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Reducing emergency services arrival time by using vehicular communications and Evolution Strategies

Javier Barrachina [a], Piedad Garrido [a], Manuel Fogue [a], Francisco J. Martinez [a,*], Juan-Carlos Cano [b], Carlos T. Calafate [b], Pietro Manzoni [b]

[a] Computer Science and System Engineering Department (DIIS), Campus of Teruel, University of Zaragoza, Ciudad Escolar s/n, 44003 Teruel, Spain
[b] Computer Engineering Department (DISCA), Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain

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ABSTRACT

Nowadays, traffic jams in urban areas have become a problem that keeps growing every year since the number of vehicles in our cities is continuously increasing. One of the most common causes producing traffic jams are vehicle accidents. Moreover, the arrival time of the emergency services could be raised due to traffic congestion. Intelligent Transportation Systems (ITS) have a key role in order to reduce or mitigate this problem. In this paper, we propose four different approaches addressing the traffic congestion problem, comparing them to obtain the best solution. Using V2I communications, we are able to accurately estimate the traffic density in a certain area, which represents a key parameter to perform efficient traffic redirection, thereby reducing the emergency services arrival time, and avoiding traffic jams when an accident occurs. Specifically, we propose two approaches based on the Dijkstra algorithm, and two approaches based on Evolution Strategies. Notice that, when an accident occurs, time is a critical issue, and the strategies here proposed contribute to find the optimal solution within a short time period.

1. Introduction

Traffic accidents represent a big problem for drivers and a serious burden for the economy of all the countries. A close look at traffic accidents shows that many of the casualties and serious medical conditions take place during the time elapsed between the accident occurrence and the arrival of the medical assistance. The so called 'Golden Hour' (Fogue et al., 2013) after a car crash is the time within which medical or surgical intervention by a specialized trauma team has the greatest chance of saving lives. If more than 60 min have elapsed by the time the injured arrives to the operating table, the chances of survival fall sharply. Typical arrival of medical help takes about 15 min, but initial access and treatment starts 25 min after the accident. Transportation of the injured to the hospital usually takes place 50 min later. Therefore, time is critical for the survival of the injured in a severe crash incident, and any technology capable of providing a fast and efficient rescue operation after a traffic accident takes place will increase the probability of survival of the injured, and reduce the injury severity.

Additionally, urban traffic congestion affects most cities around the world. This scenario is getting even worse since the number of vehicles circulating in our cities grows every year. Vehicle accidents are one of the most common causes generating traffic jams in urban scenarios, which yield a higher cost of fuel, increasing air pollution.

Intelligent Transportation Systems (ITS) are among those newly introduced technologies that promise a cure-all remedy to the ever increasing traffic congestion problem (Jawad & Ozbay, 2005). In the near future, ITS will help the city traffic to be safer and more comfortable, redistributing traffic to avoid traffic jams (Ma, Huang, & Jiang, 2012), communicating real-time information when an accident occurs (Barrachina et al., 2012), and using intelligent systems for parking search (Lu, Lin, Zhu, & Shen, 2009).

Cooperative vehicle systems have become an increasingly popular transportation paradigm in recent years. Wireless technologies, through vehicular networks, enable peer-to-peer mobile communications among vehicles (V2V), as well as communications between vehicles and infrastructures (V2I). Using these technologies, crashed vehicles are able to notify the emergency services about the occurrence of an accident. In addition, emergency services can dynamically redistribute traffic by communicating or suggesting new routes to vehicles. These routes can be calculated using different methods such as Dijkstra-based algorithms, genetic algorithms, or Evolution Strategies.

Evolutionary Algorithms imitate the principles of natural evolution as a method to solve parameter optimization problems. They

* Corresponding author. Tel.: +34 978618156; fax: +34 978618104.
E-mail addresses: barrachina@unizar.es (J. Barrachina), piedad@unizar.es (P. Garrido), mfogue@unizar.es (M. Fogue), f.martinez@unizar.es (F.J. Martinez), jucano@disca.upv.es (J.-C. Cano), calafate@disca.upv.es (C.T. Calafate), pmanzoni@disca.upv.es (P. Manzoni).

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have been successfully used to solve various types of optimization problems (Greenwood, Lang, & Hurley, 1995), since they provide an optimal solution without checking all the possible solutions, reducing the execution time drastically. Evolution Strategies are a kind of Evolutionary Algorithm with the particularity that the mutation steps are included in the chromosome. This kind of Evolutionary Algorithms obtains very good results in numerical optimization problems, especially when working on continuous variables.

There are several works where intelligent systems are used to avoid traffic jams (e.g. Ohara, Nojima, & Ishibuchi (2006), Sanchez-Medina, Galan-Moreno, & Rubio-Royo (2010) and Dezani, Gomes, Damiani, & Marranghello (2012)). However, they do not focus on reducing the rescue time of the emergency services, or exploiting the advantages of using vehicular communication capabilities. Additionally, in all these works, authors only consider a specific scenario for simulations to assess their proposal, which might lead to unrepresentative results and wrong conclusions.

