Real time traffic congestion detection and management using Active RFID and GSM technology

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Abstract--*Use of existing popular technologies for traffic congestion detection and management has been explored by several researchers in recent times. However, most of the works either deal with congestion detection strategies or address the issue of congestion control through signal manipulation or other aids. To the best of our knowledge, no effort has been made so far to develop a comprehensive system that automatically detects as well as controls traffic congestion based on detected level of congestion. The aim of this paper is to design a complete strategy for automatic road traffic congestion detection in real-time and to devise an effective scheme for control/ management of congestion using* ***Active RFID and GSM technology.*** *In this paper, we discussed some of the most widely adopted technologies for congestion detection and management, their limitations. Finally, we described the outline of our Active RFID based congestion detection and management scheme to overcome the existing problems. Further, we have illustrated a simulation model that we have developed to generate different traffic congestion scenarios, to implement and test our scheme for congestion detection and management.*

Keywords- *Real-time congestion detection, Active RFID, GSM, Coordinator, Router, Tag, Beacon, Congestion management*

I. INTRODUCTION

Road traffic congestion poses a challenge for all large and growing urban areas. Traffic congestion is a condition on road networks that is characterized by slower speeds, longer trip times, and increased vehicular queuing. Today, the number of vehicles is increasing exponentially. However, road infrastructure cannot be increased in the same ratio. This leads to increasing traffic congestion. Researchers all over the world are engaged in exploring different technologies to detect traffic congestion and making congestion management more efficient. There are a variety of technologies that are being used to detect the congestion of traffic. Most popular technology is the inductive loop system, the simplest detectors that count the number of vehicles during a unit of time. Using Airborne Camera and the image processing technology, GPS devices and webcam, Radar technology etc. congestion can also be detected. But these technologies have several drawbacks, such as installation problems and cost. Radio Frequency Identification (RFID) is an emerging technology that is still remains largely unexplored in the area of automatic congestion detection. Vehicle detection and counting can be done effectively using RFID technology.

In this paper, we propose to design a smart and fully automatic system that will detect the congestion in real time, and subsequently manage it efficiently to ensure smooth traffic flow with the use of Active RFID devices.

The paper is organized as follows. Section II describes the related works done in this area and their merits and limitations. Section III illustrates our proposed congestion detection and management scheme based on active RFID and GSM technology. Section IV describes the basic features of the simulation model and finally Section V concludes the paper with a highlight on the scope of future work.

II. RELATED WORKS

To resolve the traffic congestion problem, we not only have to consider the volume of the traffic, but also several other factors like traffic speed, road occupancy, traffic density etc. Several technologies have been proposed for congestion detection, such as inductive loop, magnetometer, infrared, acoustic, ultrasonic, visual camera, radar etc.

References [1] and [2] use Inductive loops that can be placed in a roadbed to detect vehicles that pass over the loop, while more sophisticated sensors estimate the speed, length, and weight of vehicles and the distance between them. While this system works for traffic at all speeds, it does have the drawback of a high error rate in detection and transmission of traffic information. Other drawbacks include cumbersome installation of inductive loop devices, tedious maintenance and the improbability of managing traffic locally.

Another popular technology is usage of cameras and image processing as shown in references [3, 4, 5, 6]. Here one or more cameras are installed in an airplane at a high altitude, so that all the objects on the road are visible. The optical data from both the visible and infrared spectrum as captured from the camera are studied. In reference [4], optical time series analysis is used to group the vehicle speed or traffic behavior while in reference [5] fuzzy logic is used.

The estimated velocity profiles coincide qualitatively and quantitatively quite well but these cannot be used to detect the exact cause of congestion. Also these technologies are only useful for managing traffic on highways. Moreover performance of these methods is largely dependent on the quality of the geo-referencing of overlapping images and the quality of the road database. The system is expensive too and fuzzy algorithm is not fool proof.

Passive infrared sensors, as mentioned in reference [7], do not transmit any energy of their own; rather they detect energy emitted from vehicles, road surfaces, and other objects in their field of view. Magnetic sensors can be used to sense a vehicle due to changes in earth's magnetic field caused by moving vehicle as shown in references [8, 9].

