

The proposed multicast routing is designed for use in a cooperative collision warning system with a typical system architecture that has been proposed in literature [2], [3]. Such a system may consist of several warning applications, such as forward collision warning, lane change assistant,

intersection warning, etc., all of which will depend on the situation awareness capability enabled by communication and positioning systems. The communication systems consist of at least one IEEE 802.11p DSRC/WAVE wireless device. We assume the use of an omni-directional antenna as the most cost-feasible option. The positioning systems consist of an estimator, global positioning system (GPS), and in-vehicle sensors. They provide us with the vehicle's state data, such as position, heading, speed, and acceleration. Based on the results of current positioning technologies [10], it is reasonable to assume that a vehicle can obtain the accurate relative distance between vehicles. In addition, external sensors such as radar, lidar, and camera can be used to further improve the accuracy of the situation awareness.

B. Interaction graph model

Most of the protocols for warning message dissemination are designed for a highway traffic scenario. The intended receivers (i.e. the endangered vehicles) are assumed to be all the vehicles that are: inside a region behind the sender, behind the sender but with same direction, or inside a predefined risk zone [7], [8], [9], [5]. In contrast, the main principle of our multicast scheme is that an abnormal vehicle should send warning messages only to vehicles that are possibly endangered by the abnormal vehicle's maneuver. For this purpose, we have proposed a method to identify the endangered vehicles using an interaction graph model [11]. The interaction graph represents the interaction between multiple vehicles in a specific region and at a specific time. It provides context information on how vehicles interact with each other, which is needed to determine the endangered vehicles. Figure 2 shows an example of an interaction graph that represents the traffic situation shown in Figure 1. Suppose that vehicle a is the abnormal vehicle, the endangered vehicles b, c, and g are determined by following the arrows from the node a in the interaction graph. Given the interaction graph, we can identify which vehicles are endangered by other vehicles; an arrow from node a to node b indicates that b is endangered by a.
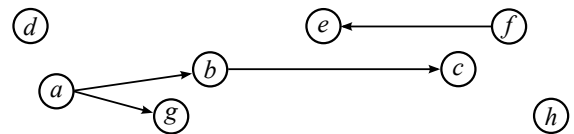
Figure 2. An interaction graph for the traffic situation shown in Figure 1

The interactions between multiple vehicles are modeled as a directed graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$, where $\mathcal{V}$ is a set of nodes representing the vehicles and $\mathcal{E} \subseteq \{\langle v_i, v_j \rangle : v_i, v_j \in \mathcal{V}, v_i \neq v_j\}$ is the set of directed edges representing interactions between vehicles. We define an interaction as a state in which two vehicles have an influence upon one another. Given vehicles v_i and v_j, the possible interaction between two vehicles can be: vehicle v_i is influencing or endangering vehicle v_j, vice versa, or both. An edge $\langle v_i, v_j \rangle \in \mathcal{E}$ represents interaction between v_i and v_j, where v_i is influencing v_j.

Given the information on the state of surrounding vehicles, such as position coordinates, width, length, speed, acceleration, deceleration, and heading, we construct an interaction graph $\mathcal{G}$ by defining the set of vertices $\mathcal{V}$, which represents the surrounding vehicles, and the set of edges $\mathcal{E}$, which initially is empty. To generate the set of edges $\mathcal{E}$, we enumerate all pairs of vehicles from $\mathcal{V}$, and for each pair (v_i, v_j) we calculate the interaction between v_i and v_j. Depending on the result, an edge $\langle v_i, v_j \rangle$, $\langle v_j, v_i \rangle$, or both may be created and added to the set of edges $\mathcal{E}$.

The interactions between vehicles are identified using rules detailed in the paper. A vehicle interacts with other vehicle if there is a possibility of collision between them. Possibility of collision is calculated using vehicle kinematics based on the motion properties of the vehicle such as trajectory and speed. The general principle is to compare the actual distance to collision point with the estimated distance required for the vehicle to stop given a specific deceleration rate. If the actual distance is less than the safe distance, the following vehicle is influenced by the leading vehicle. We define three distinct cases that need to be considered in order to determine whether there is any interaction between any pair of vehicles. The first case is *following*, where both vehicles are traveling in the same direction. The second case is *opposite*, where both vehicles are traveling in the opposite direction. The third case is *intersects,* for any other conditions besides the previous two cases.

