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Abstract
This paper focuses on metadata-based, multimedia resource representation and retrieval in a P2P environment as a means of universal multimedia access (UMA). The primary focus of the work is a P2P architecture, which uses MPEG-21 as standards based technique to dynamically adapt resources to various usage environments. In the architecture, a super peer based approach is used to cluster peers, store peer information, perform searches and instruct peers to adapt/send resources. Also a two-stages based adaptation method is introduced to adapt search results and resources in an intelligent manner based on the usage environment attributes. The concept is demonstrated using a test-bed built based on the JXTA peer-to-peer framework. In addition, simulation results show that the proposed architecture reduces download time while increasing resource availabilities and download speed in the network when compared to traditional P2P systems.

Keywords
information retrieval, meta data, multimedia communication, multimedia databases, peer-to-peer computing, resource allocation

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Dynamic Resource Adaptation in a Heterogeneous Peer-to-Peer Environment

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***Abstract*— This paper focuses on metadata-based, multimedia resource representation and retrieval in a P2P environment as a means of Universal Multimedia Access (UMA). The primary focus of the work is a P2P architecture which uses MPEG-21 as a standards based technique to dynamically adapt resources to various usage environments. In the architecture, a super peer based approach is used to cluster peers, store peer information, perform searches and instruct peers to adapt/send resources. Also a two-stages based adaptation method is introduced to adapt search results and resources in an intelligent manner based on the usage environment attributes. The concept is demonstrated using a test-bed built based on the JXTA peer-to-peer framework. In addition, simulation results show that the proposed architecture reduces download time while increasing resource availabilities and download speed in the network when compared to traditional P2P systems.**

Keywords-component; Middleware (Java, XML, JXTA), Peer-to-peer applications and services, Multimedia Technologies

I. INTRODUCTION

P2P networking has become a significant area of research since the success of Napster [4] and other P2P resource sharing applications. However, as computing devices becoming more diverse, it is important that P2P systems provide resource sharing suitable for a ubiquitous computing environment. In particular, resources should be adapted to suit the usage environment of the consuming terminal device and thus provide the user with the best possible experience [7]. There are also other factors which are independent of devices but could also be subject to vast variations. For example, the network connection bandwidth of those devices could vary from 14.4kbps to 100MBps+. The work reported in this paper is motivated by these adaptation requirements; we propose a foundation architecture that facilitates dynamic resource adaptation in a P2P environment.

The paper is structured in the following way: section 2 compares the related work in the field, outlining the shortcomings and challenges currently being faced. In section 3 the multimedia framework MPEG-21 is explained to provide readers with a general understanding of the standard which is used in our architecture. The proposed P2P system architecture is then considered in section 4 with section 5 detailing the implementation and simulation. In section 6 we draw conclusions.

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II. RELATED WORK AND CHALLENGES

Since Napster and other popular P2P resource sharing systems are limited to the use of plain text for the description and search of resources, metadata-based P2P systems have been proposed to allow improved search and resource description. Currently the best-known projects in the field are Edutella [5] and SWAP [6]. However, the main focus of both projects is to provide interoperability between different metadata schemas and thus allow local data sources to be handled in a uniform manner. Currently neither project considers the important aspect of adapting delivery of local data sources to various heterogeneous terminal devices according to usage environment and user preferences.

The only project that addresses the heterogeneity issues in a distributed network environment is the MAPS [8] framework proposed by Intel Labs. However, their work was mainly focused on the provision and management of distributed video streams. MAPS also has limitations such as a reliance on lower level network topology information to adapt video streams and requiring that peers intermittently broadcast their relevant details to surrounding peers.

The architecture proposed in this paper addresses the shortcomings and missing links from the projects mentioned above and facilitates P2P based resource and service adaptations with particular focus on the following requirements:

- The P2P network should support dynamic adaptation of resources according to all aspects of their consumption usage environment to provide users with a best-possible experience. This involves adaptation at both the search and consumption stages of the process.
- The P2P network should avoid resource redundancies by providing a means to treat resource variations as a single item with different configurations. This single item – multiple variation relationship should be transparent to the user. In particular, users should be shielded from complex configuration operations related to an item and only need to select user-oriented choices.

III. MPEG-21

Since our proposed P2P architecture uses some key components of MPEG-21 to facilitate resource representations and adaptations, we provide here a general overview of the framework. MPEG-21 is a new multimedia framework from the

Moving Pictures Expert Group (MPEG) that supports multimedia access and delivery using heterogeneous networks and terminals in an interoperable and highly automated manner [2]. Here we discuss only the parts relevant to our application.