Thus all the afore-mentioned technologies solve only a part of the problem of traffic management. The basic problem is that these systems are not mature enough to deal with real-time traffic control, which may not conform to the forecast data on which these systems work. This paper proposes a new approach to precisely detect the real time traffic congestion and tackle it with the help of the emerging active RFID technology.

III. Proposed Congestion Detection & Management Scheme

Our scheme basically consists of two parts: a) detection of congestion at any road leading to a junction and b) effective management to control that congestion ensuring smooth traffic flow. At present traffic lights are passively controlled. At the time of setting up the traffic lights at a particular junction, the concerned officials study the traffic flow pattern through that junction at different times of the day on different days of the week. From this observed flow pattern, the corresponding timers of traffic lights are programmed to operate for a predefine time-duration. However, the pre-programmed scheme for traffic lights can be overridden to control them manually, if such a need arises.

Our aim is to do away with the necessity of manual control. That is, the traffic lights should change automatically so as to ensure smooth traffic flow through the junction at all times, regardless of the occurrence of any incident.

A. System overview

Let us consider a four point crossing, and for convenience, let us name the 4 stretches leading to the junction as A, B, C and D. Let us denote the left, straight and right turn from any stretch be denoted by 1, 2 and 3 (in subscript). Thus, for example, let us denote all vehicle movement from stretch A towards stretch D (i.e. left turn) by A_1 and so on.

The salient features of our scheme are as follows.

- We check the average speed of vehicles in stretches A, B, C and D as they approach the junction.

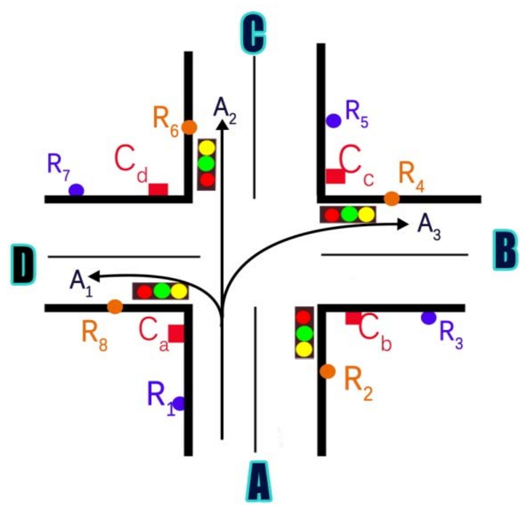

Figure 1. Model junction with RFID devices

- If the average speed of vehicles falls below a threshold at any particular stretch, the system will detect that as congestion and will also measure the intensity of congestion comparing the detected data with the normal traffic speed data already recorded for that stretch. In such a situation, a message is sent to the junction prior to the current junction in that stretch, asking to stop all inflow of traffic in that stretch.
- Since our system offers real-time congestion detection, therefore, as the congestion is released, automatically the system will send another message to the previous junction,

notifying to resume flow of vehicles in that stretch.

- Since this system is fully automatic, there should not be any need of any manual intervention.

B. Device Description

We are using active RFID devices (tags, routers and gateway/ coordinators) from PervCom Consulting Pvt. Ltd [10]. All the wireless devices namely, tags, routers and coordinators from PervCom are IEEE802.15.4 compliant low-power and short-range RF devices operating on 2.4 GHz frequency band. Tags emit radio signals that can be captured by devices like routers or coordinators. Routers are capable to capture tag data and relay the captured data to either another router or coordinator in its range. Coordinators have a serial interface through which external GSM/ GPRS devices can be interfaced with it to make it a dual-radio device, one is 2.4 GHz radio interface and the other is GSM/GPRS interface. Coordinator receives data from either router or tag using its 2.4 GHz RF interface and can communicate with remote server using its GSM/GPRS interface. The GSM/GPRS modem of WaveCom is used for our testing and the module operates at 115200-baud rate.

Figure 2. a) Tag b) Router c) Coordinator

C. Placement of Devices

- We assume that all the vehicles have a unique active RFID tag attached to them.
- We assume that all the four roads leading to the junction are 2-way and traffic can flow along three different directions from a crossing.
- C_a, C_b, C_c and C_d are coordinators and R_1 to R_8 are routers that are capable of reading active RFID tags. Routers and coordinators are placed 100 mts apart on each stretch of road leading to crossing. (Figure 1)
- Further, we ensure that all the four coordinators placed near a particular junction are not in each other's range of communication through RF. Also, R_2 and R_3 are in the range of C_b, R_4 and R_5 are in range of C_c and so on.
- All the coordinators are connected to GSM modems, and are capable of receiving and sending SMS texts to coordinators in other neighboring junctions, and also to the local traffic kiosk and central control room.
- Traffic lights at the junction are controlled by the coordinators nearest to them.
- All coordinators have a physical clock integrated with them, and they are capable to recording timestamps (the absolute time of occurrence) of events.

