A Dynamic P2P Resource Sharing Architecture for Adapting MPEG-21 Digital Items in Mobile Networks

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Abstract

Due to the vast size, real-time requirement, QoS consideration, etc., of mobile devices, techniques like multimedia transcoding are developed to satisfy the need of surfing the multimedia services using mobile devices. In this paper, we propose a P2P resource sharing architecture for adapting MPEG-21 digital items in mobile networks. In the proposed P2P architecture, digital items can be shared among heterogeneous networking environments. Meanwhile, digital items can be dynamically adapted according to the networking situation and user's device capacity. The proposed P2P system introduced a new cache and replacement algorithm for managing adapted digital items, which can smooth the transcoding delay variations of digital items during subsequent resource sharing among different networked devices.

1. Introduction

Various multimedia service platforms are used to construct and transmit multimedia objects over Internet. However, the multimedia objects cannot be shared among different multimedia service platforms because of the lack of industrial standard to support users to exchange, access, share and manipulate multimedia objects. In order to solve the above problem, an industrial standard for the exchange of multimedia objects is needed. To solve the problem, the MPEG-21 is introduced. MPEG-21 is an open standards-based framework for multimedia delivery and consumption, which aims to enable the share of multimedia resources across a wide range of networks and devices [2].

Multimedia services have become extremely popular and its use grows exponentially in recent years. The increasing use of multimedia services over Internet invokes several problems that need to be resolved. A typical example is that the overloading of the media transmission, which increases multimedia retrieval latency, makes the infrastructure's backbone be the bottleneck. The limitation of network bandwidth between a client and a remote server results in a major obstacle on the performance of multimedia presentations.

To alleviate the network problem, peer-to-peer (P2P) networks are introduced. Peer-to-peer networks make resources, e.g., storages, CPU cycles, and media contents, available at the edges of the Internet. Peer-to-peer networks have recently been realized through resource sharing applications such as Napster, Gnutella, and Freenet. However, there are still a lot of problems in transmitting and sharing the multimedia objects in peer-to-peer networks. Peer-to-peer networks have not been used effectively for adaptive multimedia services, users cannot retrieve multimedia objects at anytime, anywhere with different devices such as mobile phones and personal digital assistants. The lack of a dynamic resource sharing, locating, and adapting architecture for multimedia objects in peer-to-peer networks makes it becomes a critical issue in deploying multimedia services over heterogeneous networking environments.

How to display the same media on different devices connected to the network is becoming another important issue. This can be achieved by adapting the content according to the capabilities of the receiving user's device and the system used to display the content. Several works have been proposed on adapting multimedia objects by using transcoding proxies. Han et al. presented an adaptive image transcoding proxy for determining whether to transcode and how to transcode an image for mobile web users [5]. In [11], Mohan et al. proposed an InfoPyramid data model to adapt web contents to mobile users.

Despite the success of transcoding proxies in the Web, transcoding services have not been used effectively for adapting MPEG-21 digital items in P2P networks. In order to deal with such a problem, we will develop a peer-to-peer system using MPEG-21 digital item declaration and adaptation against the aforementioned deficiencies. By equipping digital item declaration and adaptation for different multimedia objects according to devices' capabilities, the peer-to-peer system can enhance the utilization of media transmission, and can satisfy the requirement of adaptive multimedia presentations over heterogeneous networking environments. The peer-to-peer system will provide a content-based routing algorithm for different multimedia objects, a multimedia sharing architecture for resource locating, and a distributed transcoding scheme to transform the multimedia objects according to devices' capabilities and networking environments. The peer-to-peer system not only makes the content adaptation more effectively, but also maximizes the delivered quality. Our proposed multimedia peer-to-peer system will cover the following concerns: (1) to develop a dynamic routing and resource locating algorithm for retrieving multimedia objects in peer-to-peer networks using MPEG-21 digital item declaration, (2) to invent a caching and replacement algorithm for managing transcoded MPEG-21 digital items.

The remaining part of this paper is organized as follows: Section 2 introduces some related works for MPEG-21 digital item adaptations. Section 3 describes the proposed MPEG-21 P2P resource sharing architecture. Section 4 presents the caching and replacement algorithm of the digital items in the proposed P2P architecture. Section 5 gives the test results and performance analysis of the proposed caching and replacement algorithm for adapted digital items. Section 6 has the conclusion remarks.

2. Related Works

This Section provides a brief overview of MPEG-21 multimedia framework and the digital item adaptation scheme.

