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放送・通信融合環境における放送スケジューリングと基地局キャッシングの適応的制御手法

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本稿では，放送・通信融合環境における放送スケジューリングおよび基地局キャッシングの適応的な制御手法を提案する．提案手法では，プッシュ型放送配信，プル型放送配信，プル型無線通信の三つのデータ配信形態を統合的に利用し，アクセス状況と配信能力に応じて基地局におけるキャッシュ管理および放送スケジューリングを適応的に制御する．提案方式を用いることでシステムの性能が向上することをシミュレーション評価により確認した．

Adaptive Control for Broadcast Scheduling and Base Station Caching in the Hybrid Wireless Broadcast Environment

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In this paper, we investigate an adaptive control for broadcast scheduling and base station caching in the Hybrid Wireless Broadcast (HWB) environment. The proposed adaptive method can well adapt to different access conditions and bandwidth capabilities, and make adequate use of the three data delivery ways: the push-based and the pull-based broadcast, and the pull-based wireless communication. Simulation study demonstrates that our proposed method shortens the average waiting time and heightens the success rate of the queries.

1 Introduction

As the recent advances in the wireless technologies, mobile users equipped with mobile devices, 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 look at them as a base station infrastructure network (abbr. as BS network). In such a network, mobile clients access wireless services through the base station, i.e., wireless access point, which connects with the wired network and serves the clients within the responsible area.

Most recently, mobile digital broadcast has been available. The world's first satellite digital broadcasting reception by mobile devices starts service from October, 2004 in Japan; meanwhile, Japanese terrestrial digital broadcasting service for cellular phone starts for the first time in the world in April, 2006.

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

At the same time, there has been an increased interest in research of hybrid networking and the effective data dissemination in a hybrid broadcasting environment. Some researches integrated the push-based broadcast with the pull-based broadcast or with the pull-based point-to-point data dissemination [2, 5, 8, 9]. Some studies assumed the base station takes charge of the push-based broadcast and the pull-based unicast communication. However, it is necessary to construct a more effective data delivery model to take advantage of the recent advances in wireless technology and mobile digital broadcasting.

In [3], we introduced a new hybrid data delivery model, named Hybrid Wireless Broadcast (HWB) model, which combines push-based and pull-based broadcast and pull-based point-to-point wireless communication. The HWB system can provide a flexible and complementary information service in different bandwidths and service ranges, and greatly improve responsibility, scalability, and efficiency of the system. However, it is necessary to investigate how to make coordinated use of the three data delivery ways of the HWB system, and how to adapt the HWB system to different access conditions and bandwidth capabilities to provide more efficient data dissemination.

This paper aims at developping an adaptive control for the HWB system by taking into account the complementary features of the HWB data dissemination ways and by harmonizing the broadcast scheduling and the cache management of the base station.

The rest of this paper is organized as follows. In Section 2, we sketch the HWB model and introduce the elementary problem for the adptive control in the HWB environment. In Section 3, we present our adaptive control for broadcast scheduling and base station caching of the HWB system. Section 4 shows the evaluation results of the simulation study. Finally, we summarize this paper in Section 5.

2 HWB System

2.1 HWB model

The HWB system comprises a broadcast server, lots of base stations, and a large number of clients [3]. The broadcast server broadcasts information with two distinct bandwidths: the broadband main channel and the relative narrowband on-demand sub channel. The base stations have a cache, connect with the broadcast server through the Internet, and serve local clients via the narrowband wireless channel. In such a system, mobile clients with a portable terminal can access information from the broadcast server and the base station. Specifically, mobile clients send requests to the local base station. The base stations take charge of query processing, respond to the query by themselves or transfer the query to the broadcast server. The broadcast server manages the information for broadcasting.

It is worth noting that 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 query load, namely the number of clients queries. However, the average response time depends on the volume of broadcast. On the other hand, the pull-based broadcast of the sub channel can meet individual requirements of the global clients; meanwhile any on demand response can be accessed by an arbitrary number of clients. However, the response depends on the number of different queries. 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 through the wireless channel cannot be shared due to the point-to-point communication.

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 the advantages of the others.

