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Dynamic Distribute Route Recommendation System for Multiple Destinations

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Using vehicle for evacuation from areas affected by natural disaster is an important part of a rescue plan. While fleeing to safety place or evacuation center during disaster, there is a high probability to get trapped in traffic congestion. This is because people will access shortest route to safety place and road from high-populated affected area to the nearest evacuation center will be quickly clogged with cars. We proposed a system, which will recommend routes to vehicles using current traffic state. The recommendation will be extended to every individual vehicle for smooth transportation to evacuation shelter, especially when more than one shelter is available. In case of disaster, access to evacuation center will be difficult due to heavy traffic or damage to part of the road network by disaster. For reliable navigation, we need to evaluate routes to support multiple destinations and re-route in real-time, by evaluating routes with updated congestion status at regular intervals, as situation changes. We proposed a routing algorithm for multiple destinations problem by introducing a virtual destination connecting real ones. We also proposed proper distribution of traffic to prevent and postpone traffic congestion to decrease delay to reach safety places.

1　Introduction

In disaster environment (e.g., Tsunami, Flooding) it is necessary to evacuate to safety place, using vehicle. It is important part of rescue plan especially for old, sick and disable person. Vehicles need reliable navigation system to support evacuation. In the existing navigation systems (e.g., Garmin [1], TomTom [2]), they compute routing to specific destination. With Internet technology and web service for route computation (e.g., Google [3] and Microsoft [4]) and dynamic traffic assignment (DTA) [7][11], the system can compute routing, considering road traffic congestion data, to find an optimum route for each vehicle.

The navigation system would suggest optimum routes to destination. A vehicle then follows the directions to the specific destination. The situation is different in case of disaster, when it is necessary for people to relocate to safe zone, to move to evacuation center. The destination is not specific and more than one destination is equally acceptable. More often than not, the roads leading to those shelters get clogged due to high traffic. This is especially true for coastal regions in Japan where tsunami could happen, and in hilly areas where flood is prevalent. Due to thin population, low normal traffic and mountainous landscape, the roads are narrow. At many places it is difficult to take a U-turn, or maneuver two cars. Moreover, some evacuation centers, that are easy to access, may already be not suitable for shelter at all, because they are affected by natural calamities, or already too crowded to accept more people. Even updated traffic information is available, it is difficult for a person to judge the safety/quickest route to shelter. A suitable navigation system for such a situation is not available.

Prevention of traffic congestion on road network is already supported in DTA. But for multiple destinations problem or destination specified by its properly only (like shelter, parking place), there is no support to find optimum destination and its route recommendation. We proposed an algorithm where the optimum from multiple possible destinations could be selected. For searching such an optimal route, where link cost varies dynamically and multiple destinations are equally acceptable, we propose a K-shortest routing algorithm, which is updated at predefined intervals, and recommended to the user. When K = 2, the best and second best routes are searched and randomly recommend with a probability destination depending on the respective costs of the two routes. When real-time road traffic and corresponding delay is considered as link cost, routes with heavy traffic are automatically avoided. 1-st route is the primary route recommended. Others are alternate routes for distributing the traffic to prevent traffic congestion on shortest route.

The support virtual destination, multiple destination are connected to a single virtual destination with link cost equal to zero. They are Virtual Edges. Nodes in the graph are start nodes, and shortest path to virtual destination are selected. This path would therefore include one real-destination and a virtual link of cost 0 to the virtual destination. It is trivial to shown that one and only one real destination will be selected in the shortest path. Algorithm to find routes to other real destination is discussed in Section 3. The proposed method for routing is based on dynamic traffic assignment (DTA) [7]. Link cost, inversely proportional to the traffic, will lead to select less congested routes and will distribute the traffic uniformly.

The current paper proposed road network routing algorithm based on Yen's k-shortest path algorithm. Link cost is the travel time. Thus, shortest path means the shortest travel time to destination. The rest of this paper is organized as follows. Section 2 discusses related works. Section 3 describes existing road traffic routing algorithm and how they are applied to disaster environment. Section 4 presents the simulation environment, experimental results and their analysis. The paper is finally concluded in section 5.

2 Related Works

Navigation services and devices were developed for fast searching and to recommend routes more intelligently. Some services use real-time traffic information as a component of cost to calculate route. Real-time traffic information such as INRIX [5] provides traffic information, with pre-defined delay. However, they do not cover the traffic data information of the whole area. Traffic information is collected only at a few hot spots. For delay calculation, prediction algorithm is used. Some services, such as Google, provide traffic information by forecasting congestion and its duration by performing advanced statistical predictive analysis of traffic patterns based on past conditions. For route guidance, first the shortest path is calculated, and then congested links in the path, if any, are identified. Rerouting is done to avoid the predicted congested portions.

