A Retrieval Algorithm for Time-constrained Heterogeneous Data Items in Wireless Networks

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Abstract

Homogeneous and heterogeneous data retrieval problem refers that these requested data items are retrieved on the basis of data items broadcast at some channels such that the access latency of all requested data items is minimized. The problem has an important study significance in MIMO (Multiple Input and Multiple Output) wireless communication. Almost researches are focused on proposing some schemes for solving signal antenna or multiple antennae data retrieval based on homogeneous data items, but these schemes are not suitable for heterogeneous data retrieval problem. So in this paper, we describe a SPR (Shortest Paths Retrieval) algorithm that is suitable for solving homogeneous and heterogeneous data retrieval problem at the same time. Moreover, for avoiding the retrieval time too long, when the each requested data item is set a constrained condition-deadline, we propose another DKPR (Deadline-based Key Path Retrieval) algorithm that finds the critical path with the largest number of requested data items in a broadcast cycle, so as to complete the retrieval operation of data items within the deadline of requesting data items as much as possible. Through experiments, the proposed scheme has good efficiency.

Keywords: Heterogeneous data items, Wireless networks, Time-constrained, Data retrieval, Access latency

1 Introduction

With the rapid development of science technology, people's demand for wireless network communication is increasing. While enjoying the convenience brought by cellular mobile communication system, people put forward new requirements for wireless data transmission. This kind of wireless communication is mainly used in indoor places such as homes, offices and shopping malls, and sometimes in outdoor environment. Today, with the highly intelligent of mobile terminals and the extensive deployment of wireless transmission network, people can access the Internet at any time through the transmission network. Intelligent mobile terminal has also become an indispensable part of daily life, study and works. The popularity of wireless network also brings users' high requirements for the quality of network service experience, that is, the transmission environment is not only high-speed but also stable. In addition, emerging Internet services, such as medical emergency system, power dispatching system, online ticket purchase system, e-commerce recommendation system, wireless monitoring application in the field of security equipment, etc., make wireless transmission have the characteristics of real-time and accuracy. In today's big data era, the amount of data transmitted wirelessly has also reached an unprecedented huge, which may lead to a long data transmission delay. Therefore, on the premise of huge amount of data and various types of data, in addition to solving the following basic problems in wireless network: improving service quality, enhancing transmission quality, reducing delay and ensuring real-time, there are still some problems to be solved, such as constructing the transmission of heterogeneous data.

Generally speaking, in the new field of communication engineering, data transmission gradually presents new requirements, and puts forward strict requirements and high standards in transmission speed. At the same time, the security of the whole transmission process and the accuracy and comprehensiveness of the transmission data need to be ensured, so as to ensure that the data information obtained by people is more accurate. However, at present, in the specific real-time data transmission process, the transmission effect is not ideal due to the limitations of a variety of technical and management problems. The classic technical form of data transmission mainly relies on the client and server as the carrier for achieving reasonable transmission. The client sends the requests of corresponding data transmission to the server, and the server transmits the data through the transmission channels. In this transmission process, the transmission timing of data in the channel will have an impact on the transmission effect. In addition, the data requests made by users and the reasonable order of data requests also have an impact on the propagation speed. At present, there are two main methods of data dissemination: push-based data dissemination [1] and on-demand data dissemination [2-4]. In the former, the server mainly selects a part of fixed data to broadcast in the channels based on the most frequently downloaded prior knowledge recently. The latter is to reasonably arrange the dissemination sequence of data in the channel according to the data requested by the user. Both methods are designed to facilitate the reduction of user download time for requested data items. When the

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server propagates data in the channels, it can propagate data of the same length (homogeneous) or data of different lengths (heterogeneous). How to obtain these data in the shortest time according to the requesting list of data provided by users is a focus of current research. In addition, in order to obtain data in time, a constraint of waiting time will be added to each requested data item, which will make the problem of data transmission more complex.

On the premise of homogeneous and heterogeneous data, this paper aims to realize the data retrieval operation requested by users based on the existing data items broadcast on the channels. So the main contributions of this paper are summarized as follows:

This is the work to mainly realize the data retrieval of heterogeneous data under the circumstance of client equipped by signal antenna.

A shortest path retrieval algorithm is proposed, which maps the requested data items contained in the communication channels into a graph, and looks for the shortest path with the largest number of request data items in the graph, so as to achieve the goal of retrieving the largest number of request data items in the shortest time.

In order to avoid the long waiting time of data retrieval for users, it is necessary to set a deadline for each requested data item. This paper proposes a deadline-based critical path retrieval algorithm that calculates the earliest starting retrieval time and the latest finishing time for each request data item, and applies the critical path algorithm, then find the critical path with the largest number of request data items in a broadcast cycle, so as to finish the data retrieval operation within the deadlines of requested data items as much as possible.

The rest of the paper is organized as follows: Section 2 introduces the related works of data retrieval problem. Section 3 defines the problems of homogeneous data retrieval and heterogeneous data retrieval. Section 4 describes a shortest path retrieval algorithm to retrieve the most requested data items in the shortest time. Section 5 describes a deadline-based critical path retrieval algorithm, so as to reduce the waiting time of data retrieval for users. Section 6 verifies the proposed methods. Finally, Section 7 concludes this paper.