C. Delay-constrained minimum Steiner tree

The Steiner tree problem in graphs is about finding the minimum cost tree that connects a source node to a group of destination nodes. The tree can include extra nodes not in the destination, known as the Steiner nodes. It is also called the least-cost multicast routing problem, belonging to the class of tree-optimization problems. The delay-constrained minimum Steiner tree problem is an extended Steiner tree problem that imposes a delay restriction on each destination. Both of the problems are NP-complete [12], which means that finding an optimal solution to this problem is not feasible because it takes exponential time. Therefore, the feasible approach is to use heuristic algorithms that can give a near-optimal solution.

A number of heuristics have been proposed to solve this problem such as the Kompella-Pasquale-Polyzos (KPP) heuristic [13] and the bounded shortest multicast algorithm (BSMA) heuristic [14]. Deterministic heuristic algorithms for QoS multicast routing are usually slow or cannot give good solutions [15]. Other methods that are based on computational intelligence or meta-heuristics such as genetic algorithms have been shown to give better results [16]. Meta-heuristics are general high-level strategies to guide other heuristics to find feasible approximate solutions to computationally hard optimization problems. A number of meta-heuristic algorithms have been proposed such as simulated annealing, Tabu search, genetic algorithms, and harmony search.

III. PROBLEM FORMULATION

The purpose of the multicast routing scheme is to efficiently disseminate the warning message to all endangered vehicles in a timely manner. The multicast scheme incorporates two strategies for using the wireless channel efficiently. The first strategy is to reduce unnecessary transmission by sending the warning messages only to endangered vehicles. For example, Figure 1 shows a scenario where vehicle a performs a sudden movement that may endanger vehicles b, c, and g. In such a scenario, vehicle a only needs to send warning messages to vehicles b, c, and g. Vehicles d, f, and h are excluded because they are not in immediate danger. The second strategy is to minimize the transmission range using adaptive transmitter power control. By minimizing the transmission range, we can reduce radio interference thus increasing the network capacity. However, using a smaller range may result in more hops being required for a message to reach the receivers, and thus may increase the end-to-end delay. The problem of finding the routing paths resulting in minimum total required transmissions area while ensuring timely delivery, can be defined as a delay-constrained minimum Steiner tree (D-CMST) problem.

We shall model the D-CMST problem in terms of a graph, by considering the communication devices as nodes and the transmission links as edges. The network is modeled as a directed weighted graph $G = (V, E)$ where V is a set of nodes representing the vehicles and E is a set of directed edges representing communication links between network nodes. A directed edge $e = \langle u, v \rangle \in E$ if and only if node v can receive packets from node u, where $u, v \in V$ and $u \neq v$. Two non-negative real-valued functions are associated with each node $v \in V$: delay $\delta(v) : V \to \mathbb{R}^+$, and delay constraint $\Delta(v) : V \to \mathbb{R}^+$. A non-negative real-valued cost function is associated with each link $e \in E : C(e) : E \to \mathbb{R}^+$. Function $\delta(v)$ represents the estimated one-hop delay for every packet if it was relayed through node v. Function $\Delta(v)$ represents the delay constraint of node v which defines the bound of acceptable delay for the receiver nodes. Function $C(e)$ defines the cost of a transmission, which is the transmission area that is required for sending a packet using the link e.

Let $s \in V$ be the sender of the messages, and let $R \subseteq V - \{s\}$ be the set of receivers. Nodes belonging to $V \setminus (R \cup \{s\})$ may become relay nodes, i.e., they are involved in forwarding the messages or they may remain isolated without receiving or transmitting any signal. Figure 3 shows an example of the graph model where node a is the sender and nodes b, c, and g are the set of receivers.

A multicast tree $T(s, R) = (V_T, E_T)$, where $V_T \subseteq V$ and $E_T \subseteq E$, is a tree rooted at s connecting all of the receiver nodes R. The tree may contain the relay nodes, which are called Steiner nodes. Let $|V|$ and $|R|$ be the cardinalities of the sets V and R respectively, with $|V| > |R|$. We note that if $|R| = 1$ the problem reduces to a delay-constrained shortest path problem and if $|R| = |V| - 1$ the multicasting problem reduces to a broadcasting problem.

