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Road Traffic Congestion Detecting by VANETs

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Abstract. Accurate traffic congestion detection methods are needed urgently to improve road traffic pressure and congestion, especially in metropolitan areas. This paper proposes TraD-VANET, a new road traffic detection system that employs RFID-based active vehicle positioning and vehicular ad-hoc networks (VANETs) to detect traffic congestion dynamically. The results can be used to making road traffic flow more fluent and effective. To validate the performance of TraD-VANET, we ran a simulation compared with cooperative traffic congestion detection (CoTEC). The simulation results shown that TraD-VANET has a good performance.

Introduction

The number of vehicles on roads continues to grow rapidly as living standards improve, resulting in increasing traffic density and road traffic congestion problems. It is well known that heavy road traffic density and traffic congestion increase individual travel costs, results in economic losses, and contributes to environmental pollution. Alleviating or settling road congestion is one of the most important challenges faced by transportation departments worldwide. A critical aspect of traffic management is the ability to detect road congestion accurately and swiftly. Several centralized approaches to detecting vehicle congestion have been used. However, they are not cost effective. As an alternative, decentralized approaches to detecting vehicle congestion use GPS probe vehicles [1–3]. The precision of these approaches depends on the number and distribution of the probe vehicles used.

Inter-vehicle communication (IVC) and vehicle-to-vehicle (V2V) communication systems are among the intelligent transportation system (ITS) technologies with the potential to improve traffic safety and efficiency through the continuous exchange of information between vehicles. These vehicles constitute mobile networks called vehicular ad-hoc networks (VANETs). Motivated by the pressing need for accurate road traffic congestion management in real-time, and inspired by recent development in ITS, in this paper we propose a method that we call traffic detection and guidance using vehicular ad-hoc networks (TraD-VANET). In this method, first we establish the number of vehicle nodes. Each node obtains its own accurate location by using active positioning based on RFID technology. Then, the vehicle nodes cluster autonomously by using VANETs to communicate with each other. Each cluster has a single cluster head, and the nodes send their speed and location data to the cluster head. Based on the information received from the cluster members, the cluster head calculates the lane-weighted average speed and the traffic density adaptively. Then the traffic flow in the cluster is estimated by the cluster head using fuzzy logic. Subsequently, the fused traffic information is shared among clusters through VANETs to help drivers to choose the most effective routes.

The TraD-VANET is based on two assumptions:

(1) Because GPS technology is not able to locate the lane in which a vehicle is moving, RFID-based active vehicle positioning systems are installed on all vehicles for that purpose.

(2) Each vehicle is equipped with a wireless communication unit that enables them to communicate with each other to form a cluster and exchange traffic messages.

The remainder of this paper is organized as follows. Section 2 reviews related work, and Section 3 introduces the proposed TraD-VANET. The simulation is proposed in Section 4. The conclusion is provided in Section 5.

Related Work

Currently, traffic congestion detection methods estimate congestion levels based mainly on travel speed, travel time, waiting time, traffic density, queue length, and similar factors. The congestion detection methods introduced in [1, 2] use GPS to determine the current vehicle locations and speeds, and estimate the congestion level by simple comparison between the present speed and the road's posted speed limit. Since speed is the only input other than location, the advantage of these methods is that the amount of input information is reduced. The disadvantage is that the estimated congestion result is not an accurate reflection of the actual traffic conditions.

In [3], a new method for detecting road traffic congestion was defined. This method does not need any prior knowledge and does not require the estimation of any road parameters (e.g., number of lanes, traffic light cycles). Instead, this method uses probe vehicles to detect and report the traffic conditions around them. To improve the method offered by [3], researchers [4] developed an intelligent traffic congestion monitoring and measurement system to monitor and measure road congestion using probe vehicles. This system combines active RFID and GSM technologies to calculate the average speed and waiting time of the probe vehicles at an intersection by acquiring the trip time. The congestion level is established based on the average speed and waiting time. The quality of the results of the probe vehicle-based methods described in [3] and [4] depend mainly on the distribution and number of probe vehicles. Therefore, these methods require a substantial number of probe vehicles, which could have the disadvantage of taking up additional space on the road.

The authors of [5] and [6] proposed a communication system for road congestion detection. Each vehicle plays the role of a mobile sensor that continuously records road congestion information by monitoring its own speed and travel times. In [6], vehicles send beacons at random intervals, with the maximum and minimum intervals being six seconds and three seconds, respectively. When a vehicle's monitoring equipment receives a beacon, the monitor adds that vehicle node to its list of neighbors. If the receiving vehicle does not lose any neighbors for a pre-determined period of time, the receiving vehicle concludes that it is in a congested traffic flow.