2 Related Work

With the increasing involvement of mobile applications, many works are devoted to research from many views, such as the energy efficiency [5-6], traffic [7], quality of service [8], and so on. Data retrieval is another scheme to achieve better performance in wireless networks from client side. Currently, data retrieval is studied from clients equipped with one antenna or multiple antennae. In these studies of one antenna, the researchers introduce several heuristic schemes to reduce the number of passes and the number of switches for solving the minimum switch data retrieval problem (MSDR) [9]. Juran *et al.* [10] proposed several scheduling schemes to order the accesser to the data objects on parallel broadcast channels in order to reduce access latency and power consumed by the mobile devices. Foschini *et al.* [11] proposed a context data distribution infrastructure for improving efficiency and reliability by self-adapting data distribution paths and optimizing context data pushing to interested consumers. Hurson *et al.* [12] classified the data into three categories: private data, shared data, and public data, and studied three challenges: data distribution and replication strategy, conflict resolution and data retrieval methods over air channels for reducing access time and power consumption. He *et al.* [13] proposed a data retrieval algorithm to solve data retrieval problem by topological sorting. In [14], UPF algorithm is proposed to avoid 2-slot conflicts for guaranteeing the priority of retrieval of the most urgent data items. But these schemes are mostly concentrated at mobile devices with one antenna. With the development of wireless networks, the first scheme is adopted to directly apply in mobile devices with multiple antennae [15]. Because the 2-slot conflicts still exist in data retrieval of multiple antennae, the data items of one request are divided into several subsets and a greedy algorithm is used to the retrieval of subsets in each antenna [16]. In previous studies [17-18], researchers are mainly focused on the data items that are broadcast in these channels. Under this approaches: LFOS scheduling data items of largest sizes, BFOS adopting the best matching between data items and channels, and BBOS partitioning data items properly to balance the broadcast cycles of all channels, the broadcast data items can be scheduled in channels according to the demand of clients [19]. Two different schemes (SG and WG) [20] are proposed for grouping multiple requests such that the requests can be reasonably retrieved by each antenna, and a data retrieval algorithm is designed by constructed a super tree for retrieving the grouped requests in each antenna. Kottursamy *et al.* [21] proposed an eNB/gNB aware data retrieval algorithm (D-RAN) considering the liveliness and size of data items for cost-optimized in 5G networks. The above methods are mainly measured in access latency, retrieval rate, dismiss rate, energy consumption and so on.

However, all above schemes about data retrieval schemes focus on the requested data items with fixed broadcast time applied in wireless networks. On the contrary, the existing studies of heterogeneous are extremely few, especially data retrieval problem.

3 Problem Formulation

Definition 1. (Homogeneous and heterogeneous data retrieval problem) Given the set of data items $D = \{d_1, d_2, ..., d_{|D|}\}$, the set of requested data items $R \subseteq D = \{r_1, r_2, ..., r_i\}$ and the set of channels $CH = \{ch_1, ch_2, ..., ch_k\}$, where each channel has the same length broadcast cycle, the data items in D are broadcast at multiple channel times in one broadcast cycle, $\mathcal{B} = \{\mathcal{B}_1, \mathcal{B}_2, ..., \mathcal{B}_{|D|}\}$ (Note that there are no replicated data items broadcast at channels). Assume that the needed time $l = \{l_1, l_2, ..., l_{|D|}\}$ of data items broadcast at channels in D contains the following two cases:

(1) Homogeneous: the needed time of each data item broadcast at channels in D is same, $l_i = l_j$, $i \neq j$.

(2) Heterogeneous: the needed time of each data item broadcast at channels in D cannot be same, $\exists l_i, \exists l_j, l_i \neq l_j$.

The homogeneous and heterogeneous data retrieval problem is under the circumstance of (1) and (2) to retrieve the all requested data items in R from channel set CH such that the access latency is minimized.

The above descriptions are summarized in equation (1).

$$\begin{aligned} Input:\quad & D=\{d_1,d_2,\cdots,d_{|D|}\} \\ & R\subseteq D=\{r_1,r_2,\cdots,r_i\} \\ & \mathcal{B}=\{\mathcal{B}_1,\mathcal{B}_2,\cdots,\mathcal{B}_{|D|}\} \\ & l=\{l_1,l_2,\cdots,l_{|D|}\} \\ Output:\quad & \min AL \\ s.t.\quad & i,k\in N \end{aligned} \quad (1)$$

In this application, the client wants to download some data items in limited time, so it results that the definition 1 cannot be suitable for some special cases. We conclude the following definition:

Definition 2. (Deadline-based homogeneous and heterogeneous data retrieval problem) On the basis of definition 1, each requested data item d_i in R is added a retrieval deadline dl_i ($DL = \{dl_1, dl_2, ..., dl_{|D|}\}$), that the data item can be downloaded in the limited time. And the number of retrieved data items can be maximized in minimized access latency, that the loss rate $loss$ is minimized, called deadline-based homogeneous and heterogeneous data retrieval problem.

The above descriptions are summarized in equation (2).

$$\begin{aligned} Input:\quad & D=\{d_1,d_2,\cdots,d_{|D|}\} \\ & R\subseteq D=\{r_1,r_2,\cdots,r_i\} \\ & \mathcal{B}=\{\mathcal{B}_1,\mathcal{B}_2,\cdots,\mathcal{B}_{|D|}\} \\ & l=\{l_1,l_2,\cdots,l_{|D|}\} \\ & DL=\{dl_1,dl_2,\cdots,dl_{|D|}\} \\ Output:\quad & (1)\ \min AL \\ & (2)\ \min loss \\ s.t.\quad & i,k\in N \end{aligned} \quad (2)$$

According to the definition 2, the deadline-based data retrieval model is shown in Figure 1. In this model, the scheduler firstly organizes the broadcast data items. And the ordering data items are broadcast at several channels. Then, the clients firstly sends the requests that contain text, figure, video etc. The deadline separation extracts the deadlines of requested data items, and the requested scheduler orders the requested data items on the basis of its deadline. Finally, the retrieval model retrieves the necessary data items from the channels.