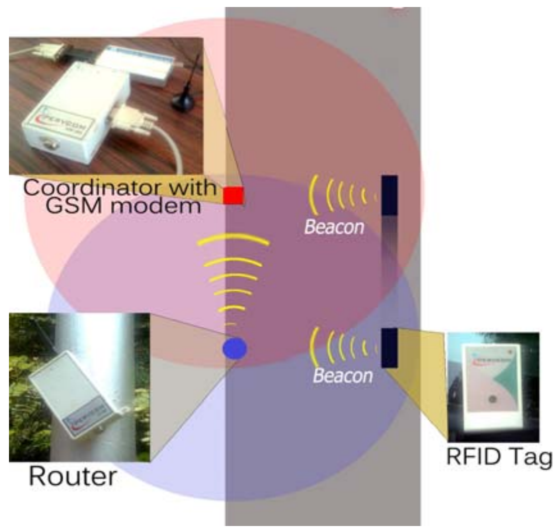

Figure 3. Actual RFID devices in operation

D. Congestion Detection Phase

- When a vehicle passes the router, the active RFID tag of that vehicle sends a beacon to the nearest router. Router then forwards it to the coordinator (Figure 3).
- As soon as the coordinator gets the router's message, immediately it saves the message and waits for getting another message from the same tag when it passes by the coordinator.
- When that tag passes by that coordinator it sends another beacon to the coordinator.
- After receiving the beacon, from its timestamp, the coordinator calculates the speed of the vehicle and sends it to the control station using GSM network.

We propose that all the stretches leading to the junction get the green signal in a cycle, for a time duration that is proportional to the population of vehicles in each stretch.

This population is calculated from the number of tags that are in the range of each coordinator. For example, the population of vehicles in stretch A that are bound towards the junction can be determined from the number of active tags read by coordinator C_a at the beginning of the light cycle.

We assume that C_a only reads those tags that have already been read by router R_1, and it rejects signals from all other tagged vehicles that are moving through other stretches and might be in its RF range.

After obtaining the count and the average speed of all vehicles, the coordinator determines the level of congestion depending on some predefined condition.

E. Congestion Management Phase

When a coordinator detects a high level of congestion, it cannot take further load since further traffic volume can create a stand-still situation. It sends a SMS to coordinators in its preceding junction notifying them to temporarily stop traffic along that stretch.

After receiving the SMS from its successor crossing point the coordinator will put the red signal on for that stretch towards that congested crossing point for a set period of time.

As soon as the congestion is released at the crossing, the corresponding coordinator will send another SMS to its earlier coordinator indicating to resume the traffic flow again in that direction.

Accepting this message the coordinator of the preceding junctions put the red light off and green signal on and restart the signal cycle as before.

F. System Operation

Routers R_1, R_3, R_5 and R_7 are placed to detect traffic flow towards the junction from all 4 stretches. Say, for example, we consider stretch A. As soon as a new tag enters within the range of R_1, say at time t_1, it sends a message (through RF) to its parent coordinator, i.e. the coordinator nearest to it (C_a in this case), and the coordinator records the time stamp of it. Then when this tag enters within the range of C_a, say at time t_2, it again records the timestamp of it. Then travel time will be calculated as

$$\Delta t = t_2 - t_1,$$

And speed will be calculated as

$$v = d / \Delta t$$

where d is the approximate distance between R_1 and C_a, which is assumed to be known.

Now when stretch A has green signal, and if we see that the average speed v of the vehicles is below a threshold value, say v_0, we perform another check:

We find out the number of tags (which is equal to the number of cars) in the range of the corresponding coordinator, C_a in this case and that value is stored in a variable, say N. Now if N is larger than a threshold value, say N_0, then we can say with surety that congestion has taken place in that road stretch. N_0 and v_0 are determined for a particular road stretch by considering factors like the width and length of the road stretch. Thus necessary and sufficient conditions for congestion to occur are:

$$N > N_0 \quad \text{and} \quad v < v_0$$

In such a situation, the immediate task would be to stop all inflow of traffic into stretch A from the preceding junction. So, immediately, C_a sends an SMS to the coordinators of the preceding junction (through its GSM modem) so as to control their traffic lights in such a way that there is no more inflow of traffic into stretch A, i.e. all traffic is either diverted or temporarily stopped at the preceding junction.

