Adaptive Preemption of Traffic for Emergency Vehicles

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Abstract - Minimizing travel time is critical for the successful operation of emergency vehicles. Preemption can significantly help emergency vehicles reach the intended destination faster. Majority of the current studies focus on minimizing and/or eliminating delays for EVs and do not consider the negative impacts of preemption on urban traffic. One primary negative impact is extended delays for non-EV traffic due to preemption that is addressed in this paper. We propose an Adaptive Preemption of Traffic (APT) system for Emergency Vehicles in an Intelligent Transportation System. We utilize the knowledge of current traffic conditions in the transportation system to adaptively preempt traffic at signals along the path of EVs so as to minimize, if not eliminate stopped delays for EVs while simultaneously minimizing the delays for non-emergency vehicles in the system. Through extensive simulation results, we show substantial reduction in delays for both EVs and non-emergency traffic under the proposed APT system.

Keywords - Emergency Vehicles, Preemption, Vehicular Network, Intelligent Transportation Systems

I. INTRODUCTION

Preemption of an Emergency Vehicle is a preferential treatment given to emergency vehicles at intersections to reduce their travel-time by reserving the right of way for their traversal [2]. Most of the preemption systems, presently available in the United States operate on an intersection-by-intersection basis [6]. An emergency vehicle is detected by sensors at each traffic light and each individual traffic light switches to preemption phase. In this kind, preemption of each intersection takes place only after the emergency vehicle reaches it, this also potentially results in the emergency vehicle to stop at each intersection as it waits for the other vehicles in the queue at the intersection to clear. Present preemption of an emergency vehicle is further complicated by peak hour traffic or after-event traffic when the route of an emergency vehicle is congested. In such conditions, preemption can create increased delays at local intersections due to lack of clearance at downstream intersections [6].

A publication in 1929 [7], by the American Engineering Council on Street Traffic Signs, Signals and markings stated that in “In any coordinated system, supplemental arrangements may be provided for breaking the system into smaller units for emergency operation, such as the runs of fire apparatus”. Though emergency vehicles are prioritized on streets using sirens and strobe lights, intersections still remain a hindrance for their uninterrupted movement. Various technologies based on hardware such as vehicle emitters and signal detectors emerged in 1960’s.

Emergency Vehicle Preemption has many advantages. These include faster response by the emergency team, improved safety for emergency vehicles as well as other vehicles, cost savings to the public because of reduced property loss which is enabled by quicker emergency response and cost savings to the authorities because of a larger service area for each emergency dispatch station [1]. The American Heart Association stated that the survival chances for a cardiac arrest patient are reduced by 7 to 10 percentage for every minute lost until defibrillation [1]. A small fire doubles every 17 seconds and can reach flashover in 7 minutes [26]. Hence, fire and rescue operations have set the operational standard response time to be less than 7 minutes. Emergency Vehicle Preemption can help achieve this goal.

Although the implementation of Emergency Vehicle Preemption can help reduce the travel time of emergency vehicles, it can affect overall traffic negatively [20]. Studies were conducted in New York City to evaluate the impact and benefits of Emergency Vehicle Preemption [12]. This study showed an improved emergency vehicle operation at all the six locations, but also showed a disruption in the coordination of the signal systems. Recovery required not less than four cycle lengths. Also, it showed an average increase in traffic delay of 4 to 58 percent. A hardware in the loop simulation using CORSIM with Leesburg, Virginia as the study area and Route 7 as the study corridor, was conducted at Federal Highway Administration’s Traffic Research Laboratory (TReL) [28]. This showed an increase in overall travel time to be one to two percent.

This paper presents an evaluation of a new approach to achieve optimal emergency response preemption along a route called traffic adaptive optimality based preemption. This preemption mechanism offers a route based clearance scheme which is designed to operate over the entire response route with a single activation followed by a series of intersection preemptions. Preemption at each intersection is timed using threshold calculated from optimal queue length and radius based average emergency vehicle speed. Real
time adjustments are then done using the queue length congestion on each link to provide uninterrupted movement of the emergency vehicle throughout the response route.

The rest of the paper is organized as follows. Section II introduces the related work. Section III describes the proposed Adaptive Preemption of Traffic (APT) system. Section IV evaluates the proposed APT system with current. Finally, in Section VI, we present concluding remarks.