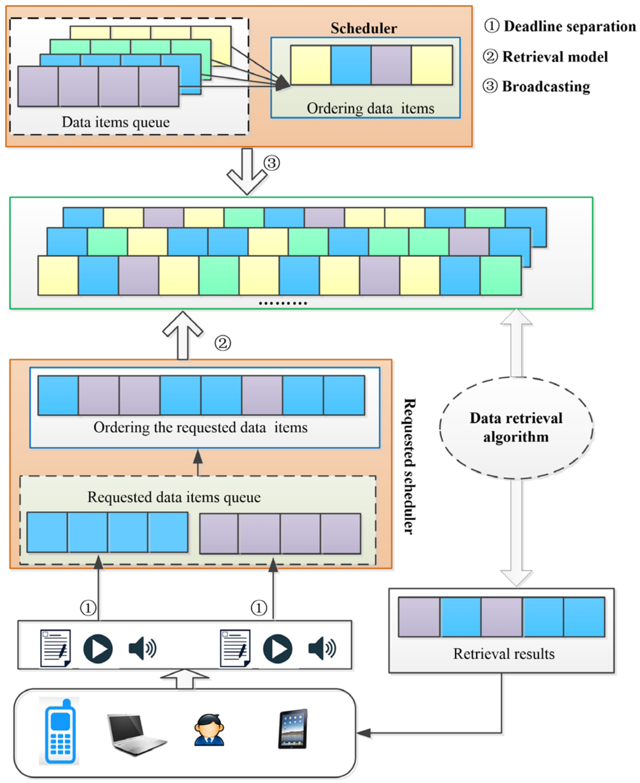

Figure 1. The deadline-based data retrieval model

4 Shortest Paths Retrieval Algorithm

In this section, we propose a data retrieval algorithm that always focuses the shortest path about the requested data items, called SPR algorithm (requests in shortest paths are firstly retrieved). In our proposed algorithm, the homogeneous and heterogeneous data retrieval problem need to be converted into the directed asyclic graph $G = (V, E)$. For the set of vertexes $V = \{v_1, v_2, ..., v_{|V|}\}$, the set of edges $E = \{e_{ij} \mid 1 \le i, j \le |V|, i \neq j\}$ and the set of broadcast data items $D = \{d_1, d_2, ..., d_{|D|}\}$, the vertex v_i denotes the broadcast data items d_i. And the edge e_{ij} denotes the switch from the vertex v_i to vertex v_j, that is to retrieve the data item d_j after retrieving the data item d_i. The weight value w_{ij} denotes the required switch time from v_i to v_j (including the time of downloading data item d_i and d_j, $w_{ij} = B_j - B_i + l_j$). On the basis of the descriptions, we design a shortest paths retrieval algorithm.

In this algorithm, for P we use it to denote the set of all shortest paths in G. The steps of algorithm are following:

Step 1: using the shortest paths algorithm, computing the shortest path P', where the set of vertexes in P' is $\tilde{V} = \{v_i \mid v_i \in P'\}$ and $\tilde{E} = \{<\dot{v},\ddot{v}> \in E,\ \ddot{v} \in P'\}$. So, $P = P \cup P'$.

Step 2: $V' = V - \tilde{V}$, $E' = E - \tilde{E}$ and compute the induced sub-graph $G'(V', E')$ of V' in graph G.

Step 3: $G = G'$, $V = V'$ and $E = E'$.

Step 4: $P' = \varnothing$, and return Step 1, until the set of all vertexes V is empty.

Step 5: according to P, computing the access latency of requested data items AL. We use an example to describe how the proposed algorithm works.

Example 1: Assume that there are six requested data items R = {d_3, d_5, d_6, d_8, d_2, d_7}, and three channels CH = {ch_1, ch_2, ch_3}, where B = {10, 3, 2, 6, 2, 4, 6, 7}, D = {d_i} (i = 1, 2, ..., 8), and l = {1, 1, 2, 2, 1, 1, 2, 3}, as depicted in Figure 2.

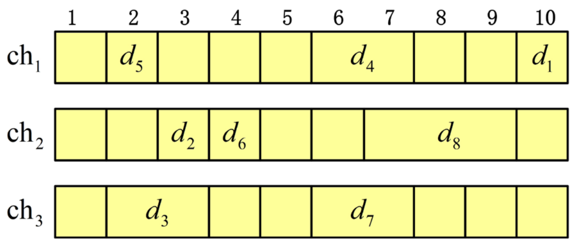

Figure 2. The deadline-based data retrieval model

First, according to R = {d_3, d_5, d_6, d_7, d_8, d_2}, we convert the wireless data broadcast system to DAG, as seen in Figure 3. When switching from one channel to another channel, we assume that the need time of switching is one time slot. In the conversion process of DAG, some rules need to be followed, as seen Rule 1.

