9-1-2015

ENHANCING TRAFFIC FLOW USING VEHICLE DASHBOARD TRAFFIC LIGHTS WITH V2I NETWORKS

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THESIS

Submitted in Partial Fulfillment of the
Requirement for Degree of

Master of Science
Computer Engineering

University of New Mexico
Albuquerque, New Mexico

July 2015

DEDICATION

To my biggest idol in this life, my father, may he rest in peace.

To my great mother who has been my greatest support and influence throughout my life.

To my family who have been always there whenever I need them.

To my friends in the US and in Iraq – my home country –, who encouraged me and continue encourage me to succeed in my studies and life projects

To Fulbright who gave me the opportunity to pursue my studies in the US through their support.

Enhancing Traffic Flow using Vehicle Dashboard Traffic Lights with V2I Networks

By

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Abstract

The increasing number of vehicles on streets nowadays makes it hard to manage traffic flow on the streets, especially in regards to intersection management. Research studies have been conducted to replace the Pre-timed traffic lights at the intersections with adaptive traffic lights control systems that base their timings on the traffic flow. Other studies have suggested the use of autonomous vehicles and traffic systems. This paper proposes the use of dashboard traffic lights, an intelligent adaptive traffic light system based on client-server communication that will send each vehicle a decision message based on the speed and direction of the vehicle. The system can be used for both human controlled vehicles and autonomous vehicles; for autonomous vehicles, the decision will be received by the vehicle system and the system will decide how to pass the intersection based on the received data. This study focuses on vehicles that are controlled by humans, and each vehicle will have its own traffic light module placed on the dashboard. A V2I (Vehicle-to-Intersection) network scheme will be used to send request messages from moving vehicles to the intersection control station that will then analyze the request message and send back a decision message based on the intersection status. This method is predicted to be more proficient than existing methods because there should be a reduced average waiting time with less vehicles stopping at the intersection to pass and more intersection throughput.

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1. Introduction

Road traffic networks play a vital role in peoples' daily activities. The expansion of cities and the emergence of new cities has led to road expansions in order to connect city sides to the city center and with each other and to interconnect different cities. Given the world's increasing population size, particularly in large cities, people have started using vehicles as a major mode of transportation between their homes, work place and other frequented locations. The increasing need for vehicle use has led to a massive increase in the number of vehicles on the road resulting in the increase of greenhouse gases emission, road congestion, time spent on route to the given destination – double the normal time at some points –, and fuel consumption and cost.

One of the critical issues that road network designers face is the coordination of vehicles flowing in perpendicular directions. The point at which these two perpendicular roads meet is called an intersection. Regulations have been made to control vehicles flow through intersections, and the oldest method was the use of Stop Signs, which was then replaced by traffic light signals. Traffic lights operates by displaying a red light when vehicles flowing in the direction of the traffic light signal are required to stop and a green light when they are allowed to move.

The world's first electric traffic signal was designed by James Hoge and placed on the corner of Euclid Avenue and East 105th Street in Cleveland, Ohio, on August 5th-1914 [1]. Police officer William Potts Created the first four-way, three-color, traffic light in Detroit, Michigan in 1920 [2]. The invention of traffic light signals made it easier to control vehicle movement through intersections.

Traffic light signals changed significantly throughout history to meet the needs of road traffic networks. Timers were added to some traffic light signals to indicate the duration of time spent as a red or green light. Currently, traffic light signals are typically defined based on predefined rules that are based on flow rate and direction importance. Other signals are programmed to set the green light duration based on data collected from sensors on the road that represent vehicle movement through an intersection. The contemporary solution for increasing the accuracy of traffic light signals is to use data networks to connect traffic light signals to on road vehicles or between vehicles themselves[3]. This thesis adapts the idea of connecting vehicles with the intersection using data networks in order to introduce a method of intersection management.

This chapter continues to introduce the research in short, section 1.1. discusses the motivation of this research followed by the problem description in section 1.2., then an introduction of the research goal and boundaries in section 1.3.

1.1. Motivation

It is a common occurrence to have to wait at an empty intersection due to a pre-timed red light signal. This waiting time increases greenhouse gases emissions, along with fuel consumption and the possible long queue of vehicles waiting to pass the empty intersection.

This research aims to create a system that reduces the waiting time and emission of greenhouse gases.

1.2. Problem Description

Due to their configuration, pre-timed traffic light signals cause unnecessary vehicle stops by preventing vehicles from moving through empty intersections, thereby ignoring the real time situation. Greenhouse gas emissions, unnecessary fuel consumption, increased fuel cost, and longer waiting time are the effect of this phenomenon.

1.3. Goals

The goals of this research is to find a system that allows for the safe and efficient flow of vehicles through intersections, ensuring a reduced waiting time and less stops. The system uses a data network to make real time decisions based on data collected from the vehicles that are approaching the intersection. This system also contributes to the enhancement of economics by reducing the fuel consumption, air pollution created by greenhouse gas emissions from vehicles, and road congestion by introducing more efficient movement through intersections.

2. Background

The development of the automotive industry led to a massive growth in the number of vehicles on the road, sometimes resulting in an overabundance of vehicles that can be managed by the road network. Many efforts have been made to solve this issue of the increasing number of vehicles such as road expansion through the addition of more lanes or building multi-level streets.

One of the most critical issues in managing the traffic networks is the management of road intersections. The most frequented solution to this issue is the use of traffic lights, which are installed at each intersection to control the flow of vehicles in each direction by giving authorization – green light - for vehicles that are flowing in the same direction for a specific amount of time to pass the intersection. They also function to stop the vehicles that are flowing in the other directions through the red light signal in order to avoid accidents. This scheme is based on pre-defined measurements, making it impractical for intersections that have unequally distributed flows of traffic.

One solution that was used to avoid this problem was to use adaptive traffic lights that adapt red and green time interval based on the flow of vehicles. These traffic light signals used data gathered from sensors or predefined ratios that were extrapolated from models to assign longer green light duration for the direction that has more vehicle flow as in [4]. The problem with this method is that vehicles flowing from the direction with low flowing density may suffer from a long time waiting in order for vehicles in the heavy loaded direction to pass smoothly.

A significant amount of research was conducted to solve these problems by either applying an intelligent traffic control system that used artificial intelligence algorithms to give the red and green light decisions to vehicles in a way that ensures fair traffic flow between all the directions, or by proposing a fully autonomous traffic system. With the use of autonomous system, vehicles flow in accordance with the intelligent algorithm, which ensures that every vehicle will be following a certain road to reach its destination. This traffic system will then make the traffic flow calculations according to these readings to ensure the lowest possible waiting time for all vehicles.

In Cheng Hu's work [5], a road cross is described in terms of lanes and directions, and a set of all possible states that can occur on the intersection is defined – each state consists of two lanes on which vehicles can get along in the intersection safely. The system computes the weight of each state based on the number of vehicles – gathered with the aid of sensors installed on the side of the road – flowing on the lanes of the corresponding states, and then gives green lights for vehicles on the combined lanes' state that has the highest weight. This solution reduced the average waiting time at an intersection. The problem with this strategy is that some vehicles may have to wait for a long time due to driving on a lane with a low weight.

In Chavan's work[6], the use of sensor networks was proposed to aid the decision of the traffic lights along with microcontrollers. The paper suggested that the sensors to be installed on the roads before every traffic light signal to count the number of vehicles flowing in a direction. Data collected by the sensors are sent as input signals to the programmed microcontroller installed at each intersection, which in turn makes the decision based on the vehicles' load on each direction in the intersection. The paper also suggested the use of GSM cell phone interface for users who wish to receive information about the latest congested position to avoid passing through these congested roads and choose an alternate route.

In Gradinescu’s work[7], vehicle-to-vehicle communication technology is deployed to collect updated information about vehicle flow on streets. This information is then collected by intersection control stations that are installed at each intersection. The decision is made based on the collected data that allows lanes with a heavier traffic load to pass. This in turn may lead to some vehicles waiting for a longer time, due to their existence on lighter load lanes.

