

A REALISATION ON THE DEPLOYMENT OF SMART TRAFFIC LIGHTS WITH WIRELESS SENSOR NETWORKS IN AN EFFORT TO ENSURE SAFETY ON THE ROADS OF THE UNIVERSITY OF NIGERIA, NSUKKA CAMPUS AREA

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Abstract— This paper provides a modelling and deployment approach to a traffic light system on The University of Nigeria, Nsukka (UNN) campus for traffic flow control. A Wireless Sensor Network (WSN) is added to the system to create a smart connected network of nodes to optimise traffic flow. Such a smart system can help speed up journeys of motorists which can also consequently reduce fuel consumption. Most importantly, a deployed smart signalling system can ensure safety on roads through the monitoring of vehicle movement, of which speed is of focus. Over the years, the amount of cars on the UNN campus area has drastically increased which exponentially increases the possibility of accidents in the area. A system that provides all the incentives a smart traffic light offers will highly be welcomed in the community of UNN. This paper, therefore, focuses on the initial modelling and deployment approach, where no existing infrastructure is in place, in installing a network architecture of traffic lights and a WSN on the UNN campus area. In essence, the approach in realising the signalling system is through the motion and path planning of a predetermined vehicle in determining the feasible locations traffic lights are to be deployed on the campus. This is achieved through the relevant equations that characterises the motion of the vehicle and the path it follows as it travels from source to destination. It is only through the defined site locations of the traffic lights that will determine the necessary deployment of WSNs on the relevant road network to efficiently monitor traffic flow for a safer road environment.

Index Terms— Wireless Sensor Networks, Traffic Lights, Deployment, Motion Planning, Path Planning, Map Planning

1 INTRODUCTION

In recent years, researchers have been focusing on the ways to add Wireless Sensor Network (WSN) to traffic light systems to make traffic light signalling smart [1][2]. The aim is to wirelessly keep track of motorists on a road network and provide vehicle flow information to the traffic lights which react according to that information, making them smart. This can help mitigate traffic congestion; speed up journeys, which as a result reduces fuel consumption, and in a way improves the surrounding air quality. It has been researched that smart traffic lights can reduce the time motorists spend waiting at intersections by more than 28% during rush hours [3]. Consequently, smart signalling can help smoothen traffic flow along intersections which as a result can decrease the possibility of accidents in the vicinity [4].

The advantages that come with the installation of a traffic light system connected with a WSN are apparent. However, certain concerns arise when undertaking the task of deploying such a scheme. These include the deployment approach and the characteristics of the network architecture which includes the number of sensors and traffic lights needed to provide and ensure an efficient monitoring system of vehicles for better traffic flow information of a particular Region of Interest (ROI). Such ROI which is used to investigate the con-

cerns and used as a case study in this paper is The University of Nigeria, Nsukka (UNN) which over the years has seen a drastic increase of vehicles on the campus which as a consequence has increased the likelihood of accidents in the region. A scheme that monitors vehicle movement as well as controls traffic flow for a safer environment will be highly appreciated for the UNN community especially when students and children are involved. This paper is an extension to Sources [5] and [6] which both also provide the relevant information on the geographic layout of the UNN campus area.

2 EXISTING WORKS AND MOTIVATION

Works on the use of WSNs for the monitoring and control of traffic flows have been pursued at different levels. Source [7] provided work on algorithms for adaptive traffic light control in a WSN based Intelligent Transportation System (ITS). Models were proposed for both isolated and multiple intersections for a more real time traffic signalling scenario. It was affirmed that the optimal length of time of the green light can be calculated based on information about traffic volumes of neighbouring intersections through the use of WSNs and therefore creating an intelligent traffic light system.

Source [8] presented work on intersection control through the gathered information of speed and volume of vehicles on the road detected by a deployed network of sensors. In addition, Sources [9] and [10] provided ways the deployed sensor network can detect traffic flow information to determine the correct green times at traffic lights. A technique was also proposed in [10] to power the sensor nodes of the suggested architecture of smart traffic light system. Linked to this is Source [11] which provides a signal control algorithm to control the state of the traffic light in an intersection based on a deployed WSN on the road to monitor vehicles dynamically.

