The Journal of Systems and Software 86 (2013) 1323–1332

Contents lists available at SciVerse ScienceDirect

The Journal of Systems and Software

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

Continuous range *k*-nearest neighbor queries in vehicular ad hoc networks

Hyung-Ju Cho*

Department of Computer Engineering, Ajou University, Suwon, South Korea

ARTICLE INFO

Article history:
Received 27 July 2011
Received in revised form 12 March 2012
Accepted 12 December 2012
Available online 29 December 2012

Keywords:
Nearest neighbor queries
Vehicular ad hoc network
Collision avoidance
Location awareness

ABSTRACT

A driver should constantly keep an eye on nearby vehicles in order to avoid collisions. Unfortunately, the driver often does not see nearby vehicles because of obstacles (e.g., other vehicles, trees, buildings, etc.). This paper introduces a novel type of query, called a continuous range *k*-nearest neighbor (CRNN) query, in vehicular ad hoc networks, and it presents a new approach to process such a query. Most existing solutions to continuous nearest neighbor (CNN) queries focus on static objects, such as gas stations and restaurants, while this work concentrates on CRNN queries over moving vehicles. This is a challenging problem due to the high mobility of the vehicles. The CRNN query has characteristics in common with continuous range (CR) and CNN queries. In terms of CNN queries, the proposed approach achieves the same goal as the existing solutions, which is to decide effectively on valid intervals during which the query result remains unchanged. The proposed scheme aims to minimize the use of wireless network bandwidth, the computational cost, and the local storage while preserving information on the continuous movement of vehicles within the broadcast range of a given vehicle. Extensive experimental results confirm the effectiveness and superiority of the proposed scheme in comparison with an existing method.

1. Introduction

In recent years, with the widespread deployment of mobile networks and the rapidly growing popularity of car navigation systems, there has been an increasing interest in wireless data services from both industrial and academic communities. Recently, a vehicular ad hoc network (VANET) has been introduced to provide safety and comfort for drivers and passengers. Each vehicle equipped with a mobile device becomes a node in the ad hoc network and can receive or relay messages through the wireless network. Collision warnings, road sign alarms, and in-place traffic views can provide drivers with useful tools to decide the best route along the way.

Spatial query processing plays an essential role in many new mobile applications. Recently, there has been a growing interest in the use of location-based spatial queries (e.g., nearest neighbor queries and range queries) that retrieve the information based on the current location (Ku et al., 2008; Tao et al., 2002; Zheng et al., 2007). This paper introduces to vehicular ad hoc networks a novel type of query called a continuous range *k*-nearest neighbor (CRNN) query. The CRNN query continuously provides a driver with the locations of the *k* nearest vehicles that are within a certain range (e.g., broadcast range of Wi-Fi). The locations of these vehicles are plotted on the car navigation system display, and make the user aware of vehicles whose visibility is obstructed by tracks, turns, blind spots, etc.

Processing CRNN queries is a challenging problem since vehicles move so fast that the query result is often invalidated within several timestamps. In addition, although a universal database in a centralized server may have received all the information about the vehicles through wireless communication, it is impossible to answer CRNN queries requested by vehicles in a timely manner.

Fig. 1 shows an example of the CRNN query with a realistic situation, where it is assumed that *A* through *G* are vehicles. The arrows and numbers indicate, respectively, the directions and speeds of movement of the corresponding vehicles. Note that the location, velocity, and time of a vehicle can actually be updated for each timestamp by a mobile device with a GPS receiver. For simplicity, the current time is assumed to be t_{cur}. Given a CRNN query that asks for the two vehicles closest to the querying vehicle which is denoted by a shaded box, the query result *R* is obtained as follows: $R=\{\langle I,R_I\rangle \mid \langle[t_{cur},t_{cur}+1],\{B,C\}\rangle, \langle[t_{cur}+1,t_{cur}+2],\{A,C\}\rangle\}$, where *I* is the time interval and R_I is the query result for the interval *I*. This is interpreted to mean that vehicles *B* and *C* are the two NNs of the querying vehicle for time interval $[t_{cur},t_{cur}+1]$ but vehicle *B* is replaced at time $t_{cur}+1$ since vehicle *A* is then closer to the querying vehicle than vehicle *B*.

There are two primary methods for delivering wireless data services: unicast (or point-to-point) and broadcast (or point-to-multipoint) systems. Compared to unicast access, a broadcast system is regarded as a very attractive alternative for mobile networks (Imielinski et al., 1997; Ku et al., 2008; Zheng et al., 2007).

* Tel.: +82 312192535; fax: +82 312191834.
E-mail addresses: hjcho@ajou.ac.kr, hjcho73@gmail.com

0164-1212/$ – see front matter © 2012 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.jss.2012.12.034

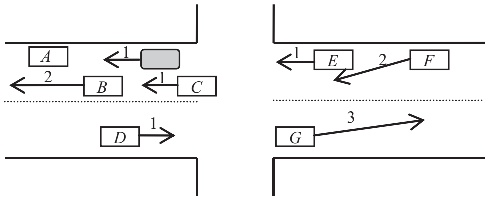

Fig. 1. Example of CRNN query.

