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On a Cooperation of Broadcast Scheduling and Base Station Caching in the Hybrid Wireless Broadcast Environment

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Abstract

In this paper, based on the Hybrid Wireless Broadcast (HWB) model, we investigate a cooperative data management strategy to provide more efficient data delivery to the mobile clients. This strategy integrates broadcast scheduling with cache management of the base station by making effective use of the HWB data dissemination, namely push- and pull- based broadcast and pull-based point-to-point wireless communication. Simulation study demonstrates that the proposed cooperation strategy can improve the system performance.

1. Introduction

1.1. Background

Various techniques have been developed to improve the performance of wireless information services, such as point-to-point data dissemination, information broadcasting, and data caching. Recent advances in computer and wireless communication technologies have increased interest on the combination of these techniques; meanwhile research on data management of a hybrid data delivery system receives more attention.

Our previous study proposed a novel wireless communication model, namely Hybrid Wireless Broadcast (HWB) model, which can provide more flexible and complementary information services in different bandwidths and service ranges, as well improve the responsibility and scalability of the system. However, it is necessary to investigate a further effective data management to provide more efficient data dissemination to the mobile clients.

A cooperation of the cache management and broadcast scheduling has been confirmed to be able to provide more efficient data delivery. However, most of research investigated the integrated control based on the push-based broadcast, and normally conducted cache management at the client side. So far, there has been no study discussing the cooperative data management based on the hybrid broadcasting environments.

This paper aims at constructing an efficient cooperation under the HWB environment by integrating the broadcast scheduling and the cache management of the base station.

1.2. HWB Model

The HWB model comprises a broadcast server, lots of base stations, and a large number of clients [2]. Mobile clients holding a portable terminal such as PDA can access information from the broadcast server and the base station. The broadcast server broadcasts information in a large scope with two distinct bandwidths, i.e., the main channel and the on-demand sub channel. Additionally, each base station connects with the broadcast server through the Internet, and serves local clients via the wireless channel by using the base station cache. The three data delivery ways of the HWB model have different features.

For the push-based broadcast of the main channel, the response is not affected by the load, namely the number of clients. However, clients may not be able to acquire the reply quickly even though the total number of queries is small. The average response time depends on a total number of the broadcast items.

The pull-based broadcast of the sub channel can meet individual requirements of the global clients; at the same time any on demand response can be accessed by an arbitrary number of clients. However, the response depends on the number of queries which request for different items, namely, the waiting time increases with the number of different requests.

In contrast, the pull-based wireless communication can meet individual requirements of the local clients, by using the base station cache. However, the on demand response

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through the wireless channel cannot be shared due to the point-to-point communication.

Among the three data delivery ways of the HWB model, it is helpful to determine more effective system control, if taking the above features into account to minimize the impact of the defect of one mode by exploiting advantages of the others.

1.3. Broadcast Scheduling and Caching

Traditionally, the server broadcasts different items at a same frequency, namely FlaT broadcast (FT), regardless of their relative importance to the clients. By comparison, in Multi-Disks (MD) broadcast [1], important items can be broadcast more often than others; normally, hot items are determined to be put to the fast disks.

On the other hand, the basic problem for cache management is to determine which items should be cached to give the best responsiveness to the clients' requests, frequently accessed data or expensive data. In pull-based systems, this is typically achieved by caching the items with the highest access probability, namely the probability-based caching. Whereas in push-based multi-disks systems, a cost-based PIX caching is efficient to cooperate with multi-disks scheduling. In such a system, caching strategy cannot favor items that are frequently broadcast, since those items can be accessed within a short time. However, it remains an unclarified question which is more suitable to the HWB system, probability-based caching or PIX caching.

Generally cache management is performed by the client side, of which the role of cache is to reduce the response latency for the client itself. In contrast, the HWB system employs the base station cache, by which serves the local client community rather than an individual client. Cache management of the base station aims at providing more efficient data delivery relevant to the local clients, namely improving the average response of the local client community by increasing the cache hits of base station. To construct a more effective data management of the HWB system, it is necessary to take into account the special role of base station cache and the cooperation of the push-based broadcast and the pull-based broadcast.

