

Broker-based Service-oriented Content Adaptation Framework

by

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Submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy



Deakin University

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Abstract

Electronic documents are becoming increasingly rich in content and varied in format and structure. At the same time, user preferences vary towards the contents and their devices are getting increasingly varied in capabilities. This mismatch between rich contents and user preferences along with the end device capability presents a challenge in providing ubiquitous access to these contents. Content adaptation is primarily used to bridge the mismatch by providing users with contents that is tailored to the given contexts e.g., device capability, preferences, or network bandwidth. Existing content adaptation systems employing these approaches such as client-side, server-side or proxy-side adaptation, operate in isolation, often encounter limited adaptation functionality, get overload if too many concurrent users and open to single point of failure, thus limiting the scope and scale of their services. To move beyond these shortcomings, this thesis establishes the basis for developing content adaptation solutions that are efficient and scalable. It presents a framework to enable content adaptation to be consumed as Web services provided by third-party service providers, which is termed as “service-oriented content adaptation”. Towards this perspective, this thesis addresses five key issues – *how to enable content adaptation as services* (service-oriented framework); *how to locate services in the network* (service discovery protocol); *how to select best possible services* (path determination); *how to provide quality assurance* (service level agreement (SLA) framework); and *how to negotiate quality of service* (QoS negotiation). Specifically, we have: (i) identified the key research challenges for service-oriented content adaptation, along with a systematic understanding of the content adaptation research spectrum, captured in a taxonomy of content adaptation systems; (ii) developed an architectural framework that provides the basis for enabling content adaptation as Web services, providing the facilities to serve clients’ content adaptation requests through the client-side brokering; (iii) developed a service discovery protocol, by taking into account the searching space, searching time, match type of the services and physical location of the service providers; (iv) developed a mechanism to choose the best possible combination of services to serve a given content adaptation request, considering QoS levels offered; (v) developed an architectural framework that provides the basis for managing quality through the conceptualization of service level agreement; and (vi) introduced a strategy for QoS negotiation between multiple brokers and service providers, by taking into account the incoming requests and server utilization and, thus requiring the basis of determining serving priority and negotiating new QoS levels. The performance of the proposed solutions are compared with other competitive solutions and shown to be substantially better.

Acknowledgements

I would like to express my heartiest gratefulness to God for His divine blessings, which has made it possible to complete this thesis successfully and for giving me the opportunity to work under the supervision of Professor Jemal Abawajy, which always provides innovative inputs, encouragement and constructive comments on my research, as well as guidance for publication. Without his supervision, this thesis would not have been completed. He always shares his experience not only on research but also about life, parenting, work and networking, among many others. Also, I would like to thank Professor Mustafa Mat Deris as the co-author for some of the papers.

I am thankful to all the past and present members of the *NCSS* (Networked Computing and System Security) research group. In particular, I thank Soon, Harinda, Shivali, Hairulnizam, Izuan, Masitah, Isredza, Nicholas, Davood, Ammar, Ahad, Raja, Fehad, Lucas, Aiden and Izzatdin for their help and comments on my work. I also had great time with them outside research. My pray is for our success and I am looking forward for future collaboration.

Many colleagues and researchers helped during my candidature by providing advice and incisive comments, and I am grateful to them. I also extend my gratitude to the staff from the Deakin's School of IT and International Office, and Universiti Tun Hussein Onn Malaysia for their support during my candidature. I am thankful to the thesis examiners for their feedbacks to improve the thesis content, structure and readability.

I acknowledge Malaysian Federal Government, Malaysian Ministry of Higher Education, Universiti Tun Hussein Onn Malaysia and Deakin University for providing scholarships and travel supports to pursue doctoral studies and attend international conferences.

I wish to give heartfelt thanks to my parents (Rohana and Md Fudzee; Suhaidah and Khalid), siblings (Farrah, Faiz, Farhana, Mariam, Luqman, Anisah, Nabelah, Busyra, Fatimah, Hakimi, Zarif, Syahnaz and Iqbal), relatives and friends (here and back there in Malaysia) for their help, support, dedication and love at all times. Without them, it would not be possible to come through the various stages of this life.