Again when the congestion is released in stretch A, C_a sends another SMS to coordinators in the preceding junction notifying them to allow traffic into stretch A. The same scheme is applied to all stretches B, C and D and at all junctions.

Coordinators also send an SMS to the central control station from time to time, notifying them about the current number of vehicles and their speed in their associated stretches and the software at central control station will parse the data and display the level of congestion at that stretch of the road on a map-based GUI.

IV. SIMULATION MODEL

Our simulator, developed with Java applet, imitates traffic flow on a predefined road map. It is complete with user controls like acceleration of the vehicles, pause and resume buttons. Our road map has 6 junctions and vehicles can approach each junction from any of the 4 directions viz. north, south, east and west. All roads are 2-way and have 3-lanes. Each junction has 4 traffic signals, each to control traffic on its corresponding side. Each traffic signal consists of 3 independent lights for controlling the left, straight and right movement of vehicles in at the junction.

A. Simulation Properties

In our simulator, under normal circumstances, left turn at all junctions from all directions, is always allowed (even when that stretch does not have green signal in general), as is the general practice in real life. The vehicles are generated randomly and independent of each other and maintain a minimum gap on all sides to prevent collision. All vehicles start from rest and then accelerate uniformly but maintain the minimum distance of separation at all times.

U-turns are not allowed. Prior to making 90 degree turns, vehicles must decelerate.

B. Simulation analysis

Our simulation model intends to dynamically control the green signal time at the junctions based on the level of congestion (number of vehicles waiting at the junction) and average waiting time. Initially all the junctions have a green signal time of 50 time units (pre-set). Next we create congestion at Junction J1 by reducing the rate of outflow by slowing down the vehicles approaching it from south. The queue of waiting vehicles built up at J1, as a result, stops vehicle movement from west direction (despite the signal being green) and vehicles for right turn from south direction at junction J2 as shown in Figure 4 below.

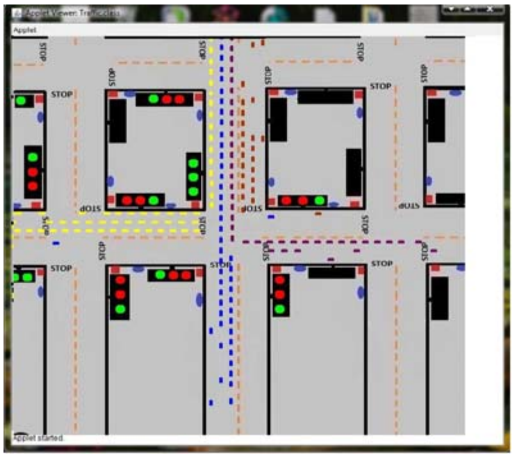

Figure 4. A congested situation at junction J_1 &J_2

This increases average waiting time for vehicles at J2 as shown in the graph below. The average waiting time is calculated by taking the total of waiting time of all vehicles divided by 240(since there are 60 vehicles per direction at J2). This is done for each duty cycle and plotted.

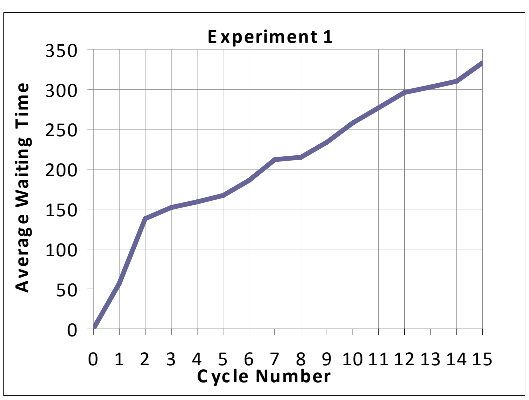

Figure 5. Average waiting time without the proposed scheme

To reduce the average waiting time of vehicles at J_2 and the congestion between J_1 and J_2 we need to reduce vehicle inflow rate at J_2 and increase the outflow rate at J_1. We do this by allowing more vehicles to leave by **increasing the green signal time at J_1** and pumping fewer vehicles by **decreasing the green signal time at J_2,** when the queue length at J_1 increases beyond a threshold. This effectively reduces average waiting time at J_2.