It has been confirmed that multi-disks scheduling is a good program for the non-uniform access; meanwhile, probability-based caching is suitable for the pull-based system. Considering that the HWB model provides two pull-based data delivery ways, and we focus on the skewed access pattern, we attempt to employ multi-disks scheduling and probability-based caching as the basic processing mode into our cooperative data management of the HWB system.

1.4. Overview of the Paper

In this paper, we propose a cooperative data management which takes account of the complementary features of HWB data dissemination and the integration of base station caching and broadcast scheduling. Additionally, we investigate the following interrelated issues by evaluating the system performance under different strategies:

- Whether multi-disks broadcast performs better than flat broadcast in the HWB environment?
- Which is the optimal way to process items with high access probability? Keeping them in the base station cache or broadcasting them with high frequency?
- Whether it is necessary to assign all items of the database for broadcasting? How about only broadcasting the items with no Cache-resident (abbr. as no_Ca)?

All the work in this paper is assumed based on the HWB model. In addition, we make the following assumptions:

- Data is read-only, and the access pattern of clients is static. We reserve the update issue for a future study.
- Clients' access patterns vary according to the base station they belong to, e.g., location dependent service.
- Broadcast server and base station have the knowledge of the clients' access patterns, which can be predicted based on the past accesses or the profile of the clients.
- Broadcast server is aware of the cache of each base station, which can be informed via the Internet.
- Client has no capability of caching, like PDA.

The rest of this paper is organized as follows. In Section 2, we present our integrated control and several implementary strategies for the HWB model. In Section 3, we show the evaluation results of the simulation study and give a further discussion on the cooperation control of the HWB system. Section 4 introduces related work. Finally, we summarize this paper in Section 5.

2. Cooperative Control Policy

2.1. Access Probability

Our cooperative control of the HWB system depends on the clients' access probability, which is distinguished as the Local Access Probability (LAP) and the Global Access Probability (GAP). We give their explication as follows.

The requests for item *i* from base station *b* generates the local access probability $P_b(i)$, where $1 \leq i \leq N$ and $\sum_{i=1}^{N} P_b(i) = 1$. Here *N* denotes the total number of the data items in the database. Additionally, the requests for item *i* from each base station are aggregated to the global access probability *P(i)*, which is calculated by

$$P(i) = \frac{1}{M} \sum_{i=1}^{M} P_b(i),$$

where M denotes the total number of base stations, and $\sum_{i=1}^{N} P(i) = 1$ is also satisfied.

Since clients in different regions normally have heterogeneous accesses, while clients in a same geographical area often have similar interests in the local information, some items may be hot in one area but cold at other areas. Taking these into account, we assume that all the items of the database are divided into several data groups in accordance with the base stations. Requests in each base station have a high tendency (k) to issue the skewed queries, and a low tendency to send uniform queries. The skewed queries follow Gaussian distribution $Gau(i, \mu, \sigma)$ with the center of hot spot μ and deviation σ. The value of μ is set as the center of each data group, while that of σ can be varied to reflect the different skewness of the clients' queries. Let $F_b(i)$ denote the query mode of the base station b for item i, which is given by

$$F_b(i) = k \times Gau(i, \mu, \sigma) + (1 - k)/N.$$

Hence, the local access probability is estimated by

$$P_b(i) = F_b(i) / \textstyle\sum_{j=1}^{N} F_b(j).$$

2.2. Cooperative Control in HWB

Figure 1 indicates the control model of the HWB system. Generally speaking, data items in the database can be assigned to the schedule of the main channel to be broadcast, or be placed into the on-demand sub channel to respond to the queries of the global clients, or be kept in the base station cache and on-demand transmitted by the wireless channel to respond to the queries of the local clients. It is essential to choose the optimal processing way, but it may be unrealistic to assume data organization of the system complies with the individual access pattern of all clients. Therefore, we focus on processing items with high access probability (i.e., hot items), for which to choose the optimal way.

The broadcast server serves clients in a global area, whereas base stations provide services only for local clients. Accordingly, we tend to keep items with the highest local access probability in the base station cache. It is good at increasing the cache hits if keeping the local hottest items in the base station cache, since the size of base station cache usually is much smaller than that of the database, also smaller than that of the interest set of the local clients.