This study alleviates the use of intelligent traffic systems by proposing the use of DTL and the deployment of the V2I network scheme, in which the red and green time for each vehicle will be calculated separately and decisions are made for each vehicle separately. In this scheme the waiting time for vehicles is very low – zero or close to zero, and the average waiting time for the intersection is very low, compared to the traditional pre-timed traffic lights systems. Moreover, the percentage of the vehicles stopping at the intersection and the longest waiting time required at the intersection are both reduced with the use of the proposed scheme.

3. System and Design

In this thesis, the proposed system aims to solve the road intersections' control problem. The system follows a client-server communication structure to connect vehicles to the intersection control station. The intersection control station represents the server node that make the decisions for the vehicles that are passing the intersection, and the vehicles represent the clients of the system. Each vehicle is treated as a job that needs to be scheduled through the intersection.

The chapter continues by describing in brief the client-server model in section 3.1., the concept of scheduling in section 3.2., and the Dashboard Traffic Light (DTL) system, its components, and the communication protocol between system components in section 3.3.

3.1. Client-Server

The client-server model of computing is a distributed computing structure that partitions tasks or workloads between the providers of a resource or service, called servers, and service requesters, called clients as shown in Figure 1. Often clients communicate with servers over a data network on a separate hardware, but both client and server may reside in the same system. Clients initiate communication sessions with servers, which await incoming requests. These requests may be for data, resource, or a function that resides on the server's side[8].

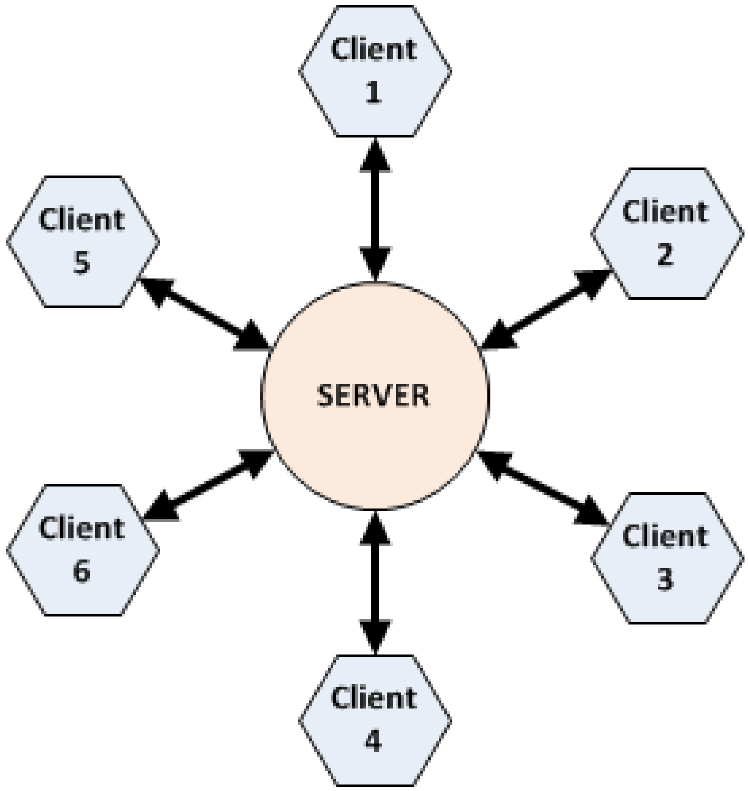

Figure 1: Client-Server Model

The server component provides a function or service to one or several clients, who must initiate requests in order to use the services. A service is an abstraction of computer resources, and a client does not have to be concerned with how the server performs while fulfilling the request and delivering the response. The client only has to understand the response based on the well-known application protocol, i.e. the content and formatting of the data for the requested service. Clients and servers exchange messages in a request-response messaging pattern; the client sends a request, and the server returns a response. For every system that use the client-server structure, a communication protocol must be defined so that the server and its clients will know what to expect when dealing with each other[9].

3.2. Scheduling

The theory of scheduling is the study of allocating resources over time to perform a collection of tasks. Such problems occur under widely varying circumstances. In the scheduling process, the type and amount of each resource must be known to determine when the tasks can feasibly be accomplished[10].

3.3. Dashboard Traffic Light

In this thesis, the proposed system replaces the traffic light signals with an intersection control station that communicates with vehicles approaching the intersection through the V2I network. These vehicles are equipped with a DTL (*Dashboard Traffic Light*) component that shows the signal color for the driver along with the counting down timer in seconds.

The thesis presents an algorithm, which is called the Safe to Pass First (SPF) algorithm, that make use of per-vehicle real time speed, position, and direction data to decide when to allow the vehicle to pass through the intersection. The algorithm checks the status of conflicting lanes, to ensure that vehicle will pass the intersection safely as shown in Algorithm 1.

Algorithm 1: Safe to Pass First

Input: Vehicle X with attributes:

S_X: The speed of the vehicle

G_X: The location of the vehicle

D_X: The direction for which vehicle is travelling

L_X: The lane on which vehicle is travelling

T_X: Required time for the vehicle to pass the intersection

Let A_X be the arrival time of vehicle X

Let S be the set of conflict lanes presented as tuples: (Lane, set of conflict lanes) where S={(0,{2,5,6,7}), (1,{2,3,4,7}), (2,{0,1,4,7}), (3,{1,4,5,6}), (4,{1,2,3,6}), (5,{0,3,6,7}), (6,{0,3,4,5}), (7,{0,1,2,5})}

Let B = {Br: the time required for lane r to be empty, r ϵ [0…7]}

Let $I(L_X)$ be an indicator for the existence of vehicles on the conflict lanes of L_X, where $I(L_X)=1$ if one or more of the conflict lanes is busy or $I(L_X)=0$ if the conflict lanes are empty.

Let G_{time} be the amount of green light time that comes after red light time in the decision.

Add vehicle X to the queue **Q**

While Q is not empty, **do**

    Consider the earliest waiting vehicle in the queue

    Check conflict lanes in $S(L_X)$:

        if all conflict-lanes are empty:

            $I(L_X)=0$

            Return (Green, T_X)

        else:

            $I(L_X)=1$

            Check set **B** for lane timers

            $\mathbf{T_{empty}}$ = the time required for all conflict lanes to be empty

            If $T_{empty} - T_X < 4$:

                $G_{time} = 4$

else:

$G_{time} = T_{empty} – TX$

Return (Red, T_{empty}, G_{time})

The following sections describe the system components in detail, along with a discussion of the communication technology that will be used for the system.

To calculate the required time for a vehicle to pass the intersection, the intersection control station will use the following formulas.

$$T(seconds) = \frac{Distance(m)}{speed(kph) * \frac{5}{18}} + \frac{D}{DS(kph) * \frac{5}{18}} \quad \dots (1)$$

$$S_{decl}\,, L = speed - 10 \quad \dots (2)$$

$$S_{decl}\,, R = speed - 15 \quad \dots (3)$$

- T: the required time for the vehicle to pass the intersection
- Distance: the distance between the vehicle and the edge of the intersection when the control station receives the request message.
- Speed: the speed of the vehicle
- D: the required distance for the vehicle to pass the intersection after reaching the edge of the intersection
- DS: Decelerated Speed for the vehicle to pass the intersection which is represented in formulas (2) and (3).

A. Vehicle DTL device

In this system, every moving vehicle is assumed to be equipped with a DTL device. The DTL device consists of a communication component to send/receive messages to/from the intersection control station, and a display component to be placed on the dashboard. The display component can be configured to show signals in various ways. Here, it is configured to exhibit the signal color along with the counting down timer in seconds, which represents the given time for the current signal color before it changes. For the display component shown in Figure 2, the red light signal will be ON for 7 seconds then go off. The green light will be ON directly after the red light being OFF and will countdown for 5 seconds.

The communication component connect to the intersection control station when the vehicle enters the communication range of the intersection control station. The communication component the issues a request message to the intersection control station as soon as the vehicle side is connected to the intersection control station in order to reserve a time slot at the intersection for the vehicle to pass safely.