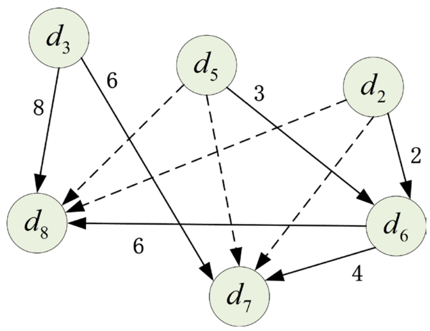

Figure 3. The un-simplified DAG

Rule 1: Assume that there is a directed edge e_{ij} between v_i and v_j , and some a path $p=\{v_i\varrho_1\varrho_2\cdots\varrho_n v_j\}$ can be hold from v_i to v_j, where $\varrho_{s,1\leq s\leq n} \in V$ = {v_1, v_2, ..., v_{i-1}, v_{i+1}, v_{i+2}, ..., $v_{|V|}$} so we give up the directed edge e_{ij} and use the path P.

The reason of Rule 1 is that we wish to connect as many vertexes as possible in one path, and it denotes that we can retrieve as many requested data items as possible in one broadcast cycle. Moreover, we can simplify the DAG. For example of the requested data items in Figure 2, there is a directed edge e_{56} between d_5 and d_6 , because d_5 of channel ch_1 can switch to d_6 of channel ch_2 . In addition, we can retrieve d_7 and d_8 by d_6 , so there are two paths p_1 = {$d_5d_6d_7$} and p_2 = {$d_5d_6d_8$} from d_5 to d_7 and from d_5 to d_8 . But there are two directed edges e_{57} and e_{58} from d_5 to d_7 and from d_5 to d_8 . So according to Rule 1, e_{57} and e_{58} will be given up in DAG. Similarly, we can have the other edges from d_3 to the other vertexes and from d_2 to the other vertexes. Finally, the simplified DAG G is shown in Figure 4. If we don't simplify the converted graph, the DAG is shown in Figure 3, and it is very complex so that the computing cost is also huge. In Figure 4, according to $w_{ij} = B_j - B_i + l_j$, we can compute all weighted values, for example $w_{38} = B_8 - B_3 + l_8 = 7 - 2 + 3 = 8$ and $w_{37} = B_7 - B_3 + l_7 = 6 - 2 + 2 = 6$.

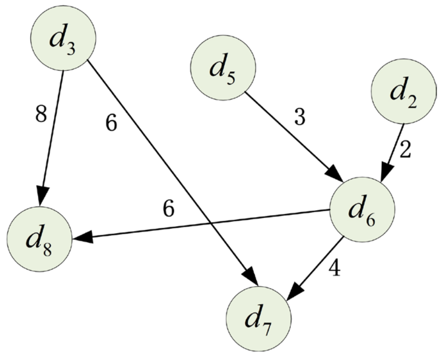

Figure 4. The simplified DAG

By the step 1 of algorithm, we firstly compute the shortest path of graph G . We don't hold all shortest paths among all vertexes, just hold the shortest paths between the vertexes that the indegree is 0 and the vertexes that the outdegree is 0. So we can hold a shortest path P' = {$d_2d_6d_7$}, and finally P = {{$d_2d_6d_7$}}. And then, delete the vertexes {d_2, d_6, d_7} from R and refresh R = {d_3, d_5, d_8}. By the step 2 of algorithm, we hold the induced sub-graph G', as shown in Figure 5. The second shortest path P' = {d_3d_8} is hold on the basis of G' and P = {{$d_2d_6d_7$}, {d_3d_8}. Finally R = {d_5} and the last shortest path P' = {d_5} is hold. As a result, P = {{$d_2d_6d_7$}, {d_3d_8}, {d_5}}. Each path in P denotes the most number of requested data items can be downloaded in one broadcast cycle. We also compute the total access latency AL = 22 . The reason is that {$d_2d_6d_7$} and {d_3d_8} respectively need one broadcast cycle, {d_5} just need two time slots.

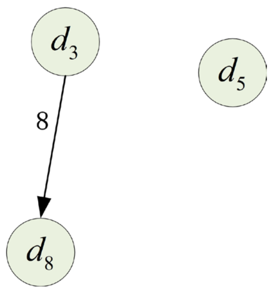

Figure 5. The induced sub-graph of G

We conclude SPR algorithm as shown in Algorithm 1. According to the shortest path algorithm, its time complexity is $O(n^2)$, in line 3. From line 2-9, we hold all shortest paths about the requested data items in R , so the total time complexity of SPR algorithm is $O(n^3)$. LFOS, BFOS and BBOS in our previous research [16] are designed for the requests of clients, and these algorithms are scheduled the requested data items of R to be broadcast at channels on the basis of the requests R of clients. Compared with the proposed algorithm in this paper, the difference is that the requested data items in R are retrieved in the channels that some data items have broadcast at channels. We focused on studying the retrieval of requested data items with fixed length and the retrieval of heterogeneous data items is few in previous study [16].

Algorithm 1. SPR algorithm

Input: CH, R, D, L;
Output: AL ;
convert R to DAG $G(V,E)$;
while ($R \neq NULL$)
hold a shortest path P' in G, where $\tilde{V} = \{v_i \mid v_i \in P'\}$
and $\tilde{E} = \{<\dot{v},\ddot{v}> \in E \text{ and } \dot{v},\ddot{v} \in P'\}$
$P = P + P'$;
hold $G'(V-\tilde{V}, E-\tilde{E})$;
$G = G'$;
$P' = \varnothing$;
$R = R - \tilde{V}$;
end while
compute AL;

5 Deadline-based Key Path Retrieval Algorithm

In SPR algorithm, we don't focus on the requested data items with deadlines, so we set a deadline dl_i for each requested data item r_i and define deadline-based homogeneous and heterogeneous data retrieval problem in Definition 2. We propose a DKPR algorithm on the basis of key path algorithm for solving this problem. First, we use the same converted method of SPR algorithm to hold DAG $G(V, E)$. Second, we compute the earliest retrieval time $ES(v_i)$ and the latest retrieval time $LF(v_i)$.

