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Dynamic Traffic Light System to Reduce The Waiting Time of Emergency Vehicles at Intersections within IoT Environment

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Abstract

Traditional traffic light system, which works based on fixed cycle can be a main reason for traffic jam, due to lack of adaptation to road conditions. Traffic jam has a bad impact on drivers and road users due to the time delay it causes for road users to reach their destinations. This delay can cause a life threat in case of emergency vehicles, such as ambulance vehicles and police cars. One key solution to solve traffic jam on intersections is the dynamic traffic lights, where traffic light operation adapts based on the intersection traffic conditions. Since few of researches projects in the literature interested in solving traffic jam problem for emergency vehicles, the contribution of this paper is to introduces a novel approach to operate traffic light system. The new approach consists of two algorithms which are pure operation mode and hybrid operation mode. These operation modes aim to reduce the waiting time of emergency vehicles on traffic intersections. They assume that there is a smart infrastructure system uses Internet of Things (IoT) that can detect emergency vehicles arrival to an intersection. The smart infrastructure system switches traffic light operation from fixed cycle mode to dynamic mode. The dynamic mode manages traffic lights at intersections to reduce the waiting time of emergency vehicles. The paper presents a simulation of the proposed algorithms, highlights their advantages. In order to evaluate the efficiency of the new technique, we compared our approach with Wen algorithm in the literature and the Traditional traffic light system. Our evaluation study indicated that the proposed algorithms outperformed Wen technique and the Traditional system under different traffic scenarios.

Keywords: Dynamic traffic light, Emergency viechle, Expert system, IoT, Waiting time, Intersections.

1 Introduction

Emergency Vehicles (EV) such as ambulances, fire brigade and police cars provide huge services to communities by saving lives and preventing theft and crimes. In 2016, around 146,000 died in India because of road accidents, 30% of deaths are caused by delayed ambulance [10]. There is a real need to find solutions that allow EV to reach the desired destinations as fast as possible.

Traffic lights are considered as the primary elements to control the traffic in urban areas. Inefficient traffic light operation can lead to traffic congestions and increases the waiting time of cars at intersections. Most of today's traffic lights work based on fixed cycle protocol and do not consider the traffic conditions. IoT which enables connected vehicles and smart city technology, allows more input information to be collected from roads to control traffic lights. For example, the number of vehicles at intersections, vehicle movement direction and vehicle's category can be used as inputs to manage a dynamic traffic light system.

Using of IoT in road infrastructure and smart cities bcame a trend because of the chances it provides to improve road safety and road efficiency. Frank et al. proposed smart traffic light system using computer vision algorithms and IoT to measure traffic density [9]. Rathore et al. have established an IoT-based Smart City by using Big Data analytics while harvesting real-time data from the city [21].

As there are few of research works concerned in solving traffic jam issue for Emergency vehicles. The contribution of this paper is to present two solutions for dynamic traffic light system. The goal of the proposed systems is to prioritize Emergency vehicles and reduce their waiting time at intersections, so emergency vehicles can arrive their destinations in shorter times compared to times taken using the fixed period traffic light systems.

The proposed system uses IoT to transmit the data between the traffic light system and the infrastructure, where AI algorithms is used to detect emergency vehicle's location. Based on the emergency vehicle's location and the current state of the traffic light, our dynamic model for traffic light system will adapt to reduce the waiting time for the emergency vehicles. We compared our approach with Wen, W. approach [27], and the fixed cycle mode.The results obtained by our approach under different scenarios outperformed those obtained by Wen's approach [27] and the Traditional traffic light system .

This paper is following the scientific rules for how to write a good paper, which is stated in [**?**], and it is organized as follows. Section 2 presents related work in the area of dynamic traffic light management. Section 3 introduces the proposed algorithms. Section 4 presents the simulation results and the comparison with Wen's approach [27]. The conclusion is presented in Section 5.

2 Related Work

Many researches have been conducted to come up with solutions for dynamic and smart traffic light systems.

Fleck et al. proposed adaptive traffic light system based on vehicles back logs [8]. They studied a quasi-dynamic policy depending on partial state information defined by detecting whether vehicle backlogs are above or below certain thresholds. The policy is parameterized by green and red cycle lengths as well as the road content thresholds.

A novel approach for dynamic traffic lights management based on wireless sensor networks and multiple fuzzy logic controllers is proposed in [5], each fuzzy controller addresses vehicles turning movements and dynamically manages both the phase and the green time of traffic lights.

Sumi et al. proposed dynamic and automatic traffic light control expert system for solving the road congestion problem. In the proposed solution, emergency vehicles are scheduled to prioritize them for a smooth passage through the traffics based on incident type [24].

Al-khateeb et al [1]. proposed a dynamic traffic light system using radio frequency identification (FRID) [1], This RFID technique deals with a multi-vehicle, multilane, multi road junction area. It provides an efficient time management scheme, in which a dynamic time schedule is worked out in real time for the passage of each traffic column.

Collotta et al. proposed dynamic traffic light system based on information gathered through a wireless sensor network. dynamically processes green times in a traffic light of an isolated intersection to reduce the red-light time [4].

Many adaptive traffic light systems are proposed to prioritize emergency vehicles and reduce their waiting time at traffic lights. Goel et al. proposed an adaptive traffic intersection system based on Wireless Sensor Network where the traffic light of one intersection can communicate with the traffic light of the next neighboring intersections and traffic clearance will be prioritized for special vehicles with the help of sensors [12].

