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Efficient Windows Query Processing with Expanded Grid Cells on Wireless Spatial Data Broadcasting for Pervasive Computing

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Abstract

Smart mobile devices and advanced wireless networks make the vision of pervasive computing come into reality through context aware services. A wireless spatial data broadcasting is a natural way of pervasive information services by providing information related to mobile clients' location context to an arbitrary number of clients. To support location aware information services efficiently, we propose a spatial index based on expanded grid cells, named SIEC, aiming at spatial data broadcasting on air. The SIEC is organized with expanded cells of a regular grid partition for spatial data items, allows mobile clients to quickly access the queried data items by lowering the number of grid cells the clients have to access. Simulation studies show that the proposed scheme outperforms the existing schemes regarding the access time, tuning time, and energy consumed while processing given queries.

Keywords: Pervasive Computing, Wireless Spatial Data Broadcast, Distributed Indexing Scheme, Grid Partition, Expanded Cell, Window Query

1. Introduction

Wearable devices and smart mobile ones such as Google Glass and smart phones equipped with mobile communication technology like 4th generation technology leverage the vision of pervasive computing [1]. A wireless data broadcasting system for spatial data items is a natural way to resolve the two challenge, i.e., scalability and location, because it can provide location dependent information services efficiently regardless of the number of clients [2, 3]. A server disseminates spatial data items in buckets, the smallest logical access unit, via a wireless channel, and then clients access the channel, retrieve desired data items, and download them from the channel [4, 5, 6]. Thus, the system can accommodate an arbitrary number of clients simultaneously. Here, a spatial data item keeps the location of a feature on the ground, such as a shopping mall, with the latitude and longitude as well as a content about the feature. With the system, clients can obtain location dependent information related to their current locations through processing window queries to retrieve spatial data items within a given query window or k Nearest Neighbors (kNN) queries to retrieve k nearest data items from a given query point [5]. A client, for example, can find shopping malls within a 1km square centered at its current location in a metropolitan area such as San Francisco or find 3 nearest gas stations from its location.

2. Related Works

The broadcasting adopts air indexing schemes to allow clients to reduce the energy consumption by listening selectively to the data items they desire. An index is broadcast in an interleaved manner with data items on the wireless channel, that holds the time when each data item appears on the channel. With the index on the channel, clients can predict the times when their desired data items appear. This allows the clients to stay in doze mode for energy-saving by the times predicted. A client processes a given query as below:

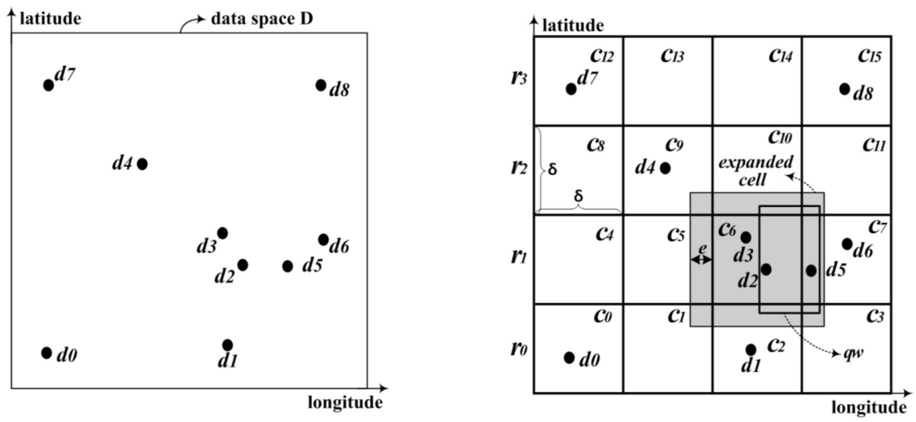
- Initial probe: With the first bucket accessed after tuning in the wireless channel, a client determines the time when the index appears on the channel and switches to doze mode by the time.
- Index search and data download: The client wakes up to active mode at the time the index appears and accesses the index on the wireless channel. Then, the client extracts the queried data items with the index and decides the times when the items appear on the channel. The client waits for the data items in doze mode till the time decided; then, it wakes up at the time in active mode and downloads the data items.