In this paper, we propose four different approaches to minimize the emergency services arrival time when an accident occurs in urban scenarios, also trying to avoid traffic jams scenarios. In particular, two of them are based on the Dijkstra algorithm, and the other two are based on Evolution Strategies. Additionally, we evaluated the four proposed solutions in three different scenarios with different topologies to determine the best solution in terms of travel times of the emergency services and the rest of vehicles.

This paper is organized as follows: In Section 2 we present our four different re-routing systems (i.e., Dijkstra, Density-Based Dijkstra, Evolution Strategy, and Density-Based Evolution Strategy). Section 3 introduces the simulation environment used to assess our proposed schemes. Section 4 shows the obtained results, and Section 5 reviews the related work regarding intelligent systems used to avoid traffic jams and minimize vehicle travel times. Finally, Section 6 concludes this paper.

2. Our proposed vehicle routing systems

In this Section, we propose four different vehicle routing approaches with the aim of ensuring that emergency services arrive at the place of the accident as soon as possible, whereas the rest of vehicles are not significantly affected, i.e., their travel times do not increase considerably, avoiding the possible traffic jams caused by the accident. Specifically, they are: (i) Dijkstra, (ii) Density-Based Dijkstra, (iii) Evolution Strategy, and (iv) Density-Based Evolution Strategy.

Table 1 presents the main features of these proposed approaches. As shown, the first two proposed approaches are simple and deterministic. The first one accounts for the number of lanes of each street to find the solution, and the second system additionally takes into account the traffic density. The other two proposed approaches are implemented using Evolution Strategies, and additionally, our last mechanism uses a real-time traffic density estimation to get better solutions.

2.1. Dijkstra

This system aims at obtaining the shortest route between two map positions by using the Dijkstra algorithm (Dijkstra, 1959), specifically adapted to roads and streets, and taking into account the length and priority of the streets. The priority of each street indicates the preference it has with respect to the others for a vehicle when it arrives to an intersection.

In this system, the street priority is calculated by using the number of lanes per street, assigning higher priority to the widest streets (i.e., with higher number of lanes). The main disadvantage of this system is noticeable when there is a high number of vehicles in a specific area, since it might produce traffic jams even in the widest streets. Fig. 1 shows an example of this situation. As shown, vehicles arrive to the junction through street *A*. Using this system and considering the priorities shown in the figure (1.0 for street *B* and 9.0 for street *C*), the majority of vehicles continue their route through street *C* (90% of vehicles since this street has a greater number of lanes), collapsing it. However, street *B* has less traffic density, with a more fluid traffic.

This proposed system uses a static model for street priorities, where a priority is given to each street, and priorities do not change under any circumstance. This issue could generate two kind of problems when an accident occurs: (i) there could be traffic jams in specific areas of the scenario, whereas other areas present very low traffic, and (ii) the streets selected as routes for the emergency services do not present low priority for the rest of vehicles in order to reduce the number of potential vehicles blocking the streets.

The main advantage of this system is the low computational cost since it does not need to know the current traffic density or the emergency service routes; in addition, when an accident occurs, this approach can be applied immediately.

2.2. Density-Based Dijkstra

This proposed system is similar to the previous one, with the difference that, in this case, we take into account the traffic density in the area when the street priorities are assigned. To develop this method, those streets leading vehicles to high traffic density areas, are penalized. When an accident occurs, all the vehicles involved send a warning message using Vehicular Networks Communications. When control systems are notified, they apply the vehicular density estimation approach presented in Section 3. In addition, the streets through which emergency services circulate to arrive at the accident site are penalized for the rest of vehicles. Specifically, in this proposed system, we proceed as follows:

- *Step 1*: we prioritize streets by normalizing the values (see Eq. (1)). As shown, the normalized values start in 1 and end in 10 (N_{min} and N_{max}, respectively).

$$N_x = \frac{(P_x - P_{min}) \cdot (N_{max} - N_{min})}{P_{max} - P_{min}} + N_{min}$$
$$\text{where}: \quad N_{min} = 1, \quad N_{max} = 10 \tag{1}$$

- *Step 2*: the normalized value for the rest of the areas (N_x) is calculated by using a proportion between the minimum and the maximum traffic density percentages, and the traffic density of the area which we want to calculate the normalized value (P_{min}, P_{max}, and P_x, respectively).

Table 1
Features of our proposals.

	Dijkstra	Density-Based Dijkstra	Evolution Strategy	Density-Based Evolution Strategy
Deterministic	✓	✓	×	×
Nondeterministic	×	×	✓	✓
Considering traffic density	×	✓	×	✓