On the other hand, the server needs to be aware of the base station caching in order to manage the broadcast program. In view of the multi-disks broadcast, if the hottest items of the local area is retained in the cache of the base station, these items should be pushed to the slower disk, otherwise the server wastes a significant portion of the fastest disk for items already in the cache of the base station.

For the meanwhile, chopping off a part of the broadcast schedule, namely shortening the broadcast cycle, has the effect of increasing the available bandwidth. Therefore, we consider the processing: all the items that have resided in the base station cache will not be broadcast any more. It is because in the HWB environment clients can pull the items that are disappeared in the main channel through the on-demand sub channel or the on-demand wireless channel.

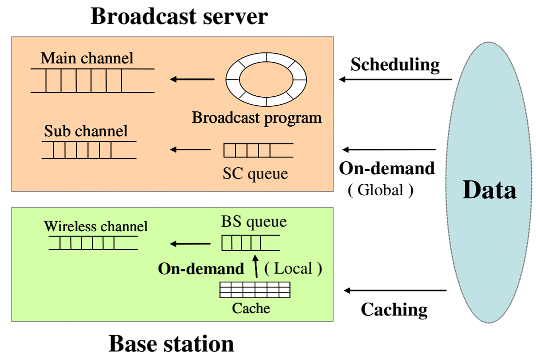

Figure 1. Control Model

Consequently, we design the following procedures for our cooperation control by using LAP and GAP.

1. Retain the hottest items with the largest estimated LAP values in the base station cache.
2. Modify the LAP values for all the items resided in the base station cache.
3. Aggregate the GAP by using the modified LAP of each base station.
4. Construct a broadcast program with the newly aggregated GAP.

To reflect the base station cache, once an item is cached, its LAP and GAP value will be modified. Additionally, in terms of multi-disks scheduling, it needs to rank all the items with the modified GAP to generate a broadcast disk program. By greatly decreasing the corresponding LAP and GAP values, the cached items are impossible to be pushed to the fastest disk. Moreover, if the modified GAP values of some items become zero, these items will not be broadcast any more.

2.3. Control Strategies

To investigate how our control idea could be implemented efficiently, and what influence on the system performance under different processing, we design four cooperative control strategies as the follows.

GAP-MD(no_Ca) Strategy

In this strategy, the global hottest items with the largest GAP values are kept in the cache of each base station; hence all base stations have identical cache. Moreover, the LAP values for all the cached items are set as zero, i.e.,

$$P_b(i) = 0 \mid i \in Cache,\ b = 1 \sim M,$$

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where $Cache = Cache_1 = \cdots = Cache_b = Cache_M$. Here $Cache_b$ denotes the set of items kept in the cache of the base station b ($1 \le b \le M$), while $Cache$ denotes the total set of items kept in each base station cache. Therefore, the GAP values for those cached items also become zero. That is to say, all the items identically cached in each base station will not be broadcast any more. The other items without cache-resident adopt the multi-disks scheduling.

LAP-MD(no_Ca) Strategy

In this strategy, each base station keeps the local hottest items with the largest LAP values in the cache. Differing from the strategy GAP-MD(no_Ca), cache of each base station is different, since each base station has distinct LAP. Moreover, the LAP values for all the items resided in any base station cache are set as zero, i.e.,

$$P_b(i) = 0 \mid i \in Cache,\ b = 1 \sim M,$$

where $Cache = Cache_1 \cup \cdots \cup Cache_b \cup Cache_M$. Therefore, the GAP values for those items resided in any base station also become zero. In other words, the items once cached in any base station will not be broadcast any more. The items without any cache-resident adopt the multi-disks scheduling. The items, which are disappeared in the main channel and requested by the clients without serving through the base station cache, will be pulled by the on-demand sub channel.

LAP-FT(no_Ca) Strategy

The cache management of this strategy is the same as the LAP-MD(no_Ca); however, the broadcast schedule is different. In this strategy, the items without any cache-resident adopts the flat broadcasting rather than the multi-disks scheduling.

