A Centralized Traffic Control Mechanism for Evacuation of Emergency Vehicles Using the DSRC Protocol*

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Abstract*—Emergency service vehicles need safety and fluent paths to save time. In this paper, a centralized traffic control mechanism is proposed for the evacuation of vehicles that drive toward the dedicated path of the emergency vehicles (EV), e.g. Ambulance, Fire Engines, Police Cars, etc, using the Dedicated Short Range Communications (DSRC) protocol. In our proposed mechanism, a centralized server is used to monitor and control all traffic information to support real time traffic information and services for emergency vehicles, and the centralized server also calculates the shortest path for emergency vehicles to pass by. If the approaching information of emergency vehicles is not announced in advance to other vehicles that will obstruct the approaching path of emergency vehicles, it will cause the traffic muddle on the road and increase the delayed time for emergency vehicles. Thus, we also propose a data dissemination scheme to transmit the warning messages to other vehicles that will obstruct the approaching road of emergency vehicles. In our experiment, we will exhibit the performance of our proposed system.

***Index Terms*—Telematics, Evacuation, Emergency Vehicle, DSRC, Navigation.**

1. INTRODUCTION

With the development of modern telecommunication and auto-electronics, the functionalities of automobiles have been improved and become a potential industry. Additionally, GPS (Global Position System) has already become a popular and general navigating device for vehicles and increased many added values for automobiles. Through the help of the maturation of these technologies on the automobiles, the industry of ITS (Intelligent Transportation system) is promoted and concentrated by many countries and automobile factories. In the research region of ITS, Telematics, which is combined telecommunication with informatics, becomes the central of development. In recent years, many drafts and projects have been proposed to develop Telematics services in many countries and automobile factories, and the most important services in these projects are devoted to the safety driving and collision avoidance systems on the road.

In U.S., Vehicle Infrastructure Integration (VII) is a project that developed Telematics infrastructure based on DSRC (Dedicated Short Range Communications) communication protocol with eight automobile factories. The mission of VII is to deploy a national communications infrastructure between vehicles and vehicles or vehicles and roadside units to increase safety on driving. There are many potential applications in VII which include advanced vehicle-to-vehicle emergency braking notification, signal violation warnings, roadway condition reporting, vehicle probe data, emergency vehicle approaching, etc.

This paper focuses on the issues of the evacuation for emergency vehicles and delivering warning messages to other vehicles through the R2V (RSU-to-Vehicle) transmission way using the DSRC protocol. The main objective of the delivered messages is to let those vehicles driving in the front of emergency vehicles or nearby vehicles travelling toward the path of the emergency vehicle make the way for emergency vehicles in the minimum time, and thus emergency vehicles can reach the destination quickly and safely.

In order to let emergency vehicles, e.g. Ambulance, Fire Engines, Police Cars, which have emergency services, to arrive at the disaster area in time, we propose a centralized traffic control mechanism that can control the traffic and announce warning messages for nearby vehicles to make the way for emergency vehicles. Three main issues to be addressed in this paper are as follows:

(1) Path arrangement for emergency vehicles: The path arrangement from source to destination of emergency vehicles is an important issue. In order to avoid wasting time for emergency vehicles, the path for an emergency vehicle must be a shortest path.

(2) Data Dissemination: Transmitting warning messages to nearby vehicles effectively such that these vehicles can change driving paths or wait and stay at the same lanes of road for emergency vehicles is another important issue. The major concern of data dissemination is to transmit the warning messages to nearby vehicles in the appropriate time.

(3) Real-time traffic information: The traffic status on the road is changed at each moment. If emergency vehicles keep to drive the same path from source to destination all the way, i.e. emergency vehicles cannot react with the dynamically changed traffic status, it cause serious delay of emergency vehicles and increase traffic chaos on the road.

The rest of this paper is organized as follows. Section 2 introduces the system architecture of the proposed mechanism. Section 3 overviews related works. Section 4 presents the path arrangement of emergency vehicles. Section 5 depicts the data dissemination of warning messages for emergency vehicles. Section 6 exhibits experiment results. Finally we summarize

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and conclude this paper in Section 7.