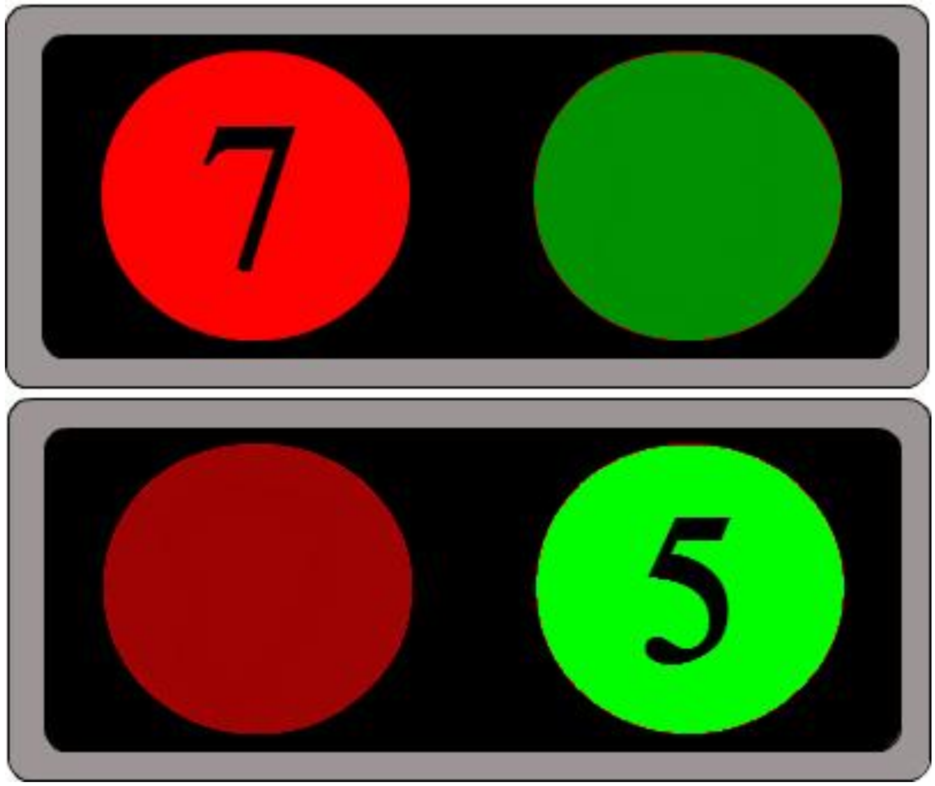

Figure 2: DTL Display Component

The vehicle system awaits for one of two expected response from the intersection control station. The first response is the green light decision with countdown timer. The second expected response is the red light decision with two countdown timers; one for the red signal duration, and the second for the green light duration that comes after the red light countdown timer is done.

After passing the intersection, the vehicle communication component informs the intersection control station with an exit message containing the lane on which the vehicle was travelling.

B. Intersection Control Station

The intersection control station is the decision maker of the system. As shown in Figure 3, an intersection control station is installed at the intersection to communicate with the vehicles approaching the intersection. This system keeps track of the vehicles trying to pass through the intersection by storing information about the number of vehicles at each lane in the intersection and the required time for each lane at the intersection to be clear.

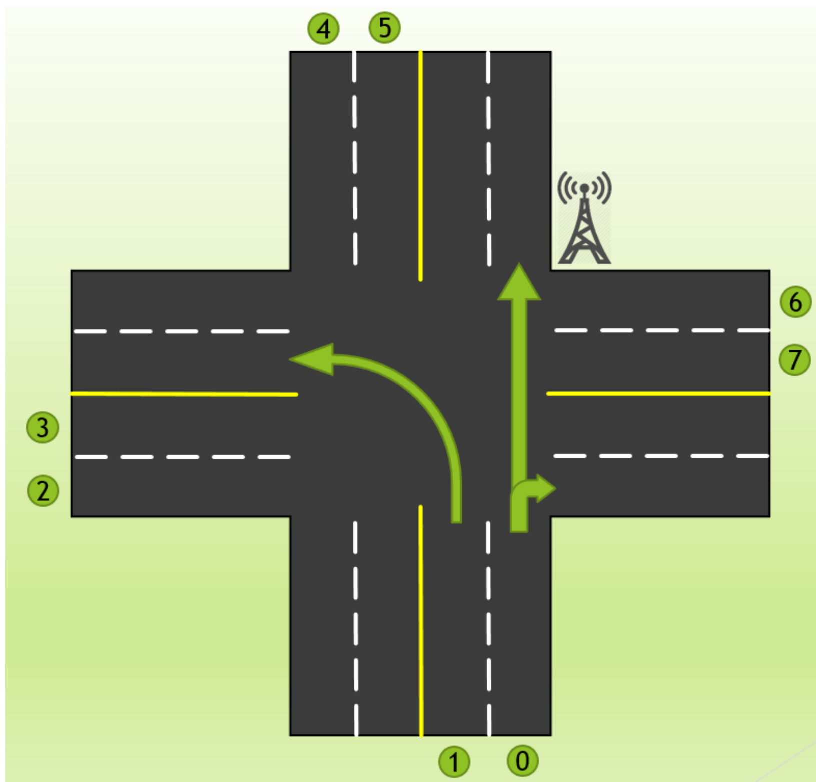

Figure 3: Typical Four Way Road Cross

The intersection control station receives requests from all the vehicles approaching the intersection. The system calculates the required time for the vehicle to pass the intersection and then compares it with the status of the intersection. Algorithm 2 shows the system behavior after receiving the request message.

Algorithm 2: Intersection Control Station

Input: Request Message

Output: Decision Message

While Request Message Received

Extract message information (Vehicle ID, Lane ID, Vehicle Location, vehicle speed, Direction, Timestamp).

Calculate the distance of the vehicle from the intersection.

Calculate required time for the vehicle to pass the intersection.

Check the given lane status:

if a slower vehicle occupies the lane:

Set required time to match the slower vehicle timer.

Call *Safe to Pass First* **(**Vehicle information**)**

Send decision message to the vehicle.

Update the counter for the number of vehicles on the given lane.

Store vehicle information to the system (Car ID, required time to pass intersection, lane ID).

The system keeps records of the requesting vehicle until it passes the intersection. The vehicle then sends an exit message specifying the lane it was occupying. The system changes its records accordingly by updating the number of vehicles on the given lane.

C. Communication System

In order to define a communication system for the proposed system, first the communication protocol between its components must be defined. A communication protocol is a system of rules that allow two or more entities of a communication system to transmit information amongst one another. These are the rules or standard that define the syntax, semantics and synchronization of communication and possible error recovery methods[11]. Communicating systems use protocols for exchanging messages. Each message has an exact meaning intended to elicit a response from a range of possible responses pre-determined for that particular situation, and communication protocols have to be agreed upon by the parties involved.

For the purpose of this system communication, the thesis presents a simple message exchanging protocol. The presented protocol defines two groups of messages. The first group is the client side messages group, this group consists of two types of messages, request messages and exit messages. The client sends the request message when it enters the communication range of the intersection control station to reserve a spot in the intersection. The request message contains the following data:

- Request: indicating message type;
- A vehicle ID, A unique system-wide ID: this ID can be the MAC address of the communication component or the VIN number of the vehicle;

- Lane ID, as specified in Figure 3;
- The current vehicle location at the time of request;
- The speed of the vehicle;
- Direction, as S (go straight), L (turn left), R (turn right);
- Timestamp, both intersection control station and vehicle DTL assumed to be synchronized with the global clock;

Once the vehicle is out of the intersection, it sends an exit message to the server indicating that this vehicle has passed the intersection safely. The exit message contains the following data:

- Exit: Indicating message type;
- Lane ID, as specified in Figure 3: the lane on which the vehicle was travelling.

The second group is the server side message group that consists of two types of messages, the green-decision message and the red-decision message. The server sends these messages as a response to the request message. The green-decision message is the response for requests from vehicles that can pass the intersection safely. Green-decision message contains the following data:

- Green, indicating that the driver can proceed through the intersection;
- Countdown value; indicating the decision duration.

