# TRAVEL TIME MEASUREMENT SYSTEM USING VEHICLE-TO-INFRASTRUCTURE COMMUNICATION

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**ABSTRACT**: Travel time of vehicles in a roadway network is one of the important information in evaluating the real time traffic condition and improving the exploitation of roadway systems. Intelligent Transportation Systems (ITS) are used to address the problem of estimating the travel time for interested authorities. Travel time information which is generally estimated from traffic data such as vehicle speed and volume is not accurate and real time. This paper presents a design, implementation and evaluation of a model which is used to measure the travel time using vehicle-to-infrastructure (V2I) communications and the Global Positioning System (GPS). The model provides measured travel time information in real time adapting with variable traffic conditions.

## 1 INTRODUCTION

The traffic volume on roads has been increased significantly as more and more people use cars as their primary mode of transport. Growing economies all over the world brings about an increase of commercial traffic on the roads. The increase of traffic volume leads to an increase of the delay on roadway networks as the capacity of some road infrastructures reach to their limit. Furthermore, not only the traffic volume but also weather conditions, driving behaviours effect on the journey delay. Road traffic authorities need accurate travel time information in order to give better traffic management services. To address this problem a good travel time estimator is required. Traditionally, the travel time is estimated from other measures such as volume, speed, and occupancy of vehicles. These measured data are collected from roadside detectors such as infra-red detectors, radars, surveillance cameras or inductance loop detectors. Among them, inductance loop detectors are the most widely used. Many studies have been developed to improve the accuracy of this estimative information. However, they can not directly provide the real time data and have limitations in capturing wide area of traffic. Recent advances in information and communication technology, such as Global Positioning Systems (GPS) and the cellular phone positioning, has shown its potential as a valuable real time traffic data source in estimating travel time using probe vehicles. Such vehicle-based systems are expected to provide high-fidelity traffic information when there are enough probe vehicles. A low probe rate causes a biased travel time estimate with a higher variance. This paper proposes a model that can directly measure the vehicle travel time which relies on the wireless communication between vehicles and infrastructure (V2I). This model will provides real time accurate measured information compared with the estimative information. Moreover, the proposed solution gives an advantage which is that the rate of communicable vehicles effects only on the availability of measured information not on the accuracy.

The paper is organized as follows. Section 2 introduces an overview of travel time estimation techniques. Section 3 describes the proposed method of measuring the travel time. The results and their discussion are shown in Section 4. Finally, we conclude the paper and discuss about our possible future works in Section 5.

## 2 OVERVIEW OF TRAVEL TIME ESTIMATION

There are generally two ways to obtain the travel time information: indirect and direct. Indirect methods refer to the estimation of travel times derived from speed, volume or occupancy of vehicles at specific positions in a road network. There are two typical indirect methods in estimating the travel time. For the first method, point speeds are estimated and transformed to the travel time based on an assumption of average vehicle lengths and constant speeds over network links. However, errors of the speed estimation and the transformation from speed to travel time effect on the travel time estimation. Several studies such as [1] have been realized to increase the accuracy of point speed estimations. The second method aims to develop a stochastic model for traffic flows and estimates the travel time by investigating the data obtained from loop detectors [2]. These mathematical models can not provide accurately the travel time under congested traffic conditions. Direct methods refer to the measure of travel time using probe vehicles. Good travel time estimation was shown in paper [3] for freeway. In this model, they collect data called Floating Car Data (FCD) in actual traffic conditions based on a broadcast radio communication between vehicles and infrastructure such as the GSM (Global System for Mobile Communications) at a tracking interval. Travel time between two reference points is calculated from FCD collected every tracking interval. So the time when FCD is collected is not always the time when probe vehicles reach these reference points. As a result, probe car information is incomplete in many cases and leads to an inaccurate travel time estimation for some specific pairs of Origin-Destination points.