All the mentioned Sources related to the utilization of WSNs for Smart Signalling System deal with the actual management and monitoring process and innovation of an already deployed network architecture with existing infrastructure, as Source [12] also bolsters. In contrast to those works, this paper focuses on the initial deployment and modelling approach for a smart traffic light system through the motion planning of a predetermined vehicle where there is no existing infrastructure in place. The UNN campus environment is chosen for such deployment of which such a system can be highly beneficial for the community.

3 A SURVEY ON THE MODELING AND DEPLOYMENT APPROACH OF A SMART TRAFFIC LIGHT SYSTEM

3.1 Motion Modeling and Path Planning of Vehicle

With no existing infrastructure in place for any traffic light system, the first step in realising the possibility is to determine the feasible locations traffic lights are to be deployed in a region. Obviously, the lights will be placed at intersections of a road network, but where exactly? Additionally, it is known that too many traffic lights without adequate spacing between them increases "stop and go" driving which increases the likelihood of rear-end collisions, increases congestion, delay and air pollution [13]. According to Source [13], the minimum spacing between signalling is 1/4 mile to 1/2 miles depending on the area operating speed. With that in mind, the next question that arises is how to model the operating speed of a vehicle to determine the spacing between the traffic lights? The approach in answering the question is related to the motion modelling of a predetermined vehicle. Furthermore, it is understood that a single vehicle is at its most dangerous element when it is at its maximum speed and maintains that speed after acceleration from rest or from a slower speed.

To mathematically model the assumption of vehicle motion, the work presented in Sources [14] and [15] is approached. It is imagined that every path the vehicle is to follow is identified as the Desired Path Length (DPL) of which the endpoints of the link or route are coordinates for the starting and destination points. The motion along the DPL is recognized as the motion in the x_L direction while motion perpendicular to the DPL is defined as movement in the y_L direction, Figure 3.1-1 illustrates this notion.

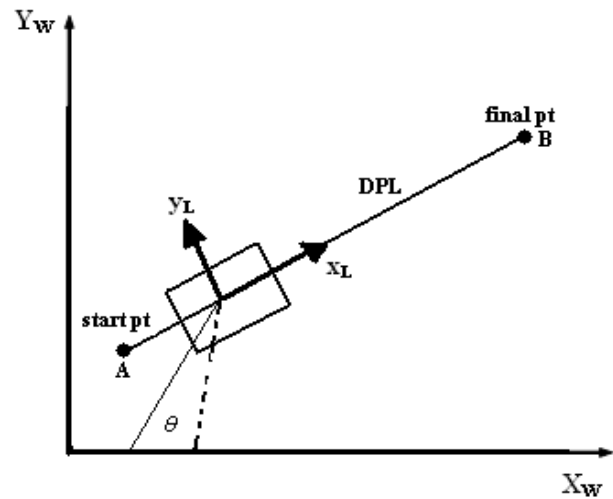


Figure 3.1-1: Motion and Path planning

The desired motion of the vehicle along the path is then considered as the following:

Given a maximum acceleration, a_{max} , and a maximum velocity, v_{max} ; the vehicle is to accelerate (by a_{max}) to the maximum speed (v_{max}) and keep moving with v_{max} for a distance. On approaching the destination point, it decelerates (by a_{max}) to slow down to a stop at the final point.

With s defined as the total distance the vehicle travels, the DPL is characterized as a 2nd order polynomial given in the form:

$$x(t) = a_x t^2 + b_x t + c_x \quad (1)$$

where a_x , b_x , and c_x define the character of motion. Taking the subsequent derivatives of equation (1) yields the velocity and acceleration as shown in equations (2) and (3).

$$v(t) = \dot{x}(t) = 2a_x t + b_x \quad (2)$$

$$a(t) = \ddot{x}(t) = 2a_x \quad (3)$$

The motion of the vehicle can now be represented graphically with time depending functions of changing position, velocity, and acceleration. Figure 3.1-2 shows this representation [14][15].