Viriyasitavat et al. proposed an approach that uses a different set of local rules at intersections, one can support priority management of emergency vehicles in a self-organized manner [26]. The proposed system suggests using Virtual Traffic Light-Priority Intersection Control (VTL-PIC) protocol that can detect the presence of an emergency vehicle and assign priority to the emergency vehicle at an intersection.

Iyyappan et al. proposed automatic accident detection and ambulance rescue with intelligent traffic light system [14]. The idea behind this system is to implement Intelligent Traffic Light System (ITLS) to control mechanically the traffic lights in the path of the ambulance. The ambulance is controlled by the control unit which furnishes adequate route to the ambulance and controls the traffic light according to the ambulance location and thus reaching the hospital safely. The controller identifies the location of the accident spot through the sensor systems in the vehicle which determined the accident and thus the controller walks through the ambulance to the spot.

Another approaches for Traffic Management for Emergency Vehicle Priority was designed based on computer vision as proposed in [18]. This paper presents an approach to schedule emergency vehicles in traffic. The approach combines the measurement of the distance between the emergency vehicle and an intersection using visual sensing methods, vehicle counting and time sensitive alert transmission within the sensor network. The distance between the emergency vehicle and the intersection is calculated for comparison using Euclidean distance, Manhattan distance and Canberra distance techniques.

Ghazal et al., [11] proposed an approach to handle high range of cars with different classes in traffic signal. A wide variety of priorities could be given to different classes of vehicles. Emergency vehicles like ambulance and fire vans, would have the first priority. Next priority is given to VIP's over the everyday vehicles. Priority can also be given depending on automobile density in a single aspect of avenue in traffic junction. The street which had better automobile number might get maximum precedence.

Bhandari et al., [29] provided a new technique to Priority-Mobility Aware Clustering Routing method for high submission of packets by giving fair weight for every packet of node. in order to set the scheduling plan in an automatic way, strengthening learning approach is incorporated. The mongrel technique for priority and self-learning generated better employment of power. The empirical result indicated a comparisons between slotted sense multiple access protocol, AODV, MEMAC and P-MACRON protocol, where the proposed technique produced better outcomes ,according to packet size, simulation time and interval.

Dangi et al. proposed an efficient and intelligent traffic control system based on the density of the traffic along with the safe pedestrian crossing. This approach is based on using a video surveillance camera and some image and video processing techniques to detect traffic congestion and make decisions [7].Other video surveillance systems are also developed and proposed by other researchers [3][6][13][22] for intelligent traffic control system.

Ata et al. provided a mechanism to predict the traffic congestion with the help of Artificial Neural Networks (ANN) which shall control or minimize the blockage and result in the smoothening of road traffic. In particular, they proposed modeling smart road traffic congestion control using artificial back propagation neural networks (MSR2C-ABPNN) for road traffic increase transparency, availability and efficiency in services offered to the citizens. This system aims to provide intelligent transportation decisions, where the neural network is the plausible way to find traffic situations and make the decisions accordingly [2].

Memiş et al. mentioned in their paper that the goal of their study was to define and grade the risk factors of road transportation, which are critical for efficient and economic supply chain arrangement. On the other hand, the authors utilized fuzzy PIPRECIA as a multi-criteria rating technique, in order to prioritize the risk factors [17].

Stojčić. stated that his paper concerned in researching the implementation of the ANFIS (Adaptive Neuro Fuzzy Inference System) model in transport and traffic by a revise of pertinent papers. ANFIS is considered as an element of artificial intelligence. It is vastly utilized within intelligent transport systems. The authors mentioned in their research that all gathered papers were partitioned into 7 sub-areas. The analysis of the suggested models was conducted for each sub-area with a tabular preview of the input and output variables. They found that the guidance and management of vehicles form a sub-area with the largest percentage in the total number of tested papers, while security implementations were in the second place [23].

Neural networks were also used by other researchers in the development of automatic traffic control systems [22][20][28]. Evolutionary algorithms and fuzzy logic were also used by many researchers [25][15][19][16]. In [27], Wen, W. proposed a dynamic and automatic traffic light control expert system for solving the road congestion problem. They leveraged the interarrival time, interdeparture time and the number of leaving cars to design traffic light operation protocol. The simulation results showed a significant drop in the waiting time at traffic lights. Fig. 1 shows the framework for the dynamic traffic light system using IoT proposed in [27].

This paper proposes two algorithms for dynamic traffic light system. The proposed algorithms aim to prioritize mergency vehicles and reduce their waiting time at intersections. Additionally, we used Wen's approach [27], which is a very popular approach and its results showed a significant improvement in the waiting time, as a reference model for our proposed algorithms, where we compared the results obtained by our algorithms with those obtained by Wen's approach.

3 Proposed Dynamic Traffic Light System

This section explains the two proposed approaches for dynamic traffic light operation. The algorithms are explained in detail with their flow charts. To be able to implement the dynamic traffic light system, IoT is used to establish a communication between vehicles and infrastructure, this communication is known as Vehicle to Infrastructure (V2I). Through V2I, the infrastructure knows how many vehicles at an intersection, and it detects the arrival of EV. The infrastructure can then control the traffic light operation mode based on the provided information about an intersection. Fig. 2 shows

