Adaptive Service Composition for Mobile Learning Applications

Atchara Rueangprathum

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Computer Engineering
Prince of Songkla University
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I hereby certify that this work has not been accepted in substance for any degree, and is not being currently submitted in candidature for any degree.

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ชื่อวิทยานิพนธ์ การประกอบเซอร์วิสที่ปรับแต่งได้ สำหรับงานประยุกต์เพื่อการเรียนรู้บนอุปกรณ์สื่อสารไร้สาย

ผู้เขียน นางสาว อัจฉรา เรืองประทุม

สาขาวิชา วิศวกรรมคอมพิวเตอร์

ปีการศึกษา 2558

บทคัดย่อ

ความสนใจที่มีมากขึ้นในการที่จะประยุกต์ใช้อุปกรณ์สื่อสารไร้สายและการเชื่อมต่ออินเตอร์เน็ตแบบไร้สายเพื่อประโยชน์ทางด้านการศึกษา ได้นำไปสู่การแพร่ขยายของงานประยุกต์เพื่อการเรียนรู้บนอุปกรณ์สื่อสารไร้สาย แต่อย่างไรก็ตาม การให้บริการจากงานประยุกต์เหล่านั้นจำเป็นต้องตระหนักถึงข้อมูลแวดล้อมต่างๆ (ได้แก่ ผู้เรียน อุปกรณ์ และเครือข่ายสื่อสาร) เพื่อที่จะนำไปใช้เพื่อปรับแต่งเนื้อหา หรือสร้างการปฏิสัมพันธ์แบบร่วมมือกันกับผู้เรียนผ่านทางอุปกรณ์สื่อสารได้อย่างเหมาะสมต่อไป ในปัจจุบัน การพัฒนางานประยุกต์ดังกล่าวถือว่าเป็นงานที่มีความยุ่งยาก เนื่องจากต้องการความรอบรู้ในหลายด้าน นับตั้งแต่การรับข้อมูลนำเข้าในระดับล่างจากบริบทหรือตัวตรวจรู้ต่างๆ ไปจนถึงการส่งออกข้อมูลของมัลติมีเดียในระดับสูง ที่สามารถปรับแต่งข้อมูลตามบริบทในการใช้งานได้ ความต้องการต่างๆ เหล่านี้ได้ส่งผลทำให้ผู้พัฒนาจำเป็นต้องมีความเข้าใจในการนำกรอบความคิดและมิดเดิลแวร์ต่างๆ มาใช้งานมากขึ้น เนื่องจากเครื่องมือต่างๆ เหล่านี้สามารถอำนวยประโยชน์ทั้งในด้านการแอบซ่อนความซับซ้อนของระบบ และการลดระยะเวลาของการพัฒนาระบบให้สำเร็จลงได้รวดเร็วมากขึ้น ไปพร้อมๆ กันได้อีกด้วย นอกจากนั้น ยังมีความต้องการอื่นในการที่จะให้อำนาจกับผู้ใช้งานอุปกรณ์ได้มีส่วนร่วมในกระบวนการปรับแต่งเนื้อหาด้วย ซึ่งมีความท้าทายเป็นอย่างมาก เนื่องจากมีศักยภาพที่จะช่วยลดความซับซ้อนของกลไกทำงานบนเครื่องผู้ให้บริการเพื่อการปรับแต่งเนื้อหาให้สอดคล้องกับความความต้องการของผู้ใช้ได้เป็นอย่างดี

วิทยานิพนธ์นี้เข้ามีส่วนร่วมในการนำเสนอชุดของแนวทางวิจัยใหม่สำหรับงานประยุกต์เพื่อสนับสนุนการเรียนรู้ผ่านอุปกรณ์สื่อสารไร้สาย ดังนี้ ประการแรก ได้นำเสนอแนวทางเชิงปฏิบัติสำหรับสร้างให้เกิดบริการสนับสนุนการเรียนรู้ผ่านอุปกรณ์สื่อสารไร้สายที่ทำงานอยู่บนพื้นฐานของเทคโนโลยีเชิงความหมาย โดยการพัฒนาแบบต่อยอดจากมิดเดิลแวร์ของ UPnP ซึ่งได้รับการออกแบบเพื่อสนับสนุนให้เกิดโครงสร้างพื้นฐานของเครือข่ายไร้สายท้องถิ่นแบบยูบิควิทัส ภายใต้สถาปัตยกรรมที่พัฒนาแบบต่อยอดนี้ อุปกรณ์สื่อสารต่างชนิดกันจะสามารถแลกเปลี่ยนข้อมูลเพื่อการเรียนรู้ต่างๆ ได้เป็นอิสระมากขึ้น ปราศจากการพึ่งพามาตรฐานทางการแลกเปลี่ยนข้อมูลการศึกษา

แบบเดิมๆ อีกต่อไป ประการที่สอง ได้นำเสนอกรอบการทำงานที่ขับเคลื่อนโดยผู้ใช้เอง ซึ่งเป็นการยกระดับความสามารถให้กับเซิร์ฟเวอร์ที่มีข้อจำกัด เพื่อให้สามารถให้บริการเนื้อหาที่ปรับแต่งได้อย่างเหมาะสมตามบริบทของผู้เรียนได้ ผ่านทางนายหน้าให้บริการแทน โดยลักษณะเด่นอยู่ที่เครื่องประมวลผลแบบใช้เหตุผล (ทำงานอยู่บนอุปกรณ์ผู้ใช้) ซึ่งมีหน้าที่ให้คำแนะนำในการตัดสินใจเลือกคุณลักษณะของข้อมูลเสียงหรือภาพที่ดีที่สุด ภายใต้เงื่อนไขข้อจำกัดของเครือข่าย ผ่านทางเทคนิควิธีกระบวนการคิดวิเคราะห์แบบลำดับชั้น (AHP) ประการสุดท้าย ได้ตรวจสอบว่ากระบวนการหาคำตอบจากเทคนิค AHP ข้างต้นควรจะนำไปประยุกต์ใช้งานอย่างเหมาะสมได้อย่างไร สำหรับโจทย์ปัญหาการใช้ทรัพยากรอย่างใช้เหตุผลในโดเมนบริการแบบคลาวด์เกมมิง ซึ่งในที่นี้ เครื่องประมวลผลแบบใช้เหตุผลบนเครื่องผู้ใช้จะถูกสร้างให้เป็นแบบจำลองของโจทย์ปัญหาการช่วยตัดสินใจแบบหลายคุณลักษณะ จากผลลัพธ์ที่ได้จากการทดลอง สนับสนุนให้เห็นว่าเทคนิควิธีที่เสนอแนะขึ้นมีความอ่อนตัวในการนำไปใช้งาน เพื่อเพิ่มสมรรถนะให้กับบริการคลาว์เกมมิงแบบพื้นฐานได้เป็นอย่างดี ในลักษณะที่ว่า ทรัพยากรถูกใช้งานอย่างมีประสิทธิภาพสูงขึ้น แม้ว่าจะอยู่ในภาวะที่มีความคับคั่งสูงก็ตาม ในขณะที่คุณภาพของการแสดงผลภาพของเกมยังคงรักษาไว้ในระดับที่น่าพอใจ ตามการควบคุมของผู้เรียนผ่านทางตัวแทนแบบชาญฉลาดซึ่งฝังตัวอยู่ในอุปกรณ์ของผู้เรียนนั่นเอง

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Major Program	Computer Engineering
Academic Year	2015

ABSTRACT

A growing interest of applying mobile devices and wireless Internet connections for educational benefits has led to the widespread of mobile learning applications. However, deploying services from these applications must be aware of artifacts (i.e. users, devices and networks) and should provide accordingly adapted contents or reactions in cooperation with learners via mobile devices. Building this sort of applications is concerned as a complex task, since it demands knowledge of design considerations, ranging from low-level inputs of contextual and sensory data to high-level outputs of context-aware multimedia adaptations. In this regard, better understanding of frameworks and middleware are needed as these development tools can encapsulate the system complexity and accelerate the system development altogether. In addition, the need for empowering users to actively involve into the process of multimedia resource adaptation is extremely challenged, since it can relief the complexity of resource adaptation mechanism on the server platform to meet the users' demands.

This thesis contributes a set of novel approaches for mobile learning applications as follows: First, we suggest a pragmatic approach for enabling semantic-enabled mobile learning service on top of UPnP middleware designed for ubiquitous network infrastructure in local area network. Under the proposed architecture, learning contents can be shared between heterogeneous devices without requiring of many distinct learning standards. Second, we propose a user-driven framework that enables the leverage of non-adaptive learning content servers for delivering context-based adaptive multimedia contents via a service broker. The dominance is on the cognitive

engine (on the learner's device) of which function is to recommend the best selection of audio/video features under constrained network conditions via the Analytic Hierarchy Process (AHP) method. Finally, we investigate on how the AHP-based solution should be applied further for solving cognitive resource allocation problem in the domain of cloud gaming service. This demands the local decision making engine at the user device to be modeled as a multiple-attribute decision-making problem. Based on experiment results, our proposed method is flexible to enhance the capability of typical cloud gaming service. It is in the sense that more efficient cloud gaming resource utilization can be obtained, particularly during heavy-congested periods, while players' quality of gaming experience can be maintained under the mandate of intelligent agent on the player devices.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my thesis supervisor: Dr.Somchai Limsiroratana and my coordinating supervisor: Asst.Prof.Dr.Suntorn Witosurapot for their patience and encouragement throughout my Ph.D. study. In addition, I would like to thank my thesis committee: Dr.Sureena Matayong and Dr.Duenpen Kochakornjarupong, not only for their insightful comments, but also for tough questions which stipulate me to broaden my research work from unnoticed perspectives.

I especially thank my fellow labmates in Wireless Information Group (WIG) to name a few such as Ritthichai Jitpukdeebodintra and Artee Abudayor, for stimulating discussions during the sleepless nights before the due dates, as well as joyfulness and sadness we all shared in the last six years.

I also would like to appreciate to the Faculty of Engineering, Prince of Songkla University, for providing me the support of scholarship.

Special thanks are given to these people: Pol.Lt.Sawat Rueangprathum, my father, and Watcharee Rueangprathum, my mother, for their unconditional love and strong encouragement, Supanat Witosurapot, my lovely son, for his sweet smiles and understanding, and at last Dr.Suntorn Witosurapot, my supportive husband. I could not imagine doing my Ph.D. without them; they really gave me the reason to continue. Words would never say how grateful I am to all of you.

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LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
DCR	Digital Content Repository
Fps	Frame per seconds
GENA	General Event Notification Architecture
IEEE-LOM	Sharable Content Object Reference Model
IP	Internet Protocol address
Kbps	Kilobit per seconds
LOR	Learning Object Repository
MADM	Multi-Attribute Decision Making
Mbps	Megabit per seconds
MCDM	Multi-Criteria Decision Making
MODM	Multi-Objective Decision Making
P2P	Peer-to-peer
QoS	Quality of Service
RDF	The Resource Description Framework
RDFa	The Resource Description Framework in Attributes
SSDP	Simple Service Discovery Protocol
SOA	Service-Oriented architecture
SOAP	Simple Object Access Protocol
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UPnP	Universal Plug and Play
UPnP-AV	Universal Plug and Play Audio Video
XML	Extensible Markup Language

GLOSSARY

Broker (Agent)	An entity that is nominated for peforming or handling special tasks. The general goal is often to release the major burden occurring on some other server.
Cognitive platform	The platform with an engine containing some Artificial Intelligent mechanism for reasoning tasks.
Content adaptation	The action of modifying user content based on quality parameters with the ultimate goal of size reduction.
Linked Data	A practical approach relying on the structured data in RDF (Resource Description Framework) format to interlink machine-understandable data via the Web infrastructure.
Semantic Web technology	A technology that enables the global Web of linked data so that communication between computers can be took place without human involvement.

Chapter 1
INTRODUCTION

1.1 Motivation

Over the last decade, the advance of mobile technologies has drastically gained their interests on applying them for educational benefits [1] Now, it is widely recognized that mobile devices (e.g. smartphones, tablets, notebooks, among others) can be used well to promote a variety of learning styles (ranging from personalized learning [2] to social learning [3]) at anywhere and anytime in various manners, such as sharing the documents, accessing the e-learning system, or even visualizing streaming multimedia contents in online games for learning purposes. While the innovational use of mobile device platforms can facilitate learners in many educational activities, it yet demands mobile learning applications for becoming awareness of ***users' demands*** and enabling the notion of customization or ***personalization*** on their offered services. Indeed, the need of user personalization is important and may be triggered from different issues in broad perspectives of related entities, such as:

- ***User's device:*** This addresses the heterogeneous features of available mobile devices, which are largely variable in screen sizes, display resolutions, as well as power (battery) consumption.
- ***User's environment:*** This encompasses not only the geographic location, but also the other surrounding factors (e.g. network speed, communication bandwidth, communication cost, etc.), and
- ***User's perception:*** This somewhat relates to preferences that can be satisfied user. For instance, a user choice of multimedia playback will be decided whether in the small size of display contents with the highest video quality or in the big size of them but with a much lower quality.

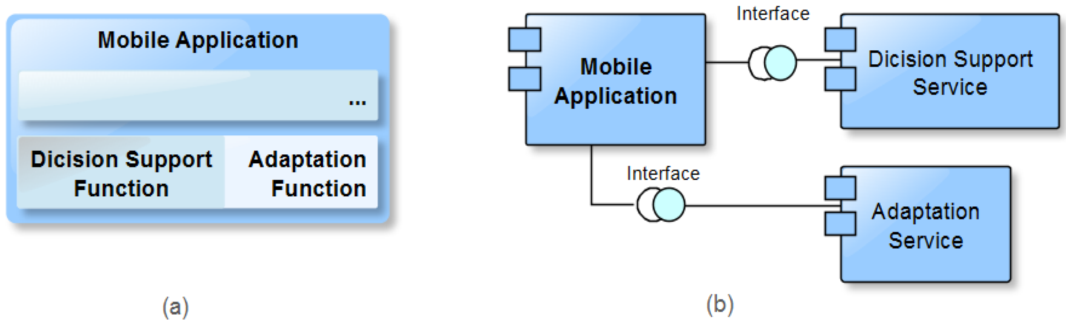


Figure 1.1 Comparison of (a) tightly-coupled functionality in general application and (b) loosely-coupled services in service-based application.

To provide a service in a personalized manner, an application inevitably requires the usage of heterogeneous components for handling the above issues in separation. However, due to a diverse set of user demands, the associated software components, as well as their interactions, can drive the application into agony, unless effective software engineering is instituted. In this respect, the architectural style of Service-Oriented architecture (SOA) [4] is attractive, since it allows an application to be designed and developed as a ***composition of loosely-coupling services***, rather than a combination of tightly coupling components, as illustrated in Figure 1.1. By working on a basis of service-orientation, the system can get better benefits of a) cost-efficiency, b) agility, and c) adaptability. It is in the sense as follows:

- By realizing SOA, a service with equivalent functionality can be promptly consumed by a number of applications that require this functionality without any additional development. This considers as cost-efficiency, since only one set of coding is maintained.
- By promoting SOA, a new application can be developed either by assembling available services or using them to implement part of its functionality. Hence, if some changes are required in the future, better agility of applications can be prompted by the creation of new services.
- When implementing SOA, services can be accessed in a standardized manner (e.g. via W3C Web services [5]) and without having to know how the services are implemented. As a consequence, when service needs to adapt in response to changes either for performance upgrades or business

needs, no impact will be made to existing applications (besides the actual interface definition changes). The service consumer does not depend directly on the service's implementation but only on the contract the service supports.

In this thesis, we advocate the exploitation of SOA for designing and developing services as reusable building blocks, which can be composed later in the standardized manner (e.g. via W3C's Web Services) for building complete solutions in mobile learning applications. Nevertheless, service-based applications can consist of several artifacts (such as services, networks, users and contexts), some special considerations and extra mechanisms on both technical and economic aspects are truly needed for providing adequate service guarantees. These requirements then pose many challenges in the field of mobile learning research (see [6], [7] and references therein), which presently remain active so far.

1.2 Research Issues and Objectives

The purpose of this thesis is to study and develop approaches and algorithms that are essential for adequate provisioning of mobile learning services in dynamic and heterogeneous environments. In particular, this thesis has emphases on three challenging issues in current ubiquitous mobile learning research as follows:

1. **Enabling semantic-enabled learning services in ubiquitous network**

   While mobile devices can be well accommodated for both teaching and learning purposes, those usages often take place in well-established infrastructure of local area networks (as normally found in the school settings). Indeed, the ad-hoc style of local area networks (e.g. via the Wi-Fi hotspots [8] is important as well especially for conducting occasional learning sessions in the remote or rural area, where the public Internet facility is unavailable or undesirable due to monetary reasons. Nevertheless, it is not always guaranteed that the automatic discovery feature is implemented in this sort of network. All networked devices may encounter difficulty for finding the other peers as well as services that are available in the same network, hence discouraging users to adopt mobile learning activities significantly. We argue that this feature should be mandatory and embedded into the communication subsystem so that mobile devices can be promptly worked without requiring redundant setup. In this regard, the home network automation technology seems to be a good candidate, but some extra functionality may be needed to support for mobile learning activities.

However, compared with many standards of home network facilitation [9], UPnP standard [10] looks attractive due to the dominant use of TCP/IP standards and Web technology for serving its foundation. This will provide us invaluable benefits, such as a) seamless interoperability with existing networks, b) native accessibility to enormous Web resources and repositories, and c) semantic capability to empower users with smart search of their learning contents and services. In this regard, a challenging problem is on how the semantically-enabled facilitation of learning content services in augmented UPnP ubiquitous network environment should be enabled so that they can be realized on UPnP-enabled mobile platforms in a proper manner. Answering to this problem will lead to a peculiar adoption of UPnP networks for educational purposes, which has been largely overlooking in the relevant research community.

2. Providing context-aware adaptive learning experiences

The difficulty of incorporating current learning services for learners with mobile devices has motivated the extension of non-capable multimedia streaming servers for desktop/notebook-based learning to recognize the constraints of mobile environments. To enable for effective solutions, a straightforward way can be done by adopting a broker entity (acting as mediator between a server and mobile learners) that will cooperatively work with the server in such a way that the required service of responsive multimedia content provision can be enabled. In this regard, it is respectively challenged to devise a broker-assisted framework for adaptive multimedia streaming services to meet the requirements of the mobile applications.

To obtain an effective service provisioning of streaming multimedia contents, it is argued in this thesis that the cooperation of user and server mechanisms will be important as it can simplify the complexity of mechanism working on the server platform. Under the client/server paradigm [11], a traditional way for resource management relies often on the server-centric approach [11], where the tasks of resource determination and allocation will be profoundly done on the server platform, but with scarce involvements of the client devices. This approach might be worked acceptably in the past, where few standard specifications and low performances of mobile devices can be only assumed. At present, this assumption is no longer valid, owing to the large availability of smartphone models with higher computing facility, better rendering capability, and faster network connectivity. As a result, it becomes difficult, or not possible, to provide customized or personalized service provisioning, without knowing the physical characteristics of mobile devices as well as the user preferences.

We argue that an effective service provisioning of streaming multimedia contents should include more cooperation of users in order to simplify the mechanism on the server platform. In this thesis, we consider developing lightweight learning services that are well adapted to the learner’s preferences and usage contexts by a means of client-server cooperative approach. In this regard, the smart agent residing on the user’s device can facilitate user for handling tedious tasks, such as the determination of multimedia attributes that will maximize user benefits or satisfaction levels in times of crucial network congestion. Hence, a challenging problem is on how to design a lightweight and adaptive reasoning policy on mobile devices, as well as associated resource allocation scheme, so that it can lessen the complexity of content adaptation process at the broker or server platform.

3. Delivering cloud gaming experiences

Since multimedia streaming contents are not necessarily generated from typical repository of learning contents, they can be issued dynamically from game-based learning practices. This represents a modern style of mobile learning, which intends to use video and networked games of cloud gaming servers [12] to gain significantly improvements on cognitive processes [13]. However, delivering good gaming experiences in this sort of environment is well-recognized [13] as a challenged problem, due to many involved factors regarding a) the distributed nature of cloud computing, b) the real-time nature of game interactivity, and c) the high-definition of multimedia contents in game streams.

On resolving this concerned problem, we are advocated on applying the user and network cooperation scheme and following the similar approach as planned to explore in the previous subsection. Then, prime considerations will be on how the multi-criteria decision support method for supporting the user's selection in cloud gaming environment should be realized, as well as the compatible cognitive resource utilization scheme on the gaming server.

Focusing on these research issues, this thesis has the following three objectives:

1. To investigate how semantic-based facilitation should be realized and promoted in the UPnP-based ubiquitous network infrastructure so that efficient learning contents can be delivered without demanding any specific learning standards.
2. To devise efficient broker-assisted framework for leveraging non-adaptive streaming servers to meet adaptive requirements of context-aware mobile learning applications in a cooperative manner.
3. To design and develop cognitive resource recommendation algorithm that capable of handling multi-criteria multimedia features according to the demand of users working in general uncertain environments and specific cloud gaming environments.

1.3 Contributions

The work conducted in this thesis, guided by the research issues and objectives posed in the previous section, has led to the following contributions.

1.3.1 A pragmatic approach for enabling semantic-enabled mobile learning service in UPnP network infrastructure

It is basically an architectural design of peer-to-peer based mobile learning service that subtly adopts the UPnP-based network infrastructure for achieving objectives of architectural simplification and fast arrangement altogether. In addition, the proposed service can yet exploit the Linked Data approach [14] for semantic integration of learning resources from a computer to computers, without human intervention, in the Web of Data [15] paradigm. The description of proposed architecture will be presented in Chapter 3.

1.3.2 A user-driven framework for providing context-aware adaptive learning service of multimedia contents

It is essentially a cooperative framework of adaptive multimedia learning service that provides benefits to learners in such a way that adaptive and personalized learning experiences can be tailored to their particular policies and personal characteristics towards maximizing their own satisfaction. In addition, the analytical hierarchical process method (AHP) [16] is proposed for serving the multi-criteria decision-making on resource utilization functionality at reasoning engine on the learner's device. Using numerical-based evaluation, effectiveness of proposed scheme in the case of adaptive streaming multimedia content service is studied on maximizing the user satisfaction according to the ratio of concerned factors like power consumption, perceived quality, and network cost. In this regard, the best combination of video frame-rate, video resolution and audio bit-rate under the availability of network bandwidth given to the user can be properly derived. This contribution will be crucial on the leverage of non-adaptive content servers for enabling adaptive service provisioning using service brokers. The description of the framework as well as AHP-based user policies will be presented in Chapter 4.

1.3.3 A decision-making support in cognitive platform for cloud gaming service

It is actually a reincarnation of the multi-criteria resource utilization scheme using AHP proposed in the second contribution, but it is modified significantly to work adequately on the cloud gaming service environment. Since only a few of multimedia attributes (i.e. video resolution, video frame-rate and audio bit-rate) are interested in this sort of environment, the AHP-based decision-making model is then proposed in such a way that it can recommend the best selection of streaming content resolutions under various user's contextual alternatives (i.e. the availability of network bandwidth, the screen resolution and power consumption of learner's mobile devices). This contribution addresses the need of cognitive platform for advanced cloud gaming services that can ensure more efficient cloud gaming resource utilization, particularly during heavy-congested periods, while learners' quality of gaming experiences can be still maintained under the mandate of intelligent agents on the learners' devices. This contribution will be presented in Chapter 5.

1.4 Structure of the Thesis

The overall organization of this thesis can be illustrated in a form of table as shown in Table 1.1.

Table 1.1 Summary of this thesis

	Introduction	**Literature Review**	**Theory**	**Experiment**	**Conclusion**
Chapter 1	✓				
Chapter 2	✓	✓(S, A,C)			
Chapter 3	✓(S)	✓(S)	✓(S)	✓(S)	✓(S)
Chapter 4	✓(A)	✓(A)	✓(A)	✓(A)	✓(A)
Chapter 5	✓(C)	✓(A, C)	✓(A, C)	✓(A, C)	✓(A, C)
Chapter 6					✓(S, A, C)

Legend: S: Semantically-enabled ubiquitous learning service in UPnP networks
A: AHP-based features selection for multimedia contents
C: Cognitive platform for Cloud gaming service

The thesis can be summarized as follows:

i) Chapter 1 provides the motivation of the thesis, following with the problem statements, research issues and objectives in this thesis.

ii) Chapter 2 introduces some backgrounds relevant to the research conducted within this thesis. These issues include the basics and research challenges of UPnP-based ubiquitous network architecture, repository of learning contents, adaptations of multimedia learning contents as well as multi-criteria decision making approaches.

iii) Chapter 3 addresses the issue of ubiquitous learning support in automatic home network environments. Extensions of standard UPnP network infrastructure are proposed in such a way that semantically-enabled ubiquitous learning services can be provided.

iv) Chapter 4 focuses on the issue of adaptive, context-aware learning content service. A user-driven resource management framework is proposed so that users are empowered to work collaboratively with a service broker of learning repository. This will allow the user to select the audio/video adaptive features suited to their needs via the Analytic Hierarchical Process method.

v) Chapter 5 deals with the issue of adaptive resource selection in Cloud gaming service environment. A decision making support via Analytic Hierarchy Process method is proposed to deploy at the player devices so that required multimedia features can be optimally selected according to the user preferences and the current network constraints.

vi) Chapter 6 concludes the thesis and summarizes our key contributions and findings. We also outline future directions for this work.

Chapter 2
BACKGROUND AND LITERATURE REVIEW

This chapter introduces the background information on essential concepts necessary for understanding the research work presented in this thesis. Section 2.1 introduces the general architecture of mobile learning system following with a review of design requirements for building effective mobile multimedia services. In addition, the frameworks and middleware that can be effectively used to encapsulate complexities in the creation of multimedia content services for mobile learning objectives are introduced. Section 2.2 emphasizes on the challenges of decision making support for user-driven resource management in mobile learning environments. Finally, Section 2.3 summarizes this chapter.

2.1 Context-aware Adaptive Mobile Learning Service

Before describing the detailed description of the context-aware adaptive mobile learning service, a set of prerequisites will be firstly presented so that necessary concept and building blocks of the service architecture can be understood in an easy manner.

2.1.1 Adaptive Mobile Learning

Adaptive mobile learning envisages a concept, where not only learning activities can occur without restrictions in time and location by using any mobile devices through wireless network and the Internet, but also learning materials can be customized to fit the individual needs of users and their mobile devices' capabilities. The concept above looks convincing, regarding the advanced technologies, e.g. the native availability of *embedded sensors* on mobile phones, and the flexibility of *responsive contents* rendering on various screen sizes and resolutions. By considering the maturity of these technologies, it is then believed that the modern generation of adaptive mobile learning system can be developed with less complexity than its former generation, where only low performance and less capable devices are involved. Regarding this consideration, issues of *context-awareness* and *content adaptation* become utterly essential in the design of mobile learning services.

