# Ambulance-to-Traffic Light Controller Communications for Rescue Mission Enhancement: A Thailand Use Case

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***Abstract*—During rescue missions, victim transferring from accident scenes to rescue sites is considered crucial and time-sensitive. Particularly, one-second delay could put more lives in danger. Though ambulances are commonly equipped with standard siren devices, such siren signals are not recognized by traffic light controllers. Therefore, the rescue missions could be delayed at intersections due to an urgency-unaware traffic light control system. In the worst case, pile-up accidents could also happen when the ambulances lawfully ignores the traffic lights. This paper proposes Ambulance-to-Traffic Light Controller Communications (A2T) to enhance the efficiency of rescue missions, by establishing the communication mechanism among ambulances and infrastructures (e.g. traffic light controllers). Thailand, as a country with the highest road traffic dead rate of the world in year 2015, is selected as a use case in this paper. A2T promotes information sharing between ambulances and traffic light controllers along the rescue path in advance. Such information, including speeds, locations, and emergency routes, allows the traffic light controllers to launch a prioritized green traffic light accordingly. This allows the ambulances through any intersections efficiently and safely. Our comprehensive performance evaluation shows that A2T remarkably achieves 100% waiting time reduction for the ambulances, while only 2.48% delay upon other vehicles at the intersections.**

***Index Terms*—Ambulances, Rescue Missions, Vehicle-to-Infrastructure Communications, Intelligent transportation Systems**

## I. INTRODUCTION

The increasing number of vehicles nowadays causes the higher number of road accidents and life losses. In 2015, The World Health Organization (WHO) [1, 2] reveal the statistics of approximated road traffic death rate per 100,000 population of all countries in the world. Among these countries, Thailand is ranked as the top in the list with the highest death rate of 36.20 times per 100,000 population. This figure rings a series warning bell to the whole country.

Additional statistics conducted by NHTSA, National Highway Traffic Safety Administration, demonstrates the number of accidents related the ambulances in US over a 20-year period from years 1992 to 2011 [3, 4]. Each year, there are approximately 6,500 accidents involving ambulances. On average, 60% of ambulance-related accidents happen during the rescue missions, and 43% of such ambulance crashes happen at road intersections. Additionally 25% of all deaths happened in the ambulances, which is seriously high and must be reduced by all means.

The statistics suggested that advanced Intelligent Transportation Systems (ITS) are highly desirable, especially for ambulances. In addition, this will help to reduce the road traffic death rate, particularly in Thailand. Although a few recent works [5 – 9] have addressed to manage the road traffic at intersections with the presence of ambulances, an optimized traffic light scheduling system for rescue mission enhancement has not yet been comprehensively investigated. To understand the system well, ambulances must be given the highest priority, in order to reduce chances of pile-up accidents and more life losses. It is also important to design the system in a distributed way, to achieve high reliability, avoiding single point failure, as well as supporting scalability of broad implementations in the future.

Thus, in this paper, a complete Ambulance-to-Traffic Light Controller Communications (A2T) is proposed to manage road traffic at intersections in a distributed manner. A use case in Thailand is investigated in the paper. Because Thailand is one of the countries in the world with high traffic jam, the study of Thailand use case representing the worst case scenario could be later as valuable references to other regions and countries with less traffic jam. Ambulances are primarily allocated the highest priority to guarantee the safe and smooth transportations, so as to give an enhanced performance of the rescue missions. It is noted that the paper considers the case that only one ambulance is involved.

The key contributions of this paper are summarized as follows;

- A2T establishes communications from ambulances to traffic light controllers in a distributed manner. For example, the communication is established on-the-fly without requirements of any centralized control units. Therefore, A2T can achieve higher level of scalability, reliability, and accuracy.
- Rescue information, such as speed, location, route, lane, and destination of ambulance, can be shared with the traffic light controllers in far advance through the A2T communications. The traffic light controllers utilize the shared information to sense the approaching ambulances and accurately switch to a prioritized green traffic light.
- The prioritized green traffic light will clear vehicle queues at any intersections and let the ambulances through the intersections immediately and safely.
- As a result, the ambulances do not get stuck by the vehicle queues at any intersections. Pile-up accidents involving ambulances are dramatically