2. Related Works

Safety driving is the major concern in the Telematics service, and approaching of the emergency vehicles is one of the important problems in safety driving. In this Section, some projects [1] [2] [3] and papers [4] [5] [6] [9] that are related to the safety topics of Telematics services and the research issues for emergency vehicle approaching are introduced.

In U.S., the Federal Highway Administration (FHWA) developed the Vehicle Infrastructure Integration (VII) project to improve safety driving on the roadways by integrating the standardized traffic management communication infrastructure with vehicle systems. In 2003, the Federal Communications Commission (FCC) allocated radio service 5.9 GHz spectrum for dedicated short-range communications (DSRC) [10] in ITS. In Japan, Advanced Safety Vehicle Project [3] is proposed for safety driving, and the research and development in this project will be promoted in connection with infrastructures, using the systems-autonomous type and infrastructure-employed type.

In [7], the authors used related mechanisms in VANET to reduce the traffic information for spatio-temporal traffic, and the proposed system provided solutions to clear the path for emergency vehicles. But the authors didn't discuss the situation of the dynamic traffic, and the path from the source to destinstion is just traced by the digital map in emergency vehicles. Thus, the proposed mechanism is not a reliable solution for emergency vehicles and will cause serious delays of emergency vehicles.

In [8] [11], the authors used the traffic light at the intersection to control the traffic to reduce collision between vehicles and vehicles, and improve the travelling time of emergency vehicles. But the proposed system can't handle the intersection without the traffic light, and the traffic light may cause more traffic chaos at intersection or nearby roadway. If the nearby vehicles are informed in advance, they can change to the other paths to get out of traffic jam. The other major problem is how to announce the nearby vehicles that are travelling in the front path of emergency vehicles. Thus, the proposed mechanism still has some problems for emergency vehicle approaching.

3. System Architecture

In our proposed mechanism, the construct of path arrangement for emergency vehicles is calculated by the centralized server. Since the centralized server can control all dynamic traffic flow in the city, the collection of the traffic information is managed by RSUs. The system architecture is depicted in Fig. 1. In our scenario, Road Side Units (RSUs), which are RSU1 and RSU2 in the Fig. 1, are installed at each intersection, and each RSU gathers the traffic information of each direction in each road periodically and sends the collection results to the centralized server to provide real time traffic information.

The traffic information includes time, average speed of vehicles, number of vehicles, the direction of each road and road ID that is sent from RSUs to the centralized server. The centralized server gathers statistics of the traffic information from each RSU to be the weight value in our proposed algorithm. In Fig. 1, the emergency vehicles (EV) can send and receive the traffic information for emergency service from RSUs. Basically, each RSU has two kind of network interfaces: one is an Ethernet network interface and the other is a DSRC network interface. The DSRC network interface is used to communicate with emergency vehicles and other vehicles. The Ethernet network interface is used to communicate with the server.

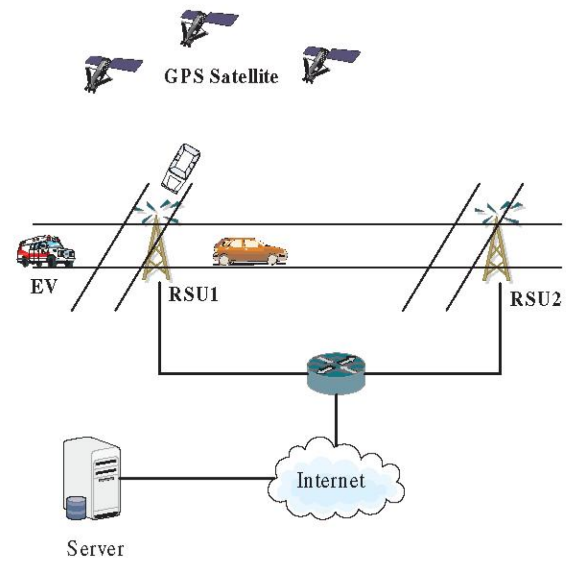

Fig. 1. The system architecture for emergency vehicle approaching.

Additionally, we assume that each vehicle is embedded with an OBU (On Board Unit) and a GPS receiver. When the emergency vehicles send the requests with their current positions and destinations that derived by the GPS receiver and digital map information, the centralized server will calculate the optimal path for emergency vehicles.