Finally, I sincerely express my heartiest gratefulness to God for giving me such a wonderful wife (Ruqayyah Khalid) to live with. Her inspiration, warmth, support and patience in educating our children (Amirul Hakim, Ainul Mardhiah, Ahmad Iskandar and Arfa Saida), organizing our daily routine and enriching our life are truly appreciated.

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September 2011*

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2012:

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Chapter 1

Introduction

The rapid development of digital media technologies has enabled the emergence of novel media content types for various domains including e-Commerce, e-Education, and e-entertainment. As a result, there is a phenomenal growth in consumable electronic information on subjects such as entertainment, security, education, and technical documentation targeted to diverse users in the form of content and services.

While online documents are becoming increasingly rich in content and varied in format and style, the original content is normally developed for a specific platform and is naturally made-up of media objects of different types with complicated structure and layout [1]. For instance, most of existing Web content is originally designed for desktop displays. At the same time, client devices are getting increasingly varied in their capabilities (e.g., processing power, input and output facilities). Therefore, direct content delivery to handheld devices without layout adjustment often leads to disorganization of information [2]. Moreover, as depicted in figure 1.1, not every handheld device can play all media types. For example, a non-multimedia mobile phone cannot play continuous video clips, while only H.264, MPEG-4 and M-JPEG formats are currently supported for iPhone video playback. As such, some widely employed video formats such as MKV and FLV will require format conversion or additional player before they can be played on iPhone.

Although content providers are under constant pressure to make content available in a variety of formats and for a variety of purposes [3], the mismatch between rich contents and the end devices capability coupled with specific users preferences

continues to present a challenge in providing seamless and ubiquitous device-independent access to the online electronic contents to interested users. It becomes apparent that a mechanism for dynamically transforming the original content to suite the end device and user's preference as appropriate is required.



Figure 1.1: Non technical view of content adaptation issue.

1.1 Motivation and Scope

Content adaptation has emerged as a potential mechanism to address some of the problems arising from the content-device mismatch [2, 4, 5, 6, 7, 8, 9, 10, 11]. Although many content adaptation approaches have been proposed, most of them tend to be fully or partially centralized. Problems with centralized adaptation scheme such as scalability and single-point failure are well known [12]. In order to address these problems, the idea of establishing content adaptation as a service that allows the use of a large number of adaptation mechanisms located in many places in the network has recently been advocated [11, 13, 14, 15]. Thus, the in-depth exploration of service-oriented architecture for content adaptation together with the enabling mechanisms is required to provide flexible and scalable content adaptation services. Unfortunately, analysis of the previous research efforts [5, 14, 16, 18] in this context reveals that there has been only a

few rudimentary frameworks exist. Also, in order to provide an efficient service-oriented content adaptation system, enabling mechanisms such as service discovery, path determination and service quality assurance are essential. However, these mechanisms have not been fully explored. The reason for this lack of progress is due to the complexity of the technological problems that need to be addressed in the practical context.

1.2 Research Significance

The content adaptation challenge is how to make the original contents readily available on a wide range of access devices for interested clients. One way to address this problem is by creating and maintaining different format of the original content suitable to the targeted access devices. However, keeping multiple copies of the original content will lead to tremendous overhead and places unwieldy burden on to the content authors.

Thus, what is required is a content adaptation system with the appropriate logic to analyse the content and all aspects of the adaptation contexts and formulate the content adaptation strategy accordingly. There are many content adaptation approaches that generate any content version from one single original version [3, 6, 7, 8, 9, 10, 16]. A request may require multiple content adaptation tasks that can lead to the requirement of multiple adaptation strategies including cross-media adaptation (e.g., media conversion, translation, summarization, and integration). None of existing standalone content adaptation systems is able to completely serve this request. Moreover, building one system that capable of providing various adaptation strategies is inefficient and costly.

On the other hand, there are many service providers offering a variety of content adaptation that can be loosely coupled. Therefore, the solution for these services is to cooperate with each other to completely serve the request that they cannot attain individually. A platform that enables such interconnection and interoperation is required. Thus, a greater scale as well as service quality can be achieved.

