CHAPTER 1

INTRODUCTION

1.1 **Overview**

Traffic congestion has become a major problem for urban areas [1]. It can occur depending on the road design and the limitations of the technologies used on the road and at intersections [2]. Accordingly, the traffic flow is not run properly (vehicle delay & traffic congestion) and the intersection's throughput might reach to very low levels [3]. In this thesis, a highly accurate traffic light controlling system is proposed to run single junctions.

Historically, the first pre-timed electric traffic lights, mainly, were composed of two components: the Traffic Light Controller (TLC) and the Traffic Light Display (TLD) as shown in Figure 1.1. The very first pre-timed electric traffic lights controller was proposed by [4] and it was given the name as Fixed Traffic Light Control. Their TLC consisted of a simple circuit for timing and switching as it performs timed switching among pre-set phases. The main problem observed with this controlling method that the green time is being wasted when given to empty approaches.

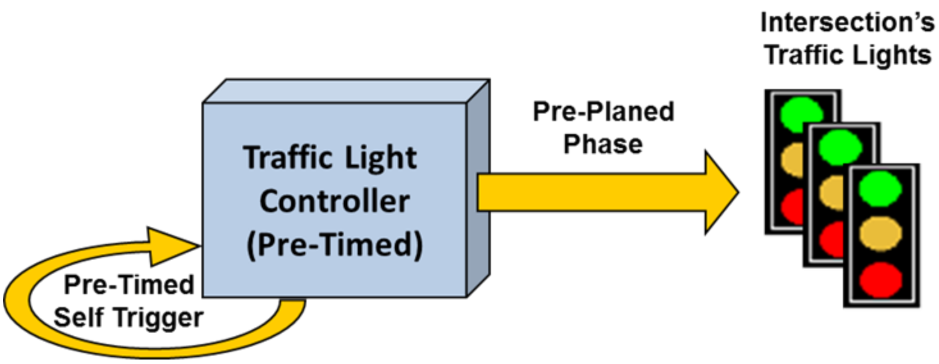

Figure 1.1: Basic Traffic Light System

A newer traffic light solution suggested that the traffic light system must have an additional input component for the actuation purpose [5]. This is why its controller was named as Actuated Traffic Light Controller. This solution suggests adding a sensor belt few meters before the traffic light stopping line to detect whether there is a vehicle queuing at the red light or not, which means adding some more flags to the traffic light controller as shown in Figure 1.2. The actuated controller aimed to solve the problem available with the fixed traffic light controlling method. Nevertheless, it did not solve the main problem completely as the green time is still being wasted when given to semi-empty approaches.

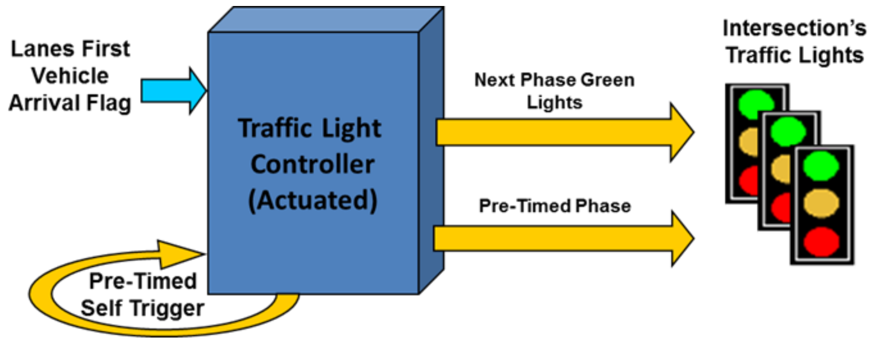

Figure 1.2: Actuated Traffic Light System Components

Most of the modern traffic light systems consist of three main components; namely, an entity for the road status input collector, Traffic Light Controller (TLC), and the Traffic Light Display entity (TLD) [6]. The differences between the current modern systems are the algorithms running in the traffic light controller and what data they are collecting to input to the traffic light controller as shown in Figure 1.3.