In [7], the authors proposed an innovative approach to deal with the problem of traffic congestion using the characteristics of VANETs and an Internet-based congestion control algorithm known as the adaptive proportional-integral rate controller. In this method, queue length and average speed data detected by sensors mounted on vehicles are sent to roadside controllers. The controllers then use the information to estimate the congestion level. In other research, [8] used the vehicles' location, speed, and travel time data, as reported by the vehicles themselves, to estimate traffic congestion. In this method, all the vehicles are used as traffic information sensors.

Elsewhere ([9]), researchers proposed cooperative traffic congestion detection (CoTEC), a cooperative technique that uses vehicle-to-vehicle (V2V) communications and fuzzy logic to detect road traffic congestion without the need to deploy infrastructure sensors. It is worth noting that CoTEC does not generate any additional communications overhead when traffic conditions are normal, since the cooperative procedure is launched only when a traffic congestion condition is detected locally.

TraD-VANET Detection Process

In the proposed TraD-VANET method, the location of the traffic density and the weighted average speed are key parameters for road traffic congestion detection. For finding the exact location of the traffic congestion, we use an active vehicle positioning method based on RFID technology, as described in [10].

Detection Scheme

The proposed traffic congestion detection process is shown in Figure 1. All vehicles act as probe vehicles that collect their location and speed information and forward the data to the cluster head. The steps shown in Figure 1 are described as follows.

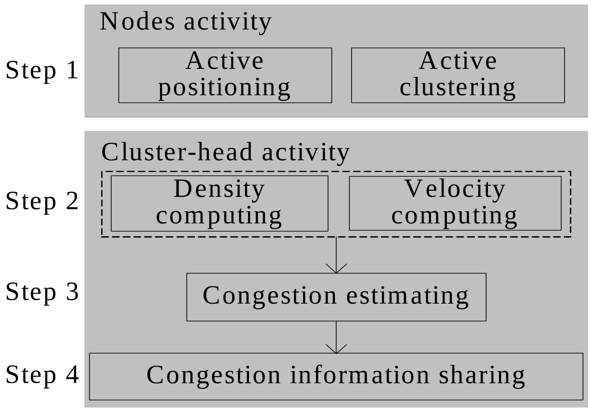

Figure 1. Congestion detecting scheme

•**Vehicular nodes activity:**

Step 1: Active positioning and clustering

Vehicle nodes establish their locations in the lanes in which they are running. The nodes form clusters actively by using wireless communication systems, and then they send their speed and location data to their cluster heads periodicity.

•**Cluster head activity:**

Step 2: Traffic density and lane-weighted average speed calculation

The cluster head calculates the traffic density based on the number of vehicles in the cluster and the cluster coverage (i.e., the number of the lanes covered by the cluster head and the communication range of the cluster head). At the same time, the cluster head assigns different weights to speeds from vehicles on different lanes, and it calculates the lane-weighted average speed for its cluster.

Step 3: Estimating the congestion status

The cluster head estimates the traffic congestion by using the traffic density and lane-weighted average speed of the cluster, as described further in Section 3.3

Step 4: Sharing of congestion information

The traffic congestion information is shared among clusters through inter-cluster communication.

Clustering

Clustering is an important data mining tool [2, 11]. In VANETs, clustering is a process of combining data points that are similar to each other (such as data for similar characteristics or for a phenomenon described by particular physical quantities) that are obtained by different categories of sensors. The cluster head then fuses the data input from the cluster with data fusion technology to reduce data redundancy and save network resources.

In this paper, we use the direction-based clustering algorithm. Cluster head selected method follows the principle of choosing the minimum distance between any two vehicle nodes. To maintain the stability of a cluster, the size of the cluster is increased to the largest possible size as shown in Figure 2. The clustering scheme used in this paper is described in [12]. After forming clusters, cluster members send their location and speed information to the cluster heads. The cluster head calculates the traffic density and the lane weighted average speed of its cluster. Afterwards, the cluster head estimates the traffic situation in the cluster based on the calculated results. Finally, cluster heads share the estimation results among clusters through VANETs. In the sharing process, traffic condition information is refreshed periodically by clusters. The length of the period varies based on the actual status of the road.

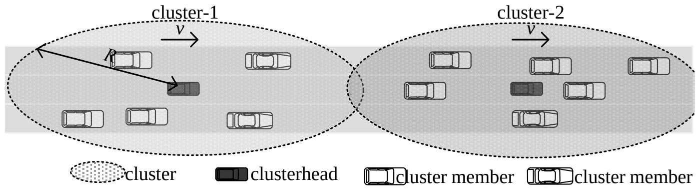

Figure 2. An illustration of vehicle clusters

Traffic Congestion Estimation

Vehicle Density. In calculating the vehicle density, the number of lanes is taken into consideration. GIS information and the vehicle location data are used in determining the number of lanes of the road under consideration. Every vehicle is assigned a unique number that is made available to the cluster head through inter-vehicle communication. The traffic density in each lane is given by

$$\rho_{lane-i} = \frac{N_i}{2R}, \tag{1}$$

Where i denotes the ith lane, N_i denotes the vehicle number on the ith lane in the cluster, and R denotes the radius of the cluster as shown in Figure 2.