LAP-MD(all) Strategy

This strategy also let each base station keep the local hottest items with the largest LAP values in the cache, however, differing from the above strategies, which only modifies the LAP values for the items resided in its own base station cache as zero, i.e.,

$$P_b(i) = 0 \mid i \in Cache_b,\ b = 1 \sim M.$$

Hence, the GAP values of the cached items are just greatly decreased, but do not become zero. All the items in the database will be broadcast with the multi-disks scheduling, based on the ranking of the modified GAP values.

In addition, we introduce two traditional strategies to compare with our strategies.

PIX-MD(all) Strategy

This strategy, employing the traditional BD approach, broadcasts all the items in the database with the multi-disks scheduling, while the cache management of base station adopts PIX caching. Therefore, the global hottest items are broadcast with the fastest broadcast frequency. Thus, this strategy completely differs from our proposed strategies.

LAP-FT(all) Strategy

Table 1. Parameter Settings

Parameters	Values
Database Size [Data Items]	10,000
Data Item Size [KB]	100
Number of Base Stations	10
Cache Size of BS [Data Items]	200
Main Channel Bandwidth [Mbps]	100
Sub Channel Bandwidth [Mbps]	10
Wireless Bandwidth [Mbps]	5
Time Slot [D/Bm]	30,000
Query Interval [ms]	50 $\sim$ 1,500
Data Group Size [Data Items]	1,000
Query Tendency [%]	80
Deviation for Gaussain	150
Number of Disks	3
Broadcast Frequency of $\text{Disk}_{1,2,3}$	4, 2, 1
Size of $\text{Disk}_{1,2,3}$ [Data Items]	500, 1,000, uncertain

The cache management of this strategy is the same as the strategy LAP-FT(no_Ca), namely keeping the local hottest items in the base station cache, moreover both of them adopt flat broadcast. However, this strategy broadcasts all the items in the database, instead of only broadcasting the items without cache-resident in LAP-FT(no_Ca). A similar strategy was adopted in our previous study of the HWB system[2].

3. Simulation Experiments

In order to evaluate the performance of the above mentioned strategies, we conduct the simulation study. Table 1 presents the default system parameter settings used in the experiments. The performance metrics are the average waiting time and the success rate of queries.

3.1. Impact of Query Interval

In the first experiment, we evaluate the system performance under different query intervals. Figure 2 shows that as the query interval increases, i.e., workload decreases, the performances of the average waiting time and the success rate upgrade for all the strategies. Notice that our proposed strategy LAP-MD(no_Ca), LAP-FT(no_Ca) and LAP-MD(all) occupy the top three among all the strategies at the main phase of the evaluation, and LAP-MD(no_Ca) always performs the best.

The reasons for these behaviors are as follows. These three strategies all keep the local hottest items in the base station cache, which can provide low-latency response to the local clients who usually have a similar access pattern. However, these strategies differ in the broadcast scheduling. LAP-MD(no_Ca) and LAP-MD(all) both adopting the

