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Searching continuous nearest neighbors in road networks on the air

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ABSTRACT

Recently, people have begun to deal with location-based queries (LBQs) under broadcast environments. To the best of our knowledge, most of the existing broadcast-based LBQ methods are aimed at Euclidean spaces and cannot be readily extended to road networks. This paper takes the first step toward processing Continuous Nearest Neighbor queries in road Networks under wireless Broadcast environments (CN^3B). Our method leverages the key properties of Network Voronoi Diagram (NVD). We first present an efficient method to partition the NVD structure of the underlying road networks into a set of grid cells and number the grid cells obtained, based on which we further propose an NVD-based Distributed air Index (NVD-DI) to support CN^3B query processing. Finally, we propose an efficient algorithm on the client side to process CN^3B queries. Extensive simulation experiments have been conducted to demonstrate the efficiency of our approach. The results show that our proposed method is about 4 and 7.6 times more efficient than a less-sophisticated D-tree air index based method, in access latency and tuning time, respectively.

1. Introduction

With the rapid development of wireless technology and ever growing popularity of smart mobile devices, location-based services (LBSs) have become popular over the past few years. Being one of the enabling technologies for LBS, location-based queries (LBQs) have been a hot research topic. An important class of LBQs is the continuous nearest neighbor (CNN) query, which continuously finds the objects nearest to a query client while the client keeps moving from one place to another. For example, "continuously finding the nearest gas station along the path on which a car moves". LBQs return results based on certain location information. Generally speaking, there are two approaches to accessing location information via wireless technology: on-demand access and periodic broadcast [1]. On-demand access employs a basic client–server model, where a mobile client (MC) submits a query to the server, which is responsible for processing a query and returning the result to the client via the dedicated point-to-point channel. This method is suitable for light-loaded systems where contention for transmission channels and server resources is not severe. However, this on-demand access method has three critical drawbacks: (1) the server processing ability and the uplink bandwidth will be the bottleneck of the system, which jeopardizes the scalability of the system; (2) the server has to process a large number of query requests simultaneously, which will affect the timeliness of the query results; and (3) it fails to exploit the similarity of content desired by all users.

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On the contrary, periodic broadcast requires the server to actively push data to the clients via a broadcast channel. Without sending any request to the server, each client simply listens to the broadcast channel to retrieve data based on its own query and processes the data retrieved to get the query result autonomously. Periodic broadcast communication provides more efficient data delivery as the broadcast data can be simultaneously accessed by an arbitrary number of MCs, and hence is especially suitable for heavy-loaded systems. For example, "a large number of people from the four corners of the world attend a large-scale event (e.g., Olympic games, art festivals, or World Cups). After the event, people would like to query the nearest hotel (or restaurant) when they are leaving the activity spot. Considering that there are so many people from all over the world and they are not acquainted with and have not stored the map of this city, it would be necessary for them to request the answer through the wireless data broadcast approach". In fact, wireless data broadcast is a matured technology and the relevant services have been available as commercial products for several years, such as StarBand and MSN Direct Service. MSN Direct Service is based on the smart personal objects technology (SPOT) and the DirectBand Network. By this service, mobile clients can continuously receive timely information such as stock quotes, airline schedules, news stories, weather, and traffic information.

Recently, researchers have begun to zero in on processing LBQs using periodic broadcast. However, to our knowledge, most of the existing broadcast-based LBQ methods are limited to Euclidean space, and few of them can be used in network space. But in real life situations, MCs always move within a certain network, such as a road network or a railway network. In a road network, the distance between objects is determined by the connectivity of the network, rather than the objects' coordinates in Euclidean space. Thus, existing LBQ methods used in Euclidean space cannot give accurate query results, and it is therefore essential to examine broadcast-based LBQ methods suitable for use in real road networks.

In this paper, we concentrate on processing Continuous Nearest Neighbor queries in road Networks under data Broadcast environments (abbreviated as CN^{3}B in the following). In the periodic broadcast method, the structure of a road network and the objects in it are broadcast periodically via a broadcast channel, and MCs are responsible for query processing. Since a road network is in a two-dimensional space whereas data sent in a broadcast channel is a linear sequence, a major challenge for CN^{3}B query processing is how to partition the underlying network and organize the partitioned network together with its objects into a set of sequential packets to be broadcast sequentially. Moreover, since MCs are usually energy-constrained, while an air index makes it possible for MCs to listen selectively to the desired data instances in the wireless broadcast channel and hence reduce energy consumption [11], how to design efficient air index is another important problem that must be addressed for CN^{3}B query processing. Moreover, the added air index will enlarge the total amount of bits in a broadcast cycle, which in turn will increase the access latency. Thus, a good air index should consider the trade-off between access latency and selective tuning ability, and greatly cuts down the energy consumption with limited access latency prolongation. In this paper, by fully utilizing the properties of Network Voronoi Diagram (NVD), we propose a novel NVD constructing and partitioning scheme, based on which we further propose an efficient distributed index to support CN^{3}B query processing. To fulfill the entire CN^{3}B query processing, we also present an efficient algorithm on the client side. The main contributions of this paper can be summarized as follows:

- We propose an efficient method to construct and partition the NVD structure of the underlying road networks to derive an NVD quad tree, and then transfer the tree into a linear sequence of data packets, with each data packet corresponding to one grid cell, which has a unique ID associated with it, in the road network. In particular, the grid cells obtained by our method are generally balanced in size and preserve good locality behavior.
- Based on the partition result derived above, we propose an NVD-based distributed index (namely NVD-DI) to support CN^{3}B query processing. NVD-DI exhibits the following properties: (i) it allows a CNN search to start its execution at arbitrary time instant; (ii) each search can be finished within one broadcast cycle; and (iii) it can significantly reduce the energy consumption at the expense of limited access time prolongation.
- Combining with the broadcasting scheme on the server side, we design an efficient algorithm on the client side to process CN^{3}B queries. We evaluate the performance of the proposed CN^{3}B query processing method via extensive experiments on both a real road network and a synthetic 2-dimensional grid network, and the experimental results show that our method outperforms the D-tree [26] air index based method significantly.

The remainder of this paper is structured as follows. Section 2 reviews related work. In Section 3, we first present a straightforward D-Tree based scheme for CN^{3}B query processing, and then propose our novel NVD-DI based method. Section 4 reports the performance evaluation of the proposed methods. Finally, we conclude the paper with a brief discussion of future work in Section 5.

2. Related work

Nearest neighbor search, one of the important research issues in location-based queries, has been studied over the last two decades, and several NN search methods [4–6,15,22,25] have been proposed. In this section, we briefly review some existing work on processing NN queries in road networks and data broadcast algorithms for NN queries in Euclidean space.

2.1. Nearest neighbor queries in road networks

Jensen et al. [12] first tackled the problem of NN search in road networks in the year 2003. Then, Papadias et al. [19] presented an architecture that integrates network and