Cloud Computing and Digital Media

Fundamentals, Techniques, and Applications

Edited by

Kuan-Ching Li, Qing Li, and Timothy K. Shih

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Foreword

Cloud computing was initially only aiming at providing on-demand computing via shared pools of computational infrastructures. In just a few years, cloud computing has dramatically expanded its horizon to offer on-demand services to a broad range of configurable resources-sharing scenarios in networking, servers, storage, software, and applications. Such a thriving development of cloud computing is largely credited to an array of attractive benefits that include on-demand self-service provision, Internet-wide and device-independent access, rapid response to dynamic service requests, and usage-based pricing. The expansion from computational infrastructure sharing to a broader range of common resource sharing propels cloud computing into many new application domains that were not considered possible even when cloud computing was originally introduced.

Although we have witnessed an unprecedented boom in the development of various cloud computing–related technologies, commercially viable cloud computing services are still considered to be at an early stage of market adoption. However, according to many marketing analysts, cloud computing service revenues have been, and continue to be, growing strongly. Based on recent forecasts by leading market analysis firms, the compound growth rate for cloud computing services should remain at 20% or even higher for the next few years. Such a strong revenue growth should in turn fuel more comprehensive innovations in both technology advancement and application development. We have every reason to anticipate a profound penetration of cloud computing technology into all walks of digital life in the years to come.

Among various technical disciplines that have been vigorously impacted by cloud computing, digital media is probably the most prominent beneficiary from the recent advances in cloud computing. One reason for this pronounced impact can be attributed to the unique characteristics of digital media in its enormous data volume and real-time requirement throughout the entire application life cycle from generation, encoding, storage, processing, transmission, reception, and consumption of digital media. Cloud computing services, with their on-demand provision in nature, have been able to offer an extremely flexible platform for hosting a wide variety of digital media applications to take full advantage of virtually unlimited resources for the deployment, management, retrieval, and delivery of digital media services.

Many digital media applications are indeed demanding high computation at the cloud data center for an efficient management of media contents so as to release the burden of computational requirements for media terminals. Such applications are very much suited for the most acknowledged cloud computing service class known as infrastructure as a service (IaaS). The demands for intensive computation typically involve processing volumetric media data with massive parallel machines at cloud centers. More recently, two new types of cloud computing services, known as software as a service (SaaS) and platform as a service (PaaS), have also been recognized as having the potential to substantially change the way digital media content is accessed by consumers distributed over scattered geographical locations worldwide. Among this diverse set of digital media applications, some can be captured as software applications running on an underlying cloud computing infrastructure as SaaS for services that are readily accessible via Web browsers from any terminal at any location. More emerging digital media applications can also be deployed at cloud computing infrastructure using programming languages and toolsets as PaaS to host a variety of digital media toolsets for both enterprise and individual consumers.

The contemporary necessity of a ubiquitous access requirement for ever-increasing mobile device users has boosted the adoption of cloud computing for digital media enterprises and executives. Most cloud centers can be considered as geographically neutral because they can be accessed by mobile devices from locations worldwide. It is this characteristic of cloud services that enables digital media companies to develop new and better ways to quickly and efficiently deliver media content to fine-grained targeted consumers. Using cloud computing services, digital media enterprises shall be able to capture the greatest opportunity of efficient delivery because cloud centers allow content storage, media processing, and media distribution to be colocated and seamlessly coordinated. The cloud-based strategy can also improve media companies' competitive advantage through a faster and universal infiltration of multichannel (both wired and wireless networks) and multiscreen (fixed, tablet, laptop, and smartphones) markets with potentially reduced operation costs.

However, mobile media also poses significant challenges in the evolving new paradigm of cloud computing. At the center of these challenges is the significant unbalance in computational and storage capabilities between the cloud centers and mobile devices that triggers the necessary shift of intensive media operations from thin client mobile devices to cloud centers. Resource optimization becomes the major challenge for cloud-based digital media applications, especially for new media services that involve multichannels and multiscreens. To meet the dynamic demands from various media flows, novel solutions are needed to shift computational and storage loads from mobile devices to the cloud, to perform load balancing within a cloud, and to allocate resources across multiple clouds.

Emerging applications of cloud computing have outspread to a much broader range beyond digital media services. Two noticeable areas of such emerging applications are in health care and education. In health care, one central issue is the migration of current locally hosted electronic health record databases to the cloud-based service infrastructure to achieve reduced health-care integration costs, optimized resource management, and innovative multimedia-based electronic health-care records. In education, the ubiquity of cloud computing service centers facilitates a pervasive learning environment for both continuing education of common people and asynchronous tutoring of personalized learners.

As the landscape of new technologies for cloud computing and its applications changes at a steadfast pace, it is very much desired to have a comprehensive collection of articles in various topics in cloud computing as well as their applications in digital media. This excellent book coedited by Kuan-Ching Li, Qing Li, and Timothy K. Shih covers the fundamentals of cloud and media infrastructure, emerging technologies that integrate digital media with cloud computing, and real-world applications that exemplify the potential of cloud computing for next-generation digital media. Specifically, this book covers resource optimization for multimedia cloud computing, a key technical challenge in adopting cloud computing for various digital media applications. It also contains several important new technologies in cloud computing and digital media such as query processing, semantic classification, music retrieval, mobile multimedia, and video transcoding. In addition, this book also includes several chapters to illustrate emerging health-care and educational applications of cloud computing that shall have a profound impact on the welfare of mass populations in terms of their physical well-being and intellectual life. This book is indeed a must read not only for the researchers, engineers, and graduate students who are working in the related research and development topics but also for technology company executives, especially media company executives, to keep pace with the innovations that may impact their business models and market trends. I expect that the timely contributions from these distinguished colleagues shall have prominent influences on the continued flourishing of research and development in cloud computing and digital media.