Assume the set of vertexes is $V = \{v_1, v_2, ..., v_n\}$, if v_1 is the starting node and v_n is the ending point, so the $ES(v_i)$ of each vertex in V can be derived from equation (3) and $LF(v_i)$ of each vertex in V can be derived from equation (4).

$$\begin{cases} ES(v_1) = B_1 \\ ES(v_j) = \max\{ES(v_i) + w_{ij} \mid <i,j> \in E, j = 2,3,\cdots,n\} \end{cases}. \quad (3)$$

$$\begin{cases} LF(v_n) = ES(v_n) \\ LF(v_i) = \min\{LF(v_j) - w_{ij} \mid <i,j> \in E, j = 2,3,\cdots,n\} \end{cases}. \quad (4)$$

In this DKPR algorithm, for P we use it to denote the set of all key paths in G , let P_{max} be a path with the maximal number of nodes in P , and let $\tilde{P} = NULL$ be he final results of key paths. The steps of algorithm are following:

Step 1: convert R into graph G . Count the number of vertexes in G which the indegree is 0, and hold the set $V_r \subseteq V$. Moreover, count the number of vertexes in G , and hold the set $V_c \subseteq V$. Let the final results of key paths $\tilde{P}$ = $NULL$.

Step 2: $P = NULL$, $P_{max} = NULL$.

Step 3: select a vertex v_q as a starting point from V_r and select a vertex v_c from V_c as a ending point. The selecting rule is that the least deadline of vertex is the most urgent and need to consider whether the deadline of this vertex is expired. If the deadline is expired, another vertex need to be selected.

Step 4: Using equation (3) derive $ES(v_i)$ of each node from the starting node v_q , and using equation (4) derive $LF(v_i)$ of each node from the ending node v_z .

Step 5: hold the key path P' from the starting node v_q to ending node v_z by key path algorithm.

Step 6: $P = P \cup P'$.

Step 7: determine whether V_c is empty, if not empty, then turn to Step 3. If empty, select a key path P_{max} with the maximal number of nodes from P . And $\tilde{P} = \tilde{P} \cup P_{max}$.

Step 8: refresh $R = R - P_{max}$, if R is not empty, then hold the new converted graph $G'(\tilde{V} \in R, \tilde{E})$, else the algorithm is end.

Step 9: refresh $G = G'$, and turn to step 2.

We use an example of homogeneous data items to describe the executing process of DKPR algorithm.

Example 2: Assume that there are the requested data items $R = \{d_1, d_2, d_3, d_4, d_5, d_6, d_7, d_8, d_9\}$, and three channels $CH = \{ch_1, ch_2, ch_3\}$, where $D = \{d_1, ..., d_8, d_9\}$, the starting broadcast times of data items $B = \{1, 7, 1, 4, 3, 8, 4, 4, 6\}$, $l = \{1, 1, 1, 1, 1, 1, 1, 1, 1\}$ and deadlines of data items $DL = \{10, 18, 2, 6, 4, 10, 5, 7, 8\}$. The wireless data broadcast system is depicted in Figure 6.

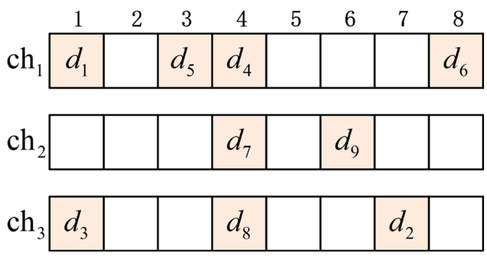

Figure 6. Wireless data broadcast system of example 2

According to R , we convert the wireless data broadcast system to DAG, as shown in Figure 7. In the converting process, we also use the Rule 1 of SPR algorithm.

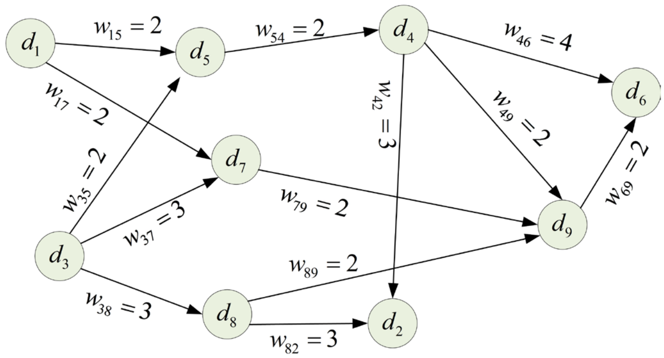

Figure 7. The converted DAG G_1

First, in the first broadcast cycle, the set of vertexes which the indegree is 0 is $V_r = \{d_1, d_3\}$, and the set of vertexes which the outdegree is 0 is $V_c = \{d_2, d_6\}$. In V_r , the remaining time of d_1 compared with its deadline is $dl_1 - B_1 = 5 - 1 = 4$, and the remaining time of d_3 compared with its deadline is $dl_3 - B_3 = 2 - 1 = 1$, so d_3 is preferentially selected as the first starting node. Similarly, according to the remaining times of d_2 and d_6 , d_6 is preferentially selected as the first ending node. In G_1 , we delete nodes d_1 and d_2 , and the adjacent edges with d_1 and d_2 . Finally, we hold $G_1^{'}$, as shown in Figure 8.