The cost of a link, when the optimizing metric is travel time, is a dynamic entity. The cost varies at subsequent time instances. We need to have the traffic information at regular intervals, and use cost prediction algorithms for routing. [8] demonstrated a fast greedy time-dependent shortest path algorithm (SP-TAG) by using time-aggregated graph (TAG) data structure instead of a time-expanded graph.

[7] is designed to help explain the basic concepts and definitions of dynamic traffic assignment (DTA) models and addresses application, selection, planning, and execution of a DTA model. It also describes the general DTA modeling procedure and modeling issues that may be of concern to the model user. DTA research can be classified into two categories: analytical methods and simulation-based models. In analytical model approach DTA is modeled as a nonlinear programming problem, or an optimal control problem, or a variational inequalities problem. They provide theoretical insights. The computational intractability prevents their deployment in real systems [12].

However, existing researches on navigation aim to find fastest route to specific destination for a routine environment. Application of existing navigation system in disaster environment is a challenge. They are inadequate to save human lives by finding the safest route and recommend proper destination in a critical time, to an individual user.

3 Route Recommendation for Disaster Environment

Navigation system calculate route by inbuilt device itself, or get route from web service system. But, native navigation system can only recommend route for a specific destination. In many practical situations, the driver can only characterize the intended destination, but not specify. For example, while looking for a parking place in an unknown town, the specification could be the distance and cost, but not a specific parking lot. To find proper destination and corresponding route recommendation, system can get road traffic information from a central system or from vehicle ad-hoc network (VANET) [14]. VANET is a ad-hoc networking technology to support communication in a challenging environment. It is still an open area of research for protocol and application design due to their potentially large scale and variety of possible situations.

VANET technology allow a vehicle to communicate with another vehicle or a base station using wireless communication of IEEE 1609 Wireless Access in Vehicular Environment (WAVE) [14], IEEE 802.11p. IEEE 1609 defines the operations of WAVE in higher communication layer. IEEE 802.11p [9] define amendments to the IEEE 802.11 MAC and PHY to support data exchange in high-speed mobile environments. The purpose of the WAVE system is to provide seamless, interoperable services and connectivity to support pedestrian and vehicle with proper application and wireless communication support.

In this work, we calculate best K-shortest path to recommend route as well as the destination. The traffic is distributed over the road network by recommending different routes to different vehicle from top K shortest routes to avoid traffic congestion.

3.1 Virtual Destination

In case of emergency evacuation, vehicles would try to reach the nearest evacuation shelter. Roads from densely populated area to the nearest shelter will be choked with traffic. All vehicles will try to reach the same shelter using the same shortest route. The basic idea of the proposed route recommendation algorithm is to consider multiple destinations simultaneously, so as to distribute the traffic, and achieve an overall shorter travel time to shelters. The optimization criterion is travel time.

Existing shortest path algorithms do not support multiple destinations. To support multiple destinations routing, they need to calculate shortest path to each destination and present lowest cost as best route. Calculating all such routes from source node, i.e., from the vehicle to all destinations will involve time-consuming computation. To reduce this computation, we introduced a new destination node, named Virtual Destination. Virtual destination is a virtual node. Virtual connections of cost (time of travel) zero will connect every real destination to the virtual node.

While we run k-shortest route algorithm, from an area to the virtual destination, real destinations will be included, as the paths to virtual destination are only from real destinations. The shortest path algorithm will give the shortest route to the real destination. The next shortest path will be via another real destination. It is possible to have route, connecting two real destinations, and finally to the virtual destination using virtual link. We modified Yen's algorithm, so that such routes are avoided. Thus, different real destinations are included in different k-shortest paths. In the simulation experiments, described in the next section, our algorithm finds k-shortest routes at regular intervals, and the first best route is selected every time. The recommended routes may change when a new route recommendation is received. Simulations results with K-shortest routes, where K>3 are not included in this manuscript.