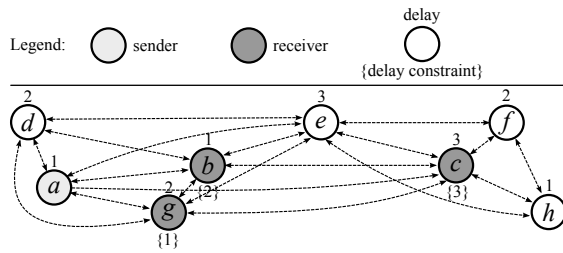Let $P_T(s, r)$ be a unique path in the tree T from the sender

Figure 3. An example of network graph for the scenario shown in Figure 1.

node s to a receiver node $r \in R$. We define $U\left(P_T(s,r)\right)$ as the set of vertices on the path $P_T(s,r)$. The total end-to-end delay from sender node s to any receiver node $r \in R$ is defined as the sum of the delay of nodes $\delta(v)$ along $P_T(s,r)$:

$$\delta\left(P_T(s,r)\right) = \sum_{v \in (U(P_T(s,r)) \setminus \{r\})} \delta(v) \qquad (1)$$

Unlike wired networks, a transmission in a wireless network with omni-directional antennas is inherently broadcasting in which signal is propagated in all directions. A certain transmission range corresponds to an area of coverage and a single transmission delivers a packet to all nodes in the coverage area. A node v can transmit the same packet to any node u, $\langle v,u \rangle \in E_T$, at the same time using the maximum area that is required to reach any of them. The total transmission area required for every transmission in a multicast tree, which is the measure we want to minimize, is therefore defined as the cost of the multicast tree. Let $E^+(v) = \{e \mid e = \langle v,u \rangle \in E_T\}$ be a set of outgoing edges from node v. Therefore, the cost of each node $v \in V_T$ is defined as:

$$C_{node}(v) = \max_{e \in E^+(v)} C(e) \qquad (2)$$

The total cost of the multicast tree is the sum of the cost of each node in the tree:

$$C_{tree}(T) = \sum_{v \in V_T} C_v(v) \qquad (3)$$

Based on these definition, we can define the objective of this problem as the minimization of the cost of the tree:

$$\min C_{tree}(T)$$

$$\text{subject to: } \delta\left(P_T(s,r)\right) \leq \Delta(r) \ , \forall r \in R$$

IV. Obtaining inputs, parameters, and functions using context information

The formalized delay-constrained minimum Steiner tree problem implies the availability of several inputs, parameters and functions that depend directly or indirectly on the context information. Such information is available on the cooperative collision warning systems since it is shared between vehicles using the beacon messages. This section elaborates how to obtain the required parameters and functions: the network model represented as a graph, cost function, end-to-end delay at each nodes, the sender node, the receiver nodes, and delay constraint at each receiver node.

A. Network modeling

In wireless networking environment, a receiver can successfully receive a message if the receiver is within the sender's coverage area. For simplicity, the coverage area is modeled as a planar circle where its radius is the transmission range of the communication node. To estimate the state of network connections and construct the network graph G, we use the information on each node's position and maximum transmission range. Maximum transmission range (R^{tx}) represents the communication range that can be achieved using maximum transmission power. The actual maximum transmission range for every communication node can be estimated based on the communication device specifications and real-time analysis.

Let $d_{uv} = d_{vu}$ be the distance between node $u \in V$ and node $v \in V$, and R_u^{tx} and R_v^{tx} be the maximum transmission range of nodes u and v, respectively. As using Cartesian coordinate is reasonable for this purpose, the distance between two points can be calculated using the well-known distance formula:

$$d_{uv} = \sqrt{(x_u - x_v)^2 + (y_u - y_v)^2} \qquad (4)$$

where (x_u, y_u) and (x_v, y_v) are the position coordinates of node u and node v, respectively. There exists a communication link represented by directed edge $\langle u,v \rangle \in E$ between node u and node v if $d_{uv} \leq R_u^{tx}$, which means that node v can successfully receive a message from node u. The link is not bidirectional since R_u^{tx} may not be equal to R_v^{tx}. Given the set of nodes V, we can generate the set of edges E by enumerating all the pairs of nodes in V.