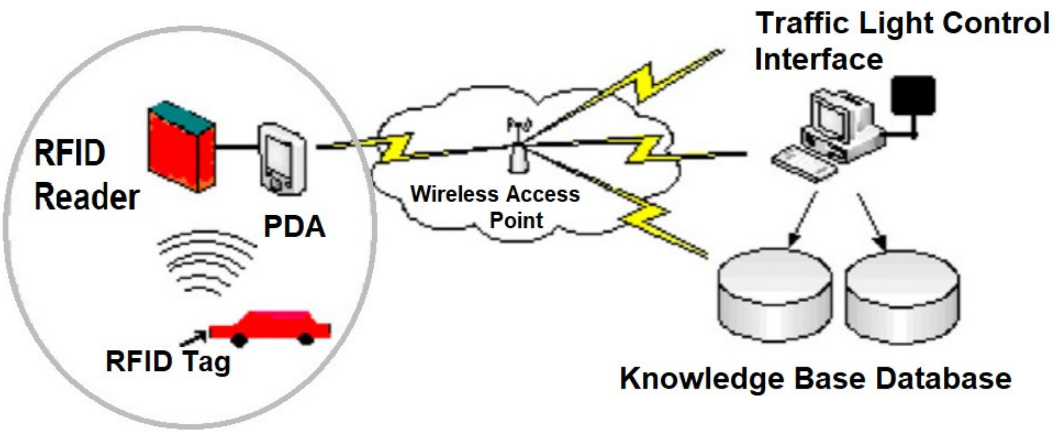

Figure 1: A framework for dynamic and automatic traffic light control expert systems using IoT (Wen [27])

a diagram for road intersection with IoT that allows V2I communication to detect road conditions and control the traffic light. The numbering of traffic lights shown in Fig. 2 will be used during the algorithm's explanation. EV always arrives to traffic light 1, and the rest of the traffic lights are incrementally numbered clockwise.

In the proposed approaches, there are many input parameters that controls the operation of the algorithms. Below are the definitions and the acronyms for the algorithms' parameters:

WT_i: Initial waiting time for the Emergency Vehicle at an intersection.
WT_f: Total waiting time for the Emergency Vehicle at an intersection.
S: Traffic light situation when Emergency Vehicle arrives (red light or green light).
Ri: Initial number of vehicles waiting at an intersection in front of the Emergency Vehicle when it arrives.
Rf: Number of vehicles that still exist in front of the Emergency Vehicle after some vehicles pass the intersection.
T_i: Average waiting time needed by R_i vehicles to pass the intersection.
T_f: Average waiting time needed by Rf vehicles to pass the intersection.
T_R: Time of the Red Light
T_G: Time of the Green Light
The goal of the proposed models are to reduce Total waiting time for the Emergency Vehicle at an intersection (WT_f).

3.1 Pure Operation Mode

Suppose that an EV reaches Traffic Light 1 at an intersection (see Fig. 1), in this case it will follow one of the following scenarios:

1. The EV passes the intersection after vehicles in front of it
   - If the EV is detected and Traffic Light 1 is green.
   - If the EV is detected and its Traffic Light (1) is red, and another traffic light within the same intersection (The current active Traffic light (2, 3, or 4)) is green, switch it to red and switch Traffic Light (1) to green.
2. The EV will wait a time equal to (3*TR+TG)*(# of Times Traffic Light 1 changed its status before the EV passes), then passes the intersection after the vehicles in front of it
   - If the EV isn't detected, Traffic Light 1 is green, but the green light time is not enough to allow all the vehicles ahead of the EV to pass.

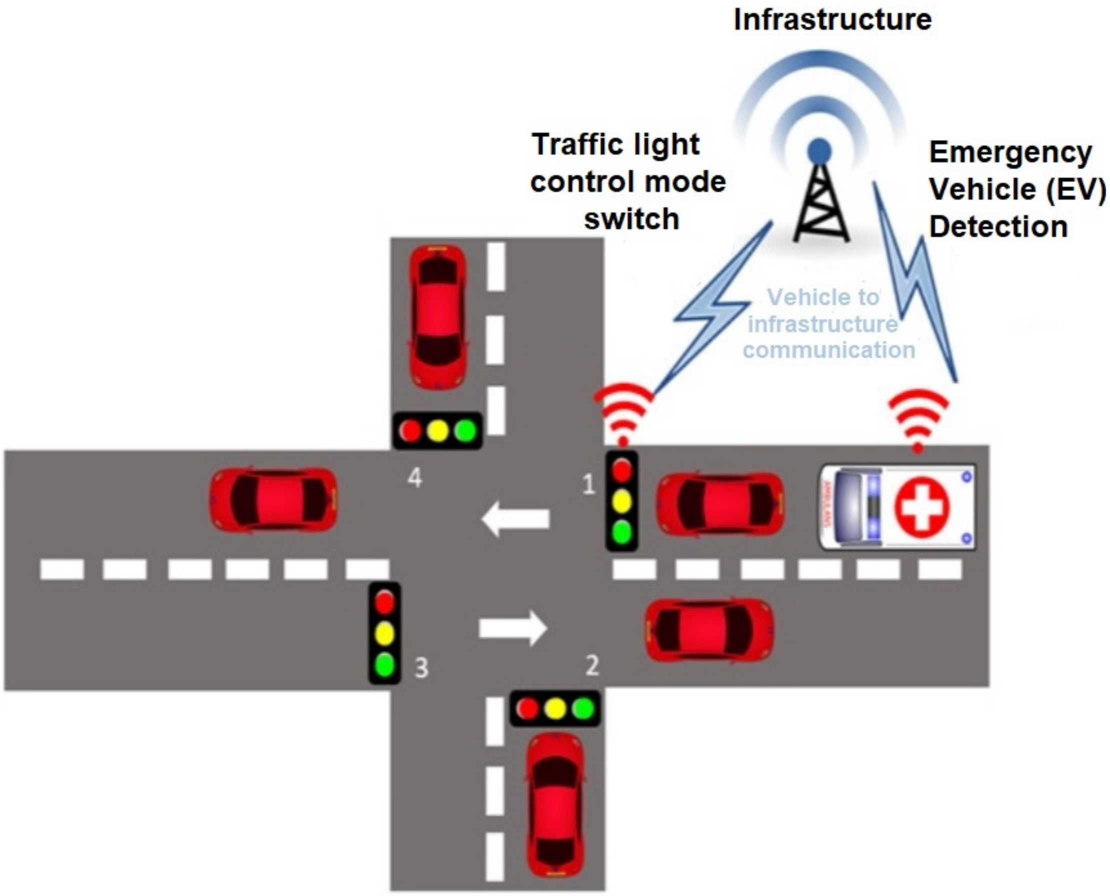

Figure 2: Road intersection with IOT that allows V2I communication to detect EV and control traffic lights operation mode