3.2 Shortest Path

Aim of the proposed routing algorithm is to avoid long immobility on some parts of the route. The system would suggest route so as to be able to reach safely to evacuation center in fastest possible time. Travel time is considered as the cost metric of route optimization algorithm. We use Greenshield's model to estimate the travel time, since it is simple and extensively used in DTA models. The model assumes that there is a linear relationship between the estimated road speed V_i on a section of a road, and the traffic density K_i (vehicles per meter) on that road segment. This is expressed in Eq. 1, where Λ_{jam} and V_f are the complete traffic jam density and the free-flow speed for the road segment i, respectively. T_i and Li are the estimated travel time and length for the same segment. The free-flow speed V_f is defined as the average speed at which a motorist would travel if there were no congestion or other adverse conditions on the road. To simplify our implementation, we consider that the free-flow speed is the road speed limit. Basically, $\Lambda_i = \Lambda_{jam}$ is the ratio between the current number of vehicles and the maximum possible number of vehicles, on the i^{th}-segment of the road. The current number of vehicles is obtained from the traffic data collected by the available service, whereas the maximum number of vehicles is proportional to length of the section of the road, the exact value being road length/(average vehicle length + minimum gap between vehicles)

$$V_i = V_f \left(1 - \frac{\Lambda_i}{\Lambda_{jam}}\right) \quad (1)$$

$$T_i = \frac{L_i}{V_i} \quad (2)$$

3.3 Road Traffic Distribution

If the algorithm calculates only the best route based on static information, the route recommendation system will not be robust to natural disaster. Traffic congestion will happen because all vehicles starting at the same area will get the same route in same period of time. We can avoid congestion by distributing vehicles over different routes. In addition, one can distribute vehicles over different destinations. We proposed a routing algorithm based on K-shortest path algorithm proposed by Yen [15]. For K=3, the best, second best and third best routes are calculated. The proposed system will distribute vehicles in K routes. The probability that a particular route will get selected depends on the calculated travel time for that route. The probability is inversely proportional to the travel time, i.e., the i^{th} path will be selected with probability P_i

Each recommendation will announce K routes, where Ci is the delay cost of the i^{th} route, and K is the number of routes recommended. Vehicle can receive a newly recommend route at some point on the road. However frequent recommendations of new routes will confuse the driver. To avoid this problem, vehicle will change route only when new K-recommend route are not partially overlapped with the previously recommended route. This situation will happen when parts of the existing route get traffic congestion, or are unusable.

$$P_i = \frac{(\sum_{j=1}^{K} C_j) - C_i}{(K-1)(\sum_{j=1}^{K} C_j)} \quad (3)$$

4 Simulation Experiment and Performance Analysis

We simulated the proposed routing algorithm in disaster environment, where the whole population from danger area needs to evacuate to safety shelter at the same time. We used the software Simulation of Urban Mobility (SUMO) 0.23 [10]. SUMO is an open-source highly portable microscopic road traffic simulation package designed to handle large road network.

For road network, we used part of the map from tsunami disaster on March 11th, 2011 in Miyako, Iwate [16]. The real road network is shown in Fig. 1, where safe shelters are marked in green and red zone Algorithm 1 Route selection strategy from the set of recommended routes is high risk area (actually submerged in water during Tsunami). Other parameters of simulation are mentioned in Table 1. We downloaded this road map from OpenStreetMap [17][18] in OSM format, and use Net-Convert tools in SUMO to convert maps into a sumo usable format. We used random trip tools in SUMO to introduce a vehicle at a random point on road map, and start moving from there.

Speed of all vehicles are limited to 15-20km/hr. This speed is adequate to evacuate from tsunami [19]. Other parameters in SUMO were set to default: vehicle length=5m, the minimal gap=2.5m, and the driver's imperfection=0.5.

For each scenario, we generate vehicles joining the road network and allow vehicles to travel to randomly selected destinations from the beginning of simulation until the first 10 minutes. The vehicles move in haphazard directions towards diverse destinations, as happen on an ordinary day. After 10 minutes the Tsunami alarm starts. Vehicles receive the alarm and route recommendation to safety shelter. Vehicles will follow route recommendation and drive to safe shelter. In each scenario, we use the same map data but different vehicle start location and mobility. For each scenario we repeat simulation 50 times, with same parameters but vehicles joining the road randomly. The average and variance of results are shown in Fig. 2 and Fig. 3. We group simulation results by number of vehicles and analyze it for number of vehicles arrived at destinations in 1 hour, and evacuation time needed.

All simulations used virtual destination to solve multiple destinations problem. We compare results using $1 \le K \le 3$, where K=1 is when only 1st.-best route is recommended, K=2 or K=3 are when 1st.-best and 2nd.-best routes, or 1st.-best, 2nd.-best and 3rd.-best routes are recommended. In those cases traffic is distributed. We assume that road traffic density at different links are available by deployment of traffic surveillance infrastructure on road (e.g., loop detectors and video cameras). The system will transmit the recommended route via GPRS/3G/4G LTE or VANET communication.

