An Adaptive Control Method in the Hybrid Wireless Broadcast Environment

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Abstract

In this paper, we investigate adaptive control for broadcast scheduling and base station caching in the Hybrid Wireless Broadcast (HWB) environment. The proposed adaptive method can adapt well to different access conditions and bandwidth capabilities and adequately exploit the three data delivery modes: push-based broadcast, pull-based broadcast, and pull-based point-to-point communication. Simulation studies demonstrated that our proposed method achieves significant performance improvement in average waiting time and success rate.

1. Introduction

Due to recent advances in wireless technologies, mobile users equipped with portable terminal, such as cellular phone, PDA, and laptop PC, can acquire information services through 3G cellular network, WiFi hotspot, or WiMAX link. Although these technologies vary in many aspects, we view them as a base station infrastructure network (abbr. as BS network). In such a network, mobile clients access wireless services through a base station, i.e., the wireless access point, which is connected to wired networks and serves clients within a particular area.

Most recently, mobile digital broadcast has become available. The world's first satellite digital broadcasting service for mobile devices was launched in October 2004 in Japan; meanwhile, Japanese terrestrial digital broadcasting service for cellular phone began for the first time in the world in April 2006.

Mobile clients, therefore, can access wireless services through BS networks as well as data broadcast, which significantly extends available information services for a single mobile terminal. Furthermore, it is possible to enjoy more efficient services by benefiting from the integration of BS networks and data broadcast.

At the same time, interest has increased in the research of hybrid networking and effective data management in hybrid broadcasting environments. Some studies have integrated push-based broadcast with pull-based broadcast or with pull-based point-to-point data dissemination [2, 5, 6, 7]. Others have investigated the cooperation of cache management and broadcast scheduling as well as adaptive control in broadcasting environments [1, 8, 9, 10]. However, most research has focused on push-based broadcast, and normally conducted cache management at the client side. More effective data dissemination must be explored to exploit recent wireless communication technologies.

In [3], we introduced a new hybrid data delivery model, called Hybrid Wireless Broadcast (HWB) model that combines push-based broadcast, pull-based broadcast, and pull-based point-to-point communication. The HWB system, which can provide a flexible information service in different bandwidths and service ranges, greatly improves the responsibility, scalability, and efficiency of the system. However, we must investigate making coordinated use of the three data delivery modes of the HWB system, and adapting it to different conditions to provide more effective data dissemination.

Considering that access load and system conditions differ greatly in real situations, this paper aims to develop an adaptive control method in an HWB environment. The proposed adaptive method takes advantage of the complementary features of HWB data dissemination, and integrates broadcast scheduling with cache management of the base station.

The remainder of this paper is organized as follows. In Section 2, we sketch the HWB model and analyze the preliminary problem of adaptive control in the HWB environment. In Section 3, we put forward our adaptive control method for broadcast scheduling and base station caching for HWB systems. Section 4 shows the experimental results of simulation study. Finally, this paper is summarized in Section 5.

2. HWB System

2.1. HWB model

An HWB system is comprised of a broadcast server, many base stations, and a large number of clients [3]. The broadcast server broadcasts information in a wide area at two distinct bandwidths: broadband main channel and relative narrowband on-demand sub channel. The base stations that have a cache are connected to the broadcast server through the Internet and serve clients within the responsible area by narrowband wireless channel. In such a system, mobile clients can access information from the broadcast server and the base station. Clients send all requests to local base stations, which take charge of query processing for local clients, respond to queries by themselves or transfer them to the broadcast server. The broadcast server manages the information for broadcasting.

The three data delivery modes of the HWB model have different features. For push-based broadcast of the main channel, response is not affected by query load, i.e., the number of client queries. However, average response time depends on the broadcast volume. Pull-based broadcast of the sub channel, which can meet individual requirements of global clients, can be accessed by an arbitrary number of clients. However, response depends on the number of different queries. In contrast, pull-based point-to-point communication of the wireless channel can meet individual requirements of local clients by using the base station cache. However, such on-demand response cannot be shared unlike the on-demand sub channel. Determining more effective system control by exploiting the advantages of one mode would help reduce the impact of the defects of others.