A. MPEG-21 and the Digital Item (DI)

The fundamental unit of distribution and transaction in the MPEG-21 framework is the Digital Item (DI). It can be considered as a structured digital object which consists of resource(s) (e.g., a photo album, a web page) and related information on the manipulation of the resource(s) (e.g., terminal capabilities, intellectual properties). A DI is declared in a Digital Item Declaration (DID) using the Digital Item Declaration Language (DIDL) [9] which is expressed in XML Schema. It is important to clarify that the DI is the basic conceptual unit in MPEG-21 and the DID is just the XML representation of that unit. A typical DI consists of resource(s), a list of Choices that correspond to the various adaptation aspects of those resources and Digital Item Adaptation (DIA) information which steers the adaptation process.

B. Digital Item Adaptation (DIA)

One of the main goals of MPEG-21 is to provide solutions for universal multimedia access (UMA). That led to the creation of a distinct part in MPEG-21: Digital Item Adaptation (DIA) [10]. It is one the largest parts in MPEG-21 and contains tools for adapting resources on the basis of descriptions to produce a modified Digital Item.

The DIA Tools represent a collection of descriptions and format-independent mechanisms that provide support for Digital Item Adaptation. The descriptors are represented in XML and can be either wrapped in a DID or be used independently. The DIA Tools are further clustered into eight major categories. In our work we predominantly use two of those tools: Usage Environment Description Tools and DIA Configuration Tools.

The *Usage Environment Description Tools* include descriptors that describe various dimensions of the usage environment: namely user characteristics, terminal capabilities, network characteristics and natural environment characteristics.

The *DIA Configuration Tools* specify how and where the related usage environment information can be used for the adaptation of DIs. Also, these identify whether a Choice in a DI should be configured manually or automatically according to the Usage Environment Descriptors associated with the Choice.

The usage of these related tools is explained in the following section. Since the scope of MPEG-21 is very broad, interested readers are referred to references for in-depth information related to MPEG-21 [1, 2].

IV. P2P SYSTEM ARCHITECTURE

A. Resource and usage environment representation

In the proposed P2P architecture, we use the Digital Item concept to represent resources. The advantage of adopting the Digital Item concept is that it broadens the concept of a media resource from that of a single file to a complete user experience. For example, a DI representing the movie trailers for the movie “Exciting” could include movie trailers and sample sound track sections. Choices such as the language option for displaying the movie subtitles could also be included explicitly in the DI. Furthermore, DIs could contain DIA descriptors information such as DIAConfiguration Tools to specify where each adaptation operation should occur (i.e., receiver side, sender side etc.). In additional, the Usage Environment Descriptions Tools of DIA Tools are used to describe the usage environment attributes in the architecture.

B. Super peer based P2P system

We take a super peer based approach [11] in building the P2P system architecture. Peers are thus grouped into clusters based on similarity of their shared contents and super peers are nominated to be in charge of one or more clusters. The motivation and advantages behind using a super peer based approach are: 1. super peers can be used to store peer and resource related information. 2. super peers can then use that information to make important decisions in a dynamic P2P system; examples might be searching for resources and assigning peers to perform adaptations. This is more scalable than a pure P2P system which requires peer and resource related information to be broadcast to surrounding peers [8], since the broadcast could be costly to perform and it has limited coverage in a large P2P network.

Peers in the proposed architecture are required to register with one or more super peers based on the nature of their shared contents. Accordingly, on joining the network, a peer must submit information about its shared contents and its related usage environment attributes (i.e., terminal capabilities) as DIA descriptors to the super peer(s). The latter is used to select adaptation peers to perform resource adaptations.

The registration information is saved on a local cluster table on the super peer. The local cluster table is a vector table with four layers; each expands further into sub-layers as illustrated in Fig. 1. The table contains one or more cluster entries that correspond to the clusters of which a super peer is in charge. Each cluster entry contains a text description of the cluster, as well as links to a number of Digital Item entries that store resources as DIs. Each Digital Item entry also contains links to one or more peer information entries which store peer-related information as DIA descriptors (i.e., usage environment descriptors). The peer information entries are further broken into a number of resource variation entries that each contain information about the configuration of the variation (i.e., file format) This demonstrates the hierarchical structure where there is one resource as a DI, multiple peer locations of that resource and then multiple resource variations. The super peer uses the local cluster table to answer peer queries, sends them the requested DIs and determines which peer(s) should be used to perform the adaptations. The adaptation process is explained in the next section.

