Ad Hoc Networks 35 (2015) 3–13

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

Estimating online vacancies in real-time road traffic monitoring with traffic sensor data stream

Feng Wang[a], Liang Hu[a], Dongdai Zhou[b], Rui Sun[a], Jiejun Hu[a], Kuo Zhao[a,*]

[a] College of Computer Science and Technology, Jilin University, Changchun 130012, China
[b] College of Software, Northeast Normal University, Changchun 130012, China

ARTICLE INFO

Article history:
Received 16 December 2014
Revised 5 July 2015
Accepted 8 July 2015
Available online 16 July 2015

Keywords:
Data stream
Road traffic monitoring
Real time
Big data

ABSTRACT

Real-time road traffic monitoring is widely considered to be a promising traffic management approach in urban environments. In the smart cities scenario, traffic trajectory sensor data streams are constantly produced in real time from probe vehicles, which include taxis and buses. By exploiting the mass sensor data streams, we can effectively predict and prevent traffic jams in a timely manner. However, there are two urgent challenges to processing the massive amounts of continuously generated trajectory sensor data: (1) the inhomogeneous sparseness in both spatial and temporal dimensions that is introduced by probe vehicles moving at their own will, and (2) processing stream data in real time manner with low latency. In this study, we aim to ameliorate the aforementioned two issues. We propose an online approach to addresses the major defect of inhomogeneous sparseness, which focuses on employing only real-time data rather than mining historical data. Furthermore, we set up a real-time system to process trajectory data with low latency. Our tests are performed using field test data sets derived from taxis in an urban environment; the results show that our proposed method lends validity and efficiency advantages for tackling the sparseness, and our real-time system is viable for low latency applications such as trafficmonitoring.

1. Introduction

As motor vehicles continue to be a transportation method of choice in developed countries, transportation infrastructure continues to be overwhelmed by the number of cars on the road, leading to traffic jams and congestion in most major metropolises worldwide. Consequently, road traffic monitoring has become an essential and vital element for providing efficient and safe road transport. Real-time road traffic monitoring has received considerable attention and is considered to be a promising approach because it offers the opportunity to employ mitigation measures–such as changing the timings of traffic lights or advising commuters to take alternate routes–in real time. However, it is a significant challenge to process the massive amounts of real-time traffic sensor data that are continuously generated in large cities.

Traditional traffic monitoring technologies include magnetic loops [1], camera-based systems [2], microwave radar [3], laser-based systems [4,5], infrared detectors [6], and ultrasonic detectors [7]. These are roadside technologies that detect passing vehicles and provide precise and stable traffic information about a specific location where they are installed. The major disadvantage of these technologies is the high cost of deployment and maintenance. For example, a magnetic loop sensor can cost hundreds of dollars, and daily maintenance can cost much more. It is infeasible to install these expensive technologies densely enough to provide data on a city's entire road network. Several studies [3,8] have

* Corresponding author. Tel.:+86 0431 85168716; fax. +86 0431 85166494.
E-mail addresses: wangfeng12@mails.jlu.edu.cn (F. Wang), hul@jlu.edu.cn (L. Hu), ddzhou@nenu.edu.cn (D. Zhou), ruisun14@mails.jlu.edu.cn (R. Sun), hujc12@mails.jlu.edu.cn (J. Hu), zhaokuo@jlu.edu.cn (K. Zhao).