3. The EV will wait a time within the interval [1 - TG] until Traffic Light 1 becomes green, then passes the intersection after vehicles in front of it
   - If the EV isn't detected and Traffic Light 2 is green.
4. The EV will wait a time within the interval [(TR+1) - (TR+TG)] until Traffic Light 1 becomes green, then passes the intersection after vehicles in front of it
   - If the EV isn't detected and Traffic Light 3 is green.
5. The EV will wait a time within the interval [(TR*2+1) - (TR*2+TG)] until Traffic Light 1 becomes green, then passes the intersection after vehicles in front of it
   - If the EV isn't detected and Traffic Light 4 is green.

Fig. 3 shows the flowchart of the pure operation mode of traffic lights at an intersection.

3.2 Hyprid Operation Mode

Suppose that an EV reaches Traffic Light 1 at an intersection, in this case it will follow one of the following scenarios:

1. The EV passes the intersection after vehicles in front of it
   - If the EV is detected and Traffic Light 1 is green.
   - If the EV is detected and Traffic Light 1 is red, after the active traffic light is changed to red, and Traffic Light 1 becomes green.

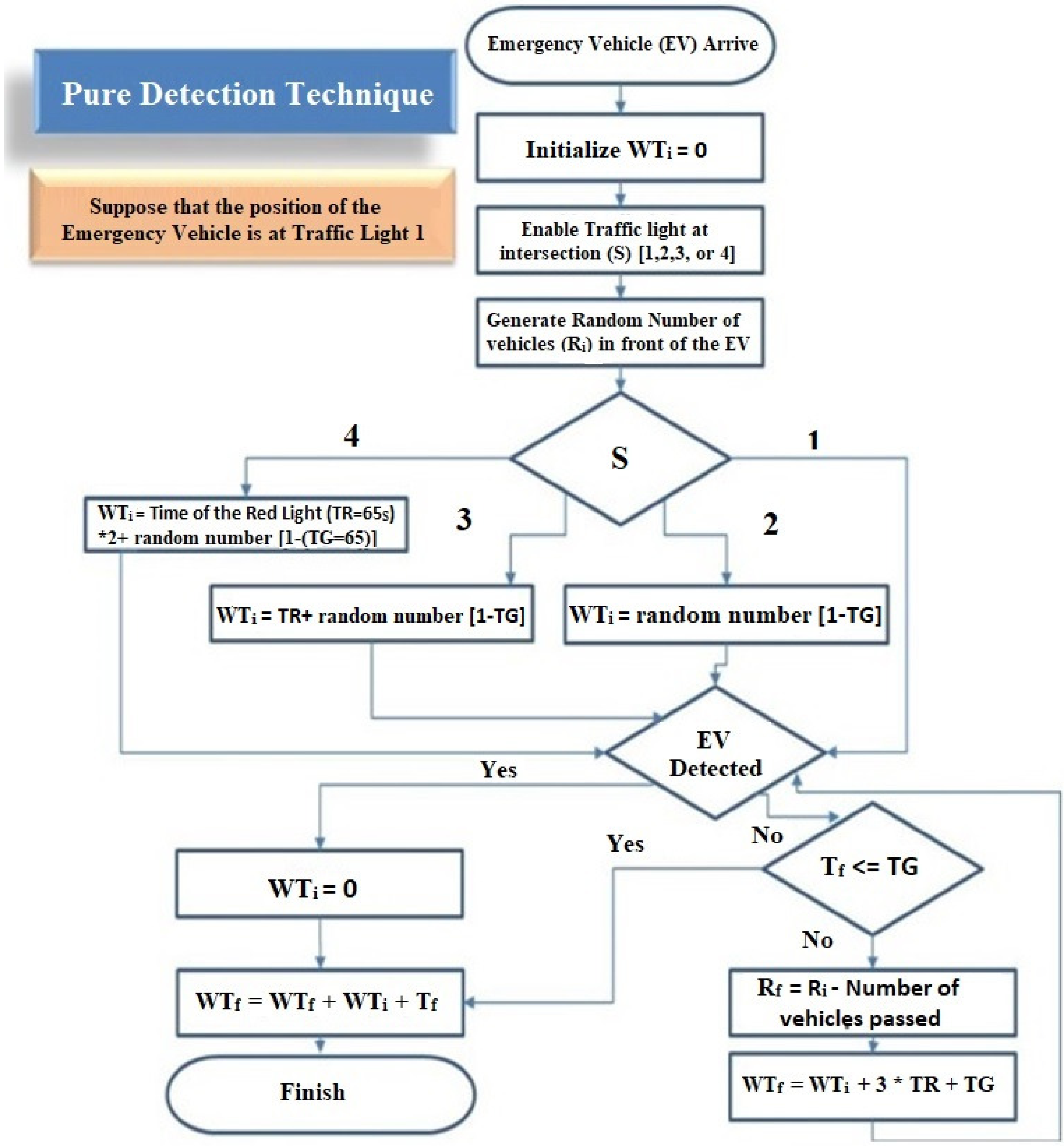

Figure 3: Flow chart of the system behavior when applying the Pure operation mode

2. The EV will wait a time equal to (TR+TG)*(# of Times Traffic Light 1 changed its status before the EV passes), then passes the intersection after the vehicles in front of it
   - If the EV isn't detected, Traffic Light 1 is green, but the green light time is not enough to allow all the vehicles ahead of the EV to pass.
3. The EV will wait a time equal to (TR) until Traffic Light 1 becomes green, then passes the intersection after vehicles in front of it
   - If the EV isn't detected and Traffic Light 2, or 3, or 4 is green.