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Preface

Cloud computing has appeared as a new trend for both computing and storage. It is a computing paradigm where hardware and network details are abstracted and hidden from the users who no longer need to have expertise in or control over the technology because the infrastructure "in the cloud" should support them. Cloud computing describes a new supplement, consumption, and delivery model based on the Internet, where shared resources, software, and information are provided on demand to computers and other devices, similar to an electricity grid. It has even been said that cloud computing may have a greater effect on our lives than the personal computer and dot-com revolutions combined due to scalability, reliability, and cost benefits that this technology can bring forth.

Digital media is a term that widely covers a large number of topics including entertainment, gaming, digital content, streaming, and authoring. Encompassed with the advancements of microprocessor and networking technologies, digital media is considered as a niche in the market as "the creative convergence of digital arts, science, technology and business for human expression, communication, social interaction and education."

The purpose of this book is to bridge the gap between digital media and cloud computing and to bring together technologies for media/data communication, elastic media/data storage, security, authentication, cross-network media/data fusion, interdevice media interaction/reaction, data centers, PaaS, SaaS, and so on. This book also aims at interesting applications involving digital media in the cloud. In addition, this book points out new research issues for the community to discuss in conferences, seminars, and lectures.

The book contains 15 chapters centered on digital media and cloud computing, covering various topics that can be roughly categorized into three levels: infrastructure where fundamental technologies need to be developed, middleware where integration of technologies and software systems need to be defined, and applications cases from the real world. The book is thus suitable as a timely handbook for senior and graduate students who major in computer science, computer engineering, management information system (MIS), or digital media technologies, as well as professional instructors and product developers. In addition, it can also be used as a textbook in senior research seminars and graduate lectures.

The development and production of this book would not have been possible without the support and assistance of Randi Cohen, computer science acquisitions editor at Chapman & Hall/CRC Press. Cohen brought this project from concept to production and has been a wonderful colleague and friend throughout the process. She deserves the credit for all the tedious AQ 2 work that made our work as editors appear easy. Her warm personality made this project fun, and her advice significantly improved the quality of this book. Kate Gallo, Samantha White, and Ed Curtis worked intensively with us and provided the necessary support to make this book ready.

With the continued and increasingly attracted attention on digital media in cloud computing, we foresee that this fast growing field will flourish just as successfully as the Web has done over the past two decades. We believe that readers can benefit from this book in searching for state-of-the-art research topics as well as in the understanding of techniques and applications in cloud computing, interaction/reaction of mobile devices, and digital media/data processing and communication. Of course, we also hope that readers will like this book and enjoy the journey of studying the fundamental technologies and possible research focuses of digital media and cloud computing.

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Qing Li is a professor in the Department of Computer Science, City University of Hong Kong, where he has been a faculty member since September 1998. He earned his BEng at Hunan University and MSc and PhD at the University of Southern California, Los Angeles, all in computer science. His research interests include database modeling, Web services, multimedia retrieval and management, and e-learning systems. He has been actively involved in the research community and is serving or has served as an editor of several leading technical journals, such as *IEEE Transactions on Knowledge and Data Engineering (TKDE)*, *ACM Transactions on Internet Technology (TOIT)*, *World Wide Web (WWW)*, and *Journal of Web Engineering*, in addition to serving as conference and program chair/co-chair of numerous major international conferences, including ER, CoopIS, and ACM RecSys. Professor Li is a fellow of the Institution of Engineering and Technology (IET, UK) and a senior member of the Institute of Electrical and Electronics Engineers (IEEE, USA) and China Computer Federation (CCF, China). He is also a steering committee member of Database Systems for Advanced Applications (DASFAA), AQ 4 International Conference on Web-based Learning (ICWL), and U-Media.

Timothy K. Shih is a professor at National Central University, Taiwan. He was the dean of the College of Computer Science, Asia University, Taiwan, and the chair of the Department of Computer Science and Information Engineering (CSIE) at Tamkang University, Taiwan. Dr. Shih is a fellow of the Institution of Engineering and Technology (IET). He is also the founding chairman of the IET Taipei Interim Local Network. In addition, he AQ 5 is a senior member of Association for Computing Machinery (ACM) and a senior member of the Institute of Electrical and Electronics Engineers (IEEE). Dr. Shih also joined the Educational Activities Board of the Computer Society. His research interests include multimedia computing and distance learning. He has edited many books and published over 490 papers and book chapters as well as participated in many international academic activities, including the organization of more than 60 international conferences. He was the founder and co-editor-in-chief of the *International Journal of Distance Education Technologies*, published by the Idea Group Publishing, Hershey, Pennsylvania. Dr. Shih is an associate editor of the *IEEE Transactions on Learning Technologies*. He was an associate editor of the *ACM Transactions on Internet Technology* and an associate editor of the *IEEE Transactions on Multimedia*. He has received research awards from the National Science Council (NSC) of Taiwan, the International Institute for Advanced Studies (IIAS) research award from Germany, the Brandon AQ 6 Hall award from the United States, and several best paper awards from international conferences. Dr. Shih has been invited to give more than 40 keynote speeches and plenary talks at international conferences as well as tutorials at IEEE International Conference on Multimedia and Expo (ICME) 2001 and 2006 and ACM Multimedia 2002 and 2007.

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CHAPTER 1

Mobile Multimedia Cloud Computing

An Overview

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1.1 INTRODUCTION

Mobile multimedia cloud computing provides access to data-intensive services (multimedia services) and data stored in the cloud via power-constrained mobile devices. With the development of multimedia computing, mobile devices, mobile multimedia services, and cloud computing, mobile multimedia cloud computing attracts growing attention from researchers and practitioners [1–3].