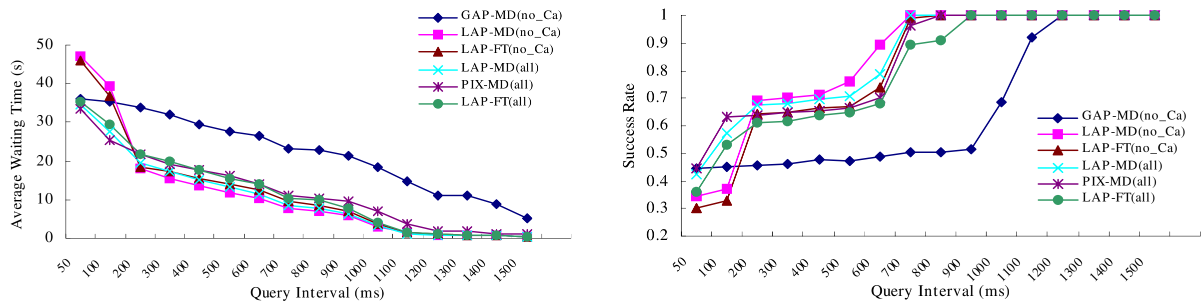

Figure 2. Impact of Query Interval

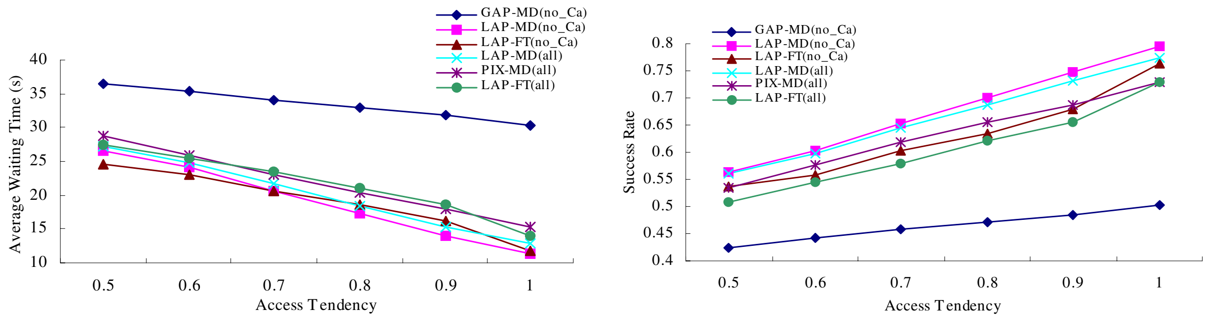

Figure 3. Impact of Access Tendency

multi-disks scheduling though, LAP-MD(all) broadcasts the whole items, while LAP-MD(no_Ca) only broadcasts the items without any cache-resident. By shortening the broadcast cycle and by utilizing the two on-demand channel to pull the items disappeared in the main channel, LAP-MD(no_Ca) can make more efficient use of the three bandwidths and thus has the best performance. By comparison, LAP-FT(no_Ca) adopts flat broadcast. In the case of the skewed access, and the cache of base station can only keep part of hottest items, it is more efficient to push the remained hot items to the fastest disk rather than flatly broadcast them.

As for GAP-MD(no_Ca), it always has the poorest performance, due to the lowest cache hits. Only when the access load is extremely heavy, it has a better performance. It is because in this case the load of the wireless channel for the strategies with a higher cache hits becomes much heavier. However, in GAP-MD(no_Ca), most queries are served by the frequent broadcast, since it broadcasts most of hottest items with the fastest disk.

On the other hand, the traditional strategies all the while perform much more poorly. The reason is that PIX-MD(all) has the longest broadcast cycle and lower cache hits, which give rise to the longer average response and lower utilization of the bandwidth. LAP-FT(all) has a higher cache hits though, it broadcasts the whole items in the database, which also cannot make efficient use of the bandwidth. Only when the access load of the system gets much heavy, PIX-MD(all) has the best performance. The best account is that in this case a large amount of queries can be better responded by the frequent broadcast of the hottest items.

3.2. Impact of Access Pattern

Next, we evaluate the impact of access pattern through two interrelated factors: the access tendency and the query deviation of the skewed access. Figures 3 and 4 show LAP-MD(no_Ca) outperforms the other strategies under the ordinarily skewed access, i.e., access tendency is above 0.7 and query deviation is from 100 to 175. As the reason explained above, LAP-MD(no_Ca) has a higher cache hits and more efficient bandwidth usage, moreover adopting the multi-disks scheduling for the skewed access.

When the query deviation of the skewed access become extremely skewed, for example, only about 50 items, PIX-MD(all) behaves best. In this case, a large amount of queries concentrate on a quite small part of hottest items, while for the probability-based strategies, these hottest items are almost all kept in the base station cache. However, the responses are transmitted by the point-to-point wireless communication; thus, the load of wireless channel becomes greatly heavy. On the contrary, PIX-MD(all) broadcasts the required hottest items more often, and the frequent broadcast can be shared by an arbitrary number of clients.

