Bandwidth Allocation Strategy for Intelligent Digital Home Networks

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Abstract

This paper presents a cousin-fair bandwidth allocation strategy for UPnP home networks that focus on the application of movie streaming. To simplify the installation process and obtain the most user preferable content among devices, UPnP and MPEG-7 are applied. In this paper, bandwidth allocation for search entities (i.e., movies) is base on a bandwidth allocation weight (Φ), and then the server containing the search entity can choose a corresponding quality of movies for streaming service. Traditionally, if the bandwidth allocation of some search entity is over the server loading, the bandwidth sharing can only be performed among the search entities from the same requestor, called sibling-fair. However, cousin-fair is a bandwidth sharing strategy that shares the over-allocated bandwidth of search entities from different requestors. Additionally, two improved methods, i.e., gated-service and re-provision, have been employed. By using the proposed bandwidth-based multi-quality streaming mechanism, both high bandwidth utilization and throughput maximization are achieved.

Index terms *– UPnP, home networks, cousin-fair, and bandwidth allocation*

1: Introduction

In the past decade, Internet applications for our life have grown rapidly. Recently, there are more and more home electronic devices capable of connecting to the network and then a home network has established to fulfill the connection requirement. The main challenge of establishing a home network is to achieve a zero-configuration environment for adding a new device in the network [1].

UPnP (Universal Plug and Play) [2,3] is a zero-configuration architecture for home networks' connectivity of various appliances, e.g. PDAs, printers and PCs. UPnP is proposed based on a series of Internet standards and technologies, e.g., HTTP, TCP/IP, SOAP, GENA, and etc. Hence it can coexist with the existing networks. The basic components of UPnP are: services, devices and control points. An UPnP device is a container of services and plays the role of a server which is responsible for dealing with the request of the control point.

In home networks, there may be lots of digital audio-visual content information in devices such as movies and music. It is convenient for users if the content can be shared among devices. However, the challenge is how to obtain the most preferable content according to user requests. To achieve a highly precise search for the content, MPEG-7 [4] is a powerful technology and is applied in this paper.

This paper is organized as follows. Section 2 presents the preliminaries of the proposed UPnP network. Section 3 compares two different bandwidth sharing strategies with their fairness, i.e. sibling-fair and cousin-fair. In Section 4, two improved methods have been proposed to achieve high bandwidth utilization. Section 5 presents the simulation result. Finally, we conclude our study in section 6.

2: Preliminaries of UPnP Networks

In this paper, we focus on achieving the application of movie streaming using UPnP networks. Two components are proposed in this work: DCNPlayer (DP) and DCNServer (DS) in which DP is an UPnP Control Point and DS is both an UPnP Control Point and a Device. When a DP is playing the movie streaming from the DS, there is a "connection" established between the DP and the DS.

To describe the problem of bandwidth allocation, some assumptions and definitions are required:

- Ability of DSs

Each DS has different ability parameter **φ** according to its inherent hardware capability. The higher the value of **φ** is, the higher the HW capability of DS is.

- Movies in each DS

Each movie contained in DS has three different qualities, i.e., high, medium and low, to achieve the effect of multi-quality streaming.

- MPEG-7 description file for each movie

Each movie in the DS is accompanied with a MPEG-7 description file (presented in XML format). The description is composed of 10 keywords (called Description keyword set, ***D***) and there is no equivalent of any two description files among all DSs.

- Search accuracy computation

When a DS receive a set of keyword sent from DPs (called Search keyword set, ***S***), the DS will calculate the searching accuracy (γ) for each movie by using the accuracy computing scheme. In this paper, γ is derived from counting the number of intersection of ***D*** set and ***S*** set, and then divided it by the number of elements in ***D*** set.

- Search Entity

When a DS receive set ***S*** sent from a DP, γ for each movie will be calculated. We define the movie with highest γ as a Search Entity (SE). Actually, a SE is the most preferable movie of the corresponding requestor. According to the different set ***S*** sent from a DP, SEs contained in a DS may be different.