2.1.2 Design Considerations

It is demanded that adaptive mobile learning system [6] must be considered both context-awareness and content adaptation. In this regard, context-awareness refers to the service capability on being aware of several contexts (e.g. user preferences, device capabilities, and surrounding conditions). Content adaptation signifies the service proficiency on generating adapted learning contents based on such awareness. The collective use of them provides usefulness and empowers the context-aware adaptive system as illustrated in Figure 2.1. While the basic concept of such a system looks simple and straightforward, the realization in practice is however complicated, due to the preliminary of technical concerns involving into the system design. According to Ismail et al.[17], these considerations can be categorized into 6 fundamental areas as summarized in Table 2.1 and described as follows:

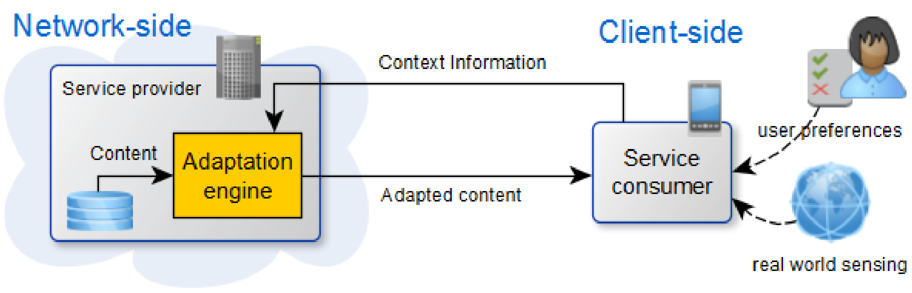


Figure 2.1 General overview of context-aware adaptive system.

2.1.2.1 Purposes

Purpose is referring to the purpose of content adaptation system, whether it will be covered a general system (including the framework), or just limited to specific tasks of adaptation in accordance to certain data type. Either of them has its own advantage and serves exclusively for different objectives. For example, UoLmP [18] and CoMoLE [19] are some representations of general frameworks that aim to support the different types of adaptive learning activities, while some research work such as in [20] focus on a special content adaptation framework that is applied particularly to slides documents in mobile Web conferencing. Our works in this thesis contain both types of purposes. In Chapter 3, our main purpose is on a general mobile learning framework utilizing on the home network infrastructure. Then, in Chapter 4 and 5, our purpose is shifted to the reasoning engine that will enable a learner to have a better handle of personalized mobile learning resource delivery.

Table 2.1 Categories in content adaptation.*

Category	Meaning	Possible approaches
Purposes	Why to perform adaptation	• General system/framework • Specific task of a system
Strategies	Who should perform the adaptation	• System • Application
Localities	Where to perform the content adaptation	• Client-side • Server-side • Proxy-side
Mechanisms and techniques	What to be adapted, and how to adapt	• Modality conversion • Content scaling
Contexts	Adapt to what	• Low-level • High-level • Situational level

* Based on categories given by Ismail et al. In [17].

2.1.2.2 Strategies

Adaptation strategy is referring to a concern regarding who or which part of the system should be responsible for carrying out the content adaptation. In general, the strategy can be taken into account by either the underlying system (where the application resides) or the application itself. Since the former seems to be particular for energy-awareness in mobile operating system [17], the latter, where the application takes care of adaptation, will be only concerned throughout this thesis.

2.1.2.3 Localities

Locality is referring to the location where the content adaptation takes place in the content delivery environment. According to the document of Mobile Web Best Practices[1] recommended by W3C Consortium (Best Practices Working Group), it has three possible locations (as shown in Figure 2.2): at the client side where content is

[1] http://www.w3.org/TR/mobile-bp/

consumed, at the server where original content is resided, and at the proxy server where content is processed by some other entity locating between the client and the server. Besides having its own advantage, each of them contains somewhat level of limitations.

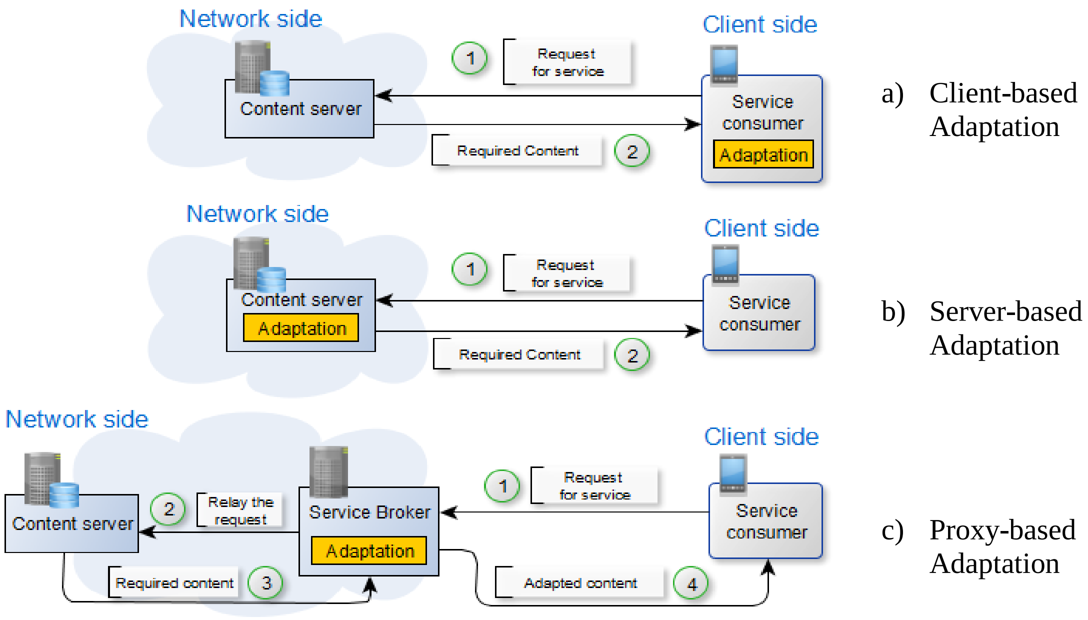


Figure 2.2 Different locations for carrying out content adaptation.

In *client-side approach*, a user may decide to override the default adaptation parameters to yield for better quality content, but needs to scarify the extra-processing of the content as well as battery-powered energy consumption. This may not be favorable to some users or always feasible to perform on rather old models of mobile devices. Worse than that, users need to install some extra-software e.g. browser plug-ins, which can be vulnerable to security attack. As a result, the client-side approach will not be considered involving in this thesis work.

In *server-side approach*, contents can be tailored easily to meet specific needs of users (such as type or scale of the adaptation process) and/or constraints of their devices, due to the wide availability of computing and memory resources. Major drawbacks are on a) the bottleneck problem at the server when an excessive number of requested users are presented, and b) the heavy burden of periodical maintenance at the server regarding a large set of adapted versions of original contents for matching with different properties of user devices. Nevertheless, this approach is prevalent for accommodating mobile learning applications, since it allows learning repository and context adaptation engine to be existed and managed altogether in the same server (or cluster of servers). Examples of the research applying this approach can be seen in [18] and [19] and in our work presented in Chapter 5 of this thesis.

In *proxy-side approach*, content is adapted on a proxy (also called broker) acting as a mediator locating between the server and the user. Adopting this approach, any content server of which facility is non-adaptive can be leveraged simply via proxy for adaptive content delivery. In this case, the extra load occurring on communication link is inevitable, owing to the negotiation between the server and the proxy. This extra burden can be, however, disregarded in the local network environment, where abundant network resource is usually available. Examples of the research applying this approach can be seen in [21] and [22] and in Chapter 4 of this thesis.

2.1.2.4 Mechanisms and Techniques

Mechanism is a terminology referring to what property of the content to be adapted. For the case of streaming multimedia content like educational video stream, its property is somewhat complex, owing to the aggregation of internal media components in different *modalities* [23], which are summarized in Table 2.2. In this regard, two major mechanisms for adapting each internal media component can work on a basis of modality conversion using *transmoding* techniques [6], [23]–[26] or that of magnitude reduction by applying *transcoding* techniques [6], [25] and [26] on selected media attributes.

Table 2.2 Different modalities within a video document.*

Types	**Descriptions**
Visual modality	Everything including motion pictures, images, etc. that can be seen in the video document
Auditory modality	Speech, music, and environmental sounds that can be heard in the video document
Textual modality	Textual resources that describe the content

* Based on descriptions given by Snoek and Worring in [26].

Table 2.3 Different transcoding techniques

Types	Methods
Spatial resolution reduction	Changing the color pattern, resolution, width or height of media component, or combination (as illustrated in Figure 2.3)
Temporal resolution reduction	**Video:** Lowering frame rate (as depicted in Figure 2.4), while the original format is still maintained. **Audio:** Lowering sampling rate, channels, bit rate, etc.
Format conversion	Converting from one format to another (e.g. from AAC to MP3 for audio files, or GIF to JPEG for images)

While the transmoding technique is aimed to convert internal media contents from one modality to a different modality (e.g. from video to image or audio to text, etc.), the transcoding technique is somewhat aimed to shrink overall media size on the tolerance of some selected quality degradation (see Table 2.3 for many possibilities).

Image

Color	24 bit color	4 bit gray	4 bit gray	Black and white
Size	469 x 513	469 x 513	200 x 216	200 x 216
Bits	277KB	137KB	68KB	6KB

Figure 2.3 Results of spatial transcoding technique.

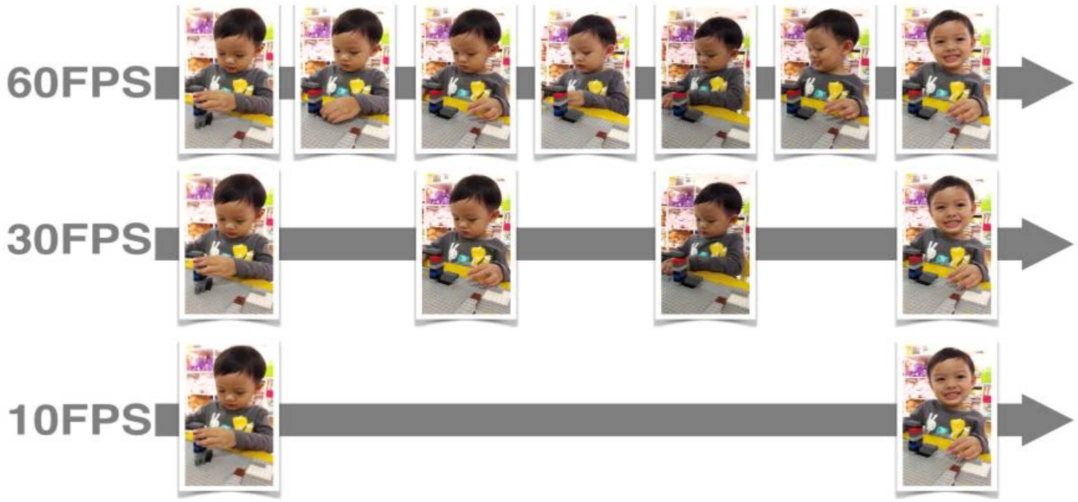


Figure 2.4 Lowering frame rate (Frame-per-Second) in temporal transcoding.

In fact, these techniques can be worked in combination [24] for producing better adaptation results of internal media components. In this case, some policy must be governed for making optimal decisions on content scaling and modality conversion. For instance, a learning multimedia content can be presented its internal media components at different resolutions on the determination of network bandwidth constraints, according to the InfoPyramid model [29] as given in Figure 2.5. When the bandwidth is plentiful, the content will be managed to send in high-definition of video/audio contents, high-color patterned image with full text description. During the periods of network congestion with decreasingly lessened bandwidth availability, lower definition of video/audio contents with summarized text will be issued alternatively. However, if the bandwidth continues falling below a certain threshold, just key frames with no audio and a few of textual sentences can be determined at last as a result. In this thesis, transcoding type of techniques will be only interested for delivering multimodal media contents to users, but taking into account several contexts occurred in the mobile learning environment.

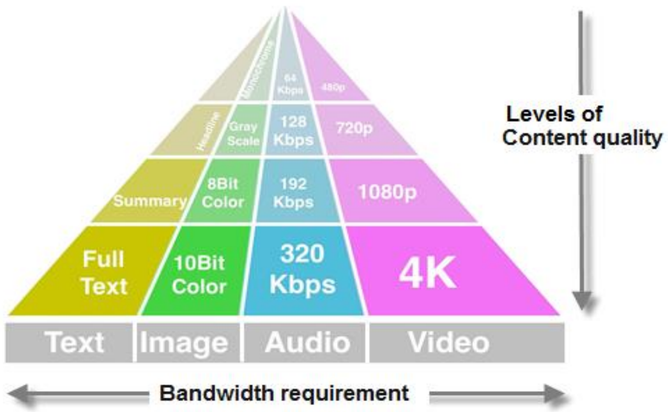


Figure 2.5 InfoPyramid model.

2.1.2.5 Contexts

Context is referring to what should be considered for content adaptation. In the literature, there exist a number of contextual definitions and classifications, depending on the researcher’s viewpoint (see [30] and reference therein). However, they are common in somewhat level though. By modifying the research work of YÜRÜR et al. in [31] and investigating another works in [30] and [32], mobile learning contexts can be unified from application points of view into three hierarchical levels of abstraction: low-level, high-level, and situational level contexts, as illustrated in Figure 2.6.

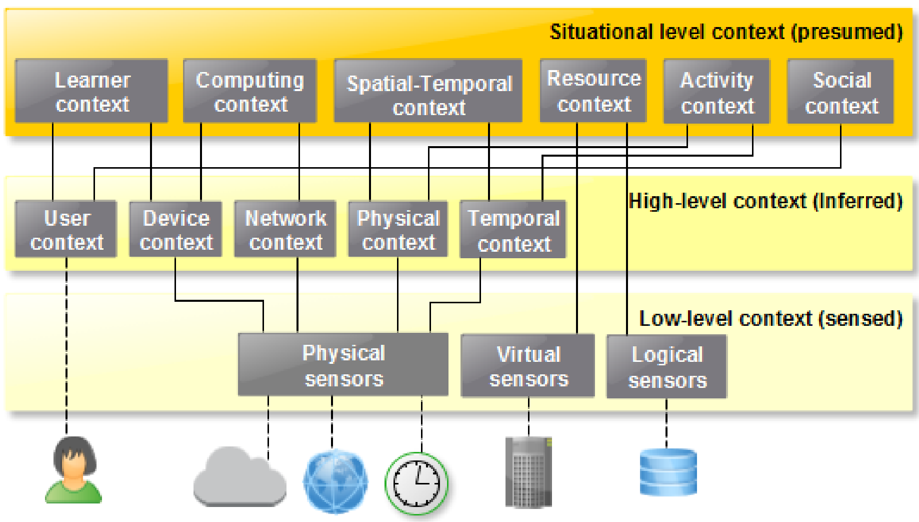


Figure 2.6 The hierarchical classification of context representation.

Table 2.4 Classifications of low-level context representation.

Low-level contexts	**Possible sources**
Physical sensors	Any physical world belonging data (e.g. geometric location from GPS sensor, activity from accelerometer, etc.)
Virtual sensors	Dynamic data or variables obtained from software applications and/or services.
Logical sensors	Data sources or repositories obtained by user interactions (e.g. GIS databases, learning repositories, etc.)

In low-level context, the contextual information can be acquired by different sensors in a number of ways, as shown in Table 2.4 above. For instance, the information can be read directly from sensing unit/hardware module embedded on mobile devices (so called physical sensors), from the interaction with software services (known as virtual sensors), or even from the request submitted to data repository (acting as logical sensors). All contexts in this level are necessitated for creating contexts in the higher levels.

Table 2.5 Classifications of high-level context representation.

High-level contexts	**Possible sources**
Device context	Input and output capabilities of device (e.g. screen size, resolution), CPU capability, battery-powered level, etc.
User context	User preferences, disabilities, media preferences, etc.
Network context	Network cost, network speed, available bandwidth, etc.
Physical context	Noise level, light intensity, etc.
Temporal context	Day, week, month, year, etc.

In high-level context, the contextual information can be inferred from sources, and classified into four groups as shown in Table 2.5. Device context is related to the capability of learner's device. User context is specific to user's preferred configuration settings (such as viewing media with available battery resource), whether or not they are related to disabilities (such as settings for blind of deaf learners). For instance, the learner may prefer the smoothness to the high quality of video rendering, when battery-powered resource becomes limited. The network context includes static and dynamic properties of the network (such as network cost and available bandwidth). The physical context describes some measure (such as for light, and noise) in the surrounding area, where the system or learner is situated. The temporal context includes temporal parameters (such as time of day and date information).

In situational level context, the context information presumes a characterization (or model) of specific entity situation, such as learner profile, computing, spatial-temporal entities, resource, activity and social relations, as shown in Table 2.6. For instance, the computing context viewing as a model can be described by the information taken from underlying network, hardware, and software contexts. It can be noticed that, by governing with standards, contextual variables of a particular entity can be then easily assumed and accessed from application developers on different purposes. However, a detailed explanation of these contexts is beyond the scope of this thesis, but can be seen elsewhere (such as in [30]).

Table 2.6 Classifications of situational level context representation

Situational level contexts (Entity)	**Characterization (Model)**	**Some standards**
Learner context	▪ Personal information (preferences, needs, interests, etc.), ▪ Competence profile (related with knowledge, skills, attitudes),	IMS Learner Information Packaging [31], IMS ePortfolio [33], FOAF [34]
Social context	▪ Social associations or connections between 2 or more learners.	
Computing context	▪ Computing facilities (i.e. network, hardware and software)	W3C Composite Capabilities/Preferences Profile [35], User Agent Profile [36], WURFL [37], MPEG-21 Usage Environment Description [38]
Spatial-temporal context	▪ Date/time information, ▪ Physical conditions in surrounding	Open GIS [39], ISO/TC [40], Contextualized Attention Metadata[41], User Interaction Context Ontology [42]
Activity context	▪ Scheduled activities, tasks or actions of learner	
Resource context	▪ Physical or virtual learning materials/resources	IEEE Learning Object Metadata [43], Dublin Core[44], MPEG-7 [45]

2.1.3 Infrastructure Overview

In previous section, the design considerations of context-aware adaptive system in mobile learning environments have been previewed. In what follow, we elaborate on the infrastructure of such a system as it has been discussed in e.g. [46], [47]. Figure 2.7 shows basic architecture (considering as web-based client/server architecture) of context-based adaptation and delivery services in mobile learning spaces, which relies mainly on a) the decision engine that will presume the characteristics of users, surrounding conditions via aggregated contexts, and b) the transcoding process that will process to transform the properties (format, quality, etc.) of one or more media internals of learning resources (obtaining from the learning content manager), regarding the digital and physical capabilities of the learner's device. The ultimate goal is to provide the adapted content service delivery that suits best to the learner's situation. This matter has been presented already in the previous subsection.

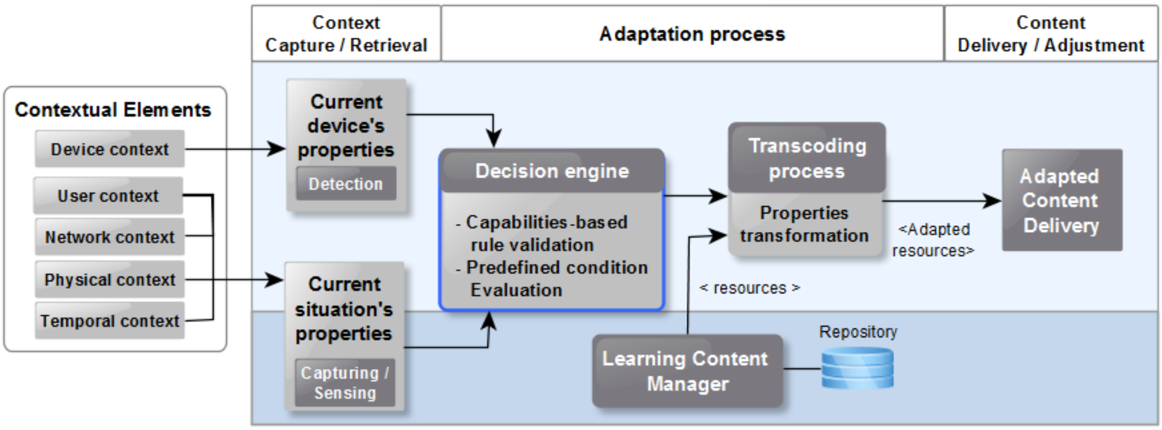


Figure 2.7 Basic architecture of context-aware adaptive mobile learning system.

However, the development of these learning applications are remarkably difficult for many researchers [46] and [7] since it requires full understanding of different protocols; dealing with distributed processes, platforms, and services; and interacting with different hardware sensors and drivers. Regarding this concern, the exploitation of frameworks and middleware as system foundation will give extreme benefits, such as

- Encapsulating many concerned issues,
- Simplifying the design and development of the system,
- Decreasing the complexity of programming tasks,
- Diminishing the risk of project failure.

In fact, according to the literature review taken by Martin et al. in [7], there are considered two categories of existing frameworks and middleware applications; the one supporting for general mobile computing applications, and the other for specific mobile learning applications. However, only the latter category will be concerned in this thesis. While a number of features are demanded in functionalities to enhance learning through mobile devices, some of them are only available or implemented in most learning-oriented frameworks and middleware depending on the different support for particular purposes (see the details of comparison in [7]). Nevertheless, none of these frameworks has never been widely recognized or implemented so far, even though some of them may contain a complete set of key features, such as M2Learn framework [48] .

To increase the broad acceptance from software industry as well as the long-term trust from general users, we argue that a properly devised framework and middleware should make use of existing technologies, protocols, and network standards as much as possible so that 3rd party developers can create applications without much difficulty. By moving toward this direction, our special attention is on the current standard related to ubiquitous network infrastructure (i.e. that of well-known UPnP standard) for serving mobile and ubiquitous learning ecosystem. Our motivation is that a framework and middleware for building a mobile and ubiquitous learning ecosystem should adopt salient facilitations of ubiquitous network infrastructure not only for architectural simplification, but also seamless integration or interoperability with existing services and applications.

2.1.4 UPnP-based Middleware Functionalities for Mobile Learning Ecosystem

By adopting ubiquitous network infrastructure, the general architecture of mobile learning framework design will be already included with network-related functionalities. In a case of UPnP-based functionalities (as shown in Fig. 2.8), the middleware will promptly support for ubiquitous connectivity and interoperability among many types of networked devices. For instances:

- Using low-level services, devices with short-range communication standards (e.g. Zigbee, and Bluetooth), Wireless or Wired LAN standards (e.g. 802.11x and 802.3), and Wide Area Network (e.g via 3G or LTE mobile Internet) can be employed for device-to-device communication in proximity.
- Using device management service, devices can dynamically join a network, obtain an IP network, report their capabilities as well as the other discovered devices, issue the eventing protocol or leave the network with conveniences.
- Using high-level services, devices or their services can be discovered, queried or commanded depending on the implementation for various purposes.

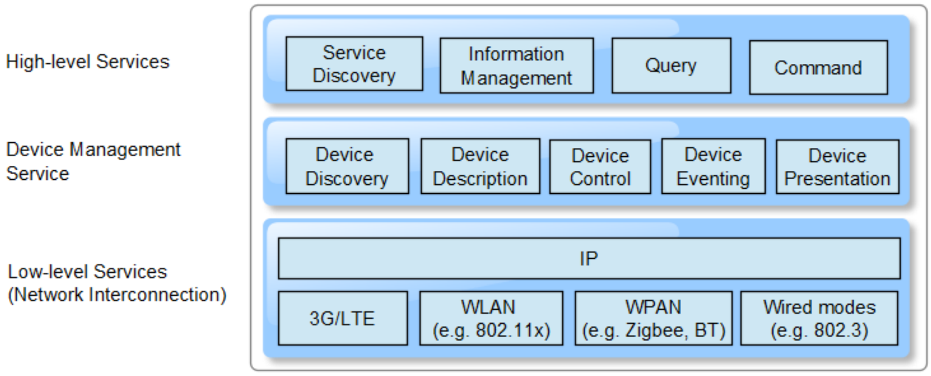


Figure 2.8 Simplified UPnP architecture.

Since these functionalities are offered in a form of services, they can be used or integrated with any other services or learning applications in the flexible manner. By promoting the Software as a Service (SaaS) paradigm, we believe that this approach is well-served as a solid foundation for a) facilitating absent functionalities of middleware to be built as needed in a form of extended services, and b) associating the required services from external learning resources or applications (e.g. those of

Moodle Learning Management System via W3C's Web Service standard). As evidence in Table 2.7, our proposed middleware tends to yield high flexibility for enabling necessary features as suggested in the work of Martin et al. [48] via extended services on some certain features. Our concept is very in similar to the M2Learn framework of Belimpasakis et al. [49], but is indeed different on supporting semantic-based operations as an alternative for accessing to learning materials without the need of distinct learning standards (e.g. IEEE Learning Object Metadata). This part of research work will be presented in Chapter 3 of this thesis.

Table 2.7 Comparison of context-aware middleware for mobile learning applications

Features	Martin et al. [48]	Belimpasakis et al. [49]	Our proposed UPnP-based middleware
Support of synchronous and/or asynchronous communication	✓	✗	✓
Provision of context-aware services	✓ (via widget)	✓ (via extended service)	✓ (via extended service)
Extensibility and ease of adding new context sources	✓	✓	✓
Use of existing ubiquitous infrastructure standards	✗	✓	✓
Access to learning materials and/or administrative services	✓	✓	✓
Support of e-learning standards and reusability	✓	✓	✓
Open source and API available	✓	✓	✓
Support of semantic operations	✗	✗	✓ (via extended service)

2.1.5 Decision Engine Functionality

Regarding the basic architecture shown in Figure 2.7, it can be noticed that the major functionality is at that of decision engine that indeed enables the excellent support of adaptive mobile applications in a wide variety of learning scenarios. By including some adaptation mechanism [6], the decision engine can adjust to ambient conditions (e.g. network state, user location, noise level, etc.) and to leverage parameters (e.g. the user's experience) to deliver a suitable learning unit in a proper form of adaptive media content or responsive learning document. A key challenge is to find the optimal selection of those contents or documents according to the given conditions and parameters. However, by formulating it as a multi-criteria decision making problem, the challenge can be managed to solve in an effective manner, but the detail will be described further in the next section.

2.2 Multi-criteria Decision Making Support for Media Streams

As mention earlier in section 2.1.2.4, multimedia streams can be modified their internal media elements (via transcoding mechanisms) for shrinking their sizes so that minimum service guarantee can be enabled, as long as adequate network resources are still available. However, it is not an easy task for users to make a right combination of internal audio or video qualities with respect to the relative important of these attributes and the current availability of network resources. Clearly, there is a need for a reliable way to make effective and consistent decisions or choices to ensure that network resources will be used effectively in such a way that user experience are maximized as well. In this regard, multi-criteria decision making (MCDM) approaches [50] can provide a systematic procedure to help decision maker select and rank alternatives among a set of multiple (and often conflicting) criteria. As MCDM approaches has shown its success in various areas, such as construction management [51], supply chain management [52], e-learning [53], and cloud computing [54], it looks promising to serve for selecting best-suited combinations of multimedia elements in the presence of contextual information obtained from different sources and governed policies, without complicated mathematical involvement.