4. The Proposed Path Arrangement for Emergency Vehicle

The proposed algorithm for path arrangement is based on A* algorithm. A* algorithm is a best-first, graph search algorithm that can find the shortest path from the source to the destination. A "heuristic function" is used to estimate the cost from the source to the destination in A* algorithm (defined as h(u) in E.q. (1)). In E.q. (1), $D(u, dest)$ is the distance from the current node (u) to the destination, and V_{avg} is the average velocity of the vehicles on the roadmap.

$$h(u) = D(u, dest)/V_{avg} \tag{1}$$

The centralized server will adopt A* algorithms to calculate the shortest path for emergency vehicles. In the proposed algorithm for the shortest path, the centralized server can design the primary path, secondary path and P-S path (the path from the intersection of the primary path to the secondary path) for emergency vehicles. Referring to Fig. 2, there are one primary path, one secondary path and three P-S paths.

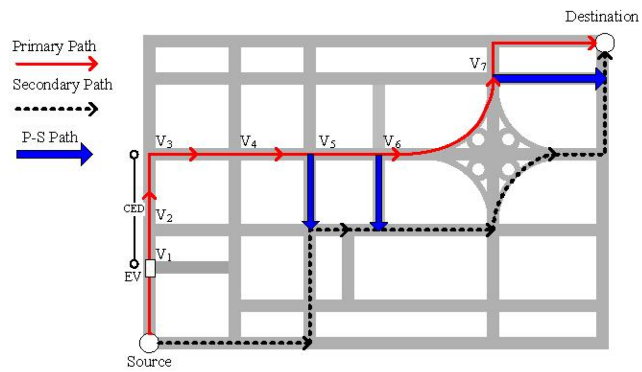

Fig. 2. The proposed path arrangement for emergency vehicles.

The secondary path is calculated to be the auxiliary path for handling the instant accident situation. In this paper, the centralized server calculates only one secondary path for each emergency vehicle because more than one secondary path may increase the processing loading of the centralized server and response time for emergency vehicles. Therefore, our proposed algorithm of path arrangement for emergency vehicles is based on (1) the shortest path for emergency vehicle, (2) dynamic traffic information.

A. Primary Path Arrangement

In order to calculate the shortest path, A* algorithm is adopted in the centralized server. In order to calculate the shortest path effectively, the centralized server will normalize and transform the street and intersection in the road map to edges and nodes. Then, each node and edge will be given an ID to be identified in the road map M(V,E). The cross point in the roadmap forms a vertex "V", and the street between two vertex forms an edge "E". Each edge in M(V,E) is assigned a weight value "W_{E_i}" which is calculated by the distance of the street "D_{E_i}" and average velocity of the vehicles "V_{avg_i}" that are depicted in Eq.(2). The wight value represents the travelling time for emergency vehicles on a street. When the weight value of each edge is calculated, A* algorithm is adopted to determine the shortest path in Algorithms 1.

$$W_{E_i} = D_{E_i}/V_{avg_i}, \forall E_i \in E \tag{2}$$

B. Secondary Path Arrangement

In this subSection, the secondary path is introduced. The secondary path is also calculated by A* algorithm. In order to save time for emergency vehicle travelling toward the secondary path from the primary path, the secondary path is determined as close to the primary path as possible, and the primary path can't have overlapped streets with the secondary path. If the primary path and secondary path have many overlapped streets after A* algorithm, these can't handle the instant traffic accidents. The main reason is that when the traffic accident occurres in the overlapped streets of the primary path and the secondary path, the sceondary path becomes useless

Algorithm 1 The A* algorithm for shortest path

```
procedure A*(Graph, Source, Destination)
    for all vertex v in Graph do
        dist[v] ← infinity
        previous[v] ← undefined
    end for
    dist[source] ← 0
    Q ← the set of all nodes in Graph
    while (Q is not empty) do
        u ← node in Q with the smallest dist[]
        remove u from Q
        for all neighbor v of u do
            alt ← dist[u] + distBetween(u, v) + h[u]
            if alt < dist[v] then
                dist[v] ← alt
                previous[v] ← u
            end if
            if v is destination then return previous[]
            end if
        end for
    end while
     return failed
end procedure
```

and causes the serious delays for emergency vehicles. Thus, the algorithm of finding the sceondary path is different from the primary path, and the different factor is the weight value of M(V,E). Some issues of the weight values that need to be considered in the A* algorithm are as follows:

(1) In order to avoid the secondary path to select some same edges of the primary path, each edge in the primary path should be multiplied by extra weight "W_P" ($W_P > 1$).