The red-decision message is the response for requests from vehicles that cannot pass the intersection safely due to the existence of vehicles on the conflict lanes at the request moment. Those vehicles will receive a red signal for a specific time that is indicated from the server side based on the intersection status. The signal will then turn into green after the end of the specific period for red. Red- decision message contains the following data:

- Red, indicating that the intersection is not clear for the vehicle to pass through at the current time;
- First countdown value, indicating the period that the vehicle has to wait at the intersection;
- A second countdown value, indicating the duration of time that the vehicle can safely pass through the intersection.

Figure 4 below shows the flow of messages between the system entities with respect to time.

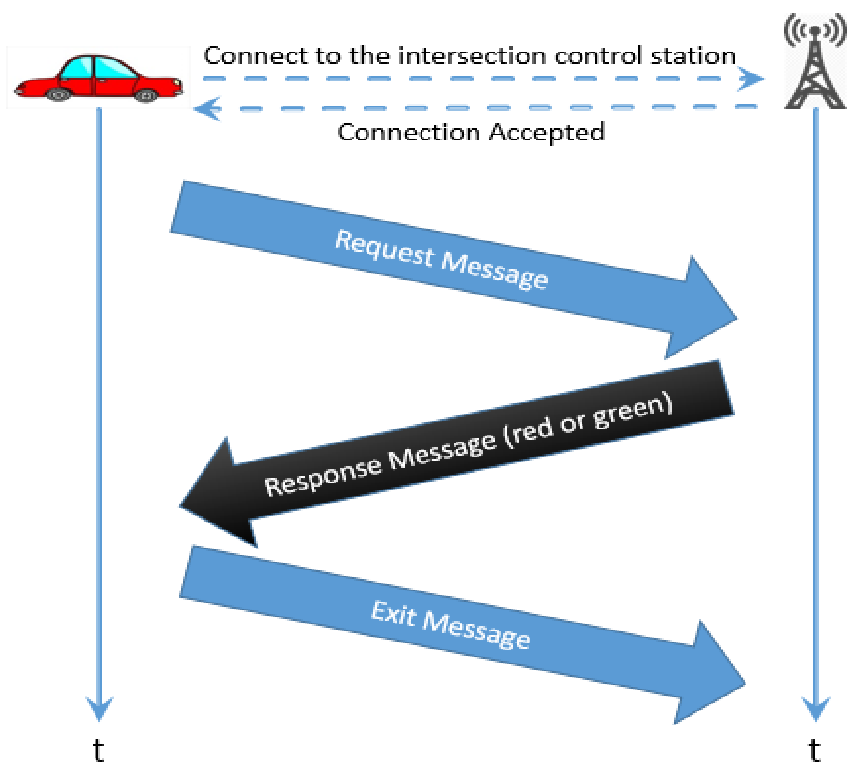

Figure 4: Messages Exchange Sequence

4. Simulation

For further investigation of the proposed system, a python code was written to simulate a standard road intersection connecting four roads. The code represents the system modules (the intersection control station and the vehicle DTL) according to the proposed algorithms and communication protocol.

The following sections describe the simulation environment used to test the system along with the study case scenarios.

4.1. Simulation environment

The system simulates a standard road cross connecting four roads. Each road consists of four lanes – two incoming and two outgoing lanes – each three meters wide. Outgoing lanes are numbered as shown in Figure 3; where vehicles traveling on odd numbered lanes are flowing into the left direction of each road, while vehicles on even numbered lanes are flowing straight or turning right at the intersection. One intersection control station is installed at the intersection instead of four traffic light signals, as is the case with traditional pre-timed traffic light systems. The intersection control station has an average communication range of 200 meters. Vehicles travel on a speed range of (30 to 65 Kph). Given the proposed distance and speed, the time required for a vehicle to reach the intersection edge after accessing the communication range will be in the interval of 11 to 24 seconds. This range is enough for the vehicles to resend lost messages in a proper time before reaching the intersection edge. Vehicles turning left or right are supposed to decelerate their speed according to formula (2) and (3). Left turning vehicles follow formula (2) and right turning vehicles follow formula (3). Vehicles that are travelling straight keep the same speed unless they have to stop at the intersection due to a red light response message, in which case they will have a maximum of four seconds to pass the intersection.

The study compares the proposed system to a regular pre-timed traffic signal. The pre-timed signal is simulated using a python code, and is designed to work according to the following rules:

- Vehicles waiting at two opposite direction odd lanes (i.e. lane 1 and lane 5) flow through the intersection for 20 seconds during rush hour and for 13 seconds during light traffic time.
- Then vehicles from the same two opposite direction but waiting on the other two lanes (i.e. lane 0 and lane 4) that are tend to go straight or right flow for 80 seconds during rush hour and for 52 seconds during light traffic time.
- At the end of the 80 or 52 seconds, vehicles that are waiting to flow in the perpendicular direction will start to flow according to the same sequence and time constraints.

4.2. Study case scenarios

This section describes the study case scenarios used to test the proposed system. For study purposes, vehicles were weighted as follows; 60% of the vehicles flow straight through the intersection, 20% of the vehicles take a right turn through the intersection, and 20% of the vehicles take a left turn through the intersection. The section is organized to show two study case scenarios as follows:

A. Scenario A

This scenario considers two parameters and compare them to the regular pre-timed traffic light system. The two parameters are the average waiting time – the difference between the ideal time for the vehicle to pass through the intersection and the actual time that the vehicle takes to pass through the intersection, and the throughput – number of vehicles per second. The scenario considers two cases; the first one considers a heavy traffic intersection, such as during rush hour, where the frequency of vehicle flow rate is one vehicle every (zero to one second), and the second scenario considers lighter traffic, perhaps at night, where vehicles flow at a frequency of one every (range of zero to five seconds).

The input variable for this scenario is the number of vehicles flowing through the intersection. The inputs vary from 400 to 1000 with a step of 100 difference for each test. These numbers represent the number of vehicles that will flow through the intersection during the simulation time.

B. Scenario B

The analysis considers four parameters for the DTL and compares them to the regular pre-timed traffic systems. The four parameters are the average waiting time of vehicles at the intersection, the longest waiting time of vehicles passing through the intersection, the number of vehicles stopping at the intersection, and the Vehicle Occupancy – number of vehicles occupying the intersection simultaneously. For study purposes, the vehicles are assumed to be flowing with a time difference between each vehicle according to the Poisson distribution function. The study considers different flowing scenarios, which starts from very low traffic flow (five vehicles per minute) up to very high traffic flow (90 vehicles per minute). Poisson distribution is working as follows:

- Poisson Distribution:

  A discrete random variable X is said to have a Poisson distribution with parameter λ > 0, if, for k = 0, 1, 2… the probability mass function of X is given by:

$$f(k;\lambda) = \Pr(X = k) = \frac{\lambda^k e^{-\lambda}}{k!} \ldots .(4)$$

Where:

e: is Euler's number (e = 2.71828...)

k!: is the factorial of k

The positive real number λ is equal to the expected value of X and to its variance

$$\lambda = E(X) = Var(X) \ldots (5)$$

The Poisson distribution applies to systems with a large number of possible events. Under the right circumstances, it is a random number with a Poisson distribution[12].

The input variable in this scenario is the mean value that the code is using for the Poisson distribution function, which in turn will vary the time difference between each vehicle and the next.

5. Results

The outcome of the simulations shows promising results for the proposed system. The following sections show the results of the two scenarios.

5.1. Scenario A

The test scenario considers a situation of uniform vehicles' flowing through the intersection. Two different cases are considered. The first one considers a heavy load traffic flow through the intersection where the difference in time between each vehicle and the next is either zero or one second, and the second case considers a normal traffic load through the intersection where the difference between each vehicle is in the range of zero to five seconds. The following sections show the results along with the some notes and observations about the results.

A. Busy Hour Analysis

The importance of rush hour analysis is ensure that the system allows for a smooth vehicle flow through the intersection with the least waiting time. Using the previously mentioned data for the simulation, results are shown in Figure 5 for the average waiting time, Figure 6 for the longest waiting time, and Figure 7 for the throughput of vehicles passing through the intersection. The results show significant improvement considering the average waiting time of vehicles at the intersection. From Figure 5, results for the average waiting time of the vehicles that are using the traditional traffic light systems is of 67 seconds. From the same figure, it can be noted that average waiting time for the proposed intelligent DTL system is almost 14 seconds.