TABLE I
RELATED WORKS

| Work | Main Features | Offline /Online | Rescue Route | Centralized/ Distributed | Objectives | Limitations |
|---|---|---|---|---|---|---|
| [5] | Prediction model for Dispatching Ambulances | Offline | Static | Centralized | Enhance an emergency route | Static Route, Scalability, Reliability, Security |
| [6] | Kullback-leibler distance to create an updated map after a disaster | Offline | Static | Centralized | Determine shortest and safest route after a disaster | Static Route, Scalability, Reliability, Security |
| [7] | M2M and GPS technologies | Online | Dynamic | Centralized | Keep traffic flow continuous at intersections | Scalability, Reliability, Security |
| [8] | Radio Frequency Identification | Online | Dynamic | Distributed | Determine a green light period and traffic congestion | Accuracy, Security |
| [9] | Communications from ambulances to traffic light controllers | Online | Dynamic | Distributed | Improve road safety and optimize road traffic | No comprehensive performance evaluations, Security |
| A2T | Ambulances-to-traffic light communications | Online | Dynamic | Distributed | Allow ambulances to pass intersections immediately and safely without stop and wait at the intersections | Communications with other vehicles, Security |

reduced. Thus, performance of the rescue missions is improved and many lives could be saved.

## II. RELATED WORKS AND STANDARDS

The siren signal is a world-wide standard implementation in ambulances. It is recognized by the other non-emergency vehicles to clear the path for the approaching ambulances. However, it is not recognized by the traffic light controllers to let the approaching ambulances pass the intersections immediately and safely. This is due to the fact that there is no proper communication platforms provided between the ambulances and the traffic light controllers. As a result, most of ambulances could not reach the place in rescue demand in a timely manner. Given that there is a higher chance for pile-up accidents, especially at intersections, there is a key requirement for advance communication-based traffic management systems.

### *A. Review of Traffic Management Systems*

In [5], an ambulance dispatch algorithm based on a prediction model is created. The information collected from different ubiquitous computing devices will be utilized to dispatch each ambulance. The main objective of the algorithm is to enhance an emergency route, under a use case of London Ambulance Service. Furthermore, the paper in [6] determines a rescue route in case of disaster. An updated map is created using the proposed Kullback-leibler distance along with image processing of the images taken before and after the disaster. Then, the updated map is used to determine the shortest and safest route for the ambulances. However, the route planning in both [5] and [6] is calculated in a centralized manner. The routes, in addition, are static and must be completely planned before dispatching the ambulances as well as it cannot be changed or updated during the missions. The paper [7] also proposes a centralized approach, in which M2M and GPS technologies are implemented to smooth traffic flow at intersections. The decision will be made by a centralized processor unit and database. Therefore, it is prone to a single point failure and scalability problems.

In [8], all vehicles are equipped with Radio Frequency Identification or RFID tags. RFID readers used to determine the number of vehicles at each road segment are located along a road side. Base on this information, a green traffic light duration and road congestion of each rescue path will be calculated. However, due to the limitations in terms of the communication range of RFID, the estimation of the number of vehicles contains a high error.

In [9], ambulances and traffic light controllers are allowed to communicate with each other. The main objectives of this paper are to improve road safety and traffic flow. However, the paper focuses on the network performance in terms of network throughput and end-to-end delay rather than the rescue mission performance, such as travel time and speed of ambulances. Without a comprehensive performance evaluation, this approach becomes unconvincing.

Table I summarized all related works presented in this paper.

### *B. Review of Vehicular Communication Standards*

Currently, there are two main standard suites proposed for the vehicular communications, which are WiFi-based DSRC/WAVE and cellular-based LTE-V standards.

#### *1) DSRC/WAVE*

DSRC/WAVE consists of three main WiFi-based sub-standards, which provide a framework to improve road safety in ITS [10].

- The first sub-standard is DSRC/WAVE. DSRC stands for licensed Dedicated Short Range Communications. The spectrum of 75 MHz in the 5.9 GHz is assigned for WAVE, which stands for Wireless Access in Vehicular Environments.
- The second sub-standard is IEEE 802.11p, which is a sub-standard for the physical layer (PHY) and the medium access control layer (MAC).
- The last standard is IEEE P1609.1–4, which covers operations on the network and the upper layers.