1.3 Research Problems

This thesis tackles the research challenges in relation to the development of scalable and efficient content adaptation solutions by enabling coordination and cooperation between

multiple service providers. While service-oriented content adaptation is appealing, the challenges in adopting it include architecting a system that analyses the required content adaptation tasks and distributes these tasks to the potential service providers. In particular, we identify and investigate the following five research issues:

- *How to enable content adaptation as services.* The platform that allows content adaptation to be performed as services by external service providers. This should include the essential mechanisms to manage client requests and service provider advertisements.
- *How to locate services in the network.* The protocol used to locate potential content adaptation service from the network. Such a protocol must take into account searching space, searching time, matching category of services and physical location of the service providers.
- *How to select best possible services.* The decision making mechanism used for choosing the best possible services to serve a request, given that multiple services can potentially perform a particular task.
- *How to provide quality assurance.* The framework used to manage service agreement between service providers and clients. It should formally specify the creation, monitoring and enforcement of such an agreement.
- *How to negotiate quality of service.* A mechanism to negotiate QoS before the agreement being settled. Service provider should ensure that the QoS they advertised is deliverable to avoid potential violation.

1.4 Research Objectives

To achieve the research aim, three main research objectives are identified and need to be fulfilled:

1. To develop the taxonomy of content adaptation systems and to determine the issue pertaining to existing content adaptation systems that have not been fully explored.
2. To design a conceptual framework for the service-oriented content adaptation based on the identified components and functions required for a complete content adaptation system.

3. To design, develop and analyse the enabling mechanisms, i.e. service discovery, path determination and service level agreement, in relation to service-oriented content adaptation.

1.5 Methodology

The proposed work will be carried out based on the experimental computer science method [17]. This method examines the research work to demonstrate two important concepts: proof-of-concept and proof-of-performance.

To demonstrate the proof-of-concept, some important steps were performed. First, the research area within content adaptation is critically reviewed to provide the overview that leads to the formulation of valid problem statements. From this review, the research work is justified. Then, the proposed conceptual framework of the service-oriented content adaptation architecture is designed and analytically analysed.

Proof-of-performance is demonstrated by conducting the implementation for the service discovery protocol, path determination and QoS negotiation using simulations. In those simulations, various parameters and workloads were used to examine and demonstrate the viability of the proposed solutions compared to the similar competitive solutions. Also, analytical analysis of some proposed algorithms is performed to evaluate the correctness.

1.6 Research Contributions

We detail the thesis contributions as the following:

1. *Content adaptation taxonomy*. This thesis presents a taxonomy of content adaptation systems. It investigates related concepts, describes the design themes and identifies implementation components required. The presented taxonomy is mapped to representative content adaptation systems to demonstrate its applicability. Also, the mapping assists to perform a gap analysis in this research field.
2. *Broker-based service-oriented content adaptation framework*. The thesis introduces an architectural model for service-oriented content adaptation. It describes the essential components, interaction sequences, and related protocols

for enabling content adaptation as services. An analytical analysis is conducted to demonstrate the framework applicability.

3. *Service discovery protocol.* The thesis investigates and presents the protocol to locate available content adaptation services from the network. Along with the derivation of the discoverability performance metric, extensive simulations have been conducted to study the performance of the service discovery protocol in this regards. The proposed protocol is able to quickly terminate the search when specified conditions are achieved. Also, the analytical analysis proved the completeness and the accuracy of the protocol.
4. *Path determination mechanism.* The thesis presents the mechanism to determine the best possible services based on the single objective assignment function. The proposed mechanism is evaluated through simulations in term of service selection execution. The mechanism is demonstrated to meet its objective i.e., appropriate service QoS value assignment.
5. *SLA framework.* This thesis introduces a framework for managing service level agreement in relation to content adaptation. It describes the interrelated phases and the essential mechanisms. Then within the framework, a QoS negotiation strategy is presented. The proposed negotiation strategy is evaluated through simulations and is shown to increase SLA settlement, and reduce request rejection and potential SLA violation as well.