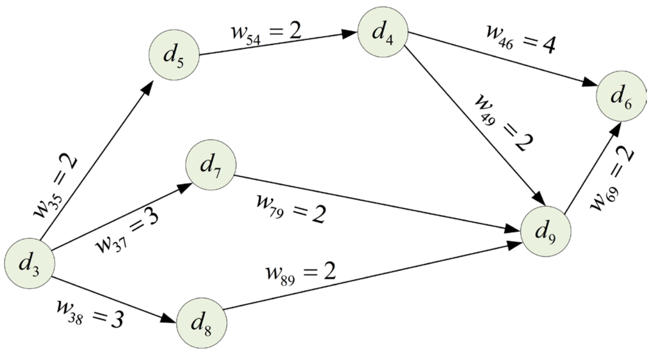

Figure 8. The simplified graph $G_1^{'}$

We compute $ES(v_i)$ and $LF(v_i)(i = \{3, 4, 5, 6, 7, 8, 9\})$ of each node in G. The topology sorting sequence of $G_1^{'}$ is $\{d_3, d_5, d_7, d_8, d_4, d_9, d_6\}$. According to equation (3), we hold $ES(d_3)$ via equation (5), $ES(d_5)$ via equation (6), $ES(d_7)$ via equation (7), $ES(d_8)$ via equation (8), $ES(d_4)$ via equation (9), $ES(d_9)$ via equation (10), and $ES(d_{11})$ via equation (11). According to equation (4), we hold $LF(v_6)$ via equation (12), $LF(v_9)$ via equation (13), $LF(v_4)$ via equation (14), $LF(v_8)$ via equation (15), $LF(v_7)$ via equation (16), $LF(v_5)$ via equation (17), and $LF(v_3)$ via equation (18).

$$ES(d_3) = B_3 = 1. \quad \textbf{(5)}$$

$$ES(d_5) = \max\{ES(d_3) + w_{35}\} = \max\{1+2\} = 3. \quad \textbf{(6)}$$

$$ES(d_7) = \max\{ES(d_3) + w_{37}\} = \max\{1+3\} = 4. \quad \textbf{(7)}$$

$$ES(d_8) = \max\{ES(d_3) + w_{38}\} = \max\{1+3\} = 4. \quad \textbf{(8)}$$

$$ES(d_4) = \max\{ES(d_5) + w_{54}\} = \max\{3+2\} = 5. \quad \textbf{(9)}$$

$$\begin{aligned} ES(d_9) &= \max\{ES(d_4)+w_{49}, ES(d_7)+w_{79}, ES(d_8)+w_{89}\} \\ &= \max\{5+2, 4+2, 4+2\} = 7 \end{aligned}. \quad \textbf{(10)}$$

$$\begin{aligned} ES(d_6) &= \max\{ES(d_4)+w_{46}, ES(d_9)+w_{69}\} \\ &= \max\{5+4, 6+2\} = 9 \end{aligned}. \quad \textbf{(11)}$$

$$LF(d_6) = ES(d_6) = 9. \quad \textbf{(12)}$$

$$LF(d_9) = \min\{LF(d_6) - w_{69}\} = \min\{9-2\} = 7. \quad \textbf{(13)}$$

$$\begin{aligned} LF(d_4) &= \min\{LF(d_6)-w_{46}, LF(d_9)-w_{49}\} \\ &= \min\{9-4, 7-2\} = 5 \end{aligned}. \quad \textbf{(14)}$$

$$LF(d_8) = \min\{LF(d_9) - w_{89}\} = \min\{7-2\} = 5. \quad \textbf{(15)}$$

$$LF(d_7) = \min\{LF(d_9) - w_{79}\} = \min\{7-2\} = 5. \quad \textbf{(16)}$$

$$LF(d_5) = \min\{LF(d_4) - w_{54}\} = \min\{5-2\} = 3. \quad \textbf{(17)}$$

$$\begin{aligned} LF(d_3) &= \min\{LF(d_5)-w_{35}, LF(d_7)-w_{37}, LF(d_8)-w_{38}\} \\ &= \min\{3-2, 5-3, 4-3\} = 1 \end{aligned}. \quad \textbf{(18)}$$

We conclude the results of $ES(v_i)$ and $LF(v_i)$ in Table 1. And then, we can hold two key paths, such as $P_1 = \{d_3, d_5, d_4, d_9, d_6\}$ and $P_2 = \{d_3, d_5, d_4, d_6\}$. Our goal is to find all possible paths from the starting node to the ending node, and yet the key path algorithm can be achieve the goal. Next, according to step 7 of DKPR algorithm, we find that the vertex d_2 in V_c is not selected as the ending node, so we continually hold the key paths in $G_1^{''}$ from the starting node d_3 to the ending node d_2 , $P_2 = \{d_3, d_5, d_4, d_2\}$. The simplified graph $G_1^{''}$ is shown in Figure 9. So, $P = \{P_1, P_2\}$. Moreover, we select a key path with the maximal number of nodes from P , $P_{max} = \{d_3, d_5, d_4, d_9, d_6\}$. The reason is to guarantee that the rate of retrieval is as far as possible. Finally, refresh $\tilde{P} = \tilde{P} \cup P_{max} = \{\{d_3, d_5, d_4, d_9, d_6\}\}$. At this time, the access latency for downloading the requested data items in $\tilde{P}$ is 8.