Fig. 4 Shows the flow chart of the hybrid operation mode algorithm

4 Simulation Results

The simulator shows the behavior of 4 different techniques. During our study we considered low, medium, and heavy traffic scenarios on different paths length.

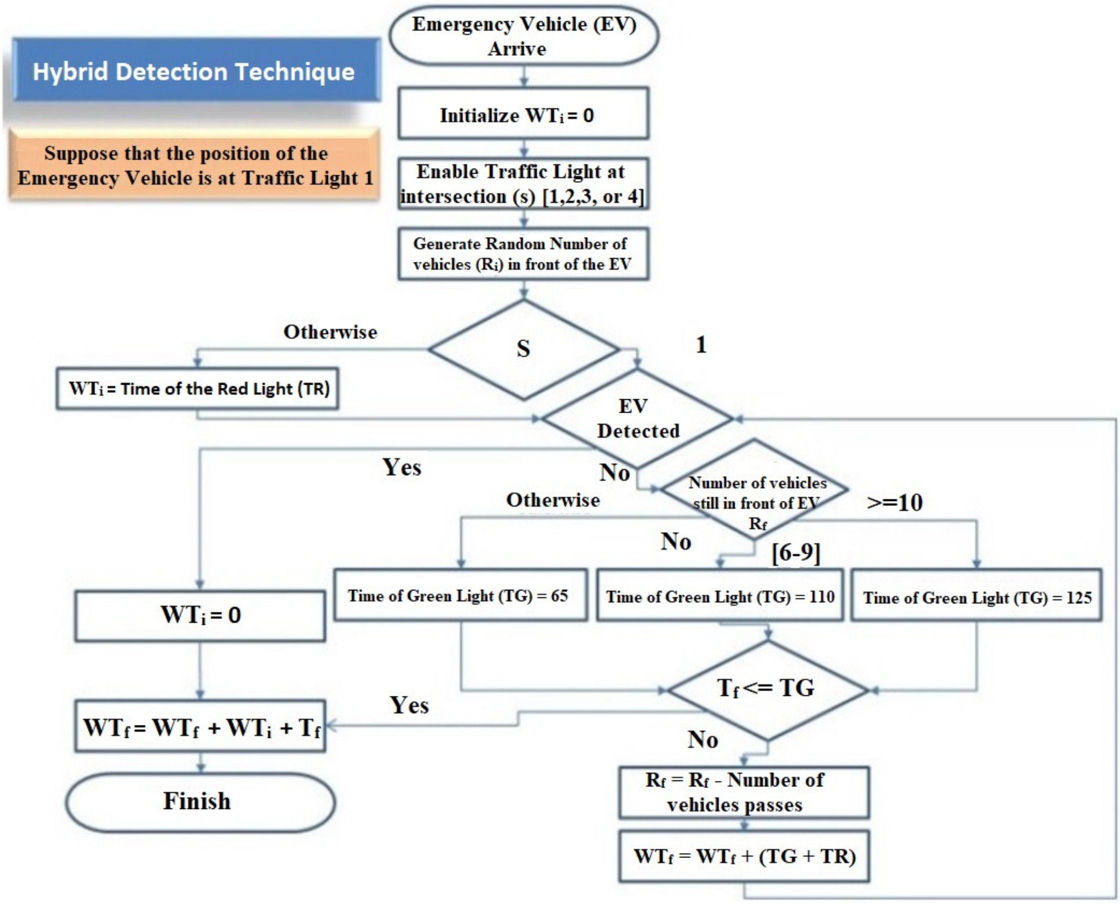

Figure 4: Flow chart of the system behavior when applying the Hybrid operation mode

However, the simulator operated on paths with one, two, three, four, and five intersections before the destination is reached. But its responses are the same when the vehicles are passing paths with one intersection or two intersections; therefore, we concentrated on the statistics of paths with two intersections. Also, the simulator's reactions are the similar when the vehicles are passing paths with three, four, or five intersections; For this reason, we concentrated on the statistics of paths with four intersections.

Figures 5 and 6 show the difference between the average Waiting Time (WT) of the vehicles at paths with two and four intersections, where it is noticeable that the WT of paths with four intersections are more affected by the Hybrid Detection Technique.

It is clear in Fig. 5, that the Pure Detection Technique is better than the others including the hybrid one in minimizing the WT of the vehicles at different distances from the traffic light's sensor when the traffic density is low ([10-30] vehicles). While in Fig. 5, we notice that the Hybrid Technique is the best solution in most cases when the traffic density is low.

Figures 7, 8, 9 and 10 demonstrate the effects of the four techniques on the WT when traffic densities are medium ([30-50] vehicles) or heavy ([50-80] vehicles). These figures support the results mentioned before in Figures 5, and 6.

We calculated the average waiting time of the four methods when traffic is low, medium and heavy. These outcomes are indicated in Table 1, 2 and 3 respectively.