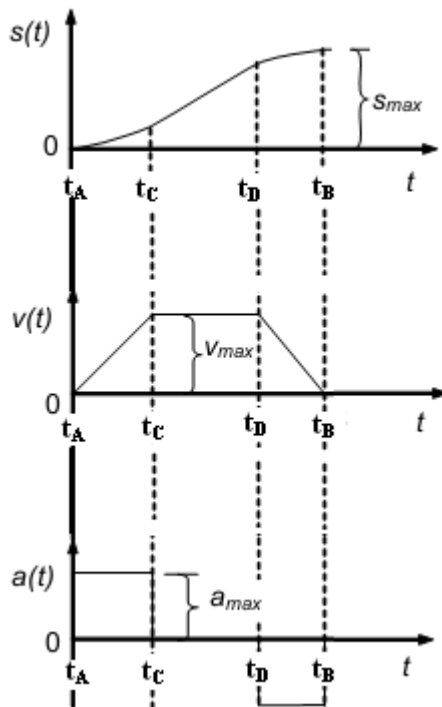


Figure 3.1-2: Motion diagram of changing position, velocity, and acceleration dependent on time

Further analysis of Figure 3.1-2 yields the following time equations and description:

At t_A , the vehicle is accelerating with a_{max} , to v_{max} at t_C . Therefore:

$$\Delta t_{AC} = \frac{v_{max}}{a_{max}} \quad (4)$$

It can also be observed that:

$$\Delta t_{AC} = \Delta t_{BD} \quad (5)$$

To find the remaining time equations requires the understanding that if equations (4) and (5) are true, then:

$$t_C = \frac{v_{max}}{a_{max}} \quad (6)$$

And,

$$t_D = \frac{s}{v_{max}} \quad (7)$$

Therefore, the final time equation, t_B , equals

$$t_B = t_D + t_C \quad (8)$$

With the given time equations, the DPL is split into four different time periods of motion which include:

$$t < \frac{v_{max}}{a_{max}} \quad (9)$$

$$\frac{v_{max}}{a_{max}} \leq t < \frac{s}{v_{max}} \quad (10)$$

$$\frac{s}{v_{max}} \leq t < \frac{s}{v_{max}} + \frac{v_{max}}{a_{max}} \quad (11)$$

$$t \geq \frac{s}{v_{max}} + \frac{v_{max}}{a_{max}} \quad (12)$$

Consequently, the motion and path model is then described as the following derived from Source 14 and using the motion diagrams of Figure 3.1-1 and 3.1-2:

- At the initial stage of motion which occurs at the time period of equation 9, the vehicle starts at point A of the DPL and then accelerates to v_{max} by a constant acceleration a_{max} . The distance that the vehicle travels along the DPL follows the characteristics of $s(t)$ from time t_A to t_C as:

$$x_i - x_{iA} = \left[\frac{1}{2} a_{max} t^2 \right] \quad (13)$$

- At the second stage of motion which occurs at the time period of equation 10, the vehicle is at constant motion of v_{max} and it travels at the characteristic of $s(t)$ from time t_C to t_D as:

$$x_i - x_{iA} = \left[\frac{v_{max}^2}{2a_{max}} + v_{max} \left(t - \frac{v_{max}}{a_{max}} \right) \right] \quad (14)$$

- At the third stage of motion which occurs at the time period of equation 11, the vehicle decelerates by a constant deceleration a_{max} and it travels at the characteristic of $s(t)$ from time t_D to t_B as:

$$x_i - x_{iA} = \left[s - \frac{v_{max}^2}{2a_{max}} + v_{max} \left(t - \frac{s}{v_{max}} \right) - \frac{1}{2} a_{max} \left(t - \frac{s}{v_{max}} \right)^2 \right] \quad (15)$$

- At the fourth and final stage of motion which occurs at the time period of equation 12, the vehicle comes to a stop at point B and therefore finishes its travel at the total distance of s at time t_B :

$$x_i - x_{iA} = [s] \quad (16)$$

3.2 Traffic Light Deployment with WSN

With the motion of the vehicle modelled, it is acknowledged that a traffic light is to be deployed at an intersection of a road network after a path that can allow the vehicle to reach a maximum specified speed and maintains that speed for specified time duration. In essence, the objective is to ensure that the

traffic lights acts as speed calmers after a path gives room to what is considered excessive speeding for a more safe environment.

For a smart system, all the deployed traffic lights are connected with a wired backbone to a controller as characterised by Source [16] and [12]. The signalling lights act as sink nodes of which all detected information from the WSN is routed to.

Unlike Source [12] where the deployed WSN consists of clusters of FFD (Full Function Device) nodes and RFD's (Reduced Function Device), the WSN architecture proposed by this paper is a single deployment of FFD sensor nodes in the middle of a four lane road structure where two lanes is for one approach and the other two is for another approach in the opposite direction. Figure 3.2-1 illustrates this notion.