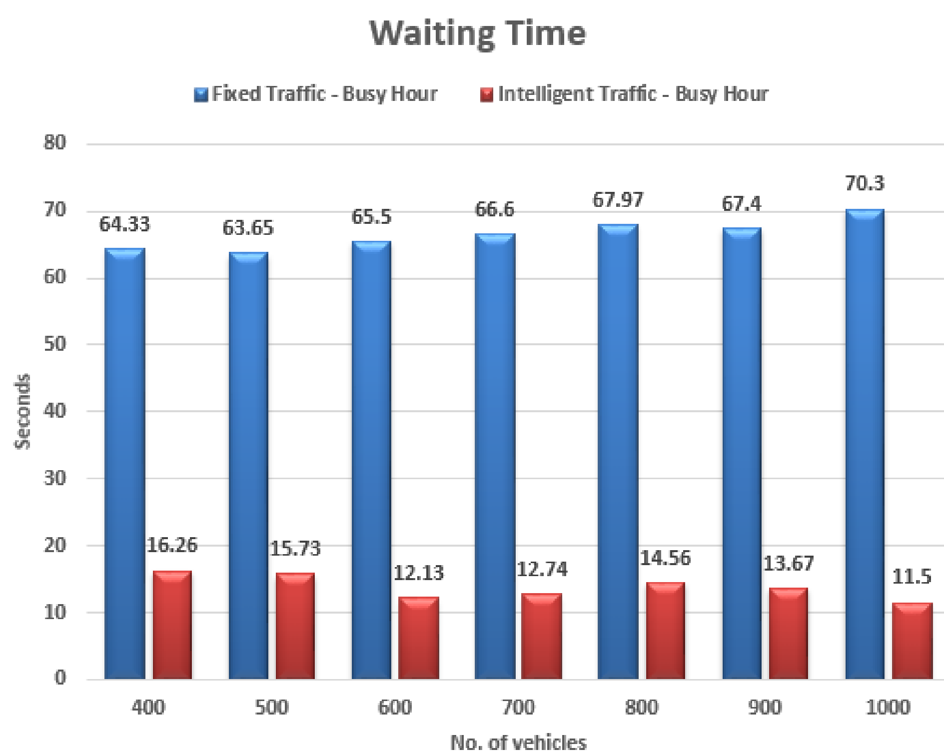

Figure 5: Scenario 1: Busy Hour – Average Waiting Time

Figure 6 shows the results for the longest waiting time that occurred while testing both systems, the proposed system and the traditional system. The figure shows a huge difference between the results of the proposed system compared to the traditional system. The test of the traditional system shows an average of 225 seconds for the longest waiting time, which is eight times greater than the results of the proposed system, for which the results are an average of 31 seconds.

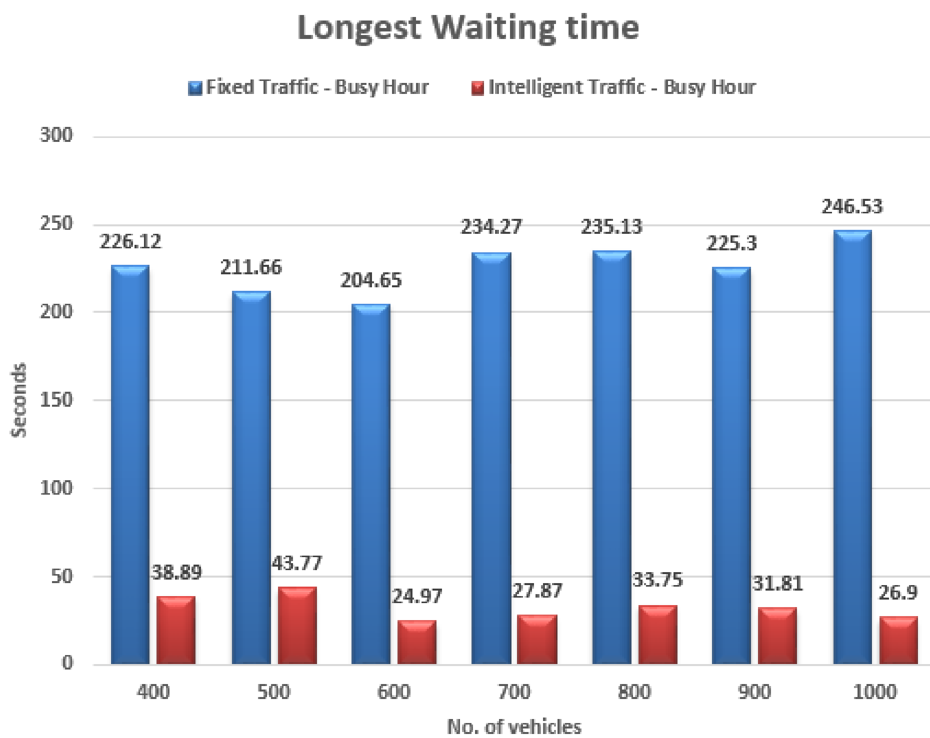

Figure 6: Scenario 1: Busy Hour - Longest Waiting Time

From figures 5, and 6, we can note that the difference between the longest and the average waiting time for the traditional system is significant, around 160 seconds. This large difference implies the unfair distribution of waiting time between vehicles at the intersection. The case is different considering the proposed system. As noted in the mentioned figures, the difference between the longest waiting time and the average waiting time is around 15 seconds. This difference implies a fair distribution of waiting time between vehicles at the intersection under the same circumstances.

Intersection throughput shows good improvement, as vehicles flow through the intersection with less waiting time. The reduction of waiting time for the vehicles flowing through the intersection leads to more vehicles flowing per a unit of time, which in turn increases the throughput of vehicles flowing per a unit of time.

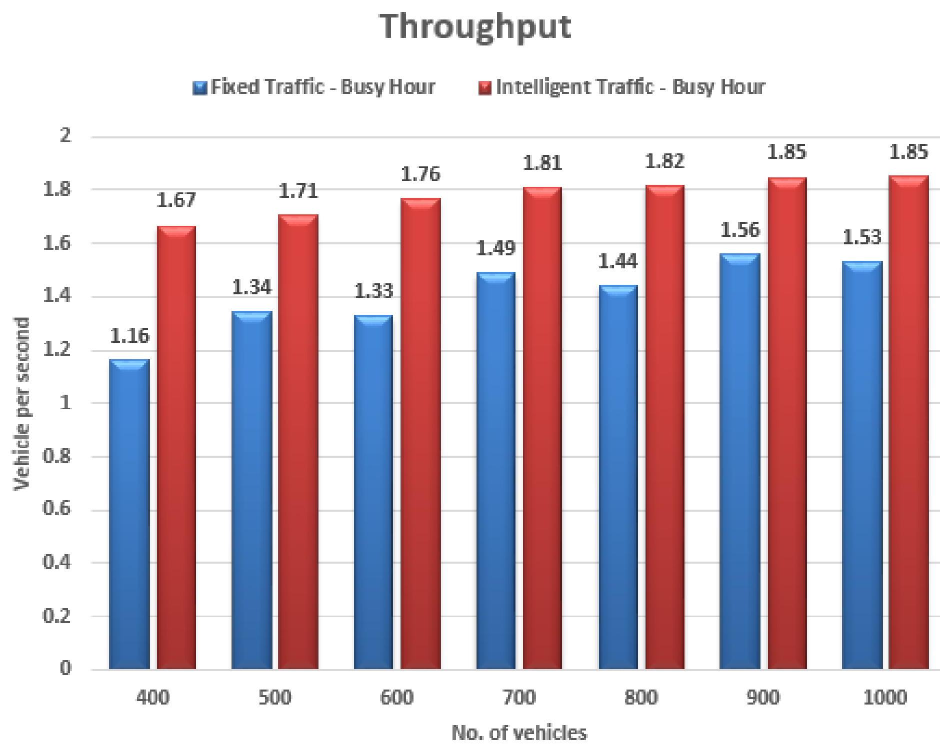

Figure 7: Scenario 1: Busy Hour – Vehicle Throughput through intersection

B. Light Traffic Analysis

The problem with light traffic intersections is that vehicles that have to wait at the intersections even when they are empty due to traffic light signals time constraints. The results shows great improvement in the average waiting time of vehicles at the intersection. The average waiting time tend to be very low, and number of vehicles waiting at the intersection is also low, while the pre-timed traffic light system shows a high waiting time, around 50 seconds, compared to the proposed system due to non-reasonable stops at empty intersections as shown in Figure 8.