Considering moving vehicles can change lanes, the average traffic density in the cluster can be calculated as

$$\rho_{cluster} = \frac{1}{L}\sum_{i=1}^{L}\rho_{lane-i}, \tag{2}$$

Where L denotes the total number of lanes.

Weighted Average Speed. There may be some road (such as major highways and some city express ways) often have different speed limits for different types of vehicles (e.g., trucks vs. passenger cars), and vehicles may travel at different speeds in different lanes on the same road, so the statistical average speed of all vehicles in a cluster cannot reflect the real traffic situation on the road. Therefore, in this paper, we compute the average speed of the vehicles in the same lane by using the statistical average method. Then we use the weighted average algorithm to obtain the lane-weighted average speed for the cluster:

$$v_{cluster} = \sum_{i=1}^{L}\sum_{j=1}^{N_i}\frac{w_i v_{ij}}{N_i}, \tag{3}$$

Where v_{ij} is the instantaneous speed of the jth vehicle in the ith lane, and w_i is the weight of the speed in the ith lane. The weights of the lanes are obtained by actual measurement. The cluster head acquires the speed of each vehicle instantaneously through inter-vehicle communication in its cluster.

Congestion Level

Table 1. Input speed & density sets with output congestion levels

		Weighted average speed on road		
		Low	Intermediate	High
Traffic density	Sparse	Slight	Free	Free
	Medium	Moderate	Slight	Free
	Dense	Severe	Moderate	Slight

In general, four levels (free, slight congestion, moderate congestion, and severe congestion) are enough to describing the traffic congestion situation as shown in Section 5. In this paper, fuzzy logic rules are used to categorize the level of congestion based on the road type, lane-weighted average speed, and traffic density of the roads. The flow chart of the decision process using fuzzy logic is shown in Figure 3. Based on the traffic congestion level categorization method described in [9], the relationship between the weighted average speed, traffic density, and congestion level is shown in Table 1.

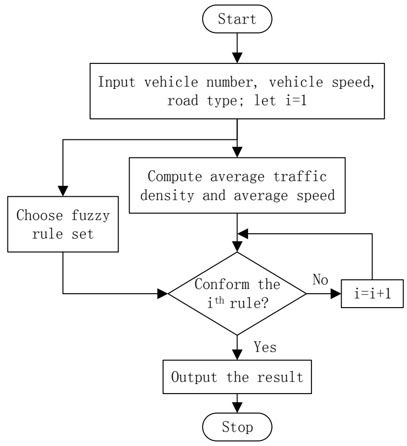

Figure 3. Flow chart of the decision process using fuzzy logic rules

Table 2. Simulation parameters

Parameter	Specification
Model Simulator	NetLogo V4.1RC5
Simulation Time	500 ticks
Lane width	1 unit
Number of Vehicles	0-100 (adjustable)
Maximum Speed	0.6
Patch size	8×60
Control Range	5 patches front and back
Road Topology	Two-way road

Simulation

The simulation was performed using NetLogo[13]. The simulation scenario is two-way road and the simulation parameters are shown in Table 2. To evaluate the accuracy of the CoTEC local estimation method and TraD-VANET, we compared the performance of each against the results attained when the traffic congestion estimation is made in a centralized fashion by infrastructure. We refer to the method used as the basis for comparison as the “Centralized” case, as in [9].

We used six scenarios in the simulation. Scenario 1: free traffic flow with 20 cars; Scenario 2: free traffic flow with 40 cars; Scenario 3: slight congestion with 60 cars; Scenario 4: moderate congestion with 70 cars; Scenario 5: severe congestion with 80 cars; and Scenario 6: severe congestion with 90 cars. The simulation results are shown in Figures 4–9.

The estimation results of these three methods are almost in keeping with expectations for the simulation Scenarios 1, 5, and 6 (as shown in Figures 4, 8, and 9, respectively). The traffic flow is stable in Scenarios 1, 5, and 6. Therefore, they have similar estimation results. However, in Scenarios 2, 3, and 4, the traffic flow is very changeable. The estimation results fluctuate slightly, as shown in Figures 5–7. The performance of TraD-VANET was much better than the results achieved by the CoTEC local estimation method. The estimation errors resulting from TraD-VANET and the CoTEC local estimation method are displayed in Table 3. As can be seen from Table 3, the TraD-VANET method was more capable than the CoTEC local estimation method of closely following the estimation obtained through the Centralized approach.