(2) If the edges on the right side of primary path, the weight of this edge should be multiplied by a weight value "W_R" ($0 < W_R \leq 1$). Because the vehicle drives on the right hand side of the road, the cost to turn right will be less than the cost to turn left.

C. P-S Path Arrangement

The path from the primary path to the secondary path (P-S path) is designed for emergency vehicles to travel between two paths in the minimal time interval. The P-S path adopts Breadth-First Search (BFS) algorithm to find the path from each cross point in the primary path to nearby cross points in the secondary path. If Depth-First Search (DFS) algorithm is adopted to find out the P-S path, the performance of the calculation will be effected in the centralized server. Because the BFS is search the graph level by level, this will find the optimal path faster than DFS.

5. Data Dissemination For Evacuating Warning Messages

In order to handle data dissemination for evacuating warning messages, four message types defined in this paper are, path arrangement message, evacuation message, traffic information indication and dynamic path arrangement message. These messages will be transmitted using the 802.11p protocol between vehicles and RSUs.

A. Path Arrangement Message

The path arrangement message is used to request for the primary path, secondary path and P-S path from the centralized server by emergency vehicles. The execution procedure is as follows:

(1) When receiving an emergency call, the emergency vehicle sends the path arrangement message to nearby RSU using DSRC protocol with source and destination positions.

(2) After receiving the request from the emergency vehicle, RSU will forward this message to the centralized server.

(3) Then the centralized server calculates the shortest path from the position of the emergency vehicle to disaster area and returns this result to RSU. After that, RSU responses this message to the emergency vehicle. The content of the response message includes primary path, secondary path and P-S path.

(4) The emergency vehicle can start to travel toward the disaster area.

B. Evacuation Message

The evacuation message is used to notify nearby vehicles, which include the vehicles in the front of the emergency vehicle and other vehicles that will travel toward the primary path, to travel the other paths or make the way for emergency vehicles. The evacuation message is controlled by the centralized server because the centralized server has all traffic information and the path that emergency vehicle will pass by. The centralized server will calculate the controlled emergency distance (CED) to predict the region that will effect the emergency vehicle. The CED is defined as the distance in the front of the emergency vehicle in E.q. (3). V_{EV} is the velocity of emergency vehicle in the last report, and t_P is the evaluated time by server for evacuation of nearby vehicles. At first, the centralized server multicasts the evacuation message to all RSUs on the CED. When RSUs receive this message, they will broadcast the warning messages to nearby vehicles. For example, there is an emergency vehicle (EV) on the node (V1) in Fig. 2. After the calculation of CED that is from V1 to V3, the RSUs from V1 to V3 will receive the evacuation messages from server and broadcast these to nearby vehicles.

$$CED = V_{EV} * t_P \tag{3}$$

C. Traffic Information Indication

In order to handle the dynamic traffic situation for calculation of the shortest path for emergency vehicle, the traffic information indication is used to collect the current average velocity of each street. This message is transmitted by each RSU. After collecting the velocities of vehicles on the street, the RSU will transmit the traffic information indication periodically.

D. Dynamic Path Arrangement Message

Dynamic path arrangement message is used to find a better shortest path for emergency vehicle, because the traffic status is changed dynamically. If the emergency vehicle adopts the same shortest path from the original position to the disaster area, the travelling time may be delayed. Thus, the emergency vehicle will periodically transmit the dynamic path arrangement message to the centralized server and then the centralized server will calculate the real-time shortest path and response the result to the emergency vehicle. But the major problem is how to return the calculated result to the emergency vehicle, because the emergency vehicle dynamically changes its position. In this subSection, in order to send the result of calculation exactly to the emergency vehicle, the centralized server used E.q. (4) to predict the moving distnace of the emergency vehicle. Then, the server send the calculated results to all RSUs on the predicted distance. The parameters of the E.q. (4) are depicted as follows:

(1) D_{EVM} is the predicted moving distance of the emergency vehicle.