B. Cost function

The goal of reducing radio interference by minimizing the total transmission area is achieved by using the area measurement in cost function instead of distance measurement. Under this model, the transmission area required to send a packet from node u to node v is proportional to d_{uv}^2. Therefore, based on Equation 4, we define the cost function for each $e = \langle u,v \rangle \in E$ as:

$$C(e) = (x_u - x_v)^2 + (y_u - y_v)^2 \qquad (5)$$

C. Delay function

The total end-to-end delay experienced by a packet sent from a sender node to any receiver is the sum of the delay at each node between the sender (inclusive) and receiver (exclusive). It depends on the number of intermediary nodes between them and the delay experienced at each intermediary node (one-hop delay). The details of how to measure the one-hop delay is beyond the main focus of this paper. However, because of its significant impact on this routing problem, we briefly outline a possible approach to estimating the one-hop delay based on existing works [17].

The one-hop delay can be estimated by finding the value of actual delay experienced by the routine safety messages or *beacon* messages. We assume synchronized clocks for all of the nodes via GPS. Each beacon message includes its creation time, and when a neighbor node receives the

message, the one-hop delay can be measured by calculating the difference between the creation time and the received time. The measured one-hop delay mostly consists of the queuing delay and the transmission delay. Propagation delay can be neglected because the value is very small. Note that we set the priority of beacon messages to be lower than the priority of warning messages. Therefore, the actual delay experienced by warning message is expected to be less than the estimated delay.

D. Identifying the sender node

The sender node is defined as a vehicle that needs to send warning messages. There are two cases where a vehicle needs to send warning messages:

1) There is any sudden change of vehicle state or unexpected circumstances experienced by the vehicle. Sudden change of vehicle state can be defined as changes in motion that exceed a certain threshold, such as hard braking, turning the steering abruptly, etc. Unexpected circumstances are other dangerous factors that may cause an accident, such as engine breakdown, braking failure, or any other vehicle malfunction.

2) The warning system predicts an inevitable collision with any other vehicles based on current vehicles motion. It is possible that collision happens without any sudden maneuver, for example in a car following scenario, if the leading vehicle moves slower than the following vehicle, they will eventually collide. This kind of accident is most likely to be caused by inattentive drivers. Using the interaction graph, the warning system can keep track of the predicted critical interactions between vehicles and react accordingly.

E. Identifying receiver nodes

The receiver nodes are vehicles that will be endangered by the abnormal vehicle. Given the interaction graph $\mathcal{G}$ and the sender node s, a set of receiver nodes R can be obtained by performing a breadth-first search from node s. In the process of identifying the receivers, the delay constraint for each receiver is also calculated. Algorithm 1 shows the procedure to identify the receiver nodes along with their delay constraint. Using the interaction graph shown in Figure 2 as an example, suppose node a is the sender, nodes b, c, and g are the receivers resulted from Algorithm 1.

F. Determining the delay constraint at each receiver node

A receiver node is a potentially endangered vehicle that may collide within a certain extent of time. The collision may be avoided if the endangered vehicle performs an evasive maneuver (such as braking), before a certain critical time which can be calculated based on the vehicle kinematics. The crucial time is the latest time for each endangered vehicle to receive the warning message in order to avoid the danger, which can be used as the delay constraint. Using Figure 1 as an example, assume that vehicle b is braking abruptly at a specific time t which may result in a collision with vehicle c.

Algorithm 1: Procedure to identify the receiver nodes and calculate the delay constraint for each node.

Input : $\mathcal{G}(\mathcal{V}, \mathcal{E})$- the interaction graph
s - the sender or source node

Output: R - the set of receiver nodes
$\Delta_r, \forall r \in R$ - delay constraint for every receiver nodes

1 unmark all nodes in $\mathcal{V}$
2 $R \leftarrow \emptyset$
3 $\Delta_s \leftarrow 0$
4 $\Delta_r \leftarrow \infty, \forall r \in R$
5 create an empty queue Q
6 mark s
7 enqueue(Q, s) // enqueue s into Q
8 **while** Q is not empty **do**
9    $i \leftarrow$ dequeue(Q)
10   **for** $\langle i, j \rangle \in \mathcal{E}$ **do**
11   **if** $\Delta_j > (f_\Delta(i, j) + \Delta_i)$ **then**
      $\Delta_j = f_\Delta(i, j) + \Delta_i$
12   **if** j is unmarked **then**
13   mark j
14        $R \leftarrow R \cup \{j\}$
15   enqueue(Q, j) // enqueue j into Q
16   **end**
17   **end**
18 **end**

