Cloud Mobile Media: Opportunities, Challenges, and Directions

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***Abstract*—Three recent developments - increasing adoption of smart phones and tablets as desired platforms for infotainment, increased access to mobile broadband networks globally, and availability of public Clouds - are aligning to possibly enable a new generation of truly ubiquitous multimedia services on mobile devices: Cloud Mobile Media (CMM) services. Such services will be able to avail of the elasticity of cloud computing and ubiquity of cloud storage, and thereby not constrained either by mobile device capabilities, or availability of content. In this paper, we look at early trends in CMM services, and opportunities and benefits for new CMM services in the near future. We analyze the possible impact of such services, and issues that need to be addressed to make CMM services viable, including response time, user experience, energy, privacy, cost and scalability. We provide several directions for possible solutions, which include developing response time management techniques, scalable cloud media application, and cloud user experience measurement techniques. We also propose extending the Cloud beyond the traditional Internet to the edge of the wireless networks.**

***Keywords*-Cloud Computing; Cloud Rendering; Cloud Mobile Gaming; User Experience; Scalability**

I. INTRODUCTION

Over the last few years, there has been an increased number of services that have "migrated to the Cloud", and new Cloud-based services that have become popular. Most of the early adopters of Cloud have been enterprise applications and IT departments; according to Juniper Research, revenue from mobile enterprise cloud-based services is expected to rise from nearly $2.6 billion in 2011 to $39 billion in 2016 [1]. Interestingly, a recent survey by Yankee Group reveals that beyond the conventional motivation of shifting IT budgets from capital to operating expenses, IT managers consider the primary benefit for end-users to be ability to work from anywhere, collaborate more effectively, and have simpler access to business applications regardless of the client device [2].

Similar motivations that have driven mobile enterprise cloud services are also driving adoption of mobile consumer cloud services: the ability to access media from anywhere: any device, platform, and network. According to Juniper Research, revenues from consumer cloud mobility services, initially driven by cloud based music and video storage and download services like the ones recently launched by Amazon's Cloud Drive and Apple's iCloud,, are expected to reach $6.5 billion per year by 2016 [1].

Besides such storage and download services, we believe a big boost to mobile consumer cloud services will come from a major shift in the mobile applications market, from primarily native applications to ones utilizing the cloud more, thereby enabling much richer media experiences. While according to MarketsandMarkets.com, the global mobile applications market is expected to be worth $25.0 billion by 2015 [3], we believe use of the Cloud will enable more powerful applications, and hence more significant growth. We also note initiatives such as GSMA's OneAPI [4], which will allow access to network information, regardless of operator, via Web applications rather than device clients, and will further motivate and ease development of cloud-based mobile applications.

In this paper, we focus on Cloud Mobile Media (CMM) applications and services, which will enable mobile users to not only access rich media from any mobile device and platform, but even more importantly, which will enable mobile users to engage in new, rich media experiences that are not possible otherwise from their mobile devices. CMM will also enable service providers and network operators to offer services much more efficiently, with lower cost and better user experience. As more consumers adopt smart phones and tablets as one of their primary media experience platforms, we believe CMM will significantly boost the revenue of Cloud SaaS providers. Some of the media rich CMM services will require new and richer platform and infrastructure capabilities as explained in the next sections, thereby providing a new set of revenue opportunities for Cloud PaaS and IaaS providers. And finally, CMM offers new opportunities for mobile network operators to close the growing gap between growth in data usage and data revenue by offering innovative CMM services and experiences, outside of conventional app stores where initiative and revenue share have both belonged mostly to non-operator participants.

In the rest of the paper, in Section II, we discuss different types of CMM services that we expect to see develop, including their advantages, but also challenges that will be faced in making them successful. In Section II, we elaborate on two major challenges of CMM services, ensuring good and consistent user experience, and cost and scalability of CMM services. In Section III, we propose directions for possible solutions to the challenges.

