User-Driven Multimedia Adaptation Framework for Context-aware Learning Content Service

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***Abstract*—Typical learning repository server may face the problems of incompatibility or accessibility when its serving media contents are requested in variously adaptive forms by heterogeneous devices or from different usage contexts. To mitigate these problems, a service broker is considered necessary as it will work cooperatively with the repository server so that the required service of responsive multimedia content provision can be enabled. In this paper, we propose a cooperative framework of adaptive multimedia learning service, where the cognitive engine on the user's device will select the audio/video features that are suited to the need via the AHP method so that the complex of content adaptation mechanism on the broker platform can be lessen. Our proposed framework is then notably different from many previous works, but is still practical for implementation due to the availability of computational resources and relevant performances in smartphones and computers at present.**

***Index Terms*—cognitive agent, AHP, multimedia adaptation, context-awareness, learning repository**

I. Introduction

Context-aware mobile learning [1] generally requires an infrastructure that makes its learning contents not only accessible to learners via their mobile devices, but also available in many forms that are adapted to changing environments and rendering capabilities of distinct devices. Obviously, such a requirement will never be fulfilled in traditional learning repository, of which service merely returns *one-size-fits-all* contents to all learners regardless of differences in device capabilities and usage contexts. This has led to an increased interest on research works that attempts to improve the basic service of traditional repository for coping better with adaptive and context-aware features. A promising approach is to employ the mobile computing broker (such as [2], [3]) to provide abstraction and provision of adaptive multimedia contents that are aware of the context in which they run, while the native functionality of legacy repository is still intact. The key challenge is how to utilize the constrained network resource so that the user experience of individual session can be always maintained at the maximum level.

To address this research challenge, many previous studies have confirmed the helpful support of advanced audio and video processing techniques (see [4] and references therein) for creating new forms of multimedia contents by converting their media sizes, resolutions or even encoding/decoding formats. Nevertheless, it may not guarantee the best-performing of content adaptation under all possible user contexts, if the adaptation decision mechanism is performed solely on the content provider's viewpoint (as done in [5]). Moreover, by assuming a limited computing facility and constrained resources at the users' devices, this provider-centric mechanism is then complex inevitably. In fact, computational resources and relevant performances in modern devices are rich and eligible to do some tasks so that the number (or complexity) of associated tasks on the provider-side can be potentially lessen. Therefore, by taking smart devices into account for giving a beneficial recommendation on adaptive multimedia content delivery, the process of adaptation decision engine at the service broker can be not only simplified, but also potentially modified to suit the needs and preferences of individual learners.

In this paper, we present the Analytical Hierarchical Process (AHP) method [6] applying at the learner's device for decision support on the best selection of adaptive multimedia features under its own criteria, and also the counterpart mechanism of adaptive content service at the broker, which will work in conjunction with a legacy learning repository. Our contribution is a user-driven resource management framework for delivering adaptive multimedia contents in a cooperative manner.

This rest of paper is organized as follows. In Section II, we provide a background of multimedia adaptation techniques and users' adaptation preferences, following with the related work on user-preference based selection methods and brokers for adaptive content. In Section III, we present our proposed framework for enabling adaptive multimedia services via a broker and a repository server in detail. In Section V, we present the validation of the proposed framework by means of numerical analysis. Finally, in Section IV, we conclude the paper.

II. Background and Related Work

A. Quality of Multimedia Contents

Learning service can offer multimedia streaming, such as during the session of game-based learning [7] or in a mobile social learning community [8], to its active users. Obviously, a certain level of multimedia quality becomes a great expectation of users so that the media streams can

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be smoothly rendered on their devices, regardless of any changes occurred in the network. Then, many spatial or temporal adaptation techniques [3] can be served well at the content provider for changing the media contents in several dimensions. For instance, the video contents can be altered either the spatial resolution of each frame of the video or the number of frames per second (frame rate). Similarly, the audio contents can be varied on the sample rate, the number of bit per sample, or even the number of audio channels. Nevertheless, there also exists another kind of adaptation (known as *Transmoding*) [9] that can be used to transform the modality of a moving picture into a slide show. In essence, the multimedia adaptation will be used to alleviate the unpleasant effects causing due to the mismatch of user's device capability and offered contents, and the fluctuation of network bandwidth so that the user acceptance can be improved.

