An Analysis of Emergency Message Delivery Scheme in Inter-Vehicular Networking

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EXTENDED ABSTRACT

Inter-vehicle networking has been proved to be an efficient and enabling system for the enhancement of road safety. With the help of inter-vehicle networking, a driver can be notified with a warning message for a traffic jam or collision in a real-time mode, and thus, take a positive action promptly to avoid entering jam areas or multiple-vehicle collisions. In this paper, we study the performance of an emergency message delivery scheme in an inter-vehicle network. When a critical safety-related event occurs in a vehicle, such as a sudden brake or the emerging of a road hazard, an emergency message is automatically generated and broadcast to the neighboring vehicles within a safety area through an one-hop or multiple-hops delivery. If the message is received by all the vehicles with the safety area before the deadline, the safety is guaranteed. However, the emergency message delivery scheme encounters significant challenges to meet the high requirements on both latency and reliability. At first, the topology of an inter-vehicle networking is normally unknown and time varying. Moreover, wireless coverage and channel fading under diverse road situations seriously impact the connectivity among the vehicles within the safety area. In this paper, we build up a simplified model to study the relation between the size of safety area and the message delivery distance per hop and the number of hops. Through theoretical analysis and computer simulations, the statistical characteristics of the size of safety area \((D_s)\) as a function of the message delivery distance per hop \((R)\), the number of hops \((N)\), and the vehicle arrival rate \((\gamma)\) will be carefully investigated. The obtained research results can be used to estimate the required number of hops and possible latency to deliver emergency messages within a designed safety area.

Key words: emergency message delivery—inter-vehicle networking—safety
INTRODUCTION

As a fundamental element of contemporary society, road transportation has been playing a vital role in commercial activities and the daily lives of the majority of U.S. citizens. Yet road transportation in the United States is presently in difficult circumstances in terms of two aspects: safety and efficiency. The National Highway Traffic Safety Administration (NHTSA) has reported that there are 6.2 million crashes annually, resulting in more than 43,000 fatalities and a cost to society of more than $230 billion [1]. Safety systems widely adopted by automakers are typically based on individual vehicle implementations, such as seat belts, air bags, and anti-lock brakes. Thus, beyond some substantial initial gains, those single-vehicle systems can hardly further alleviate fatalities or injuries. Figure 1 shows that death number has been gradually increased in recent years, even though most of the states have laws strongly supporting highway safety. Road accidents are often caused by drivers’ carelessness or ignorance, simple misconduct, or lack of experience, and it is extremely difficult to eliminate these “human” factors due to the inherent limits of human sensing and reaction speeds. All other measures applied failed to reduce the number of fatalities for the last 17 years, and more people in the United States give their lives in transportation-related accidents than any other single cause.

Besides crashes, due to aging and increasing usage of the road transportation infrastructure in the United States, congestion has emerged as another critical issue that negatively impacts our lives in multiple ways: it creates inefficiencies in roadway use, wastes fuel, causes widespread pollution and noise, and reduces personal “quality time.” For example, traffic congestion costs Chicago $7.3 billion per year [2]. The average commuting time increased 14% in the last 10 years from 22.4 minutes in 1990 to 25.5 minutes in 2000 [3]. In many areas of the country, traffic congestion has become a major quality of life issue that impacts decisions as fundamental as where to buy a home or where to work [3]. “We are experiencing increasing congestion on our nation's highways, railways, airports and seaports. And we're robbing our nation of productivity and our citizens of quality time with their families” [4]. However, it is an expensive strategy to relieve congestion solely through major road infrastructure expansion.