With the popular usage of wireless/mobile Internet devices, content providers receive an additional opportunity to become a distributor of the Mobile Internet too. In order to provide various content to users with different mobile devices, the adaptation of Digital Items is required. The goal of the adaptation of Digital Items is to achieve interoperable transparent access to distributed multimedia content [2] Part 7 of the MPEG-21 framework depicts the syntax and semantics of tools that are used to assist adaptation of Digital Items [6]. Figure 1 shows the concept diagram of the MPEG-21 digital item adaptation. In Figure 1, a Digital Item is subject to a resource adaptation engine, as well as a descriptor adaptation engine, which produces the adapted Digital Item. MPEG-21 DIA tools are description schemes that help the digital item adaptation engine to process and transform digital items. The MPEG-21 DIA tools consist of Usage Environment Description Tools, Digital Item Resource Adaptation Tools, and Digital Item Declaration Adaptation Tools [13].

The Usage Environment Description (UED) Tools describe the (i) user characteristics, including preferences to particular media resources, preferences regarding the presentation of media resources, and the mobility characteristics of a user, (ii) terminal capabilities, including media resource encoding and decoding capability, hardware, software and system-related specifications, as well as communication protocols that are supported by the terminal, (iii) network characteristics, including bandwidth utilization, delay and error characteristics, and

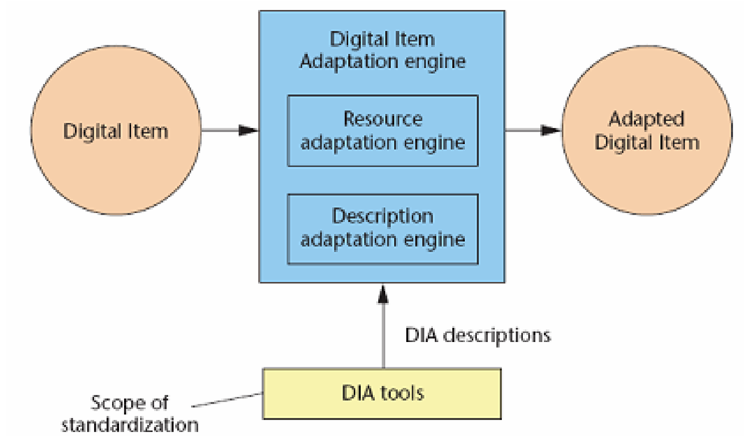

Figure 1. MPEG-21 digital item adaptation.

(iv) natural environment characteristics, including auditory noise levels and illumination properties. The Digital Item Resource Adaptation Tools is used to perform the adaptation of resources in a Digital Item. The bitstream syntax description (BSD) describes a way to retrieve a bitstream from a variety of adapted binary media resources. In the case of bitstream syntax description, tools are specified to alleviate the scaling of bitstreams in a codec-independent manner. AdaptationQoS schema deals with the resource adaptation to constraints that are from terminals or networks for QoS management. Metadata adaptability makes easier to filter and scale the XML instances with low complexity. The Digital Item Declaration Adaptation Tools target to adapt the Digital Item Declaration.

3 System Architecture

In order to have a more efficient content adaptation over wireless mobile networks, a new P2P system architecture should be designed for sharing MPEG-21 digital items. The proposed system uses a super-peer topology for routing message among heterogeneous networking environments.

A super-peer provides routing service and metadata exchanging service. Several super-peers form a super-peer network for resource discovery of MPEG-21 digital items. The super-peer is able to provide (i) a message routing mechanism to route the query messages among connected peers and (ii) a message exchanging mechanism that can ease the communication among different peers.