II. TYPES OF CLOUD MOBILE MEDIA SERVICES

We expect a very heterogeneous set of Cloud Mobile Media services and applications to emerge, with different types of consumer experiences and advantages enabled. In this section, we attempt to categorize CMM services, and analyze for each category the cloud infrastructure and platform needs, advantages and user experiences enabled, and challenges to make the services successful. Table 1 summarizes the different categories of mobile multimedia applications that we expect to be driven by the use of the Cloud, including store and download services, audio and video streaming services, interactive services like multi-way video conferencing and interactive advertisements, rich rendering based services like mobile multi-user gaming and augmented reality, and cloud based media analytics that will provide better understanding of user preferences and experiences, and drive personalized mobile

	Storage and Download	Audio/Video Streaming	Interactive Services	3D/Multiview Rendering	Media Analytics
Content/services enabled on mobile devices	Photos, Music, Files	Streaming audio, video, movies; Cloud DVR	Video Chat; Remote Desktop; Interactive advertisements	Mobile Gaming; Augmented Reality	Personalized services
Iaas, Paas features needed	Cloud Storage with high availability and integrity	Cloud Transcoding, Transrating, Caching	Cloud Transcoding, Transrating	Multi-core GPUs; Efficient cloud rendering;	Cloud media usage/QoE probes; Media classification engines
Advantages	Ubiquitious access; Sharing	Low CAPEX; high scalability with demand	Easier support for multiple devices/platforms	Enables highest quality rendering; multi-player, multi-platform	Unified analytics for media usage across devices and networks
Challenges	Ensuring content security, privacy; Additional wireless traffic	Cloud service cost; Cloud energy, cooling costs	Response time; Video quality; Cloud service cost; Cloud energy, cooling costs	Response time; User experience; Cloud service cost; Additional wireless traffic; Cloud energy, cooling costs	Data protection; privacy

Table 1: Analysis of different categories of potential Cloud Mobile Media services, including cloud capabilities needed, advantages derived by having the services based on cloud, and challenges to make the services successful.

services. For each category of CMM services, we list the IaaS and PaaS features that will be needed, including some which are available today, and some that need to be developed. We also list the advantages of each category of CMM services, including what multimedia experience can be enabled that cannot be supported currently, and the challenges that need to be addressed to make the service category successful.

As discussed before, *Cloud based storage and download* is the most commonly used category of CMM service today, with recent high profile launches by Amazon, Apple, and Google among others. The most important enabler by this category of services is the ease of access of media from any device anywhere, irrespective of the source of the media and/or the device used to generate the media. To enable mass adoption of such services, the PaaS providers will need to ensure high availability and integrity of data, and the SaaS provider will need to ensure content security and user privacy. However, a major impact of the mass adoption of this category of CMM service will be significant increase in mobile data traffic, and potentially larger data bills for mobile subscribers.

Audio and video streaming based services and applications can benefit by utilizing cloud computing resources to perform compute intensive tasks of encoding, and transcoding and transrating needed to adjust to different devices and networks. For on-demand video, computing costs can be reduced by caching popular videos at different resolutions and bit rates. Besides lower initial capital expenses, the advantage of cloud based audio/video services is the use of elasticity in cloud computing resources to more cost-effectively handle differing and peak demands. However, to support the expected significant increase in demand for mobile video [5], the Cloud will need to provide server architectures and tools that can enable massively concurrent transcoding/transrating implementations, at efficiencies and cost points that can be enabled today with custom hardware solutions. The concern is particularly critical for the use of public Clouds to offer video services, as current public Cloud capabilities and price structures, including network bandwidth costs, may make operating expenses of video services very high.

We expect the *Interactive Services* category to be a rapidly growing segment of mobile multimedia services, including mobile video communications, remote desktop access from mobile, and interactive mobile advertisements. As shown in Table 1, besides the typical consideration of lower capex, use of the cloud will lead to easier support for multiple devices and operating platforms. One of the biggest challenges of such applications will be the potentially high latency and packet loss of the wireless network that may be experienced by the video stream, both from and to the mobile device, thereby potentially affecting the strict response time requirements of such interactive applications, and also the video quality, depending on what transport protocol is used. As in audio/video streaming, the operating cost can also be a concern, till Cloud capabilities and pricing structures are improved as suggested in the previous paragraph.