- Device types of DSs

The maximum number of the SEs in the DS is dependent on the DS loading. According to the loading degree, DS can be classified into two device types:

  - Type 1 (Heavy load):
    It can only support limited bandwidth w^{min} (usually defined same as the minimum bandwidth requirement of low quality movie), i.e. it can only accept one connection.
  - Type 2 (Light load):
    Bandwidth allocation is according to the bandwidth allocation weight (**Φ**) of each SE without any bandwidth limitation.

- Bandwidth allocation weight (**Φ**)

SE is the basis of bandwidth allocation in the proposed bandwidth allocation strategy that is based on the following factors: Inherent ability of DSs (φ) and user preference (γ). According to these factors, a bandwidth allocation weight (**Φ**) of each SE is determined so as to allocate bandwidth to each connection.

3: Bandwidth Allocation Strategy

In this section, we will show a scenario which illustrates the problem of general bandwidth allocation strategy; then two fair bandwidth allocation strategies are introduced. In the beginning, a UPnP network is composed of two DPs and three DSs where the total network bandwidth is assumed to be 600 bandwidth units. Inherent ability (φ) of DS 1 to DS 3 is 2, 3 and 4, respectively.

Initially, each DP sends its own set ***S*** to all DSs, and several SEs are generated. At this time, the device type of DS 1, DS 2 and DS 3 is 2, 2 and 1, respectively. We assume that the limited bandwidth supported by Type 1 Device is 20 bandwidth units. After receiving set ***S*** sent from DPs, six SEs (SE 1~SE 6) will be generated among DSs (Fig. 1). And as the search accuracy computing process finish, γ of SE 1 to SE 6 is derived in which assumed to be 0.8 、0.8 、0.6 、0.9 、1.0 and 0.8, respectively.

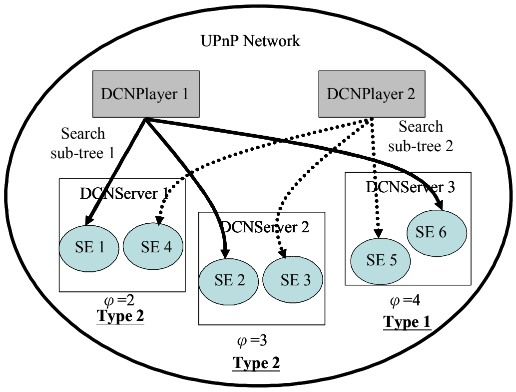


Fig. 1. Generated SEs after searching process of DP 1 and DP 2

According to the accuracy adjustment table (Table 1), the bandwidth allocation weight **Φ** of each SE is derived. The **Φ** of SE 1 to SE 6 is 2 、3 、2 、3 、5 and 4, respectively. Notice that Type 1 device can accept only one connection, hence the system will keep only the SE with the highest γ (In this case, SE 5 is served.).

Table 1. Accuracy Adjustment Table

γ	Φ
γ>=0.9	φ + 1
0.9>γ>=0.8	φ + 0
0.8>γ>=0.6	φ - 1
<0.6	0

Since the number of different requestors (DPs) is two, all SEs are divided into two groups accordingly. The network will build up a search tree and enforce a bandwidth allocation in proportion to **Φ** of each SE, in which w_i means the allocated bandwidth of SE_i (Fig. 2). As mentioned above, Type 1 device can support only 20 bandwidth units, so the bandwidth is over-allocated to SE 5 with 180 units. Such strategy is called general bandwidth allocation.

As the bandwidth allocation of a SE is either over the server loading or exceeding the bandwidth needed for high quality movie, which is called bandwidth over-allocation. To solve bandwidth over-allocation problem of Type 1 SEs, we have considered the device type of SEs so as to share the redundant bandwidth among all Type 2 SEs.

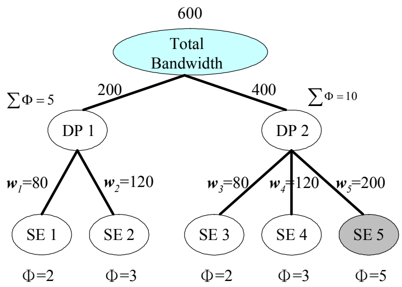


Fig. 2. A general bandwidth allocation

There are two sharing strategies for bandwidth allocation: Sibling-fair and Cousin-fair [5]. In a sibling-fair bandwidth allocation, excess bandwidth of SE 5 is shared by Type 2 SEs that generated from the same DP in proportion to their $\mathbf{\Phi}_i$ as shown in Fig. 3.