Since changing human behavior and/or significantly enhancing human abilities critical for safe driving is unlikely and major road infrastructure expansion for congestion relief is expensive, technological solutions to improve road safety and efficiency are thus essential. For example, Mr. Paul Brubaker, the administrator of the Research and Innovative Technology Administration (RITA) of the U.S. Department

Figure 1. The U.S. traffic fatalities in recent years (left) and percentage of the states with laws supporting various highway safety efforts (right)
of Transportation (U.S. DOT), has challenged the nation to reduce transportation accident-related deaths in the United States by 90% over the next decade through the use of better information technologies. With the wireless access for vehicular environment (WAVE) technology, the wireless transceivers installed on vehicles and roadsides form a local road areas network supporting inter-vehicle (V2V and V2I) communications and provide drivers perception, early warning, and assistance through accurate and fast sensing, surveillance, and information sharing among vehicles. As shown in Figure 2 [5], the local road area network will help drivers:

1. Maintain local vehicular awareness of surroundings in a real-time manner
2. Extend perception from local and transient to global and long-term to make prediction and preemptive responses possible
3. Translate situational information to appropriate actions, and develop multiple and collaborative automatic vehicle safety control strategies

<table>
<thead>
<tr>
<th>Example</th>
<th>Description</th>
<th>Image</th>
</tr>
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<tbody>
<tr>
<td>Obstacle Warning</td>
<td>Stopped/skidding/slowing down vehicle warning, road obstacle/object-on-road warning</td>
<td></td>
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<tr>
<td>Lane Merge/Lane Change Assistance</td>
<td>Merging/lane-changing vehicle communicates with vehicles in lane to safely and smoothly merge</td>
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<tr>
<td>Adaptive Cruise/Cooperative Driving</td>
<td>Automatically stop and go smoothly, when vehicles are in heavy roadway traffic; cooperative driving by exchanging cruising data among vehicles</td>
<td></td>
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<tr>
<td>Intersection/Hidden Driveway Collision Warning</td>
<td>Vehicles communicate to avoid collision at intersection without traffic light or hidden driveway</td>
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<tr>
<td>Roadway Condition Awareness</td>
<td>Vehicles communicate to extend vision beyond line of sight (e.g., beyond a big turn or over a hill)</td>
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**Figure 2. Major functions of a local road area network**

Furthermore, as depicted in Figure 3, when many local road areas networks are connected with each other through dedicated networking or the Internet in either wired or wireless links, a vehicle integrated information infrastructure is formed, where vehicles work as information probes and report timely traffic and road condition information to transportation agencies, and then the obtained information can be shared by a large community to reduce transportation accidents and relieve congestion. It is expected that with the aid of the vehicle-integrated information infrastructure for delivering real-time, local and global traffic messages, and further assuming that most drivers will be acting rationally, U.S. transportation systems will become more controllable and predictable.

Vehicles have been operating on roadways on this planet for more than a century in an isolated way. We are at the right time to connect these vehicles together and bring our society into a new age. Similar evolution happened on computer networks: when millions of computers were connected to share resources and information, the Internet emerged, and some profound positive changes were made to the way of our life and work. Once vehicle infrastructure integration (VII) based on the WAVE technology is
implemented, it will radically improve road transportation environments in terms of safety, efficiency, and information access; fundamentally smooth the progress of intelligent transportation systems (ITS) advocated by the U.S. DOT; and turn driving and riding into a completely new experience—safer and more pleasant than ever before. Except for the WAVE-based VII, no other solution has the promise to save so many lives by actively avoiding crashes, improve the nation's productivity by relieving road congestions, promote an eco-friendly environment by reducing vehicle induced crude oil usage, and enhance the nation security by enabling the usage of vehicle recording and tracking. Furthermore, the enormous potential market for WAVE-related products can sustain several tier-one automobile suppliers and many supporting companies. Thousands of workshops will be needed to install WAVE systems to existing billions of vehicles. Moreover, the services supported by the vehicle-integrated information infrastructure could foster the generation of several service operators, the size of which could be comparable to that of cellular carriers. In summary, the WAVE-based VII has the potential to generate a fresh information technology industry based upon roadway vehicles, and it will bring the United States an opportunity to grow the high-tech sector of its economy and enhance its international economic competitiveness. The magnitude and breadth of the impacts of the WAVE-based VII on the economy of the United States are substantial, multi-layered, and profound.