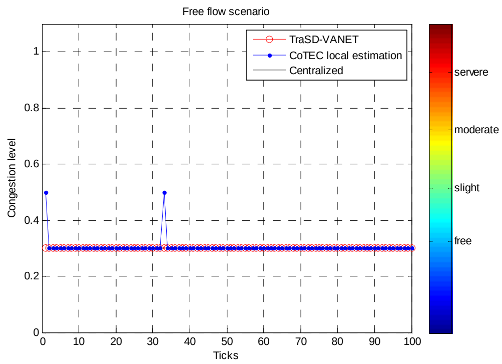

Figure 4. S-1: Free traffic flow (20)

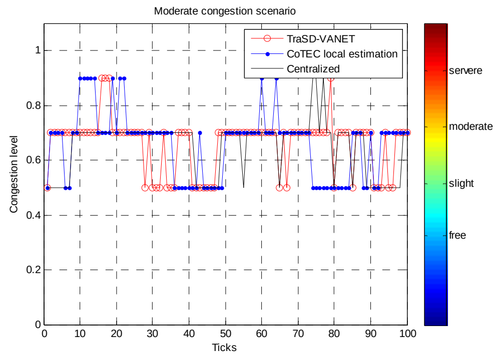

Figure 7. S-4: Moderate traffic congestion (70)

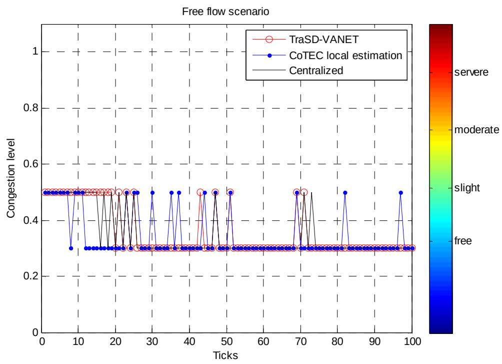

Figure 5. S-2: Free traffic flow (40)

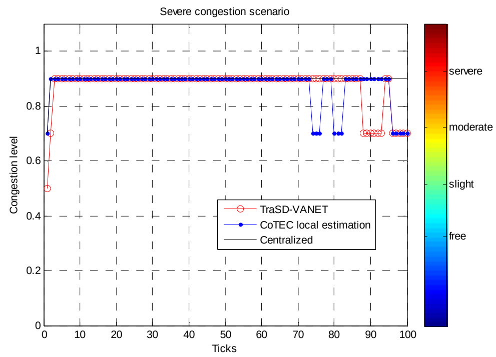

Figure 8. S-5: Severe traffic congestion (80)

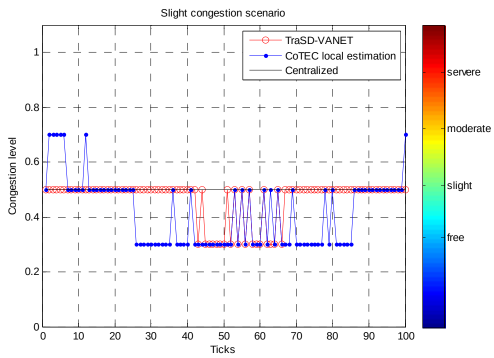

Figure 6. S-3: Slight traffic congestion (60)

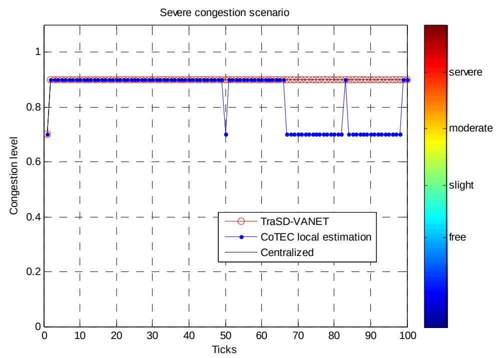

Figure 9. S-6: Severe traffic congestion (90)

Table 3. Comparison of estimation results between TraD-VANET and CoTEC local estimation method for different scenarios

Items	S-1	S-2	S-3	S-4	S-5	S-6
TraD-VANET	0	6%	17%	29%	13%	0
CoTEC	2%	19%	56%	43%	11%	32%

Summary

In this paper, we proposed a new road traffic congestion detection method called TraD-VANET. Vehicles create clusters automatically by using inter-vehicle communication. The cluster head then estimates traffic congestion based on vehicle speed and location data gathered from its cluster members to calculate the lane weighted average speed and traffic density. Our simulation results demonstrated that TraD-VANET can estimate the state of the traffic more precisely than the CoTEC local estimation method.

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