LETTER

An Index Based on Irregular Identifier Space Partition for Quick Multiple Data Access in Wireless Data Broadcasting*

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SUMMARY This letter proposes an Index based on Irregular Partition of data identifiers (IIP), to enable clients to quickly access multiple data items on a wireless broadcast channel. IIP improves the access time by reducing the index waiting time when clients access multiple data items, through the use of irregular partitioning of the identifier space of data items. Our performance evaluation shows that with respect to access time, the proposed IIP outperforms the existing index schemes supporting multiple data access.

key words: *wireless data broadcast system, air index, irregular space partition, multiple data access*

1. Introduction

A wireless data broadcast system is a promising way of delivering information to an arbitrary number of clients in bandwidth-limited communication environments. In the system, a broadcast server periodically disseminates data items, such as stock market data, over a wireless channel in buckets, the smallest logical broadcasting unit. After tuning into the channel, an arbitrary number of clients can independently search and download their desired items. For example, a client can find stock prices of Microsoft, Google and Apple from the wireless broadcast channel devoted to the stock market. After tuning into the channel, constantly listening to the channel until the desired content appears, the client can then download it [1]–[3]. Thus, wireless data broadcast has the merit of scalability: the server can support a great number of clients simultaneously accessing data items, without needing to expand the physical capacity of the server though the rapid increase of the clients. Currently, practical services in wireless data broadcast are available through the DAB/DAB+ system [10] and ADS-B system [11]. In particular, the DAB+ system Journaline service efficiently disseminates text-based information, such as traffic and weather reports, sports events and results, advertisements, and stock market information.

Wireless data broadcast introduces an air index to allow clients to selectively access the items they wish to download on the channel, without needing to listen continuously. An air index maintains unique identifiers of data items and time pointers to them, their broadcasting times. The server disseminates the index by interleaving it with data items on the channel. The clients use the index to find their desired items and the time pointers to them. Thus, using the time pointers, the clients can selectively access only the desired data items on the channel [4], [5].

The access time is the time duration from the time a client tunes in to the broadcast channel, to the time the client finishes downloading all of their desired items. The access time consists of initial probe, index waiting time, and the time for searching and downloading data items. In the initial probe, the clients obtain the time pointer to the first index from the bucket they first meet after tuning in. Here, each bucket carries the time pointer to the first index appearing after itself. Then the clients wait for the index in sleep mode, and wake up in active mode at the time pointer, and access the index. Through accessing the indexes, the clients search time pointers to their desired items. Using the pointers, the clients selectively download the items from the channel. To improve the access time, it is important to reduce the size of the index because the size lengthens the length of a broadcast cycle, called *Bcast*. The index waiting time should also be reduced. The index waiting time is affected by the spaces between interleaved indexes on the channel. In general, keeping the spaces regular makes the best index waiting time when the interleaving number of the indexes is fixed.

Related Works. For clients' efficient data access, various indexes have been proposed, using integers as the unique identifier of data items. Here, we review the existing indexes to enable clients to access multiple data in a search, through an access to the indexes. Multiple data access in a search is common and realistic, because there is no restriction on the number of data items for the clients to be able to access in a search [7]–[9]. For example, using a wireless data service such as the Journaline service on DAB+ systems, the clients can access multiple data items in a search. Through the wireless data broadcast service disseminating sports events information with an index to support multiple data access, the clients can access 3 sports events information in a search, e.g., soccer, baseball, and basketball.

Exponential index (EXP) is a distributed indexing table that is allocated to each data item [4]. EXP for a data items holds identifiers and time pointers of items that are separate from the item in exponential distance on the channel. A

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data item and its indexing table are combined in units of chunks, then the chunks are broadcast. EXP enables the clients to access multiple data on the channel with an index table holding multiple time pointers in itself. However, the access time by EXP rapidly increases, due to the increase of the size of EXP according to the increment of data items.

GDI is a distributed indexing table that is allocated to groups of data items, unlike EXP [5]. GDI regularly partitions the identifier space (IS) of data items to disjoin whole data items into groups. GDI is broadcast prior to the data group allocated to it, and can support the clients accessing multiple data on the channel by time pointers in an indexing table. However, when the identifier distribution is skewed over IS, regular partition of IS makes different the number of data items that each group has, rather than uniform. This makes irregular the spaces between indexing tables on the channel, and deteriorates the access time.

Our Contribution. We propose an Index based on Irregular Identifier space Partition (IIP) to support the clients quickly accessing multiple data on the channel in a wireless data broadcast environment. IIP is an indexing table for a group of data items, and is broadcast prior to the group in the channel. IIP targets improvement of the access time, although the data distribution over IS is skewed.