Each super peer also has a super peer table which stores information about the other super peers in the network. The information includes super peer IDs, the clusters of which each super peer is in charge and their related usage environment descriptors as DIA descriptors. This table serves the purpose of allowing decisions to be made on how to merge/divide clusters when super peers join/leave the network.

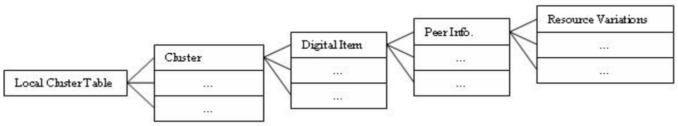

Figure 1. the structure of the local cluster table

Super peers are monitored and controlled according to their loads and capacities. When the load of a certain cluster exceeds the maximum load of a given super peer, that super peer can nominate a peer from its cluster to either share the load (as a new super peer) or completely take over the task. The selection of the new super peer is performed on the basis of its usage environment descriptors stored in the local cluster table on the original super peer. In addition, when a super peer leaves the network, it simply sends the tables to a new nominated super peer and notifies other super peers about the change.

C. Two-stage adaptation approach

A two-stage adaptation approach is proposed in the architecture. The aim is to guide users through the search and consumption cycle of adapted resources without exposing them to unnecessary technical details. The approach consists of following stages: 1. the adaptation of the initial search results, and 2. the adaptation of the requested multimedia resource (see Fig. 2).

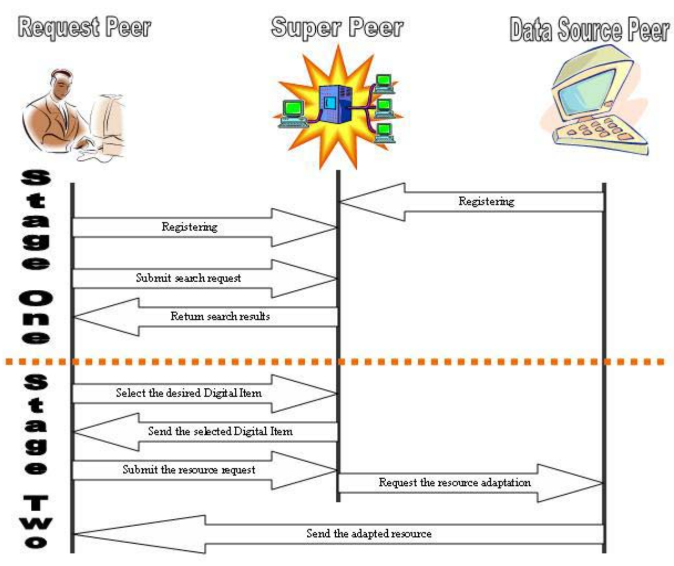

Figure 2. two-stages based adaptation approach

The initial search function is performed by submitting a request with the search keyword to the corresponding super peer based on the cluster for which the user would like to search in. The request also includes DIA descriptors (i.e. user preferences) that relates to the search. Once the super peer receives the request, it scans through its local cluster table and search for DIs according to the search keyword and DIA descriptors of the user. This filtering process is considered to be the first adaptation phase in the approach as it uses the usage environment knowledge from the user to adapt the search result to that user's requirements. An example of this mechanism in operation would be a user in Japan who is only interested in receiving information about the movie "Lost in Translation" in Japanese.

The second adaptation stage starts once the request peer receives the result which contains descriptions of the DIs that meet the search criteria. This stage consists of a content negotiation approach which was initially proposed in our previous work [12], adapted and modified to accommodate dynamic resource adaptations in the P2P architecture.

The approach is initiated by the user selecting a DI from the search result list and requesting it from the searched super peer. The super peer could perform some adaptations on the requested DI according to the DIA descriptors it has received during the first adaptation stage before forwarding it to the requesting peer. An example of possible adaptations in the step above would be the short-listing of the Choices in the requested DI. The result might be to remove Choices in a DI which are not related to the user's preferences. Then, after the request peer receives the modified DI, it performs certain adaptation and Choice selections based on its DIA descriptors (e.g., select the video format on the basis of available decoders). This is followed by sending a resource request to the super peer. The request could include further DIA descriptors to be used by the adaptation peer during the resource adaptation process (e.g., screen resolution of the requesting peer). The super peer then selects a peer capable of performing the adaptation based on registered DIA descriptors in the local cluster table and forwards the resource request to that peer. The adaptation peer performs the resource adaptation accordingly and then transmits the resource directly to the requesting peer.

Once the transfer is complete, the super peer adds information about the request peer and downloaded/adapted resource into the local cluster table by inserting a new peer information entry under the Digital Item entry of the requested DI. The corresponding peer information entry of the adaptation peer is also updated if new resource variations were generated on its side during the adaptation process.