2.2. Broadcast Scheduling and Base Station Caching

To construct better data dissemination of the HWB system, coordination must be considered between base station caching and broadcast scheduling of the server. We have investigated cooperative broadcast scheduling and base staion caching in hybrid wireless broadcast environments, and reached several valuable conclusions [4].

Keeping local hot items in the base station cache can provide low-latency response to local clients with a homogeneous access interest. Meanwhile, removing unnecessary items from the periodic broadcast can increase the available bandwidth of the main channel as well as the on-demand sub channel. However, if there is no limit on the use of these two processes, system performance will worsen when the increasing query load is beyond the bandwidth of the wireless channel and when too many items are removed from the main channel. Moreover, current cooperative methods are separately suitable for different access loads and system conditions.

The critical issues for more suitable control of the HWB system are as follows:

- How to prevent the increasingly query load beyond the wireless channel?
- How to make adequate use of the sub channel?
- How to avoid low utilization of the main channel?
- How to integratedly adapt the HWB system to different access conditions and bandwidth capabilities?

The motivation of this paper is to address the above issues and coordinate broadcast scheduling and base station caching to produce effective adaptive control of the HWB system.

2.3. Two-layered Access Probability

Adaptive control of the HWB system depends on client access probability, which is distinguished as Local Access Probability (LAP) and Global Access Probability (GAP). LAP plays an important role in base station caching; whereas GAP has much more of a relation with broadcast scheduling of the server.

Assume that the number of queries in a unit time for item i from base station b is Q_i^b. Aggregated number of queries for base station b is Q^b, where $Q^b = \sum_{i=1}^{N} Q_i^b$. Here N denotes the total number of data items in the database. Aggregated number of queries for item i by all base stations is Q_i, where $Q_i = \sum_{b=1}^{M} Q_i^b$. Here M denotes the number of base stations. Hence, the total number of queries for the entire system is Q, where $Q = \sum_{i=1}^{N} Q_i$ or $Q = \sum_{b=1}^{M} Q^b$.

The local access probability from base station b for item i is L_i^b, which is calculated by

$$L_i^b = Q_i^b / Q^b; \tag{1}$$

meanwhile, the global access probablility for item i is G_i, which is calculated by

$$G_i = Q_i / Q. \tag{2}$$

3. Adaptive Control for the HWB System

Several important factors greatly impact the adaptive control of hybrid data delivery systems, which include the access conditions of clients and the system conditions. The query load of clients in a real environment may differ greatly in many cases. For instance, during a day, morning and evening may be a peak time for demanding information services. On the other hand, system configurations differ greatly in real situations, and configurations for each base station, such as wireless bandwidth and cache size, may be different because any type of wireless network such as cellular network, WiFi or WiMAX link can be adopted in the HWB system. Meanwhile, for the base station itself, the disposed configuration may not match each other, such as high cache hit ratio with narrow wireless bandwidth. All these factors will be considered in our adaptive control so that the HWB system can adapt to various conditions.

The proposed adaptive control assumes that each base station has knowledge of the number of queries in a unit time for every data item, namely, Q_i^b defined in Section 2.3. This can be done in practice: in evaluation period *T*, base stations count the number of queries for each data item, i.e., TQ_i^b; thus, $Q_i^b = TQ_i^b/T$. Moreover, the other items defined in Section 2.3, including the local and global access probabilities, can also be calculated according to the corresponding definition formulae.

In the following section, we first separately explain adaptive control for base station caching and broadcast scheduling and then introduce a procedure for integrated adaptive control.