A promising category of CMM applications that has the potential of significantly enhancing the media experience of mobile users is *Cloud based rendering*. Despite the progress in the capabilities of mobile devices, there is a widening gap with the growing computing/power requirements of the latest 3D and multi-view rendering techniques and that can be supported by today's and near future mobile devices, including tablets. Cloud based rendering can bridge that gap by allowing rendering to be executed in the cloud, instead of on the mobile device, thereby potentially enabling mobile users to play the same rich Internet games available to high-end PC users [6], or participate in rich augmented reality and/or multi-view immersive experiences that are being developed primarily with PC users in mind. Moreover, analogous to transcoding, we expect a new capability to emerge that we term trans-rendering - the ability to automatically adjust rendering to different device and platform capabilities, thus relieving game and augmented reality application developers from the expensive cycle of developing device and platform specific mobile versions. We believe the ability to enable such rich experiences on all mobile devices and platforms, coupled with the inherent advantages of ubiquity and location information associated with the use of mobile devices, will drive a new generation of cloud based mobile media applications.

As summarized in Table 1, enabling cloud mobile rendering applications will require additional capabilities from Cloud infrastructure and platforms, as well as addressing some significant challenges. Clouds will need to include architectural provisions, like massively multi-core GPUs, and software support for developing highly concurrent cloud rendering applications like cloud gaming engines, as each cloud rendering session will need to be supported by a separate cloud rendering instance. Moreover, in applications like cloud mobile gaming, in response to gaming commands from the mobile device, not only does rendering need to be performed in the cloud, but the rendered video will need to be encoded and delivered over wireless networks to the mobile device, all

in near real time, as user experience for such applications is highly dominated by fast response time [6]. Also, the need to transmit the rendered video for each rendering/gaming session can mean significant additional bandwidth cost leading to high operating expenses for the service provider, significant additional traffic on the wireless networks possibly leading to overloading of the networks, loss of video quality, and additional cost for mobile subscribers due to tiered data plans.

Because of the high levels of multimedia computation and transmission involved, the above three categories of CMM services can lead to a significant increase in cloud energy and cooling costs, which will need to be addressed through new developments in green computing and sustainability research.

Cloud Media Analytics: While data analytics is playing an ever important role in the related Internet, Media, and Telecommunications market segments, we believe cloud based mobile media services will offer tremendous opportunities for unified media analytics that can be utilized by cloud platform providers, mobile network operators, and CMM service providers to offer more personalized services, and with better quality of experience. Cloud media analytics will be able to expand on current data analytics and reporting capabilities to include the rich multimedia content that are consumed by users, across different cloud platforms and mobile networks, and from different types of devices. For example, such services may be able to understand user preferences and intent from the videos watched by users. Similarly, cloud media analytics may be able to provide new cloud access and performance metrics, including quality of experience, which can be used to improve the Cloud designs and offerings. As noted in Table 1, cloud media analytics will need new PaaS capabilities, like cloud media usage probes, cloud quality of experience measurement techniques, and media classification engines, for example, which can automatically classify the category of videos watched by different users. However, cloud media analytics will need to address significant concerns that will naturally arise regarding the ability to maintain user privacy, and protection and sharing of media analytics data collected.

In summary, we envision media-rich cloud based mobile applications to emerge, besides many current mobile media services migrating to the cloud. These developments can lead to new and efficient mobile media experiences, and thereby revenue growth opportunities. However, as pointed in this section, several technical and eco-system challenges will need to be addressed, including ensuring high availability, data integrity and user privacy, lowering energy consumption and cooling costs, ensuring response time and user experience over wireless networks, and reducing cloud service cost associated with high computing and bandwidth needed by CMM services, and thereby ensuring service scalability. In the next section, we take a deeper look at the last two challenges, as they are crucial to understand and address to make CMM services attractive to end users, as well as economically viable for service providers, thus leading to mass adoption and monetization.