Air indexes are allocated in two schemes, (1,*m*) index allocation scheme and distributed indexing scheme. In (1,*m*) indexing scheme, an index of entire data items to broadcast is repeated *m* times for every 1/*m* data fraction. Distributed index allocation scheme distributes the indexes of partitions of data items to broadcast with the partitions.

The authors propose CEll-based Distributed Index (CEDI) in [6] to support window queries. CEDI is organized over a regular grid partition of data space and holds real locations of data items with coordinates. CEDI outperforms HCI and DSI because of listening to only queried data items by extracting them with real coordinates, unlike HCI and DSI. In [7], the authors propose Cell-based Hybrid Index (CHI) on a regular cell-partition alike CEDI to support kNN queries. CHI provides global knowledge of data distribution along with local knowledge to decide quickly the search space guaranteeing kNN and to prune the queried kNN from the search space. CEDI and CHI, however, make clients access excessive cells when query windows are overlapped slightly with neighboring cells. Those results in the performances deteriorated.

3. Spatial Indexed based on Expanded Grid Cells

We present a spatial data index based on expanded grid cells (SIEC) for a wireless data broadcasting system and a window query processing algorithm with SIEC. The proposed SIEC purposes that clients quickly obtain the answer to a given window query by reducing the number of grid cells to access for a given window query. As the environment for the proposed SIEC, we consider a broadcasting system, in which a server disseminates a set of *N* spatial data items, $\{d_1, \ldots, d_N\}$, via a high-bandwidth wireless channel and then clients access the channel and download queried data items. Here, the data items are on a two-dimensional region, called data space *D*, and their locations are described with the longitude and latitude as ones of stationary features on the ground such as shopping malls. For example, Figure 1(a) shows nine spatial data items, $\{d_0, d_1, \ldots, d_8\}$ on *D* that are about shopping malls.



(a) Data space *D* (b) 4 x 4 grid for Figure 1(a)

Figure 1: Data space *D* and its grid partition

To organize the proposed SIEC, we partition D into a regular $n \times n$ grid, where δ is the length of all sides of the grid cells and e is the expanding factor, the ratio of the expanded length of sides of cells to δ. Each grid cell has the expanded coverage within D, that is, a square of $\delta+2e$. We label the i-th row as r_i ($0 \le i < n$) with r_0 as the bottom row, and the j-th cell in Z-order as c_j ($0 \le j < n^2$), with c_0 as the first cell. For example, Figure 1(b) depicts a 4×4 grid laid upon D in Figure 1(a), where e is 0.25; rows are labeled from r_0 to r_3; cells are labeled from c_0 to c_{15}. The coverage in gray shows c_6 expanded by e that contains d_5 of c_7 as well as d_2 and d_3. In order for a client to process a window query with a query window, such as qw in Figure 1(b), the proposed SIEC allows the clients to access only cell c_6, rather than six cells, i.e., c_2, c_3, c_6, c_7, c_{10}, and c_{11}. This makes SIEC different from the other existing schemes using a regular grid partition.

4. Index Structure and Channel Organization

SIEC has two kinds of indexing tables: a row table RT_i for r_i and a cell table CT_j for c_j. Row table RT_i is defined as a table that keeps information about: what rows of the grid have data items, the broadcasting time for the rows, what cells in r_i have data items, and the broadcasting time for the cells. RT_i is organized as follows:

$$RT_i = < RI, CI > \quad (1)$$

- RI (Row Information): $\{< r_k, t_k > | 0 \le k < n\}$, where r_k is the row having data items and t_k is the time when RT_k of r_k is broadcast on the wireless channel.
- CI (Cell Information): $\{< c_k, t_k > | i \cdot n \le k < (i+1) \cdot n\}$, where c_k is a cell of r_i that has data items and t_k is the time when CT_k for c_k is broadcast on the wireless channel.