3.1. Adaptive Base Station Caching

Keeping local hot items (those with high local access probability) in the base station cache can acquire more cache hits; meanwhile, increasing cache size can also increase cache hits. However, under too many cache hits, the increased query load may easily exceed the bandwidth of the wireless channel. To prevent wireless channel congestion, it is necessary to determine the optimum conditions for base station caching. To adapt to wireless bandwidth and different query loads, we consider suitable cache size as a balance bar. For instance, under a heavy query load, reducing available cache size to decrease cache hits alleviates the congestion of the wireless channel; for the idle wireless channel, cache size should be increased as much as possible until maximum available cache size is attained. Therefore, suitable cache size depends on query load and wireless bandwidth of the base station. Moreover, each base station has its own adaptive cache size since conditions of base stations may differ with each other.

Adaptive cache size A^b for base station b is calculated by

$$A^b = max\{j|\sum_{i=1}^{j} Q_i^b \leq W^b/D \times \alpha\}; \quad (3)$$

meanwhile, $A^b \leq C^b$. Here W^b and C^b denote the bandwidth and the maximum available cache size of base station b, α is a coefficient for the utilization of the wireless channel. We assume each data item has the same size D, and all data items for base station b are ranked by descending values of local access probability $\{L_i^b\}$, where $1 \leq i \leq N$ and $1 \leq b \leq M$. Adaptive cache size must ensure the total number of local client queries in a unit time for the cached items cannot exceed the bandwidth capacity of the base station. Meanwhile, adaptive cache size cannot exceed the maximum available cache size of local base station.

As a result, in our adaptive base station caching, items with larger LAP values, i.e., local hot items, are kept in the base station cache as much as possible until the estimated adaptive cache size is attained.

3.2. Adaptive Broadcast Scheduling

Multi-disks broadcasting [1], which let hot items be broadcast more often, is employed for the broadcast of the main channel, since we pay more attention to the skewed access of clients. Moreover, unnecessary items are removed from the periodic broadcast of the main channel to shorten the broadcast cycle. However, if too many items, even hot items, are removed from the main channel, as mentioned in Section 2.2, system performance will worsen. Therefore, the key issue for the adaptive broadcast scheduling of the HWB system is to determine what items should be removed from the broadcast and how many items will not be broadcast.

For the HWB system, global cold items or cached items can be removed from the broadcast of the main channel. The reason is that for global cold items, few queries of clients demand them. For suitable cached items, if there are only a few queries for them from other base stations, we consider removing them from the main channel because they can be responded to by the on-demand sub channel, although there is no broadcast on the main channel or without a cache resident in local base station.

For suitable cached item i at base station b, the number of local queries is modified as zero after being cached, i.e., $Q_i^b = 0$, where $1 \leq i \leq A^b$ and $1 \leq b \leq M$. Hence, the total number of queries for the cached items will be greatly decreased, and global access probability for the cached items is also greatly decreased. As a result, items with smaller values of global access probability, i.e., global cold items or some suitable cached items, will be removed from the broadcast of the main channel.

The optimum number of non-broadcasting items (abbr. as N_{noBr}) depends on the bandwidth of sub channel B_s and main channel B_m. We assume all data items of the system are ranked by ascending values of modified global access probability $\{G_i^{'}\}$, where $1 \leq i \leq N$.

On one hand, removing items from the main channel broadcast means driving the on-demand sub channel to pull the items that disappeared from the main channel. The number of non-broadcasting items depends on the bandwidth of the sub channel and query load of the entire system, which is calculated by

$$N_{noBr} = max\{k|\sum_{i=1}^{k} Q_i \le B_s/D \times \beta\}, \qquad (4)$$

where β is a coefficient for the utilization of the sub channel. To adequately use the sub channel, items with smaller values of global access probability will be removed from the broadcast of the main channel as much as possible. However, the total number of queries in a unit time for the removed items should not exceed the capacity of the sub channel, i.e., the number of queries in a unit time the sub channel can transmit.