In this paper, broadcast access is considered. In other words, the information that a vehicle sends via a wireless channel simultaneously reaches most other vehicles within the broadcast range of the vehicle.

Many CNN queries focus on static objects, while this paper deals with moving objects like vehicles. However, this paper pursues the same goal of effectively discovering valid intervals during which the query result remains fixed. The primary contributions of this work can be listed as follows:

- Movement information (e.g., location, velocity, and timestamp of a vehicle) is stored, broadcast, and managed instead of a transient current location. This helps save on communication costs among vehicles as well as computational costs.
- The proposed method achieves minimization of the total number of disseminated reports while preserving information on the continuous movement of a vehicle.
- A comprehensive experimental evaluation shows the validity and effectiveness of the proposed method over those of an existing method in terms of network bandwidth consumption and the accuracy of measured results.

The rest of this paper is structured as follows: Section 2 surveys the related work. Section 3 presents the background information for this work. Section 4 details the proposed approach to the CRNN query. Section 5 presents experimental results for real road networks. Finally, Section 6 concludes this paper.

2. Related work

The method of modeling the future locations of a moving object is introduced through the concept of dynamic attributes (Sistla et al., 1997). The database location of the moving object is modeled with the start time, start location, and velocity of the object. In this paper, the dynamic attributes are chosen to predict the future locations of a vehicle. These are directly obtained from the GPS receiver and a small amount of space is required to save these attributes (i.e., time, location, velocity).

The final report of a vehicle safety communications (VSC) project (VSCPFR, 2006) refers to comprehensive safety-related application scenarios of interest. Among the list of application scenarios, the scenarios in Table 1 are closely associated with the CRNN query. To support these services, the report argues that packets which include movement information such as the position, velocity, and heading should be broadcast periodically (every 0.1 s) and the communication range should be up to 150 m. Naturally, such frequent transmissions result in wasting the limited bandwidth of wireless networks and increasing the computational cost, particularly when vehicles halt at a stop sign or proceed on a straight highway at a fixed speed.

Table 1
Safety-related application scenarios (VSCPFR, 2006).

Service name	Service description
Cooperative Collision Warning	This service aids the driver in avoiding or mitigating a collision with the rear end of a vehicle in the forward path of travel through driver notification or warning of the impending collision.
Lane Change Warning	This service warns the driver when an intended lane change may cause a crash with a nearby vehicle.
Pre-Crash Sensing	This service prepares the driver for an imminent collision.

Recently, spatial query processing techniques for wireless broadcast systems have been studied (Ku et al., 2008; Zheng et al., 2007). Ku et al. (2008) proposed a query processing technique for location-based spatial (LBS) queries. In their approach, the LBS queries are dealt with by the use of query results cached in neighboring mobile peers of a querying vehicle. This approach is not appropriate to CRNN queries since cached results for moving objects like vehicles are liable to become invalid and the results received from peers are not helpful to the querying vehicle in most cases. Zheng et al. (2007) developed a generalized search algorithm based on a Hilbert curve index for the CNN query. The first step of the algorithm is to find an approximate search range that includes all the candidates. Unfortunately, it is not always appropriate to decide on a route to the destination before departure. Although the route is known beforehand, it is very expensive to predict the vehicles which will traverse the route. In addition, the algorithm concentrates on static objects.

CNN search algorithms for client–server systems have been studied for a variety of environments and have provided satisfactory results (Cho and Chung, 2005; Mouratidis et al., 2006; Tao and Papadias, 2002; Tao et al., 2002). Therefore, in the simplest tactic, a vehicle establishes a unicast connection with the server so that its queries can be answered on demand. However, this approach has several disadvantages. First, it may not scale to very large populations. Second, to communicate with the server, a vehicle likely must use a fee-based cellular-type network to achieve a reasonable operating range. Third, drivers have to reveal their current location to the server, which may be undesirable for privacy reasons. Sistla et al. (2011) have analyzed the lower and upper bounds on the maximum number of valid intervals.

Xu et al. (2006) and Wu et al. (2007) developed query processing algorithms for range and NN queries, respectively, with the consideration of sensor nodes to gather information. These contribute to forming a well-devised conceptual itinerary structure in order to let sensor nodes collect partial results and propagate the query efficiently along the itinerary. However, both approaches suffer from the continuous movement of a vehicle which issues a CRNN query, since new itineraries should be generated whenever the querying vehicle moves to another place.

Many studies have been performed on data dissemination in mobile ad hoc environments (Datta et al., 2004; Denardin et al., 2011; Hu et al., 2011; Mai et al., 2011; Mondal et al., 2007; Wang and Wu, 2007; Wolfson et al., 2007) (see Datta et al., 2004 for a good survey). These ware aimed at the optimization of the usage of energy, communication bandwidth, and storage. In this paper, the energy efficiency does not have to be considered, since running vehicles can provide sufficient energy for mobile devices. However, the communication bandwidth and storage should be consumed prudently. Accordingly, this paper presents a method which minimizes the total amount of data broadcast among vehicles and improves the usage of local storage while preserving the information necessary to capture the continuous movement of vehicles around the querying vehicle.

3. Preliminaries

Section 3.1 introduces a vehicular ad hoc network and a traffic stream model used in this work. Section 3.2 presents a new method