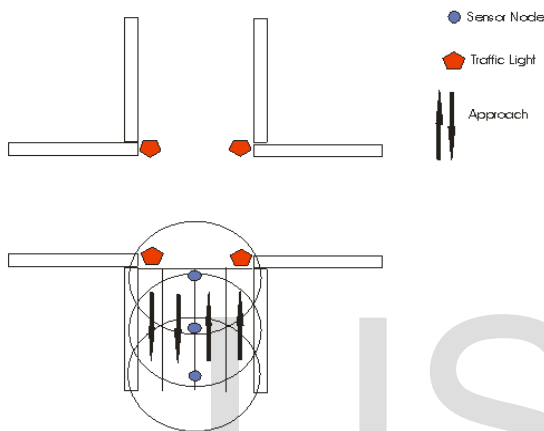


Figure 3.2-1: Traffic Light Deployment with WSN

The reason for just a single deployment of FFD nodes monitoring all lanes is because it is assumed that each sensor node's communication range can cover the entire four lane structure of which each lane is just 4 meters wide with a total of 16 meters width. Most sensors have a range of 50 to 100 meters which depends on the transmit power capability of the device. For magnetic sensors used for road monitoring as Source [17] demonstrated, a range of 50 meters was used to show performance evaluation in detecting traffic volume.

The sensor node distinguishes between the different approaches of the lane structure through the Angle of Arrival (AoA) location sensing technique. In essence, vehicles coming from opposite direction would have a plus or minus (\pm) angle difference depending on the path reference coordinate system. Figure 3.2-2 illustrates this notion.

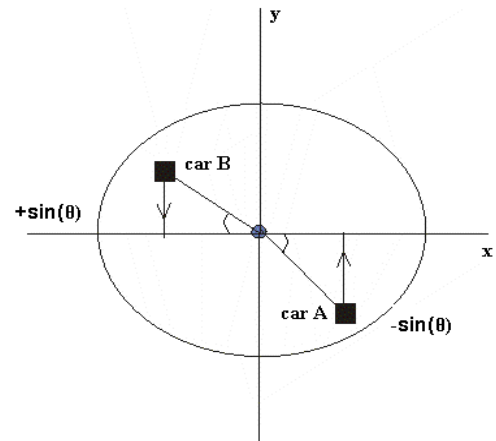


Figure 3.2-2: Angle difference of different approaches

Apart from the coverage criteria, connectivity between sensor nodes would need to be ensured for any kind of network formation as described by Source [6]. This means coverage overlap of all nodes including the sink nodes of the traffic lights to guarantee a smart traffic light monitoring system.

4 DEPLOYMENT APPROACH OF A SMART TRAFFIC LIGHT SYSTEM ON UNN CAMPUS AREA

4.1 Motion Modeling and Path Planning Approach

In modelling the motion of a predetermined vehicle to be used to determine the optimum deployment location of a traffic light on the UNN campus area, a MATLAB simulation is used and an operating speed criterion is specified as Table 1 shows.

Table 1: Operating Speed Criterion of Vehicle

Maximum Velocity mi/hr	30
Acceleration mi/second ²	3

With the given criterion and derived model equation of (9), the motion operation of the vehicle is characterised by Figure 4.1-1 which shows the Distance vs. Time and Velocity vs. Time features of the vehicle. The graphs of Figure 4.1-1 are what are expected in the motion of operation for the vehicle.

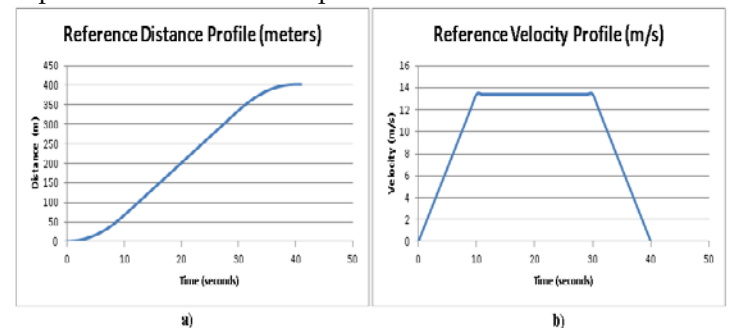


Figure 4.1-1: Motion Operation of Vehicle to be used as Reference: a) Distance Characteristic b) Velocity Characteristic

Focusing on the Velocity characteristic of Figure 4.1-1b it can be seen that the time it took the vehicle to reach the max velocity of 30mi/hr, which approximates to 13.4112 m/s, with the specified acceleration of 3 mi/s² or 1.34112m/s², was 10 seconds. The max velocity was maintained for 20 seconds before decelerating with the same acceleration features to rest 10 seconds later. Therefore with the specified motion operation, the entire vehicle journey took 40 seconds.