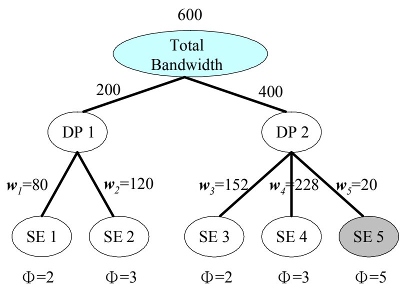


Fig. 3. A sibling-fair bandwidth allocation

According to the allocated bandwidth ($\boldsymbol{w}_i$) and bandwidth allocation weight ($\mathbf{\Phi}_i$), each Type 2 SE has derived a fairness weight $\boldsymbol{f_i}$ (the ratio of $\boldsymbol{w}_i$ to $\mathbf{\Phi}_i$, i.e., $\boldsymbol{w}_i/\mathbf{\Phi}_i$). In the example of Fig. 3, $\boldsymbol{f_i}$ of Type 2 SEs that number from 1 to 4 is 40, 40, 76 and 76, respectively. Obviously, the fairness of sibling-fair only exists in the sibling of each Type 1 SE. To show the fairness of bandwidth allocation, the fairness degree (***df***) is employed as shown in equation (1), in which $\boldsymbol{f_{avg}}$ is the average of $\boldsymbol{f_i}$ and $\boldsymbol{f}_{\min}$ is the minimum of $\boldsymbol{f_i}$ among all Type 2 SEs. The lower value $\boldsymbol{d_f}$ has, the higher the fair of bandwidth allocation is. In the example of bandwidth allocation in Fig. 3, ***df*** is equal to 0.45. Additionally, because the bandwidth is all allocated to SEs, the available bandwidth in the network is 0.

$$f_{avg} = f_{\min} \times (1 + d_f) \qquad (1)$$

On the other hand, if the cousin-fair bandwidth allocation strategy is used, sharing the excess bandwidth of Type 1 SEs among all Type 2 SEs can be achieved. Therefore, after applying cousin-fair bandwidth allocation, $\boldsymbol{f_i}$ of each Type 2 SE is equal to 58(Fig. 4). The fairness degree ($\boldsymbol{d_f}$) in this case is equal to 0. Hence, a complete fairness of bandwidth allocation is done as well. The available bandwidth in the network also equals 0.

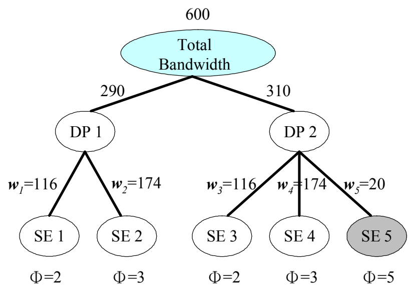


Fig. 4. A cousin-fair bandwidth allocation

After the bandwidth allocation process, SEs can choose movie quality for DPs streaming based upon Table 2. In the example of Fig. 3, SE 1 to SE 4 and SE 5 will choose high and low quality movie for streaming, respectively.

Table 2. Minimum Bandwidth Needed of Different Quality Movies

Movie Quality	Minimum Bandwidth Needed for SEs
Low	20
Medium	30
High	40

To form a formal definition of cousin-fair allocation, some parameters are considered as follows. $\boldsymbol{T}$ is defined as the set of Type 1 SEs while $\boldsymbol{N_T}$ is the number of elements of $\boldsymbol{T}$. $\boldsymbol{B^{Total}}$ is defined as the total bandwidth of UPnP networks.

Equation (2) shows the formal definition of cousin-fair allocation, where $\boldsymbol{b_i}$ is the allocated bandwidth with cousin-fair of SE_i.