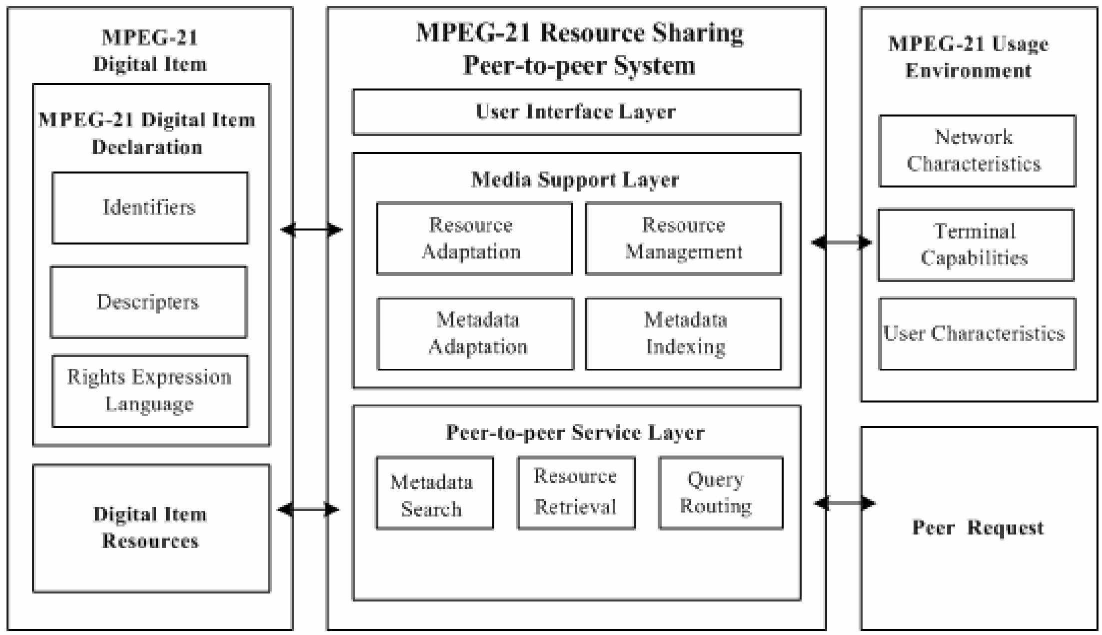

Figure 2. The abstract system diagram of the proposed P2P architecture.

Each peer consists of following layers: (1) User Interface Layer, (2) Media Support Layer, and (3) Peer-to-peer Service Layer. The User Interface Layer is responsible for handling the user interface. The Media Support Layer is responsible for content adaptation, metadata transform, metadata indexing, and resource management. The Peer-to-peer Service Layer is responsible for metadata searching, resource retrieval, and query routing.In Media Support Layer, the resource and metadata adaptation modules are responsible for transforming the digital item from original one to the adapted one, which are based on the information of the requester's usage environment description (UED) and universal constraints description (UCD). The resource management module is responsible for managing cached digital items, including transformed metadata and adapted bitstream resources. The metadata and bitstream resources of the digital items are stored in the metadata cache and resource cache respectively. The metadata indexing module is responsible for indexing metadata descriptions of MPEG-21 digital items. In Peer-to-peer Service Layer, the metadata search module is responsible for searching MPEG-21 digital items in local and remote peers. The resource retrieval module is responsible for retrieving the desired MEPG-21 digital item from remote peers. The query routing module is responsible for routing the messages that are based on the XML-formatted metadata message to/from different peers. Figure 2 depicts the abstract P2P system architecture for adapting digital items in MPEG-21 space.

3.2 Resource Discovery and Retrieval

In order to achieve resource sharing among heterogeneous networking environments, the proposed P2P system uses various approaches to integrate super-peers with heterogeneous networking environments. In the proposed P2P model, a super-peer acts as a normal peer that cooperates with other peers in a resource sharing network of MPEG-21 digital items. From a normal peer's view, the super-peer is nothing different with other normal peers despites it forwarding message to/from super-peer network. super-peer also acts as a server that provides resource lookup service for a resource sharing network. When a super-peer receives a query message from peers, it forwards the query message to the super-peer network if it cannot find any result from its lookup service. Figure 3 shows the proposed P2P resource sharing network.

Most of currently existing P2P resource sharing applications use application-dependent discovery format for resource searching. Some of them just support filename matching using a simple query string. For example, Gnutella and Napster share resources by matching user