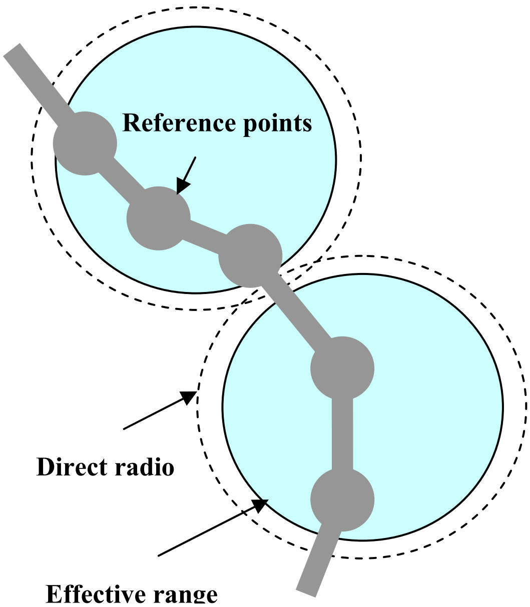



**Fig.1. Effective range of V2I stations**

# 3 PROPOSED MODEL

In the proposed model, vehicles and communication roadside equipment form an ad-hoc network which has no pre-arranged infrastructure. The vehicles which are considered as nodes in the network are mobile, so a vehicular ad-hoc network (VANET) is created [5]. Roadside equipment called V2I station manages an area within its direct radio range. We assume the vehicle's transmission range is long enough for the connection to V2I stations, whenever they enter the range of the V2I stations. In fact, the overlap between coverage areas of V2I stations can lead to an inaccurate detection of vehicles. Therefore, we define an effective range for each V2I station instead of using their direct radio range. In the example of Fig. 1 there are two V2I stations covering a roadway. The effective range is smaller than or equal to the direct radio range so that there is no overlap between effective areas. Every query period Tquery, V2I stations broadcast a query message to all vehicles in their effective range. Vehicles reply to the query with a ”Hello” message which contains their own information such as the identification number (ID), location, sending time. The vehicle speed is given by the on-car speedometer. Each vehicle is assigned a different ID. We define different reference points in the range of V2I stations. Collected vehicular data is then analyzed to estimate travel time between reference points.

## *3.1 Query period*

In order to ensure the communication, query period must be longer than the maximum transmission delay. Before dealing with the query period, we first need to estimate the transmission delay between vehicles and a V2I station. We assume the size of exchanged messages does not exceed 50 bytes or 400 bits. If the communication follows the WLAN (wireless local area network) standard 802.11 at a bit rate of 11Mbps, the transmission delay for each message is : $\frac{400}{11} = 36(\mu s)$. This delay increases if there are many vehicles communicating with the V2I station at the same time. If the effective range (R) of V2I stations is 200 (m), the coverage area of each is given by: $\pi * R^2 = 125600(m^2)$. We also assume the average space size for a vehicle is 5 (m) in length and 3.5 (m) in width (equals to the lane width). The maximum number of vehicles present in this area is N = $\frac{125600}{3.5*5} = 7177$. The maximum transmission delay is $D = 7177*36*10^{-6} \approx 0.26(s)$. Tquery is set to 0.5 second in this model.

## *3.2 Offline data processing*

Each V2I station stores offline data containing information about their ID, location, range as well as information of reference points within their range. All offline data are represented in the form of Station tables and Point tables as follows. Location parameters are 2 dimensional coordinates (X,Y).

- Station_table = { X, Y, ID, effective range}
- Point_table ={X, Y, ID, radius}

## *3.3 Online data processing*

Online data refers to all information received from Hello messages of vehicles. V2I stations update online data every query period and keep only data of vehicles which are located within their effective range. Online data are in the form of Vehicle tables as follows.

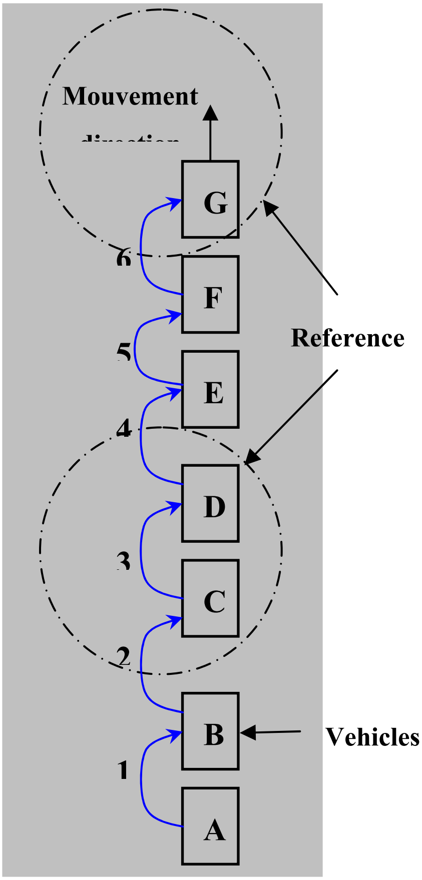
- Vehicle_table = {X vehicle, Y vehicle, vehicle ID, current time, speed, station ID, current point , precedent point, precedent time, communication index}

V2I stations can localize vehicles and predefined reference points relying on online and offline data. Current point and precedent point refer to the reference points where the vehicle currently and previously passes within Tquery. They are determined by comparing the position of the vehicle and reference points. Current time and precedent time refer to two instants of time when the vehicle currently and previously pass a reference point. Communication index is a variable which presents whether the vehicle is equipped with a communication device to exchange data with V2I stations. It is used to evaluate the impact of communication capacity rate on the calculation result. Fig. 2 shows an example of how a vehicle is tracked between two reference points. There are 7 possible positions of a vehicle: A, B, C, D, E, F, G tracked every Tquery. So we can discriminate 6 possible cases of mutual space relation between the two successive positions of the vehicle and 2 reference points within Tquery.