Table 1. The results of $ES(v_i)$ and $LF(v_i)$ in $G_1^{'}$

	d_3	d_5	d_7	d_8	d_4	d_9	d_6
ES	1	3	4	4	5	7	9
LF	1	3	5	5	5	7	8

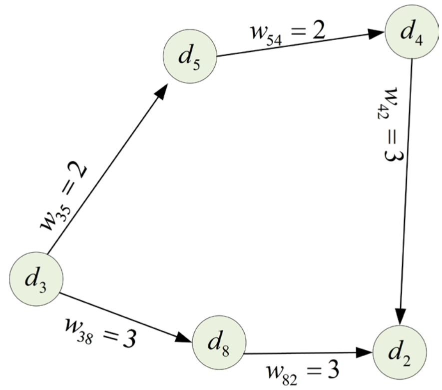

Figure 9. The simplified graph $G_1^{''}$

In the second broadcast cycle, we firstly delete the vertexes in $P^{'}$ from R and hold $R = \tilde{V} = \{d_1, d_2, d_7, d_8\}$. According to the step 8 of DKPR algorithm, we hold the derived sub-graph $G_2(\tilde{V}, \tilde{E})$, as shown in Figure 10. By $G = G_2$, we compute the key paths in G again. In graph G , $V_r = \{d_1, d_8\}$ and $V_c = \{d_7, d_2\}$. Because the deadline of d_1 is 10, the deadline of d_8 is 7, the deadline of d_7 is 5 and the deadline of d_2 is 18, at the same time the retrieval process is the second broadcast cycle, so the deadlines of d_7 and d_8 are expired. For improving the retrieval rate, we select d_1 as the starting node and d_2 as the ending node. By executing DKPR algorithm again, we hold the key path $P = \{d_1, d_2\}$, so $P_{max} = P$. Finally, $\tilde{P} = \tilde{P} \cup P_{max} = \{\{d_3, d_5, d_4, d_9, d_6\}, \{d_1, d_2\}\}$. Because the requested data items d_7 and d_8 are expired, so delete them from V , and $R = V = \{\varnothing\}$. In the second broadcast cycle, the retrieval time for downloading $\{d_1, d_2\}$ is 7, so the total access latency for retrieving R is 17, and the retrieval rate $\alpha = \frac{7}{9}$.

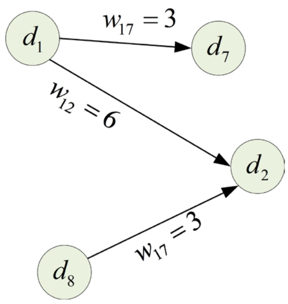

Figure 10. The converted graph G_2

We conclude the DKPR algorithm in Algorithm 2. From line 9 to line 12 and line 14-17, we select the suitable starting node and ending node. In line 7-23, we find a key path with the maximal number of vertexes from v_q in V_r to v_r in V_c in one broadcast cycle. And in line 2 to line 23, we find all key paths about R in all broadcast cycles.

Algorithm 2. DKPR algorithm

Input: CH, R, D, l, B, DL;
Output: $\tilde{P}, AL, \alpha$;
1: $\tilde{P} = NULL$; $AL = 0$;
2: **while** ($R \neq NULL$)
{
3: $P = NULL$;
4: $P_{max} = NULL$;
5: hold a converted graph G about R ;
6: in G hold V_r and ;
7: **while** ($V_r \neq NULL$)
{
8: $P' = NULL$;
9: **do**
{
10: select v_q with the minimized deadline from V_r ;
11: $V_r = V_r - v_q$;
}
12: **while** ($dl_{v_q} \geq AL$)
13: **while** ($V_c \neq NULL$)
{
14: **do**
{
15: select v_c with the minimized deadline from V_c ;
16: $V_c = V_c - v_c$;
}
17: **while** ($dl_{v_c} \geq AL$)
18: hold all key paths P' from v_q to v_c ;
19: $P = P \cup P'$;
20: if ($V_c = NULL$)
{
21: hold P_{max} in P , and $\tilde{P} = \tilde{P} \cup P_{max}$;
22: AL ;
23: $R = R - P_{max}$;
}
}
}
24: compute α ;

6 Experimental Results

6.1 Experimental Environments

Some existing studies analyzed the access latency in multiple channels environment [22]. So we also use the access latency as the main evaluating metric. For verifying the adaptability of proposed algorithm in homogeneous and heterogeneous broadcasting environment, we set a simulated broadcasting environment that contains 550 homogeneous data items and another simulated broadcasting environment that contains 550 heterogeneous data items in Matlab of PC. These data items are randomly selected as broadcasting data items in k channels in each broadcasting cycle (10 time slots). And the client will randomly send the requests to achieve the retrieval process.

In the data retrieval algorithm with deadline, the loss rate are seriously affect the success of retrieval, so we wish to reduce the loss rate of requested data items and use it as another evaluating metric.

6.2 Access Latency

In this subsection, we use our proposed algorithms (SPR and DKPR) to compare the access latency from the perspective of requested data items without deadline and with deadline.

6.2.1 Access Latency without Deadline

We conduct two groups of experiments to validate the access latency of SPR and DKPR compared with FCFS and

DRMR [13] in the performance of access latency when the requested data item is not set the deadline. And each group is executed 10 times.

In the first group of experiments with homogeneous broadcasting environment, the number of requested data items is verified from 5, 10, 15, 20, 25 under the circumstance of fixed broadcasting channels (5). From the results in Figure 11, the results of SPR, DKPR and DRMR are similar, but are prior to the results of FCFS.