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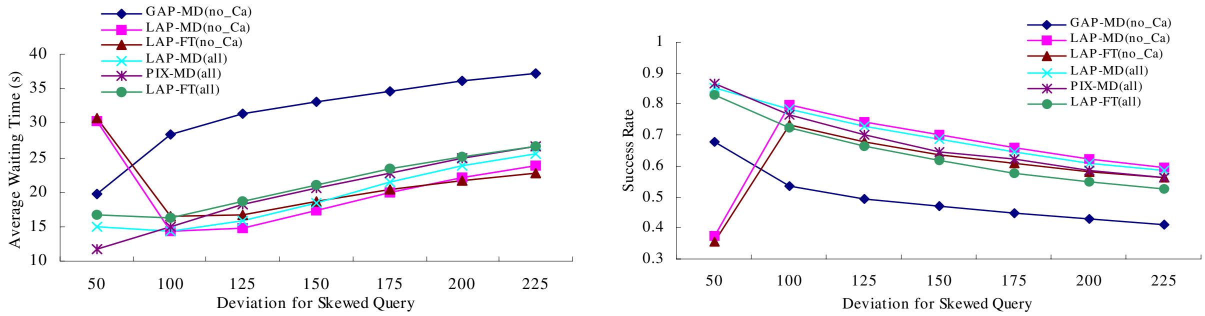

Figure 4. Impact of Query Deviation

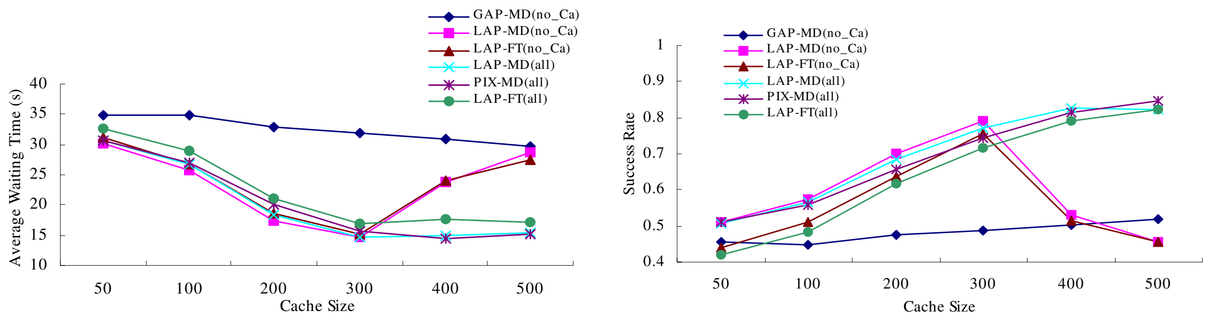

Figure 5. Impact of Base Station Cache Size

When clients' access becomes uniform, i.e., access tendency is below 0.7 and query deviation is above 175 items, LAP-FT(no_Ca) performs the best. The reason is that this strategy adopts the flat broadcast with the shortest broadcast cycle, which is more suitable to the case when queries of clients are uniform or relevant to a large number of global data. In addtition, when the access tendency of the skewed queries approaches 1, the performance of LAP-FT(no_Ca) is also increased greatly. It is because in this case the skewed queries concentrate on the local data, while most of the requested items are cached in the local base station, less response from the broadcast, and thus performance difference between the multi-disks broadcast and the flat broadcast becomes small.

3.3. Impact of BS Cache Size

We then examine the impact of cache size of the base station. As Figure 5 shows, when the size of base station cache is below 300 items, namely relatively smaller than that of the access range of the local clients, the performance of all strategies upgrades markedly as the cache size increases, and LAP-MD(no_Ca) has the best performance. It is because in this case cache hits increases with the cache size. In addition, LAP-MD(no_Ca) makes the best use of the three bandwidths of the HWB model, by keeping a part of local hottest items in the base station cache, pushing the remained hot items to the fastest disk, and removing the cached items from the broadcast.

However, when the size of the base station cache approaches 300 items, the performance differences of almost all strategies become very small. Moreover, when the cache size is above 300 items, the performance of LAP-MD(no_Ca) and LAP-FT(no_Ca) drops sharply, whereas there is a little change for the other strategies. The reason is that these two strategies keep the local hottest items in the base station cache, and these items once kept in the cache will not be broadcast any more. When the cache size of the base station is so huge to keep most of local hottest items, the load of wireless channel becomes too heavy; in the meanwhile, the bandwidth utilization of the main channel gets too low. By comparison, PIX-MD(all) performs the best under a large cache size, since the hottest items are pushed to the fastest disk, and the increasing cache size has no influence on the broadcast schedule but only increases the cache hits.

