Information Sciences 325 (2015) 324–341

Contents lists available at ScienceDirect

Information Sciences

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

Moving range k nearest neighbor queries with quality guarantee over uncertain moving objects

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ARTICLE INFO

Article history:
Received 20 February 2014
Revised 21 August 2014
Accepted 8 July 2015
Available online 16 July 2015

Keywords:
Moving range k nearest neighbor query
Uncertain moving object
Mobile peer-to-peer environment

ABSTRACT

To avoid traffic accidents, drivers must constantly be aware of nearby vehicles. Unfortunately, nearby vehicles often go unnoticed because of various obstacles such as other vehicles, buildings, or poor weather. In this paper, we study Moving range k-nearest neighbor (MRkNN) queries as a tool for continuously monitoring nearby moving objects. A simple approach to processing MRkNN queries is to have each object periodically broadcast information regarding its movements (i.e., location and velocity at a particular time) to other objects. However, this simple technique cannot be used to process MRkNN queries owing to the limited network bandwidth in mobile peer-to-peer environments. Therefore, we address this bandwidth limitation by proposing a probabilistic algorithm, called MINT, for MovIng range k-NN queries with qualiTy guarantee over uncertain moving objects. MINT provides users with approximate answers with a quality guarantee, rather than exact answers, with near optimal communication costs. Using a series of simulations, we demonstrate the efficiency and efficacy of MINT in evaluating MRkNN queries with a quality guarantee.

1. Introduction

Paralleling the advances in positioning and wireless network technologies, peer-to-peer (P2P) query processing has attracted many techniques for location-based queries (e.g., range queries [26], k-NN queries [7, 8, 9, 11, 23, 27, 29], and top-k queries [22]) in a mobile P2P environment, where neither fixed communication infrastructures nor centralized/distributed servers are available. In this paper, we study Moving Range k-Nearest Neighbor (MRkNN) queries in a mobile P2P environment. MRkNN queries are of practical importance in traffic collision avoidance systems because they provide drivers with information on the k-nearest objects within a certain range, such as a Wi-Fi transmission range. Specifically, using MRkNN queries, drivers are alerted to nearby vehicles, some of which may be hidden from sight owing to the presence of obstacles such as other vehicles, buildings, or poor weather, thereby reducing the risk of traffic accidents.

Ensuring low network bandwidth consumption is essential for query processing in mobile environments where the available network bandwidth is often severely limited. A simple method to address MRkNN queries is to request that moving objects periodically disseminate information regarding their movements (i.e., location and velocity) to other objects within their vicin-

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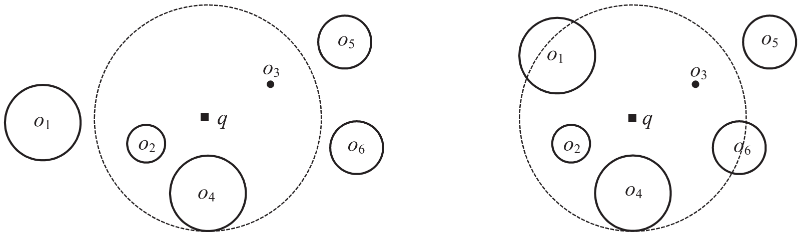
http://dx.doi.org/10.1016/j.ins.2015.07.034
0020-0255/



(a) Certain answer set (b) Uncertain answer set

Fig. 1. Example of a 3-NN query over uncertain moving objects.

ity. This enables each object to monitor its k-closest objects continuously. However, this simple technique is inappropriate in mobile environments. Consequently, to optimize the network bandwidth use, we propose a probabilistic approach to MRkNN queries in mobile P2P environments that adopts approximate answers rather than exact answers. It is typically acceptable to provide a query issuer (e.g., a driver) with approximate answers with sufficiently high accuracy. To achieve this, the query issuer is first requested to define a desired level of accuracy (e.g., 95%) for the approximate answers to their MRkNN queries. Naturally, during critical situations where approximate answers could have fatal consequences the query issuer may choose to receive only exact answers, with the desired accuracy level being set at 100%. On the other hand, under normal situations, approximate answers with accuracy greater than a specified value (for example, greater than 90%) may be acceptable while conserving a limited network bandwidth.

Fig. 1 shows a certain answer set and an uncertain answer set to a 3-NN query for finding the three closest objects to query issuer q, denoted by the black square, among six objects, o_1 through o_6, near q. The exact location of an object or its uncertainty region is denoted by a dot (e.g., o_3) or solid-line circle (e.g., o_1), respectively. Fig. 1(a) shows a certain answer set, $A = \{o_2, o_3, o_4\}$, where o_4 is the most-probable third NN of q. Therefore, the required search area, denoted by the dotted circle, is a circular area with a radius equal to the distance between q and the farthest point in the uncertainty region of o_4 from q. Conversely, Fig. 1(b) shows an uncertain answer set. Object o_4 is still the most probable third NN of q; thus, the required search area in Fig. 1(b) is the same as the region in Fig. 1(a). However, because the exact location or uncertainty regions of the five objects, o_1, o_2, o_3, o_4, and o_6, intersect the required search area, any three of these five objects could be the actual answer set. Therefore, in this study, we devise a probabilistic algorithm, called MINT, for MovIng range k-NN queries with qualiTy guarantee over uncertain moving objects, which determines approximate answers using a probability density function (pdf) and a cumulative distribution function (cdf) of the distance between a query issuer and an uncertain moving object.

The contributions of this paper are as follows:

- We propose a probabilistic algorithm, called MINT, for processing MRkNN queries with a quality guarantee over uncertain moving objects.
- We present a pdf and a cdf of the distance between a query issuer and a moving object whose locations follow a uniform or non-uniform distribution in the uncertainty region.
- We conduct a series of simulations that demonstrate that MINT markedly outperforms a conventional solution under various conditions.

The remainder of this paper is organized as follows: In Section 2, previous related works are discussed. Section 3 then presents background information relevant to our study. Next, Section 4 presents the pdf and cdf of the distance between a query issuer and an uncertain moving object. Section 5 presents how to determine the proximity between two objects to a query issuer. Section 6 presents a probabilistic algorithm to evaluate MRkNN queries over uncertain moving objects. Finally, Section 7 presents the simulation settings and results, and Section 8 offers some concluding remarks regarding this research.

2. Related works

With the development of wireless communication technologies such as Wi-Fi and Bluetooth, mobile P2P collaborative caching has been attracting increasing attention as an alternative for information sharing among mobile nodes over standard centralized models. Consequently, many studies have been conducted on location-based query processing in this context [10, 17, 23, 29]. Ku and Zimmermann [17] introduced the first on-demand P2P data-sharing algorithm for k-NN queries in a mobile environment. In their algorithm, the query node collects and verifies information from its peers. However, caching solutions cannot handle MRkNN queries in mobile environments because the cached information regarding the movements of objects becomes invalid very quickly.

The management of uncertain data has been studied extensively in the context of moving object databases [2, 5, 6, 11, 15, 20, 21, 30, 31]. Because location uncertainty is inherent in such databases, the development of efficient and effective solutions providing probabilistic query results is in high demand. Cheng et al. [3] were the first to formulate uncertain retrieval in general