We notice in Table 1 that when the traffic is low and the number of intersections before the destination is two, Pure Detection Technique is 29% better than Hybrid Detection, 43.1% better than Wen's-Best Case, and 17.5% better than without detection. whereas when the traffic is low and the

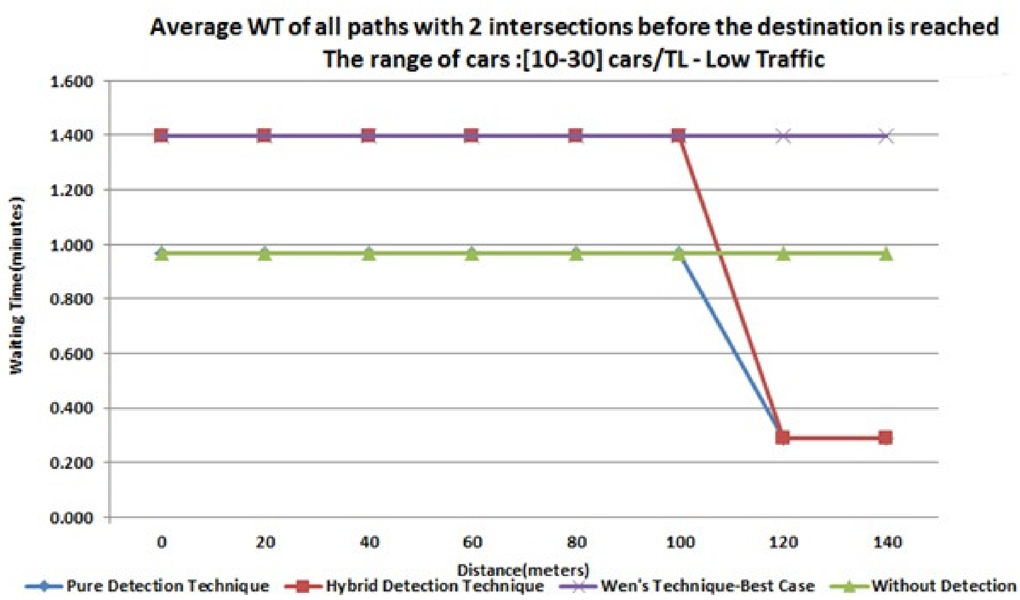

Figure 5: Average Waiting Time (WT) of the vehicles at low traffic paths with two intersections before the destination is reached.

Table 1: Average waiting time of vehicles when traffic is Low

Approach	*Two intersections*	*Four intersections*
	Average waiting time (minutes)	*Average waiting time (minutes)*
Pure system	0.797	3.169
Hybrid system	1.121	2.563
Wen's- best case	1.399	3.796
Traditional system	0.966	5.179

number of intersections before the destination is four, Hybrid Detection Technique is 19% better than Pure Detection, 32.5% better than Wen's-Best Case, and 50.5% better than without detection.

Table 2: Average waiting time of vehicles when traffic is Medium

Approach	*Two intersections*	*Four intersections*
	Average waiting time (minutes)	*Average waiting time (minutes)*
Pure system	0.797	3.169
Hybrid system	1.121	2.563
Wen's- best case	1.399	3.796
Traditional system	0.966	5.179

Table 2 shows that when the traffic is medium and the number of intersections before the destination is two, Pure Detection Technique is 24.8% better than Hybrid Detection, 33.3% better than Wen's-Best Case, and 9.4% better than without detection. whereas when the traffic is low and the number of intersections before the destination is four, Hybrid Detection Technique is 20% better than Pure Detection, 19.2% better than Wen's-Best Case, and 39% better than without detection.

As we notice in Table 3, the outcomes when the traffic density is heavy are the same to those of low and medium results, but with little decrease in the percentages.

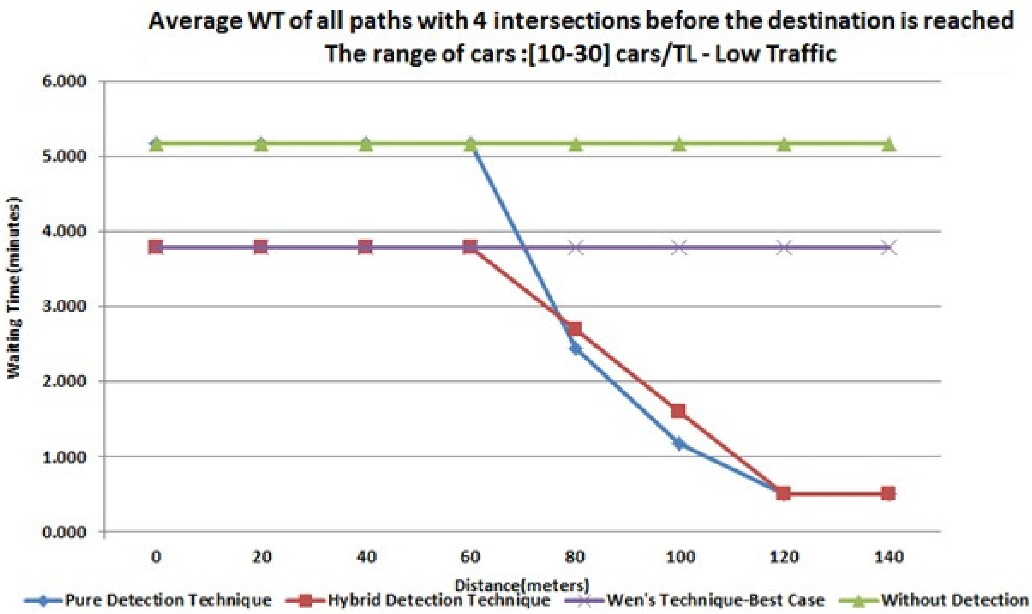

Figure 6: Average Waiting Time (WT) of the vehicles at low traffic paths with four intersections before the destination is reached.