2.2 Broadcast Scheduling and Base Station Caching

In the HWB system, the broadcast server serves mobile clients in a global area, whereas the base stations serve the clients within the responsible area. Data items in the database can be assigned to the schedule of the main channel, 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. To construct a more effective data dissemination of the HWB system, moreover, it is necessary to take into consideration the coordination between the base station caching and the broadcast scheduling of the server.

The cooperation of cache management and broadcast scheduling has been confirmed to be able to provide more efficient data delivery [1, 6, 7, 10]. However, most of research discussed the integrated control based on the push-based broadcast, and normally conducted cache management at the client side. We investigated a cooperation of broadcast scheduling and base staion caching in the hybrid wireless broadcast environment, and reached some valuable conclusions[4].

Keeping local hot items in the base station cache can provide low-latency response to the local clients with a homogeneous access interest. Meanwhile, removing some 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 to use these two processes, when the increasing query load is beyond the bandwidth of the wireless channel, and when so many items are removed from the main channel, system performance will become worse. Moreover, the current cooperative methods are separately suitable for different conditions: normal conditions or extreme 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 staion caching in the hybrid broadcasting environment to produce an effective adaptive control of the HWB system.

2.3 Two-layered Access Probability

The adaptive 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). LAP plays an important role in the base station caching; whereas GAP has much more relation with the broadcast scheduling of the server.

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

$$L_i^b = Q_i^b / Q^b; \qquad (1)$$

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

$$G_i = Q_i / Q. \qquad (2)$$

3 Adaptive Control for the HWB System

Several important factors have much impact on the adaptive control of the Hybrid data delivery system, 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, the configurations of the system differ greatly in real situation, and the configurations for each base station, such as the wireless bandwidth and cache size, may be different. It is because we assume the HWB system can adopt any type of wireless network, such as cellular network, WiFi or WiMAX link. Meanwhile, for the base station itself, the disposed configuration may not match with each other, like large cache size with narrow wireless bandwidth. All these factors will be considered in our adaptive control such that the HWB system can adapt to various conditions.

The proposed adaptive control is based on the assumption that each base station has the 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 an evaluation period T, the base stations count the number of queries for each data item, i.e., TQ_i^b; and thus, $Q_i^b = TQ_i^b / T$. Moreover, the other items defined in Section 2.3, including the local access probability and the global access probability, can also be calculated according to the corresponding definition formulae.

In the following section, we first explain the adptive control seperatedly for base station cacing and broadcast scheduling, and then introduce a procudure for the integrated adaptive control.

3.1 Adaptive Base Station Caching

Keeping local hot items, i.e., the items with a high local access probability, in the base station cache can acquire a higher cache hits; meanwhile, increasing cache size also can increase cache hits. However, under a high cache hits, the increasing query load may be easy beyond the bandwidth of the wireless channel. For preventing the possible congestion of the wireless channel, it is necessary to find out the optimum condition for base station caching. To adapt to the wireless bandwidth and different query loads, we consider a suitable cache size as a balance bar. For instance, under a heavy query load, decreasing the available cache size to decrease the cache hits can alleviate the congestion of the wireless channel; whereas for the idle wireless channel, it should increase cache size as much as possible until the maximum available cache size. Therefore, the suitable cache size depends on the query load and the wireless bandwidth of the base station. Moreover, each base station has its own adaptive cache size, since the conditions of the base stations may differ with each other.

The adaptive cache size A^b for the base station b is calculated by

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

meanwhile, $A^b \leq C^b$. Here W^b and C^b are the bandwidth and the maximum available cache size of the 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 the base station b are ranked by the descending values of the local access probability $\{L_i^b\}$, where $1 \leq i \leq N$, $1 \leq b \leq M$. The adaptive cache size should ensure the total number of the local clients' queries in a unit time for the cached items cannot exceed the bandwidth capacity of the local base station. Meanwhile, the adaptive cache size cannot exceed the maximum available cache size of the local base station.

As a result, in our adaptive base station caching, the items with larger LAP values, namely local hot items, will be kept in the base station cache as more as possible until the estimated adaptive cache size.

3.2 Adaptive Broadcast Scheduling

Multi-disks broadcasting [1], i.e., hot items are broadcast more often, is employed for the broadcast of the main channel, since we pay more attention to the skewed access of clients. Moreover, some unnecessary items are removed from the periodic broadcast of the main channel, so as to shorten the broadcast cycle and make efficient utilization of the main channel and sub channel. However, if so many items, even some hot items are removed from the main channel, as mentioned in Section 2.2, system performance will become worse. Therefore, the key issue for the adaptive broadcast scheduling of the HWB system is to dertermine what items are better to be removed from the broadcast and how many items will not broadcast.