V. IMPLEMENTATION AND SIMULATION

A. M21 middleware

A prototype of the architecture has been developed at the University of Wollongong. The core component of the implementation is the M21 middleware application that implements the base concepts of MPEG-21. This was used in our previous work [12] to enable multimedia content to be adapted to various devices/terminals in a ubiquitous environment according to usage environment attributes. The M21 middleware is installed on all peer/super peer nodes on the network. Project JXTA [3] is adopted as the underlying infrastructure for standard P2P communications in the architecture, with M21 based JXTA services implemented on top. As shown in Fig. 3, the M21 middleware bridges the upper application layer and lower JXTA P2P service layer which, in turn, connect with the network/transport layers. Four different engines are implemented in the middleware to support various functions in the P2P network environment: P2P Engine, Application Launch Engine, Digital Item Adaptation Engine and Digital Item Declaration Engine.

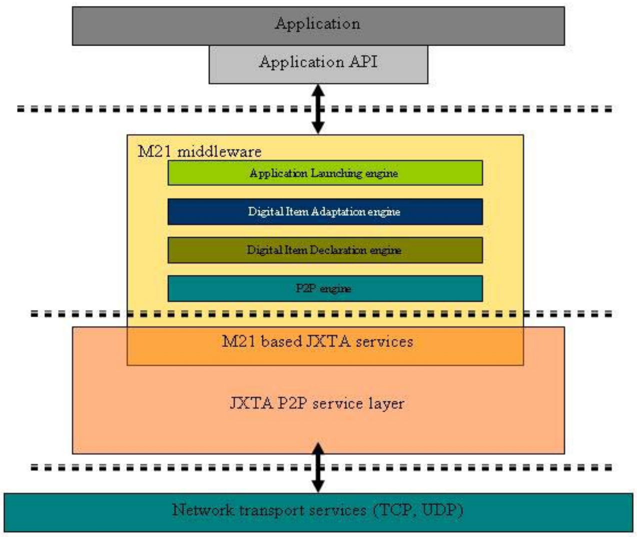

Figure 3. M21 middleware and related service modules

The P2P Engine is the key component in the middleware as it performs two separate streams of important tasks; 1) the P2P Engine acts as the inter-connector between the JXTA P2P service layer and the remaining M21modules. It embeds request and response messages into standard JXTA services before transmitting them to peers through the JXTA network, and unwraps the messages when they are received. 2) The second stream of tasks performed by the P2P engine is different for the cases of super peers and normal peers. For the former, the P2P engine is responsible for performing tasks such as handling peer search requests and determining suitable adaptation peers. On the normal peer side, it is responsible for scanning the local directory for DIs, submitting search requests, receiving selected DIs and finally adapting/receiving the resources.

The Application Launch Engine is responsible for launching appropriate multimedia applications with adapted resources as input streams. It requires different application "drivers" to support various applications through their APIs. An example of this functionality is to launch a MPEG-4 player when a MPEG-4 file is received.

Finally, both the Digital Item Adaptation Engine and Digital Item Declaration Engine are used for parsing and generating DIA and DID elements respectively.

B. P2P system prototype

The P2P architecture was verified by installing M21 as the middleware layer application on computers connected to a 100Mbps full-duplex local area network.

Currently, a set of movie trailer related DIs is used to simulate a movie trailers distributing P2P network for movie enthusiasts. The user can search for movie trailers on the network after logging on through M21. The two-stages adaptation approach described in section *III-C* is used to adapt both the search results and requested movie trailer on the basis of the surrounding usage environment descriptors. Presently, the testbed supports the following usage environment descriptors and Choices for the movie trailers: Storage, EncodingCapabilities, CPUBenchmark, CoarseLanguage, CharacterSet, DecodingCapabilities and Resolution. The descriptor Storage is used to determine which peers should be nominated as super peers and when a super peer split/join operation should be performed. The descriptors EncodingCapabilities and CPUBenchmark are sent to super peer(s) by normal peers during the registration stage and super peers use those descriptors to determine the adaptation peers. Next, the descriptor CharacterSet is transferred to the super peer during the initial search stage to filter out search results, while VideoFormat and Resolution are used to adapt movie files in the second resource adaptation stage. Finally, the Choice CoarseLanguage is an option required to be manually selected by the user on the request peer side.

In terms of resource adaptations, a JAVA based video transcoder has been implemented using the Java Media Framework (JMF). It can transcode videos into various formats, frame rates and bit-rates on the fly during the adaptation process. Also, audio files at various bit rates and web sites of different resolutions are incorporated into movie trailer DIs to demonstrate resource versatilities with the Digital Item concept.