2.2.1 Classification of Multi-Criteria Decision Making Approaches

Based on the literature review in [55], [56] , MCDM approaches can be broadly classified into two main groups as shown in Figure 2.9 ; Multi Objective Decision Making (MODM) and Attribute Decision Making (MADM). While the MODM can be simply seen as a mathematical programming problem with multiple objective functions, the MADM [56] avoids complicated mathematical involvement in making preference decisions by means of prioritization on a limited number of alternatives, which are often characterized by multiple conflicting attributes. Similar to [57], we give some widely used MADM methods: MAUT (Multi-Attribute Utility

Theory), Outranking (including PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) and ELECTRE (ELimination and Choice Expressing Reality)) and AHP (Analytical Hierarchy Process). These methods are all common in steps for calculating values to alternatives, multiplying them by weights, and combining them to produce a total score, are different significantly in the way to calculate values as well as manipulation, due to differences in mathematical properties and concerns [57]. Detailed comparison of them can be found in the literature (such as [55] and [57]).

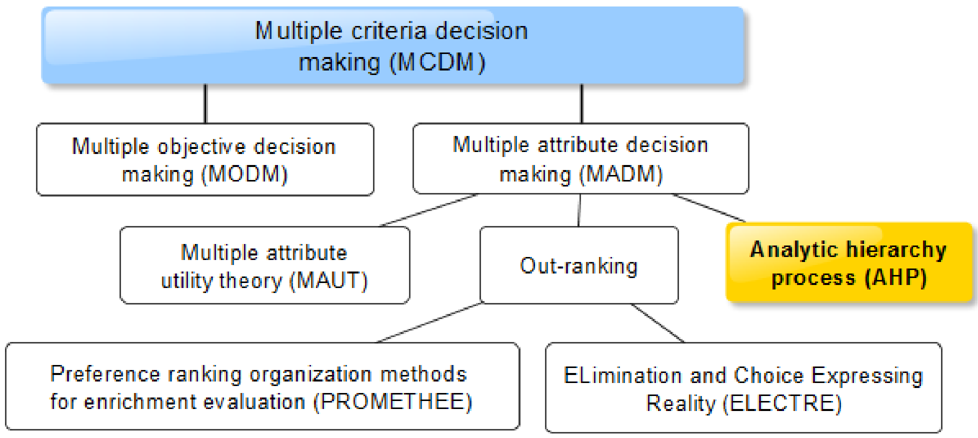


Figure 2.9 Classification of Multi Criteria Decision Making.

Among the MADM methods mentioned above, AHP is perhaps the best known and most widely used MCDM approach according to the recent literature review in [58]. The key and salient features [59] that motivates the explorations in Chapter 4 and 5 of this thesis are follows:

a) Handling both qualitative and quantitative factors in an intuitive manner by structuring them into a hierarchical decision model based on a number of criteria.
b) Quantifying relative priorities of decision criteria with pair wise comparisons, so that ranking a finite set of alternatives can be possible.
c) Detecting inconsistency of data that are inherent in the decision-making process for comparing alternatives.

As a consequence, AHP has been successfully applied for giving decisions in various research areas (see [60] for the literature review of selected areas and references therein). In fact, there have been some research works in decision related to web and communication networks as well. For instance, the work [61] suggested how AHP can be used to evaluate the level of user satisfaction based on the user-perceived quality of service (QoS) so that the qualities of service classes in the wireless cellular networks can be known and improved if necessary. In [62] and [63] they advocated on the use of AHP to solve the cloud service selection problem of which decision factors related to user subjective assessment are concerned. It can be noticed that these works are common on applying AHP-based method for decision, but are different on the returned benefit whether it is for the user or the service provider. Unlike our work, the AHP-based decision-making method will be served at the learner's device for decision support on the best selection of adaptive multimedia features under its own criteria.

2.2.2 Basics of Analytic Hierarchy Process Method

In using AHP, the steps can be summarized below:

1. Hierarchical Structure Modeling

Modeling the problem into a hierarchical analysis structure constituting an objective or decision goal is on the topmost level, the third level is a group of performance matrix or alternatives for reaching the goal and a group of factors or criteria that relate the alternative to the goal on the second level as in Figure 2.10.

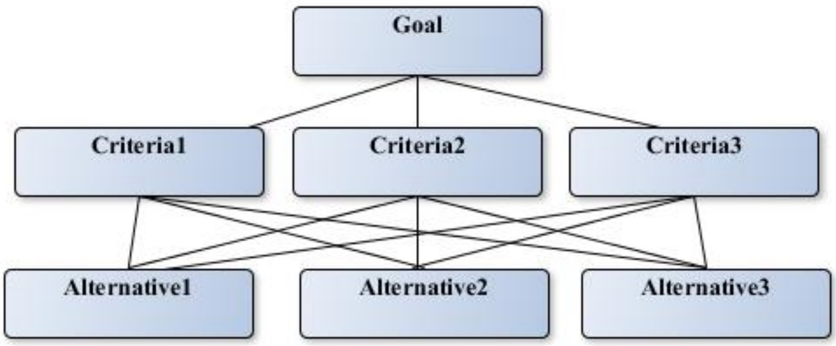


Figure 2.10 The hierarchical structure of the decision making problem.

2. Judgment Matrixes

AHP allows us to calculate the relative weight of decision criteria and alternatives in an intuitive manner. The basic steps are described as follows:

a) Making pairwise comparison for criteria and alternatives:

In this step the relative importance of involved performance metric is judged by a pair wise comparison. Rating the relative priority of each metric is done by assigning a value 1-9 of Saaty's nine-point scale as shown in Table 2.10. For example, the value of 1 means equally preferred and 9 means extremely preferred.

Table 2.8 AHP Rating Scale of judgment.

Value	Verbal judgment between pair wised values
1	Equally preferred
3	Moderately preferred
5	Strongly preferred
7	Very Strongly preferred
9	Extremely preferred
2,4,6,8	Between the judgment above

Generally, there are three types of rating priority methods [64], namely Questionnaire Result, Expert Experiences, and Literature Survey. But using the expert experiences is preferred in this thesis, because a) there is no explicit evident in the area of decision making user-driven context-aware adaptive learning and b) taking questionnaire is a time consuming process. As a result, the reciprocal matrix of decision criteria and alternatives can be obtained as shown in Table 2.11 and Table 2.12 respectively.

This matrix table is described with two considerations that are horizontal and vertical matrix comparison. For example, 1/3 on C1:C2 means the decision maker likes C1 three times less than C2. On the other hand, C2:C1 means the value of C2 is 3 times more than that of C1, this idea is as same as Table 2.12.

Table 2.9 Matrixes for the 3 criteria.

Criteria	C1	C2	C3
C1	1	1/3	3
C2	3	1	5
C3	1/3	1/5	1

Legend: C1= Criteria1, C2= Criteria2 and C3=Criteria3

Table 2.10 Matrixes for the 3 alternatives from each criterion.

	C1			C2			C3		
	A1	**A2**	**A3**	**A1**	**A2**	**A3**	**A1**	**A2**	**A3**
A1	1	3	5	1	1/3	5	1	3	5
A2	1/3	1	3	3	1	7	1/3	1	3
A3	1/5	1/3	1	1/5	1/7	1	1/5	1/3	1

Legend: C1, C2, C3 are Criteria1, Criteria2 and Criteria3, respectively
A1, A2, A3 are Alternative1, Alternative2 and Alternative3, respectively

b) Computing priority vector (weights) for decision criteria and alternative.

By definition, the priority of the Goal is 1.000. The priorities of the criteria and alternative are also always added up to 1.000 as well, see Figure 2.11 for example.

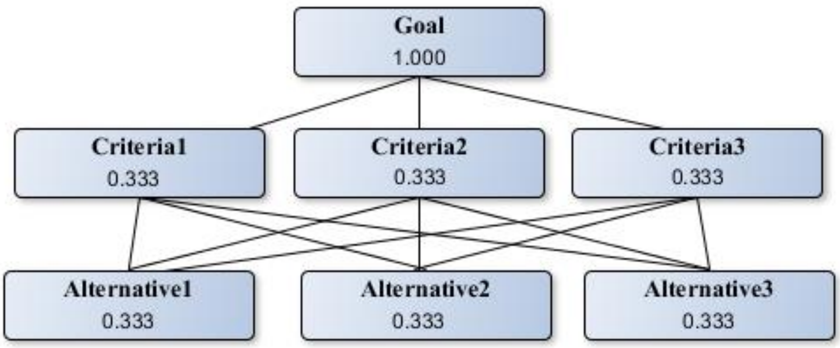


Figure 2.11 The fundamental of finalize priority (weight) of AHP hierarchy

Having a reciprocal matrix, we then want to compute the priority vectors, which are the normalized Eigenvector of the matrix. Eigenvector [65] is a short computational way to obtain this ranking is to raise the pairwise matrix to powers that are successively squared each time the row sums then calculated and normalized regarding to Table 2.11 (matrix of criteria), we use the table showing the calculating processes (Table 2.13-2.15).

Table 2.11 Squaring the Matrix

Criteria	C1	C2	C3
C1	1	0.333	3
C2	3	1	5
C3	0.333	0.2	1

Legend: C1= Criteria1, C2= Criteria2 and C3=Criteria3

After convert the fractions to decimals (Table 2.13) and then we square this matrix (i.e. (1*1) + (0.333*3) + (3*0.333) = 3) and the results have shown in Table 2.14 below:

Table 2.12 Squaring the Matrix

Criteria	C1	C2	C3
C1	3	1.266	7.665
C2	7.665	3	19
C3	1.266	0.511	3

Legend: C1= Criteria1, C2= Criteria2 and C3=Criteria3

Here, we sum the rows and the row total is sum then these are normalized by dividing the row sum by the row totals (i.e. 11.931 divided by 46.373 equals 0.257) the processes can be show in Table 2.15. Finally, the Eigenvector (weight of criteria) are calculated (Table 2.16).

Table 2.13 Compute the Eigenvector

Criteria	C1	C2	C3		
C1	3	1.266	7.665	11.931	0.257
C2	7.665	3	19	29.665	0.640
C3	1.266	0.511	3	4.777	0.103
			Totals	46.373	1.000

Legend: C1= Criteria1, C2= Criteria2 and C3=Criteria3

Table 2.14 Eigenvector (Weight of Criteria)

Criteria	Weights
C1	0.257
C2	0.640
C3	0.103

Similar to the process in previous steps of comparing the decision criteria, all pairs of alternatives are now compared using the AHP rating value, and priority weights are calculated for each of the alternative. The results are given in Table 2.17.

Table 2.15 Weight of each Alternatives

	C1	C2	C3	Weight	Ranking
A1	0.164	0.178	0.067	**0.409**	**2**
A2	0.067	0.414	0.027	**0.507**	**1**
A3	0.027	0.046	0.011	**0.083**	**3**

Legend: C1, C2, C3 are Criteria1, Criteria2 and Criteria3, respectively
A1, A2, A3 are Alternative1, Alternative2 and Alternative3, respectively

Finally, the summary of all the weights in the hierarchy can be illustrated in Figure 2.12.

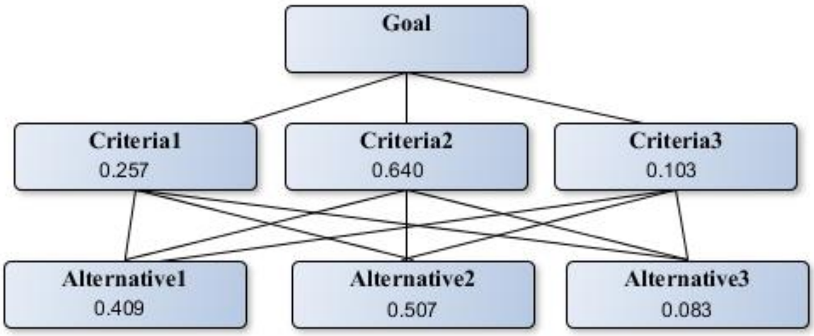


Figure 2.12 Summary of all weights in the hierarchy

c) Checking for consistency:

The consistency Ratio (CR) tells the decision maker how consistent we have been when making the pair wise comparison. The AHP will check consistency of data in evaluation through a ratio:

$$CR = (CI/RI) \tag{2.1}$$

where RI is a random consistency index and the typical values are given inTable 2.18, and n refers to the number of parameters. Since n = 3 in this example, RI is then set to 0.58; CI is consistency index, and is defined as:

$$CI = \frac{(\lambda max - n)}{(n-1)} \tag{2.2}$$

where λ_{max} is the maximum Eigen value of the judgment matrix (consistency threshold). Saaty suggested a threshold of 10% for the CR values.

Table 2.16 Random Consistency Index (RI)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

d) Evaluate alternatives according weighting

The AHP help to determine the benefits (weight) of each alternative (in 2.17). The weights are utilized to compute the overall priorities to support the best selection among possible choices together with the incurred costs of them, the method is as follow:

$$x = \sum_{i=1}^{n} w_i c_i \tag{2.3}$$

Where x is the total requested resources of alternative, w_i is the weight of alternative i, c_i is the cost of alternative i, i and n is number of alternative. Cost analysis is also done in this phase to evaluate the impact of each alternative on the total resource costs. The cost of each alternative can be calculated as follow:

$$c = \frac{r}{m} \tag{2.4}$$

Where c is the cost of resource of alternative, r is the requested resource of alternative, m is user's maximal availability of resource of alternative, and i is a number of alternative.

2.3 Summary

This thesis provided the background information on mobile learning, context-awareness, content adaptation, and design considerations necessary for building the context-based adaptive services in mobile learning environments. These issues will be helpful for readers who may not be familiar with these issue needed to follow in this thesis. Firstly, the concept of context aware mobile learning system was introduced. Then, the terms such as context, content adaptation, including the six relevant issues are described as they are important for the design of context-aware learning system. Then, the key limitation of general framework or middleware designed for mobile computing applications like UPnP is introduced so that the first research issue in the thesis can be understood. At last, the decision engine, as well as the multi-criteria decision making support by a means of AHP method are given in such a way that its crucial applications for dealing with context-aware multimedia recommendation of research works in Chapter 4 and 5 can be appreciated.

CHAPTER 3
ENABLING LINKED DATA FOR SEMANTIC INTEGRATION OF LEARNING RESOURCES IN UPNP NETWORK

In this chapter, we present a design of P2P-based mobile learning service that adopts existing UPnP network infrastructure for architectural simplification, and exploits Linked Data for semantic integration of learning resources. Section 3.2 gives a background of UPnP network environment and the Linked Data approach for lightweight semantics. Section 3.3 describes the proposed system architecture and functional component designs. Section 3.4 provides the detail of our prototype and simple use case. Then, Section 3.5 reviews the related work. Finally, Section 3.6 summarizes the chapter.

3.1 Introduction

Smart home network technology has provided excellent opportunities for people to experience both local services in home/office automation and public services from the Internet accesses to premises. However, for the educational purposes, smart home network is often used to facilitate for the remote access of e-Learning facility, but it is rarely utilized to provide for group-based learning among computers or mobile devices at homes or enterprises. This is crucially due to the lack of adequate systems and tools, which are indeed necessary for the arrangement of ubiquitous and mobile learning inside or outside premises.

Although a number of mobile learning systems have been researched to date (see [7] and Refs therein), they do not take advantages of existing ubiquitous network infrastructures designed for smart home into consideration. Therefore, their architectures are complex inevitably, due to the necessity for handling many basic (but crucial) issues, such as associating heterogeneous devices, discovering devices nearby, or enabling collaborative learning operations on a peer-to-peer (P2P) basis. We argue that the complexity of these architectures can be lessened by involving the support of pervasive network infrastructure, such as Universal Plug and Play (UPnP) [66], which is targeted for smart home/office service automation.

In addition, we encourage the exploitation of web-related technologies for many reasons. For instance, they are the technologies that are founded in the UPnP infrastructure for handling the problem of platform heterogeneity. Developers can then take advantages of deploying their applications via Web browsers, regardless of platform technology. More importantly, it is possible that the Semantic Web technology, such as that of Linked Data approach [14], can be involved for resource integration and generation in the Web-enabled UPnP environment. Then, learning resources and associated metadata can be reused, discovered, and interoperated among local UPnP devices via the Web infrastructure and protocols.

3.2 Background

3.2.1 UPnP Network Environment

Universal Plug and Play [66] is a well-recognized ubiquitous network infrastructure containing with features, such as zero-configuration for network startup, automatic detection of devices and services in the same local network, and seamless network connection on P2P basis. Dominant features are on the adoption of Service-oriented Architecture (SOA), Web technologies and Internet standards, i.e. TCP/IP and HTTP, to serve at the lower-layer of UPnP protocol stack (as illustrated in Figure 0.1). Hence, web-based applications can be readily implemented at any UPnP devices for performing various tasks, such as interacting with the other networked UPnP devices, consuming UPnP services, or extending them for improved functionality.

A notable UPnP extension is UPnP-AV [67], which enables ubiquitous multimedia services for home entertainments. Two extra-devices called Media Server and Media Renderer are introduced in UPnP-AV system architecture for specially managing Audio-Video (AV) content distribution on top of UPnP networks. The guideline in [68] suggests us how these special servers can be handled by User agent of UPnP device via HTML5 scripts in Web Applications for browsing and viewing the AV contents, or even managing to display them at the other device serving as

Media Renderer. By working in this manner, it looks promising that UPnP-AV system can be augmented to share or distribute user-generated contents or resources among UPnP devices for learning purposes as well.

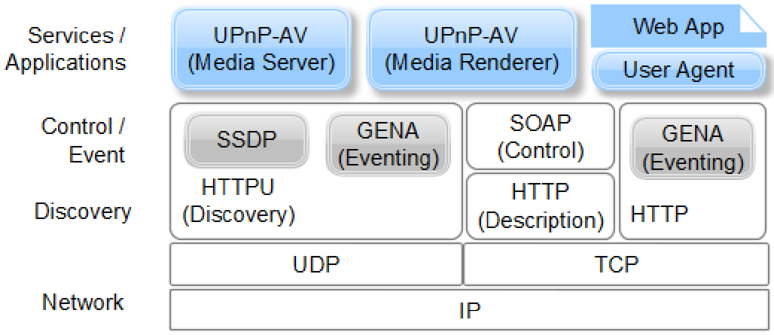


Figure 0.1 Simplified UPnP protocol stack.

3.2.2 Linked Data for Semantic-based Learning Resources

In order to provide adequate service for ubiquitous mobile learning, it is required that the all of learning contents must be involved not only with metadata for easing interoperability at the syntax level between devices, but also semantic-based operations for serving human-centric usability. In this regard, sharing and distributing multimedia contents in UPnP-AV system with MPEG-7 and MPEG-21 metadata standards are not adequate [68], especially in the aspects of learning resource with technologies of Learning Object. This is also applicable to the interoperability using popular educational metadata standards [69] e.g. IEEE-LOM and SCORM.

To accomplish the above requirement, traditional web pages crucially serving for human-centric operations will need to extend with semantic technology so that they can allow smart agent in a device to carry out tedious works, such as finding and combining learning resources on the Web, without human interventions. This requirement is indeed the vision of Semantic Web, but will be implemented by means of Linked Data approach [14], which is widely used to realize the Web of Data. It provides a smart way to expose, share, and reuse learning contents over the Web, thus giving benefits to lecturers or developers to create learning materials or quizzes in shorter period of time by combining contents from the other local devices or several public web sites.

From the technical aspect, the concept of Linked Data can be summarized by a) utilizing the Web as a single global database, b) describing the resource with the Resource Description Framework (RDF) annotation, and c) interlinking the data from different sources via Web addresses (URI). Once these resources are in RDF annotation, they become machine-readable, and hence give benefits to web developers in a number of ways. For instance, they can be viewed using generic data browsers, accessed via the links from the other resources, or even composed on-the-fly by smart agents residing at user-devices. Noticed that the RDF data may be exposed as a standalone RDF or embedded into HTML documents via special attributes known as RDFa [70] for serving both machines and humans.

3.3 UPnP-based Ubiquitous Learning Architectural Design

This section illustrates the proposed architecture design that minimally extends the UPnP architecture in such a way that ubiquitous mobile learning activities, either within a peer group or between a pair of devices, can be enabled.

3.3.1 Design Abstraction

In the provision of ubiquitous mobile learning services in the UPnP environments, the basic of UPnP-AV architecture will be taken into account (see Figure 0.2) so that existing service entities can still be utilized, but realized in the new context. For instance, the Media Server and Media Renderer remain dealing with MPEG-21 multimedia resources, which may be now alternately used as learning contents in some scenarios. Two exclusive services for handling educational resources are included into the system:

a) Semantic data repository service working at a special server for storing and retrieving static learning resources, and

b) Linked Data service residing at the user-devices for manipulating and rendering linked data.

These services can ensure that semantic interoperability of educational resources will be occurred properly in the system as explained in the previous section

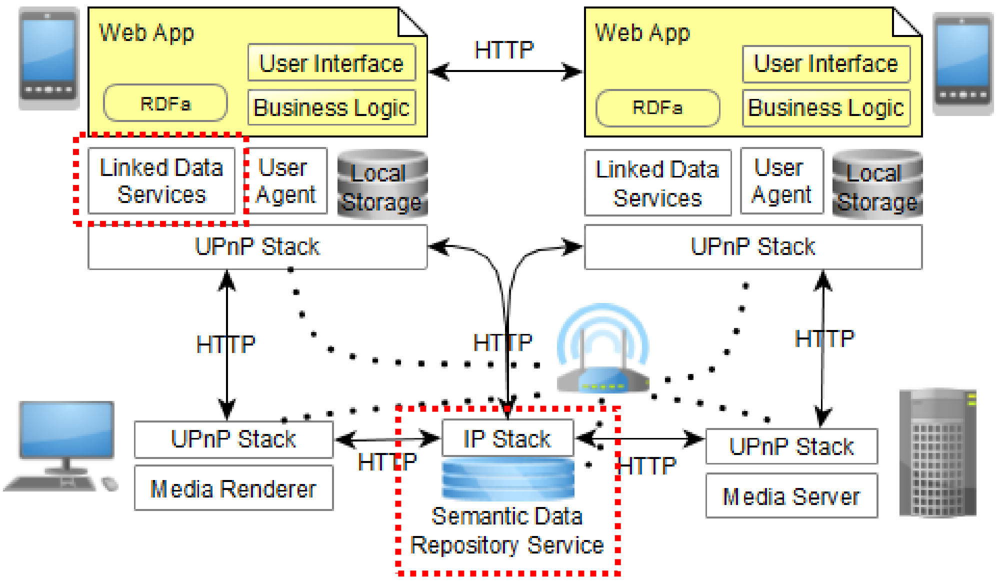


Figure 0.2 Architecture overview.

3.3.2 Semantic Data Repository Service

Since some learning materials, e.g. shared lessons or media objects, must be kept as long as necessary after creations, a repository of learning objects is then required not only for making them available for search and reuse, but also enabling a means for an authoring application to publish its resources. In this regards, Digital Content Repository (DCR) that works on generic metadata specifications (e.g. Dublin Core or MARC) for documenting general contents is more suitable than the counterpart of Learning Object Repository (LOR) [71] that is rather restricted to specific metadata standards (e.g. IEEE LOM) for describing learning contents. Therefore, the DCR will be selected in our proposed architecture so that a wider range of content types (e.g. photograph and AV files) can be accommodated.

3.3.3 Linked Data Service

In many cases, learning resources may be instantly created on-demand, such as snapshots with some contextual contents (e.g. the current geo-location) or sensory data in a timely fashion. It is certain that storing these contents is not so useful at the central repository, but would rather be better at the local for immediate response, e.g. during the collaborative activity. In this regards, Linked Data Service will be required for exposing them in a Linked Data-compliant way. By means of RDF URIs, linked data resources from different sources can be discovered, shared and consumed by the other peer devices. This will be convenient if an authoring application can be involved for enabling semi-automatic composition and automatic generation of Web Mashups [72], which is quite popular for modern Web 2.0 applications.

3.4 Prototype and a Simple Case

This section introduces the general architecture of our prototype and describes a simple case of Mashup application, in order to demonstrate the linked-data usage and integration of learning data from different sources.

3.4.1 Prototype Architecture

A simple implementation for realizing ubiquitous learning services in a P2P manner can be illustrated in Figure 3.3. The ad-hoc network is supported over the Wi-Fi network infrastructure. All computers are turned into UPnP-capable devices by enabling the UPnP support in Windows Platform. It is noticed that the semantic-based repository is not UPnP-compliance, but works in compatibility with UPnP devices via standard TCP/IP protocol. Indeed, this repository is a computer running Apache Tomcat Web server and Fedora Commons [73] open source software (which will be called Fedora hereafter) for providing RDF-enabled repository in our mobile learning environment.

Due to many distinct features, Fedora server allows users of UPnP devices to access the semantic repository for searching, adding, modifying and retrieving digital objects together with their metadata, in many different ways. For instance, by means of SOAP-based or RESTful Web services, developers of Web applications can have automatic association with Fedora in several programming languages. Alternatively, by using Web browser, users can interface manually to administrative module of Fedora, or issue query statements written in SPARQL language and view the results in response accordingly.

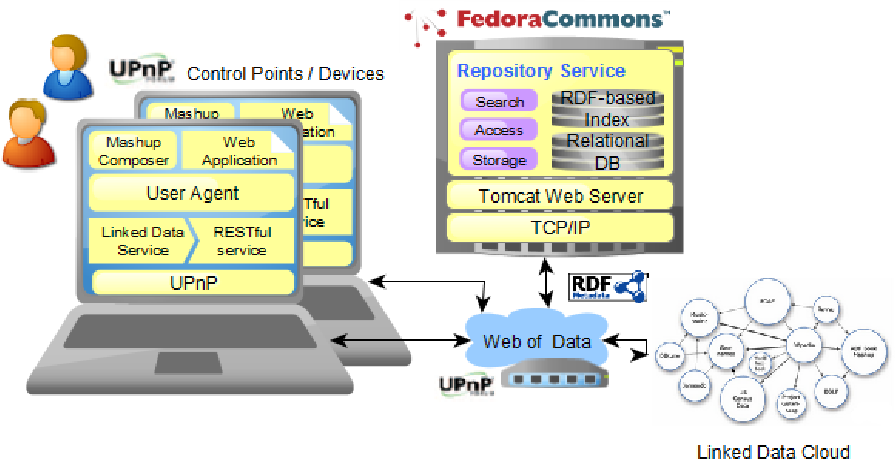


Figure 0.3 Demonstration setup.

3.4.2 Mashup Application

To make the proposed system more comprehensible, we conducted a simple example that illustrates how learning resources (such as assessment quizzes) can be generated by a combined set of RDF data collecting from different Linked Data sources. A simple example as shown in Figure 3.4 has been implemented, which is slightly more complex than the work in [15]. It is a "Song Guess" Application that displays an artwork of song that is currently playing and the user are about to pick up the correct song title from the displayed list. According to our design, each element is generated from a digital object that aggregates a number of contents (known as datastreams in the Fedora context) from multiple sources locating either in the Fedora repository or from the external data sources referenced by URLs as they can be noticed in the left part of Figure 0.4.

In our design, the primary data objects are AR:11, AR:12, and AR:13 and are specified the handle or linkage to actual resources in different manners. For example, the datastream of AR:11 that has the type of "Managed Content (MC)" will store the content (e.g., jpg file of Artwork) in the Fedora repository, but the type of "Inline XML (IL)" will be stored the element of data source as part of XML structure. In contrast, the datastream of AR:12 that has the type of "Redirected Content (RC)" will only delivered the content to the client without any mediation by the Fedora. It should be noticed that the secondary data object (AR:200) is designed particularly to provide the linkages to those primary ones for constituting the structure of RDF data that will be promptly used in the quiz application. In Figure 3.5, these linkages can be easily noticed in the bottom part of the Fedora administration interface.