The motion characteristic of Figure 4.1-1 is what is used as a reference in evaluating the speed profile of a path to determine the deployment location of a traffic light. In other words, if the speed profile of a road is smaller than the reference, this indicates that the path cannot accommodate what is perceived as excessive driving and therefore at the end of that road, coming to an intersection, a traffic light is not necessary. However, if the speed profile of a path is equal to or greater than the reference, this suggests excessive driving and a traffic light is necessary at the approaching intersection.

4.2 Map Planning and Traffic Light Deployment with WSN

Given a map of the UNN campus area as shown in Figure 4.2-1, the road network was extracted to create a map of all the available paths of the campus as shown in Figure 4.2-2.

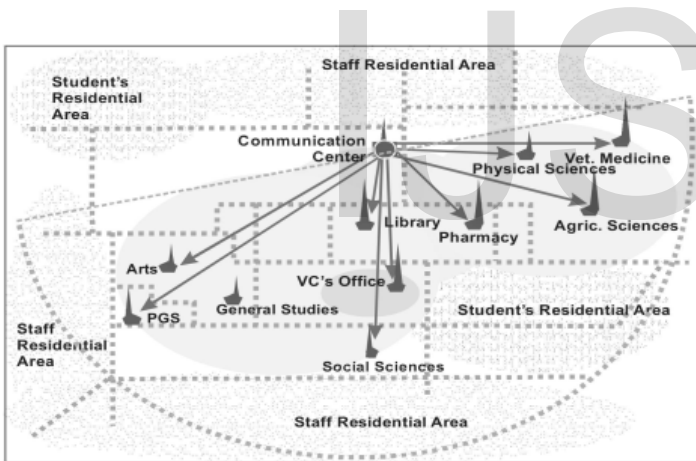


Figure 4.2-1: Map of UNN [6]

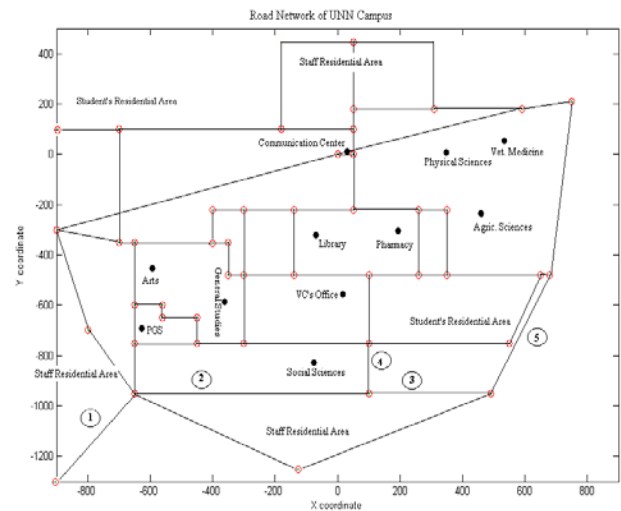


Figure 4.2-2: Road Network of UNN campus

Each individual path was numbered and a speed profile simulation was done for each path to indicate the road that enabled excessive driving. It is important to mention that a speed profile simulation was only pursued for ambiguous paths that could not be concurred if they led to excessive driving or not coming up to an intersection. Figure 4.2-3 shows the simulation result for a sample of five paths taken from Figure 4.2-2.