On the other hand, to avoid low utilization of the main channel, the maximum number of non-broadcasting items should not exceed the total number of data items excluding the number of items that the main channel can transmit, which is calculated based on the bandwidth of the main channel:

$$N_{noBr} \le N - B_m/D \times \theta, \qquad (5)$$

where θ is a coefficient for the utilization of the main channel.

The adaptive number of non-broadcasting items in the HWB system should satisfy both Formulae (4) and (5).

3.3. Integrated Adaptive Control

We design the following procedure to accomplish the integrated adaptive control of the HWB system by adopting two-layered access probability LAP and GAP.

Step 1: Estimate LAP by each base station, according to Formula (1).

Step 2: Determine adaptive cache size by each base station, according to Formula (3).

Step 3: Keep the items with the largest LAP values in the base station cache under the adaptive cache size.

Step 4: Modify the number of local queries for the cached items as zero.

Step 5: Aggregate GAP with the modified query number from all base stations, according to Formula (2).

Step 6: Determine the adaptive number of non-broadcasting items, according to Formulae (4) and (5).

Step 7: Construct a multi-disks broadcasting program by removing the adaptive number of non-broadcasting items with the smallest GAP values.

Steps 1 to 4 are first conducted by each base station, and then Steps 5 to 7 are performed by the broadcast server.

In our adaptive control of the HWB system, each base station independently determines the adaptive caching based on local query load and its own bandwidth capacity. Furthermore, the broadcast server determines the adaptive broadcast scheduling by taking into account global query load and the bandwidth capacity of the main channel and the sub channel as well as coordination with base station caching. As a result, the adaptive cache size and number of non-broadcasting items are not fixed, which depend on the access load of clients and system conditons. Meanwhile, it is effective for solving the issues mentioned in Section 2.2 and the problems stated in the beginning of Section 3, since our adaptive method can effectively use the three bandwidths.

4. Simulation Experiments

A simulation study was conducted in two parts to evaluate the efficiency of the proposed adaptive control method of the HWB system. First, in experiments 1 to 4, configurations for each base station were identical to examine the adaptivity of the proposed method to different access loads and system conditions. Second, in experiment 5, each base station had different wireless bandwidth and maximum available cache size to further examine adaptivity to different base station conditions.

Two previous approaches were introduced in our experiments for comparison with the proposed adaptive method. In LAP-no_Ca [4], each base station also keeps the local hottest items with the largest LAP values in the cache; however, unlike our adaptive method (donoted by "Adaptive"), LAP-no_Ca consumes the entire available cache size. Meanwhile, all the items once cached in any base station will no longer be broadcast; only uncached items are broadcast. PIX-all follows the traditional Broadcast Disks approach [1]. The global hottest items are frequently broadcast, while items with the largest PIX values are kept in the base station cache. Here, PIX value of an item is the ratio of its local access probability to its broadcast frequency.

Table 1 summarizes the default parameter settings used in the experiments. The bandwidth for the main channel, the sub channel, and the wireless channel were assumed to be 100, 10, and 5 Mbps, respectively. The number of items in the database was 10,000; all data items had an equal size of 100 KB. The number of base stations was 10. Gaussian distribution was used to model skewed access, whose default deviation was 100 items, and each base station had different access center. Multi-disks scheduling was adopted by all approaches, of which the number of disks was 3 and their broadcast frequency was 4, 2, and 1. The size of the fastest disk and the medium disk were set at 500 and 1,000

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]	100,000
Query Interval [ms]	$50 \sim 1{,}000$
Deviation for Gaussian Distribution	100
Number of Disks	3
Broadcast Frequency of $\mathrm{Disk}_{1,2,3}$	4, 2, 1
Size of $\mathrm{Disk}_{1,2,3}$ [Data Items]	500, 1,000, uncertain
Coefficient for Three Channels (α, β, θ)	0.8, 1, 10

items; but the size of the slowest disk and the broadcast cycle depended on the approaches. Additionally, considering the communication of the wireless channel is point-to-point, the coefficient for the utilization of the wireless channel was set at 0.8 to lower the possible congestion of the wireless channel. The coefficient for the utilization of the main channel and the sub channel were set at 10 and 1, which is proportional to the ratio of the two bandwidths. The performance metrics of the experiments were average waiting time and success rate of queries.