IEEE P1609.1 is proposed to deal with command message formats, resource management, data flows, and data storage formats in WAVE. Routing and

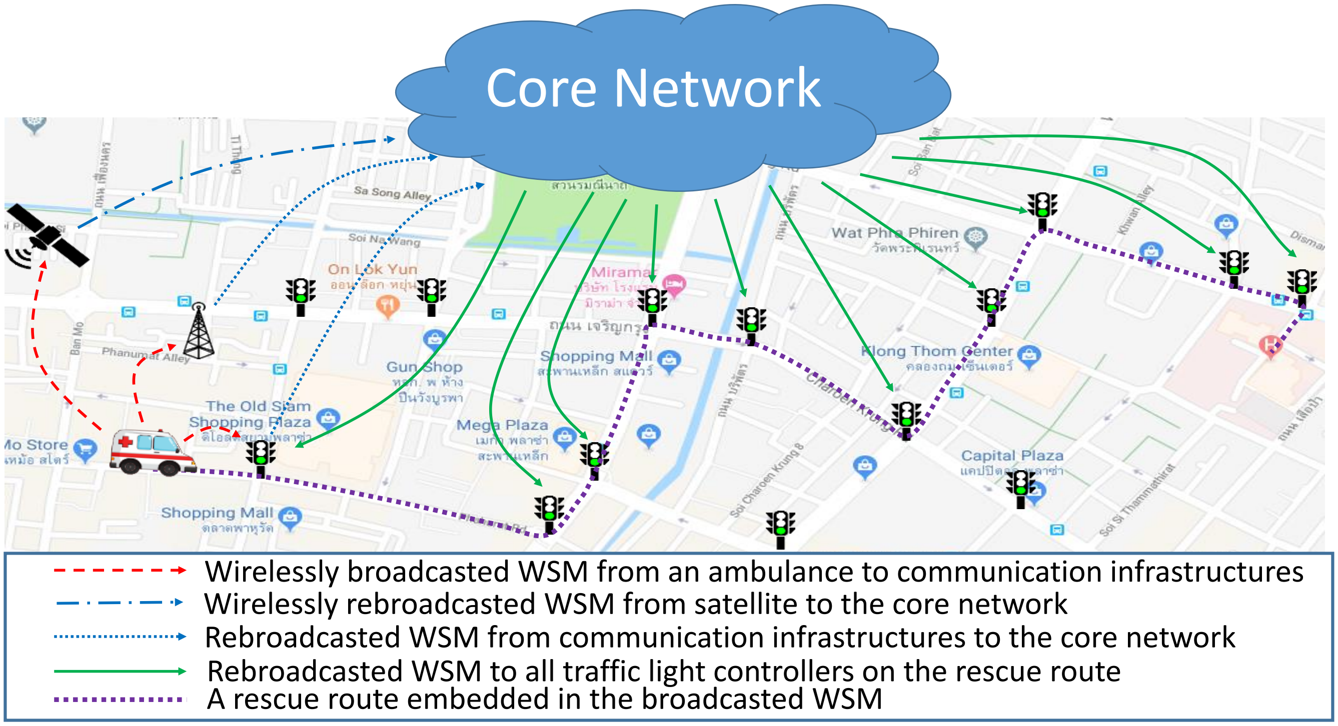


Fig. 1 A2T Paradigm

addressing of WAVE Short Messages (WSM) are managed by IEEE P1609.3, while network interface mechanisms on both PHY and MAC layers are managed by IEEE P1609.4 and IEEE 802.11p. They also deal with Quality of Service (QoS), channel allocation, access control, and etc. Finally, security services of all communication layers for WAVE applications and messages is provide by IEEE P1609.2.

*2) LTE-V*

LTE-V [11] provides vehicular communications over a wide area network LTE interface (Uu) and a direct communications interface (PC-5). The Uu interface is a wireless interface between eNB (evolved Node B) and UEs (user equipment). The Uu interface normally operates at the licensed band of 2 GHz. The PC5 interface operating at ITS dedicated 5.9 GHz allows vehicles to communicate with other vehicles, UE-type RSUs, and pedestrians directly.

Even though LTE-V has been able to deal with high mobility in VANETs, it still has some limitations. For instance, the vehicles must always be synchronized with the cellular network all the time. Thus, the communications may be disrupted in some areas, such as tunnels. In addition, the communication in LTE-V normally experiences longer latency compared to DSRC/WAVE, due to the signaling overhead in the cellular network. Therefore, DSRC/WAVE has been selected as the main standard for vehicular communications in this paper.