IIP achieves this goal by reducing the index waiting time and its size. For the improved index waiting time, we equalize the spaces between successive indexing tables, using disjointed groups that have the same number of items. For the same sized groups, we partition IS irregularly. Thus, IIP keeps equal the spaces between indexing tables, notwithstanding the skewed data distribution over IS. This irregular partition makes IIP different from GDI, which uses regular partition and deteriorates the indexing waiting time in skewed data distribution over IS. IIP contributes to improving the access time by reducing the index waiting time for an index after the initial probe, through the equal spaces between indexes.

IIP introduces parent groups and child groups by a two-leveled irregular space partition, to which its own index is allocated, named a parent and child index. The information on irregular partition and data items is carried efficiently using the two kinds of indexes. To support clients' linear channel access pattern, the indexes are organized in table form. Also, the indexes distributed in equal spaces provides multiple access paths to data items on the channel.

The rest of the letter is organized as follows. Section 2 presents the proposed IIP. Section 3 describes simulation environments, and then evaluates their performance. Finally, Sect. 4 concludes the letter.

2. Irregular ID Partition-Based Indexing Scheme

We consider the environment where the clients search the answers to their own multipoint queries, Q_k defined below, on the wireless channel, the server broadcasting the N data items of dataset D.

The item d_i of D has non-negative integer i as its unique

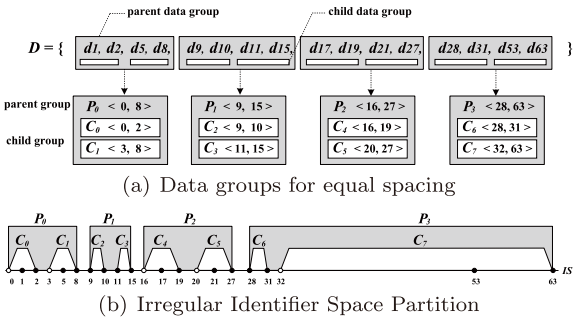


Fig. 1 Data grouping and irregular identifier space partition.

identifier. For the dataset D, identifier space IS is defined as the set of integers from 0 to the biggest identifier of the items of D. For example, Fig. 1 shows that for dataset $D = \{d_1, d_2, d_5, d_8, d_9, d_{10}, d_{11}, d_{15}, d_{17}, d_{19}, d_{21}, d_{27}, d_{28}, d_{31}, d_{53}, d_{63}\}$, IS is $0 \le IS \le 63$.

Definition 1: Multipoint Query Q_k: Q_k is a set of integer identifiers of k data items to search on the channel.

When a client processes $Q_3 = \{2, 10, 63\}$, the client searches and downloads data items d_2, d_{10}, and d_{63} from the channel.

In order to organize the proposed IIP, we disjoin N data items into two-leveled groups, the parent data group and the child data group. After sorting D in ascending order of identifiers, we set every $n_p = \lceil N \cdot r_p \rceil$ data items as a parent data group, where r_p is the size factor for the parent data group. Then, every $n_c = \lceil n_p \cdot r_c \rceil$ data items in a parent data group is split up into a child data group, where r_c is the size factor for the child data group. Figure 1 (a) shows the parent and child data groups at $r_p = 0.25$ and $r_c = 0.5$. Parent group P_i and its child group C_j for corresponding data groups are defined in the way of irregular IS partitioning as below:

Definition 2: Parent group P_i. P_i is the tuple of the minimum and the maximum identifiers that contain the i-th parent data group, and is represented as below.

$$P_i = <id_i^m, id_i^M>, \text{ for } 0 \le i < \lceil 1/r_p \rceil \quad (1)$$

Here, id_i^M is the maximum identifier of the i-th parent group, and id_i^m is the minimum identifier of the parent group with the value of $id_{i-1}^M + 1$.

Definition 3: Child group C_j. C_j is the tuple of the minimum and the maximum identifiers that cover the j-th child data group in P_i, and is represented as below.

$$C_j = <id_j^m, id_j^M>, \text{ for } \lceil 1/r_p \rceil \cdot i \le j < \lceil 1/r_p \rceil \cdot (i+1) \quad (2)$$

Here, id_j^M is the maximum identifier of the j-th child data group, and id_j^m is the minimum identifier of the child group with the value of $id_{j-1}^M + 1$.

Figure 1 (a) shows parent and child data groups of D, as well as parent and child groups corresponding to data groups. Figure 1 (b) depicts the skewed identifier distribution and the two-leveled hierarchical groups by irregular partition.

2.1 Index Structure

We organize the proposed IIP with two kinds of linear indexing tables: parent index PI_i for P_i, and child index CI_j for C_j.