For the HWB system, global cold items or some cached items, can be removed from the broadcast of the main channel. The reason is that for the global cold items, seldom queries of clients demand them. For the cached items, according to the Section 3.1, local hot items with a suitable cache size are cached in the base station, they can be well transmitted by the wireless channel of the local base station. If there are a few queries for the cached items from other base stations, we consider remove these cached items from the main channel, since those queries can be responded by the on-demand sub channel, even if there is no broadcast of the main channel or without cache resident in the local base station.

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

The optimum number of the no broadcasting items (abbr. as N_{noBr}) depends on the bandwidth of the sub channel B_s and the main channel B_m. We assume all data items of the system are ranked by the ascending values of the modified global access probability $\{G_i^{'}\}$, $1 \leq i \leq N$.

On one hand, removing some items from the broadcast of the main channel means drive the on-demand sub channel to pull the items disappeared in the main channel. In this point, the number of the no broadcasting items depends on the bandwidth of the sub channel, and the query load of the system, which is calculated by

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

where β is a coefficient for the utilization of the sub channel. To make effective use of the sub channel, the items with smaller values of the global access probability will be removed from the broadcast of the main channel as more as possible. However, the total number of the queries in a unit time for the removed items should not exceed the capacity of the sub channel, i.e. the number of the 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 the no broadcasting items cannot exceed the total number of the data items excluding the number of the items that the main channel can transmit, which is calculated according to the bandwidth of the main channel:

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

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

The adaptive number of the no broadcasting items should meet both Formula 4 and Formula 5.

3.3 Integrated Adaptive Control

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

Step 1 *:* Estimate the LAP for each base station, according to Formula 1.

Step 2 *:* Determine the adaptive cache size for 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 the local queries for the cached items as zero.

Step 5 *:* Aggregate the GAP with the modified query number, according to Formula 2.

Step 6 *:* Determine the adaptive number of the no broadcasting items, according to the Formulae 4 and 5.

Step 7 *:* Construct a multi-disks broadcasting program, by removing the suitable number of no broadcasting items with the smallest GAP values.

The step 1∼4 are first conducted by each base station, then the step 5∼7 are performed by the broadcast server.

In our adaptive control of the HWB system, each base station independently determines the adaptive caching according to the local query load and its own bandwidth capacity. Furthermore, the broadcast server dertermines the adaptive broadcast scheduling by taking into account the global query load and the bandwidth capacity of the main channel and the sub channel, and coordinating with the base station caching. As a result, the adaptive cache size and the adaptive number of the no broadcasting items is not fixed, which depends on the access load of the clients and the system conditons. Hence, it is effectively to solve the issues mentioned in the Section 2.2 and the problems stated in the beginning of the Section 3.

4 Simulation Experiments

In order to evaluate the efficiency of the proposed adaptive control of the HWB system, we conduct a set of experiments, by varying the query load and the access pattern of clients, the communication bandwidth and the available cache size. Table 1 summarizes the default parameter settings used in the experiments. The bandwidth for the main channel, the sub channel, and the wireless channel are assumed as 100Mbps, 10Mbps, and 5Mbps, respectively. The number of items in the database is 10,000; all data items have an equal size 100KB. The number of base station is 10; each base station has the default cache size with 200 items. Considering the communication of the wireless channel is point-to-point, the threshold for the utilization of the wireless channel is set as 0.8, to lower the possible congestion of the wireless channel. The threshold for the utilization of the main channel and the sub channel are set as 10 and 1, which is proportional to the ratio of the two bandwidths. The performance metrics of the experiments are the average waiting time and the success rate of queries.