II. RELATED WORK

Granting priority to emergency vehicles has been prevalent long before the existence of ITS preemption technologies. Safety concerns and increasing traffic volumes, combined with improved technologies, encouraged the implementation of ITS strategies to provide a special green interval to the emergency vehicle while ensuring red intervals to conflicting approaches [1]. The need for supplemental arrangements for emergency vehicle operation in a coordinated system was first described by American Engineering Council publication in 1929. In 1960, technology for incorporating preemption in signal systems was initially developed [1]. This provided the impetus for first of its kind preemption system devised by 3M in the early 1970s [10].

Emergency vehicle preemption was first adopted into a signal system with almost 100 percent of the traffic controllers having preemption control. St. Paul, Minnesota [11]. In 1979, 3M built a new system which could prioritize preemption requests [10]. This marked the beginning of Transit Signal Priority with the system allowing two priorities, a higher for emergency vehicles and a lower for transit vehicles. The brand name Opticom was given to these preemption products which included a separate emitter unit required for emergency vehicles and transit vehicles. Soon, infrared emitters and detectors replaced strobes because of the public use of strobe lights to fool traffic signals [3]. In 1992, 3M added encryption codes to its infrared transmitters to avoid false preemption calls made by hackers [10].

Emergency vehicle preemption has undergone major changes with advancements in ITS. Some of the hardware advancements in the preemption industry are Automatic Vehicle Location using Global Positioning System [10] and Vehicle to Road Side Communication that utilizes encrypted infrared and radio waves. However the preemption logic still remains unchanged. Majority of the systems in United States are classified as detection, preemption and transition systems that involve detection of emergency vehicle which in turn invokes preemption at an intersection and controller switches to a predefined preemptive phase. A survey conducted by Research and Innovative Technology Administration in major Metropolitan areas about ITS deployment of emergency vehicle preemption systems indicates the use of some type of EVP system in almost 93 metropolitan areas. Survey results show that nearly 33,000 intersections or 24% of the total signalized intersections were found to have some sort of an EVP mechanism installed. The results also indicate that almost 4800 emergency vehicles are equipped with Roadside Communication devices and 4650 use Automatic Vehicle Location systems [4].

Sound based systems, radio based systems, light and infrared systems are the major preemption technologies currently in use [2, 4]. Biggest challenge for light/infrared based systems is they require clear line of sight and can be easily affected by the weather. Sound based systems do not require line of sight. However, their range is limited since loudness is limited by tolerance of nearby traffic and community. Further, since they are not directed, all traffic signals in the nearby vicinity are preempted. Radio based systems also do not require line of sight. However, current implementations also preempt all traffic signals in the vicinity rather than just those in the EV’s path.

Reducing the travel time of emergency vehicle at both coordinated and non-coordinated signalized intersections is the major responsibility of preemption logic [1]. However current preemption technologies do not perform satisfactorily along congested paths where spillbacks and gridlocks do occur [6]. In such conditions, even when the emergency vehicle preempts a signal controller, the queued vehicles from the next intersection delays movement because the emergency vehicle cannot preempt that controller until it is within range of the VRC. In such situations, the preemption needs advanced clearing of downstream approaches so that the emergency vehicle can move with minimal delay or stops.

Research has shown emergency response times can be significantly reduced through route wide preemption methods [5]. Technology for communicating between the controller and emergency vehicles is now available and can aid implementation of systems which involve real-time optimality based preemption. Also, more routes can be monitored for traffic conditions using vehicle detection and traffic flow measurement systems. These improvements, along with increasing congestion, have provided the tools and motivation for the development of an Optimality based Traffic Adaptive preemption method for emergency vehicles.

Recently, technological advancements, such as use of GPS to calculate the latitude, longitude, speed and heading of emergency vehicles, came into common use [3]. Today, the 3M Opticom Preemption System is the most commonly used in the United States [23, 24]. Ninety-eight metropolitan areas have installed it in more than 30,000 intersections which represents one-fifth of all signalized intersections in the United States [1]. Cities like Bellingham (WA), Boise City (ID) and Syracuse (NY) have recently implemented preemption systems in more than 90% of their signalized intersections [10].