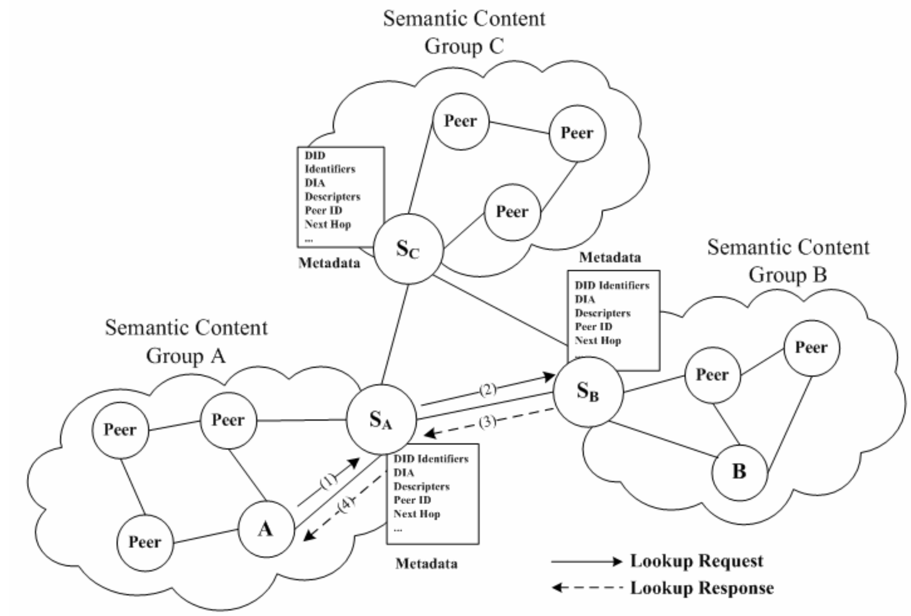

Figure 3. The proposed P2P resource sharing network.

specified query string. For P2P file-sharing applications, searching files by matching string may be enough. However, it restricts these applications to extend their systems to share other types of resources.

In order to solve the problem of resource discovery in different networking environments, we proposed an XML-based message for the resource discovery in P2P resource sharing networks. The XML-formatted message consists of a query request and a query response. We adopt the MPEG-21 digital item description as the resource description part of XML-formatted message. In the proposed P2P system, a message received by a super-peer is forwarded to all its neighbors, except the one from which message was received. Each message is in the XML format and has a Time To Live (TTL) field. The TTL field is decremented by one at each visited super-peer. When the value of TTL reaches zero, the message is stop forwarding. Each message has a 32 byte identifier to uniquely identify it on the super-network. When a message is passed through a super-peer, the super-peer keeps the identifiers of messages. If a super-peer receives a message with the same identifier that it has received before, the message is ignored and is not forwarded. By checking the identifiers of messages, the proposed P2P system can prevent loops and indefinite propagation in super-peer network. The query flow is explained as follows:

1. Peer A issues a searching request for finding a desired MPEG-21 digital item.

2. When the request is received by super-peer S_a, super-peer S_a parses the XML-formatted message and checks the resource list to find the desired MPEG-21 digital item. Super-peer S_a then broadcasts the XML-formatted message to all connected super-peers if it doesn't have the metadata of MPEG-21 item that Peer A is required
3. When super-peer S_b receives the XML-formatted query message, it checks the resource list to find the desired MPEG-21 digital item. Super-Peer S_b responses a resource-found message to super-peer S_a if it has the metadata of MPEG-21 item that Peer A is required.
4. When super-peer S_a receives the XML-formatted response message, it sends the message to the original peer A. Peer A receives the XML-formatted response message and is ready for resource retrieving.

When a peer gets a response message from a super-peer, it has the detail information of the desired MPEG-21 digital item and the digital item provider (peer). Since the peer knows the digital item provider's address, the peer can send a request to the digital item provider in order to retrieve the digital item. Since some MPEG-21 digital items need to be transcoded to display among heterogeneous P2P mobile networks, the resource-providing peer contains an adaptation engine that is responsible for transforming digital item according requester's device and networking environments.

When a user wants to perform digital item adaptation, the user connects the resource-providing peer. The user sends a request for fetching a remote digital item. The resource-providing peer performs content adaptation according to the user's usage environment description (UED) and universal constraints description (UCD). After the digital item is adapted, the transformed digital item description is cached in the description cache, and the adapted bitstream resource is cached in the resource cache. Meanwhile, the adapted digital item is sent to the user. The detail steps are depicted as follows.

1. A user connects with the resource-providing peer and sends a request for retrieving the selected bitstream resource with user's usage environment description (UED) and universal constraints description (UCD). These information are represented in the form of a XML metadata. The usage environment description (UED) contains terminal descriptors, natural environment descriptors, and user preferences. The universal constraints description (UCD) expresses various constraints, e.g., constraint on usage and constraint on usage environment, which can limit adaptation operation itself and/or result of adaptation.
2. The resource-providing peer receives the request and retrieves usage environment description (UED) and universal constraints description (UCD) from the XML metadata. The resource-providing peer then determines the appropriate resource adaptation based on the request from the user, the XML metadata, and contents of the requested DI. If a similar bitstream was requested in the past and the cached bitstream is transcoded, the resource-providing peer sends back the requested bitstream resource directly to the user. For the requesting bitstream that is not adapted, the resource-providing peer performs transcoding actions to the bitstream resource based on the information in the DIA tools. Finally, the adapted bitstream resource is sent to the user.