PI_i for P_i is configured as follows:

$$PI_i = \langle P_i, CGT, PGT \rangle \tag{3}$$

- P_i: the tuple representing parent group P_i.
- CGT (Child Group Table): {<C_j, t_j>}, where C_j is a child group in P_i, and t_j is the time pointer to CI_j for C_j for $\lceil 1/r_p \rceil \cdot i \le j < \lceil 1/r_p \rceil \cdot (i+1)$.
- PGT (Parent Group Table): {<P_a, t_a>}, where P_a is a parent group, and t_a is the time pointer to PI_a for P_a for $0 \le a < \lceil 1/r_p \rceil$.

P_i informs the clients of the identifier coverage of PI_i. Using P_i, the clients can decide whether they access the child groups of P_i or not. The table CGT enables the clients to obtain the local view of the identifier partition, i.e., the coverage of each child group of P_i, and the time pointer to the child group. Using CGT, the clients access child groups containing identifiers in a given multi-point query Q_k. The table PGT provides the clients with a global view of the identifier partition, and the time pointers to parent groups on the channel.

CI_j for CI_j is configured as follows:

$$CI_j = \langle IDT, NCG, t_{nc}, t_{np} \rangle \tag{4}$$

- IDT (ID Table): {<id, t_d>} where, id is the identifier of a data item in C_j, and t_d is the time pointer to the data on the wireless channel.
- NCG (Next Child Group): the tuple of the next child group of C_j.
- t_{nc}: the time pointer to the next child group of C_j.
- t_{np}: the time pointer to the next parent group of C_j.

The table IDT enables the clients to extract identifiers within a given multipoint query Q_k, and the time pointers to the identifiers. NCG informs the clients of the coverage of the next child group C_{j+1}, and t_{nc} enables the clients to access C_{j+1}. NCG and t_{nc} construct the chain connecting all the child groups on the channel. Using NCG and t_{nc}, the clients access all the child groups on the channel, one after another. The time pointer t_{np} supports the clients accessing the next parent index of CI_j, and obtaining the global information on the partition of IS.

2.2 Channel Structure

Using the proposed IIP, the wireless channel is organized as follows. Figure 2 shows that every parent index is followed by all the child indexes, and the data items in the child groups in the increasing order of group number.

Figure 2 shows the channel structure by the proposed IIP for the dataset D in Fig 1. The proposed scheme enables the spaces between successive indexes on the channel to be equalized. That makes reduced the index waiting time on the channel, and improves the access time.

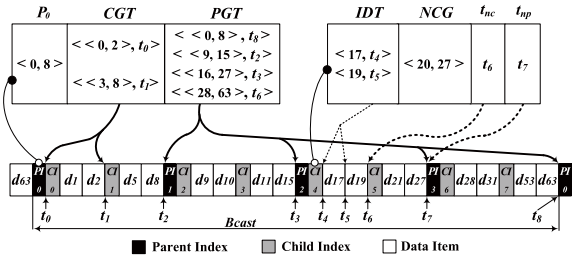


Fig. 2 The structure of the broadcast channel with the proposed scheme.

Algorithm 1 *Multipoint Query Processing*

Input: Q_k, a multipoint query
Output: A_k, a set of data items belonging to Q_k
1: initialize A_k, $gpQueue$ and $dpQueue$;
2: tuning in on the wireless broadcast channel;
3: $Index \leftarrow$ the first encountered index after tuning-in;
4: **while true**
5: **if** ($Index$ is a parent index)
6: $gpQueue \leftarrow$ getTimeFromCGT($GCT, gpQueue$);
7: $gpQueue \leftarrow$ getTimeFromPGT($PCT, gpQueue$);
8: **else if** ($Index$ is a child index)
9: $gpQueue \leftarrow$ getTimeFromCI($Index, gpQueue$);
10: $dpQueue \leftarrow$ extractDataWithCI($Index, dpQueue$);
11: **while** ($dpQueue$ is not empty)
12: $t \leftarrow$ dequeue from $dpQueue$;
13: $A_k \leftarrow$ the accessed data item at t;
14: delete id of the accessed data item from Q_k;
15: **if** (Q_k is empty) **break**;
16: $t \leftarrow$ dequeue from $gpQueue$;
17: $Index \leftarrow$ the index accessed at t;
18: **return** A_k ;

2.3 Multipoint Query Processing

Using the parent and child indexes of the proposed IIP, a client can process its own multipoint query Q_k. The client begins the process with access to the first encountered index on the channel. For the processing, the client uses two priority queues, $gpQueue$ and $dpQueue$. These are queues to hold the time pointers to indexes and data items in increasing order, respectively.

Algorithm 1 depicts the procedure for processing a multipoint query using the proposed IIP. When accessing parent index PI_i for P_i in lines 6 and 7, $gpQueue$ is updated by function getTimeFromCGT( ) and getTimeFromPGT( ), as Functions 1 shows. With child index CI_j for C_j in lines 9 and 10, $dpQueue$ is updated by function getTimeFromCI( ) and extractDataWithCI( ) in Functions 1, respectively.