Petri Nets serve as a visual and mathematical formalism to model ITS systems. Multiple researchers have designed emergency traffic-light control systems by using Petri net models to prevent large-scale traffic congestions induced by accidents at intersections [8, 14].
From the above discussion, it can be noted that there are many techniques for providing clearance for emergency vehicles. Each of these techniques seems to have merits and demerits. However, few works utilize the real time locations of the vehicles that is made possible with advancements in an ITS.

III. ADAPTIVE PREEMPTION OF TRAFFIC

The goal of this paper is to develop and evaluate a preemption method for emergency vehicles which utilizes some of the technology available in intelligent traffic systems to adjust controllers along a route to minimize the travel-time of emergency vehicles and thereby improve emergency level of service. Objectives of this research are:

- Develop a preemption method which utilizes information from real-time traffic monitoring to provide a faster emergency response without compromising safety.
- Evaluate the method using a case study for its effectiveness in providing faster emergency response and minimizing its impact on overall traffic.

This paper presents a strategy for emergency vehicle preemption along a busy road. This strategy while adapting to real time traffic conditions minimizes the emergency vehicles delay and optimize overall system delay. The approach uses optimality based queue length at intersections to compute the threshold used for preempting along the route of emergency vehicle. As queue lengths depend on traffic conditions the proposed preemption logic forms the basis for a dynamic preemption approach.

A. Network Model

We assume an Intelligent Transportation System where the emergency vehicles are equipped with onboard units (OBUs) and stationary units installed at the traffic signals, termed roadside units (RSU) [25]. Typically, OBU installed on a vehicle integrates the technologies of wireless communications, micro-sensors, embedded systems, and Global Positioning System (GPS). The communication channel connecting the RSUs and the ITS is a secure and reliable peer-to-peer channel. The medium used for communications between neighboring OBUs and between OBUs and RSUs is 5.9 GHz Dedicated Short Range Communication (DSRC) as detailed in IEEE 802.11p [27]. Finally, we assume that the traffic signals have access to path of traversal of an EV and EV’s location in real time. The traffic signals also can compute the queue lengths in any direction and have an accurate estimate of traffic arrival rates.

B. Adaptive Preemption of Traffic (APT)

In the proposed method of the preemption, the preemption of intersections along a route is adapted to optimize the movement of an emergency vehicle with primary objective being minimize stopped delay of EV and an additional objective being to minimize the additional waiting times of all other vehicles in the system caused by the pre-emption.

The APT system constitutes of following primary components: Initialization, Preparation and Preemption phase.

1) Initialization:

Once the emergency vehicle receives a call, the route from source to destination is computed and later transmitted to the nearest traffic signal controller, which then transmits the request to all the downstream traffic signal controllers. The time of departure of the EV and location of departure is also transmitted to all traffic signals.

2) Preparation

Each traffic signal estimates the time of arrival of EV at the signal based on the path of the EV, distance, and speed limits along the path. The estimated time of arrival is based on the assumption that the EV does not have to stop or slow down anywhere along the path. Since, the existing traffic conditions can impact the actual time of traversal, the estimated time of arrival can change and hence, by accessing the location of EV in real time, the traffic signal adapts the estimated time of arrival.

3) Preemption phase

The traffic signal controller initiates traffic preemption by computing the accurate time to preempt all the traffic currently waiting in the queue and also any further traffic arriving during the preemption phase.

For computing the time taken to preempt the queue, we adopt the queue discharge model [32]:

\[
v_s = v_n \left[ 1 - e^{-m_s(t-t_s)} \right] \\
q_s = q_n \left[ 1 - e^{-m_q(t-t_s)} \right] \\
h_s = h_n \left[ 1 - e^{-m_h(t-t_s)} \right]
\]

where \( t \) is time since start of green phase, \( t_s \) is start response time, \( v_s \) is queue discharge speed, \( v_n \) is maximum queue discharge speed, \( m_s \) and \( m_q \) are model parameters, and \( q_s \) is queue discharge flow rate.