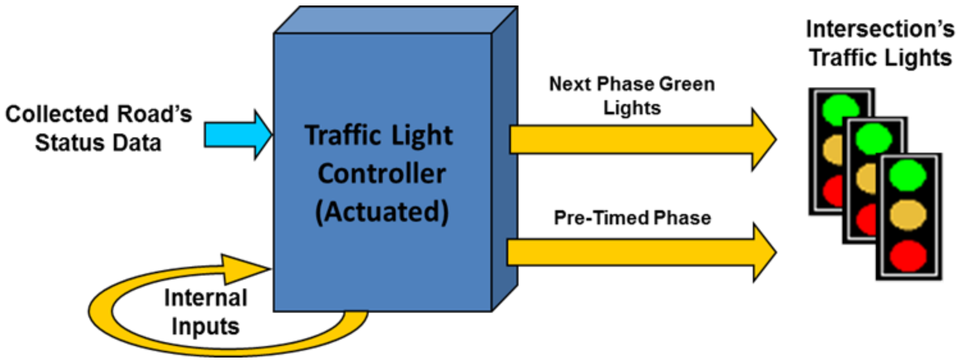

Figure 1.3: Latest Traffic Light System Components

Although, the first two solutions had some green time being wasted, they still maintain giving green time to all the approaches on intersections without neglecting any of them according to miscalculations as appeared in many newer solutions. This is why both of the fixed and actuated traffic lights controllers still being deployed on the roads.

As with many approaches, the approach in this thesis uses Intelligent Transportation Systems (ITS) [7-9], in addition, this approach involves more specific technology for vehicle networking; the Vehicular Ad-hoc Networks (VANET) architecture is used to collect the road status data [10-21]. VANET is a subclass of the Mobile Ad-hoc Networks (MANET). VANET has been introduced aiming to solve the problem of providing connectivity among vehicles themselves and with a nearby infrastructure places on the road side. VANET is still facing plenty of challenges those preventing it from being a standard technology to be used yet. Such as; the broadcast storm problem, reliable routing-protocols for high mobility topologies, channel congestion, etc. Nevertheless, it is aimed to deploy VANET technology in the near future on the roads and within the vehicles. The automobile manufacturers are about to take a leap, placing a black-box like entity within the near future vehicles, which will give the ability for the vehicles to communicate with other vehicles (Vehicle-to-Vehicle or V2V communication) and with road side infrastructures (Vehicle-to-Infrastructure or V2I communication). That is why within this thesis, VANET is assumed to be valid providing a full connectivity between the participating nodes.

As in this research, a road data collecting system setup and the vehicle-to-infrastructure and infrastructure-to-infrastructure messaging system has been developed in addition to evolving a traffic light controller algorithm which makes two decisions for the traffic light: the next phase green lights and the next phase time. The main concern of this research is the type of data to be collected and their role within the traffic light controller to make decisions for the traffic light phases.

The developed traffic light controller algorithms will be evaluated using a customized traffic light simulation tool created by MATLAB which has been validated using an existing simulator used by civil engineers, which is named "Sidra Intersection Simulator". The developed approach's performance will be compared with four traffic controlling methods; two benchmark methods: pre-timed-fixed phase plan controller and fully-actuated intersection controller, and two other methods of the latest related works have been chosen.

1.2 Problem Statement

Traffic light management is a highly significant topic especially in modern cities as they always have traffic congestion as one of their major problems [22–23] and [3]. Despite the fact that numerous researchers have looked into this problem and proposed a variety of solutions, their works tend to be more into solving much more specified problems, such as reducing the vehicle queue lengths in the approaches. Whilst, they neglect others, such as maintaining the approaches' waiting time. That makes their systems unsuitable for redeployment for any signalized intersection. So, the authors of this work have found a need for creating a more general solution that can provide accurate decisions. Those which mainly help in increasing the green time utilization and maintaining the system stability when implemented on any traffic light site.

After an evaluation of previous related studies in the literature, it can be summarized that the present challenges in this work would be:

1. Collecting only a little number of the road's status data types, would lead to inaccurate traffic light phase plan decision making. That accuracy is expected to be increased when collecting more related data types. That has sparked the idea of using the VANET framework for collecting the road's queue length, vehicle waiting time, total filled ratio of the road with vehicles, and availability of the next road for receiving vehicles.