4.1. Impact of Query Interval

The first experiment examined system performance under different access load by varying average query intervals from 50 to 1000 ms. Figure 1 shows that as query interval increases, i.e., access load decreases, performance upgrades for all approaches; meanwhile, the performance for LAP-no_Ca and PIX-all crosses each other. Under a heavy access load, PIX-all performs better; under a relatively light access load, LAP-no_Ca performs better. Observing the entire evaluation region, the proposed adaptive method outperforms the other two approaches under any access load.

The reasons for these behaviors are as follows. Under a relatively light access load, keeping items with larger LAP values in the base station cache can provide low-latency response to local clients. Hence, LAP-no_Ca and Adaptive methods perform better than PIX-all. Moreover, Adaptive method can make more adequate use of the main channel and the sub channel. The number of non-broadcasting items for LAP-no_Ca is fixed; only the cached items are removed from the main channel even the sub channel is too idle under a low query load. In contrast, Adaptive method can remove not only the cached items but also some cold items, whose suitable number of non-broadcasting items depends on the access load of the system and the bandwidth of the main channel and the sub channel.

Under a heavy access load, the waiting time of the wireless channel for LAP-no_Ca is too long, since LAP-no_Ca consumes the entire available cache size for caching the hottest local items, and none of the cached items will be broadcast any longer by the main channel, so that cache hits ratio is too high and many queries can only be responded to by point-to-point communication. In this case, a large number of queries can be better responded to by the frequent broadcast of the hot items. Hence, PIX-all behaves better. For Adaptive method, smaller cache size and fewer non-broadcasting items will be determined to adapt to heavy access load, so that most hot items are pushed in the fast broadcast, and suitable number of items is cached in the base station or removed from the main channel. Hence, Adaptive method can make the most proper use of the three channels and performs the best.

4.2. Impact of Access Pattern

Next, we evaluated the impact of the access pattern of clients by varying query deviation of the skewed access from 50 to 200 items. The smaller the query deviation gets, the more skewed the access is.

As Figure 2 shows, LAP-no_Ca and Adaptive methods perform better than PIX-all under a mildly skewed access. The reason is that both methods cache the local hottest items in the base station and remove some items from the main channel to increase efficient bandwidth usage. The proposed adaptive method performs the best, since it can make the most adequate utilization of the three channels by adaptively determining the maximum suitable number of cached items and non-broadcasting items.

When client access becomes highly skewed, the performance of LAP-no_Ca rapidly falls. This is because in this case a large number of queries concentrates on quite a small part of the hottest items and most of the hottest items are only kept in the base station cache, so that a large amount of point-to-point responses causes the wireless channel to get very congested. On the contrary, PIX-all broadcasts hot items more often, and frequent broadcast can be shared by an arbitrary number of clients, and thus it behaves better. Even in this case, Adaptive method also performs the best since the number of cached items is greatly decreased to adapt to concentrated queries, and more cold items are removed from the main channel so that the required hot items can be broadcast more frequently and more quickly.