3.4. Impact of Pull Bandwidth

Finally, we examine the impact of pull bandwidth. As Figure 6 shows, when the bandwidth of wireless channel is very small, i.e., below 3Mbps, PIX-MD(all) performs the best. The reason is that the narrow wireless channel limits the strategies with a higher cache hits to behave better. Once the bandwidth becomes larger, these strategies perform better than the strategies with a lower cache hits. Our proposed

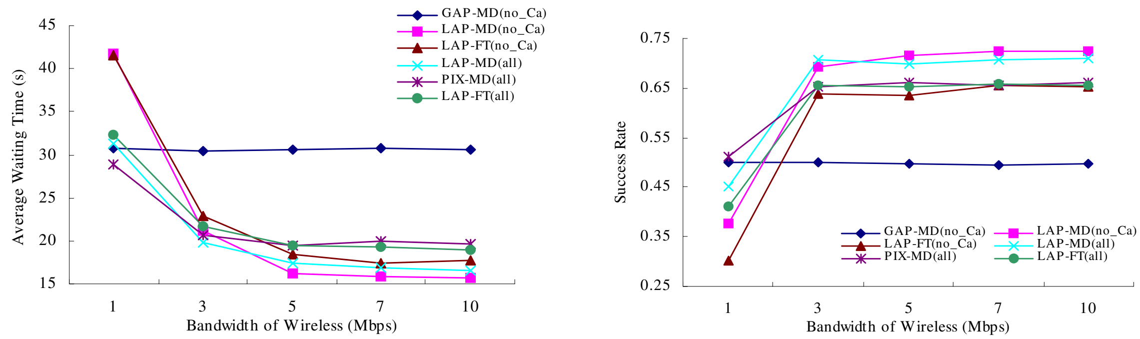

Figure 6. Impact of Bandwidth of Wireless Channel

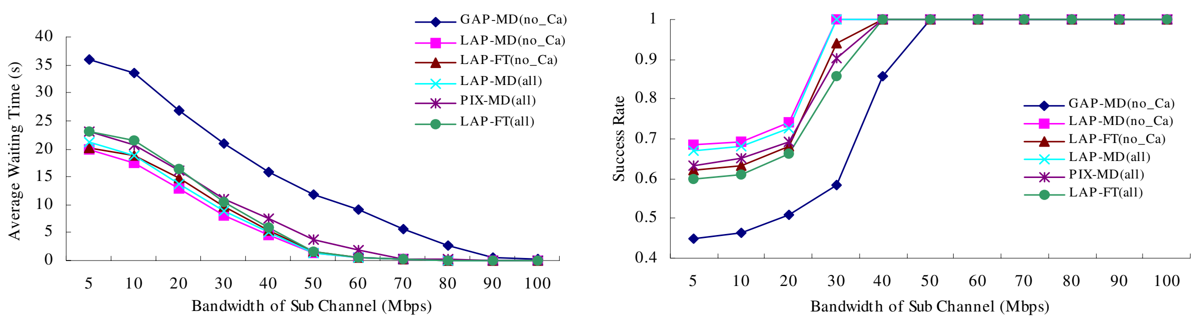

Figure 7. Impact of Bandwidth of Sub Channel

strategy LAP-MD(no_Ca) performs the best when the bandwidth is above 5Mbps. Additionally, Figure 7 indicates that the performance of all strategies upgrade as the bandwidth of sub channel increases. However, when the bandwidth gets very large, the differences among almost all strategies become very small, since in this case the bandwidth of sub channel is so huge that all the strategies mainly use the sub channel to respond to the queries.

3.5. Discussion

From the above experimental results, we come to the conclusion of the evaluation as follows. The most suitable strategy of the HWB system depends on the different situations. In the ordinary condition, i.e., when system load is ordinarily heavy, access is ordinarily skewed, and the cache size of the base station is relatively smaller than the number of local hot items, LAP-MD(no_Ca) is the most suitable strategy. In the case when the clients' access gets uniform, while system load is ordinarily heavy, LAP-FT(no_Ca) is the best choice. Additionally, in the case when system load is extremely heavy, clients' access is extremely skewed, while the cache size of the base station is very large, or the bandwidth of the wireless channel is quite small, PIX-MD(all) is the best.