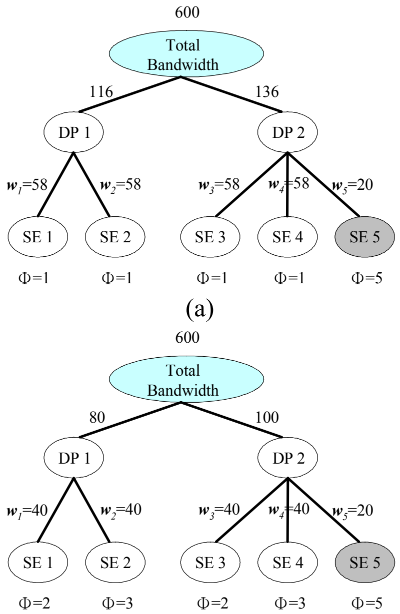
$$b_i = \begin{cases} w^{\min} & i \in T \\ w_i + \left(B^{Total} - \sum_{j \notin T} w_j - w^{\min} \times N_T\right) \dfrac{\Phi_i}{\sum_{j \notin T} \Phi_j} & i \notin T \end{cases} \qquad (2)$$

Although the bandwidth allocation with cousin-fair can achieve both complete fairness and high bandwidth utilization, the throughput is unable to maximize. The reason is due to bandwidth over-allocation to SEs. The throughput in the network is determined by the number of connections can be established. Assumed that t is the longest movie streaming time for a DP, the throughput in the example of Fig. 4 is 5/t (connection/second) while the bandwidth utilization is 100%.

4: Improved methods

Two improved methods are applied to achieve both throughput maximization and high bandwidth utilization in our bandwidth allocation system, i.e., gated-service and re-provision.

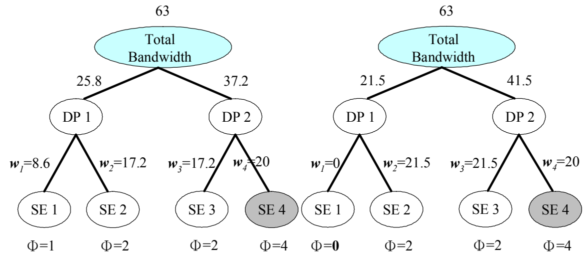
Gated-service defines an upper bound of the bandwidth allocation of SE. According to the fairness, gated-service is able to be divided into two catalogs, which are soft gated-service and hard gated-service. Soft-gated service defines a soft upper bound that multiplies fairness weight by an incremental value starting from 1 until the product is larger than the minimum bandwidth needed of high quality movie (Fig. 5(a)). On the other hand, hard gated-service defines a hard upper bound that is the same as the minimum bandwidth needed of high quality movie (Fig. 5(b)). By applying gated-service to Fig. 3, the remaining bandwidth now is 348 (Fig. 5(a)) and 420 (Fig. 5(b)). Obviously, hard gated-service has more reaming bandwidth so as to achieve higher throughput than soft gated-service. However, soft gated-service can keep the complete fairness ($\boldsymbol{d_f}$=0) while the $\boldsymbol{d_f}$ of hard gated-service in the example of Fig. 5(b) is raising to 0.25.



(b)

Fig. 5. Cousin-fair bandwidth allocation with soft gated-service and hard gated-service

From Table 2, a SE is unable to support streaming for DP as the allocated bandwidth is less than the minimum bandwidth needed for low quality movie and it is called bandwidth under-allocation. Re-provision is a method that can re-allocates the gathered bandwidth of under-allocated SEs by erasing the SE with lowest Φ until the gathered bandwidth is sufficient for supporting the streaming of low quality movie. For example, if the remaining bandwidth of the network is 63 bandwidth units, cousin-fair bandwidth allocation will be enforced as Fig. 6 (a), in which the search tree only can support one connection, i.e., SE 4. Applying re-provision in Fig. 6 (b), two low quality connections have established. Therefore, the throughput is increased by establishing the low quality connection.