III. Major Challenges: User Experience and Cost

CMM applications, unlike other cloud applications, will need to overcome the challenges of the wireless network, including limited bandwidth and impact on QoE. Moreover, many of the CMM applications will be very compute and network bandwidth intensive, unlike for example Cloud-based mobile enterprise applications. In this section, we discuss in more details the above two challenges, while providing some empirical data we collected.

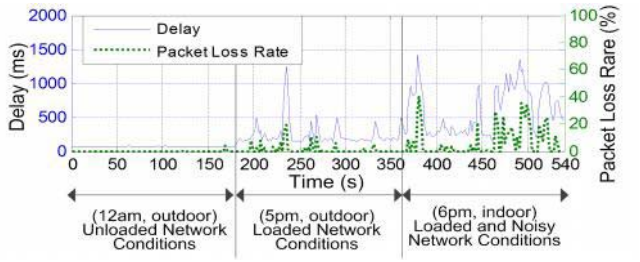

Figure1: Cloud Mobile Video: Network delay and packet loss.

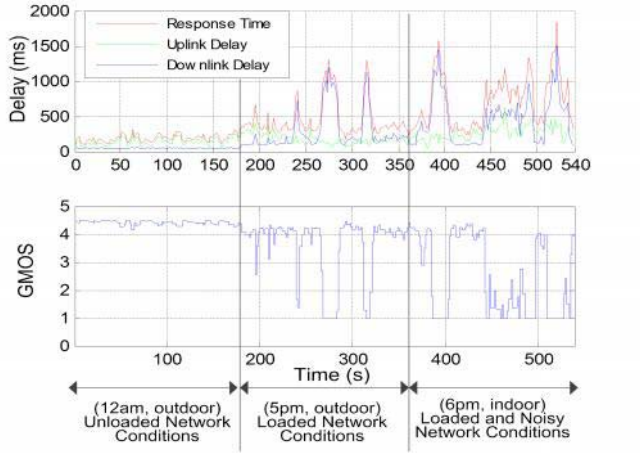

Figure 2: Cloud Mobile Gaming: Delays, response time, and QoE.

A. Wireless Network Factors and Impact on User Experience

To study the impact of wireless networks on the quality of CMM services, we conducted two experiments with two different categories of CMM services. In the first experiment, we implemented a video streaming application on a public cloud platform, and measured the delay and packet loss, shown in Figure 1, when video is streamed over a 3G wireless network from the cloud to the mobile client. We conducted the second experiment with a cloud mobile gaming application we have developed, which as described in Section II is highly interactive, with gaming commands transmitted uplink from the mobile device to the cloud servers, and the rendered video needs to be streamed downlink from the server to the mobile client in near real time. Since this application is highly sensitive to response time, we measured uplink delay, downlink delay, and round-trip response time, as shown in Figure 2. We also report the user experience as measured by a metric GMOS that was developed and validated in [6]. Both the experiments were conducted under different network conditions – Figures 1 and 2 show 180 seconds data samples collected under three different conditions: when the network was not loaded (data collected at mid night), when the network was loaded (data collected at 5pm), and when the network was loaded and the signal conditions were not strong (data collected at 5pm, and inside a building).

Figure 1 shows that when the network is not loaded and the signal strength is strong, video streaming from the cloud experienced low delay between 40-90 ms, and low packet loss between 0-3%, leading to good video quality. However, when the 3G network was loaded, or when the user is in noisy network condition with poor signal strength, the delay experienced by the video application can become as high as 1.5 seconds and the packet loss as high as 40%, thereby sometimes severely impacting the video quality of experience.

Cloud Provider	Computing Price ($/MIPS)	Storage Price ($/GB/sec)	Network Price ($/kb)	Cost for WoW Session ($/hour)
Cloud Provider 1	4.30e-9	3.85e-8	1.50e-8	0.110
Cloud Provider 2	5.54e-9	5.78e-8	1.65e-8	0.135
Cloud Provider 3	6.66e-9	5.78e-8	1.88e-8	0.161

Table 2: Cloud service price for Cloud Mobile Gaming using different cloud platforms

Figure 2 shows significant increase in uplink, downlink, and round-trip response time when the network is congested and/or the user is in poor signal conditions, leading to significant adverse impact on the quality of gaming experience, as measured by the GMOS scores reported (where a GMOS score above 4.0 indicates very good experience, between 4.0 and 3.0 indicates acceptable experience, and below 3.0 indicates unacceptable experience [6]).