To summarize, the work presented in this thesis is in line with the current trends that enable multitude content adaptation services without having to build a dedicated infrastructure [5, 14]. Therefore, it is our thesis to present service-oriented content adaptation solutions that are scalable and efficient.

1.7 Thesis Organization

The chapters of this thesis are derived from various papers published during the PhD candidature. The remainder of the thesis is organized as the following:

- *Chapter 2: Content Adaptation Systems.* This chapter provides an in-depth analysis and overview of existing content adaptation systems, presented within a comprehensive taxonomy.

- *Chapter 3: Service-oriented Content Adaptation.* This chapter presents an architecture to enable content adaptation to be consumed as services. It describes the key components to realize service-oriented content adaptation.
- *Chapter 4: Service Discovery Protocol.* This chapter presents a service discovery protocol in relation to service-oriented content adaptation. The simulation results are discussed as well.
- *Chapter 5: Path Determination.* This chapter presents a path determination mechanism in relation to service-oriented content adaptation and the related simulation results.
- *Chapter 6: Service Level Agreement.* This chapter presents a framework for managing service level agreement and QoS negotiation strategy in relation to service-oriented content adaptation. The simulation results of the negotiation strategy are discussed as well.
- *Chapter 7: Conclusion and Future Directions.* The concluding chapter provides a summary of contributions and a future research challenges.



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Chapter 2

Content Adaptation Systems

The ever-increasing amount of electronic information coupled with proliferation of diverse and heterogeneous devices, data sources, user preferences and networks has significantly increased the demand of content adaptation. This makes content adaptation as a thriving research field. There are many projects focused on the content adaptation being introduced constantly. This chapter provides an in-depth analysis of current content adaptation technologies, organized as a comprehensive taxonomy. The taxonomy provides a basis for categorizing related solutions and being mapped to a few representative systems to demonstrate its applicability. Then, a “gap analysis” is performed from the presented literature and used to position the thesis.

2.1 Introduction

Today, computing is no longer limited to a specific location using desktops devices, but can be done on laptop computers and information appliances (e.g., PDAs, smart phones, etc.) from anywhere at any time. This new computing platform is known as pervasive or ubiquitous computing and has recently attracted a lot of attention. However, the characteristics of this paradigm shift (including device heterogeneity, limited device capability, and user’s high mobility) bring about new challenges in the delivery of information, content and services in these environments. This makes the ability to adapt information, content and services to a diversity of computing devices a key to pervasive computing.

Specifically, devices, standards and software develop rapidly, but still often independently of each other [15]. This creates problems in terms of content suitability. Also, in pervasive environment, user and system-level applications must execute subject to a variety of resource constraints that generally can be ignored in modern desktop environments. Moreover, Web applications are designed with desktop platform in mind that usually contains rich media content and authored in a single version. In order to increase the usability of mobile Internet services, content adaptation is required. Also, the emergence of these requirements (e.g., device heterogeneity, user preferences, rich content) demands efficient content adaptation architecture. Designing such an architecture that will meet these requirements is challenging due to several issues: (a) supporting scalability, (b) meeting computational constraints, and (c) enhancing adapted content quality.

In this chapter, we present the literature of the content adaptation field. The research field of content adaptation have been growing rapidly during the past ten years and this has resulted in a plethora of new concepts, models and systems. An abstract architecture for a content adaptation system that succinctly captures the essential components and functions of a content adaptation system is presented. The significance of the different components and functions of the model are also discussed. A taxonomy that classifies the approaches that form the design space and implementation requirements of content adaptation systems is presented. The applicability of the taxonomy is demonstrated by mapping representative existing systems. Also, this taxonomy is used to perform “gap analysis” by revealing some of the areas that are yet to be fully explored that can lead to creative solutions.

2.2 Background

In this section, we present a generic content adaptation architecture that outlines the different components of content adaptation system architecture. The architecture is important to provide a central knowledge regarding the architecture (i.e., components, functions) choices made by existing content adaptation systems. To keep the model compact, only the core functions of the content adaptation systems are included. The essential definitions for content adaptation are also presented.

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