To compare with the proposed adaptive method, two previous approaches are introduced in our experiments. In LAP-no_Ca [4], each base station also keeps the local hottest items with the largest LAP values in the cache; however, unlike Adaptive method, LAP-no_Ca uses up the entire available cache size. Meanwhile, all the items once cached in any base station will not broadcast any more; the uncached items are broadcast according to the multi-disks scheduling. PIX-all follows the traditional Broadcast Disks approach [1]. The global hottest items are frequently broadcast, while the 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: 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∼1,500
Data Group Size [Data Items]	1,000
Query Tendency [%]	80
Deviation for Gaussain	150
Number of Disks	3
Broadcast Frequency of $Disk_{1,2,3}$	4, 2, 1
Size of $Disk_{1,2,3}$ [Data Items]	500, 1,000, uncertain
Threshold for Three Channels (α, β, θ)	0.8, 1, 10

4.1 Impact of Query Interval

The first experiment examines the system performance under different access load, by varying average query intervals from 50ms to 1000ms. Figure 1 shows that as the query interval increases, i.e., access load decreases, the performances of the average waiting time and the success rate upgrade for all the approaches; meanwhile, the performances for LAP-no_Ca and PIX-all cross with each other. Under a heavy access load (query interval less than 200ms), PIX-all performs better; under a normal access load (query interval more than 200ms), LAP-no_Ca performs better. Observing the entire region of the evaluation, the proposed adaptive method outperforms the other two approaches under any access load.

The reasons for these behaviors are as follows. Under a normal access load, keeping the items with the highest LAP values in the base station cache can provide low-latency response to the queries of clients with a homogeneous access interest in the local information. Hence, LAP-no_Ca and Adaptive perform better than PIX-all. However, the proposed adaptive method can make more adequate use of the main channel and the sub channel, since the number of the no broadcasting itmes for LAP-no_Ca is fixed, only the cached items are removed from the broadcast of the main channel, even the sub channel is too idle under low query load. On the contrary, Adaptive method can remove not only the cached items but also some cold items, of which the suitable number of the no 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