Table 3: Average waiting time of vehicles when traffic is Heavy

Approach	*Two intersections*	*Four intersections*
	Average waiting time (minutes)	*Average waiting time (minutes)*
Pure system	1.081	4.376
Hybrid system	1.348	3.621
Wen's- best case	1.771	4.743
Traditional system	1.338	6.126

5 Conclusion

This paper proposes two techniques to operate traffic lights, in order to minimize the waiting time of emergency vehicles on traffic intersections, which occures by using the Traditional traffic light system. These techniques are pure operation mode and hybrid operation mode. The proposed models suppose that there is a smart infrastructure system utilize Internet of Things (IOT), which can discover emergency vehicles incoming to an intersection. Then, the smart infrastructure system moves from the Traditional traffic light mode to dynamic mode, which will manage the traffic lights system. To evaluate the efficiency of these algorithms, We calculated their average waiting time, and compared it with Wen algorithm and the fixed cycle mode when traffic is low, medium and heavy. The results are shown in table I,2 and 3 respectively. They show that when the traffic is low and the number of intersections before the destination is two, Pure Detection Technique is 29% better than Hybrid Detection, 43.1% better than Wen's-Best Case, and 17.5% better than without detection. While when the traffic is low and the number of intersections before the destination is four, Hybrid Detection Technique is 19% better than Pure Detection, 32.5% better than Wen's-Best Case, and 50.5% better than without detection.

In addition, we noticed that when the traffic is medium and the number of intersections before the destination is two, Pure Detection Technique is 24.8% better than Hybrid Detection, 33.3% better than Wen's-Best Case, and 9.4% better than without detection. While when the traffic is low and the number of intersections before the destination is four, Hybrid Detection Technique is 20% better than Pure Detection, 19.2% better than Wen's-Best Case, and 39% better than without detection. Furthermore, the results of heavy density traffic where similar to those of low and medium results,

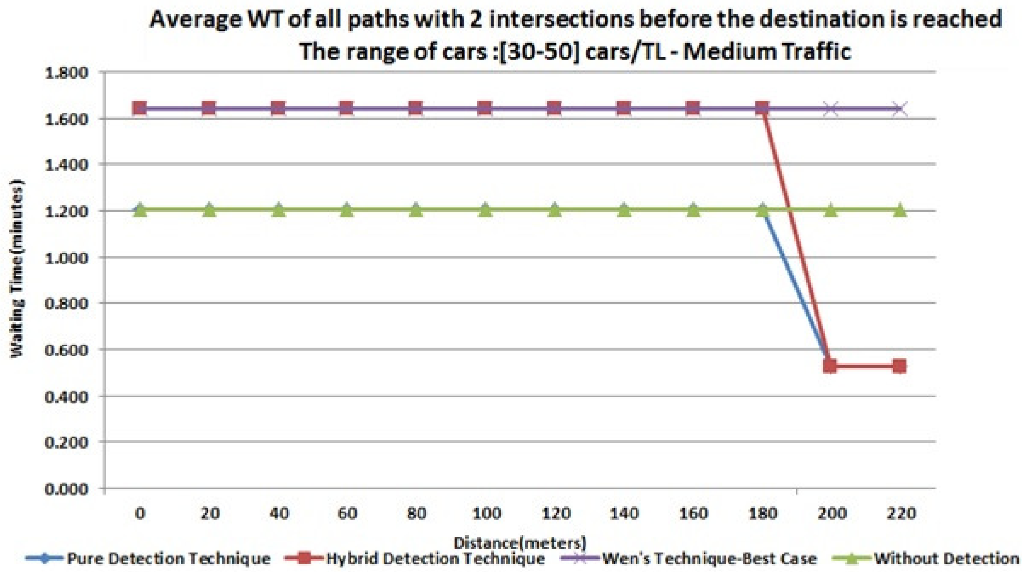

Figure 7: Average Waiting Time (WT) of the vehicles at medium traffic paths with two intersections before the destination is reached.

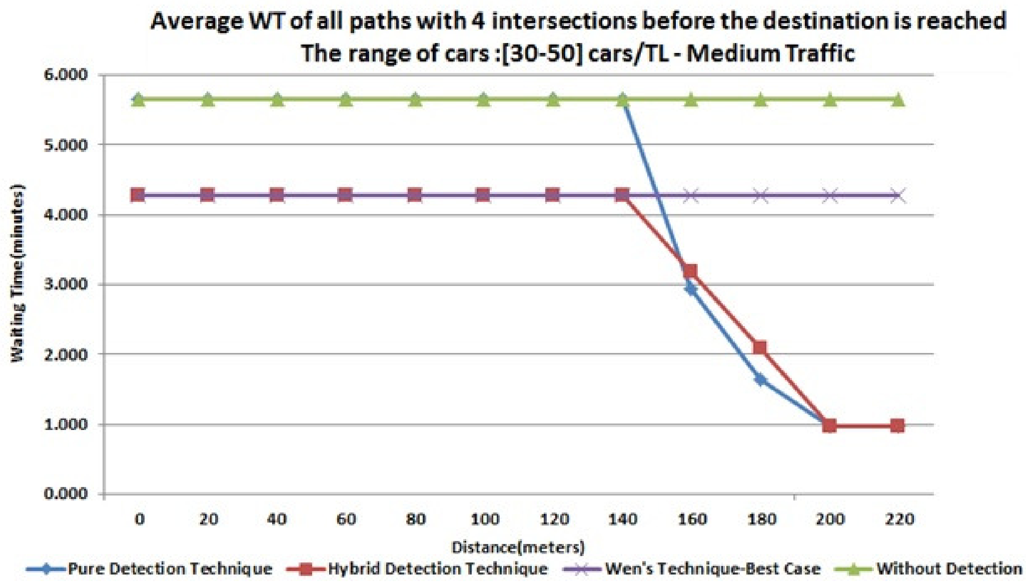

Figure 8: Average Waiting Time (WT) of the vehicles at medium traffic paths with four intersections before the destination is reached.