- Case 1: precedent point and current point are unspecified
- Case 2 : precedent point is unspecified and current point is specified
- Case 3 : precedent point and current point are the same and specified
- Case 4: precedent point is specified and current point is unspecified
- Case 5: precedent point is specified (the same as case 3 and 4) and current point is unspecified
- Case 6 : precedent point and current point are specified and different

In order to provide the travel time information, vehicles have to pass through as least 2 reference points. As a result, in the cases number 1, 3, 5 there is no travel time information update. Current point is updated in case 2, and precedent point is updated in case 4. Only in case 6, when origin and destination reference points are specified, we can get the travel time information which is the difference between 2 instants of time. Every time when there is a vehicle in case 6, we obtain one value of the travel time between two reference points.

**Fig.2. Vehicles and reference points distribution**



## 3.4 *Travel time calculation process*

Offline data of all V2I stations is available in the traffic control centre and online data is updated frequently every Tquery. We define a travel time table (Table 1) between reference points in the road network in the form of an Origin-Destination table where each cell presents the travel time value between an origin and a destination point. Raw travel time data from V2I stations is collected every Tquery. After every data extraction period which is much longer than Tquery we calculate mean values of raw data at each cell of the travel time table. The calculated mean value shows us the mean travel time during an extraction period. In traffic engineering, travel time information is collected during longer intervals of time (generally 15 minutes). In this paper, we use 60, 90 and 120 seconds for data extraction periods.

**Table.1. Origin-Destination table**

| Origin\Destination | … | Point i | Point (i+1) |
|---|---|---|---|
| … | | | |
| Point i | | X | |
| Point (i+1) | | | X |

# 4 EVALUATION OF THE PROPOSED METHOD

The proposed method was tested with the traffic simulator VISSIM [4] on Windows platform. We created a roadway network in VISSIM with traffic to provide online and offline data. An external module was also made using Visual Basic language. It collects online and offline data from VISSIM every Tquery to calculate the travel time every data-extraction period.

The simulation roadway model is considered as shown in Fig. 3. The road system consists of six 2-lane roadways which form 8 intersections. Three 200m-effective-range V2I stations cover several defined areas in the roadway network. Vehicles were set to move through the network at speed up to 36 m/s with a static routing decision. The simulation was for 600 seconds, 900 seconds, and 1200 seconds executed with 10 data-extraction periods of 60 sec, 90sec, and 120 sec respectively. Nine reference points from 0 to 8 were defined at 8 intersections and a curved joint on a road. Their diameters are equal to the road width so that we can detect all vehicles at reference points. We defined also nine travel time points which are placed at the same positions of reference points to measure the travel time of the simulation. As a result, travel time information obtained from the proposed method was then compared with the information from the simulation. The simulation parameters are shown in Table 2.

**Table.2. Simulation parameters**

| Parameters | Value |
|---|---|
| Query period [sec] | *0.5* |
| Data extraction period [sec] | *60, 90, 120* |
| Vehicle length [m] | *5* |
| Effective range [m] | *200* |
| Maximum vehicle speed [m/s] | *36* |
| Message size [byte] | *48* |
| Input volume [vehicle/h] | *150-650* |