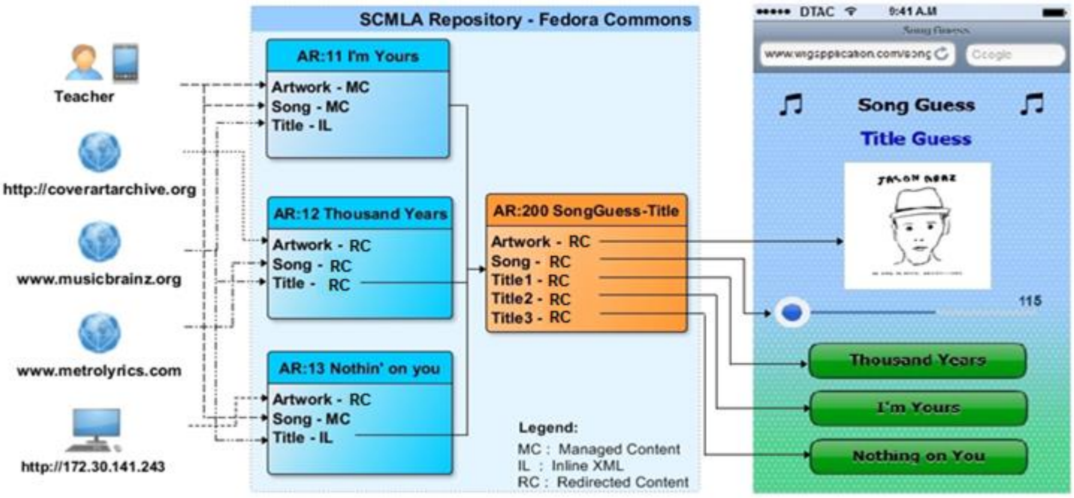


Figure 0.4 Example quiz for guessing the song title.

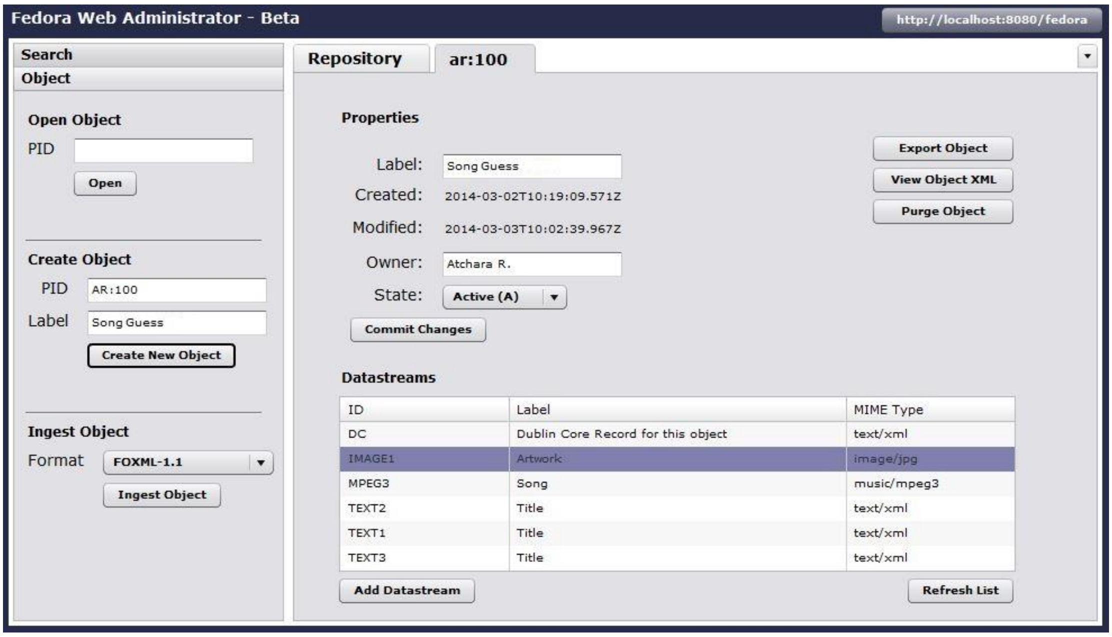
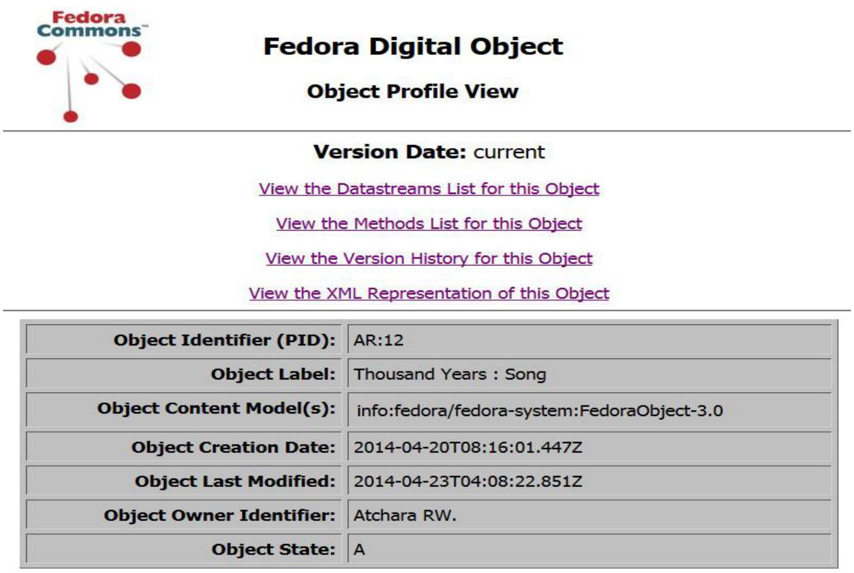


Figure 0.5 Screenshot of the Fedora admin with a digital object example.

Hence, by means of different types of datastreams, the Fedora repository can be mandated to support different ways of manipulation and relationship establishment among content objects to suit our needs. In this regard, it will become easy and flexible for lesson developers to rely on the Fedora repository for storing resulted Linked Data of Mashup composer or some other applications.

3.4.3 Miscellaneous

To summarize, the prototype implementation described in the previous sub-section is a preliminary evaluation for our pilot application, which takes Semantic Web and Linked Data to facilitate for quiz-like question development by taking Linked Data cloud as a source of knowledge. In general, this development process may become a tedious work, since it requires the SPARQL Query Language to access data from several Linked Data resources of interest. However, in our system, this is much easier through the use of administrative Web Interface (e.g. as examples shown in Figure 0.5 to Figure 0.7), which obviously does not need any programming skill for creating, viewing, or managing digital learning objects at all. In addition, by deploying Fedora at the backend of digital repository, user application can be accessed to powerful functionalities either via SOAP Service or REST API using programming language of choice. This is far more complex in traditional system, where SPARQL is needed, and the other software for serving RDF data over HTTP (e.g. Apache's Jena Fuseki[2]) is inevitable.



[2] https://jena.apache.org/documentation/fuseki2/

Figure 0.6 Screenshot of Fedora admin for viewing a digital object profile.


```xml
- <foxml:digitalObject VERSION="1.1" PID="AR:12" xsi:schemaLocation="info:fedora/fedora-system:def/foxml# http://www.fedora.info/definitions/1/0/foxml1-1.xsd">
  + <foxml:objectProperties></foxml:objectProperties>
  + <foxml:datastream ID="AUDIT" STATE="A" CONTROL_GROUP="X" VERSIONABLE="false"></foxml:datastream>
  + <foxml:datastream ID="DC" STATE="A" CONTROL_GROUP="X" VERSIONABLE="true"></foxml:datastream>
  - <foxml:datastream ID="Artwork" STATE="A" CONTROL_GROUP="R" VERSIONABLE="true">
    - <foxml:datastreamVersion ID="Artwork.0" LABEL="Christina Perri" CREATED="2014-04-23T03:01:35.799Z" MIMETYPE="image/jpg">
        <foxml:contentLocation TYPE="URL" REF="http://coverartarchive.org/release-group/74346120-d933-489a-abb1-140e1f8f801e/front.jpg"/>
      </foxml:datastreamVersion>
    </foxml:datastream>
  - <foxml:datastream ID="Song" STATE="A" CONTROL_GROUP="R" VERSIONABLE="true">
    - <foxml:datastreamVersion ID="Song.0" LABEL="A Thousand Years" CREATED="2014-04-23T03:19:17.800Z" MIMETYPE="music/mp3">
        <foxml:contentLocation TYPE="URL" REF="http://www.metrolyrics.com/a-thousand-years-lyrics-christina-perri.html"/>
      </foxml:datastreamVersion>
    </foxml:datastream>
  - <foxml:datastream ID="Title" STATE="A" CONTROL_GROUP="R" VERSIONABLE="true">
    - <foxml:datastreamVersion ID="Title.0" LABEL="A Thousand Years" CREATED="2014-04-23T04:08:22.851Z" MIMETYPE="text/xml">
        <foxml:contentLocation TYPE="URL" REF="http://musicbrainz.org/ws/2/release-group/74346120-d933-489a-abb1-140e1f8f801e?inc=artist-credits releases"/>
      </foxml:datastreamVersion>
    </foxml:datastream>
  </foxml:digitalObject>
```


Figure 0.7 Screenshot of Fedora admin with a XML list of digital object.

3.5 Related Work

There exist some similar efforts within the research field of our research. For example, the work [74] developed a prototype of *SWmLOR* system, which attempted to provide a better facilitation of mobile learning resources by accompanying standard learning objects with ontology-based semantic contents. Although their architectural framework provides the same functionalities as that of our works, it contains three major drawbacks; a) facilitating the poor support for collaborative learning community between mobile devices in the local network, due to the intrinsic limitation of client-server based learning environment, b) overlooking the use of Linked Data approach for exposing learning resources and allowing them to be reused or shared in the simplified manner at mobile devices, and c) ignoring the exploitation of open source software for digital repository tool (i.e. Fedora in our case), which can immensely simplified the programming tasks. Li, Chen and Huang [75] takes the advantages of Fedora open source software as well for building a prototype of learning resource management and sharing system (called *SULOMS*) with adaptive capabilities, which is claimed to be suitable for mobile learning. Our work takes a broader view of sharing semantic learning objects via the Web of Linked Data.

To provide a better support for collaborative learning environment, several works attempts to bring P2P technology into consideration. For example, Jin *et al.* [76] described a peer-to-peer based learning environment over the Internet, named *APPLE*, which has a combination of P2P overlay network, Internet broadcast system, and grid technology, and reported satisfactory results in educational experiments with general computers. Compared to this research work, our system is much simpler and does not require any burden of P2P routing algorithms, due to the dominant feature of UPnP protocol stack and service-oriented architecture involved. Yen *et al.* [77] described their developed system called *iServe* that is Linked Data-driven and works on service-oriented architecture and claimed its efficiency in resolving the problem of interoperability issues due to various metadata standards of learning objects in a distributed and heterogeneous environment. Unlike our system, the *iServe* system lacks the support for P2P operations in the scope of this work. The summarized view of the aforementioned comparison of related systems can be seen in Table 3.1.

Table 0.1 Summarized comparison of related works.

System	P2P Support	Linked Data Approach	SOA Principle	Fedora Engine
SWmLOR[74]	No	No	No	No
SULOMS [75]	No	Yes	No	Yes
APPLE [76]	Yes	No	No	No
iServe [77]	No	Yes	Yes	No
Our work	Yes	Yes	Yes	Yes

3.6 Summary

This thesis introduced UPnP technology in the ubiquitous learning area and suggested the lightweight semantic web of Linked Data approach to publish learning data on the Web so that other peer devices can access and interpret the data using merely standard Web technologies. Comparing with traditional mobile and ubiquitous learning, our system has advantages as follows: 1) It can discover any networked UPnP devices automatically and provides the instant support of peer-to-peer networking; 2) It enables the web-driven technology and thus allows for the Linked Data to be utilized across the network domain via the Internet if the security policy can be met; 3) It does not need any tedious operations for accessing the elements of shared data, which is inevitable in many cases of metadata standards for learning object interoperability. In addition, we show the Linked-Data usage and integration of learning data from different sources through a simple quiz example, which can be potentially led towards more realistic or advanced explorations, which is currently an ongoing work.

Chapter 4
USER-DRIVEN MULTIMEDIA ADAPTATION FRAMEWORK FOR CONTEXT-AWARE LEARNING CONTENT SERVICE

In this thesis, we present a user-driven resource management framework for delivering adaptive multimedia contents in a cooperative manner. In Section 4.2, 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 4.3, we present our proposed framework for enabling adaptive multimedia services via a broker and a repository server in detail. In Section 4.3.4, we present the validation of the proposed framework by means of numerical analysis. Finally, in Section 4.4, we summarize the chapter.

4.1 Motivation

Context-aware mobile learning [78] 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 [79], [80]) 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 [17] 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 [81]). 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 chapter, we present the AHP method [60] 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.

4.2 Background and Related Work

4.2.1 Quality of Multimedia Contents

Learning service can offer multimedia streaming, such as during the session of game-based learning [82] or in a mobile social learning community [83], to its active users. Obviously, a certain level of multimedia quality becomes a great expectation of users so that the media streams can be smoothly rendered on their devices, regardless of any changes occurred in the network. Then, many spatial or temporal adaptation techniques [80] 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*) [25] 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 [25]), the combined consideration of them may be needed in some complex scenario (such as [84]) and a trade-off of them is inevitable.

4.2.2 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 [60] 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 [85] 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 [84] 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 thesis, 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. The other work in [86] also takes into account users' perception, but with the aim to switch the other access point of wireless LAN so that quality-of-service of multimedia communication can be maintained.

4.2.3 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 [80] 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 [79]) 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 [81] will have to take a full load of responsibility, since no significant task is assigned at the users' devices.

4.3 User-driven Multimedia Adaptation

4.3.1 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.

Figure 4.1 illustrates the UDAD architecture.

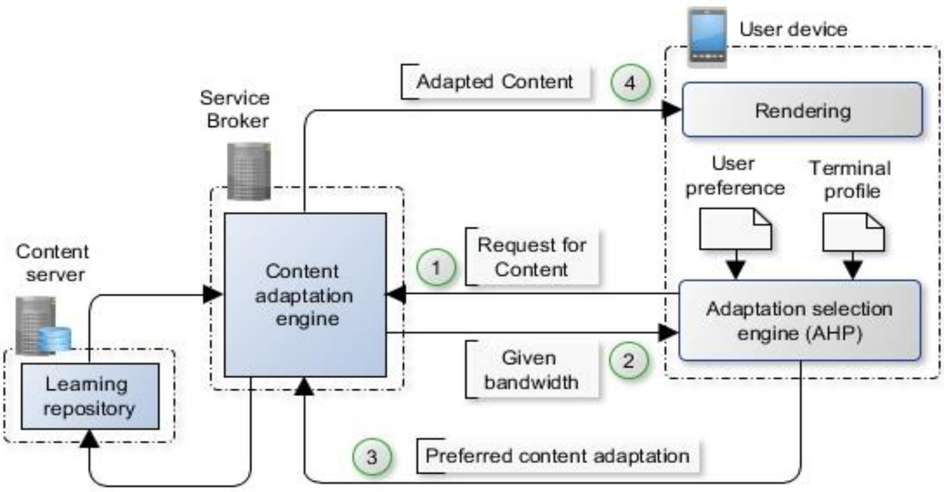


Figure 4.1 Proposed framework architecture.

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.

4.3.2 Adaptation Selection Engine at the User's Device

To maximize user preferences in an intuitive manner, we use the AHP, which is popular MCDM tool. We formulate the selection of multimedia adaptation at the user's device as a MCDM problem. Based on the AHP, the steps [87] are summarized below:

- Modeling the problem into a hierarchical structure constituting goal, criteria and alternatives. As shown in Figure 4.2, 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. Depending on the user preferences, data from the decision maker can be arbitrarily set on each criterion.
    - For instance, if the user gives the preference on the perceived quality more than the other issues of power consumption and payment, the value of "Perceived Quality" will be then assigned with the relatively highest value as seen in the Figure 4.2. As a consequence, the video frame-rate and video resolution will be assigned with the values to reflect their importance on yielding clear and smooth running scenes.
- Each set of comparisons will be entered into a matrix, creating the comparison matrix for criteria and for alternatives with respect to each criterion.

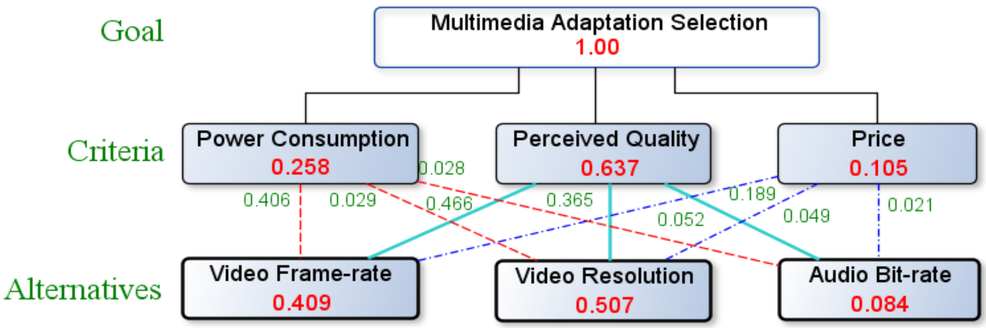


Figure 4.2 Adaptation selection hierarchy.

With all pairwise comparison tables, the final weights for three alternatives can be obtained as shown in Table 4.1. We can use these weights to find the adaptation factors that maximize the network bandwidth allocated to user. 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 [87], which is used to compute the performance index is not included in this thesis.

Table 4.1 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 weighted sum ratio as calculated by Equation (2.3 and 2.4) of Chapter 2. This ratio will be used to support the best selection among possible choices (called performance index) in such a way that the explicit values of the desired multimedia attributes (i.e. video frame-rate, video resolution and audio bit-rate) can be known and managed to send later to the service broker.

Refer to the mandated of cost ratio (Equation (2.3) of Chapter 2), in this chapter we define as:

x is the requested BW of alternative,

w_i is the weight of alternative i , and

c_i is the cost of alternative i that is the total cost (r) of bandwidth utilization (for each alternative) can be calculated.

Due to, the different units of resource cost (c), some conversions are needed to make the final value of bandwidth utilization in Mbps as in Figure 4.3.

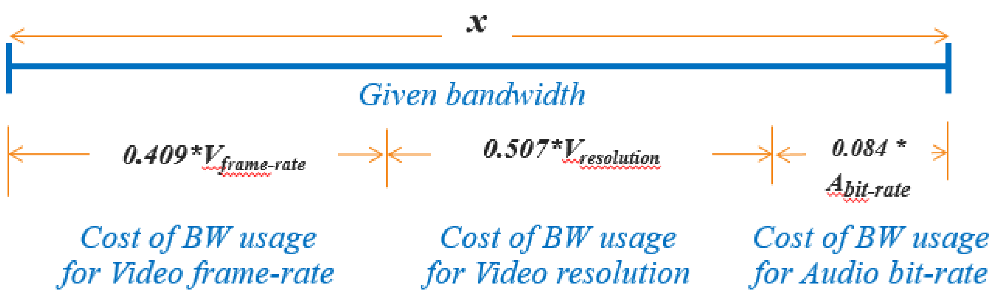


Figure 4.3 Cost-Benefit Ratio Procedures.

The bandwidth for weighted of video frame-rate and video resolution is multiply with bit per pixel (0.125) and divide by data transfer rate (i.e. bit per second to megabit per second (1^{e-6})). And the Mbps for weighted audio bit-rate can be calculated by data transfer rate (i.e. kilobit per second to megabit per second (0.001). This total cost for alternatives r from first evaluation will be calculated further to obtain the final scores called "Performance Index (p_i)" by using the following calculation;

Refer to the mandated of weight sum ratio Equation (2.4) of Chapter 2), in this chapter we define as:

where c is performance index (p_i) of multimedia attribute,

r is required bandwidth of alternative, and

m is user's maximal availability of bandwidth.

When the p_i has a value of 1.00, the server-given bandwidth and user-required bandwidth are in equal.

4.3.3 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 thesis.

4.3.4 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.

4.3.5 Scenario Description

Case I: "Best fit at different bandwidth"

We assume there are 4 users concurrently connecting to a service broker for multimedia content connections at different speeds of 5, 10, 16 and 30 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. The results are as shown in Table4.2.

Table 4.2 Best fit at different bandwidth.

Available BW (Mbps)	Video Frame-rate (fps)	Video resolution (pixels)		Audio bit-rate (kbps)	Performance Index
		Width	Height		
5	30	1600	900	32	1.00
10	60	1600	900	32	1.00
16	60	1920	1080	128	1.00
30	30	3840	2160	32	1.00

Case II: "Same bandwidth with different user-preference"

There are 2 users with different user-preference, best fit and fixed resolution (e.g. 1920x1080 pixel) respectively, at the same bandwidth speeds of 10 Mbps. The results are as shown in Table 4.3 and Table 4.4 below:

They can be noticed that the highlight lines in the Tables are best selection data in each test case by using the equations described in Section 4.3.3. The value of performance index is 1 in the case of best fit (i.e. Table 4.2 and closest to 1 when users request their own attribute value as same as Discussion.

Table 4.3 Best fit resolution for 10 Mbps bandwidth.

Available BW (Mbps)	Video Frame-rate (fps)	Video resolution (pixels)		Audio bit-rate (kbps)	Performance Index
		Width	Height		
10	30	1280	720	32	0.321
10	30	1600	900	32	0.501
10	30	1920	1080	32	0.720
10	30	2048	2160	32	0.819
10	60	1280	720	32	0.640
10	60	1600	900	32	1.000
10	60	1920	1080	32	1.439
10	60	2048	2160	32	1.638

Table 4.4 Given resolution (1920x1080pixel) for 10 Mbps bandwidth.

Available BW (Mbps)	Video Frame-rate (fps)	Video resolution (pixels)		Audio bit-rate (kbps)	Performance Index
		Width	Height		
10	30	1920	1080	32	0.720
10	30	1920	1080	64	0.722
10	30	1920	1080	128	0.724
10	60	1920	1080	32	1.439
10	60	1920	1080	64	1.441
10	60	1920	1080	128	1.443

The findings for this scenario description can also be explained from the perspective of numerical analysis with evaluation function of cost-benefit ratio. These show how the user preferences can be effectively applied in different cases of bandwidth availability. The correctness of these choices has been confirmed by our experiments on the real video feeds in the actual network environment.

4.4 Summary

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.

CHAPTER 5
AHP-BASED ADAPTIVE RESOURCE SELECTION FOR COGNITIVE PLATFORM IN CLOUD GAMING SERVICE

In this chapter, we consider a cognitive platform, which is capable of modifying its multimedia quality requirement in response to the network constraint, and notifying the cloud gaming server for updating the corresponded workload. In this regard, we propose an Analytic Hierarchy Process (AHP) method deploying at the cognitive platform for cloud gaming service to select an optimal resource allocation strategy that is capable of satisfying various multimedia requirements and energy-awareness. Section 5.1 gives motivation of this work, following with the reviews of the related work in Section 5.2. Section 5.2.3 presents the detailed framework of user-driven cloud gaming resource utilization. Section 5.3 gives the experimental results on performance evaluation. Finally, Section 5.4 summarizes the chapter.

5.1 Motivation

Cloud gaming [12] is a kind of cloud service that allows the low-performance computers or mobile devices to run highly sophisticated games. However, due to the intrinsic limitation of rendering the game remotely in the cloud and streaming the scenes as video frames back to the player over the Internet, the cloud gaming service relies intensely on the adequate network availability [88] in order to deliver acceptable user experience in gaming. The issue of multimedia content adaptation is then a prime consideration for achieving two ultimate goals: a) The utmost gaming resource utilization at the server-side and b) The highest satisfaction level at the player-side. Nonetheless, it is not easy to achieve such requirements by simply relying on a server-centric mechanism and naive gaming devices [89], since the server merely attempts by default to deliver real-time media streaming to a player device at the highest possible quality, in accordance with the notified physical device resolution.

To enrich the default operations in typical cloud gaming, it is required that somewhat of cognition must be existed at the player's device so that the rational tuning of performance parameters at run-time can be enabled. For instance, it can be then possible to make a trade-off between the higher video resolution and the lower bit rate of video transmission, in order to preserve the overall bandwidth usage and the player's satisfaction simultaneously. To date, the realization of this requirement is still an active research in the field of cognitive cloud gaming, where reasoning engine plays a crucial role of evaluating the game player's environment and deciding on the proper demand of adaptive multimedia contents according to the evaluations and the player's preferences.

In this thesis, we model the local decision making engine at the cognitive device for deriving the user demand in adaptive video playback quality as a multiple-attribute decision-making (MADM) problem under an uncertain environment. We then propose an Analytic Hierarchy Process (AHP) algorithm for dealing with this problem, since it can handle both qualitative and quantitative criteria related to audio/video multimedia resources and the battery-energy level simultaneously. Our key contribution is on the application of AHP method for finding the optimal content determination at cognitive gaming platform that can potentially meet the balance of maximizing its own player's gaming experience and reducing the server workload for involved gaming session altogether.

5.2 Related Work

5.2.1 Cognitive Resource Allocation in Cloud Gaming

In cloud gaming environment, the local cognitive agent at the gaming device are demanded for altering a passive gaming device into the active one so that the better support of cloud gaming resource provision at the cloud gaming server can be expected. To address this demand, many research studies have proposed solutions contributed to the domain.

For instance, the work [89] focused on a data-collecting solution on the cognitive gaming platform, where the proposed environment perception procedure enables the local cognitive agent to learn the player's environment in real time and push this information to the server so that the respective gaming service adaptation can be derived in a relaxed manner. Indeed, this useful procedure can be well supported for the case of sophisticated cognitive platform as shown in the other [90], where elaborated features, e.g. the migration and partitioning of game components, as well as partial offline execution, can be offered.

In addition, the work [91] also concentrated on cognitive cloud gaming environment and proposed a rather complicated framework, where seven types of agents may be needed for executing and delivering adaptive game contents to the players. The work [92] concerned on a simpler solution for improving the server's workload in realistic cloud gaming environment. To fulfill the goal, an extra demand of player's display resolution is required for complementing their hybrid version of trans-coding or trans-rendering processes at the gaming server.

While the aforementioned studies can reduce the workload of gaming video rendering at the server-side on the expense of incurred burden at the players' devices, their mechanisms are much in common on the purely technical consideration. Hence, no means of user involvement are provided for governing preferential resource determination. As a result, their technical-oriented solutions becomes complex inevitably for maintaining the adequate service-quality and may not yield the results that conform to the player's expectation. In contrast, by taking into account the user's requirements and contexts, our proposed algorithm can potentially match to what user needs, since both of the technical parameters and user-concerns are considered altogether.