2. Running the impropriate algorithm with a small limit for queue length detection to manage an intersection might lead to system stability loss. In addition to establishing a dynamic queue length detection mechanism, this project considers the problem of finding an algorithm for optimizing the traffic light control for an intersection to preserve its stability at all levels of demand; adding to that, finding the optimum integrated traffic signal phase plan that helps in reducing both the average queue length and total wasted green time.

3. When evaluating and validating the proposed approach against others, the controlling algorithms are needed to be customized. That ability is not available in Sidra Intersection simulator, which urges the creation of a customised simulation tool which has that ability for evaluating and validating different approaches.

1.3 Research Objectives

In this thesis, a set of objectives has been identified as key:

a) To develop a data collection system for collecting road status data including the directions, queue length, total filled ratio of the road with vehicles, total waiting time for the first vehicle arriving to the traffic light's stopping line, and availability of the next road for receiving vehicles. Developing this system would lead to making a more accurate decision when determining an intersection direction's priority.

b) To establish an algorithm for rationing a traffic light full cycle time between the competing directions according to their queue lengths which would lead to a more accurate phase time decision.

c) To develop a single intersection's traffic light customized simulation tool environment by adopting the traffic light operation model concepts used by the Sidra Intersection simulator [24]. Mainly, to simulate the proposed approach and compare it with some of the existing solutions.

1.4 Research Scope

This thesis presents the research activities on the traffic light control system for signalised intersections in urban cities and proposes a protocol for collecting road status and a processing algorithm for optimising the intersection throughput and enhancing its performance. The developed ITS device's hardware setup uses the Vehicular Ad-Hoc Network (VANET) devices and infrastructure which is assumed to be providing a valid communication among the vehicles and the infrastructure devices.

1.5 Contributions

In this thesis, the traffic light system's optimization problems have been addressed, and its solutions were taken as the main objectives for this thesis research as a set of contributions are listed as:

1. The development of the VANET networking infrastructure setup, for a highly accurate Real-time Road status data collection. In addition, a messaging protocol to run over the VANET infrastructure networking devices to provide communication among those devices and to deliver the collected data to the traffic light controller is established. This VANET infrastructure setup allowed the development of a dynamic queue length detection mechanism.

2. The development of the Dynamic Traffic Light Phase Plan Protocol (DT3P) to make more accurate decisions for single-isolated intersections

control which maintains high efficiency of intersection's traffic control at all levels of demand.

3. The development of the simulation tool for single-isolated intersection traffic lights with the ability to customize the controlling algorithm.

1.6 Research Questions

In completing this research, a set of questions were required to be answered:

1. How could the road status data be collected using VANET?

2. (a) Does collecting more road status factors help in enhancing the optimization of an intersection's capacity? (b) Does it help in utilizing the given green time more efficiently?

3. Does the established algorithm help in reducing the average queue length at an intersection?

4. Will the established rationalization of the green time among the directions according to their queue lengths add more accuracy to the traffic light performance than the Fuzzy logic technique?

5. Is the developed traffic light controlling technique affective and stable at all levels of demand?

1.7 Thesis Organization

The rest of the thesis is organized as follows:

In Chapter 2 (Related Work and Literature Review), a more detailed background about the traffic light management field has been written to give some deeper knowledge about traffic light systems and what they need to work. In addition, a set of related works has been surveyed and critically assessed. This chapter shows the need for a new solution to be proposed.

In Chapter 3 (Methodology), the proposed approach has been illustrated in detail including the system setup, communication system used to collect the road data and deliver it to the traffic light controller, and a detailed description for the decision making algorithms. In addition, a full illustration has been provided about creating the traffic light customized simulation tool, its validation, and its functionality map.

In Chapter 4 (Results and Discussion), a detailed description for the experimental work has been demonstrated, listing down all of the experimental results with a comprehensive comparative study between four related works and this thesis' developed approach.

Chapter 5 (Conclusions and Recommendations), summarizes the whole thesis context and gives concluding remarks. In addition, it lists down some recommendations as the next steps to be taken to expand the developed approach.