![Figure 3. The vehicle integrated information infrastructure based on the WAVE technology](image)

**EMERGENCY MESSAGE DELIVERY SCHEME**

As one of important functions of the WAVE-based VII, when an emergency event or a danger is detected by a vehicle, a warning message is automatically generated and broadcasted to neighboring vehicles within a defined safety area. If messages are surely received by all the vehicles within the safety area before a deadline, which relates to the reasonable action time of a driver, emergency events or dangers can be known in a real-time mode and earlier actions can be taken by drivers to avoid collisions, and thus, safety can be significantly enhanced. However, the delivery of emergency messages is very challenging because the topology of the inter-vehicle network varies rapidly with time, which is related to the distributions and movements of vehicles, and guaranteed latency is required for the delivery of emergency message. Some research activities on emergency message delivery schemes have been done recently [6]. In this paper, we develop a simplified model to study the relation between the size of safety area and the message delivery distance per hop and the number of hops.
System Model

For simplicity, a one-dimensional road model is used in this paper. As shown in Figure 4, vehicles travel along a lane independently. The number of vehicles, $n$, within a given zone of $x$ follows a Poisson distribution given by

$$P(n, x) = \frac{(\gamma x)^n e^{-\gamma x}}{n!},$$  \hspace{1cm} (1)

where $\gamma$ is vehicle arrival rate. As a consequence, the distance $d_i$ between the $i^{th}$ and the $(i+1)^{th}$ vehicles follows an exponential distribution, and its probability density function (pdf) can be expressed as

$$P(d_i) = e^{-\gamma d_i}.$$

Therefore, the distance from the $n^{th}$ vehicle to the first vehicle that generates an emergency message is given by

$$D_n = d_1 + \cdots + d_{n-1}, \quad n \geq 2,$$

and after simple derivations, the pdf of $D_n$ can be expressed as

$$P(D_n) = \frac{\gamma^n D_n^{n-1}}{(n-1)!} e^{-\gamma D_n}.$$

![Figure 4. One-dimensional road model for emergency message delivery system](image)

When the emergency message is delivered through multiple hops, in order to avoid messages flooding everywhere, it is assumed that only the vehicle that satisfies the following condition will relay the emergency message: the vehicle is the furthest vehicle from the vehicle transmitting the emergency message but still within the message delivery distance per hop. Therefore, if the message delivery distance per hop equals $R$ and the number of hops equals $N$, the relation between the size of safety area, $D_n$, which becomes a distance in a one-dimensional road model, and $R$ and $N$ can be summarized as follows:

i) when $N=1$, $D_1=R$

ii) when $N=2$, $D_2=D_1+R$ with $D_{n1}\leq R$ and $D_{n1+1}>R$

iii) when $N=3$, $D_3=D_2+R$ with $D_{n2}\leq R$, $D_{n1+1}>R$, $D_{n2}-D_{n1}\leq R$, and $D_{n2+1}-D_{n1}>R$
iv) when \( N = i \), \( D_s = D_{n(i-1)} + R \) with \( D_{n1} \leq R, D_{n1+1} > R, D_{n2} - D_{n1} \leq R, D_{n2+1} - D_{n1} > R, \ldots, D_{n(i-1)} - D_{n(i-2)} \leq R, \) and \( D_{n(i-1)+1} - D_{n(i-2)} > R \)

In this paper, through theoretical analysis and computer simulations, the authors will carefully investigate the statistical characteristics of the size of safety area \( (D_s) \), as a function of the message delivery distance per hop \( (R) \), the number of hops \( (N) \), and the vehicle arrival rate \( (\gamma) \) based upon the above described relation. The obtained research results can be used to estimate the required number of hops and possible latency to deliver emergency messages within a designed safety area.
REFERENCES