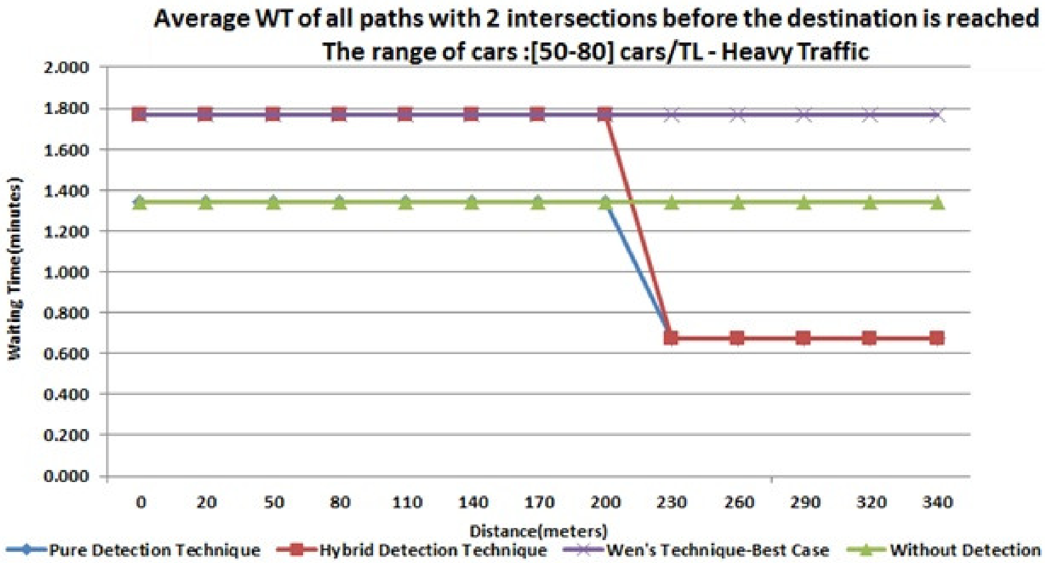

Figure 9: Average Waiting Time (WT) of the vehicles at heavy traffic paths with two intersections before the destination is reached.

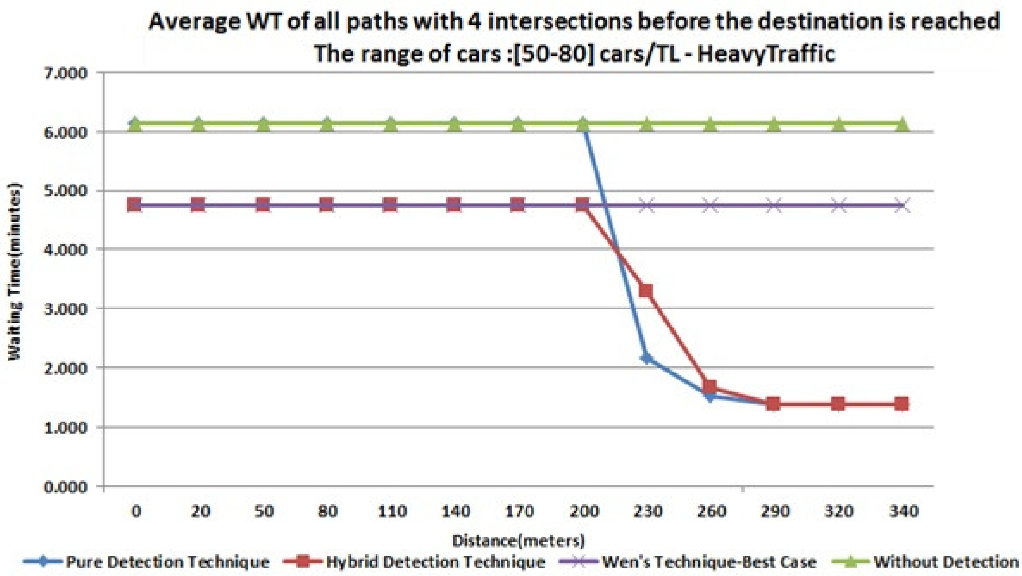

Figure 10: Average Waiting Time (WT) of the vehicles at heavy traffic paths with four intersections before the destination is reached.

but with a slight decrease in the percentages.

The reason behind the simulator's different reactions in the cases of two intersections paths and four intersections paths is because the Hybrid Detection Technique is more efficient in reducing the waiting time than the Pure Detection Technique only if the number of intersections is three or more. Such that the additional time given to the green light of the traffic light in the Hybrid Detection Technique, generates a higher initial waiting time if the Emergency vehicle didn't pass the intersection from the first turn, but this effect decreases after the second intersection. As a result, a noticeable improvement is produced by the Hybrid Detection Technique as the path consists of more intersections, while the Pure Detection Technique is preferred when paths include one or two intersections.

Actually, we have some limitations for our research as the smart infrastructure is not supported in all countries. On the other hand, if several emergency vehicles reached at the same time how we would set priorities and organise between them. That will be addressed in future works.

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