## III. Ambulance-to-Traffic Light Controller Communications (A2T)

The proposed A2T aims to promote the information sharing between ambulances and traffic light controllers along rescue routes in advance, through V2I communications. As a result, the traffic light controllers can switch to a green traffic light to allow the approaching ambulances pass any intersections immediately and safely. Here, Traffic Light Rescheduling Distance (TLRD) is defined as a distance from an ambulance to any traffic light controllers. The traffic light controllers will change to a prioritized green traffic light scheduling, whenever the ambulance is in this TLRD distance. The prioritized green traffic light scheduling will alleviate the vehicle queues and let the ambulance pass through the intersections immediately and safely. The TLRD is generally embedded in every WSM along with other emergency information. WSMs are basically broadcasted by the ambulances periodically.

### *A. A2T Paradigm*

The paradigm of the A2T is illustrated in Figure 1:

- ***Ambulance*** acts as a source of information in the A2T system. The ambulance proactively keeps broadcasting the WSMs periodically. Each WSM contains emergency information, which includes a rescue route shown as the purple dot line in Figure 1. The WSM could be wirelessly broadcasted to the core network through any available wireless channels, such as wireless broadband, cellular, and satellite networks represented by the red dash arrows.
- ***Traffic light controller*** is a key party in the A2T system that receives information from the ambulance, either directly or via the core network. Such information allows the traffic light controllers to sense the ambulance in proximity and efficiently manage the traffic light at the intersections to enhance the rescue missions.

- ***Infrastructure unit*** serves as a bridge for the ambulance to interact with the core network. The WSMs will be rebroadcasted from the infrastructure unit to the core network shown as the blue arrows in Figure 1, of which the dash-dot and the dot arrows represent the wireless and the wired communications, respectively. The infrastructure unit in the proposed A2T could be cellular base stations, satellites, Roadside Units (RSU), and even the traffic light controllers themselves depending upon the currently available communication platforms on each ambulance.
- ***Core network*** provides interconnections of all traffic light controllers through reliable channels, such as fiber optic cables. All information will be forwarded from the core network to the traffic light controllers to always manage a proper traffic light scheduling. This communication is represented by the green solid arrows in Figure 1.

### *B. A2T Functional Framework*

There are some notations defined in this section as follows;

- Vector $\vec{S}$ denotes a speed direction of an ambulance.
- Node $E$ denotes an emergency vehicle, such as an ambulance, with its location.
- Node $T_i$ denotes a traffic light controller $i$ with its location.
- Thus, the vector $\vec{D}_i$ denotes a direction from the node $E$ to each node $T_i$.

The ambulance periodically broadcasts an emergency WSM. When an infrastructure, including traffic light controller $T_i$, receives the broadcasted WSM, it will start the following processes:

**Step 1:** The traffic light controller $T_i$ checks if it is in front or behind the ambulance.

- If the vectors $\vec{D}_i$ and $\vec{S}$ are in an opposite direction, the traffic light controller $T_i$ is now behind the ambulance. Thus, it will operate on a normal traffic light scheduling.
- In contrast, if the vectors $\vec{D}_i$ and $\vec{S}$ have a common direction, the traffic light $T_i$ is concluded to be front of the ambulance.

**Step 2:** Once a traffic light controller has received a WSM from the ambulance, it will rebroadcast the emergency WSM to all other traffic light controllers through the core network. Only the traffic light controllers along the rescue route will keep tracking the approaching ambulance.

**Step 3:** The traffic light controller checks if the distance from itself to the ambulance $|\vec{D}_i|$ is less than the TLRD value.

- If $|\vec{D}_i|$ is greater than the value of TLRD, the traffic light controller $T_i$ is out of the TLRD range. Thus, it will continue operating on the normal traffic light scheduling.
- If $|\vec{D}_i|$ is less than or equal to the TLRD value, the traffic light controller $T_i$ is within the TLRD range. Thus, it will start operating on the prioritized green traffic light scheduling.