Mobile devices refer to miniaturized personal computers (PCs) [4] in the form of pocket PCs, tablet PCs, and smart phones. They provide optional and portable ways for users to experience the computing world. Mobile devices [5] are also becoming the most frequently used terminal to access information through the Internet and social networks. A mobile application (mobile app) [4,6] is a software application designed to run on mobile devices. Mobile apps such as Apple App Store (http://store.apple.com/us), Google Play (https://play.google.com/store?hl = en), Windows Phone Store (http://www.windowsphone.com/en-us/store), and BlackBerry App World (http://appworld.blackberry.com/webstore/?) are usually operated by the owner of the mobile operating system. Original mobile apps were for general purposes, including e-mail, calendars, contacts, stock market information, and weather information. However, the number and variety of apps are quickly increasing to other categories, such as mobile games, factory automation, global positioning system (GPS) and location-based services, banking, ticket purchases, and multimedia applications. Mobile multimedia applications are concerned with intelligent multimedia techniques to facilitate effort-free multimedia experiences on mobile devices, including media acquisition, editing, sharing, browsing, management, search, advertising, and related user interface [7]. However, mobile multimedia service still needs to meet bandwidth requirements and stringent timing constraints [8].

Cloud computing creates a new way of designing, developing, testing, deploying, running, and maintaining applications on the Internet [9]. The cloud center distributes processing power, applications, and large systems among a group of machines. A cloud computing platform consists of a variety of services for developing, testing, running, deploying, and maintaining applications in the cloud. Cloud computing services are grouped into three types: (1) application as a service is generally accessed through a Web browser and uses the cloud for processing power and data storage, such as Gmail (http://gmail.com); (2) platform as a service (PaaS) offers the infrastructure on which such applications are built and run, along with the computing power to deliver them, such as Google App Engine (http://code.google.com/appengine/); and (3) infrastructure as a service (IaaS) offers sheer computing resources without a development platform layer, such as Amazon's Elastic Compute Cloud (Amazon EC2; http://aws.amazon.com/ec2/). Cloud computing makes it possible for almost anyone to deploy tools that can scale up and down to serve as many users as desired. The cloud does have certain drawbacks, such as service availability and data security. However, economical cloud computing is being increasingly adopted by a growing number of Internet users without investing much capital in physical machines that need to be maintained and upgraded on-site.

With the integration of mobile devices, mobile multimedia applications, and cloud computing, mobile multimedia cloud computing presents a noteworthy technology to provide cloud multimedia services for generating, editing, processing, and searching multimedia contents, such as images, video, audio, and graphics via the cloud and mobile devices. Zhu et al. [3] addressed multimedia cloud computing from multimedia-aware cloud (media cloud) and cloud-aware multimedia (cloud media) perspectives. Multimedia cloud computing eliminates full installation of multimedia applications on a user's computer or device. Thus it alleviates the burden of multimedia software maintenance and upgrades as well as saving the battery of mobile phones. Kovachev et al. [10] proposed the i5CLoud, a hybrid cloud architecture, that serves as a substrate for scalable and fast time-to-market mobile multimedia services and demonstrates the applicability of emerging mobile multimedia cloud computing. SeViAnno [11] is an MPEG-7-based interactive semantic video annotation Web platform with the main objective of finding a well-balanced trade-off between a simple user interface and video semantization complexity. It allows standard-based video annotation with multigranular community-aware tagging functionalities. Virtual Campfire [12] embraces a set of advanced applications for communities of practice. It is a framework for mobile multimedia management concerned with mobile multimedia semantics, multimedia metadata, multimedia content management, ontology models, and multimedia uncertainty management.

However, mobile multimedia cloud computing is still at the infant stage of the integration of cloud computing, mobile multimedia, and the Web. More research is needed to have a comprehensive review of the current state of the art and practices of mobile multimedia cloud computing techniques. This chapter presents the state of the art and practices of mobile multimedia cloud computing. The rest of the chapter is organized as follows: Section 1.2 reviews the scenario examples of mobile multimedia cloud computing examined in recent studies. Section 1.3 explains the requirements for multimedia cloud computing architecture. Section 1.4 describes the architecture for mobile multimedia cloud computing designed in recent studies. Section 1.5 discusses existing and potential multimedia cloud services. And Section 1.6 draws a conclusion.

1.2 OVERVIEW OF MOBILE MULTIMEDIA CLOUD COMPUTING SCENARIOS

In this section, we review the scenarios examined in the existing literature for identifying the challenges imposed by mobile multimedia cloud computing, which need to be addressed to make mobile multimedia applications feasible. Table 1.1 presents the scenarios examined in recent studies with the application name, its description, and its focused cloud services.

In the cloud mobile gaming (CMG) scenario, Wang et al. [1] presumed to employ cloud computing techniques to host a gaming server, which is responsible for executing the appropriate gaming engine and streaming the resulting gaming video to the client device. This is termed CMG and enables rich multiplayer Internet games on mobile devices, where computation-intensive tasks such as graphic rendering are executed on cloud servers in response to gaming commands on a mobile device, with the resulting video being streamed back to the mobile device in near real time. CMG eliminates the need for mobile devices to download and execute computation-intensive video processing.

In the Virtual Campfire scenario, Cao et al. [12] examined the following three services enabling communities to share knowledge about multimedia contents. (1) In multimedia creation and sharing, the user creates and enriches multimedia content with respective metadata on various mobile devices, such as the Apple iPhone. Technical and contextual semantic metadata on the mobile device (device type, media file size, video codec, etc.) are automatically merged with manual annotations by the user. (2) In the multimedia search and retrieval, the user uses various multimedia search and retrieval methods such as plain keyword tags and semantic context-aware queries based on SPARQL [9,13]. The multimedia search results are presented as a thumbnail gallery. (3) In the recontextualization in complex collaboration, there are three services for the recontextualization of media. The first service facilitates the user to record the condition of the destroyed Buddha figures in the Bamiyan Valley during a campaign. All contents with additional stored GPS coordinates can be requested.