However, it is respectively difficult to obtain a high level of user satisfaction, due to various preferences of a user on the obtained multimedia qualities. For instances, mobile users using smartphones may prefer to choose the adaptive content in such a level that the incurred energy consumptions are kept minimum. In contrast, users who work on desktop computers may disregard the energy saving and consider the perceived multimedia quality. Obviously, users with the pay-per-use type of payment plan may want to pay less, but have to tolerate the lower quality of multimedia contents. In the above cases, user preferences are expressed through the attributes of energy consumption, perceived quality, and network cost. While these preferences are often used separately in user-driven multimedia adaptation mechanisms (such as [9]), the combined consideration of them may be needed in some complex scenario (such as [10]) and a trade-off of them is inevitable.

B. User Preference Based Selection Method

Some existing studies involving the determination of users on preferential adaptation of consumed multimedia contents can be seen in the literature. However, they can be categorized into two groups of *utility maximization-based* and *mathematical-based* methods by the way that multi-criteria situations are modeled and analyzed in decision making. In the former method, the high-level goal is defined by a utility function of which optimal solution is the maximization of utility associating with concerned attributes in the user preferences. In the latter method, the high-level goal is instead considered as the decision objective of a multi-level hierarchical system structure of attributes and alternatives, based on their relationship. The AHP [6] is used to weigh attributes and the resulted weights will be further incorporated in a mathematical formulation to yield the best alternative, which regards as the solution in the last step.

Regarding the two methods as categorized above, the utility maximization-based method exposes weaknesses on the demand of equivalent utility functions [11] for each attributes considering in the user preferences, and the required knowledge in solving the optimization problem. Evidences can be seen in many studies. For instance, the authors in [10] suggest the mathematic-derived utility functions, which are claimed for energy saving, quality in terms of received bandwidth, and monetary cost. These utility functions will be actively served for solving an optimization problem to decide whether to adapt the multimedia stream or to handover to a cheaper network. In this paper, the mathematical-based method using AHP is particularly interested, since it does not involve any complex mathematics for solving multi-criteria decision problem at all. An example of work applying the AHP method can be seen in [12], where the aim is to improve the quality-of-service of multimedia communication by taking users' perception into account.

C. Broker-assisted Content Adaptation Service

Various studies often introduce a broker with the aim of extending the current capability of limited servers. For instances, the authors [3] propose the use the proxy server in their adaptive multimedia framework that performs on-the-fly transcoding and dynamic adaptation of the video and audio contents based on the feedback from the users. Due to the aware of user preferences as well as the utility of the adapted content for each user, the difficulty in solving a complex optimization problem (e.g. constraints satisfaction problem [2]) is inevitable at their utility-based adaptation decision engine. In contrast, our framework is better, even sharing the similar idea, since the simplicity of adaptation decision engine can be possible by taking the benefit of separately determined adaptation features using AHP on the user's device. The opposite concept to our framework can be found though. For instance, the broker of framework proposed in [5] will have to take a full load of responsibility, since no significant task is assigned at the users' devices.

III. User-driven Multimedia Adaptation

A. Proposed Framework

The proposed framework of User-driven Multimedia Adaptation (which is called UDAD hereafter) is aimed especially at extending the traditional learning repository with a multimedia content service that is adapted to the learner's context by a means of service broker. The UDAD architecture is summarized in Fig. 1. When a user device requests a service for the required content from the broker, it will be notified with the information of bandwidth allocated currently to the user session. Based on the given information, the adaptation selection engine at the user's device determines the best selection of adaptive audio/ video qualities by using the AHP method and sends the preferred content adaptation (in terms of video resolution, video frame-rates and audio bit-rates) back to the service broker. The adapted content will be accordingly streamed to the user via the service broker, depending on the result of searching returned from the learning repository. If success, the matched content can be executed straightaway. Otherwise, the lower quality of the same content or newly generated one may be chosen, depending on the broker policy. The details of each engine are described in the following subsections.

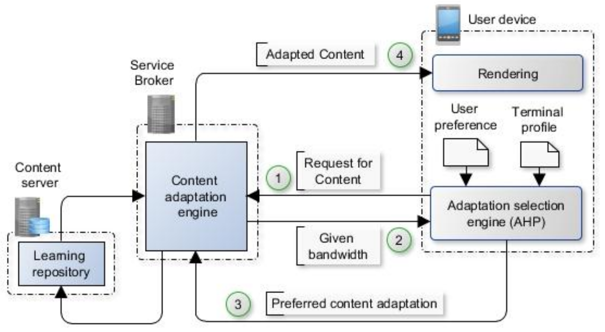

Figure 1. Proposed framework architecture.