The P2P network could easily be expanded to cater for resources from other various domains and facilitate more complex adaptations by "injecting" new DIs into the network and use more complex usage environment descriptors respectively.

TABLE I. SIMULATION SETTINGS

Total no. of peers	3000
No. of super peers	60
No. of provider peers	540
No. of freeloaders	2400
No. of unique resources	500
Resource size	10-300 Mbs
Percentage of total resources owned by freeloaders	30%
Percentage of total resources owned by provider peers/super peers	70%
Zipf skew factor	0.271
Total no. of requests	10000

C. Simulation

To evaluate the performance of the proposed dynamic resource adapting p2p architecture, a simulation was created. This allows us to compare our architecture with traditional p2p systems where resources are simply downloaded and consumed by peers without any adaptations.

The simulation is initialized by preloading the network with a specified number of normal peers, super peers and resources. Normal peers are further classified into provider peers and freeloaders. The resources are populated into the network according to the Zipf distribution. To simulate heterogeneous devices, three classes of device and bandwidth are currently used in the simulation. These system settings and peer behaviors conform to the findings in the survey from [13]. During the simulation, requests are generated by peers in the system at random time intervals and the simulation terminates when all requests are completed. The results below were obtained based on the simulation settings in TABLE I.

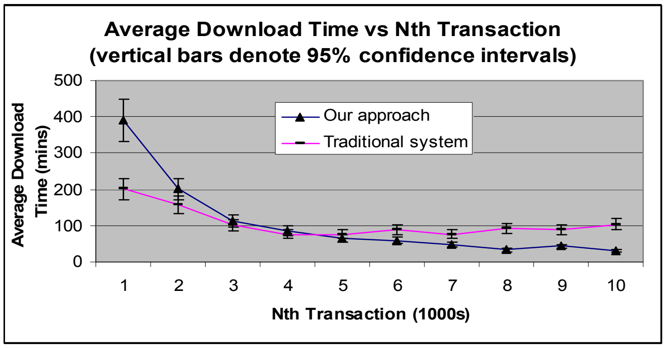

Figure 4. average downloading time comparison of different approaches

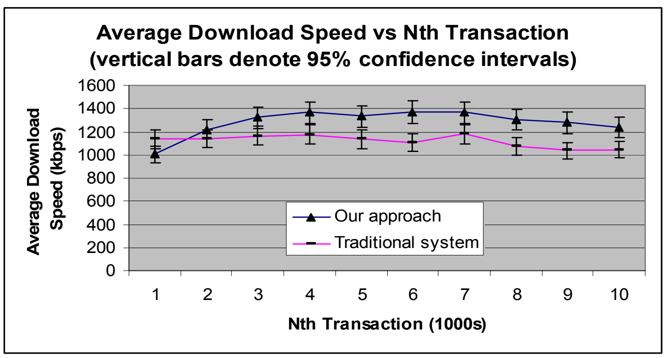

Figure 5. average downloading speed comparison of different approaches

We use average download time as a performance metric to compare our proposed architecture with a traditional system. Fig. 4 shows that the average download time of a resource was initially much higher for our approach as extra time are spent adapting/down-scaling resources to appropriate sizes. However, the additional adaptation time is quickly negated as more adapted resource variations becoming available and peers can download resources that match their capabilities. This is shown in the graph as the average download time of our system dropped below the average download time of the traditional system after approximately 4000 transactions were completed.

The number of resources on the network was also periodically recorded. We found that the proposed dynamic adaptation approach results in, on average, 10-15% more resources in the P2P network than the traditional system as every time when adaptation occurs during a transaction, two adapted copies of the resource are created (i.e., on both the provider peer and request peer side). This increase in available resources increases the average download speed as less congregated downloads (i.e., multiple peers downloading from the same peer) would occur in the network and it is shown in Fig. 5.

VI. Conclusion

In this paper, we have proposed an architecture that facilitates dynamic resource adaptation in a P2P network. The architecture utilizes the Digital Item and DIA concepts from MPEG-21 to support a UMA concept for P2P resource sharing. A super peer based approach is taken in designing the architecture to ensure it is scalable. Also, a two-stages based adaptation approach is proposed to guide users through resource search and configuration details without exposing them to unnecessary technical details and requested contents are transparently adapted to heterogeneous terminal devices. The architecture is verified on our test-bed and simulation results have shown that our system reduces the average download time while increasing resource availabilities and download speeds.

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