(a) (b)

Fig. 6. Bandwidth allocation with re-provision

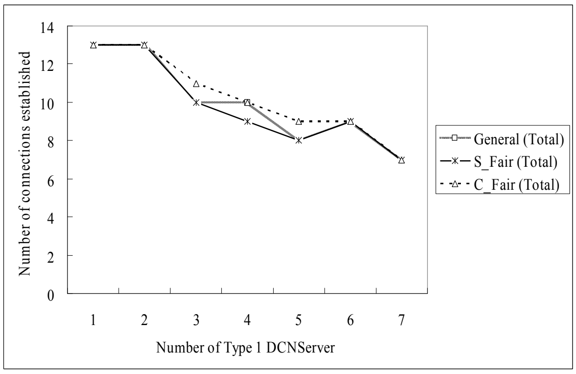
5: Simulation

In this section, this article compares two bandwidth sharing strategies with the number of supportable connections. The simulation measures the number of connections can be established with different qualities of movies under the different numbers of Type 1 DSs. The simulation parameters are listed in Table 3 in which the total network bandwidth is assumed 1000 Mbps. And the criteria used in Table 1 and 2 are also adopted.

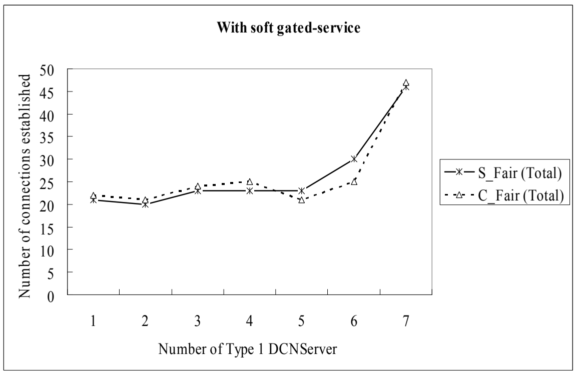
Table 3. Network Parameters Table

DCNServer	Number of DS	7
	Number of movies of each DSs	{2,3,2,2,1,2,3}
	Size of set ***S***	10
	$\boldsymbol{\varphi_i}$	{4,3,5,2,1,4,2}
	$\boldsymbol{w}^{min}$(Mbps)	20
DCNPlayer	Number of DP	2~4
	Size of set ***D***	10
Network	Total Bandwidth (Mbps)	1000

The result shows that general bandwidth allocation with two bandwidth sharing strategies, i.e., cousin-fair and sibling-fair, achieve approximately the same throughput (Fig. 7(a)). However, only cousin-fair bandwidth can achieve a complete fairness ($\boldsymbol{d_f}$ =0) while the fairness degree of sibling-fair is 0.16. To achieve the throughput maximization, two improved methods are applied. Two gated-service methods, i.e., soft gated service and hard gated-service are applied to the two bandwidth sharing strategies in Fig. 7 (a) and the results are shown in Fig. 7(b) and Fig. 7(c), respectively. Obviously, the throughput is increased substantially. The throughput of hard gated-service is higher than soft gate-service of 1.2 times while the fairness degree is lower than 2.8 times. Actually, soft gated-service and hard gated-service is the trade-off between throughput and fairness. Finally, based on Fig. 7(b) and Fig. 7(c), another improved method, i.e., re-provision are also applied and the result are shown in Fig. 7(d) and Fig. 7(e), respectively. After applying the re-provision, the throughput has increased 1.1 times and the new established connections are all low quality connections.



(a)



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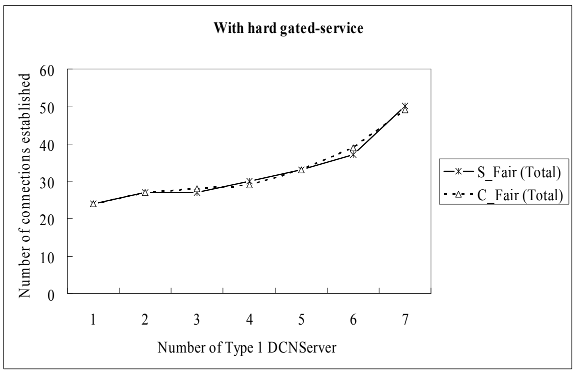