TABLE 1.1 Scenarios Examined in the Existing Literature toward Mobile Multimedia Cloud Computing

Name	Brief Description	Cloud Services
CMG [1]	One of the most compute- and mobile bandwidth-intensive multimedia cloud applications	Graphic rendering
Virtual Campfire [12]	Established in the German excellence cluster UMIC,[a] intending to facilitate intergenerational knowledge exchange by means of a virtual gathering for multimedia contents	Multimedia content creation and sharing, search and retrieval, recontextualization in collaboration
Collaborative metadata management and multimedia sharing [2]	Provide a set of services for mobile clients to perform acquisition of multimedia, to annotate multimedia collaboratively in real time, and to share the multimedia, while exploiting rich mobile context information	Metadata management
Mobile and Web video integration [2]	Platform-independent video sharing through an Android application for context-aware mobile video acquisition and semantic annotation	Multimedia annotation and rendering
Mobile video streaming and processing [2]	Android-based video sharing application for context-aware mobile video acquisition and semantic annotation	Video streaming
MEC-based Photosynth [3]	Cloud-based parallel synthing with a load balancer, for reducing the computation time when dealing with a large number of users	Image conversion Feature execution Image matching Reconstruction

[a] UMIC, Ultra High-Speed Mobile Information and Communication.

The user can collaboratively tag contents by using recombination or embedding techniques. The second service is a mobile media viewer. The third service is a collaborative storytelling service. In the end, Cao et al. illustrate two future scenarios including (1) the 3D video scenario and (2) the remote sensing scenario. In the first scenario, further integration of device functionalities (GPS, digital documentation) and 3D information can be realized by using cost-efficient standard video documentation hardware or even advanced mobile phone cameras. Thus, computational efforts can be incorporated into new 3D environment for storytelling or game-like 3D worlds, such as Second Life (http://secondlife.com/). In the second scenario, the remote sensing data from high-resolution satellites can be incorporated into complex and collaborative planning processes for urban or regional planners, for example, in cultural site management.

In the collaborative metadata management and multimedia sharing scenario, Koavchev et al. [2] depicted the workflow as follows: Imagine that a research team, consisting of experts on archeology, architecture, history, and so on, is documenting an archeological site. (1) The documentation expert takes pictures or videos of a discovered artifact on-site. (2) He tags the content with basic metadata. (3) He stores the tagged content to the cloud. (4) The architecture expert annotates the multimedia content and (5) pushes the updates to the local workforce or historian. (6) The historian corrects the annotation, stores the corrections in the cloud, and (7) pushes the updates to all the subscribed team members. Zhou et al. [14] examined a similar scenario to address how multimedia experiences are extended and enhanced by consuming content and multimedia-intensive services within a community.

In the mobile and Web video integration scenario, Koavchev et al. [2] demonstrated an Android-based video sharing application for context-aware mobile video acquisition and semantic annotation. In this application, videos are recorded with a phone camera and can be previewed and annotated. The annotation is based on the MPEG-7 metadata standard. The basic types include agent, concept, event, object, place, and time. After the video content is recorded and annotated, the users can upload the video content and metadata to the cloud repository. In the cloud, the transcoding service transcodes the video into streamable formats and stores the different versions of the video. At the same time, the semantic metadata services handle the metadata content and store it in the MPEG-7 metadata store.

In the video streaming and processing scenario, Koavchev et al. [2] stated that the cloud computing paradigm is ideal to improve the user multimedia experience via mobile devices. The scenario shows the user records some events using the phone camera. The video is live streamed to the cloud. The cloud provides various services for video processing, such as transcoding and intelligent video processing services with feature extraction, automatic annotation, and personalization of videos. This annotated video is further streamed and available for watching by other users. Figure 1.1 illustrates the user experience of cloud-enhanced video browsing.

To reduce the computation time when dealing with a large number of users, Zhu et al. [3] demonstrated a cloud computing environment to achieve the major computation tasks of Photosynth, that is, image conversion, feature extraction, image matching, and reconstruction. Each

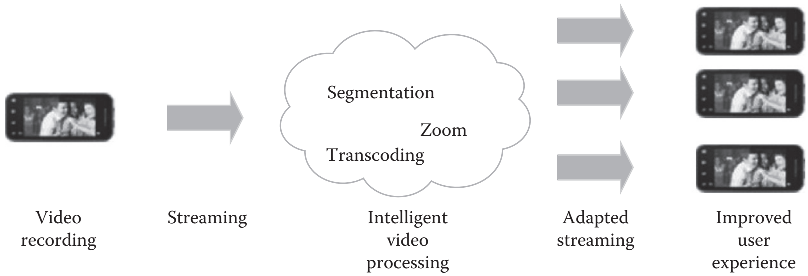

FIGURE 1.1 Improving user experience for mobile video by video processing cloud services.

computation task of Photosynth is conducted in a media-edge cloud (MEC). The proposed parallel synthing consists of user- and task-level parallelization. In the former, all tasks of synthing from one user are allocated to one server to compute, but the tasks from all users can be done simultaneously in parallel in the MEC. In the latter, all tasks of synthing from one user are allocated to *N* servers to compute in parallel.

In sum, the mobile multimedia cloud computing shares the same scenario with the traditional multimedia applications for distributedly and collaboratively creating, annotating, and sharing the content to enhance and extend the user multimedia experience. However, in the mobile multimedia cloud service, it is a big problem for mobile devices to provide intelligent video processing, such as processing of videos, because they need a lot of resources and are very central processing unit (CPU) intensive. The integration of multimedia applications into cloud computing is investigated as an efficient alternative approach that has been gaining growing attention. The efficient use of scalable computational resources in cloud computing enables a great number of users to concurrently enhance and extend the user multimedia experience on mobile devices.