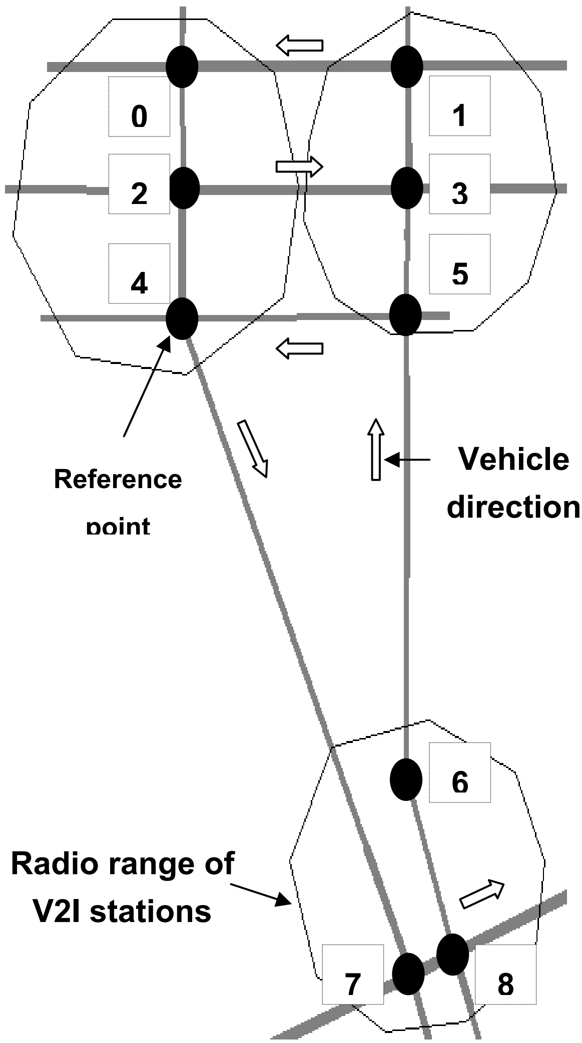



**Fig.3. Simulation roadway network**

Fig. 4 represents the error rate of travel time values obtained using V2I communication compared with values measured from the simulation. It is the percentage of this difference and the values measured from the simulation. To calculate the error rate, average of travel time values are calculated for all links between 2 reference points in the network. Three lines in Figure 4 show error rate calculated with 3 different values of data extraction period: 60, 90, 120 seconds. The horizontal axis presents 10 data extraction periods. This result is obtained under the condition that all the vehicles are equipped with a communication device. We see that the difference rate increases when data extraction period increases. It is because reference points are defined in the form of a circle while travel time points defined in VISSIM are cross lines over the road. The longer data extraction period is, the more significantly this difference effect to the result.

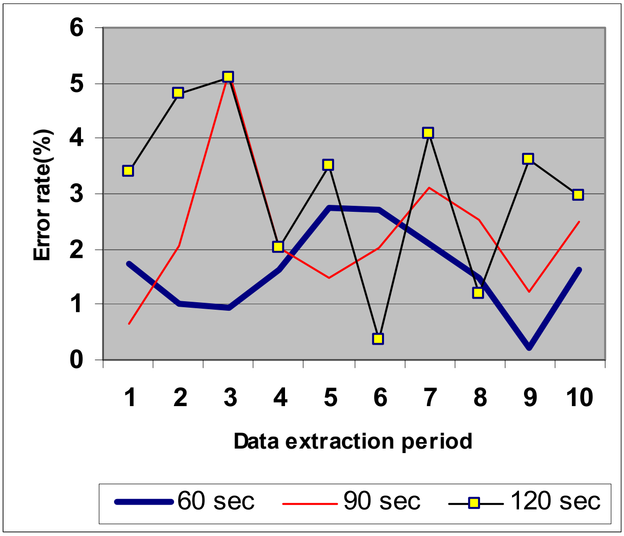



**Fig.4. Error rate**

In order to evaluate effects of the percentage of V2I communication on the calculation of travel time, we run the simulation under conditions that 10%, 30%, 50%, 100% of vehicles in the network can communicate with the infrastructure. Table 3 and 4 present the percentage of data availability and error rate of the travel time calculated. They are calculated under different values of data extraction period and different percentage of V2I communication. Both of them are the average value over 10 data extraction periods. The results show that using V2I communication we can have sufficient information of travel time with more than 50% of vehicles equipped with communication devices.

**Table.3. Data availability [%]**

| | Period [s] | | |
|---|---|---|---|
| V2I rate[%] | 60 | 90 | 120 |
| 100 | 100 | 100 | 100 |
| 50 | 90 | 100 | 100 |
| 30 | 60 | 60 | 100 |
| 10 | 60 | 50 | 50 |

**Table.4. Error rate [%]**

| | Period [s] | | |
|---|---|---|---|
| V2I rate[%] | 60 | 90 | 120 |
| 100 | 1.62 | 2.28 | 3.11 |
| 50 | 3 | 2.12 | 2.16 |
| 30 | 2.5 | 2.22 | 2.38 |
| 10 | 3.8 | 5.62 | 3.05 |

# 5 CONCLUSION

This paper proposes a model using wireless communication to track vehicles and register the time when they pass reference points. Relying on the collected data, we calculate the travel time between each pair of reference points. This is an important traffic data for traffic control centres. The proposed model is simulated in the traffic simulator VISSIM. As compared to traditional loop-detector based systems; the wireless-communication based traffic control system can provide continuous data of vehicle tracking which improves the detail of traffic information. The simulation results show that the travel time measured is precise compared with the data provided by the simulation and the communication capacity rate of vehicles does not influence significantly on the availability of data. However, the difference of shape between reference points and travel time measure points in the simulation affects the measure precision. Every value of travel time collected from a vehicle contains an error. So the number of vehicles in the network as well as the interval of data extraction period will increase the total error. In future works, we will determinate the optimal value of data extraction period with a road network correspondent to improve the precision of the model.

# 6 REFERENCES

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