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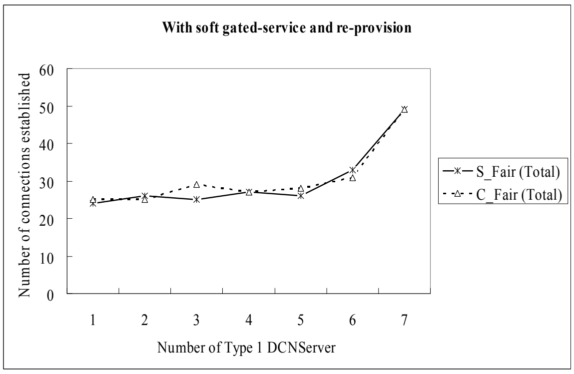
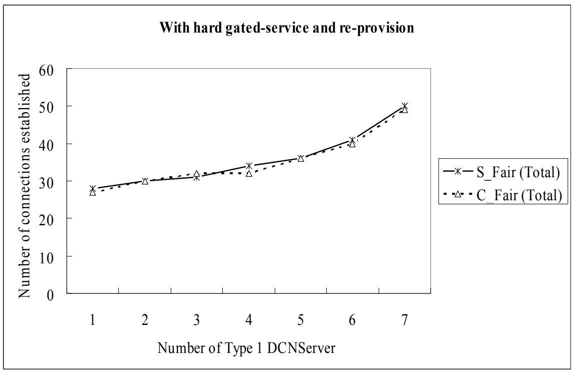


(d)



(e)

Fig. 7. The simulation result

To present the simulation result clearly, the number of established connections and the fairness degree of bandwidth allocation are summarized in Table 4 and Table 5, respectively.

Table 4. The number of connection of two bandwidth sharing strategies with improved methods

	Sibling-Fair	Cousin-Fair
With no improved methods	69	72
With soft gated-service	186	185
With hard gated-service	228	229
With soft gated-service and re-provision	210	214
With hard gated-service and re-provision	250	246

Table 5. The fairness degree of two bandwidth sharing strategies with improved methods

	Sibling-Fair	Cousin-Fair
With no improved methods	0.16	0
With soft gated-service	0.16	0
With hard gated-service	0.44	0.47
With soft gated-service and re-provision	0.25	0.13
With hard gated-service and re-provision	0.51	0.64

6: Conclusion

This paper presents a cousin-fair bandwidth allocation strategy for home networks that focus on the application of multimedia streaming, especially for movies. Bandwidth allocation for search entities (i.e., movies) is based on the bandwidth allocation weight (Φ), and then the server can choose a corresponding quality of movies (i.e., high, medium and low) for streaming service. The bandwidth allocation weight (Φ) is determined by both user preference and server hardware capability.

As the bandwidth allocation of the search entity is either over the server loading or exceeding the bandwidth needed for high quality movie, which is called bandwidth over-allocation. To share the over-allocated bandwidth among search entities, two sharing strategies are presented. One is called sibling-fair, i.e., as the bandwidth sharing can only be performed among the search entities from the same requestor (i.e., media player). The other one is called cousin-fair which is a bandwidth sharing strategy that shares the redundant bandwidth of some search entity to other search entities from all the requestors. Although the bandwidth allocation with cousin-fair can achieve both complete fairness among search entities and high bandwidth utilization, the throughput is unable to maximize. Therefore, bandwidth allocation of a search entity is needed to be adjusted from over-allocating. Two improved methods, e.g., (soft/hard) gated-service and re-provision, have been employed to take advantage of the over-allocation bandwidth. Gated-service defines an upper bound of the bandwidth allocation and can be categorized into soft gated-service and hard gated-service according to the fairness degree of bandwidth allocation. As the bandwidth allocation of a search entity is lower than the bandwidth needed for low quality movie, it is called bandwidth under-allocation. Re-provision is a method that re-allocates the gathered bandwidth of under-allocated search entities by erasing the SE with lowest Φ until the gathered bandwidth is sufficient for the low quality movie. By using the proposed bandwidth-based multi-quality streaming mechanism, both high bandwidth utilization and throughput maximization are achieved in the UPnP-based home networks.

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