1.3 OVERVIEW OF ARCHITECTURAL REQUIREMENTS FOR MOBILE MULTIMEDIA CLOUD COMPUTING

Multimedia processing is energy consuming and computing power intensive, and it has a critical demand for quality of multimedia experience as well. Due to the limited hardware resources of mobile devices, it may be promising to investigate the paradigm of multimedia cloud computing using cloud computing techniques to enhance and extend the user multimedia experience. On the one hand, cloud computing efficiently consolidates and shares computing resources and distributes processing power and applications in the units of utility services. On the other hand, multimedia cloud computing needs to address the challenges of reducing the cost of using mobile network and making cloud multimedia services scalable in the context of concurrent users and communication costs due to limited battery life and computing power as well as the narrow wireless bandwidth presented by mobile device [1,2,15]. This section presents the architectural requirements for mobile multimedia cloud computing indicated by recent studies (Table 1.2).

Concerning the design of the cloud multimedia streaming on limited mobile hardware resources, Chang et al. [16] presented the following three key challenges for system developers.

1. Data dependence for dynamic adjustable video encoding. Multimedia encoding and decoding often depends on the information on mobile devices. A suitable dynamic adjustable video encoding through a cloud needs to be designed to prevent failure of decoding.

2. Power-efficient content delivery. Mobile devices usually have limited power supplies; therefore, it is necessary for mass data computing to develop power-efficient mechanisms to reduce energy consumption and achieve user experience quality.

3. Bandwidth-aware multimedia delivery. If network bandwidth is not sufficient, it may easily cause download waiting time during play. Therefore, an adjustable multimedia encoding algorithm is required to dynamically adjust the suitable encoding for the multimedia file playing in the mobile device.

TABLE 1.2 Requirements for Mobile Multimedia Cloud Computing Indicated by the Recent Studies

Requirement	**Description**
Cloud multimedia stream [16]	Data dependence for adjustable video encoding, power-efficient content delivery, and bandwidth-aware multimedia delivery
Multimedia cloud computing [3]	Heterogeneities of the multimedia service, the QoS, the network, and the device
Cloud mobile media [1]	Response time, user experience, cloud computing cost, mobile network bandwidth, and scalability
Mobile multimedia cloud computing [2]	Three crucial perspectives: technology, mobile multimedia, and user and community

Zhu et al. [3] stated that multimedia processing in the cloud imposes great challenges. They highlighted several fundamental challenges for multimedia cloud computing. (1) Multimedia and service heterogeneity. Because there are so many different types of multimedia services, such as photo sharing and editing, image-based rendering, multimedia streaming, video transcoding, and multimedia content delivery, the cloud has to support all of them simultaneously for a large base of users. (2) Quality-of-service (QoS) heterogeneity. Different multimedia services have different QoS requirements; the cloud has to support different QoS requirements for various multimedia services. (3) Network heterogeneity. Because there are different networks, such as the Internet, wireless local area networks (WLANs), and third-generation wireless networks, with different network characteristics, such as bandwidth, delay, and jitter, the cloud has to adapt multimedia content for optimal delivery to various types of devices with different network bandwidths and latencies. (4) Device heterogeneity. Because there are so many different types of devices, such as televisions, PCs, and mobile phones, with different capacities for multimedia processing, the cloud has to adjust multimedia processing to fit the different types of devices, including CPU, graphics processing unit (GPU), display, memory, storage, and power.

Wang et al. [1] analyzed the requirements imposed by mobile multimedia cloud computing, including response time, user experience, cloud computing cost, mobile network bandwidth, and scalability to a large number of users; other important requirements are energy consumption, privacy, and security.

Koavchev et al. [2] investigated the requirements for mobile multimedia cloud architecture from three crucial perspectives: technology, mobile multimedia, and user and community. The technology perspective establishes a basic technical support to facilitate mobile cloud computing. The mobile multimedia perspective concerns the capabilities of multimedia processing. The last perspective is related to users' experiences in multimedia delivery and sharing. Table 1.3 details the three perspectives.

1.4 OVERVIEW OF THE ARCHITECTURE DESIGN TOWARD MOBILE MULTIMEDIA CLOUD COMPUTING

This section reviews the architecture toward mobile multimedia cloud computing designed in recent studies (Table 1.4).

In order to improve the current development practices, combining with a mobile cloud computing delivery model, Koavchev et al. [2] proposed a four-layered i5 multimedia cloud architecture (Figure 1.2). The infrastructure and platform layer focus on requirements from the

TABLE 1.3 Three Perspectives Addressing Requirements of Mobile Multimedia Cloud Computing

	Perspective	Description
	Data management	Cloud storage is well suitable for content management, but is inferior to metadata management.
	Communication	Broadband Internet connection is needed to meet the required QoE.[a] XMPP (http://xmpp.org) and SIP[b] [17] together with their extensions are powerful for cloud services.
	Computation	The huge cloud processing power is not fully accessible to mobile devices.
Mobile multimedia	Multimedia formats and transcoding	Different mobile device media platforms are based on different formats and coding.
	Multimedia semantics	Multimedia semantic analysis is needed for discovering complex relations, which are serving as input for reasoning in the media interpretation.
	Multimedia modeling	Modeling multimedia content sensed by mobile devices provides valuable context information for indexing and querying of the multimedia content.
User and community	Sharing and collaboration	XMPP-based communication is needed to enhance real-time multimedia collaboration on multimedia metadata, adaptation, and sharing.
	Ubiquitous multimedia services	Users expect to have ubiquitous access to their multimedia content by switching from one device to another.
	Privacy and security	Ensure that the data and processing is secure and remains private, and the data transmission between the cloud and the mobile device is secured.

[a] QoE, quality of experience.
[b] SIP, session initiation protocol.

technology perspective and use virtualization technology, which separates the software from the underlying hardware resources. The virtual machines are grouped into three realms: processing realm for parallel processing, streaming realm for scalable handling of streaming requests, and general realm for running other servers such as extensible messaging and presence protocol (XMPP) or Web server. DeltaCloud application programming interface (API) layer enables cross-cloud interoperability on infrastructure level with other cloud providers, for example, Amazon

TABLE 1.4 Architecture Designed in Recent Studies toward Mobile Multimedia Cloud Computing

Architecture	Brief Description
i5CLoud architecture [2]	It consists of four layers of infrastructure, platform, multimedia services, and application.
Cloud mobile media architecture [1]	It is capable of dynamically rendering multimedia in the cloud servers, depending on the mobile network and cloud computing constraints.
Multimedia streaming service architecture over cloud computing [16]	It provides dynamic adjustable streaming services while considering mobile device resources, multimedia codec characteristics, and the current network environment.
Multimedia cloud computing [3]	It provides multimedia applications and services over the Internet with desired QoS.