(2) V_{EV} is the velocity of the emergency vehicle in the current report.

(3) t_c is the calculation time of server.

(4) t_{tx_i} is the transmission time from the RSU_i to server.

(5) $t_{tx_{avg}}$ is the average transmsission time of RSUs in the traffic information indication.

$$D_{EVM} = V_{EV} * (t_c + t_{tx_i} + t_{tx_{avg}}) \tag{4}$$

6. Experiments

In order to reduce the travelling time of emergency vehicles, the proposed path arrangement provides the primary path, the secondary path and P-S path for emergency vehicles by the centralized server. In the calculation of the secondary path and P-S path, the weight value "W_P" in the IV-(B), will be the effective factor of the path arrangement. In this section, we design the simulation experiment and discuss the cost effect of this factor. In the simulation, there are many different maps testing in our simulation. The simulation results are shown in Fig. 3 and Fig. 4. In Fig. 3, the simulation results is shown that if the "W_P" is set to be smaller, then the cost of time for secondary path will be less. But the P-S path doesn't necessarily exist in the any road map. If there are more number of P-S paths, the driving path of emergency vehicles will be more reliable and safer when the instant traffic accident is occurred on the primary path. Therefore in order to increase the number of the P-S path to enlarge the probability of finding the P-S path to change the the primary path to the secondary path. Referring to Fig. 3 and Fig. 4, the optimal probability of weight value should be from 1.06 to 1.18.

7. Conclusion

In order to provide the safe travelling path and reduce the traffic chaos when emergency vehicles approaching, we have proposed a centralized traffic control mechanism for evacuation of vehicles that drive in the front of emergency vehicle or drive toward the path of emergency vehicles. The proposed system can provide the shortest path for emergency vehicles to save time. In addition, the real-time traffic information is considered for emergency vehicles to change the primary path dynamically. And the secondary path and P-S paths are calculated by the server to handle the instant traffic accident

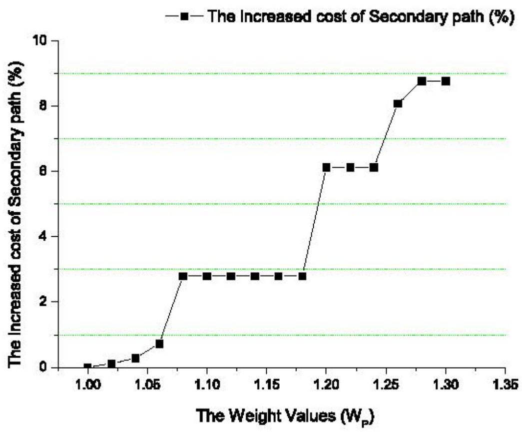

Fig. 3. The time cost of secondary path with different weight values.

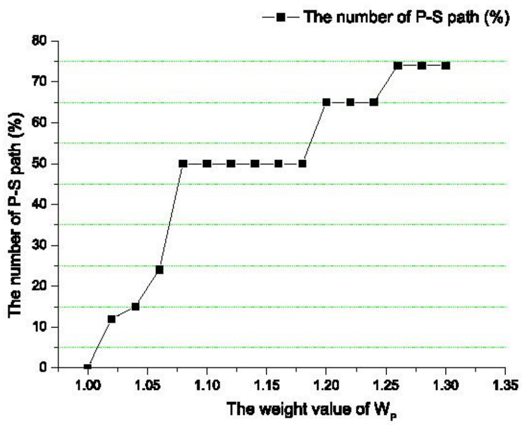

Fig. 4. The number of P-S path with different weight values.

for emergency vehicles. In the experimental results, we discuss the effect of weight value in the proposed path arrangement. In order to supply the reliable path from primary path to secondary path and reduce the cost of secondary path, the proper weight value is determinated. In the future, we will consider how to navigate the nearby vehicles that receive the evacuation message to the appropriated path.

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