A traffic signal monitors the location of the EV and initiates pre-emptying the traffic using the time computed to preempt traffic completely using above model, so that upon the arrival of the EV there is no stationary or obstructive traffic and the EV can have a safe passage. We also accommodate a small buffer period equivalent to an yellow phase to ensure that any additional traffic beyond estimated arrival rates are preempted as well.
IV. EXPERIMENTAL RESULTS

We developed a microscopic simulator to evaluate the behavior of proposed APT preemption method. Java was the corresponding language used to model the simulator. Simulations were done for duration of an hour in the following three cases:

1. No preemption
2. Present preemption using Opticom Preemption System [18]
3. Proposed APT Preemption

The measures of effectiveness used for comparison of the three cases included average travel time, average delay for the emergency vehicle movements and average system delay for various traffic levels ranging from minimum to maximum number of cars the system can support. The measures were calculated for five different scenarios were the number of cars is 500, 750, 1000, 1250 and 1500. For each scenario the simulation was done for about hundred times and the mean of the measures was calculated with a confidence interval of 94%. Table 2 shows the summary of simulation results.

The proposed preemption technique showed a 31.5% reduction in travel time of the emergency vehicle compared to the case where no preemption was used, whereas, local preemption was able to reduce the travel time of emergency vehicle by only 13.7%. A similar trend was found in the delay experienced by the emergency vehicle during its movement. The proposed method was able to reduce the delay by an average of 2.94 min whereas; local preemption was able to reduce the delay by only 1.28 min. However, it should be noted that the proposed method caused a minor 0.17 min increase in the average of system delay in the simulation. We can see from the above results that the proposed method of preemption more efficiently in higher levels of congestion and performs almost closer with a slight improvement comparing to the presently available preemption technique.

Figure 1 shows a comparison of average travel times in different levels of traffic for the emergency vehicle to reach its destination. As shown, the average travel time of emergency vehicle reduces from no preemption case to the present preemption case and further reduces in the case of the optimality based traffic adaptive preemption.

Figure 2 shows a comparison of average delay time at different levels of traffic for the emergency vehicle to reach its destination. As shown, the average delay time of emergency vehicle reduces from no preemption case to the present preemption case and further reduces in the case of the optimality based traffic adaptive preemption.

Figure 3 shows a comparison of average system delay caused by the emergency vehicle in different scenarios of preemption by varying the traffic congestion and preemption type. As shown, the average system delay increases from no preemption case to the present preemption case and increases a bit more in the case of the optimality based traffic adaptive preemption.

Table 1: Results of Simulation

<table>
<thead>
<tr>
<th>Performance measure</th>
<th># veh in the system</th>
<th>No pre-emption</th>
<th>Present pre-emption</th>
<th>APT pre-emption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency Vehicle Travel Time</td>
<td>1250</td>
<td>11.10 Min</td>
<td>9.78 Min</td>
<td>8.86 Min</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>9.54 Min</td>
<td>8.29 Min</td>
<td>7.65 Min</td>
</tr>
<tr>
<td></td>
<td>750</td>
<td>7.46 Min</td>
<td>6.35 Min</td>
<td>6.12 Min</td>
</tr>
<tr>
<td>Emergency Vehicle Delay</td>
<td>1250</td>
<td>2.24 Min</td>
<td>0.92 Min</td>
<td>0 Min</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>1.89 Min</td>
<td>0.64 Min</td>
<td>0 Min</td>
</tr>
<tr>
<td></td>
<td>750</td>
<td>1.34 Min</td>
<td>0.23 Min</td>
<td>0 Min</td>
</tr>
<tr>
<td>System Delay</td>
<td>1250</td>
<td>0 Min</td>
<td>2.28 Min</td>
<td>2.40 Min</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>0 Min</td>
<td>2.28 Min</td>
<td>2.37 Min</td>
</tr>
<tr>
<td></td>
<td>750</td>
<td>0 Min</td>
<td>2.28 Min</td>
<td>2.33 Min</td>
</tr>
</tbody>
</table>

Figure 1: Average Travel Time of an Emergency Vehicle
Optimal traffic adaptive preemption was evaluated and we propose an effective method in improving the emergency vehicle movement through congested routes. The method performs better than the present preemption at individual intersections across the emergency vehicle travel time and the delay of emergency vehicle while increasing the system delay by a minute factor. This indicates the ability of the proposed methodology to improve the emergency response level of service along with widening the range of emergency dispatch stations without sacrificing safety.

**REFERENCES**


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