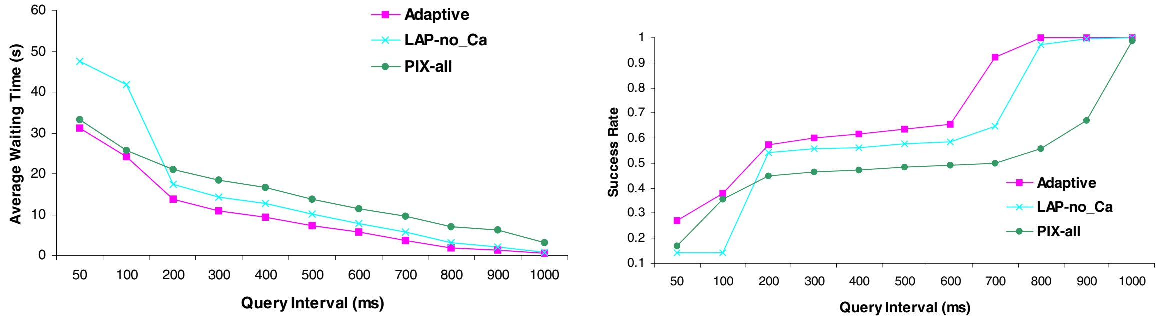

Figure 1. Impact of Query Interval

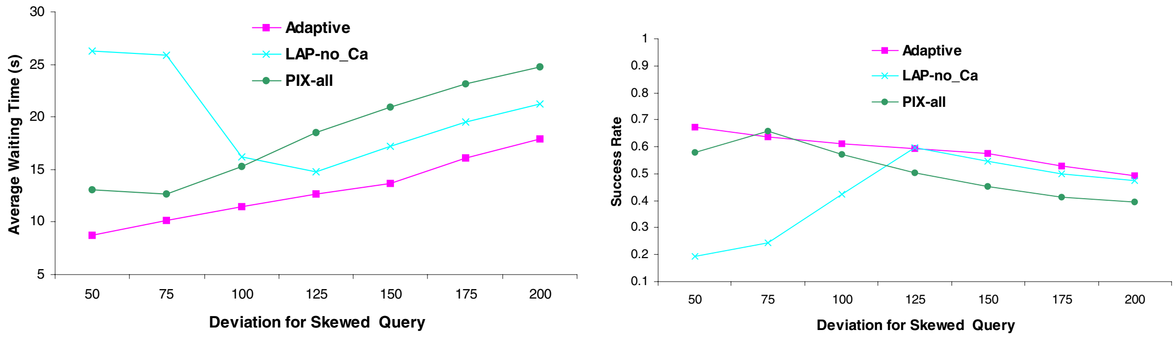

Figure 2. Impact of Query Deviation

4.3. Impact of BS Cache Size

We examined the impact of the available cache size of the base station in this experiment. As Figure 3 shows, when the available cache size is relatively small (less than 300 items), the performance of all methods is markedly improved as cache size increases; meanwhile, LAP-no_Ca and Adaptive methods perform better. This is because in this case cache hits ratio increases with cache size, and both approaches have more cache hits than PIX-all. Adaptive method has the best performance because it makes more efficient use of the main channel and the sub channel.

When the available cache size of the base station is too large, the performance of LAP-no_Ca drops sharply. The best explanation is that LAP-no_Ca consumes the entire available cache size for caching, and any cached items will no longer be broadcast. In this case, cache size is large enough to cache most of the local hottest items so that the workload of the wireless channel becomes too heavy, whereas the bandwidth utilization of the main channel becomes too low. On the contrary, increasing cache size has little influence on PIX-all due to all the items being broadcast in the main channel. There is no influence on Adaptive method. This is because Adaptive method always adopts a suitable size for caching, unlike LAP-no_Ca; meanwhile, increasing cache size also has no influence on the broadcast schedule.

4.4. Impact of Pull Bandwidth

This experiment examined the impact of the pull bandwidth of the wireless channel and the sub channel. As Figure 4 shows, when the bandwidth of the wireless channel is narrow, PIX-all performs better than LAP-no_Ca, since narrow wireless bandwidth limits the performance improvement of LAP-no_Ca with more cache hits. Once the bandwidth increases, LAP-no_Ca outperforms PIX-all. The proposed adaptive method always performs the best because it can decrease the workload of the wireless channel when with a narrow bandwidth, and it can make adequate use of the wireless channel when with a broad bandwidth.

Additionally, Figure 5 indicates that the performance of all methods upgrades as the bandwidth of the sub channel increases. The proposed adaptive method also has the best performance, since it can make full use of the sub channel for on-demand broadcasting. When the bandwidth of the sub channel gets too large, performance differences become very small, since in this case the bandwidth of the sub channel is huge enough for all methods to be mainly used to respond to the queries.