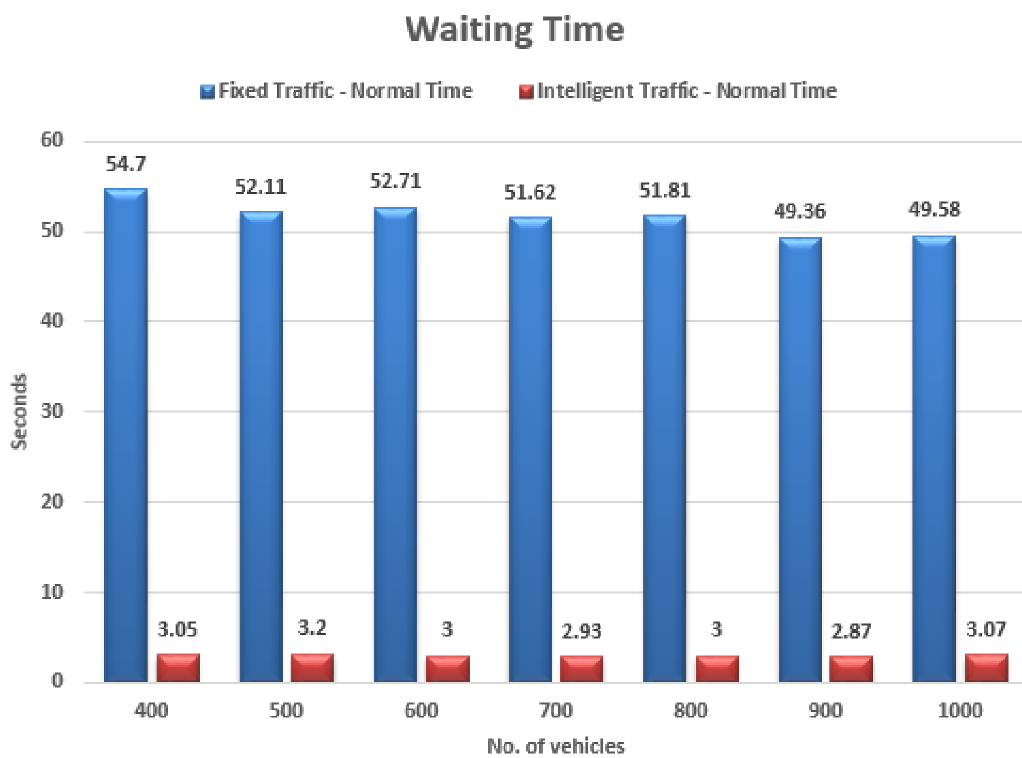

Figure 8: Scenario 1: Normal Traffic – Average Waiting Time

Figure 9 shows the results for the longest waiting time for both systems. The results for the traditional system is almost nine times greater than the proposed system. As noted in the previously mentioned figure, the average value for the traditional system values is 190 seconds. For the proposed system, the average value is around 20 seconds.

From figures 8, and 9, we can note that the difference between the longest and the average waiting time for the traditional system is significant, around 140 seconds. Again, this difference shows the unfair distribution for the waiting time at the traditional intersection. Comparing the results of the proposed system shows a difference of 17 seconds, which also implies a fair distribution of the waiting time for vehicles passing through the intersection under the same circumstances.

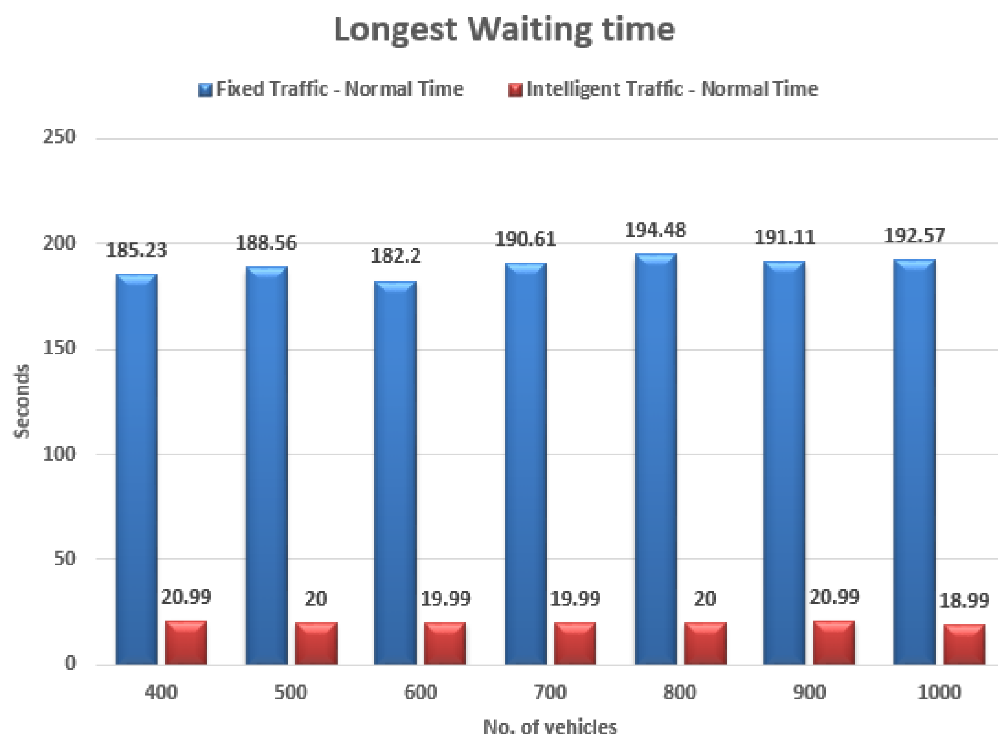

Figure 9: Scenario 1: Normal Traffic – Longest Waiting Time

Figure 10 shows almost the same values of throughput for the proposed system compared to the traditional system, due to the fact that the vehicle flow frequency is low.

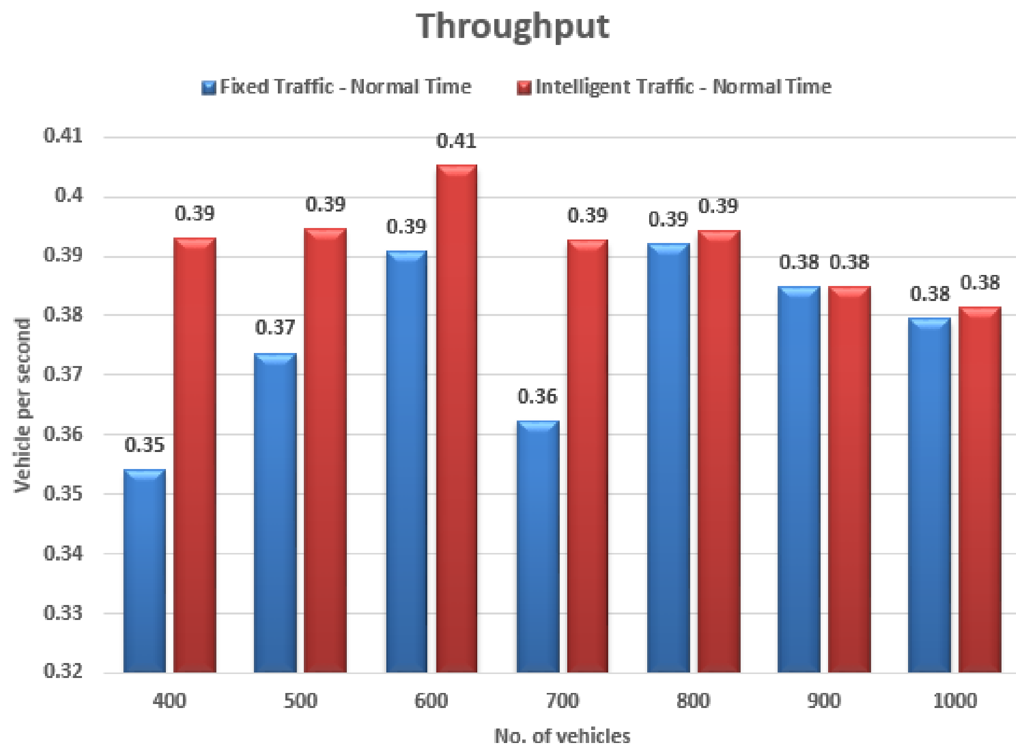

Figure 10: Scenario 1: Normal Traffic – Vehicle Throughput through intersection

5.2. Scenario B

The test scenario considers a situation of random vehicle flow through the intersection, based on the Poisson distribution scheme. The test outcomes are shown in figures 11, 12, 13, and 14.