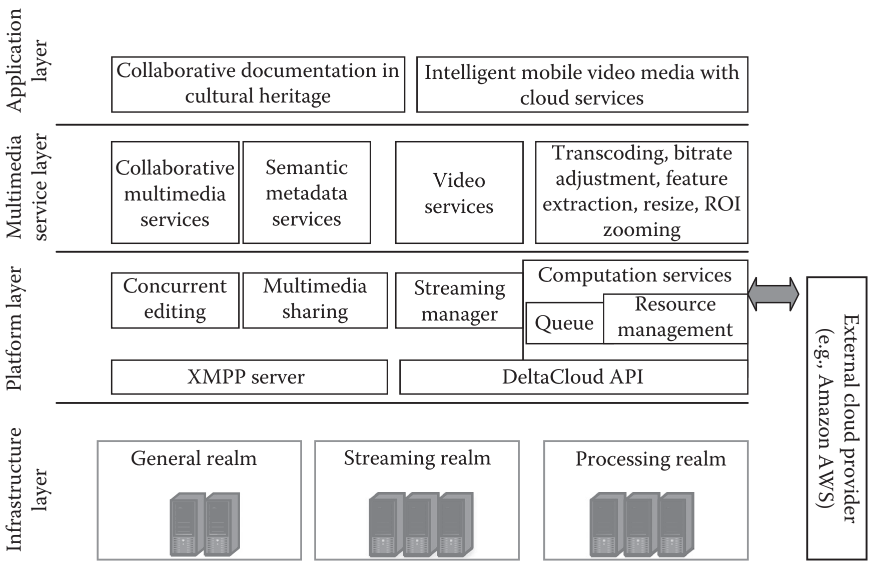

FIGURE 1.2 i5CLoud architecture for multimedia applications. ROI, region-of-interest.

EC2. The DeltaCloud core framework assists in creating intermediary drivers that interpret the DeltaCloud representational state transfer (REST) API on the front while communicating with cloud providers using their own native APIs on the back. The concurrent editing and multimedia sharing components are the engine for the collaborative multimedia and semantic metadata services. MPEG-7 metadata standards are employed to realize semantic metadata services. Video processing

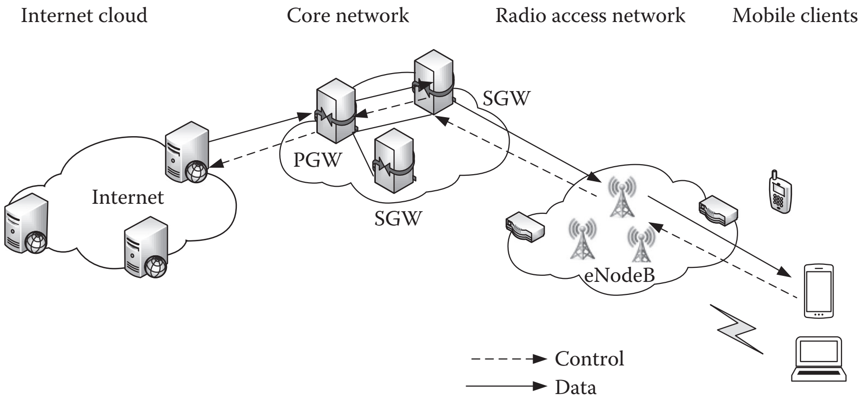

FIGURE 1.3 Cloud mobile multimedia architecture with control and data flows. PGW, packet data gateway; SGW, service gateway. (From Wang, S. and Dey, S., *IEEE Transactions on Multimedia,* 99, 1, 2013. With permission.)

services improve mobile users' experience. The application layer provides a set of services for mobile users to create multimedia to collaboratively annotate and share.

Wang et al. [1] described a typical architecture for cloud mobile multimedia applications, including end-to-end flow of control and data between the mobile devices and the Internet cloud servers (Figure 1.3). A typical cloud multimedia application primarily relies on cloud computing IaaS and PaaS resources in public, private, or hybrid clouds. A multimedia application has a thin client on mobile devices, which provide the appropriate user interfaces (gesture, touch screen, voice, and text based) to enable users to interact with the application. The resulting control commands are transmitted uplink through cellular radio access network (RAN) or WiFi access points to appropriate gateways in an operator core network (CN) and finally to the cloud. Consequently, the multimedia content produced by the multimedia cloud service is transmitted downlink through the CN and RAN back to the mobile device. Then the client decodes and displays the content on the mobile device display.

To address the restricted bandwidth and improve the quality of multimedia video playback, Chang et al. [16] proposed a novel cloud multimedia streaming architecture for providing dynamic adjustable streaming services (Figure 1.4), which consist of two parts: the service function of the cloud equipment (i.e., cloud service) and the information modules provided by the mobile device (i.e., mobile device service). Table 1.5 describes the architecture modules.