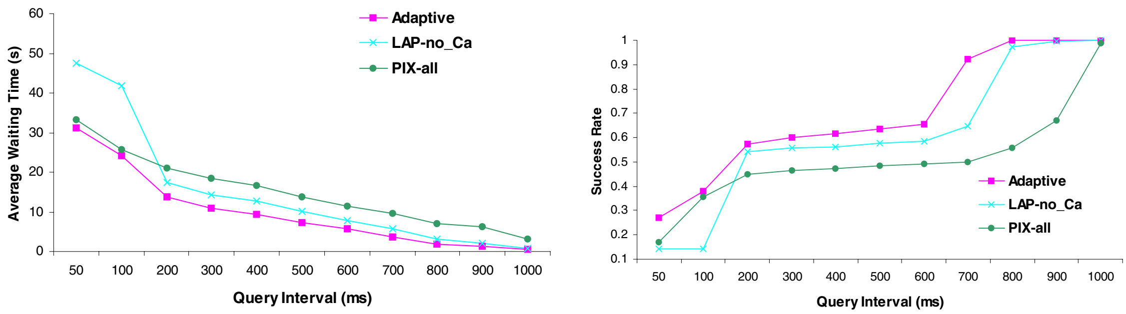

Figure 1: Impact of Query Interval

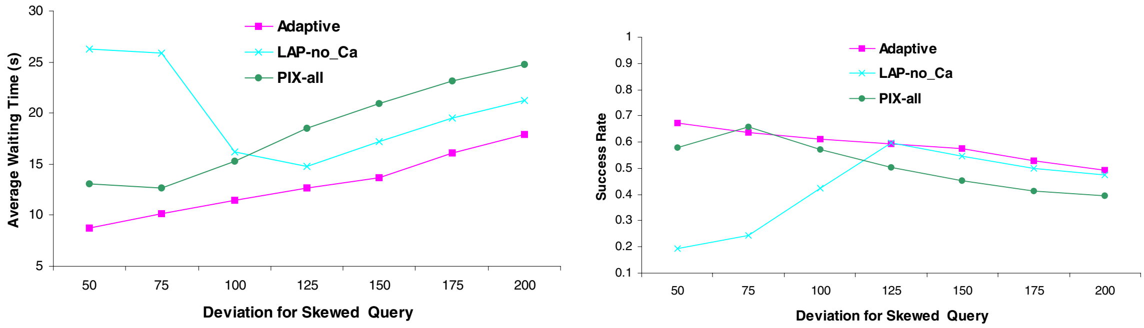

Figure 2: Impact of Query Deviation

LAP-no_Ca use the entire cache size for caching the local hotest items, and the cached items will not broadcast, such that cache hits is too high and so many queries can only be responded by the point-to-point wireless communication. In this case, a large number of queries can be better responded by the frequent broadcast of the hot items. For Adaptive method, smaller cache size and smaller number of the no broadcasting items will be determined to adapt to the three bandwidths and heavy access load, such that most of hot items are pushed in the fast broadcast, and suitable number of items are 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 evaluate the impact of the access pattern of clients by varying the query deviation of the skewed access from 50 items 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 ordinarily skewed access (query deviation above 150 items). The reason is that both of them cache the local hottest items in the base station and remove some items from the main channel so as to achieve more efficient usage of the bandwidth. The proposed adaptive method performs the best, since it can make the most adequate utilization of the three channels by adptively adopting the maximum suitable number of the cached items and the no broadcasting items.

When the access of clients becomes extremely skewed (e.g, query deviation only about 50 items), the performance of LAP-no_Ca rapidly falls down. It is because in this case a large number of queries concentrate on a quite small part of hottest items, while most of the hottest items are only kept in the base station cache, such that a large amount of point-to-point responses cause the wireless channel to get very congested. On the contrary, PIX-all broadcasts hot items more often, while the frequent broadcast can be shared by an arbitrary number of clients, and thus it behaves better. In this case, Adaptive method also performs the best, since the number of the cached items are greatly decreased to adapt to the concentrated queries, and more number of cold items can be removed from the main channel such that the intensively required hot items can be broadcast more frequently and more quickly.

4.3 Impact of BS Cache Size

We then examine the impact of the available cache size of the base station. As Figure 3 shows, when

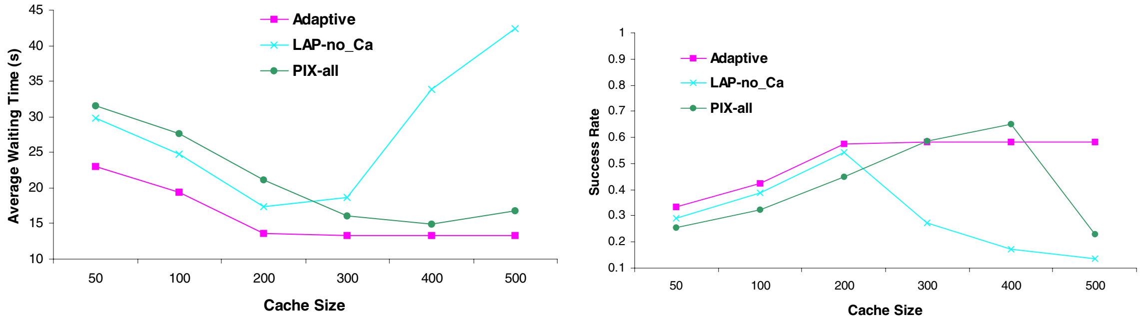

Figure 3: Impact of Base Station Cache Size

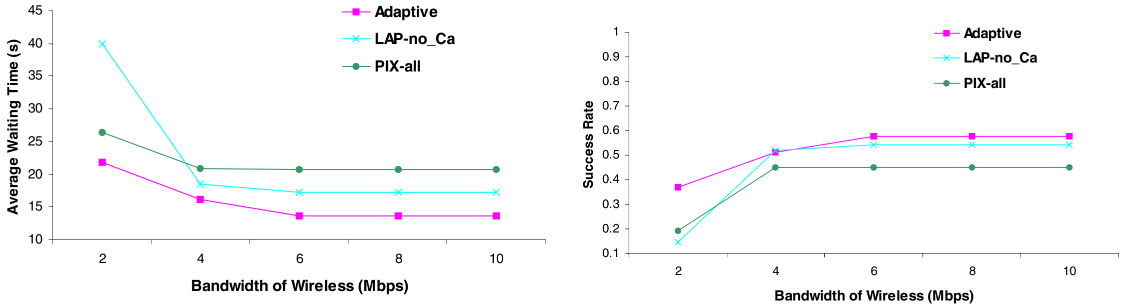

Figure 4: Impact of Bandwidth of Wireless Channel

the available cache size is relatively smaller (below 300 items), the performance of all methods upgrades markedly as the cache size increases; meanwhile, LAP-no_Ca and Adaptive methods perform better. It is because in this case cache hits increases with the cache size, and these two approaches have a higher cache hits than PIX-all. Moreover, Adaptive method has the best performance, by making more efficient usage of the main channel and the sub channel, together with the efficient usage of the wireless channel.