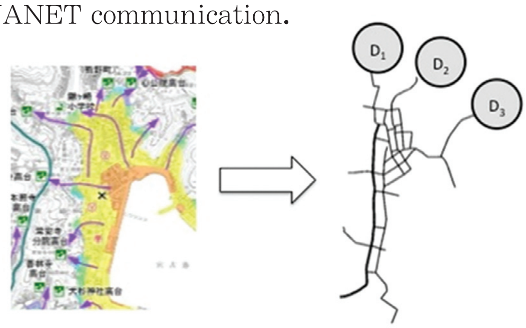

Fig.1 : Map data used for experiment

Table 1 : Parameters Used For The Simulation

Parameters	Value
Road speed limit (km/hr)	15
Road traffic update frequency (min)	5
Number of vehicle	1000-2000
Number of safety area	3

4.1 Number of arrivals

The success of the navigation algorithm is reflected in the number of vehicles that could reach safe shelter in a disaster environment. Fig. 2 shows the number vehicles arrived at one of the three safety shelters at the end of the simulation. The result clearly shows a better performance using the distributed method, when K>1, i.e., more than 1 route in searched and recommended probabilistically. However, in case of low traffic-density, the results are the same. Result using 2-route and 3-route recommendation is the best for high density. As the traffic volume increases, distributed method gives better results. Thus, for lightly populated area, we do not need distribution, but it is effective for highly populated area.

We can conclude that distributing traffic improves safety, instead of navigating all vehicles on the best route, when the number of vehicles in network is increases. But there is no difference when the number of routes recommend is 2 or 3, in this particular setting, i.e., road network.

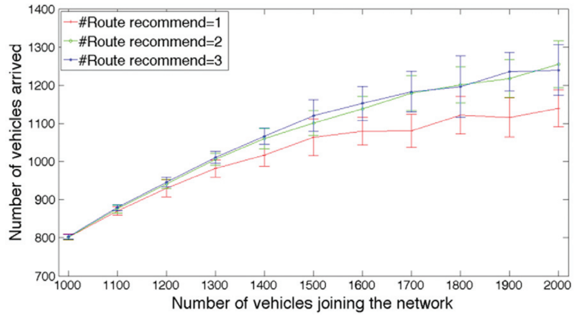

Fig. 2. Number of vehicles arrived at destination in 1 hour

4.2 Evacuation Time

Evacuation time is the time required from starting of alarm until all vehicles are in safety shelter. Fig. 3 shows the result of the evacuation time required. From the plot, we can see that evacuation time increases with the number of vehicles on the road network. Using K=2 and K=3 we could achieve a shorter evacuation time compared to K=1, when number of vehicles is high.

We can conclude that distributing traffic improves evacuation time, when the number of vehicles in network is increase. But there is no difference between cases when the number of routes recommended is 2 or 3, in this particular setting, i.e., road network. This result strongly depends on the road network of a particular town. For a town

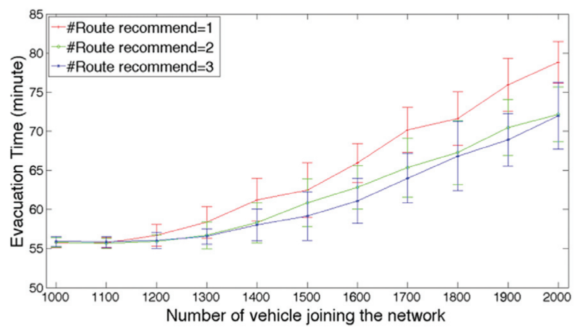

Fig. 3. Evacuation Time used ,i.e., travel time to evacuation shelter

prone to tsunami or similar natural disaster, we can find the minimum value of K (above which the congestion does not improve) from its road network and number of cars.

5 Conclusion and Future Work

In this paper, we proposed a road navigation algorithm. The proposed algorithm can find K shortest routes to a number of target destinations. We introduce the idea of virtual destination for efficient search. By searching multiple routes, we could distribute vehicles over different routes to prevent traffic congestion. To evaluate our proposed algorithm, we simulated evacuation situation in case of tsunami. We used real map data from Miyako, Japan. This map includes information of tsunami on March 11th, 2011. With realistic simulation, we could conclude that the proposed algorithm was successful to lead more vehicles to safe destinations. We also varied that distributing traffic could increase number of vehicles arrived at safe destination, and reduce evacuation time.

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