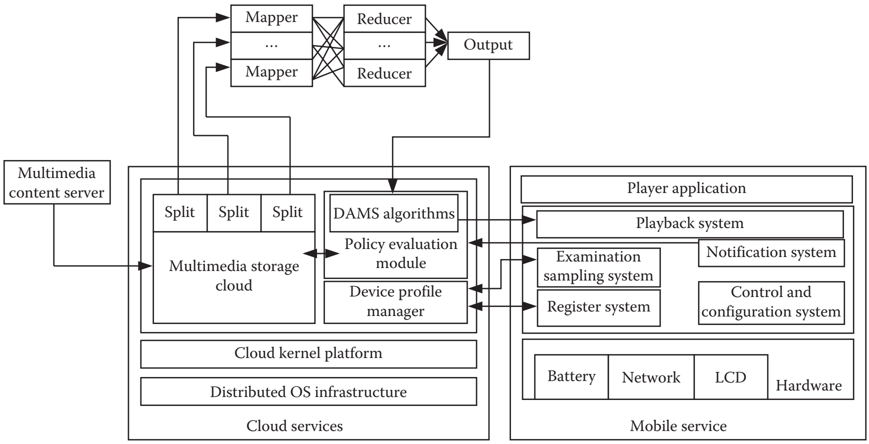

FIGURE 1.4 Multimedia streaming service architecture over cloud computing. OS, operating system. DAMS, dynamic adjustable streaming; LCD, liquid-crystal display. (From Chang, S., Lai, C., and Huang, Y., *Computer Communications,* 35, 1798–1808, 2012. With permission.)

TABLE 1.5 Module Description for the Multimedia Streaming Service Architecture

Module	**Sub-Module**	**Description**
Cloud service	Device profile management	Records the features of mobile devices such as the maximum power of the processor, the codec type, the available highest upload speed of the network, and the highest available download speed of the network
	Policy evaluation module	Determines the multimedia coding parameters, in terms of mobile device parameters
	Multimedia storage cloud	Provided by some multimedia storage devices
Mobile device service	Register system	Registers a device profile manager over the cloud
	Notification system	Has the hardware monitor and notification component, which is used to monitor the real-time information of battery and network bandwidth
	Examination sampling system	Measures system efficiency, including the parameters in the DPM[a]
	Playback system	Parses metadata to obtain film coding characteristics and relevant information
	Control and configuration system	Offers user–machine interface interaction settings and controls hardware module functions

[a] DPM, device profile manager.

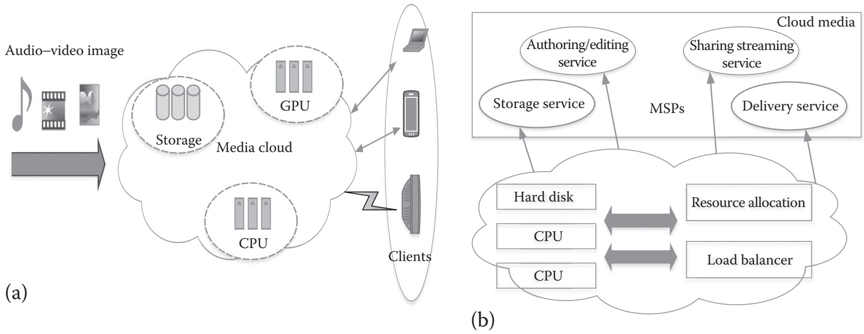

FIGURE 1.5 Architecture of multimedia cloud computing: Media cloud (a) and cloud media (b) services. (From Zhu, W., Luo, C., Wang, J., and Li, S., "Multimedia Cloud Computing," *IEEE Signal Processing Magazine,* 28, 59–69, 2011. ©2011 IEEE. With permission.)

It is foreseen that cloud computing could become a disruptive technology for mobile multimedia applications and services [18]. In order to meet multimedia's QoS requirements in cloud computing for multimedia services over the Internet and mobile wireless networks, Zhu et al. [3] proposed a multimedia cloud computing framework that leverages cloud computing to provide multimedia applications and services over the Internet. The principal conceptual architecture is shown in Figure 1.5. Zhu et al. addressed multimedia cloud computing from multimedia-aware cloud (media cloud) and cloud-aware multimedia (cloud media) perspectives. The media cloud (Figure 1.5a) focuses on how a cloud can perform distributed multimedia processing and storage and QoS provisioning for multimedia services. In a media cloud, the storage, CPU, and GPU are presented at the edge (i.e., MEC) to provide distributed parallel processing and QoS adaptation for various types of devices. The MEC stores, processes, and transmits media data at the edge, thus achieving a shorter delay. In this way, the media cloud, composed of MECs, can be managed in a centralized or peer-to-peer (P2P) manner. The cloud media (Figure 1.5b) focuses on how multimedia services and applications, such as storage and sharing, authoring and mashup, adaptation and delivery, and rendering and retrieval, can optimally utilize cloud computing resources to achieve better quality of experience (QoE). As depicted in Figure 1.5b, the media cloud provides raw resources, such as hard disk, CPU, and GPU, rented by the media service providers (MSPs) to serve users. MSPs use media cloud resources to develop their multimedia applications and services, for example, storage, editing, streaming, and delivery.

1.5 OVERVIEW OF MULTIMEDIA CLOUD SERVICES

Mobile multimedia cloud computing presents a significant technology to provide multimedia services to generate, edit, process, and search multimedia contents via the cloud and mobile devices. Traditionally, there exist different types of multimedia services, such as photo sharing and editing, multimedia streaming, image searching and rendering, and multimedia content delivery. A typical multimedia life cycle is composed of acquisition, storage, processing, dissemination, and presentation [3]. Theoretically, the cloud should support these types of multimedia services. This section presents multimedia cloud services examined by the recent studies (Table 1.6).

Cloud multimedia authoring as a service [3] is the process of editing multimedia contents, whereas a mashup deals with combining multiple segments from different multimedia sources. A cloud can make online authoring and mashup very effective, providing more functions to clients, since it has powerful computation and storage resources that are widely distributed geographically. Cloud multimedia authoring can avoid the preinstallation of an authoring software in clients. With the use of the cloud multimedia authoring service, users conduct editing in the media cloud. One of the key challenges in cloud multimedia authoring is the computing and communication costs in processing multiple segments from single or multiple sources. Zhu et al. [3] pointed out that future research needs to tackle distributed storage and processing in the cloud, online previewing on mobile devices.