TABLE II

Default configurations in the simulations

| **Parameters** | **Configured Values** |
|---|---|
| Maximum speed of non-emergency vehicles | 80 km/h |
| Maximum speed of ambulances | 120 km/h |
| Length of the main road | 2 km |
| Length of the crossing road | 1 km |
| Number of lanes of each direction | 2 lanes |
| Speed limitation of the high-speed lane | 80 km/h |
| Speed limitation of the low-speed lane | 50 km/h |
| Total number of non-emergency vehicles | 50-300 vehicles |
| Total number of ambulances | 1 vehicles |
| TLRD | 10-400 meters |
| WSM broadcast rate | 10 WSM/second |
| Number of Traffic Light Programs | 2 programs |
| Normal Traffic light cycle | 120 seconds |
| Standard | DRSC/WAVE |
| Transmission power | 20 mW |
| Bitrate | 6 Mbps |
| Sensitivity | -89 dBm |
| Thermal noise | -110 dBm |
| Simulation time | 1,500 seconds |
| Number of simulations | 100 times |

**Step 4:** The traffic light controller $T_i$ will continue operating on the prioritized green traffic light scheduling until the ambulance has passed the intersection. Then, the traffic light controller $T_i$ will switch back to the normal scheduling.

It is noticed that the larger value of TLRD allows the traffic light controllers to switch to a green light earlier. In case of a high traffic density, the traffic light controllers may need a longer time to properly clear a queue of non-emergency vehicles at the intersection. This, the larger TLRD value is recommended for a road with higher traffic density.

## IV. Simulation Scenarios and Configurations

The main simulator used in this paper is an open-source Veins [12], which is an integration of SUMO [13] and OMNet++ [14] simulators. To simulate a realistic intersection with a traffic light scenario, a use case in Thailand has been conducted. The Kluai Nam Thai junction between the Rama IV and Kluai Nam Thai roads in Bangkok is used as a sample scenario. Next to this intersection, there is Theptarin Hospital served as the final destination of the simulated rescue missions. The length of Rama IV road (the main rescue road) and Kluai Nam Thai road (the crossing road) are 2 km and 1 km, respectively. There is a traffic light module located in the middle of such intersection. Both roads consist of two lanes in each directions. Thus, there are 4 lanes in total for both directions. The speeds of 80 and 50 km/h are set as the speed limitations of the high-speed and the low-speed lanes, respectively. Such values are the real speed limitations of such road. However, in case of emergency, the ambulances can break these speed limitations.

According to a traditional case, only one ambulance will be randomly added into the simulation. To investigate an impact of the total number of non-emergency vehicles on each road, the number of vehicles is ranged from 50 to 300 vehicles to represent different traffic densities from 4 vehicles/km to 22 vehicles/km. Each vehicles will be assigned a random speed and time to enter the simulation. The maximum speed limitation of the ambulances is set at 120 km/h, while that of other general vehicles is 80 km/h. The transmission rate of WSM is set to 10 WSM/s according to the widely-implemented beacon rate in the literature. Each simulation takes 1,500 seconds and is repetitively conducted for 100 times with different seed values to guarantee the confidence of the simulation results. Other configurations used in this paper such as communication protocols as well as channel models are in accordance with the DSRC/WAVE standard.

To study an impact of TLRD value, the TLRD is varied from 10 to 400 meters to approximately cover one-hop communication range. In addition, as shown in section V, the value of TLRD larger than 400 meters does not make any benefits to ambulances. There are two traffic light programs called "Normal" and "Green".

- The normal traffic light program circularly operates on 10s yellow light, 50s green light, 10s yellow light, and 50s red light. Therefore, a cycle of the normal program is 120 seconds, which is the common cycle time used in Thailand. This normal traffic light program basically operates, when there is no approaching ambulance.
- The prioritized green program, in contrast, will be switched on, when the traffic light controllers are within the TLRD range. The traffic light controllers will return to the normal program, once the ambulances have passed the intersections. Table II summarizes all default configurations in the simulations.

## V. PERFORMANCE EVALUATION RESULTS

In this section, an Average Accumulative Waiting Time (AAWT) is defined as an accumulation of waiting time due to stops at all intersections along the travel route of each individual vehicle. The performance evaluation results of the A2T system in terms of AAWT are discussed as follows.

### A. *Simulation Cases*

There are two main simulation cases conducted in the paper:

- ***Standard Case****:* In this case, ambulances are equipped with only a standard siren device. There is no communications with the traffic light controllers. Thus, this standard case is used as a benchmark solution of the current rescue operations.
- ***A2T Case****:* A2T supports ambulance-to-traffic light controller communications. Through this communications, the traffic light controllers can gain information related to the rescue mission in advance. Therefore, the traffic light controllers can calculate an optimal scheduling to let the approaching ambulances pass the intersection immediately and safely.