When the available cache size of the base station is too large (more than 300 items), the performance of LAP-no_Ca drops sharply. The best reason is that LAP-no_Ca uses up the entire available cache size for caching, and any cached items will not be broadcast. In this case, cache size is large enough to cache most of local hottest items such that the workload of wireless channel becomes too heavy, whereas the bandwidth utilization of the main channel gets too low. On the contrary, the increasing cache size has a little influence on PIX-all due to the increasing cache hits, and has no influence on Adaptive method. This is because Adaptive method adopts a suitable size for caching, unlike LAP-no_Ca, and the increasing cache size also has no influence on the broadcast schedule.

4.4 Impact of Pull Bandwidth

This experiment examines the impact of pull bandwidth of the wireless channel and the sub channel. As Figure 4 shows, when the bandwidth of wireless channel is narrow (below 4Mbps), PIX-all performs better than LAP-no_Ca, since narrow wireless bandwidth limits LAP-no_Ca with a higher cache hits to behave better. Once the bandwidth gets larger, LAP-no_Ca performs better than PIX-all. The proposed adaptive method all the time performs the best, because it can decrease the workload of the wireless channel when it has a narrow bandwidth, and also can make adequate use of the wireless channel when it has a broad bandwidth, by adaptively adjusting the suitable cache size.

Additionally, Figure 5 indicates that the performance of all methods upgrade as the bandwidth of 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, by adaptively adjusting the suitable number of the no broadcasting items. When the bandwidth of the sub channel gets too large (more than 40Mbps), the performance differences become very small, since in this case the bandwidth of sub channel is so huge that all the methods mainly use the sub channel to respond to the queries.

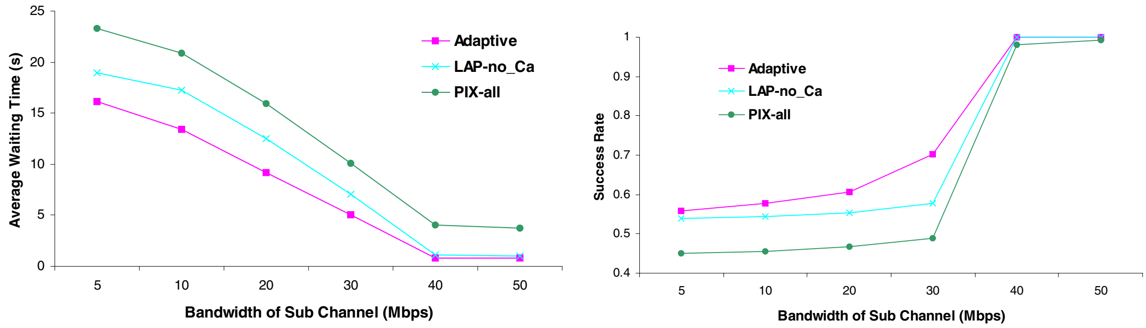

Figure 5: Impact of Bandwidth of Sub Channel

4.5 Summary of Experiments

We conclude the above experimental results as follows. The proposed adaptive method can well adapt to different access load, different access pattern of clients, different cache size of the base station, and different bandwidth of the wireless channel and sub channel, by adaptively adjusting cache size of the base station and the number of no boradcasting items, and by making the most proper use of the three channels. Meanwhile, the simulation study confirms that the proprosed adaptive control of the HWB system can well solve the issues mentioned in the previous sections.

5 Conclusion

In this paper, we investigated an adaptive control in the hybrid wireless broadcast environment, considering the access load and system conditions differ greatly in real situation. We designed the adaptive base station caching and broadcast scheduling of the HWB system, by adaptively determining a suitable cache size and suitable number of no boradcasting items to make appropriate use of the bandwidth of the three data delivery ways. Simulation study demonstrates that our proposed adaptive method can well adapt to different access load and system conditions, and reveals that the system performance can be greatly improved by the suitable adaptive control.

The current work is conducted on the knowledge of the clients' queries. Considering the situation 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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