Using Vehicular Networks to Collect Common Traffic Data

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ABSTRACT

State transportation departments are required to annually report various traffic statistics to the US government. Currently, this data is measured using older technologies that are susceptible to failure and are difficult to maintain and repair. In this paper, we propose using vehicular ad-hoc networks (VANETs) to measure this common traffic data. In addition to collecting information required for reporting purposes, VANET-based traffic monitoring can provide highly-desired metrics such as travel times, which cannot be directly measured using commonly used traffic monitoring approaches. We show that with 100% penetration rate, our methods can collect precise traffic data and that even with low penetration rates or low density traffic, we can collect high quality estimates of travel times, time mean speeds, and space mean speeds.

Categories and Subject Descriptors

D.2.0 [Computer-Communication Networks]: Data Communication

General Terms

Design, Measurement, Performance

Keywords

VANETs, Traffic Data, Data Collection, Task Organizer

1. INTRODUCTION

Departments of Transportation in the US must collect various types of data for traffic monitoring purposes. The most common of these are *traffic volume*, *time mean speed (TMS)*, *space mean speed (SMS)*, *traffic density*, *travel time*, and *vehicle miles of travel (VMT)*. These pieces of important data for states are usually collected by technologies such as inductive loop detectors (ILD), video detection systems, acoustic tracking systems, or microwave radar sensors [1]. Among these, ILDs are the most prevalent, generally have the highest accuracy, and can collect all of the fundamental traffic data except travel times. However, they are prone to failure. Maintenance, installation, and replacement can be problematic, and because of this, large portions of an ILD network may not be returning quality data at any given time. In this paper, we propose techniques to collect common traffic data using vehicular ad-hoc networks (VANETs). We use a few pieces of roadside infrastructure, which we call *task organizers*

(TO), to gather the information and report it to local traffic management centers. TOs can be deployed at various points of interest along the roadway and can be used to collect data from locations up to tens of kilometers away. A TO is able to collect data on dynamic length segments and at various points on the desired roads with little or no extra cost for maintenance, replacement, calibration, or infrastructure. A TO can also report good estimates of traffic data in low penetration or low density traffic situations.

2. ARCHITECTURE AND ASSUMPTIONS

We assume that some percentage of vehicles are equipped with a Global Positioning System (GPS) device for positioning, a detailed digital road map for route guidance, and a transceiver for communication using Dedicated Short-Range Communications (DSRC) [2]. We assume that there is at least one *task organizer* deployed along the road. This device is equipped with a DSRC transceiver and communicates with passing equipped vehicles to assign tasks to vehicles. We use well-known neighbor discovery, geographical routing, and message forwarding techniques [3, 4] to pass tasks and information through the VANET and to the TO. A *virtual strip*, or *strip* (similar to that described in [5]), is an imaginary line that crosses a road and is used to define the measurement areas. A vehicle can reside on only one side of a strip. Two virtual strips can be used to create a *virtual segment*, or *segment*.

3. COLLECTING TRAFFIC DATA

Here we briefly describe how our system can be used to collect various types of traffic data.

Volume, TMS, VMT: To collect the traffic volume at a desired virtual strip, the TO broadcasts a `VOLUME` task containing the location of the TO and the strip of interest, s_1 . Each vehicle passing the TO receives the `VOLUME` task. Once the vehicle passes strip s_1 , the task is triggered, and the vehicle sends a message back to the TO containing the `VOL` tag and its current speed. Once several messages have been received by the TO, it can calculate the volume, TMS, and VMT metrics. The TMS, or average speed at a point over a time interval, can be computed since the TO already knows the total number of vehicles that have passed the desired strip and their speeds. The VMT is the product of the volume and the length of the examined segment. It can be computed since the TO knows the distance from the TO to the strip.

Travel Time, SMS: If vehicles include a timestamp when reporting volume, the travel time is the difference between the timestamps gathered from two different strips for each vehicle. This can be done by the TO or by the vehicles. The TO can then calculate the SMS, or average speed over a segment, as the length of the segment divided by the average travel time.

Density: To collect the traffic density of a desired segment, the TO periodically selects a vehicle that is in range and sends it a `Density` task containing the location of the TO, the boundaries of the segment of interest (s_1 and s_2). If the vehicle is inside the segment of interest, the task is triggered. The vehicle counts the number of its neighbors that are both inside the communication range R and before s_2 and then updates the count in the task message. If the distance to s_2 is greater than R , the vehicle will forward the task to its farthest neighbor inside R and before s_2 . Otherwise, the updated task message will be forwarded back to the TO. If the vehicle receiving the task from the TO is outside the segment of interest, it will initiate message forwarding to a vehicle either at the edge of its communications range or to a vehicle just inside the segment of interest. It is possible that messages cannot be forwarded due to low density traffic or an obstacle blocking the roadway. In such situations, if a delegate vehicle cannot collect and forward the message, it will forward to the TO the density up to the last strip it was able to collect.

In situations where there are few equipped vehicles (either due to low penetration rate or low density traffic), message forwarding may fail, and the TO may count a much lower volume and density than the ground truth. We believe there are ways that the TO can determine the difference between low density traffic and low penetration rate by examining the speed limit of the segment, the density of the segment, and the current vehicles' speeds. Low density traffic usually results in a higher average vehicle speed (vehicles are traveling in free-flow). Low penetration rates in mid-to-high density traffic will likely have a lower average speed due to transient periods of congestion. Road profiles and past history of the roadway may also be a great help in determining the difference between low penetration rates and low traffic density. We suggest measuring traffic volume at some point in the communications range of a TO to avoid the need for forwarding and mitigate the effects of low traffic density.

4. EVALUATION AND CONCLUSION

Our evaluations are based on several simulations developed using the ns-3 network simulator. The mobility of vehicles, including lane changes, is controlled by a revised version of the IDM/MOBIL car-following model [6]. Our roadway is a bi-directional highway with three lanes in each direction. Based on simulation results, it only takes 1.6 seconds for a TO to receive messages from strips 9 km away. As the penetration rate was assumed to be 100%, the TO collected

precise data. For low density traffic with 50% penetration, the TO does not receive 60% of generated messages due to network disconnectivity. Therefore, the TO will miss 80% of the total information ($0.5 + 0.6 \times 0.5$) in comparison to the actual roadway status. The amount of information the TO receives will decrease as the penetration rate decreases. To mitigate the effect of low penetration rates, we took advantage of vehicles traveling in the opposite direction for message forwarding, and the results were desirable. Low message reception rates (either due to network disconnectivity or low penetration rates) affect volume statistics, but average statistics such as SMS, TMS, and travel times are not be greatly affected. Table 1 shows the average travel times and their percentage of difference for a 3 km virtual segment with 100% and 5% penetration rates. The results confirm a negligible deviation in calculated travel times at 5% penetration rate, even though 95% of vehicles were not equipped. This means that only a few vehicles need to be equipped in order to report accurate travel time information.

In our future work, we plan to investigate how density and volume can be approximated in situations of low penetration rate. We also plan to evaluate the use of several TOs for more complex roadways and in urban areas.

Table 1. Calculated average travel time and percentage of difference.

v_0 (m/s)	Travel Time (s) at 100%	Travel Time (s) at 5%	% Difference
5	625	624.7	0.048
10	309.28	307.6	0.543
15	203.4	202.1	0.639
20	158.73	157.9	0.523
25	126.58	124.6	1.564
30	106.76	105.2	1.461

5. REFERENCES

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