5.2.2 AHP Method for Resolving Network-related Problems

Unlike our work, the AHP-based decision-making method will be served for a mutual benefit of user and server in the distinctive area of cloud gaming service. It is in the sense that the AHP-based method will assist the game player to select the best content resolution that is satisfy not only their own preference, but also the current network condition. At the same time, the less workload at the game server can be feasible due to the sensible demand of user's content resolution. In addition, our work relies heavily on the combined AHP-mathematical programming approach [87], rather than the standalone AHP, since the relative important weights of alternatives in the AHP process must be calculated further to yield a value of content resolution as a final decision.

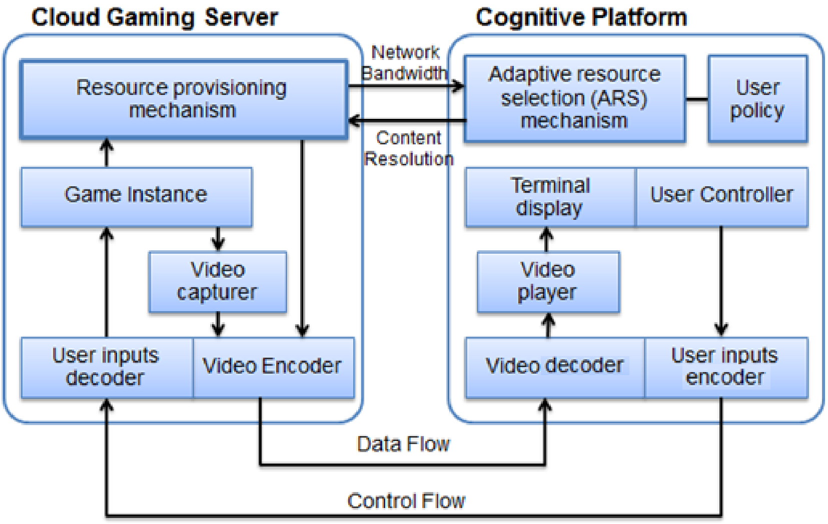


Figure 0.1 Cognitive resource allocation architecture

5.2.3 Optimal Selection of Content Resolution

The methodology given in this section is indeed an optimal resource utilization mechanism that empowers a cognitive platform to make a decision on the optimal content resolution of adaptive multimedia that can maximize gaming experience (regarding the user's policy) under a given network constraint (according to the server's notification) as illustrated in Figure 0.1. We model this mechanism as a MADM problem and manage to solve it through the AHP method so that the weighted values of context-aware parameters (i.e. network bandwidth, screen resolution and power consumption) can be obtained, and used later in an optimal resource allocation problem.

Although many performance metrics (as shown in Table 5.1) can be considered in adaptive cloud gaming contents [91], some of them [17] will be particularly interested depending on various viewpoints (i.e. application (game), network, or device). Nonetheless, these metrics will need to be managed in such a way that they can be processed by the AHP method of which basic procedure are described in the following subsections.

Table 0.1 Performance metrics under consideration.

Viewpoint	Performance Metric	Symbol	Unit
Application (Game)	Video resolution	-	pixels
	Video frame-rate	-	fps
	Audio bit-rate	-	kbps
Network	Network bandwidth	BW	Mbps
Device	Screen resolution	SR	pixels
	Power consumption	PW	mWh

5.2.4 Modeling a hierarchical analysis structure

When using AHP, it is demanded to define a hierarchical structuring model of the decision-making problem, where the objective, criteria, and alternatives are structured into a hierarchy. As seen in Figure 0.2, the proposed model is a three-level hierarchy and can be described as follows: the top-level is the goal of the decision-making problem (i.e. optimal content determination), the mid-level consists of various evaluation criteria (i.e. video frame-rate, video resolution and audio bit-rate), the bottom-level consists of alternatives (i.e. network bandwidth, screen resolution, and power consumption).

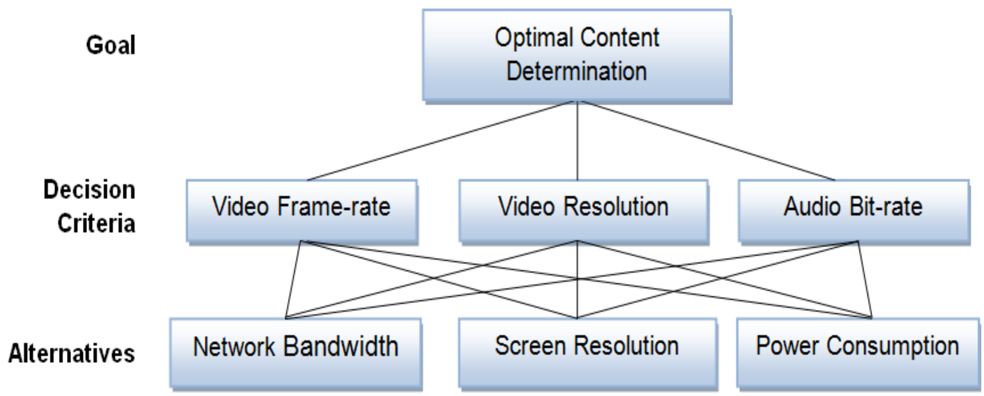


Figure 0.2 Hierarchical structure of the model.

5.2.5 Assigning the weights

AHP allows us to calculate the relative weight of decision criteria and alternatives in an intuitive manner. The basic steps are as follows:

a) Making pairwise comparison

In this step, the relative importance of involved performance metrics is judged by a pairwise comparison. Rating the relative priority of each metric [61] is done by assigning a value according to Table 0.2. For example, the value of 1 means equally preferred and 9 means extremely preferred.

Table 0.2 AHP Rating scale of judgment.

Value	Verbal judgment between pair-wised values
1	Equally preferred
3	Moderately preferred
5	Strongly preferred
7	Very Strongly preferred
9	Extremely preferred
2, 4, 6, 8	Between the judgment above

In Table 5.3, we show the reciprocal matrix obtaining from the data given by the expert using evidences reported in literature in [93] and [94] as summarized below:

a) As the rates of demanded network bandwidth at different resolutions is higher than those rates of power consumptions, the "Network bandwidth (BW)" is then assigned with the value (of importance) higher than that of "Power consumption (PW)".
b) Since the network bandwidth is essential on supporting the adaptation process of any required screen resolution, especially during the congestion periods, the assigned value of "Network bandwidth (BW)" is then higher than that of "Screen resolution (SR)".
c) As the network bandwidth has influence on all decision criteria, our case is however preferred the smooth running of video streams. The assigned value of "Video frame-rate" is then relatively higher than those of the rest criteria.

Table 0.3 Matrixes for the 3 alternatives from each criteria.

	Video Frame-Rate			Video Resolution			Audio Bit-Rate		
	BW	***SR***	***PW***	***BW***	***SR***	***PW***	***BW***	***SR***	***PW***
BW	1	3	9	1	3	5	1	3	5
SR	1/3	1	5	1/3	1	3	1/3	1	3
PW	1/9	1/5	1	1/5	1/3	1	1/5	1/3	1

Legend: BW: Bandwidth SR: Screen Resolution PW: Power Consumption

Table 0.4 Weights of decision criteria.

Decision Criteria	Weights	Consistency Ratio (CR)
Video Frame-rate	0.637	0.037
Video Resolution	0.258	
Audio Bit-rate	0.104	

b) Computing priority vector for decision criteria

Having a reciprocal matrix, we then want to compute the priority vectors, which are the normalized Eigen vectors of the matrix. Here, we calculate them by using the technique of normalized relative weight and the results are shown in Table 0.4.

c) Checking for consistency

Since the data in a reciprocal matrix may not be consistent. This is due to the imposition of 1 to 9 rating scale of judgment as performed in Step 1. The AHP will check consistency of data in evaluation through a ratio called Consistency Ratio (CR):

$$\mathrm{CR} = \frac{CI}{RI}; \qquad \mathrm{RI} = 0.58 \tag{5.1}$$

where RI is a random consistency index and the typical values are given in Table 0.5, and n refers to the number of parameters. Since $n = 3$ in this case, RI is then set to 0.58; CI is consistency index, and is defined as

$$CI = \frac{(\lambda max - n)}{(n-1)} \tag{5.2}$$

where λ_{max} is the maximum eigenvalue of the judgment matrix, which is set to 3.0383 in this case.

Table 0.5 Random consistency index.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 0.6 Weights of alternatives under each decision criteria.

Decision Criteria	Alternatives			Consistency Ratio (*CR*)
	BW	**SR**	**PW**	
Video Frame-Rate	0.671	0.265	0.063	0.027
Video Resolution	0.637	0.258	0.104	0.037
Audio Bit-Rate	0.659	0.156	0.185	0.028

Legend: BW: Bandwidth SR: Screen Resolution PW: Power Consumption

If the value of CR is smaller or equal to 0.1, then the inconsistency is acceptable. In our case, Table 0.6 shows how the priority vectors and the consistency ratio of the judgment matrix are generated. It should be noticed that the CR in each decision criteria is less than 0.1, so the judgment matrix is consistent.

d) Computing priority vector for alternatives :

Similar to the process in Step 2 of comparing the decision criteria, all pairs of alternatives are now compared using the AHP rating value. Similar to Step 3, a judgment matrix is determined, and priority weights are calculated for each of the alternative. The results are given in Table 5.7.

Table 0.7 Weights of each alternative.

Alternatives	**Weights** (*w*)	**Consistency Ratio** (*CR*)	**Ranking**
Network Bandwidth	0.661		1
Screen Resolution	0.252	0.033	2
Power Consumption	0.086		3

Finally, the summary of all the weights in the hierarchy can be illustrated in Figure 0.3. It can be noticed that the optimal ratio of factors influencing on the adaptive contents will be largely contributed to the concern of network bandwidth, following with the device resolution and power consumption accordingly.

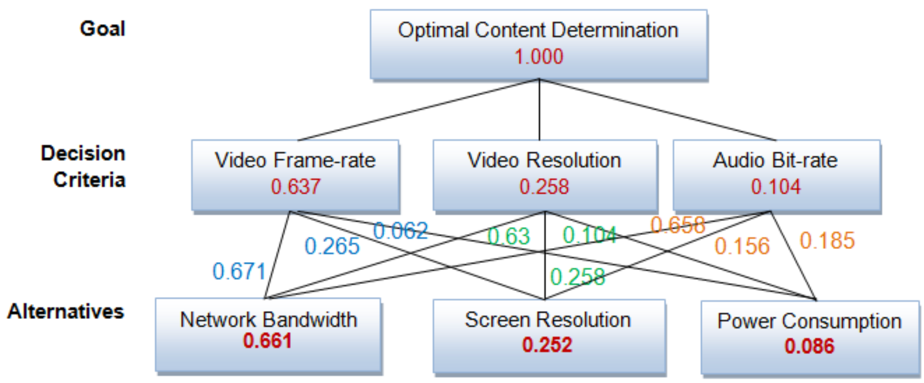


Figure 0.3 Weighted values of cognitive resource allocation model.

e) Formulating resource allocation problem

Based on the AHP weighted values obtained in the previous step, we can use them to calculate the value of required content resolution that satisfies our requirement. However, the possible values will be preferably specified in discrete values following the list of common graphics display resolution[3], as shown in Table 0.8. In the other word, we classify the output video resolution into 5 levels, ranging from the ultra-low to the very high video resolutions. The direct advantage is on the ease of manipulation by the proposed mechanism, since the effective bandwidth utilized for content adaptation is rather in a stepwise fashion. The indirect advantage

3 https://wikipedia.org/wiki/Graphics_display_resolution

is on the ease of User Interface (UI) implementation, since only a set of limited choices will be displayed for allowing users to have a fast selection.

To compute the value of optimal video resolution, which is the product of AHP weighted values (i.e. benefits) of the bottom-level (alternatives) and the incurred cost of them, using the method are shown in (2.3) and (2.4) in Chapter2.

- Refer to (2.3), here x is the required content resolution, w_i is the weight of alternative i (Table 5.7), n is the number of alternatives and c_i is the cost of alternative i.
- Refer to (2.4), here r_j is the required resource, m_j is the maximal availability of that resource, and j is the number of level ranging from 1 to 5 as given in Table 0.8.

Table 0.8 Five levels of available content resolutions.

Level	Video resolution	Pixels
Ultra Low (**UL**)	640 x 480	307,200
Low (**L**)	1280 x 720	921,600
Medium (**M**)	1600 x 900	1,440,000
High (**H**)	1920 x 1080	2,073,600
Very High (**VH**)	2048 x 1152	2,359,296

In what follow, we propose how to calculate the cost of each alternative:

1) Network bandwidth: The cost is an inverted ratio of the network's current capability to fulfill the user's requirements and hence includes both the user's required bandwidth (r_j), as well as the network's available bandwidth (m_j). In order to obtain the r_j, we conduct a simple experiment to observe the bandwidth consumed by j multimedia streams with different resolutions given in Table 0.8. We then summarize the cost incurred by the deliveries of different adaptive streams in a variety of network technologies[4], i.e. 2G-Edge (16 Mbps), 3G (16 Mbps), 3G (42 Mbps), 4G (42 Mbps), and 4G-LTE (100 Mbps) as shown in Table 5.9.

[4] https://wikipedia.org/wiki/Comparison_of_mobile_phone_standards

Table 0.9 Costs of bandwidth for delivering target content resolutions**.**

r (Mbps)	Costs on different network types				
	m (1.6 Mbps)	m (14.4 Mbps)	m (21.0 Mbps)	m (42.0Mbps)	m (100 Mbps)
7.92	4.95	0.55	0.38	0.19	0.08
12.64	7.90	0.88	0.60	0.30	0.13
18.32	11.45	1.27	0.87	0.44	0.18
27.92	17.45	1.94	1.33	0.66	0.28
42.56	26.60	2.96	2.03	1.01	0.43

Experiment: H.264 encoded and 60-fps video streaming, 3.5 GHz 6-core server and Gigabit network

2) **Screen resolution**: The cost is the ratio of the desired content resolution (r_j) and the screen resolution (m_j). Here, the costs incurred by the deliveries of adaptive streams at different resolutions can be summarized in Table 0.10.

Table 0.10 Costs of screen resolutions for delivering target content resolutions.

r (pixels)	Costs on different screen resolutions				
	m (307,200 pixels)	m (921,600 pixels)	m (1,440,000 pixels)	m (2,073,600 pixels)	m (2,359,296 pixels)
307,200	1.00	0.33	0.21	0.15	0.13
921,600	3.00	1.00	0.64	0.44	0.39
1,440,000	4.69	1.56	1.00	0.69	0.61
2,073,600	6.75	2.25	1.44	1.00	0.88
2,359,296	7.68	2.56	1.64	1.14	1.00

3) Power consumption: The cost is a ratio of the power consumption needed to transmit the desired content resolution and the battery-power life. Here, we assume the energy measurement setup and experimental results as given in [94] to support our pilot study so that the relationship of the power consumption for different resolutions can be feasibly derived. In this regard, the power consumption (rj) in each j level according to the given values in Table 0.8 can be computed. However, we consider dividing the total capacity of battery (with the 20% safety factor) into 5 levels. Therefore, in a case of the battery with 1650 mAh and 3.7 volt specification, the maximum power consumption (mj) of the battery in each j level can be computed and summarized in Table 5.11.

Table 0.11 Costs of power consumptions for delivering target content resolutions

r (mWh)	Cost on different power consumptions				
	m (976.80 mWh)	m (1953.60 mWh)	m (2930.00 mWh)	m (3907.00 mWh)	m (4884.00 mWh)
876.00	4.95	0.55	0.38	0.19	0.08
912.87	7.90	0.88	0.60	0.30	0.13
943.97	11.45	1.27	0.87	0.44	0.18
981.99	17.45	1.94	1.33	0.66	0.28
999.13	26.60	2.96	2.03	1.01	0.43

5.3 Experimental Evaluation

In order to evaluate the efficacy of the proposed method, we consider an example of its application in a simple network scenario. We assume there are a number of clients concurrently connecting to a server for cloud gaming service consumption. Our evaluation is on the conformance of the user's expectation and the actual allocation occurred in different cases of network bandwidth and power resource availability.

5.3.1 Plentiful resource environment

It is a situation where the network is under-utilized and the player's battery-power level is high. In this case, the player will tend to receive whatever content resolution it desires. As shown in Table 5.12, the player who demands a "very high (VH)" screen resolution will be granted with the "very-high (VH)" content resolution (i.e. the highlighted line) as desired.

Table 0.12 Summary of case in over-utilized network**.**

BW=H, SR=VH, PW=VH	Alternatives (W_iC_i)			Total score (x)
	BW	SR	PW	
UL	0.125	0.033	0.015	0.173
L	0.199	0.098	0.016	0.313
M	0.288	0.154	0.017	0.459
H	0.439	0.221	0.017	0.678
VH	0.670	0.252	0.018	0.939

Legend: BW: Bandwidth SR: Screen Resolution PW: Power Consumption

5.3.2 Scarce resource environment

In a contrast situation, the network is over-utilized and the role of content adaptation becomes crucial. The player, however, may be assigned with the much lower level of content resolution than the desired one, unless the availability of network bandwidth are adequate. Based on the data given in Table 5.13, the user in case 1, who demands the “very high (VH)” screen resolution, will get merely the “Low (L)” content resolution, due to the low availability of both network bandwidth and battery power. Since the BW alternative has a much higher weight than the other alternatives (referring to Table 5.7), the influence of PW alternative is rather limited in all cases. It is obvious in the case 2 and 3, where the influence of BW is dominant. The best selection of suitable content resolution can be issued, according to the best-maximum value below the value 1 (i.e. the upper boundary of feasible case) of the total score in all cases as shown in Table 0.14 to Table 0.16.

In order to illustrate the clear advantages of our proposed method over the method found in traditional remote-rendering cloud gaming, we have performed experiments (in a network scenario as described in [92]), to investigate the performance in terms of utilization cost and saving cost of both cases.

Table 0.13 Summary of cases in under-utilized network.

	Availability			Result (x)
	BW	SR	PW	
Case 1 (Table 0.14)	L	VH	L	L
Case 2 (Table 0.15)	L	H	VH	L
Case 3 (Table 0.16)	H	VH	UL	H

Legend: BW: Bandwidth SR: Screen Resolution PW: Power Consumption

Table 0.14 Case 1

BW=L, SR=VH, PW=L	**Alternatives** ***(W_iC_i)***			**Total score (x)**
	BW	**SR**	**PW**	
UL	0.36	0.03	0.04	0.43
L	0.58	0.10	0.04	0.72
M	0.84	0.15	0.04	1.04
H	1.28	0.22	0.04	1.55
VH	1.95	0.25	0.04	2.25

Legend: BW: Bandwidth SR: Screen Resolution PW: Power Consumption

Table 0.15 Case 2

BW=L, SR=H, PW=VH	**Alternatives** ***(W_iC_i)***			**Total score (x)**
	BW	**SR**	**PW**	
UL	0.364	0.125	0.015	0.504
L	0.580	0.199	0.016	0.795
M	0.841	0.288	0.017	1.146
H	1.282	0.439	0.017	1.738
VH	1.954	0.670	0.018	2.641

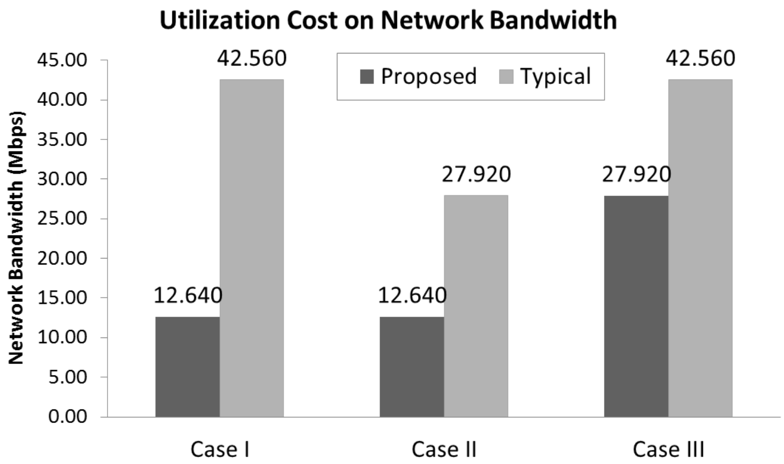
Legend: BW :Bandwidth SR :Screen Resolution PW :Power Consumption

Table 0.16 Case 3

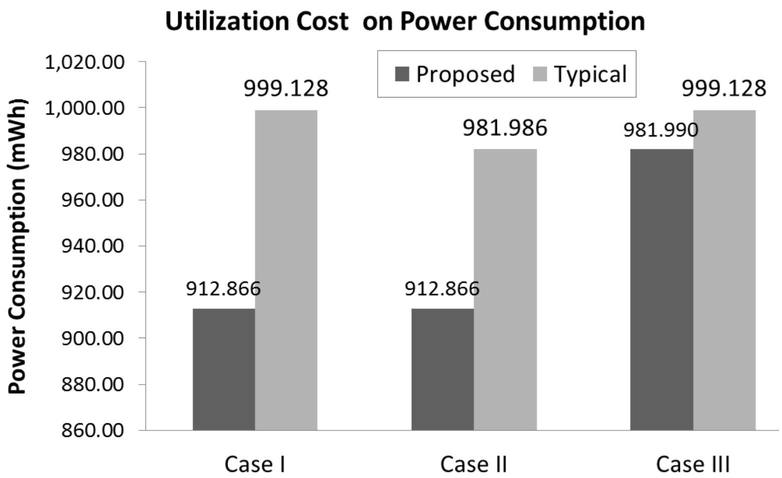
BW=H, SR=VH, PW=UL	**Alternatives** ***(W_iC_i)***			**Total score (x)**
	BW	**SR**	**PW**	
UL	0.125	0.033	0.077	0.235
L	0.199	0.098	0.080	0.378
M	0.288	0.154	0.083	0.525
H	0.439	0.221	0.086	0.747
VH	0.670	0.252	0.088	1.010

Legend: BW: Bandwidth SR: Screen Resolution PW: Power Consumption

As shown in Figure 0.4, the lower utilization cost can be attained in our case, due to the less, but sufficient, demanding of network bandwidth, and hence less power consumption, at the gaming device. As a consequence, by subtracting the values compared in both cases, the saving cost for network bandwidth utilization and power consumption can be illustrated in Figure 0.5.

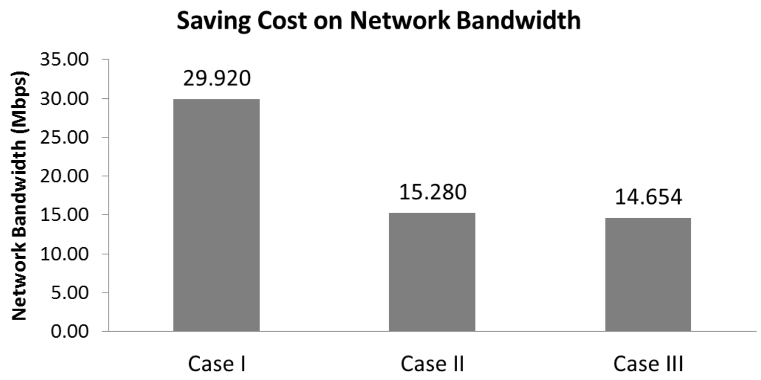


(a) Bandwidth (BW)

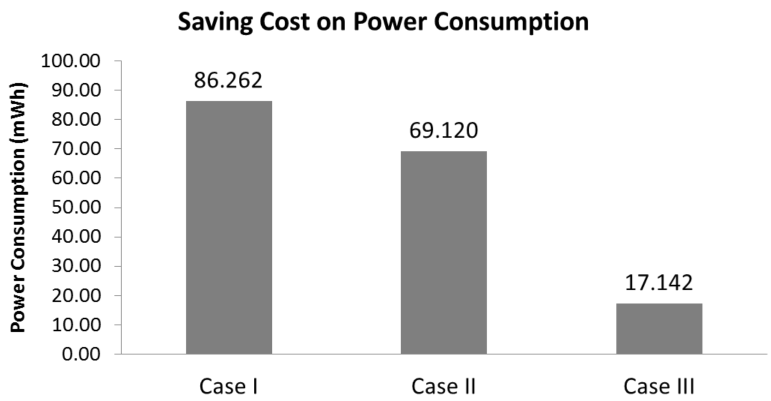


(b) Power Consumption (PW)

Figure 0.4 Comparison of the utilization cost in all cases



(a) Bandwidth (BW)



(b) Power Consumption (PW)

Figure 0.5 Saving cost consideration in all cases

5.4 Summary

In this chapter, we encourage the notable use of local computing facility to give mutual benefits for player and server in cloud gaming service. By enabling the AHP-based decision-maker at the gaming device, we show that the player's benefit in term of reasonable demands for adaptive resource under dynamic network availability can be issued, due to the hierarchical analytic decision upon the different criteria, and alternatives. At the same time, the server's benefit in term of the improved gaming workload of a certain session can be realized. Our experimental results can confirm the validity of the proposed method, which is remarkably simple and flexible for enabling cognitive resource utilization in the cloud gaming environment.

CHAPTER 6
CONCLUSION AND OUTLOOK

This chapter concludes the thesis by summarizing its contributions occurred mainly in the area of web intelligence and cognitive resource allocation for context-aware adaptive system in advanced mobile learning environments. Section 6.1 summarizes the thesis outcomes of the conducted research work. Finally, Section 6.2 discusses the constraints of the achieved contributions, as well as the potential of future research directions that go beyond this research work in Section 6.3.

6.1 Summary of Contributions

In the following, the contributions achieved throughout this thesis are summarized by revisiting two issues in ubiquitous mobile learning research, which are identified in Section 1.2, on a) enabling semantic-enabled learning services in local ubiquitous network environment, and b) providing context-aware adaptive and personalized learning experiences.

The goal of the first issue is to investigate how the standard UPnP-based network infrastructure designed initially for home/office service automation can be turned out to support for ubiquitous learning objective, if somewhat level of semantic capability will be involved. The investigation is explored extensively in Chapter 3. The contribution is on a design of peer-to-peer based mobile learning service that adopts existing UPnP middleware for architectural simplification, and exploits Linked Data for semantic integration of learning resources.

The intent of the second issue is on resolving the problem of incompatibility or accessibility of non-adaptive learning repository server, of which serving media contents are requested in various formats either by heterogeneous devices or from different usage contexts. This problem is addressed in Chapter 4. In this regard, we proposed a user-driven multimedia adaptation framework targeted to this sort of repository, where the cognitive engine nominating 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.

The aim of the third issue is to resolve an inherent problem of cloud gaming service, which relies heavily on the demand of high network communications, since the major loads of heavy video-processing tasks are offloaded up to the cloud server so that mobile devices can be eligible to run sophisticated games. This problem is addressed in Chapter 5. We advocate the necessity of enabling cognitive platform, which is capable of modifying its multimedia quality requirement in response to the network constraint, and notifying the gaming server for updating the corresponded workload. The contribution is on applying AHP method to find the optimal content determination at cognitive gaming platform that can potentially meet the balance of maximizing its own player's gaming experience and reducing the server workload for involved gaming session altogether.

6.2 Constraints to address

In this section, we discuss some major constraints of the research contributions achieved throughout this thesis. In essence, they are related to inherent limitations of the AHP method; a) The huge number of pairwise comparisons in judgment matrix, and b) the rating scale of relative importance.