3. Performance Evaluation

3.1 Simulation Environments

For the evaluation, we implemented a simulation testbed

Functions 1

Function getTimeFromCGT (CGT of PI, $gpQueue$)
1: **if** ($P_i \cap Q_k \neq \phi$)
2: **for** (all C_j of CGT)
3: **if** ($C_j \cap Q_k \neq \phi$) **then** $gpQueue \leftarrow t_j(\in CGT)$;
4: **return**

Function getTimeFromPGT (PGT of PI, $gpQueue$)
1: **for** (all P_a of PGT)
2: **if** ($P_a \cap Q_k \neq \phi$) **then** $gpQueue \leftarrow t_a(\in PGT)$;
3: **return**

Function getTimeFromCI (CI, $gpQueue$)
1: **if** ($NCG \cap Q_k \neq \phi$) **then** $gpQueue \leftarrow t_{nc}$;
2: **else** $gpQueue \leftarrow t_{np}(\in PGT)$;
3: **return**

Function extractDataWithCI (CI, $dpQueue$)
1: **if** ($C_j \cap Q_k \neq \phi$)
2: **for** (all id in Q_k)
3: **if** ($id \in IDT$) **then** $dpQueue \leftarrow t_d(\in IDT)$
4: **else if** ($id \in C_j$) delete id from Q_k
5: **return**

that consists of a broadcast server, a wireless channel, and a client, using the discrete time simulation package, SimJava. Because in a wireless data broadcast, clients do not affect each other, we implemented one client in the testbed. In simulation using the testbed, we measured the access time by the proposed IIP, GDI, and EXP in the unit of buckets.

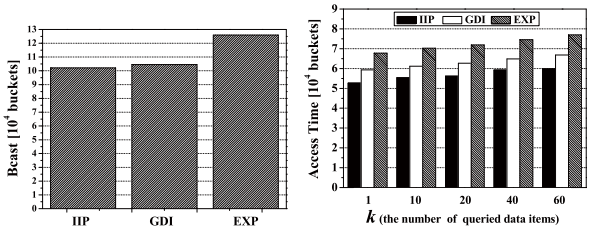
For the simulation, we used a real dataset of 5922 cities of Greece [6]. After applying the Hilber Curve to the $2D$ space containing the locations of cities, we used the Hilbert Curve value for the location of each city as the unique integer identifier of the city. Thus we can obtain natural skewed identifier distribution.

As the parameters for simulations, we set both the identifier size and the time pointer size to 8 bytes. We set the size of a data item to 1024 bytes, and the bucket size to 64 bytes. Also we set r_p and r_c for the parent and child group to 0.01 and 0.1, respectively. We apply the same value of r_p and r_c to GDI for fair comparison. Also for fairness, we set the base of EXP to 2, to provide the client with the most time pointers in an indexing table of EXP. We set k of Q_k to 1, 10, 20, 40, and 60. For each k, we ran 50,000 multipoint queries, and measured the average access time.

3.2 Comparison of the Performance

In order to evaluate the performance of the proposed IIP, we compare *Bcast*, the length of a broadcast cycle, and the access time by IIP, GDI, and EXP that support the client to process multipoint query, Q_k, on the broadcast channel.

Figure 3 (a) shows that *Bcast* by IIP and GDI based on grouping are shorter than that by EXP. This reveals group-based indexing is more efficient for the client to access queried data items. The shorter *Bcast* results from the smaller size of IIP and GDI, than that of EXP.



(a) Bcast (b) Access time

Fig. 3 Comparison of IIP with other schemes in the index size and access time.

Figure 3 (b) shows the access time of the proposed IIP, GDI, and EXP in the number of buckets, when the client processes single point queries, Q_k, $k = 1$, and multipoint queries, Q_k, $k = 10, 20, 40$ and 60. This depicts that in the case of the access to multiple data, as well as to a single datum, the proposed IIP is superior to GDI and EXP. Also, it demonstrates that IIP helps the client to quickly access the queried data items through the reduced index waiting time by the equal spaces among successive indexes on the channel, from irregular ID space partition over skewed identifier distribution. Our evaluation shows that the reduced index waiting time by the proposed IIP is effective in reducing the access time not only for multiple data, but also for a single datum.

4. Conclusion

We propose an index based on irregular identifier space partition to enable the clients to process time-efficient multipoint queries on a wireless data broadcast channel, where the distribution of identifiers of data items is skewed over the identifier space. Aimed at supporting the clients quickly accessing multiple data items, the proposed IIP partitions the data through irregular space partition into two-leveled groups. This allows the client's index waiting time on the channel to be reduced, by virtue of the equal distances among successive indexes. By simulation, we demonstrate the proposed IIP outperforms the existing indexes for multiple data access.

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