Cloud multimedia storage as a service is a model of networked online storage where multimedia content is stored in virtualized pools of storage. The

TABLE 1.6 Multimedia Cloud Services Examined by the Recent Studies

Service	Description
Cloud multimedia authoring	The process of editing segments of multimedia contents in the media cloud
Cloud storage	The advantage of being "always-on," higher level of reliability than local storage
Cloud multimedia rendering	Conducting multimedia rendering in the cloud, instead of on the mobile device
Cloud multimedia streaming	Potentially achieving much a lower latency and providing much a higher bandwidth due to a large number of servers deployed in the cloud
Cloud multimedia adaptation	Conducting both offline and online media adaptation to different types of terminals
Cloud multimedia retrieval	Achieving a higher search quality with acceptable computation time, resulting in better performance

cloud multimedia storage service can be categorized into consumer- and developer-oriented services [3]. Consumer-oriented cloud storage service holds the storage service on its own servers. Amazon Simple Storage Service (S3) [19] and Openomy [20] are developer-oriented cloud storage services, which go with the typical cloud provisioning "pay only for what you use."

Cloud multimedia rendering as a service [1] is a promising category that has the potential of significantly enhancing the user multimedia experience. Despite the growing capacities of mobile devices, there is a broadening gap with the increasing requirements for 3D and multiview rendering techniques. Cloud multimedia rendering can bridge this gap by conducting rendering in the cloud instead of on the mobile device. Therefore, it potentially allows mobile users to experience multimedia with the same quality available to high-end PC users [21]. To address the challenges of low cloud cost and network bandwidth and high scalability, Wang et al. [1] proposed a rendering adaptation technique, which can dynamically vary the richness and complexity of graphic rendering depending on the network and server constraints, thereby impacting both the bit rate of the rendered video that needs to be streamed back from the cloud server to the mobile device and the computation load on the cloud servers. Zhu et al. [3] emphasized that the cloud equipped with GPU can perform rendering due to its strong computing capability. They categorized two types of cloud-based rendering: (1) to conduct all the rendering in the cloud and (2) to conduct only computation-intensive part of the rendering in the cloud while the rest would be performed on the client. More specifically, an MEC with a proxy can serve mobile clients with high QoE since rendering (e.g., view interpolation) can be done in the proxy. Research challenges include how to efficiently and dynamically allocate the rendering resources and design a proxy for assisting mobile phones on rendering computation.

Cloud multimedia streaming as a service utilizes cloud computing resources to perform computation-intensive tasks of encoding and transcoding in order to adapt to different devices and networks. Cloud multimedia streaming services utilize the elasticity provided by cloud computing to cost-effectively handle peak demands. Cloud-based streaming can potentially achieve a much lower latency and provide a much higher bandwidth due to the large number of servers deployed in the cloud. Cloud multimedia sharing services also increase media QoS because cloud–client connections almost always provide a higher bandwidth and a shorter delay than client–client connections. The complexities of cloud multimedia sharing mainly reside in naming, addressing, and accessing control [3].

Cloud multimedia adaptation as a service [3] transforms input multimedia contents into an output video in a form that meets the needs of heterogeneous devices. It plays an important role in multimedia delivery. In general, video adaptation needs a large amount of computing, especially when there are a vast number of simultaneous consumer requests. Because of the strong computing and storage power of the cloud, cloud multimedia adaptation can conduct both offline and online media adaptation to different types of terminals. CloudCoder is a good example of a cloud-based video adaptation service that was built on the Microsoft Azure platform [22]. CloudCoder is integrated into the origin digital central management platform while offloading much of the processing to the cloud. The number of transcoder instances automatically scale to handle the increased or decreased volume. Zhu et al. [3] presented a cloud-based video adaptation framework in which the cloud video adaptation in a media cloud is responsible for collecting customized parameters, such as screen size, bandwidth, and generating various distributions either offline or on the fly. One of the future research topics is how to perform video adaptation on the fly.

Cloud multimedia retrieval as a service is a good application example of cloud computing used to search digital images in a large database based on the image content. Zhu et al. [3] discussed how content-based image retrieval (CBIR) [23] can be integrated into cloud computing. CBIR includes multimedia feature extraction, similarity measurement, and relevance feedback. The key challenges in CBIR are how to improve the search quality and how to reduce computation time. Searching in a database such as the Internet is becoming computation intensive. With the use of the strong computing capacity of a media cloud, one can achieve a higher search quality with acceptable computation time, resulting in better performance.

1.6 CONCLUSION

Multimedia computing needs powerful computing and storage capacity for handling multimedia content while achieving the desired QoE, such as response time, computing cost, network bandwidth, and concurrent user numbers. Mobile devices are constrained in resources of memory, computing power, and battery lifetime in the handling of multimedia content. Cloud computing has the ability to develop on-demand computing and storage capacities by networking computer server resources. Integrating cloud computing into mobile multimedia applications has a profound impact on the entire life cycle of multimedia contents, such as authoring, storing, rendering, streaming and sharing, and retrieving. With the use of cloud multimedia services, potential mobile cloud multimedia applications include storing documents, photos, music, and videos in the cloud; streaming audio and video in the cloud; coding/decoding audio and video in the cloud; interactive cloud advertisements; and mobile cloud gaming.

In this chapter, we presented the state of the art and practices of emerging mobile multimedia cloud computing with perspectives of scenario examination, requirement analysis, architecture design, and cloud multimedia services. Research in mobile multimedia cloud computing is still in its infancy, and many issues in cloud multimedia services remain open, for example, how to design a proxy in a media cloud for manipulating 3D content on demand to favor both network bandwidth usage and graphical rendering process, how to optimize and simplify 3D content to reduce the energy consumption of a mobile device, how to accelerate mobile multimedia cloud computing utilizing P2P technology (i.e., P2P-enabled mobile multimedia cloud computing), and so on.

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