http://dx.doi.org/10.1016/j.adhoc.2015.07.003
1570-8705/

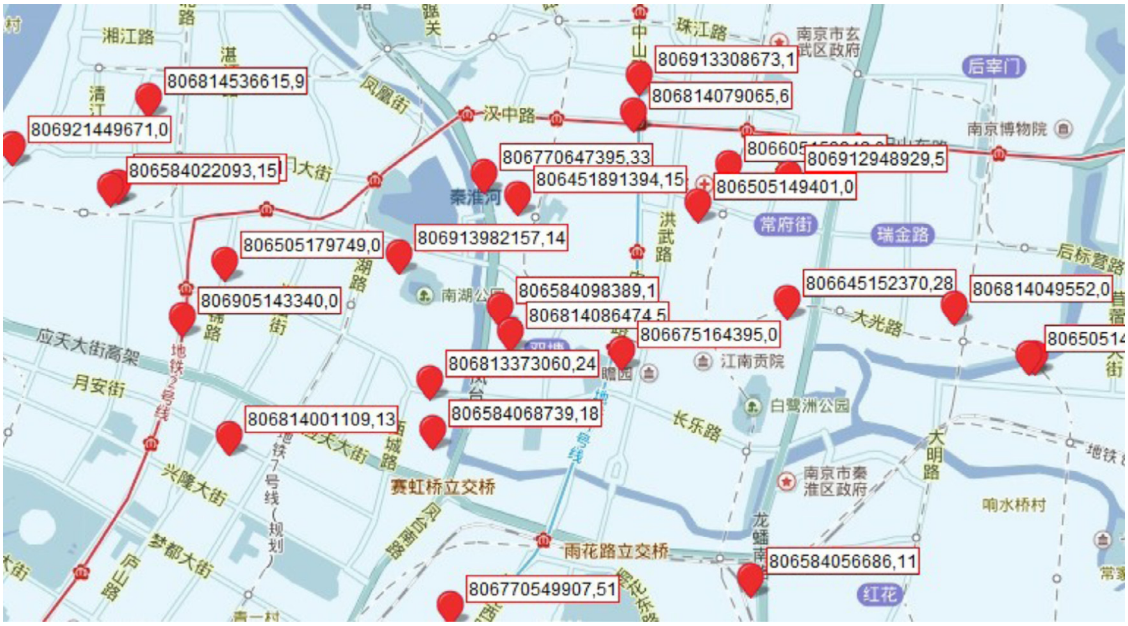

Fig. 1. A distribution snapshot of vehicles over the partial study region (red icons are probe taxis).

been published that have explored ways to overcome the limitations of coverage with traditional technologies by making a trade-off between precision and scalability. Some studies proposed using high-resolution satellite imagery to make up for coverage shortages [9–11]. However, the availability of the proposed approaches is limited by weather and other factors that impact the precision and timeliness of the data provided by these traditional technologies.

In this paper, we present a real-time road traffic monitoring system that uses global positioning system (GPS) data collected through wireless communication in probe vehicles, such as taxis, to monitor the real-time traffic scenario. However, obtaining traffic monitoring information directly from the raw reports of GPS is still a significant challenge. First, the data include spatio-temporal vacancies because the probe vehicles move at their own will. The random distribution of probe vehicles inevitably leads to inhomogeneous sparseness in data, which is an obstacle in acquiring the real-time traffic state in the entire study region. Second, computing infrastructure continues to be overwhelmed by the massive amounts of continuously generated trajectory sensor stream data.

In this study, we attempt to circumvent those obstacles. We present an online approach to addresses the major defect of inhomogeneous sparseness, which focuses on employing only real-time data rather than mining historical data. Furthermore, we set up a real-time system to process trajectory streaming data with Apache Storm which is an open-source distributed real-time computation framework.

To validate the system, we experiment with a field test data set from an urban environment, which contains one-day trajectories of 7,648 taxis. The total number of points in this data set is about 18 million. Fig. 1 shows a snapshot of vehicle distribution over the partial study region. Every red icon is a probe taxi, and the labels indicate the taxi number and its velocity. Velocity information is not collected in the data set and is computed in real time on the basis of longitude, latitude, and time. The results show that our proposed method lends validity and efficiency advantages for tackling the sparseness, and the real-time system is viable for low latency applications such as traffic monitoring.

The rest of the paper is organized as follows: Related work is presented in Section 2. The problem is formally defined and an algorithm is detailed in Section 3. The implementation of the proposed system is described in Section 4. The validation results are presented in Section 5. Finally, we conclude our paper and suggest avenues for future work in Section 6.

2. Related work

Traditionally, radar sensors, cameras, and similar equipment are static and are placed in roadside positions. For instance, traffic cameras were deployed and magnetic induction coils were installed under road surfaces in monitored areas. Through consecutive images captured by traffic cameras or electromagnetic signals, it was possible to easily measure vehicle speed and frequency of passing. However, these kinds of monitoring equipment cannot be installed at the density needed to monitor traffic in real time, particularly in large urban areas. This presents an unprecedented opportunity to harness traffic monitoring by developing some other approaches.

Some research [12–15] focuses on the potential of crowdsourcing, such as smartphones and mobile cellular networks, to facilitate the collection of vast amounts of traffic management data from probe vehicles and pedestrians throughout a city. In [16] and [17], the authors present crowd-based route recommendation systems for urban transportation. However, the energy and capability of mobile phones can become a problem, as [18] discusses in a review of the feasibility of utilizing smartphones as sensors to gather and disseminate location-relevant information to build a global view of a