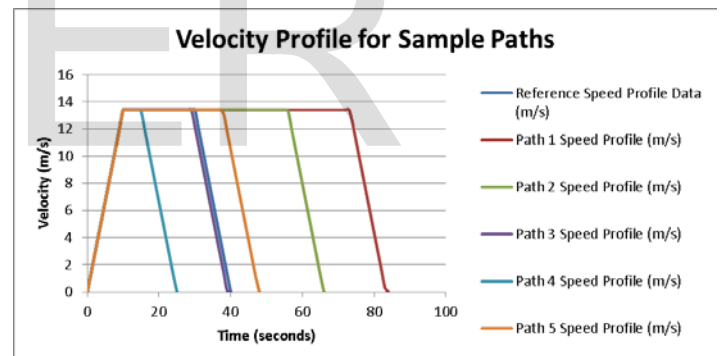


Figure 4.2-3: Speed Profile for five sample paths

As observed from Figure 4.2-3, paths 1,2,3, and 5 simulated for a speed profile greater than the reference, while path 4 gave results for a speed profile less than the reference. This concurs that paths 1,2,3 and 5 enabled excessive driving and traffic lights will need to be deployed at the incoming intersections to act as speed calmers; whereas path 4 does not have the sufficient path length to allow excessive speeding, and therefore a signalling light is not necessary at the corresponding intersection. Figure 4.2-4 shows the deployment sites of the traffic lights after simulation of the entire road network of Figure 4.2-2.

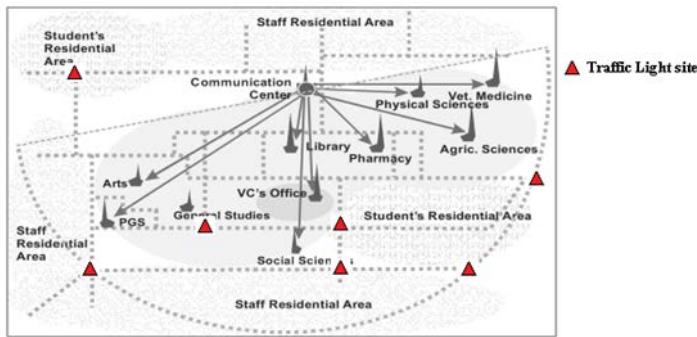


Figure 4.2-4: Traffic Light Deployment Sites on UNN Campus

With the given traffic light sites of Figure 4.2-4, sensors with 50m communication range (in accordance with the magnetic sensors of Source 12) are deployed along the corresponding paths at a sufficient distance between them to ensure an overlap of adjacent sensors and therefore connectivity to create a WSN. In providing a smart traffic light system, the coverage of the sensor closest to the sink node of the traffic light is to overlap to guarantee connectivity between the two devices as demonstrated in Section 3.2. It is important to mention that no traffic light site is to be isolated and must be connected to the rest of the network with a WSN to ensure that the entire system efficiently monitors traffic flow of the region. Figure 4.2-5 shows the deployment of the signalling light sites with a connected network of sensors to achieve a smart traffic light system on the UNN campus area.

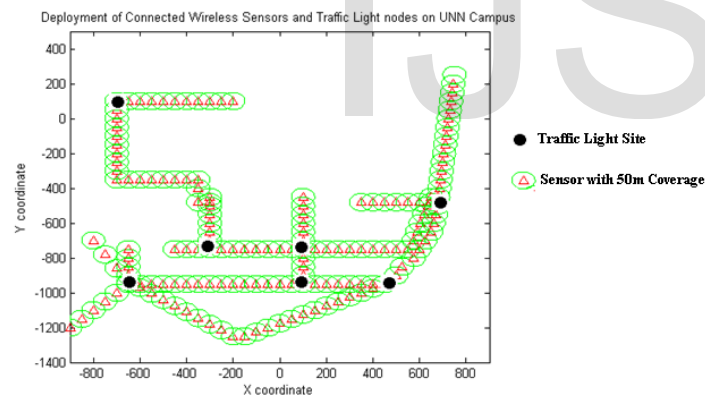


Figure 4.2-5: Traffic Light Deployment Sites with WSN on UNN Campus

5 CONCLUSION

This paper provides a study on the initial deployment and modeling approach of a wireless sensor network for a smart traffic light system on The UNN campus area. The approach is through the eyes of a predetermined vehicle where there is no existing infrastructure in place. Through the modeled motion characteristic of a vehicle, optimum locations are determined for the deployment of traffic lights on the campus area. This is based on the theory that a traffic light is to be placed at an incoming intersection where the path before that intersection gives room to a suggested excessive speeding characteristic. In essence, the traffic lights are to act as speed calmers to ensure

a safer environment of vehicle driving. A network of sensors is then deployed on the corresponding roads of which the sensor closest to signaling light, which acts as a sink, is wirelessly connected through an overlap of coverage. With such a study undertaken, the reviewed sources can now play a vital role how to manage such network architecture on the deployed region.

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