B. *Adaptation Selection Engine at the User's Device*

To maximize user preferences in an intuitive manner, we use the AHP, which is popular multi-criteria decision-making (MCDM) tool. We formulate the selection of multimedia adaptation at the user's device as a MCDM problem. Based on the AHP, the steps [13] can be summarized below:

- Modeling the problem into a hierarchical structure constituting goal, criteria and alternatives. As shown in Fig. 2, the topmost level is the goal of the analysis, which is the best selection of the multimedia adaptation features. The second level contains multi-criteria parameters (i.e. power consumption, perceived quality and price). The third level contains the alternative choices (i.e. attributes of video frame-rate, video resolution and audio frame-rate).
- Computing pairwise comparison for criteria, and then for the alternatives with respect to each criterion, in terms of relative importance using a numeric scale ranging from 1 - 9. Each set of comparisons will be entered into a matrix, creating the comparison matrix for criteria and for alternatives with respect to each criterion.

With all pairwise comparison tables, the final weights for three alternatives can be obtained as shown in Table I. We can use these weights to find the adaptation factors that maximize the network bandwidth allocated to user.

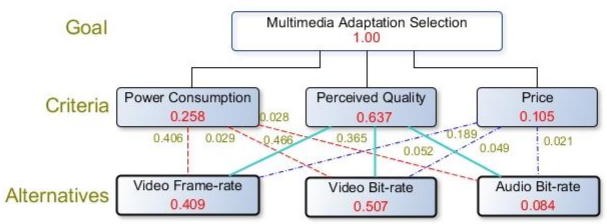

Figure 2. Adaptation selection hierarchy.

TABLE I. FINAL WEIGHTS FOR EACH ALTERNATIVES

Alternatives	Weights	Ranking
Video Resolution	0.507	1
Video Frame-rate	0.409	2
Audio Bit-rate	0.084	3

However, the final weighted values of the alternatives will be further calculated for finding possible candidates of suitable multimedia attributes. In our case, we use the *performance index* to support the best selection among possible choices so that the explicit values of the desired multimedia attributes (i.e. video frame-rate, video resolution and audio bit-rate) will be sent directly to the service broker. However, for the sake of brevity, the combined AHP-mathematical programming [13], which is used to compute the performance index is not included in this paper.

C. *Adaptation Decision Engine at the Service Broker*

Since the user' device is capable of recommending the desired attributes of video and audio contents, the role of adaptation engine can be simply seen in what level those user requirements can be accomplish. In fact, the basic functionality for adapting the multimedia contents by Scaling, Transcoding or Transmoding techniques as well as the policy management are still necessary, especially when the exact match of the required contents cannot be found on the content repository. However, the details of this engine will not include in this paper.

IV. NUMERICAL ANALYSIS AND DISCUSSION

Since the notable feature of our framework is at the adaption selection engine performing at the user's device, we conduct the following numerical case study, in order to evaluate the efficacy of proposed adaptation decision engine.

A. *Scenario Descripition*

We assume there are 4 users concurrently connecting to a service broker for multimedia content connections at different speeds of 5, 10 and 16 Mbps. Each user will use the AHP-based adaptation selection engine to determine the best choice of content attributes. In addition, all users are assumed to pay their most attention to the perceived quality, rather than the power consumption and price.

B. *Results*

TABLE II. CANDIDATE LIST OF ADAPTED CONTENTS IN TEST CASES

Test cases (Mbps)	Adaptation Factors			Performance Index
	Video frame-rate (fps)	Video resolution (pixels)	Audio bit-rate (kbps)	
5	30	900p	32	0.958
	60	720p	32	1.225
	30	1080p	32	1.377
10	60	900p	32	0.980
	30	1152p	128	0.819
	60	1080p	128	1.440
16	60	1080p	128	1.00
	60	1152p	128	1.138
	60	900p	128	0.694

Based on the results as shown in Table II, they are selective data of some possible adaptation factors in each test case by using the equations described in the section III.B. It can be noticed that the topmost line contains the value of performance index closest to the value of 1 (the highlight lines in the Table), and hence representing the best choice of multimedia adaptation factors in the certain case. The correctness of these choices has been confirmed by our experiments on the real video feeds in the actual network environment.

V. CONCLUSION

It becomes necessary that multimedia contents of learning repository should be adaptive and delivered to distinct users for obtaining efficient utilization of both network and computing resources. In this perspective, we have presented a user-driven multimedia adaptation framework targeted to non-adaptive learning repository, where the personalized content delivery can be enabled by the collaborative operations between service broker and the empowered users. Under this framework, it is found that the AHP method is simple and efficient to apply at the user devices for allowing them to determine the best combination of adaptive features of video and audio contents, under various constraints of current network condition and users' context and preferences. However, it is noticed that the final decision of adapted contents will belong to the content adaptation process deployed at the broker. Thus, as a future work, some sort of smarter mechanism at the user devices has to consider so that frequent resource determination can be avoided in response to insignificant network fluctuation.

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