### B. *Simulation Results and Analysis*

#### ***1) AAWT of Ambulances***

Figure 2 demonstrates the performance comparisons in terms of AAWT of the ambulances. The simulation covers different road densities of both previously-presented cases. The larger number of non-emergency vehicles makes the increase of AAWT of ambulances at the intersections in both standard and A2T cases. This is due to the fact that the larger number of non-emergency vehicles causes the longer vehicle queues at the intersections. All vehicles including the ambulances, as a result, will experience a longer AAWT at the intersections.

When A2T is implemented, a significant reduction of the AAWT of the ambulances is noticed. For instance, the AAWT of the ambulances is reduced by more than 50%, when A2T with 10-meter TLRD is implemented. The AAWT of the ambulances is further reduced, when the value of TLRD increases. Additionally, A2T with the value of TLRD greater than 100 meters can completely get rid of the AAWT of the ambulances (100% reduction). This means that the ambulances in this case do not have to stop at any intersections at all.

The reduction of AAWT can be explained as follows. Because the traffic light controllers can sense the proximity of ambulances in advance, the green light period will be switch on and the vehicle

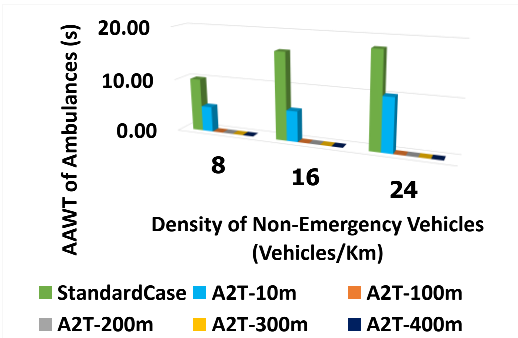


Fig. 2 Performance comparisons in terms of AAWT of ambulances in both cases

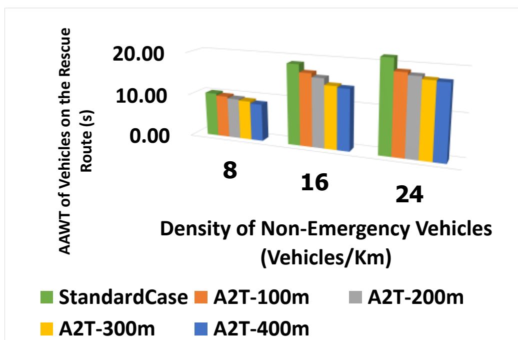


Fig. 3 Performance comparisons in terms of AAWT of non-emergency vehicles on the rescue route in both cases

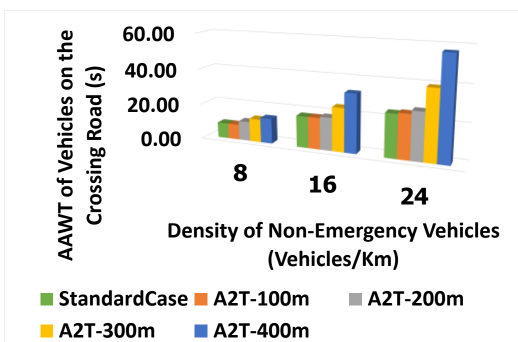


Fig. 4 Performance comparisons in terms of AAWT of non-emergency vehicles on the crossing road in both cases

queue at the intersections will be reduced. This contributes to a congestion-free motion of ambulances when they pass through the intersections. Therefore, the implementation of A2T helps to significantly reduce AAWT. However, in case the value of TLRD is less than 100 meters, ambulances still experience a small AAWT. This is because the TLRD is too short for switching to the green light, and this cannot completely remove the vehicles queue at the intersections. Thus, a number of ambulances get stuck into the vehicle queue at the intersections for a short period. In contrast, in case the value of TLRD is greater than 100 meters, the AAWTT is completely removed, since the TLRD is large enough to completely alleviate the vehicle queue in advance.

***2) AAWT of Non-Emergency Vehicles on the Rescue Road***

Figure 3 shows the performance comparisons in terms AAWT of non-emergency vehicles on the rescue road in both cases. It is noticed that the AAWT of non-emergency vehicles of the standard case is larger than that of the A2T case. For instance, the AAWT of the non-emergency vehicles on the rescue route is reduced by 13.10% in the A2T-100m case (with 300 vehicles).

This is because when A2T switches to the prioritized green scheduling to allow the ambulances go through the intersections immediately, other vehicles on the same route also are also benefited from this situation, by waiting at the intersection shorter. Thus, the AAWT is deduced.