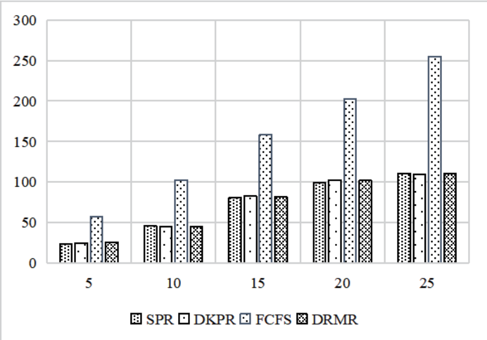

Figure 11. The results of access latency in homogeneous broadcasting environment without deadline

In the second group of experiments with heterogeneous broadcasting environment, the number of requested data items is verified from 5, 10, 15, 20, 25 under the circumstance of fixed broadcasting channels (5). From the results in Figure 12, the results of DKPR are prior to the results of SPR, FCFS and DRMR.

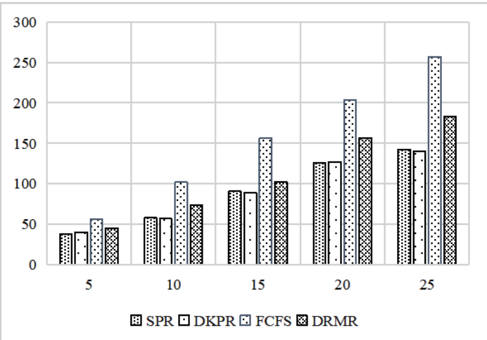

Figure 12. The results of access latency in heterogeneous broadcasting environment without deadline

6.2.2 Access Latency with Deadline

We also set two groups of experiments under the conditions of subsection 6.2.1, but the requested data items are set the deadlines. Focused on Figure 13 and Figure 14, the experimental results of access latency show that the performance of DKPR is better than those of SPR, DRMR and FCFS. The reason is that we consider the deadline limitation when designing the DKPR.

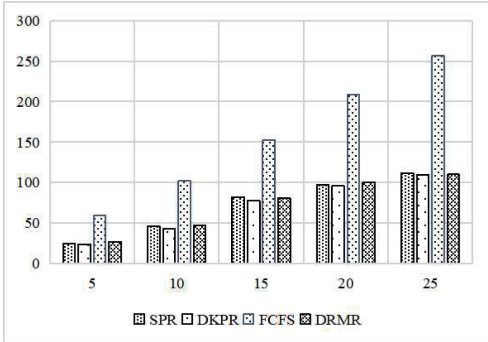

Figure 13. The results of access latency in homogeneous broadcasting environment with deadline

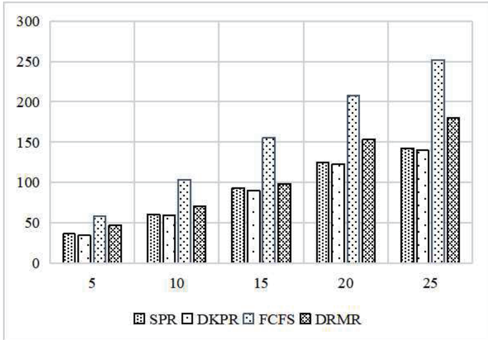

Figure 14. The results of access latency in heterogeneous broadcasting environment with deadline

6.3 Loss Rate with Deadline

In this subsection, we compare the loss rate from the perspective of requested data items with deadline in SPR, DKPR, FCFS, and DRMR. In addition, we compute the loss rate (%) of each method in heterogeneous broadcasting environment similar to subsection 6.2, as shown in Figure 15. The results show that the KDPR is the least one, and the loss rate is increasing when the number of requested data items is also increasing.

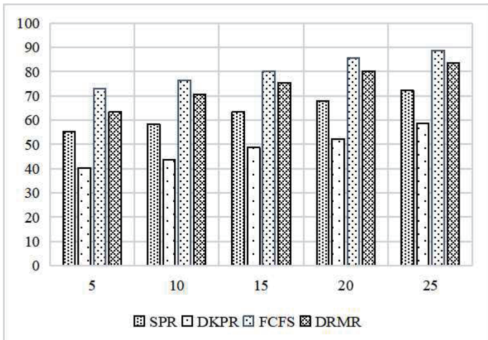

Figure 15. The results of loss rate in in heterogeneous broadcasting environment with deadline

7 Conclusion

Nowdays, there are many types of data, a large amount of data and inconsistent data network structure, which make it more difficult to achieve rapid information transmission in wireless networks with big data service architecture [23]. Therefore, in this paper, we study the heterogeneous data retrieval problem with deadlines, which has very typical application value in the current big data environment. Based on the idea of achieving as much data retrieval as possible in a broadcast cycle, this paper proposes SPR and KDPR methods. The former is mainly designed to complete the retrieval of homogeneous and heterogeneous data items without setting a deadline, and the latter is mainly designed to complete the retrieval of homogeneous and heterogeneous data items with time constraints. Compared with traditional methods, it has obvious advantages. In addition, during the experiments, we use the random method to select the data items to be broadcast in the channel, but we find that selecting the data items to be broadcast in the channel will seriously affect the performance of the data retrieval algorithm. Therefore, in future we combine some methods, such as deep learning method, monarch butterfly optimization (MBO) [24], earthworm optimization algorithm (EWA) [25], elephant herding optimization (EHO) [26], moth search (MS) algorithm [27], slime mould algorithm (SMA) [28], hunger games search (HGS) [29], runge Kutta optimizer (RUN) [30], colony predation algorithm (CPA) [31], and Harris hawks optimization (HHO) [32], to recommend the corresponding data items to be broadcast in the channel according to some external factors and customers' preferences, so as to further reduce the access delay and improve the performance of the data retrieval algorithm.

8 Acknowledgments

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