It is clear that in a more normal situation our proposed LAP-MD(no_Ca) and LAP-FT(no_Ca) outperform the other strategies, by integrating broadcast scheduling with the base station caching, and by making the best use of the three bandwidths of the HWB model. Specifically, these two strategies adopt the following processing key points for cooperation control.

One point is to keep the items with the highest local access probability in the base station cache, which is more effective than broadcasting them with high broadcast frequency, also better than caching the global hottest items. This processing is suitable for the heterogeneous access of the clients in different areas, and can provide low-latency service to the clients in the same region with a similar access pattern. Results reveal that those strategies keeping the local hottest items in the base station cache normally have better performance.

Another point is to remove the cache-resident items from the broadcast program. This processing can greatly shorten the broadcast cycle, increase the available bandwidth of the main channel, and also can make effective use of the sub channel and the wireless channel to pull the items disappeared in the main channel. The experiments confirm that the strategies adopting this processing perform better than those strategies which broadcast the whole items.

On the other hand, if there is no limit to use these two processing, when the increasing cache hits is beyond the

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bandwidth of wireless channel, and when most of the hottest items are removed from the main channel, system performance will become worse, due to the heavy load of the wireless channel and the low bandwidth utilization of the main channel.

4. Related Work

Recent advances in computer and wireless communication technologies have increased interest on combination of data broadcasting and data caching. Many researches investigated the collaborative control methods by integrating broadcast scheduling and cache management [1, 3, 4, 5, 6, 7].

Broadcast Disks was well known on integrating the multi-disks scheduling with the cost-based PIX caching [1]. The relationship between broadcast scheduling and caching of the broadcast disk systems was explored in [5]. Yajima et al. investigated the broadcast scheduling and the suitable caching policy by taking into account the correlation among data items [7]; while Kim et al. dicussed the joint approach by considering the structure relation of the information items through a linked data model [4]. The common point of these studies is that they did not consider the heterogeneous and the homogeneous access of the clients.

Su et al. proposed an integrated method to simultaneously produce the broadcast schedule and the scheme of the prefetch by considering the heterogeneous access of the clients [6]. However, it did not consider utilizing data caching to provide low-latency service to the clients with a similar access pattern. Additionally, Ercetion et al. addressed the joint issue in two stage satellite-terrestrial wireless broadcast system by considering the lower average latency of the local clients [3], of which the motivation partly is similar with ours. However, there is no uplink between the clients and the local stations or between the local stations and the main server. They suggested the further work needs to be extended to consider the hybrid system.

The above studites revealed that the joint design of the broadcast scheduling and cache management can provide more efficient data delivery. However, among these studies, almost all are based on a push-based broadcasting, and mostly conduct cache management at the client side. To our best knowledge, none of studies discussed a cooperative control of the broadcast scheduling and cache management based on the hybrid broadcasting environments, by taking account of the heterogeneous and the homogeneous access of the clients.

Our previous study proposed the HWB model and confirmed the HWB approach can enhance system performance [2]. However it isolatedly employed flat broadcasting and LRU caching, which did not investigate whether the cooperation of broadcast scheduling and base station caching can further improve the system performance.

5. Conclusion

In this paper, we investigated a cooperation control of the HWB system by integrating broadcast scheduling and cache management of the base station, and designed several cooperative strategies to evaluate the system performance. The simulation study revealed that the system performance can be further improved by a suitable cooperation control. Furthermore, it was confirmed that our proposed control strategies normally outperform the traditional strategies, by taking advantage of the complementary features of the HWB data dissemination and by taking advantage of the base station cache and its cooperation with the broadcasting.

The current work is conducted on the static condition of the system. However, the access pattern and the query load of clients are dynamically changed in a real environment. Hence, dynamic control of the HWB system is an interesting problem for further study. The work in this paper is helpful to design an appropriate control mechanism in a dynamic system.

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