***3) AAWT of Non-Emergency Vehicles on the Crossing Road***

Figure 4 illustrates the performance comparisons in terms of AAWT of non-emergency vehicles on the crossing road in both cases. The AAWT of non-emergency vehicles in the standard case is smaller than that of the A2T case. This is because in the A2T system, the traffic light controller switches to the prioritized green scheduling for the rescue road more often and stays green longer. Thus, vehicles on the crossing road will experience longer periods of the red traffic light frequently. Consequently, the AAWT of vehicles on the crossing road becomes lager than that of the standard case. However, this impact is quite small. For example, at the TLRD value of 100 meters with the total number of vehicles of 300 vehicles, the AAWT of the vehicles on the crossing road is only 2.48% higher than that of the standard case.

## VI. Discussions and Future Works

### *A. Number of Ambulances*

Apart from the traditional case, there could be a large incident involving a high number of ambulances. Even if it is very rare, this could be the case that two or more ambulances approaching an intersection at the same time. In this case, urgency levels could be embedded into the exchanged WSMs to show how critical the on-board patient inside each ambulance is. Thus, the traffic light will be rescheduled to allow the most urgent ambulance to pass through the intersection first. Therefore, this prioritization scheme could be further investigated in the future for A2T enhancement.

### *B. Ambulance-to-Vehicle Communications*

***1) Straight Route Clearing***

Apart from a major delay at intersections, ambulances could also be delayed by other non-emergency vehicles along the rescue roads. For instance, the other vehicles may not be capable of clearing the routes for the ambulances in time due to high road traffic density. Even this delay is minor compared to the delay occurred due to the red traffic light at intersections, it is still worth to reduce this delay. One-second faster could save a lot more lives. Thus, a study of Ambulance-to-Vehicle communications (A2V) for rescue route clearing must be investigated along with an integration of our proposed A2T.

***2) Road Merging***

In addition to the path clearing mechanism, A2V could be further investigated to deal with road merging scenario without traffic light. Since the risk of merging roads sometimes could be higher and more concerned compared to the case of intersections with traffic lights. The A2V could be utilized to cooperate with vehicles on the main road to be aware of and clear the path for the approaching ambulances on the merging road. Consequently, an integrated system of A2T and A2V could lead to a uniquely complete solution or a novel standard for the future enhancement of the rescue missions.

### *C. Security*

***1) Authentication***

Since A2T is very sensitive and critical involving people's lives, impersonating could lead to a serious loss. For example, a malicious vehicle may impersonate an ambulance to go through any intersections immediately. This could cause a longer delay for other vehicles including a real ambulance. Therefore, a distributed authentication mechanism should be embedded into the system to prove a real identity of each ambulance.

***2) Non-Repudiation***

Moreover, a vehicle, which sent any WSMs, must not be able to deny its responsibility of the WSM sending. This helps an investigator in case of a law enforcement investigation to track a malicious person. For example, a person may intentionally send out any fraud WSMs to mislead other vehicles and traffic light controllers. As a result, a non-repudiation mechanism, such as a digital signature, should be designed to prevent such issue.

***3) WSM Integrity***

Message integrity is also another concern related to security. Emergency information stored in WSMs is considered very sensitive and critical. Thus, any emergency WSMs must not be altered during any transmissions, i.e. both first-time broadcasting and rebroadcasting. Modifications of message content may benefit a group of malicious vehicles, but could involve a higher loss of people lives. Thus, message integrity mechanisms, such as check sum, hash function, or even a recently emerging BlockChain, could be further investigated to be implemented on top of the proposed A2T to guarantee originality of all broadcasted WSMs.

## VII. Conclusion

The V2I has been proposed in this paper to allow ambulance-to-traffic light controller communications, namely A2T. Based on the application of A2T in a use case of Thailand, ambulances gain benefits for faster and safer movement by getting rid of stops at the intersections. Our performance evaluation shows that A2T remarkably accomplishes 100% stop removal for the ambulances at the intersection. Other vehicles on the rescue road also get a benefit from A2T by experiencing 13.10% improvement in terms of AAWT. Other vehicles on the crossing road, in contrast, experience only 2.48% increase of AAWT. Therefore, A2T is positioned as promising approach to enhance rescue operations in the near future.

## ACKNOWLEDGMENT

The authors would like to acknowledge the support from Newton Fund (PDG61W0010), British Council, and Thailand Research Fund.

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