On the first issue, some may ask a question about the large number of pairwise comparisons need to be complete. This can be regarded as a drawback of AHP [95], [96], since it may need $n(n-1)/2$ comparisons, where n is the number of decision criteria. Then, with the large number of comparisons, the overall task will become tedious and prone to errors. It is in the sense that consistency is difficult to achieve, since users may not consider their past assigned values when giving new ones on assigning the relative values of a large set of attributes. Therefore, it is generally recommended [97] that the number of criteria and alternatives in AHP should not exceed 9 criteria / alternatives at maximum. It is then plausible in our cases, since only 3 criteria and 3 alternatives are considered.

On the second issue, some may raise a concern on the rational refinement in the rating scale used in the process of a pairwise comparison. While the 1-9 linear scale is usually considered as the default scale of relative importance, it can be alternatively extended to 1-13 or 1-50 linear scale. However, it is showed in [96] that the final ranking will not necessarily follow the actual times of importance. Some attention should be given on this concern when using the AHP, otherwise some other extended AHP method through the use of suggestion matrix [96] can be used instead.

6.3 Future work

Future work can be researched into the performance evaluation of practical experiments with UDAD framework as well as the decision analytics using AHP on some other aspects as follows:

- Involving some other contexts in mobile learning environments (referring to Subsection 2.1.2.5) will bring our AHP-based decision-making support for resource utilization closer to realistic situations in daily life. However, due to the different behaviors of some contexts, more advanced version of AHP method such as those including fuzzy logic consideration to mitigate imprecise judgments of the real world may be necessary.
- Taking into account the dynamics of contexts should be investigated further to see how they would affect in somewhat level to the over performance. It is our assumption that some enhancement may be needed at the user's device, in order to reduce unnecessary updates.
- Realizing the other kind of learning documents, such as web pages, will be challenged as it represents an example of considerable contents utilized mostly in the Internet. By containing internals, such as textual contents and scalable images, special consideration must be taken for realizing the responsiveness of the overall web pages. Indeed, this is a necessary feature for deploying effectively in the mobile device environment.

REFERENCE

[1] E. Baran, “A Review of Research on Mobile Learning in Teacher Education,” *J. Educ. Technol. Soc.*, vol. 17, no. 4, pp. 17–32, 2014.

[2] P. Nedungadi and R. Raman, “A new approach to personalization: integrating e-learning and m-learning,” *Educ. Technol. Res. Dev.*, vol. 60, no. 4, pp. 659–678, Aug. 2012.

[3] M. E. Sousa-Vieira, J. C. López-Ardao, C. López-García, M. Rodríguez-Pérez, and J. C. López-Ardao, “Using social learning in network engineering curricula,” *2015 IEEE Glob. Eng. Educ. Conf. EDUCON*, pp. 471–478, Mar. 2015.

[4] B. C. M. Fung, T. Trojer, P. C. K. Hung, L. Xiong, K. Al-Hussaeni, and R. Dssouli, “Service-Oriented Architecture for High-Dimensional Private Data Mashup,” *IEEE Trans. Serv. Comput.*, vol. 5, no. 3, pp. 373–386, Third Quarter 2012.

[5] “Web Services Architecture.” [Online]. Available: https://www.w3.org/TR/ws-arch/. [Accessed: 13-May-2016].

[6] V. Adzic, H. Kalva, and B. Furht, “A survey of multimedia content adaptation for mobile devices,” *Multimed. Tools Appl.*, vol. 51, no. 1, pp. 379–396, Dec. 2010.

[7] S. Martin, G. Diaz, I. Plaza, E. Ruiz, M. Castro, and J. Peire, “State of the art of frameworks and middleware for facilitating mobile and ubiquitous learning development,” *J. Syst. Softw.*, vol. 84, no. 11, pp. 1883–1891, 2011.

[8] M. Aljohani and T. Alam, “Design an M-learning framework for smart learning in ad hoc network of Android devices,” in *2015 IEEE International Conference on Computational Intelligence and Computing Research (ICCIC)*, 2015, pp. 1–5.

[9] C. E. Association, “A Web-based Protocol and Framework for Remote User Interface on UPnP Networks and the Internet (Web4CE),” CEA-2014-B, 2006.

[10] M. P. Bodlaender, “UPnP^{TM} 1.1-designing for performance & compatibility,” *Consum. Electron. IEEE Trans. On*, vol. 51, no. 1, pp. 69–75, 2005.

[11] A. Yazidi, O.-C. Granmo, B. J. Oommen, M. Gerdes, and F. Reichert, “A user-centric approach for personalized service provisioning in pervasive environments,” *Wirel. Pers. Commun.*, vol. 61, no. 3, pp. 543–566, 2011.

[12] R. Shea, J. Liu, E. C.-H. Ngai, and Y. Cui, “Cloud gaming: architecture and performance,” *IEEE Netw.*, vol. 27, no. 4, pp. 16–21, Jul. 2013.

[13] S. Tobias, J. D. Fletcher, and A. P. Wind, “Game-Based Learning,” in *Handbook of Research on Educational Communications and Technology*, J. M. Spector, M. D. Merrill, J. Elen, and M. J. Bishop, Eds. Springer New York, 2014, pp. 485–503.

[14] C. Bizer, T. Heath, and T. Berners-Lee, “Linked data-the story so far,” *Semantic Serv. Interoperability Web Appl. Emerg. Concepts*, pp. 205–227, 2009.

[15] G. Á. Rey, I. Celino, P. Alexopoulos, D. Damljanovic, M. Damova, N. Li, and V. Devedzic, “Semi-automatic generation of quizzes and learning artifacts from linked data,” 2012.

[16] T. L. Saaty, "Decision making with the analytic hierarchy process," *Int. J. Serv. Sci.*, vol. 1, no. 1, pp. 83–98, Jan. 2008.

[17] M. N. Ismail, R. Ibrahim, M. F. Md Fudzee, M. N. Ismail, R. Ibrahim, and M. F. Md Fudzee, "A Survey on Content Adaptation Systems towards Energy Consumption Awareness, A Survey on Content Adaptation Systems towards Energy Consumption Awareness," *Adv. Multimed. Adv. Multimed.*, vol. 2013, 2013, p. e871516, Jul. 2013.

[18] S. Gómez, P. Zervas, D. G. Sampson, and R. Fabregat, "Context-aware adaptive and personalized mobile learning delivery supported by UoLmP," *J. King Saud Univ. - Comput. Inf. Sci.*, vol. 26, no. 1, Supplement, pp. 47–61, Jan. 2014.

[19] "Supporting the Development of Mobile Adaptive Learning Environments: A Case Study." [Online]. Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4745628&tag=1. [Accessed: 28-Apr-2016].

[20] H. Louafi, S. Coulombe, and U. Chandra, "Robust QoE-aware Prediction-based Dynamic Content Adaptation Framework Applied to Slides Documents in Mobile Web Conferencing," *Multimed. Tools Appl*, vol. 74, no. 18, pp. 7883–7920, Sep. 2015.

[21] J. He, T. Gao, W. Hao, I.-L. Yen, and F. Bastani, "A flexible content adaptation system using a rule-based approach," *Knowl. Data Eng. IEEE Trans. On*, vol. 19, no. 1, pp. 127–140, 2007.

[22] J.-L. Hsiao, H.-P. Hung, and M.-S. Chen, "Versatile transcoding proxy for internet content adaptation," *Multimed. IEEE Trans. On*, vol. 10, no. 4, pp. 646–658, 2008.

[23] A. Vetro and C. Timmerer, "Digital item adaptation: overview of standardization and research activities," *IEEE Trans. Multimed.*, vol. 7, no. 3, pp. 418–426, Jun. 2005.

[24] T. C. Thang, Y. J. Jung, and Y. M. Ro, "Effective adaptation of multimedia documents with modality conversion," *Signal Process. Image Commun.*, vol. 20, no. 5, pp. 413–434, Jun. 2005.

[25] S. Lee, S. Rho, and J. H. Park, "Multimedia contents adaptation by modality conversion with user preference in wireless network," *J. Netw. Comput. Appl.*, vol. 37, pp. 25–32, Jan. 2014.

[26] C. G. M. Snoek and M. Worring, "Multimodal Video Indexing: A Review of the State-of-the-art," *Multimed. Tools Appl.*, vol. 25, no. 1, pp. 5–35, Jan. 2005.

[27] J. Xin, C.-W. Lin, and M.-T. Sun, "Digital Video Transcoding," *Proc. IEEE*, vol. 93, no. 1, pp. 84–97, Jan. 2005.

[28] A. M. A. Ahmad, *Multimedia Transcoding in Mobile and Wireless Networks*. Information Science Reference, 2008.

[29] R. Mohan, J. R. Smith, and C.-S. Li, "Adapting multimedia internet content for universal access," *Multimed. IEEE Trans. On*, vol. 1, no. 1, pp. 104–114, 1999.

[30] K. Verbert, N. Manouselis, X. Ochoa, M. Wolpers, H. Drachsler, I. Bosnic, and E. Duval, "Context-Aware Recommender Systems for Learning: A Survey and

Future Challenges," *IEEE Trans. Learn. Technol.*, vol. 5, no. 4, pp. 318–335, Oct. 2012.

[31] Ö. Yürür, C. H. Liu, Z. Sheng, V. C. M. Leung, W. Moreno, and K. K. Leung, "Context-Awareness for Mobile Sensing: A Survey and Future Directions," *IEEE Commun. Surv. Tutor.*, vol. 18, no. 1, pp. 68–93, Firstquarter 2016.

[32] W. Du and L. Wang, "Context-aware Application Programming for Mobile Devices," in *Proceedings of the 2008 C3S2E Conference*, New York, NY, USA, 2008, pp. 215–227.

[33] "IMS ePortfolio | IMS Global Learning Consortium." [Online]. Available: https://www.imsglobal.org/ep/index.html. [Accessed: 09-May-2016].

[34] "The FOAF Project." [Online]. Available: http://www.foaf-project.org/. [Accessed: 09-May-2016].

[35] "Composite Capabilities/Preferences Profile Home Page." [Online]. Available: https://www.w3.org/Mobile/CCPP/. [Accessed: 09-May-2016].

[36] "User Agent Profile V2.0 | The Open Mobile Alliance." [Online]. Available: http://technical.openmobilealliance.org/Technical/technical-information/release-program/current-releases/user-agent-profile-v2-0. [Accessed: 09-May-2016].

[37] "WURFL - Mobile Device Database by ScientiaMobile." [Online]. Available: http://wurfl.sourceforge.net/. [Accessed: 09-May-2016].

[38] "A Survey on Delivery Context Description Formats - A Comparison and Mapping Model (bibtex)." [Online]. Available: http://www-itec.uni-klu.ac.at/bib/index.php?key=Timmerer2010_DeliveryContextDescriptionFormats&bib=itec.bib. [Accessed: 09-May-2016].

[39] M.-A. Sicilia, H. Ebner, S. Sánchez-Alonso, F. Álvarez, A. Abián, and E. García-Barriocanal, "Navigating learning resources through linked data: a preliminary report on the re-design of Organic. Edunet," *Proc. Linked Learn.*, vol. 2011, p. 1st, 2011.

[40] P. Dolog and W. Nejdl, "Challenges and benefits of the semantic web for user modelling," in *Proceedings of the Workshop on Adaptive Hypermedia and Adaptive Web-Based Systems (AH2003) at 12th International World Wide Web Conference, Budapest*, 2003.

[41] V. Butoianu, P. Vidal, K. Verbert, E. Duval, and J. Broisin, "User Context and Personalized Learning: a Federation of Contextualized Attention Metadata.," *J UCS*, vol. 16, no. 16, pp. 2252–2271, 2010.

[42] M. Wolpers, J. Najjar, K. Verbert, and E. Duval, "Tracking actual usage: the attention metadata approach," *Educ. Technol. Soc.*, vol. 10, no. 3, pp. 106–121, 2007.

[43] W. Hodgins and E. Duval, "Draft standard for learning technology-Learning Object Metadata-ISO/IEC 11404," *IEEE P1484 122D1*, 2002.

[44] S. Weibel, J. Kunze, C. Lagoze, and M. Wolf, "Dublin core metadata for resource discovery," 1998.

[45] J. M. Martinez, "MPEG-7 overview (version 10), ISO," IEC JTC1/SC29/WG11, 2004.

[46] A. Soylu, P. D. Causmaecker, and P. Desmet, "Context and Adaptivity in Pervasive Computing Environments: Links with Software Engineering and Ontological Engineering," *J. Softw.*, vol. 4, no. 9, Nov. 2009.

[47] R. Benlamri and X. Zhang, "Context-aware recommender for mobile learners," *Hum.-Centric Comput. Inf. Sci.*, vol. 4, no. 1, pp. 1–34, Aug. 2014.

[48] S. Martin, R. Gil, E. Sancristobal, G. Díaz, M. Castro, J. Peire, M. Milev, and N. Mileva, "Enabling Innovations in Mobile-Learning: A Context-aware and Service-based Middleware," *Int. J. Adv. Softw. IARIA*, vol. 3, no. 1–2, 2010.

[49] P. Belimpasakis, J.-P. Luoma, and M. Börzsei, "Content sharing middleware for mobile devices," in *Proceedings of the 1st international conference on MOBILe Wireless MiddleWARE, Operating Systems, and Applications*, 2008, p. 30.

[50] E. Triantaphyllou, B. Shu, S. N. Sanchez, and T. Ray, "Multi-criteria decision making: an operations research approach," *Encycl. Electr. Electron. Eng.*, vol. 15, pp. 175–186, 1998.

[51] V. Balali, B. Zahraie, A. Hosseini, and A. Roozbahani, "Selecting appropriate structural system: Application of PROMETHEE decision making method," in *Engineering Systems Management and Its Applications (ICESMA), 2010 Second International Conference on*, 2010, pp. 1–6.

[52] M. S. Zaeri, A. Sadeghi, A. Naderi, A. Kalanaki, R. Fasihy, S. M. H. Shorshani, and A. Poyan, "Application of multi criteria decision making technique to evaluation suppliers in supply chain management," *Afr. J. Math. Comput. Sci. Res.*, vol. 4, no. 3, pp. 100–106, 2011.

[53] M. W. Mastalerz, "Electre method for choosing an e-learning platform," in *Perspective Technologies and Methods in MEMS Design (MEMSTECH), 2010 Proceedings of VIth International Conference on*, 2010, pp. 168–171.

[54] J.-S. Wang, C.-H. Liu, and G. T. Lin, "How to manage information security in cloud computing," in *Systems, Man, and Cybernetics (SMC), 2011 IEEE International Conference on*, 2011, pp. 1405–1410.

[55] M. Pirdashti, A. Ghadi, M. Mohammadi, and G. Shojatalab, "Multi-criteria decision-making selection model with application to chemical engineering management decisions," *World Acad. Sci. Eng. Technol.*, vol. 49, pp. 54–59, 2009.

[56] P. Zhou, B. W. Ang, and K. L. Poh, "Decision analysis in energy and environmental modeling: An update," *Energy*, vol. 31, no. 14, pp. 2604–2622, Nov. 2006.

[57] I. B. Huang, J. Keisler, and I. Linkov, "Multi-criteria decision analysis in environmental sciences: ten years of applications and trends," *Sci. Total Environ.*, vol. 409, no. 19, pp. 3578–3594, 2011.

[58] C. Kahraman, S. C. Onar, and B. Oztaysi, "Fuzzy Multicriteria Decision-Making: A Literature Review," *Int. J. Comput. Intell. Syst.*, vol. 8, no. 4, pp. 637–666, Jul. 2015.

[59] C.-C. Chou and K.-W. Yu, "Application of a New Hybrid Fuzzy AHP Model to the Location Choice," *Math. Probl. Eng.*, vol. 2013, p. e592138, Jun. 2013.

[60] O. S. Vaidya and S. Kumar, "Analytic hierarchy process: An overview of applications," *Eur. J. Oper. Res.*, vol. 169, no. 1, pp. 1–29, 2006.

[61] C. E. Otero, I. Kostanic, L. D. Otero, and S. L. Meredith, "Characterization of User-Perceived Quality of Service (QoS) in Mobile Devices using Network Pairwise Comparisons," *Int. J. Wirel. Mob. Netw.*, vol. 2, no. 3, pp. 142–154, 2010.

[62] M. Godse and S. Mulik, "An approach for selecting software-as-a-service (SaaS) product," in *Cloud Computing, 2009. CLOUD'09. IEEE International Conference on*, 2009, pp. 155–158.

[63] S. K. Garg, S. Versteeg, and R. Buyya, "SMICloud: a framework for comparing and ranking cloud services," in *Utility and Cloud Computing (UCC), 2011 Fourth IEEE International Conference on*, 2011, pp. 210–218.

[64] G. Işıklar and G. Büyüközkan, "Using a multi-criteria decision making approach to evaluate mobile phone alternatives," *Comput. Stand. Interfaces*, vol. 29, no. 2, pp. 265–274, 2007.

[65] T. L. Saaty, "Decision-making with the AHP: Why is the principal eigenvector necessary," *Eur. J. Oper. Res.*, vol. 145, no. 1, pp. 85–91, 2003.

[66] A. Presser, L. Farrell, D. Kemp, and W. Lupton, "Upnp device architecture 1.1," in *UPnP Forum*, 2008, vol. 22.

[67] H. Shin, *Challenges and the solutions for multimedia metadata sharing in networks*. INTECH Open Access Publisher, 2012.

[68] M. Svensson, A. Kurti, and M. Milrad, "A linked data approach for enriching emerging learning objects with contextual metadata," in *Fourth European Conference on Technology Enhanced Learning, Nice, France*, 2009.

[69] "Integration of UPnP with HTML5." [Online]. Available: https://html5.cablelabs.com/upnp/last-version/html5-upnp-integration.html. [Accessed: 15-May-2016].

[70] B. Adida, I. Herman, M. Sporny, and M. Birbeck, *RDFa 1.1 Primer*. 2012.

[71] R. Klemke, S. Ternier, M. Kalz, and M. Specht, "Implementing infrastructures for managing learning objects," *Br. J. Educ. Technol.*, vol. 41, no. 6, pp. 873–882, 2010.

[72] H. H. Hoang, T. N.-P. Cung, D. K. Truong, D. Hwang, and J. J. Jung, "Semantic information integration with linked data mashups approaches," *Int. J. Distrib. Sens. Netw.*, vol. 2014, 2014.

[73] C. Lagoze, S. Payette, E. Shin, and C. Wilper, "Fedora: an architecture for complex objects and their relationships," *Int. J. Digit. Libr.*, vol. 6, no. 2, pp. 124–138, 2006.

[74] R. Pathmeswaran and V. Ahmed, "SWmLOR: Technologies for developing Semantic Web based mobile learning object repository," *Built Hum. Environ. Rev.*, vol. 2, no. 1, 2011.

[75] Y. Li, Z. Chen, R. Huang, and X. Cheng, "An integrated learning resource management system with web services," in *New Trends in Information and Service Science, 2009. NISS'09. International Conference on*, 2009, pp. 863–868.

[76] H. Jin, Z. Yin, X. Yang, F. Wang, J. Ma, H. Wang, and J. Yin, "APPLE: a novel P2P based e-learning environment," in *Distributed Computing-IWDC 2004*, Springer, 2004, pp. 52–62.

[77] H. Q. Yu, S. Dietze, N. Li, C. Pedrinaci, D. Taibi, N. Dovrolls, T. Stefanut, E. Kaldoudi, and J. Domingue, "A linked data-driven & service-oriented architecture for sharing educational resources," 2011.

[78] M. Yaghmaie and A. Bahreininejad, "A context-aware adaptive learning system using agents," *Expert Syst. Appl.*, vol. 38, no. 4, pp. 3280–3286, Apr. 2011.

[79] F. López, J. M. Martínez, and V. Valdés, "Multimedia Content Adaptation Within the CAIN Framework Via Constraints Satisfaction and Optimization," in *Adaptive Multimedia Retrieval: User, Context, and Feedback*, S. Marchand-Maillet, E. Bruno, A. Nürnberger, and M. Detyniecki, Eds. Springer Berlin Heidelberg, 2006, pp. 149–163.

[80] M. Prangl, I. Kofler, and H. Hellwagner, "An MPEG-21-driven utility-based multimedia adaptation decision taking web service," in *Proceedings of the 1st international conference on Ambient media and systems*, 2008, p. 7.

[81] D. Zhang, A. Jangam, L. Zhou, and I. Yakut, "Context-Aware Multimedia Content Adaptation for Mobile Web," *Int. J. Networked Distrib. Comput.*, vol. 3, no. 1, p. 1, 2015.

[82] K. M. Kapp, *The Gamification of Learning and Instruction: Game-based Methods and Strategies for Training and Education*. John Wiley & Sons, 2012.

[83] F. Xia, N. Y. Asabere, A. M. Ahmed, J. Li, and X. Kong, "Mobile Multimedia Recommendation in Smart Communities: A Survey," *IEEE Access*, vol. 1, pp. 606–624, 2013.

[84] R. Trestian, O. Ormond, and G.-M. Muntean, "Energy–quality–cost tradeoff in a multimedia-based heterogeneous wireless network environment," *Broadcast. IEEE Trans. On*, vol. 59, no. 2, pp. 340–357, 2013.

[85] J. O. Kephart and R. Das, "Achieving Self-Management via Utility Functions," *IEEE Internet Comput.*, vol. 11, no. 1, pp. 40–48, Jan. 2007.

[86] K. G. Ham, H. J. Kim, and S. G. Choi, "User preference based selection method to provide personalized multimedia service with service quality," in *2012 14th International Conference on Advanced Communication Technology (ICACT)*, 2012, pp. 623–627.

[87] W. Ho, "Integrated analytic hierarchy process and its applications – A literature review," *Eur. J. Oper. Res.*, vol. 186, no. 1, pp. 211–228, Apr. 2008.

[88] W. Cai, M. Chen, and V. C. M. Leung, "Toward Gaming as a Service," *IEEE Internet Comput.*, vol. 18, no. 3, pp. 12–18, May 2014.

[89] W. Cai, C. Zhou, V. C. M. Leung, and M. Chen, "Environment Perception for Cognitive Cloud Gaming," in *Cloud Computing*, V. C. M. Leung and M. Chen, Eds. Springer International Publishing, 2013, pp. 3–13.

[90] W. Cai, C. Zhou, V. C. M. Leung, and M. Chen, "A Cognitive Platform for Mobile Cloud Gaming," in *2013 IEEE 5th International Conference on Cloud Computing Technology and Science (CloudCom)*, 2013, vol. 1, pp. 72–79.

[91] C. Hull, D. K. Charles, P. J. Morrow, and G. Parr, “FRAGED: A framework for adaptive game execution and delivery to improve the quality of experience in network aware games,” 2015.

[92] R. Jitpukdeebodintra and S. Witosurapot, “Hybrid Method for Adaptive Cloud Gaming Contents,” *GSTF J. Comput. JoC*, vol. 4, no. 2, Mar. 2015.

[93] R. Jitpukdeebodintra and S. Witosurapot, “A Study on the Impact of Client Display Resolutions in Cloud Gaming Workloads,” 2015.

[94] I. Ghergulescu, A.-N. Moldovan, and C. H. Muntean, “Energy-aware Adaptive Multimedia for Game-based e-learning,” in *2014 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB)*, 2014, pp. 1–6.

[95] C. Macharis, J. Springael, K. De Brucker, and A. Verbeke, “PROMETHEE and AHP: The design of operational synergies in multicriteria analysis.: Strengthening PROMETHEE with ideas of AHP,” *Eur. J. Oper. Res.*, vol. 153, no. 2, pp. 307–317, Mar. 2004.

[96] M. F. Hossain, Z. H. Adnan, and M. Hasin, “Improvement in weighting assignment process in analytic hierarchy process by introducing suggestion matrix and likert scale,” *Int. J. Supply Chain Manag.*, vol. 3, no. 4, 2014.

[97] R. Gawlik, “Preliminary Criteria Reduction for the Application of Analytic Hierarchy Process Method,” University Library of Munich, Germany, 2008.

APPENDIX

LIST OF PUBLICATION AND PROCEEDINGS

Paper 1 A. Rueangprathum, S. Limsiroratana, and S. Witosurapot, "**Enabling Semantic-Based Ubiquitous Learning in UPnP Network Environment**", "International Journal of Information and Education Technology", Vol. 5, No. 10, pp. 794-798, October, 2015.

Paper 2 A. Rueangprathum, S. Limsiroratana, and S. Witosurapot, "**User-Driven Multimedia Adaptation Framework for Context-aware Learning Content Service**, "Proceedings of IACT Melbourne Conferences", pp. 193-196, January, 2016.

Paper 3 A. Rueangprathum, S. Limsiroratana, and S. Witosurapot, "**AHP-based Adaptive Resource Selection for Cognitive Platform in Cloud Gaming Service**", "GSTF International Journal on Computing (JoC)", Vol.4 No.4, pp.52-58, April, 2016.