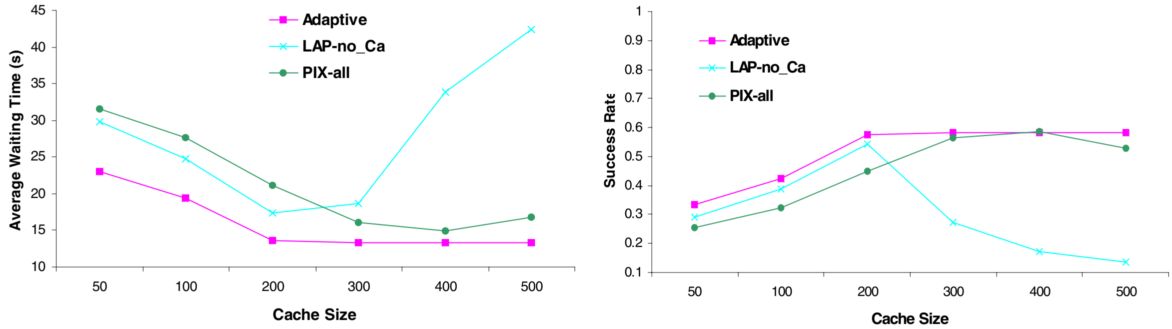

Figure 3. Impact of Base Station Cache Size

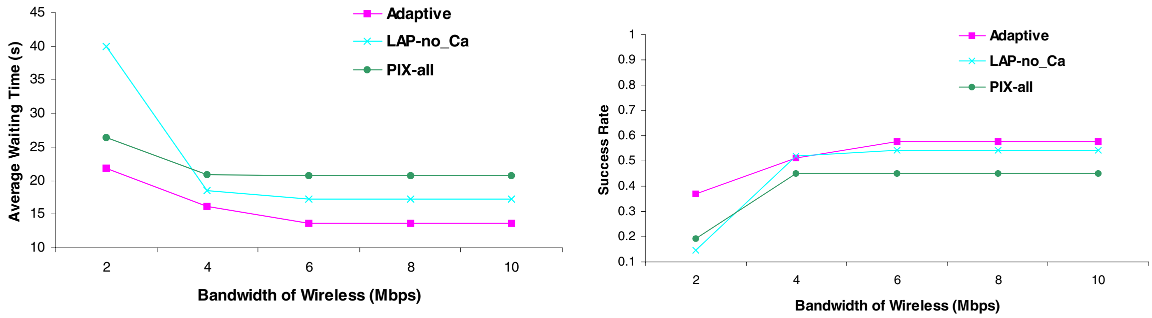

Figure 4. Impact of Bandwidth of Wireless Channel

4.5. Impact of Different Base Station Configurations

To further examine the adaptivity of the proposed method to individual base station conditions, in this experiment the ten base stations have different wireless bandwidths ranging from 1 to 10 Mbps; meanwhile, maximum available cache sizes are randomly generated from 50 to 500 items.

The experimental results of Figure 6 resemble those of Figure 1 in Section 4.1. Note that LAP-no_Ca suffers the most significant impact of the severe conditions of the base stations, since it becomes even worse under heavy access load. This is because LAP-no_Ca cannot completely adapt to conditions where the wireless bandwidth does not match cache size and access load. On the contrary, the proposed adaptive method behaves very well under the mismatched conditions of the base stations by adaptively adjusting suitable cache size and non-broadcasting items, and individually processing each base station based on local conditions. In this case, there is little influence on PIX-all, of which the broadcast of the main channel only depends on access probability of items, but has no relation to conditions of the base stations.

