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Approximate Path Searching for supporting shortest path queries on road networks

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A R T I C L E I N F O

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A B S T R A C T

Although various efficient indexing techniques have been proposed to improve the performance in distributing road data to mobile clients to perform shortest path searches on road networks, how to minimize the tune-in and path searching costs are still important performance goals since the clients usually have limited processing capability and energy supply. In this paper, based on the *Next Region* (*NR*) approach, we propose a new method called *Approximate Path Searching (APS)* for constructing the broadcast index at mobile clients with soft arrival times to destinations. *APS* adopts an *approximation* technique in calculating the sets of required regions for each <start, destination> region pair in a road network to reduce the index generation cost at the road server and the tune-in and path searching costs at the clients. Different from *NR*, which only provides one set of required regions containing the shortest path from a client's start region to its destination region, *APS* generates *n*-sets of required regions for a client to choose. Each set of required regions contains different numbers of regions. Although choosing a smaller region set may give a slightly longer delay in arrival, the tune-in and path searching costs could be significantly reduced. Theoretical analysis and extensive simulation experiments have been performed to demonstrate the effectiveness of *APS* in improving the system performance with just a few percentages delay in arrival time on average comparing with *NR* using data sets from real road networks.

1. Introduction

Data broadcast has been shown to be an efficient technique for distributing a large amount of data to a large group of clients through a mobile network which has limited bandwidth for the uplink channels [1,2]. To reduce the total tune-in time for receiving broadcast data, various efficient methods [2–7] have been proposed for constructing the broadcast index which defines the broadcast time of each data item in a broadcast cycle. Longer tune-in time results in higher energy cost (or simply called tune-in cost in the rest of the paper). After reading the broadcast index, the clients may switch to doze mode of operation to conserve energy and only tune-in to the broadcast channels at the times when their required data are being broadcast.

One of the important applications of data broadcast is to support location-dependent services [8–13]. For example, data broadcast has been commonly adopted for distributing road data (*e.g.*, the data about the road connections and their traffics in a road network) from a central server (called *road server* in the rest of the paper) to a large group of mobile clients, *e.g.*, vehicles on the roads. As shown in Fig. 1, one of the mobile clients C_i may generate a shortest path query to ask the shortest path to its

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0020-0255/

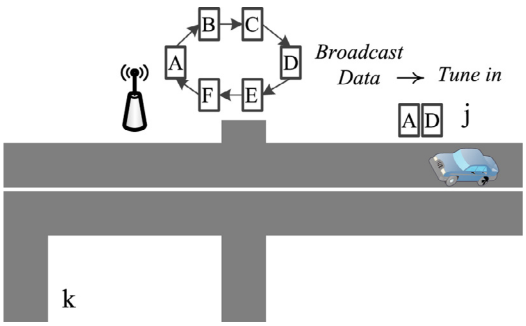

Fig. 1. An example of processing shortest path query at a mobile client through data broadcast.

destination k from current location j. Instead of submitting the query to be processed at the road server, it will be processed at C_i locally through data broadcast. C_i tunes in to the broadcast channel of a roadside supporting station (called a *broadcast server* in the rest of the paper) to get road data for building its local road network and then the shortest path search will be performed in the local road network to get the path to k. The key benefit of this approach is that distributed processing of shortest path searches can greatly improve the scalability of the system and reduce the uplink data communication cost. At the same time, the clients' location privacy [14] can be better ensured since the road server does not know the current locations of the clients. However, the performance problem is that the road network could be very large and the energy cost (called the *tune-in cost* in the rest of the paper) for getting all the road data could be very expensive. Similarly, the path searching cost (*i.e.*, the computational complexity) on its local road network could be very high.

To improve the efficiency in data broadcast and reduce the costs for performing the shortest path search at a mobile client, the *Next Region (NR)* approach [6] is proposed. In *NR*, the road network is partitioned into a set of regions. The road server performs a computation to determine a set of required regions for each region pair in the road network to be included in the broadcast index. The set of required regions for a region pair contains the shortest path connecting the region pair. Therefore, the client only needs to get the required regions according to its current location and destination to build its local road network. Since the set of required regions for a region pair could be significantly smaller than the total number of regions in the road network, both tune-in and path searching costs at the clients could be greatly reduced with the tradeoff of higher index generation cost at the road server. The index generation cost is the computation performed at the road server for identifying a set of required regions for each region pair in broadcast index generation.

In this paper, we study how to construct the broadcast index to support shortest path searches at the mobile clients. Unlike previous works, we target at the clients which have soft arrival times to their destinations, i.e., a slight delay in arrival will not result in great punishment although it is preferable to minimize the delay. In addition to minimizing the arrival times to destinations, other performance measures such as minimizing the tune-in cost for getting road data from data broadcast and the path searching cost at the clients, are also important performance goals since the mobile clients usually have limited processing capability and energy supply. Following the region-based and pre-processing approaches in *NR*, we propose a new method called *Approximate Path Searching (APS)* to construct the broadcast index to reduce the index generation cost as well as the costs (e.g., tune-in cost and path searching cost) at the clients for obtaining the paths to destinations. Different from *NR*, *APS* generates *multiple* sets (or call n-sets) of required regions for each region pair in the road network for the clients to choose. Different sets of required regions for a region pair have different sizes resulting in different tune-in and path searching costs. The set with more regions incurs higher costs but may give an earlier arrival to destination.

The remaining parts of the paper are organized as follows. In Section 2, we briefly review the important indexing techniques for supporting shortest path searches at mobile clients using data broadcast. In Section 3, we introduce the model of a road network system. *NR* and its drawbacks are discussed in Section 4. In Section 5, we introduce the principles of *APS* and the technical details in constructing n-sets of required regions. The cost analysis of *APS* is presented in Section 6. In Section 7, the performance evaluation on *APS* is reported. We conclude the paper with a brief discussion on the future work in Section 8. Table 1 summarizes the definitions of frequently used symbols in this paper.

2. Related work

A number of one-dimensional [2,3] and multi-dimensional [4,5,15] air-indices (indexing schemes on wireless data broadcast) have been designed to support efficient distribution of spatial data and query processing on a road network. To support range queries and KNN queries, the Hilbert curve index (HCI) [4] converts the two-dimensional space into a one-dimensional space by using the Hilbert spacing-filling curve. The one-dimensional data are then indexed by an B^+-tree to be broadcast on the air. To reduce the access latency (the waiting time) for getting broadcast data from HCI, the distributed spatial index (DSI) [15] is proposed at the expense of higher tune-in cost. DSI also adopts the Hilbert spacing-filling curve and the data ordered by Hilbert values are divided into *frames* with fixed number of data and each frame contains an index table.

To support snapshot queries, continuous range queries and KNN queries, the broadcast grid index (BGI) is introduced by Mouratidis et al. [5]. In BGI, a regular grid is imposed on the road network to generate a number of cells. The information (e.g.,

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