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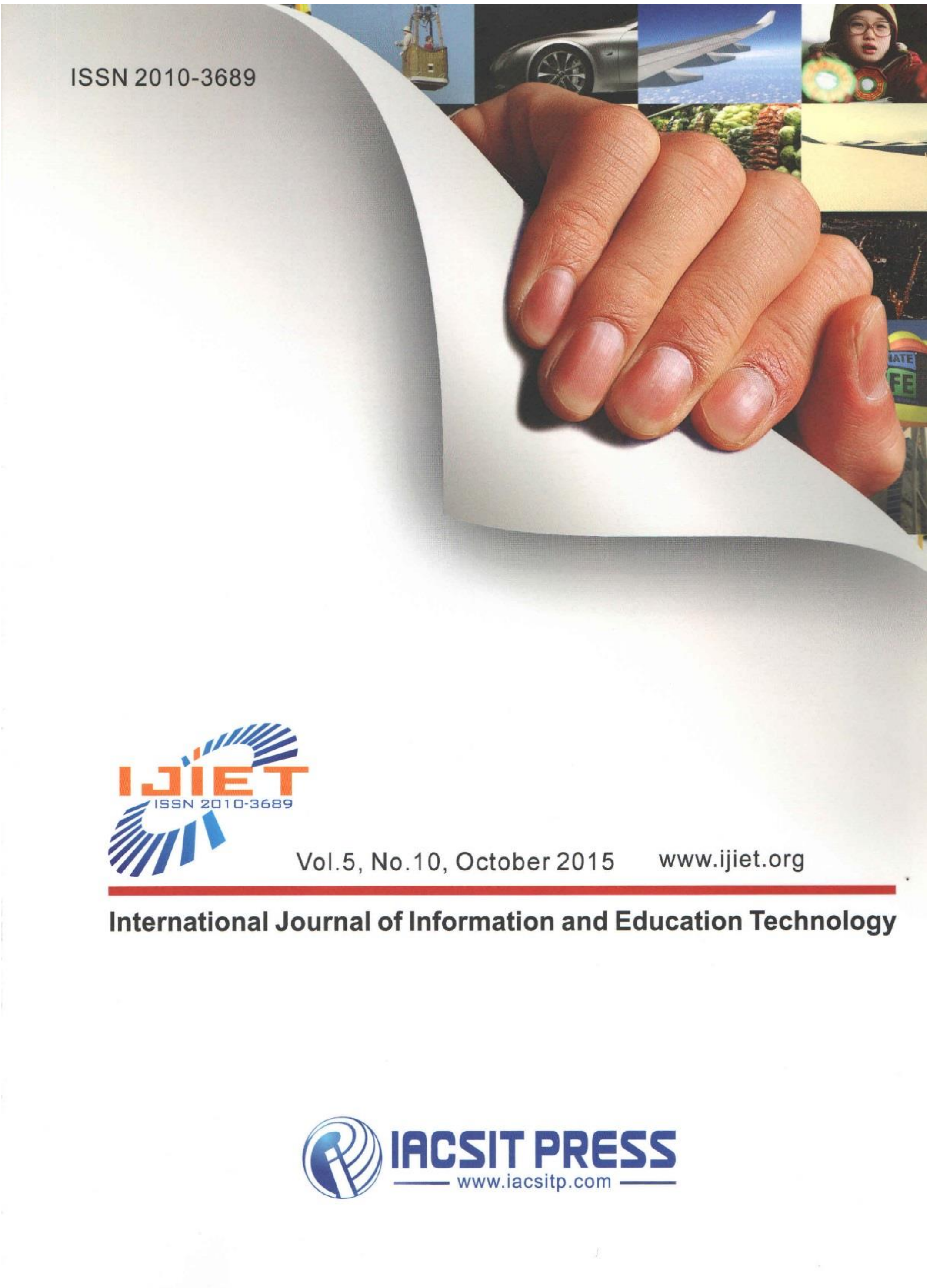
RESERCH PAPER 1

Enabling Semantic-Based Ubiquitous Learning in UPnP Network


ISSN 2010-3689

IJIET
ISSN 2010-3689

Vol.5, No.10, October 2015 www.ijiet.org

International Journal of Information and Education Technology

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International Journal of Information and Education Technology, Vol. 5, No. 10, October 2015

Enabling Semantic-Based Ubiquitous Learning in UPnP Network Environment

Atchara Rueangprathum, Somchai Limsiroratana, and Suntorn Witosurapot

Abstract—**Although Universal Plug and Play (UPnP) network is aimed basically at home/ office service automation for general purposes, it can turn out to support for ubiquitous learning objective as well, if somewhat level of semantic capability will be involved. In this paper, we discuss how the UPnP network infrastructure should be polished with the Linked Data principle for enabling semantic-based ubiquitous learning services so that sharing digital contents can be done between heterogeneous devices in an effective manner, without the need of many distinct learning standards. In addition, we describe a case of simple quiz to illustrate how the Linked Data publishing of distributed multimedia resources can be utilized in our extended UPnP architecture.**

Index Terms—**Linked data, semantic web, ubiquitous mobile learning, UPnP.**

I. Introduction

Smart home network technology has provided excellent opportunities for people to experience both local services in home/office automation and public services from the Internet accesses to premises. However, for the educational purposes, smart home network is often used to facilitate for the remote access of e-learning facility, but it is rarely utilized to provide for group-based learning among computers or mobile devices at homes or enterprises. This is crucially due to the lack of adequate systems and tools, which are indeed necessary for the arrangement of ubiquitous and mobile learning inside or outside premises.

Although a number of mobile learning systems have been researched to date (see [1] and Refs therein), they do not take advantages of existing ubiquitous network infrastructures designed for smart home into consideration. Therefore, their architectures are complex inevitably, due to the necessity for handling many basic (but crucial) issues, such as associating heterogeneous devices, discovering devices nearby, or enabling collaborative learning operations on a peer-to-peer (P2P) basis. We argue that the complexity of these architectures can be lessened by involving the support of pervasive network infrastructure, such as Universal Plug and Play (UPnP) [2], which is targeted for smart home/office service automation.

In addition, we encourage the exploitation of web-related technologies for many reasons. For instance, they are the technologies that are founded in the UPnP infrastructure for handling the problem of platform heterogeneity. Developers can then take advantages of deploying their applications via Web browsers, regardless of platform technology. More importantly, it is possible that the Semantic Web technology, such as that of Linked Data approach [3], can be involved for resource integration and generation in the Web-enabled UPnP environment. Then, learning resources and associated metadata can be reused, discovered, and interoperated among local UPnP devices via the Web infrastructure and protocols.

The contribution of this paper is a design of P2P-based mobile learning service that adopts existing UPnP network infrastructure for architectural simplification, and exploits Linked Data for semantic integration of learning resources. The remaining part of this paper is organized as follows. Section II gives a background of UPnP network environment and the Linked Data approach for lightweight semantics. Section III describes the proposed system architecture and functional component designs. Section IV provides the detail of our prototype and a simple use case. Finally, Section V concludes the paper.

II. Background

A. UPnP Network Environment

Universal Plug and Play [2] is a well-recognized ubiquitous network infrastructure containing with features, such as zero-configuration for network startup, automatic detection of devices and services in the same local network, and seamless network connection on P2P basis. Dominant features are on the adoption of Service-oriented Architecture (SOA), Web technologies and Internet standards, i.e. TCP/IP and HTTP, to serve at the lower-layer of UPnP protocol stack (as illustrated in Fig. 1). Hence, web-based applications can be readily implemented at any UPnP devices for performing various tasks, such as interacting with the other networked UPnP devices, consuming UPnP services, or extending them for improved functionality.

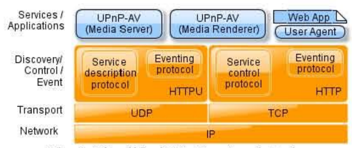

Fig. 1. Simplified UPnP protocol stack.

A notable UPnP extension is UPnP-AV [4], which enables ubiquitous multimedia services for home entertainments. Two extra-devices called Media Server and Media Renderer are introduced in UPnP-AV system architecture for specially managing Audio-Video (AV) content distribution on top of UPnP networks. The guideline in [5] suggests us how these

Manuscript received May 5, 2014; revised July 25, 2014.

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special servers can be handled by User agent of UPnP device via HTML5 scripts in Web Applications for browsing and viewing the AV contents, or even managing to display them at the other device serving as Media Renderer. By working in this manner, it looks promising that UPnP-AV system can be augmented to share or distribute user-generated contents or resources among UPnP devices for learning purposes as well.

B. Linked Data for Semantic-Based Learning Resources

In order to provide adequate service for ubiquitous mobile learning, it is required that the all of learning contents must be involved not only with metadata for easing interoperability at the syntax level between devices, but also semantic-based operations for serving human-centric usability. In this regard, sharing and distributing multimedia contents in UPnP-AV system with MPEG-7 and MPEG-21 metadata standards are not adequate [5], especially in the aspects of learning resource with technologies of Learning Object. This is also applicable to the interoperability using popular educational metadata standards [6], e.g. IEEE-LOM and SCORM.

To accomplish the above requirement, traditional web pages crucially serving for human-centric operations will need to extend with semantic technology so that they can allow smart agent in a device to carry out tedious works, such as finding and combining learning resources on the Web, without human interventions. This requirement is indeed the vision of Semantic Web, but will be implemented by means of Linked Data approach [3], which is widely used to realize the Web of Data. It provides a smart way to expose, share, and reuse learning contents over the Web, thus giving benefits to lecturers or developers to create learning materials or quizzes in shorter period of time by combining contents from the other local devices or several public web sites.

From the technical aspect, the concept of Linked Data can be summarized by a) utilizing the Web as a single global database, b) describing the resource with the Resource Description Framework (RDF) annotation, and c) interlinking the data from different sources via Web addresses (URI). Once these resources are in RDF annotation, they become machine-readable, and hence give benefits to web developers in a number of ways. For instance, they can be viewed using generic data browsers, accessed via the links from the other resources, or even composed on-the-fly by smart agents residing at user-devices. It was noticed that the RDF data may be exposed as a standalone RDF or embedded into HTML documents via special attributes known as RDFa [7] for serving both machines and humans.

III. Extending UPnP-AV for Ubiquitous Learning

This section illustrates the proposed architecture design that minimally extends the UPnP-AV architecture in such a way that ubiquitous mobile learning activities, either within a peer group or between a pair of devices, can be enabled.

A. Design Abstraction

In the provision of ubiquitous mobile learning services in the UPnP environments, the basic of UPnP-AV architecture will be taken into account (see Fig. 2) so that existing service entities can still be utilized, but realized in the new context. For instance, the Media Server and Media Renderer remain dealing with MPEG-21 multimedia resources, which may be now alternately used as learning contents in some scenarios. Two exclusive services for handling educational resources are included into the system: a) Semantic data repository service working at a special server for storing and retrieving static learning resources, and b) Linked data service residing at the user-devices for manipulating and rendering linked data. These services can ensure that semantic interoperability of educational resources will be occurred properly in the system as explained in the previous section.

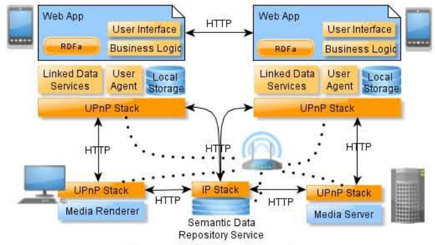

Fig. 2. Architecture overview.

B. Semantic Data Repository Service

Since some learning materials, e.g. shared lessons or media objects, must be kept as long as necessary after creations, a repository of learning objects is then required not only for making them available for search and reuse, but also enabling a means for an authoring application to publish its resources. In this regards, Digital Content Repository (DCR) that works on generic metadata specifications (e.g. Dublin Core or MARC) for documenting general contents is more suitable than the counterpart of Learning Object Repository (LOR) [8] that is rather restricted to specific metadata standards (e.g. IEEE LOM) for describing learning contents. Therefore, the DCR will be selected in our proposed architecture so that a wider range of content types (e.g. photograph and AV files) can be accommodated.

C. Linked Data Service

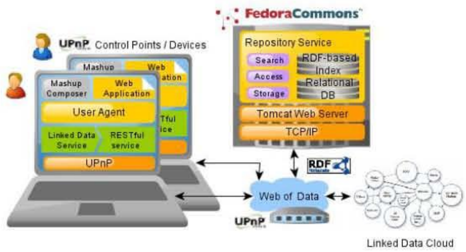

Fig. 3. Demonstration setup.

In many cases, learning resources may be instantly created on-demand, such as snapshots with some contextual contents (e.g. the current geo-location) or sensory data in a timely fashion. It is certain that storing these contents is not so useful at the central repository, but would rather be better at the local for immediate response, e.g. during the collaborative activity. In this regards, linked data service will be required for exposing them in a Linked Data-compliant way. By means of RDF URIs, linked data resources from different sources can be discovered, shared and consumed by the other peer devices. This will be convenient if an authoring application can be involved for enabling semi-automatic composition and automatic generation of Web Mashups [9], which is quite popular for modern Web 2.0 applications.

IV. Prototype and a Simple Case

This section introduces the general architecture of our prototype and describes a simple case of Mashup application, in order to demonstrate the linked-data usage and integration of learning data from different sources.

A. Prototype Architecture

A simple implementation for realizing ubiquitous learning services in a P2P manner can be illustrated in Fig. 3. The ad-hoc network is supported over the Wi-Fi network infrastructure. All computers are turned into UPnP-capable devices by enabling the UPnP support in Windows Platform. It is noticed that the semantic-based repository is not UPnP-compliance, but works in compatibility with UPnP devices via standard TCP/IP protocol. Indeed, this repository is a computer running Apache Tomcat Web server and Fedora Commons [10] open source software (which will be called Fedora hereafter) for providing RDF-enabled repository in our mobile learning environment.

Due to many distinct features, Fedora server allows users of UPnP devices to access the semantic repository for searching, adding, modifying and retrieving digital objects together with their metadata, in many different ways. For instance, by means of SOAP-based or RESTful Web services, developers of Web applications can have automatic association with Fedora in several programming languages. Alternatively, by using Web browser, users can interface manually to administrative module of Fedora, or issue query statements written in SPARQL language and view the results in response accordingly.

B. Mashup Application

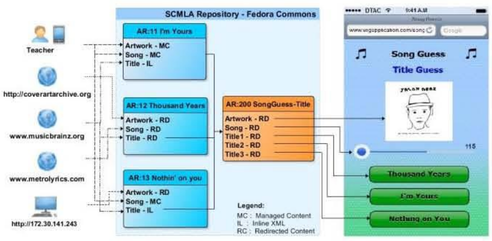

Fig. 4. Example quiz for guessing the song title.

To make the proposed system more comprehensible, we conducted a simple example that illustrates how learning resources (such as assessment quizzes) can be generated by a combined set of RDF data collecting from different Linked Data sources. A simple example as shown in Fig. 4 has been implemented, which is slightly more complex than the work in [11]. It is a "Song Guess" Application that displays an artwork of song that is currently playing and the user are about to pick up the correct song title from the displayed list. According to our design, each element is generated from a digital object that aggregates a number of contents (known as datastreams in the Fedora context) from multiple sources locating either in the Fedora repository or from the external data sources referenced by URLs as they can be noticed in the left part of Fig. 4.

Fig. 5. A screenshot of the Fedora administration interface with an example of digital object.

In our design, the primary data objects are AR:11, AR:12, and AR:13 and are specified the handle or linkage to actual resources in different manners. For example, the datastream of AR:11 that has the type of "Managed Content (MC)" will store the content (e.g., jpg file of Artwork) in the Fedora repository, but the type of "Inline XML (IL)" will be stored the element of data source as part of XML structure. In contrast, the datastream of AR: 12 that have the type of "Redirected Content (RC)" will only deliver the content to the client without any mediation by the Fedora. It should be noticed that the secondary data object (AR: 200) is designed particularly to provide the linkages to those primary ones for constituting the structure of RDF data that will be promptly used in the quiz application. In Fig. 5, these linkages can be easily noticed in the bottom part of the Fedora administration interface.

Hence, by means of different types of datastreams, the Fedora repository can be mandated to support different ways of manipulation and relationship establishment among content objects to suit our needs. In this regard, it will become easy and flexible for lesson developers to rely on the Fedora repository for storing resulted linked data of Mashup composer or some other applications.

C. Miscellaneous

To summarize, the prototype implementation described in the previous sub-section is a preliminary evaluation for our pilot application, which takes Semantic Web and Linked Data to facilitate for quiz-like question development by taking Linked Data cloud as a source of knowledge. In general, this development process may become a tedious work, since it requires the SPARQL Query Language to access data from several Linked Data resources of interest. However, in our system, this is much easier through the use of administrative Web Interface (e.g. as examples shown in Fig. 5 to Fig. 7), which obviously does not need any programming skill for creating, viewing, or managing digital

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learning objects at all. In addition, by deploying Fedora at the backend of digital repository, user application can be accessed to powerful functionalities either via SOAP Service or REST API using programming language of choice. This is far more complex in traditional system, where SPARQL is needed, and the other software for serving RDF data over HTTP (e.g. Apache's Jena Fuseki) is inevitable.

Fig. 6. A screenshot of the Fedora administration interface for viewing a digital object profile.

Fig. 7. A screenshot of the Fedora administration interfacewith a XML list of digital object.

V. Related Works

There exist some similar efforts within the research field of our research. For example, Pathmeswaran and Ahmed [12] developed a prototype of *SWmLOR* system, which attempted to provide a better facilitation of mobile learning resources by accompanying standard learning objects with ontology-based semantic contents. Although their architectural framework provides the same functionalities as that of our works, it contains three major drawbacks; a) facilitating the poor support for collaborative learning community between mobile devices in the local network, due to the intrinsic limitation of client-server based learning environment, b) overlooking the use of Linked Data approach for exposing learning resources and allowing them to be reused or shared in the simplified manner at mobile devices, and c) ignoring the exploitation of open source software for digital repository tool (i.e. Fedora in our case), which can immensely simplified the programming tasks. Li, Chen and Huang [13] takes the advantages of Fedora open source software as well for building a prototype of learning resource management and sharing system (called *SULOMS*) with adaptive capabilities, which is claimed to be suitable for mobile learning. Our work takes a broader view of sharing semantic learning objects via the Web of Linked Data.

To provide a better support for collaborative learning environment, several works attempts to bring P2P technology into consideration. For example, Jin *et al.* [14] described a peer-to-peer based learning environment over the Internet, named *APPLE*, which has a combination of P2P overlay network, Internet broadcast system, and grid technology, and reported satisfactory results in educational experiments with general computers. Compared to this research work, our system is much simpler and does not require any burden of P2P routing algorithms, due to the dominant feature of UPnP protocol stack and service-oriented architecture involved. Yen *et al.* [15] described their developed system called *iServe* that is Linked Data-driven and works on service-oriented architecture and claimed its efficiency in resolving the problem of interoperability issues due to various metadata standards of learning objects in a distributed and heterogeneous environment. Unlike our system, the *iServe* system lacks the support for P2P operations in the scope of this work. The summarized view of the aforementioned comparison of related systems can be seen in Table I.

TABLE I: Summarized Comparison of Related Works

System	P2P Support	Linked Data Approach	SOA Principle	Fedora Engine
SWmLOR [12]	No	No	No	No
SULOMS [13]	No	Yes	No	Yes
APPLE [14]	Yes	No	No	No
iServe [15]	No	Yes	Yes	No
Our work	Yes	Yes	Yes	Yes

VI. Conclusion

This paper introduced UPnP technology in the ubiquitous learning area and suggested the lightweight semantic web of Linked Data approach to publish learning data on the Web so that other peer devices can access and interpret the data using merely standard Web technologies. Comparing with traditional mobile and ubiquitous learning, our system has advantages as follows: 1) It can discover any networked UPnP devices automatically and provides the instant support of peer-to-peer networking; 2) It enables the web-driven technology and thus allows for the Linked Data to be utilized across the network domain via the Internet if the security policy can be met; 3) It does not need any tedious operations for accessing the elements of shared data, which is inevitable in many cases of metadata standards for learning object interoperability. In addition, we show the linked-data usage and integration of learning data from different sources through a simple quiz example, which can be potentially led towards more realistic or advanced explorations, which is currently an ongoing work.

References

[1] S. Martin, G. Diaz, I. Plaza, E. Ruiz, M. Castro, and J. Peire, "State of the art of frameworks and middleware for facilitating mobile and ubiquitous learning development," *J. of Systems and Software*, vol. 84, no. 11, pp. 1883–1891, November 2011.

[2] *UPnP Device Architecture version 1.1*, UPnP Forum, Oct 2008.

[3] C. Bizer, T. Heath, and T. Berners-Lee, "Linked data - The story so far," *Int. J. on Semantic Web and Information Systems*, vol. 5, no. 3, pp. 1–22, 2009.

[4] H. Shin, "Challenges and the solutions for multimedia metadata sharing in networks," in *Multimedia - A Multidisciplinary Approach to Complex Issues*, I. Karydis, Ed., 2012, pp. 263-276.
[5] M. Svensson, A. Kurti, and M. Milrad, "A linked data approach for enriching emerging learning objects with contextual metadata," presented at Fourth European Conference on Technology Enhanced Learning, Nice, France, September 29-October 2, 2009.
[6] B. Lund. (November 2011). Integration of UPnP with HTML5. [Online]. Available: http://html5.cablelabs.com/upnp/html5-upnp-integration.html.
[7] M. Birbeck. (June 2009). Introduction to RDFa. [Online]. Available: http://alistapart.com/article/introduction-to-rdfa.
[8] R. Klemke, S. Ternier, M. Kalz, and M. Specht, "Implementing infrastructures for managing learning objects," *British Journal of Educational Technology*, vol. 41, no. 6, pp. 873–882, 2010.
[9] H. H. Hoang, T. N.-P. Cung, D. K. Truong, D. Hwang, and J. J. Jung, "Semantic Information Integration with Linked Data Mashups Approaches," *Int. J. of Distributed Sensor Networks*, vol. 2014, p. e813875, April 2014.
[10] C. Lagoze, S. Payette, E. Shin, and C. Wilper, "Fedora: an architecture for complex objects and their relationships," *Int. J. on Digital Libraries*, vol. 6, no. 2, pp. 124–138, April 2006.
[11] G. Á. Rey, I. Celino, P. Alexopoulos, D. Damljanovic, M. Damova, N. Li, and V. Devedzic, "Semi-automatic generation of quizzes and learning artifacts from Linked Data," presented at the Linked Learning 2012: 2nd Int. Workshop on Learning and Education with the Web of Data, Lyon, France, April 17, 2012.
[12] R. Pathmeswaran and V. Ahmed, "SWmLOR: Technologies for developing semantic web based mobile learning object repository," *The Built & Human Environment Review*, vol. 2, no. 1, Jul. 2011.
[13] Y. Li, Z. Chen, R. Huang, and M. X. Cheng, "An Integrated Learning Resource Management System with Web Services," in *Proc. Int. Conf. on New Trends in Information and Service Science,* 2009, pp. 863–868.
[14] H. Jin, Z. Yin, X. Yang, F. Wang, J. Ma, H. Wang, and J. Yin, "Apple: A novel P2P based e-learning environment," in *Distributed Computing - IWDC 2004*, A. Sen, N. Das, S. K. Das, and B. P. Sinha, Eds., Springer Berlin Heidelberg, 2005, pp. 52–62.
[15] H. Q. Yu, S. Dietze, N. Li, C. Pedrinaci, D. Taibi, N. Dovrolls, T. Stefanut, E. Kaldoudi, and J. Domingue, "A linked data-driven & service-oriented architecture for sharing educational resources," presented at the 1st Int. Workshop on eLearning Approaches for Linked Data Age (Linked Learning 2011), 8th Extended Semantic Web Conference (ESWC2011), Heraklion, Greece, 2011.

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RESEARCH PAPER 2

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


Proceedings of IACT Melbourne Conferences

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.

Manuscript received December 20, 2015; revised January 10, 2016; accepted January 25, 2016.

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 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.

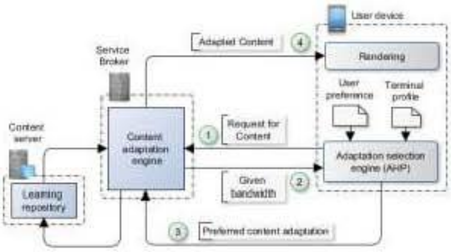

Figure 1. Proposed framework architecture.

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.

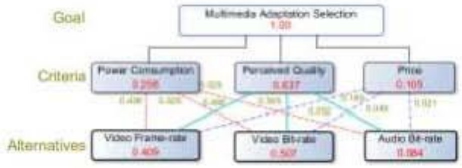

Figure 2. Adaptation selection hierarchy.

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*

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.

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

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.

REFERENCES

[1] M. Yaghmaie and A. Bahreininejad, "A context-aware adaptive learning system using agents," *Expert Systems with Applications*, vol. 38, no. 4, pp. 3280–3286, Apr. 2011.

[2] F. López, J. M. Martínez, and V. Valdés, "Multimedia content adaptation within the CAIN framework via constraints satisfaction and optimization," in *Adaptive Multimedia Retrieval: User, Context, and Feedback*, S. Marchand-Maillet, E. Bruno, A. Nürnberger, and M. Detyniecki, Eds. Springer Berlin Heidelberg, 2006, pp. 149–163.

[3] M. Prangl, I. Kofler, and H. Hellwagner, "An MPEG-21-driven utility-based multimedia adaptation decision taking web service," in *Proc. 1st Int. Conf. on Ambient Media and System*, ICST, Brussels, Belgium, 2008, pp. 7:1–7:8.

[4] M. N. Ismail, R. Ibrahim, and M. F. Md Fudzee, "A survey on content adaptation systems towards energy consumption awareness," *Adv. in Multimedia*, vol. 2013, pp. e871516, July 2013.

[5] D. Zhang, A. Jangam, L. Zhou, and I. Yakut, "Context-aware multimedia content adaptation for mobile web," *Int. J. of Networked and Distributed Computing*, vol. 3, no. 1, pp. 1-9, 2015.

[6] O. S. Vaidya and S. Kumar, "Analytic hierarchy process: An overview of applications," *European Journal of Operational Research*, vol. 169, no. 1, pp. 1–29, Feb. 2006.

[7] K. M. Kapp, *The Gamification of Learning and Instruction: Game-based Methods and Strategies for Training and Education*, CA: John Wiley & Sons, 2012, ch.4.

[8] F. Xia, N. Y. Asabere, A. M. Ahmed, J. Li, and X. Kong, "Mobile multimedia recommendation in smart communities: A survey," *IEEE Access*, vol. 1, pp. 606–624, 2013.

[9] S. Lee, S. Rho, and J. H. Park, "Multimedia contents adaptation by modality conversion with user preference in wireless network," *J. of Network and Computer App.*, vol. 37, pp. 25–32, Jan. 2014.

[10] R. Trestian, O. Ormond, and G.-M. Muntean, "Energy-quality-cost tradeoff in a multimedia-based heterogeneous wireless network environment," *IEEE Trans. on Broadcasting*, vol. 59, no. 2, pp. 340–357, Jun. 2013.

[11] J. O. Kephart and R. Das, "Achieving self-management via utility functions," *IEEE Internet Computing*, vol. 11, no. 1, pp. 40–48, Jan. 2007.

[12] K. G. Ham, H. J. Kim, and S. G. Choi, "User preference based selection method to provide personalized multimedia service with service quality," in *Proc. 14th Int. Conf. on Advanced Communication Tech. (ICACT)*, 2012, pp. 623–627.

[13] W. Ho, "Integrated analytic hierarchy process and its applications – A literature review," *European J. of Operational Research*, vol. 186, no. 1, pp. 211–228, Apr. 2008.

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RESEARCH PAPER 3

AHP-based Adaptive Resource Selection for Cognitive Platform in Cloud Gaming Service


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Journal
on Computing
The Official Journal of Global Science and Technology Forum (GSTF)
Available online in GSTF Digital Library: http://dl.globalstf.org
December 2015
VOLUME 4, NUMBER 4
ISSN: 2251-3043

GSTF Journal on Computing (JoC) Vol.4 No.4, April 2016

AHP-based Adaptive Resource Selection for Cognitive Platform in Cloud Gaming Service

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Abstract— **Cloud gaming service enables offloading heavy video-processing tasks up to the cloud server so that simple computers or mobile devices can be eligible to run sophisticated games, but on the expense of high network communications. In this regard, the adequate network utilization must be realized for delivering good gaming experiences to the game players. This necessitates a cognitive platform, which is capable of modifying its multimedia quality requirement in response to the network constraint, and notifying the cloud gaming server for updating the corresponded workload. In this regard, the Analytic Hierarchy Process (AHP) method has been proposed to deploy at the cognitive platform for cloud gaming service to select an optimal resource allocation strategy that satisfies various multimedia requirements and energy-awareness. Experiment results can confirm that the proposed method is flexible to enhance the capability of cloud gaming service in term of more efficient cloud gaming resource utilization, particularly during heavy-congested periods, while players' quality of gaming experience can be still maintained under the mandate of intelligent agent on the player devices.**

Keywords-mobile cloud gaming; cognitive agent; multimedia adaptation; context awareness; AHP

I. INTRODUCTION

Cloud gaming [1] is a kind of cloud service that allows the low-performance computers or mobile devices to run highly sophisticated games. However, due to the intrinsic limitation of rendering the game remotely in the cloud and streaming the scenes as video frames back to the player over the Internet, the cloud gaming service relies intensely on the adequate network availability [2] in order to deliver acceptable user experience in gaming. The issue of multimedia content adaptation is then a prime consideration for achieving two ultimate goals: a) the utmost gaming resource utilization at the server-side, and b) the highest satisfaction level at the player-side. Nonetheless, it is not easy to achieve such requirements by simply relying on a server-centric mechanism and naive gaming devices [3], since the server merely attempts by default to deliver real-time media streaming to a player device at the highest possible quality, in accordance with the notified physical device resolution.