4.6. Summary of Experiments

We conclude the above experimental results as follows. By adaptively adjusting the available cache size of the base station and the number of non-broadcasting items and by making the most proper use of the three channels, the proposed adaptive method can adapt well to different access loads and access patterns, different cache sizes of the base stations, and different bandwidths of the wireless channel and the sub channel, even the mismatched conditions of base stations. Simulation studies also confirmed that our adaptive control method of the HWB system can solve well the issues mentioned in the previous sections.

5. Conclusion

In this paper, we investigated an adaptive control method in a hybrid wireless broadcast environment by considering that access load and system conditions differ greatly in real situations. We designed adaptive base station caching and broadcast scheduling of the HWB system by adaptively determining suitable cache size and non-broadcasting items to appropriately use the bandwidth of the three data delivery modes. Simulation studies demonstrated that our proposed adaptive method can adapt well to different access loads and

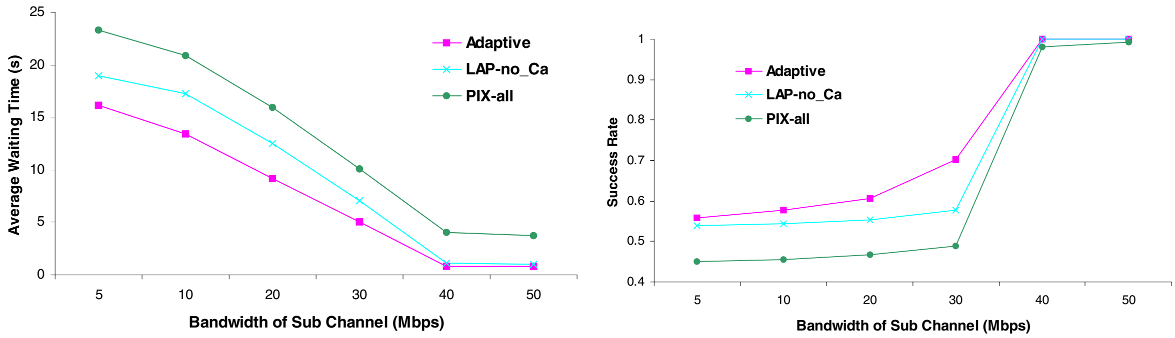

Figure 5. Impact of Bandwidth of Sub Channel

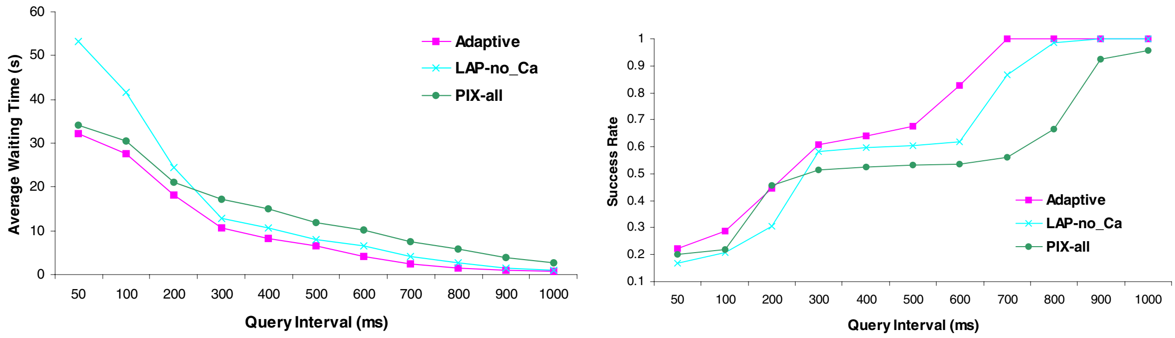

Figure 6. Impact of Different Base Station Configurations

system conditions, and revealed that system performance can be significantly improved by suitable adaptive control.

The current work is conducted on the knowledge of client queries. Considering situations where access load is dynamically changed, we reserve the dynamic control of the HWB system as an interesting problem for further study. The adaptive method proposed in this paper is helpful to design an appropriate control mechanism in a dynamic system.

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