Figure 11 shows the results for the average waiting time at the intersection. The average waiting time at the intersection shows a significant enhancement for the proposed system over the traditional pre-timed traffic system. The waiting time for the cases of light traffic flow (5, 10 cars per minute) is very low – less than one second – compared to the traditional scheme in which the average waiting time is almost 40 seconds. The proposed system shows a higher average waiting time with the heavier traffic flow values; the values are going up to almost 10 seconds for the proposed system, while it reaches over 70 seconds for the traditional traffic system.

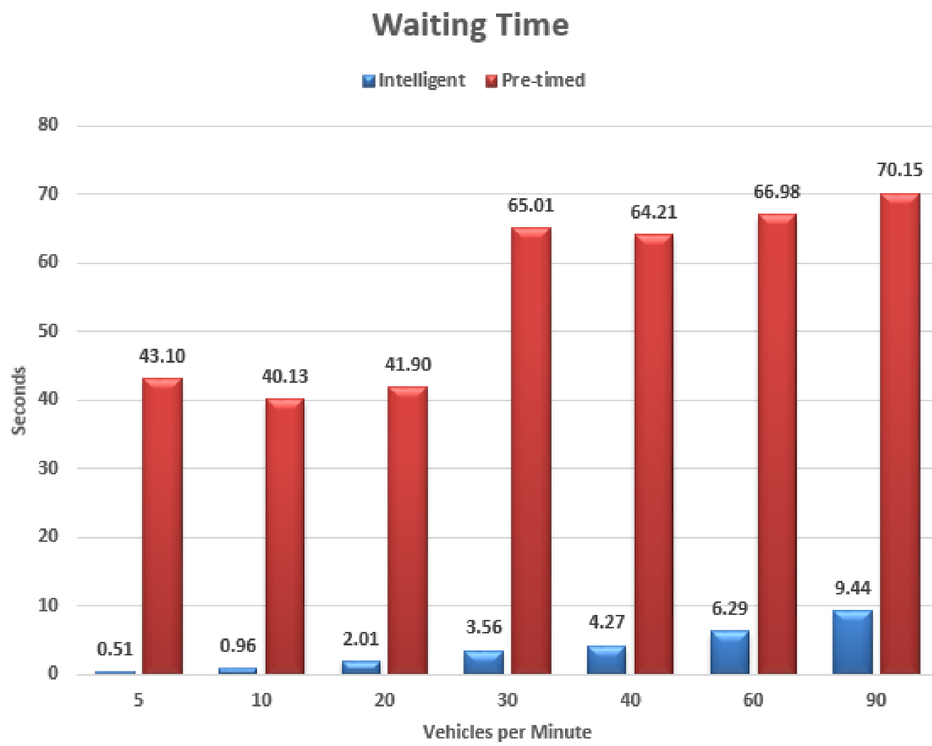

Figure 11: Scenario 2 – Average Waiting Time

As Figure 12 shows, another advantage of using the proposed system is the reasonable waiting time at the intersection, which is not the case with the pre-timed traffic system. The highest value for the waiting time given a heavy traffic flow is around 25 seconds, which is quite reasonable compared to a value of 315 seconds, which is almost 12 times the value of the intelligent system, with the use of the traditional system. The light traffic flow values spans from two to 12 seconds, which is very low compared to the values of 176 and up seconds for the traditional system.

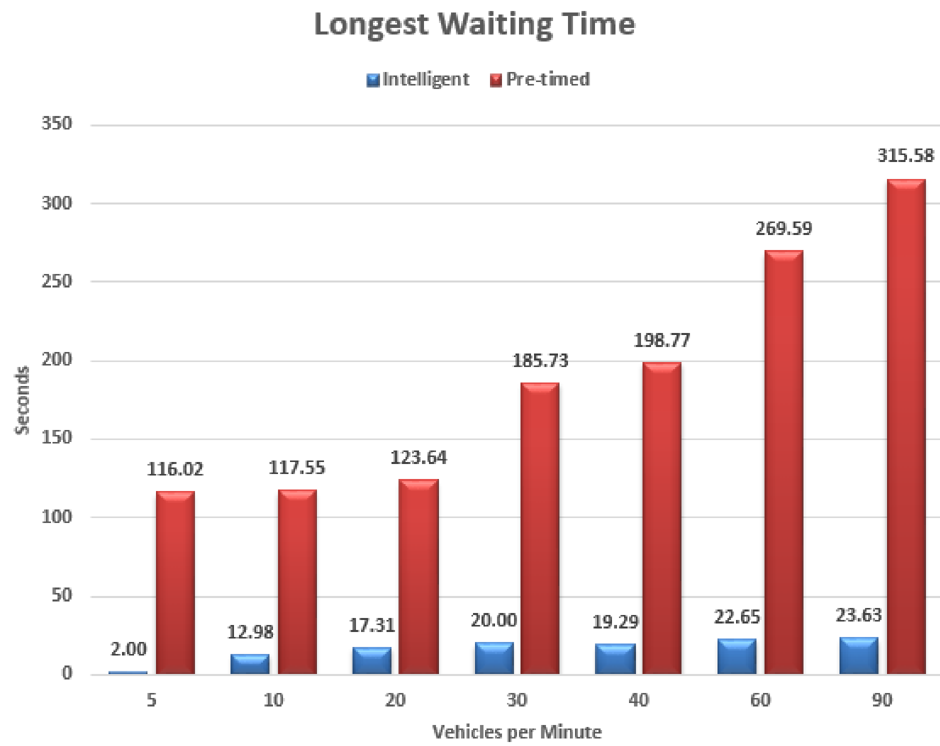

Figure 12: Scenario 2 - Longest Waiting Time

From figures 11, and 12, we can note that the difference between the longest and the average waiting time for the traditional system is significant, around 120 seconds as a minimum and it reaches up to 230 seconds in the case of heavy traffic. This difference shows the unfair distribution for the waiting time at the traditional intersection. Comparing the results of the proposed system shows a difference of 10 seconds, which also implies a fair distribution of the waiting time for vehicles passing through the intersection under the same circumstances.

Figure 13 shows the percentage of vehicles having a full stop at the intersection. The percentage of stopping vehicles is reduced to the half for the case of light traffic flow, while it is almost the same for the case of heavy traffic flow. The reason behind this behavior is the fact that vehicles do not need to stop at empty intersections using the proposed system, which is not the case for the traditional pre-timed scheme.