4. Cache and Replacement Scheme of Adapted Digital Items

In the proposed P2P system, the management of adapted digital items is important. With a well-designed caching scheme, the transcoding delay variations of digital items can be reduced during subsequent resource sharing among different networked devices. Consider that a request of a digital item, i.e., version *u* of bitstream *i,* is arrived at the digital item provider and no such version is stored in the cache. The adaptation engine is responsible for transforming bitstream *i* according the requester's device and networking environments. After the version *u* of bitstream *i* is adapted, the version *u* of bitstream *i* is cached. If the available storage space is greater than the size S_u of the version *u* then it causes no problem, the version *u* of bitstream *i* is put into the cache. If the available storage is less than the size *Su* of the version *u*, then some storage space are required to be freed from the cache.

If there has several versions of bitstream *i* are cached, the profit for caching a version *v* of bitstream *i* is defined as the minimal cost for transcoding bitstream from version *u* to version *v*, where $u \in V[G_i]$ has the minimal cost path $p'(u,v)$. The caching profit value $Profit_{seq}$ is defined as follows:

$$\text{Profit}_{seq} = \min_{u,v \in V[G_i]} \frac{TC(u,v)}{S_v}$$

where *seq* denotes the sequence number of requesting the version *u* of bitstream *i*. $TC(u, v) = TD_{uv} * CU_{uv}$ which denotes the cost of transcoding bitstream from *u* to version *v*. The value is calculated from transcoding delay time TD_{uv} and average CPU usage CU_{uv}. If there doesn't have any version of bitstream *i* is cached, the profit for caching a version *v* of bitstream *i* is defined as the cost of downloading version *u* from media source peer *SP* plus the minimal cost for transcoding bitstream from version *u* to version *v*. The caching profit value $Profit_{seq}$ is defined as follows:

$$\text{Profit}_{seq} = \frac{DC_{sp,u} + \min_{u,v \in V[G_i]} TC(u,v)}{S_v}$$

where $DC_{sp,u}$ denotes the transmission time for downloading version *u* from media source peer *sp*. On the transcoding from version *u* to version *v*, the version *u* is be referenced. If the version *u* is cached, the contribution of version *u* should be take into account because of the cached version *u* can reduce the cost of transcoding. The profit of cached version *u* is using the similar equations as above. The total caching profit of all the requested version *v* of bitstream *i* is defined as follows:

$$\text{TotalProfit}(\text{B}_{\text{i,v}}) = \sum_{\text{seq}=1}^{\text{N}} \text{Profit}_{seq}$$

where *N* denotes the total number of requests for version *u* of bitstream *i*.

The proposed caching policy reflects the bitstream access pattern by calculating the profit value. It selects the least used bitstream for replacement when the cache capacity is exceeded. Considering that a new version *x* of bitstream *i* of size S_x arrives and needs to be cached. If the free cache space is greater than S_x, then it causes no problem. If the available space is less than S_x, then some bitstreams are required to be removed from cache. The proposed caching policy sorts the entries in the cache table in the ascending order of priority and selects the objects in that order for eviction. Thus, least priority objects are replaced first. A high priority value indicates that bitstreams with high *TC* are given preference over bitstreams with low TC_i for caching, which ultimately reduces the transcoding cost.

5. Performance Evaluation

To evaluate the performance of the proposed architecture and control schemes, an Internet streaming media objects and workloads generator named GISMO is used to synthesize the workloads of user behaviors [7]. In the proposed system, the object popularity is modeled by the Zipf-like distribution. Zipf-like distributions imply that the access frequency of an object is inversely proportional to its popularity, i.e., P(r) ~ $r^{-\alpha}, 1 < r \le N$, where N is the number of objects, r is the rank, and P is the access frequency of the r-ranked object [8]. The object

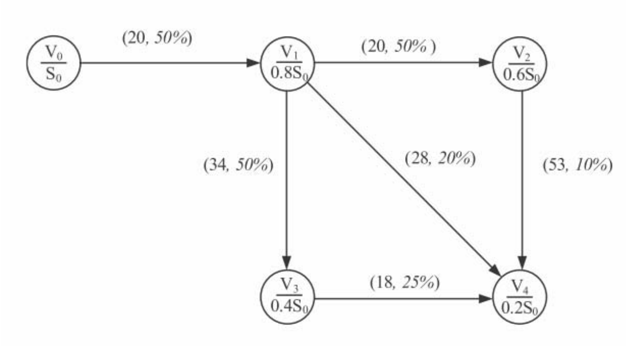

Figure 4. The configuration of the bitstream transcoding diagram in the simulations.

size is modeled by a Lognormal distribution, which determines the size of the bitstream resources. In the simulation, we generate a total of 10,000 requests to 500 bitstream objects stored in the P2P network. The popularity skew is set as α = 0.7$. The bitstream object size (in number of 1M bytes) is modeled by a Lognormal distribution with μ = 10.5$ and σ = 0.63, resulting in a mean object size of approximately 43M bytes.