RI and CI provide clients with links to access other rows and cells efficiently. The links enable clients to take various multiple paths to a cell they try to access for a given query and result in the access time improved. Cell table CT_j is defined as a table that keeps information about: the locations of data items within c_j , the times when the items are appearing on the channel, the row and cell appearing immediately after c_j on the channel and their broadcasting time. CT_j is organized as follows:

$$CT_j = < t_{nr}, (nc, t_{nc}), DT_j > \quad (2)$$

- t_{nr} is the broadcasting time for the row table appearing immediately after c_j on the wireless channel.

- (nc, t_{nc}): nc is the cell appearing immediately after c_j on the wireless channel and t_{nc} is the broadcasting time for the cell table of nc.

- DT_j (Data Table):

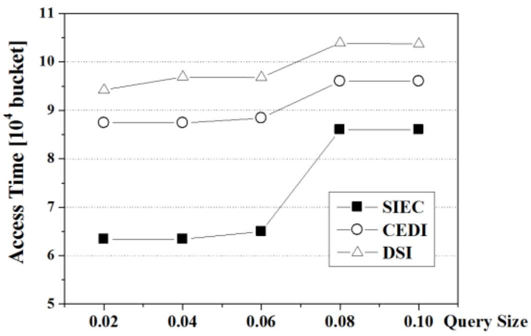
  $\{ ((d_x, d_y), t_d) | (d_x, d_y)$ is the coordinates of data item, d, belonging to expanded c_j, and t_d is the time when d is appearing on the wireless channel$\}$.

t_{nr} and (nc, t_{nc}) help clients access the neighboring row and cell, respectively. Data table DT_j enables clients to extract the queried data items within a given query window using real locations, before accessing them.

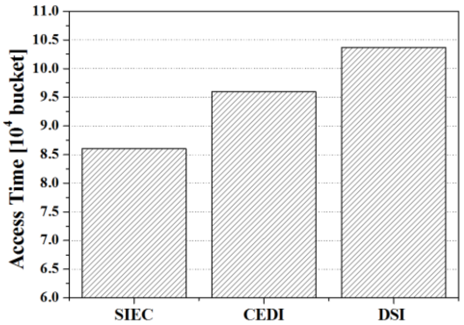
With the proposed SIEC, the wireless channel is structured in row major order as follows. Row tables are placed in row number's increasing order. Row table RT_i is followed by cell tables for the cells of r_i. Cell table CT_j is also followed the data items in c_j.

5. Performance Evaluation

To evaluate the performance of the proposed SIEC, we compare the scheme with the existing indexing schemes for spatial data regarding the access time and tuning time. Figure 2(a) shows the access time over various query sizes. The figure reveals that the proposed SIEC outperforms the existing indexing schemes for various query size, especially CEDI based on the grid partition like SIEC. That results from the reduced number of cells to access for a given query by adopting the expanded grid cells. The reduced number leads to quickly completing the given query. In addition, the links SIEC provides play the role of dropping down the access time by allowing multiple access paths to a target cell. Figure 2(b) shows the access time in details when query size is 0.08. The access time of SIEC is about 89 % and 83 % of CEDI and DSI, respectively.



(a)Access time over various query size



(b) Access time at query size, 0.08

Figure 2: Comparison of SIEC with other schemes regarding the access time

6. Conclusion

In this paper, we have addressed processing window queries on the wireless spatial data broadcast stream for pervasive computing. We proposed a Spatial data Index based on Expanded grid Cells(SIEC) to support efficiently location dependent information service, one of the context-aware computing services. SIEC is organized over a regular grid partition with each grid cell expanded by a given factor in order to reduce the number of cells that clients have to access to get the queried data items when a given query window overlaps slightly with neighboring cells. The expansion makes SIEC unique from the other indexing schemes using a regular grid partition. SIEC with link information to rows and cells provides multiple access paths to a target cell in order to help clients access the cell efficiently. For the future study, we are investigating *k* nearest neighbors over expanded grid cells.

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