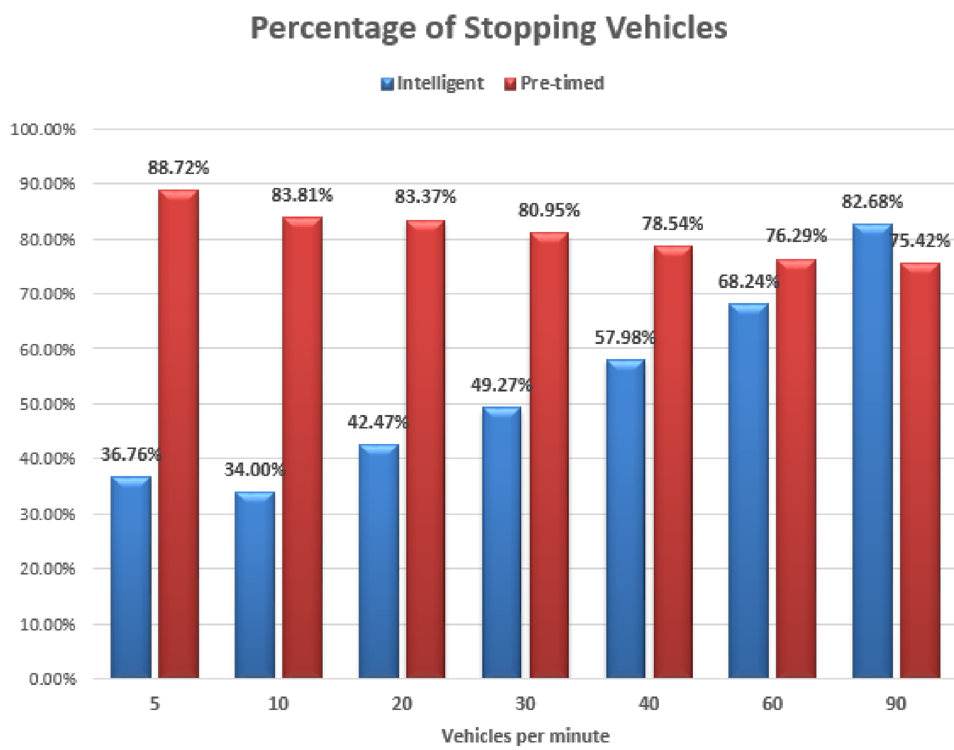

Figure 13: Scenario2 – Percentage of Stopping Vehicles at the intersection

Intersection occupancy is one of the important characteristics in reducing the waiting time at the intersection; the intersection occupancy represents the number of vehicles that are passing through the intersection simultaneously. Figure 14 shows the intersection occupancy statistics throughout the simulation period. As noted in the figure, the intersection occupancy reached six vehicles during the simulation of heavy load traffic and four simultaneous passing vehicles during the light traffic. 116 seconds of the heavy load traffic simulation showed the passage of three or more vehicles through the intersection simultaneously. A criterion cannot be found in the traditional traffic light systems, as the maximum number of vehicles passing through the intersection simultaneously is two.

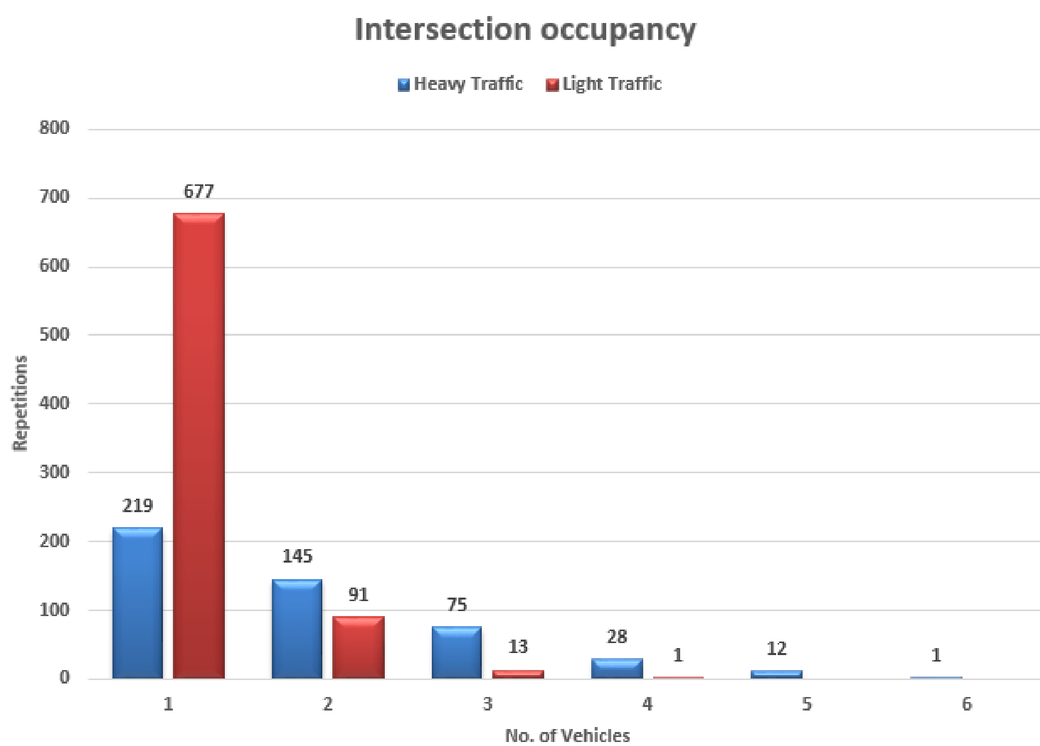

Figure 14: Scenario 2 – Intersection Occupancy

Figure 15 shows the case in which the intersection occupancy is equal to six, where vehicles were flowing into six lanes that did not conflict with each other.

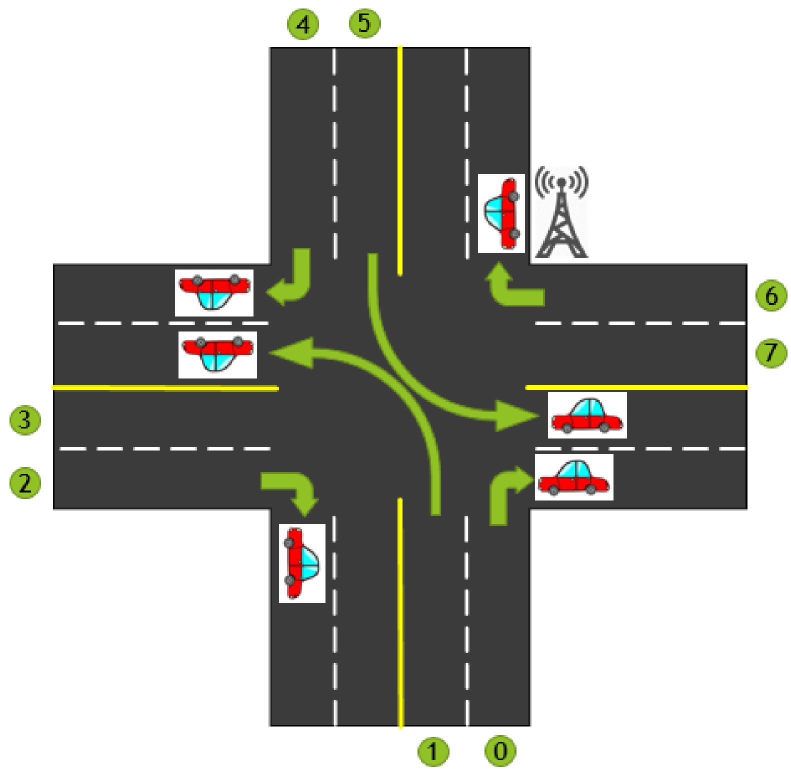

Figure 15: Intersection Occupancy Example

The proposed system shows significant performance results compared to the traditional traffic systems, given the notable reduction in the average waiting time of vehicles at the intersection and the reduction of stopped vehicles.

6. Conclusion and Future Work

The thesis suggests the use of an intelligent traffic system that deploys the Dashboard Traffic Lights with the aid of V2I network technology to enhance the existing traffic systems. Two simulation scenarios were conducted to show the benefits of using this technique. Simulation results show significant reduction in the average waiting time of vehicles at the intersection, the number of stopped vehicles at the intersection, number of vehicles that are passing the intersection simultaneously, and the vehicles throughput throughout the intersection. This reduces the fuel consumption and the pollution emitted CO_2 from the moving vehicles.

This study covers the use of DTL for standard traffic light intersection. This work facilitates the possibility of expanding the system to cover more than one traffic light intersection by synchronizing these intersections together. Considering vehicles that are not equipped with the DTL device as part of the system will play a vital role in getting the system to be an actual traffic light system that is deployed on the streets.

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