To enrich the default operations in typical cloud gaming, it is required that somewhat of cognition must be existed at the player's device so that the rational tuning of performance parameters at run-time can be enabled. For instance, it can be then possible to make a trade-off between the higher video resolution and the lower bit rate of video transmission, in order to preserve the overall bandwidth usage and the player's satisfaction simultaneously. To date, the realization of this requirement is still an active research in the field of cognitive cloud gaming, where reasoning engine plays a crucial role of evaluating the game player's evironment and deciding on the proper demand of adaptive multimedia contents according to the evaluations and the player's preferences.

In this paper, the local decision-making engine has been modeled at the cognitive device for deriving the user demand in adaptive video playback quality as a multiple-attribute decision-making (MADM) problem under an uncertain environment. Analytic Hierarchy Process (AHP) algorithm has been proposed for dealing with this problem, since it can handle both qualitative and quantitative criteria related to audio/video multimedia resources and the battery-energy level simultaneously. Our key contribution is on the application of AHP method for finding the optimal content determination at cognitive gaming platform that can potentially meet the balance of maximizing its own player's gaming experience and reducing the server workload for involved gaming session altogether.

The rest of the paper is organized as follows. The review of related work is given in Section 2. Then, the framework of user-driven cloud gaming resource utilization is introduced in Section 3, following with a model of user's decision-making problem and its AHP-based solution for yielding the user demand that will maximize user gaming experience at given network constraint. The experimental results on performance evaluation is presented and discussed in Section 4. Finally conclusion of the paper is in Section 5.

II. RELATED WORK

A. Cognitive Resource Allocation in Cloud Gaming

In cloud gaming environment, the local cognitive agent at the gaming device are demanded for altering a passive gaming device into the active one so that the better support of cloud gaming resource provision at the cloud gaming server can be expected. To address this demand, many research studies have proposed solutions contributed to the domain.

DOI: 10.5176/2251-3043_4.4.344

For instance, The work [3] focused on a data-collecting solution on the cognitive gaming platform, where the proposed environment perception procedure enables the local cognitive agent to learn the player's environment in real time and push this information to the server so that the respective gaming service adaptation can be derived in a relaxed manner. Indeed, this useful procedure can be well supported for the case of sophisticated cognitive platform as shown in the other work [4], where elaborated features, e.g. the migration and partitioning of game components, as well as partial offline execution, can be offered.

In addition, the work [5] also focused on cognitive cloud gaming environment and proposed a rather complicated framework, where seven types of agents may be needed for executing and delivering adaptive game contents to the players. In contrast, the work [6] concerned on a simpler solution for improving the server's workload in realistic cloud gaming environment. To fulfil the goal, an extra demand of player's display resolution is required for complementing their hybrid version of trans-coding or trans-rendering processes at the gaming server.

While the aforementioned studies can reduce the workload of gaming video rendering at the server-side on the expense of incurred burden at the players' devices, their mechanisms are much in common on the purely technical consideration. Hence, no means of user involvement are provided for governing preferential resource determination. As a result, their technical-oriented solutions becomes complex inevitably for maintaining the adequate service-quality and may not yield the results that conform to the player's expectation. In contrast, by taking into account the user's requirements and contexts, our proposed algorithm can potentially match to what user needs, since both of the technical parameters and user-concerns are considered altogether.

B. *AHP Method for Resolving Network-related Problems*

AHP is well-recognized as one of the most extensively used multicriteria decision-making methods in the recent literature review [7]. The dominance [8] is due to the following features:

- Handling both qualitative and quantitative factors in an intuitive manner by structuring them into a hierarchical decision model based on a number of criteria
- Quantifying relative priorities of decision criteria with pairwise comparisons, so that ranking a finite set of alternatives can be possible.
- Detecting inconsistency of data that are inherent in the decision-making process for comparing alternatives.

As a consequence, AHP has been sucessfully applied for giving decisions in various research areas (see [9] for the literature review of selected areas and references therein). In fact, there have been some research works in decision related to web and communication networks as well. For instance, the work [10] suggested how AHP can be used to evaluate the level of user satisfaction based on the user-perceived quality of service (QoS) so that the qualities of service classes in the wireless cellular networks can be known and improved if necessary. In [11] and [12], they advocated on the use of AHP to solve the cloud service selection problem of which decision factors related to user subjective assessment are concerned. It can be noticed that these works are common on applying AHP-based method for decision, but are different on the returned benefit whether it is for the user or the service provider. Unlike our work, the AHP-based decision-making method will be served for a mutual benefit of user and server in the distinctive area of cloud gaming service. It is in the sense that the AHP-based method will assist the game player to select the best content resolution that is satisfy not only their own preference, but also the current network condition. At the same time, the less workload at the game server can be feasible due to the sensible demand of user's content resolution. In addition, our work relies heavily on the combined AHP-mathematical programming approach [13], rather than the standalone AHP, since the relative important weights of alternatives in the AHP process must be calculated further to yield a value of content resolution as a final decision.

III. OPTIMAL SELECTION OF CONTENT RESOLUTION

The methodology given in this section is indeed an optimal resource utilization mechanism that empowers a cognitive platform to make a decision on the optimal content resolution of adaptive multimedia that can maximize gaming experience (regarding the user's policy) under a given network constraint (according to the server's notification) as illustrated in Fig.1. this mechanism is modeled as a MADM problem and manage to solve it through the AHP method so that the weighted values of context-aware parameters (i.e. network bandwidth, screen resolution and power consumption) can be obtained, and used later in an optimal resource allocation problem.

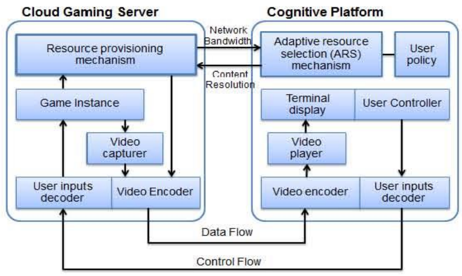

Figure 1. Cognitive resource allocation architecture.

Although many performance metrics can be considered in adaptive cloud gaming contents [5], some of them [14] will be particularly interested as shown in Table I, According to the different viewpoints of application (game), network, and device. Nevertheless, these metrics will need to be managed in such a way that they can be processed by the AHP method of which basic procedure are described below:

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TABLE I. PERFORMANCE METRICS UNDER CONSIDERATION

Viewpoint	Performance Metric	Symbol	Unit
Application (Game)	Video resolution	-	pixels
	Video frame-rate	-	fps
	Audio bit-rate	-	kbps
Network	Network bandwidth	BW	Mbps
Device	Screen resolution	SR	pixels
	Power consumption	PW	mWh

A. Modeling a hierarchical analysis structure

When using AHP, it is demanded to define a hierarchical structuring model of the decision-making problem, where the objective, criteria, and alternatives are structured into a hierarchy. As seen in Fig. 2, the proposed model is a three-level hierarchy and can be described as follows: the top-level is the goal of the decision-making problem (i.e. optimal content determination), the mid-level consists of various evaluation criteria (i.e. video frame-rate, video resolution, and audio bit-rate), the bottom-level consists of alternatives (i.e. network bandwidth, screen resolution, and power consumption).

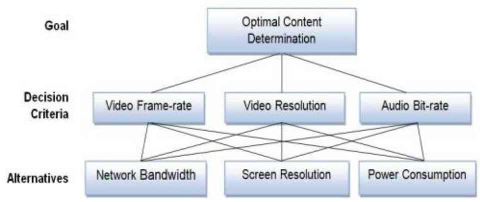

Figure 2. Hierarchical structure of the model.

B. Assigning the weights

AHP can calculate the relative weight of decision criteria and alternatives in an intuitive manner. The basic steps are decribed as follows:

1) Making pairwise comparison:

In this step, the relative importance of involved performance metrics are judged by a pairwise comparison. Rating the relative priority of each metric is done by asssigning a value according to Table II [11], for example the value of 1 means equally preferred and 9 means extremely preferred. By working in this manner, the reciprocal matrix can be obtained as shown in Table III.

TABLE II. AHP RATING SCALE OF JUDGMENT

Value	Verbal judgment between pairwised values
1	Equally preferred
3	Moderately preferred
5	Strongly preferred
7	Very Strongly preferred
9	Extremely preferred
2, 4, 6, 8	Between the judgment above

TABLE III. MATRIXES FOR THE 3 ALTERNATIVES FROM EACH CRITERIA

	Video Frame-Rate			Video Resolution			Audio Bit-Rate		
	BW	*SR*	*PW*	*BW*	*SR*	*PW*	*BW*	*SR*	*PW*
BW	1	3	9	1	3	5	1	3	5
SR	1/3	1	5	1/3	1	3	1/3	1	3
PW	1/9	1/5	1	1/5	1/3	1	1/5	1/3	1

Legend: BW: Bandwidth SR: Screen Resolution PW: Power Consumption

2) Computing priority vector for decision criteria:

Having a reciprocal matrix, the priority vectors, which are the normalized Eigen vectors of the matrix, can be computed. Here, they can be calculated by using technique of normalized relative weight and the results are shown in Table IV.

TABLE IV. WEIGHTS OF DECISION CRITERIA

Decision Criteria	Weights	Consistency Ratio (CR)
Video Frame-rate	0.637	0.037
Video Resolution	0.258	
Audio Bit-rate	0.104	

3) Checking for consistency:

Since the data in a reciprocal matrix may not be consistent. This is due to the imposition of 1 to 9 rating scale of judgment as performed in Step 1. The AHP will check consistency of data in evaluation via a ratio called Concistency Ratio (CR):

$$CR = (CI/RI), \qquad RI = 0.58 \tag{1}$$

where RI is a random concistency index and the typical values [15] are given in Table V, and n refers to the number of parameters. Since $n = 3$ in this case, RI is then set to 0.58; CI is concistency index, and is defined as

$$CI = (\lambda_{max} - n)/(n - 1) \tag{2}$$

where λ_{max} is the maximum eigenvalue of the judgment matrix, which is set to 3.0383 in this case.

If the value of CR is smaller or equal to 0.1, then the inconsistency is acceptable. In our case, Table VI shows how the priority vectors and the consistency ratio of the judgment matrix are generated. Noticed that the CR in each decision criteria is less than 0.1, so the judgment matrix is consistent.

4) Computing priority vector for alternatives:

Similar to the process in Step 2 of comparing the decision criteria, all pairs of alternatives are now compared using the AHP rating value. Similar to Step 3, a judgment matrix is determined, and priority weights are calculated for each of the alternative. The results are given in Table VII.

TABLE V. RANDOM CONSISTENCY INDEX

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

TABLE VI. WEIGHTS OF ALTERNATIVES UNDER EACH CRITERIA

Decision Criteria	Alternatives			Consistency Ratio (*CR*)
	BW	*SR*	*PW*	
Video Frame-Rate	0.671	0.265	0.063	0.027
Video Resolution	0.637	0.258	0.104	0.037
Audio Bit-Rate	0.659	0.156	0.185	0.028

Legend: BW: Bandwidth SR: Screen Resolution PW: Power Consumption

TABLE VII. WEIGHTS OF EACH ALTERNATIVES

Alternatives	Weights (*w*)	Consistency Ratio (*CR*)	Ranking
Network Bandwidth	0.661	0.033	1
Screen Resolution	0.252		2
Power Consumption	0.086		3

Finally, the summary of all the weights in the hierarchy can be illustrated in Fig. 3. It can be noticed that the optimal ratio of factors influencing on the adaptive contents will be largely contributed to the concern of network bandwidth, following with the device resolution and power consumption accordingly.

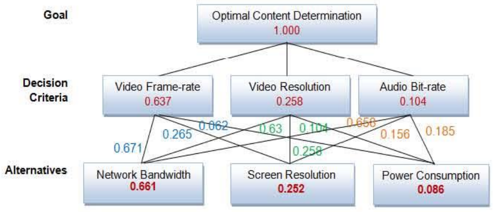

Figure 3. Weighted values of cognitive resource allocation model.

C. *Formulating resource allocation problem*

Based on the AHP weighted values obtained in the previous step, they can be used to calculate the value of required content resolution that satisfies our requirement. However, the possible values will be preferably specified in discrete values following the list of common graphics display resolution[1], as shown in Table VIII. In the other word, the output video resolution is classified into 5 levels, ranging from the ultra low to the very high video resolutions. The direct advantage is on the ease of manipulation by the proposed mechanism, since the effective bandwidth utilized for content adaptation is rather in a stepwise fashion. The indirect advantage is on the ease of User Interface (UI) implementation, since only a set of limited choices will be displayed for allowing users to have a fast selection.

TABLE VIII. 5 LEVELS OF AVAILABLE CONTENT RESOLUTION

Level	Video resolution	Pixels
1. Ultra Low (UL)	640 x 480	307,200
2. Low (L)	1280 x 720	921,600
3. Medium (M)	1600 x 900	1,440,000
4. High (H)	1920 x 1080	2,073,600
5. Very High (VH)	2048 x 1152	2,359,296

[1] https://wikipedia.org/wiki/Graphics_display_resolution

To compute the value of optimal video resolution, which is the product of AHP weighted values (i.e. benefits) of the bottom-level (alternatives) and the incurred cost of them, the method is as follows:

$$x = \sum_{i=1}^{n} w_i c_i \qquad (3)$$

where *x* is the required content resolution, w_i is the weight of alternative *i* (referring to the Table VII), *n* is the number of alternatives and c_i is the cost of alternative *i* that is reflected by the following equation:

$$c_i = \frac{r_j}{m_j}, j = 1,..,5 \qquad (4)$$

where r_j is the required resource, m_j is the maximal availability of that resource, and *j* is the number of level ranging from 1 to 5 according to the levels specified in Table VIII.

In this paper, the cost of each alternative can be calculated as follow:

1) Network bandwidth: The cost is an inverted ratio of the network's current capability to fulfill the user's requirements and hence includes both the user's required bandwidth (r_j), as well as the network's available bandwidth (m_j). In order to obtain the r_j, the simple experiment is conducted to observe the bandwidth consumed by *j* multimedia streams with different resolutions given in Table VIII. Then, the cost incurred by the deliveries of different adaptive streams in a variety of network technologies[2], i.e. 2G-Edge (16 Mbps), 3G (16 Mbps), 3G (42 Mbps), 4G (42 Mbps), and 4G-LTE (100 Mbps) can be summarized as shown in Table IX.

TABLE IX. THE COSTS OF BANDWIDTH FOR DELIVERING TARGET CONTENT RESOLUTIONS IN VARIOUS NETWORK TECNOLOGIES

r (Mbps)	Cost on various network types				
	m *(1.6 Mbps)*	***m*** *(14.4 Mbps)*	***m*** *(21.0 Mbps)*	***m*** *(42.0Mbps)*	***m*** *(100 Mbps)*
7.92	4.95	0.55	0.38	0.19	0.08
12.64	7.90	0.88	0.60	0.30	0.13
18.32	11.45	1.27	0.87	0.44	0.18
27.92	17.45	1.94	1.33	0.66	0.28
42.56	26.60	2.96	2.03	1.01	0.43

Experiment: H.264 encoded and 60-fps video streaming, 3.5 GHz 6-core server and Gigabit network

2) Screen resolution: The cost is the ratio of the desired content resolution (r_j) and the screen resolution (m_j). Here, the costs incurred by the deliveries of adaptive streams at different resolutions can be summarized in Table X.

[2] https://wikipedia.org/wiki/Comparison_of_mobile_phone_standards

TABLE X. THE COSTS OF SCREEN RESOLUTIONS FOR DELIVERING TARGET CONTENT RESOLUTIONS

r (pixels)	Cost on various screen resolutions				
	m (307,200 pixels)	*m* (921,600 pixels)	*m* (1,440,000 pixels)	*m* (2,073,600 pixels)	*m* (2,359,296 pixels)
307,200	1.00	0.33	0.21	0.15	0.13
921,600	3.00	1.00	0.64	0.44	0.39
1,440,000	4.69	1.56	1.00	0.69	0.61
2,073,600	6.75	2.25	1.44	1.00	0.88
2,359,296	7.68	2.56	1.64	1.14	1.00

3) Power consumption: The cost is a ratio of the power consumption needed to transmit the desired content resolution and the battery-power life. Here, the energy measurement setup and experimental results are assumed as given in [16] to support our pilot study so that the relationship of the power consumption for different resolutions can be feasibly derived. In this regard, the power consumption (r_j) in each j level according to the given values in Table VIII can be computed. However, the capacity of battery (with the 20% safty factor) is devided into 5 levels. Therefore, in a case of the battery with 1650 mAh and 3.7 volt specification, the maximum power consumption (m_j) of the battery in each j level can be computed and summarized in Table XI.

TABLE XI. THE COSTS OF POWER CONSUMPTIONS FOR DELIVERING TARGET CONTENT RESOLUTIONS

r (mWh)	Cost on various power consumptions				
	m (976.80 mWh)	*m* (1953.6 mWh)	*m* (2930.00 mWh)	*m* (3907.00 mWh)	*m* (4884.00 mWh)
876.00	4.95	0.55	0.38	0.19	0.08
912.87	7.90	0.88	0.60	0.30	0.13
943.97	11.45	1.27	0.87	0.44	0.18
981.99	17.45	1.94	1.33	0.66	0.28
999.13	26.60	2.96	2.03	1.01	0.43

IV. EXPERIMENTAL EVALUATION

In order to evaluate the efficacy of the proposed method, an example of its application is considered in a simple network scenario, where a number of clients are concurrently connecting to a server for cloud gaming service consumption. Our evaluation is on the conformance of the user's expectation and the actual allocation occurred in different cases of network bandwidth and power resource availability.

A. Plentiful resource environment

It is a situation where the network is under-utilized and the the player's battery-power level is high. In this case, the player will tend to recieve whatever content resolution it desires. As shown in Table XII, the player who demands a "very high (VH)" screen resolution will be granted with the "very-high (VH)" content resolution (i.e. the highlighted line) as desired.

TABLE XII. SUMMARY OF CASES IN OVER-UTILIZED NETWORK

BW=H, SR=VH, PW=VH	Alternatives (W_iC_i)			Total score (*x*)
	BW	*SR*	*PW*	
UL	0.125	0.033	0.015	0.173
L	0.199	0.098	0.016	0.313
M	0.288	0.154	0.017	0.459
H	0.439	0.221	0.017	0.678
VH	0.670	0.252	0.018	0.939

B. Scarce resource environment

In a contrast situation, the network is over-utilized and the role of content adaptation becomes crucial. The player, however, may be assigned with the much lower level of content resolution than the desired one, unless the availability of network bandwidth are adequate. Based on the data given in Table XIII, the user in case 1, who demands the "very high (VH)" screen resolution, will get merely the "Low (L)" content resolution, due to the low availability of both network bandwidth and battery power. Since the BW alternative has a much higher weight than the other alternatives (refering to Table VII), the influence of PW alternative is rather limited in all cases. It is obvious in the case 2 and 3, where the influence of BW is dominant. The best selection of suitable content resolution can be issued, according to the best-maximum value below the value 1 (i.e. the upper boundary of feasible case) of the total score in all cases as shown in Table XIV – XVI.

In order to illustrate the clear advantages of our proposed method over the method found in traditional remote-rendering cloud gaming, the experiments have been performed (in a network scenario as described in [6]), to investigate the performance in terms of utilization cost and saving cost of both cases. As shown in Fig. 4, the lower utilization cost can be attained in our case, due to the less, but sufficient, demanding of network bandwidth, and hence less power consumption, at the gaming device. As a consequence, by subtracting the values compared in both cases, the saving cost for network bandwidth utilization and power consumption can be illustrated in Fig. 5.

TABLE XIII. SUMMARY OF CASES IN OVER-UTILIZED NETWORK

	Availability			Result (*x*)
	BW	*SR*	*PW*	
Case 1 (Table XIV)	L	VH	L	L
Case 2 (Table XV)	L	H	VH	L
Case 3 (Table XVI)	H	VH	UL	H

TABLE XIV. CASE 1

BW=L, SR=VH, PW=L	Alternatives (W_iC_i)			Total score (*x*)
	BW	*SR*	*PW*	
UL	0.36	0.03	0.04	0.43
L	0.58	0.10	0.04	0.72
M	0.84	0.15	0.04	1.04
H	1.28	0.22	0.04	1.55
VH	1.95	0.25	0.04	2.25

TABLE XV. CASE 2

BW=L, SR=H, PW=VH	Alternatives (W_iC_i)			Total score (*x*)
	BW	*SR*	*PW*	
UL	0.364	0.125	0.015	0.504
L	0.580	0.199	0.016	0.795
M	0.841	0.288	0.017	1.146
H	1.282	0.439	0.017	1.738

VH	1.954	0.670	0.018	2.641

TABLE XVI. CASE 3

BW=H, SR=VH, PW=UL	Alternatives (W_iC_i)			Total score (x)
	BW	*SR*	*PW*	
UL	0.125	0.033	0.077	0.235
L	0.199	0.098	0.080	0.378
M	0.288	0.154	0.083	0.525
H	0.439	0.221	0.086	0.747
VH	0.670	0.252	0.088	1.010

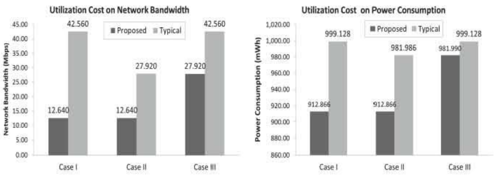

Figure 4. Utilization cost comparison in a) BW and b) PW experiments

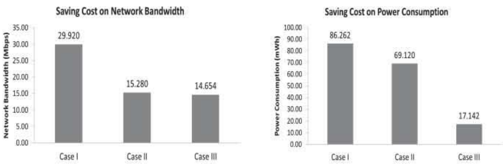

Figure 5. Saving cost consideration in a) BW and b) PW experiments

V. CONCLUSION

In this paper, the notable use of local computing facility is encouraged to give mutual benefits for player and server in cloud gaming service. By enabling the AHP-based decision-maker at the gaming device, the player's benefit in term of reasonable demands for adaptive resource under dynamic network availablity can be issued, due to the hierarchical analytic decision upon the different criteria, and alternatives. At the same time, the server's benefit in term of the improved gaming workload of a certain session can be realized. Our experimental results can confirm the validity of the proposed method, which is remarkably simple and flexible for enabling cognitive resource utilization in the cloud gaming environment.

REFERENCES

[1] R. Shea, J. Liu, E. C.-H. Ngai, and Y. Cui, "Cloud gaming: architecture and performance," *IEEE Network*, vol. 27, no. 4, pp. 16–21, Jul. 2013.

[2] W. Cai, M. Chen, and V. C. M. Leung, "Toward Gaming as a Service," *IEEE Internet Computing*, vol. 18, no. 3, pp. 12–18, May 2014.

[3] W. Cai, C. Zhou, V. C. M. Leung, and M. Chen, "Environment Perception for Cognitive Cloud Gaming," in *Cloud Computing*, V. C. M. Leung and M. Chen, Eds. Springer Int. Publishing, 2013, pp. 3–13.

[4] W. Cai, C. Zhou, V. C. M. Leung, and M. Chen, "A Cognitive Platform for Mobile Cloud Gaming," in *2013 IEEE 5th Int. Conf. on Cloud Computing Tech. and Sci. (CloudCom)*, 2013, vol. 1, pp. 72–79.

[5] C. Hull, C. Darryl, M. Philip and P. Gerard, "FRAGED: A Framework for Adaptive Game Execution and Delivery to Improve the Quality of Experience in Network Aware Games," In Proc. of PGNET'14, Liverpool (UK), June 2014.

[6] R. Jitpukdeebodintra and S. Witosurapot, "Hybrid Method for Adaptive Cloud Gaming Contents," *GSTF Journal on Computing (JoC)*, vol. 4, no. 2, Mar. 2015.

[7] C. Kahraman, S. C. Onar, and B. Oztaysi, "Fuzzy Multicriteria Decision-Making: A Literature Review," *Int. J. of Computational Intelligence Systems*, vol. 8, no. 4, pp. 637–666, Jul. 2015.

[8] C.-C. Chou and K.-W. Yu, "Application of a New Hybrid Fuzzy AHP Model to the Location Choice," *Mathematical Problems in Engineering*, vol. 2013, pp. e592138, Jun. 2013.

[9] O. S. Vaidya and S. Kumar, "Analytic hierarchy process: An overview of applications," *European J. of Operational Research*, vol. 169, no. 1, pp. 1–29, Feb. 2006.

[10] C.E. Otero, I. Kostanic, L. Otero and L. Meredith, "Characterization of user-perceived quality of service (QoS) in mobile devices using network pairwise comparisons, " *Int. J. of Wireless & Mobile Networks*, vol. 2, no. 3, pp. 141–153, Aug. 2010.

[11] M. Godse and S. Mulik, "An Approach for Selecting Software-as-a-Service (SaaS) Product," in *IEEE Int. Conf. on Cloud Computing, 2009. CLOUD '09*, 2009, pp. 155–158.

[12] S. K. Garg, S. Versteeg, and R. Buyya, "SMICloud: A Framework for Comparing and Ranking Cloud Services," in *2011 Fourth IEEE Int. Conf. on Utility and Cloud Computing (UCC)*, 2011, pp. 210–218.

[13] W. Ho, "Integrated analytic hierarchy process and its applications – A literature review," *European Journal of Operational Research*, vol. 186, no. 1, pp. 211–228, Apr. 2008.

[14] M. N. Ismail, R. Ibrahim, and M. F. Md Fudzee, "A Survey on Content Adaptation Systems towards Energy Consumption Awareness," *Advances in Multimedia, Advances in Multimedia*, vol. 2013, pp. e871516, Jul. 2013.

[15] T. L. Saaty, "Decision making with the analytic hierarchy process," *Int. J. of Services Sciences*, vol. 1, no. 1, pp. 83–98, Jan. 2008.

[16] I. Ghergulescu, A.-N. Moldovan, and C. H. Muntean, "Energy-aware Adaptive Multimedia for Game-based e-learning," in *2014 IEEE Int. Sym. on Broadband Multimedia Systems and Broadcasting (BMSB)*, 2014, pp. 1–6.

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Scholarship Awards during Enrolment

Scholarship for Engineering Graduates

List of Publication and Proceeding

A. Rueangprathum, S. Limsiroratana, and S. Witosurapot, "Enabling Semantic-Based Ubiquitous Learning in UPnP Network Environment", "International Journal of Information and Education Technology", Vol. 5, No. 10, pp. 794-798, October, 2015.

A. Rueangprathum, S. Limsiroratana, and S. Witosurapot, "User-Driven Multimedia Adaptation Framework for Context-aware Learning Content Service, "Proceedings of IACT Melbourne Conferences", pp. 193-196, January, 2016.

A. Rueangprathum, S. Limsiroratana, and S. Witosurapot, "AHP-based Adaptive Resource Selection for Cognitive Platform in Cloud Gaming Service", "GSTF International Journal on Computing (JoC)", Vol. 4 No. 4, pp. 52-58, April, 2016.