For the transcoding model, each bitstream has four transcodable versions, including the original one. The size of four versions of each bitstream are assumed to be 100%, 80%, 60%, 40% and 20% of the original bitstream size. The transcoding costs of four versions of each bitstream are represented as an ordered list in **Error! Reference source not found.**. Our experiments assess (i) how caching policy can save the backbone bandwidth for workload that is over the simulation period and (ii) how caching policy can reduce the costing for transcoding bitstream resources that are over the simulation period.

To evaluate the cache performance, we compare the proposed transcoding caching policy with other caching algorithms, i.e., LRU and LFU. **Figure** shows the object hit ratio using different replacement policies. The proposed transcoding caching policy has better performance than LFU and LRU. It is because the proposed transcoding caching policy associates every bitstream i with a reference counter and the value of profit is related to $1/S_i$. Therefore, by keeping more bitstreams that have smaller sizes and higher popularities in cache, the cache hit ratio is improved. LRU and LFU only consider bitstreams' access patterns rather than objects' size. By keeping bitstreams that have small size can release more cache space to store other bitstreams.

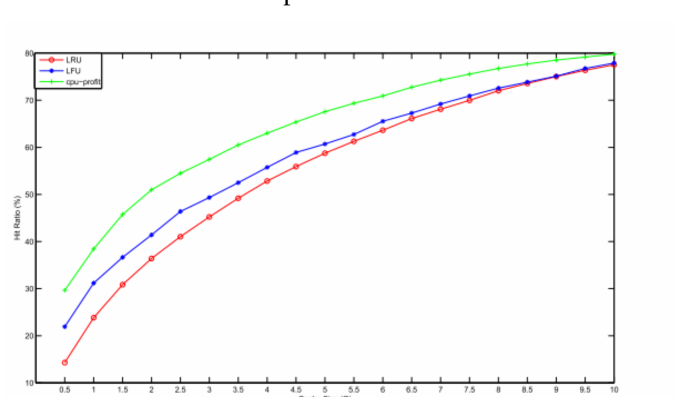

Figure 5. Hit Ratio.

Figure 5 shows the average transcoding delay of the caching replacement policies. The proposed transcoding caching policy has a small average transcoding delay than LFU and LRU. It is because that the proposed transcoding caching policy considers the bitstreams' sizes, which affects the cache hit ratio. The higher cache hit ratio can reduce objects' transcoding time because clients' requests can directly serviced from cache hit.

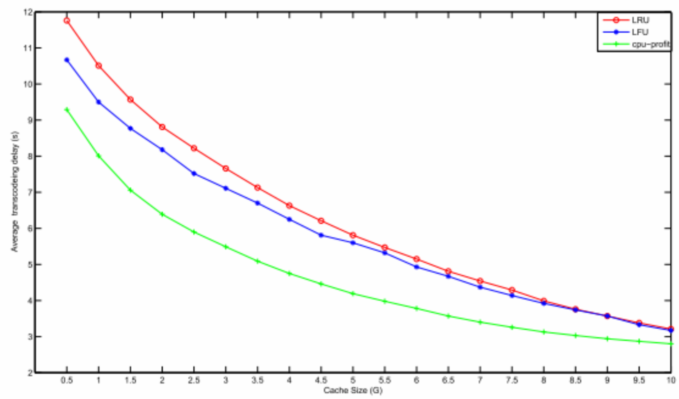

Figure 5. Average Transcoding Delay.

Furthermore, the proposed caching policy also considers the bitstreams' transcoding time, only bitstreams with higher transcoding profits will be kept on the cache.

6. Conclusion

In this paper, a dynamic P2P resource sharing architecture for adapting MPEG-21 digital items in mobile networks is proposed. With the aid of the proposed P2P architecture, digital items can be shared among heterogeneous networking environments. Digital items can be dynamically adjusted according to the networking situation and user's device capacity. The proposed P2P system introduced a new cache and replacement algorithms for managing adapted digital items, which can smooth the transcoding delay variations of digital items during subsequent resource sharing among different networked devices.

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