Vehicle c may avoid the collision if it can receive the warning message before $t + \Delta_c$, where Δ_c is the delay constraint for vehicle c. One method that can be used to calculate the delay constraint in this scenario is by considering the safety distance between vehicles. We assume that when a vehicle receives a warning message, it will immediately perform braking after a certain reaction time. Given a pair of vehicles (i, j), we define the braking distance of each vehicle as:

$$d_b = v \cdot t_\mathcal{R} + \frac{v^2}{2 \cdot \alpha} \tag{6}$$

where v is the speed of the vehicle, $t_\mathcal{R}$ is the reaction time of the driver, and α is the maximum deceleration. If the vehicle is the sender then we set its reaction time to zero. The delay constraint function for a pair of vehicles then can be defined as:

$$f_\Delta(i, j) = \frac{d_a(i, j) + d_b(i) - d_b(j)}{v_j} \tag{7}$$

where $d_a(i, j)$ is the actual distance between vehicles i and j, which can be calculated using Equation 4.

Let $\mathcal{P}(s, r)$ be the set of all possible paths in $\mathcal{G}$ from node s to node r. A path $p = \langle s, 1 \rangle \langle 1, 2 \rangle \cdots \langle n, r \rangle$ from s to r is a sequence of edges. The delay constraint for node r for the path p is the minimum of the sum of the delay contraint for each pair $\langle i, j \rangle \in p$:

$$\Delta_r = \min_{p \in \mathcal{P}(s,r)} \left\{ \sum_{\langle i,j \rangle \in p} f_\Delta(i,j) \right\} \qquad (8)$$

The delay must be calculated in an orderly manner using the breath first search originating from sender node. This can be done along with the process of identifying receivers, as shown in Algorithm 1.

V. DISCUSSION

By formulating the problem as a delay-constrained minimum Steiner tree (D-CMST) problem, we can use any of the existing D-CMST algorithms to find the solution. Given the inputs, parameters, and functions required by the algorithms, the solution is the multicast tree $T(s,R)$ that represents the routing paths to disseminate the warning messages. The existing D-CMST algorithms may not be designed for multicast routing in a wireless network environment, thus requiring some minor modifications, particularly on the procedures that use the cost and delay functions. For a relatively small input size, deterministic heuristic algorithms such as BSMA can give a sufficiently low computation time. However, a more efficient and intelligent algorithm is required for a larger input size.

The advantages of this multicast scheme compared with prior broadcast schemes can be summarized as follow: 1) applicability in various cases of traffic accidents; 2) optimization of the wireless channel utilization by minimizing the transmission area and the number of unnecessary transmission; and 3) the prioritization of the receivers based on the delay constraint. Because of the pages limitation, the analysis and arguments of these advantages will be presented in a separate paper.

VI. CONCLUSION AND FUTURE WORK

In this paper we have presented a multicast routing strategy for disseminating warning messages in CCWSs. Unlike prior broadcast schemes, the proposed multicast scheme incorporates the concept of adaptive transmission range and utilizes the vehicle interaction graph to identify the receiver nodes. Using this scheme, the wireless channel efficiency can be improved by reducing the number of sent messages and by minimizing the radio transmission range. At the same time, the receivers can be prioritized based on their critical time to avoid collision, ensuring in-time delivery of the warning messages. We have shown that the concept can be formulated as a delay-constrained minimum Steiner tree (D-CMST) problem, which is a well-known NP problem in literature. All the required inputs, parameters and functions can be obtained from the context information made available by the beacon messages. Therefore, we can use any of the existing D-CMST algorithms to solve this specific multicast routing problem.

Future work includes a performance evaluation and comparison with other broadcast protocols that will be based on experiments conducted in a network simulator. Further research is needed to develop a complete communication protocol based on this multicast scheme. Such a protocol should consider various aspects such as reliability, message encoding, multiple sender, transmission scheduling, and multi-channel operation. We will also investigate better D-CMST algorithms that can take advantage of the context information such as position, and can be efficiently implemented in a distributed computing environment.

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