C. Results

Initial Conditions:

1. Maximum number of vehicles per direction per junction is 60
2. Acceleration of all vehicles is unit distance/(unit time)^2.

By implementing our scheme, green signal time of signal TL_1 and TL_2 are automatically decreased (refer Figure 4) at J_2 from 50 time units to 30 time units and green signal time at J_1 is increased from 50 time units to 70 time units. To keep the total duty cycle at J_2 constant, signal timings of other two signals viz. TL_3 and TL_4 are automatically adjusted. The result is as shown below:

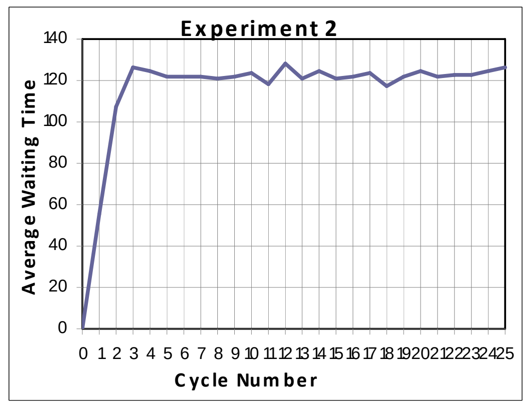

Figure 6. Average waiting time applying the scheme.

We observe a significant decrease in the average waiting time of vehicles. Moreover, it is to be noted that the average waiting time attains a near constant value of 122 time units after a few cycles. The traffic scenario is shown below in Figure 7. We observe a significant decrease in congestion level at J_1. We see that signal A at J_2 is red while signal is still green at J_1. This facilitates more vehicles to leave the J_1 thus reducing queue length of vehicles approaching J_1

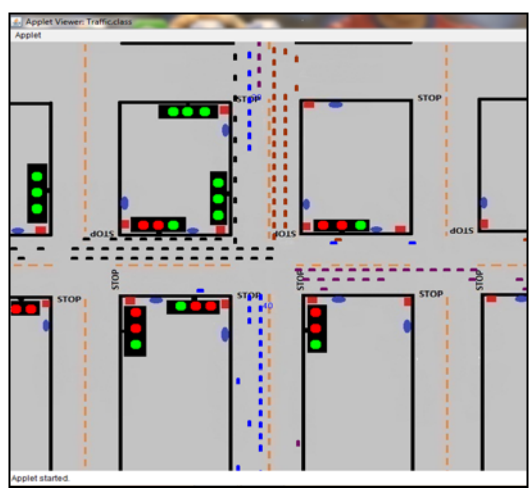

Figure 7. Reduced congestion level near junction J_1

V. Conclusions and Further Research

In this paper we have adopted the active RFID technology to automatically detect and manage road traffic congestion in near real-time since it is cost effective, easily manageable and reliable. Moreover, this method provides comprehensive way of congestion detection and management as a whole while most other methods are restricted only to congestion detection. The simulation results give us a fair idea of the extent of congestion occurred at a particular crossing and how the proposed schemes of congestion management reduce the waiting time significantly.

There are further scope of enhancement and extension of this idea to improve congestion management process ensuring smooth traffic flow in city in busy hours.

Here, we have used the GSM network to exchange SMS among the coordinators, which is not fully reliable. Loss of message or delay may hamper the correct detection of congestion and real time delivery of message. It is better to design an indigenous network solely dedicated for this process.

The router and the coordinator needs to be **solar powered and weather-proof** as they will be kept in outdoor environment and relies on battery power. Therefore, we can work towards integration of solar cells as supplementary source of energy which can further reduce the cost.

We have taken into consideration only the velocity of the vehicles as the main criteria to determine the degree of congestion in a particular stretch of road. Other criteria, such as, average waiting time of vehicles, average queue length, and some special cases (site of incident) might be taken to consideration to measure congestion more accurately.

Finally, we can also dynamically control the signal timing of the traffic light depending on the degree of congestion at a particular lane.

Acknowledgment

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