The above experiments indicate that for CMM services to be successful, serious attention has to be given to (a) address challenges imposed by mobile networks like latency and response time, and (b) ensure good user experience.

B. *Cloud Service Cost and Scalability*

While one of the primary advantages of using cloud services is to eliminate capital expenses, and depend on the elasticity of cloud computing to scale to varying capacity needs, in this section we elaborate on the challenges that will be faced by some of the computing and bandwidth intensive CMM applications, like cloud based mobile gaming and rendering, in terms of prohibitively high operating expenses.

Table 2 shows the cloud pricing structures of three popular cloud service providers (whose names have been withheld to maintain anonymity), including CPU price, storage price, and network bandwidth price. It also shows the cost per hour of a VGA resolution cloud mobile gaming session of the popular Multiplayer Online Role-Playing Game (MMORPG), World of Warcraft, (WoW), assuming each session needs 1GB cloud storage space, 600kbps cloud network bandwidth, and up to 5000 MIPS cloud computing capacity. Assuming average playing time of 23 hours/week [7], from Table 2 the monthly operating expense for a cloud mobile gaming provider using public cloud platforms will be at least $10/month per WoW player. Considering typical subscription prices (for example, current price of WoW prepaid card is $15/month), this level of opex will be too high, even to support VGA resolution.

Figure 3 shows our estimate of concurrent WoW online gamers according to hours of day in China, one of the large online gaming markets. Our estimate is based on a study showing daily usage patterns for WoW gamers [8], and extrapolating with the number of WoW peak concurrent users

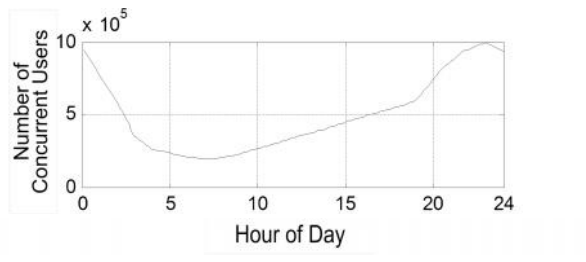

Figure 3: Daily concurrent user pattern for game WoW.

Video Resolution	480p	720p	1080p
Hourly cost per session ($)	0.110	0.193	0.275
Daily operating cost for Fig. 3 usage (million $)	1.308	2.294	3.236

Table 3: Cloud Mobile Gaming operating cost for game WoW.

in China, that has been steady for several years at 1 million [9]. Figure 3 highlights the advantage of using the rental model offered by cloud computing, instead of owning servers: peak concurrent session demands can be very high, and provisioning with service provider's own servers can lead to significant capex cost. However, since each gaming session has to execute its own rendering and encoding session in the cloud, supporting the significant number of concurrent sessions with can be very challenging. Table 3 shows the cost to support WoW cloud mobile gaming per session per hour for different resolutions, as well as the daily operating cost for the concurrent user profile shown in Figure 3, assuming each similar resolution gaming session has similar computing, storage, and bandwidth needs. From Table 3 we see that the daily operating expense can be very high, up to $3.24M for WoW, which puts a question mark on the scalability of cloud mobile gaming, as the level of concurrency that need to be supported may be even much higher to support all the other popular games.

Besides the potentially high operating expenses, the other scalability concerns for CMM services like audio/video streaming, interactive services, and cloud rendering applications are the very high demand on wireless network bandwidth that will be imposed, and in particular, during peak demand periods, and its implication on network latency, packet loss, and response time.

IV. Proposed Directions for Solutions

In this section, we outline possible directions to address the major challenges facing rich CMM services. In particular, we briefly discuss techniques that look promising, and maybe even necessary, to address the challenges of ensuring low latency and response time, high user experience, low cloud operating expenses, low wireless network bandwidth needed, high scalability, and support for diverse devices and platforms.

A. *Cloud Delay and Response Time Management Techniques*

We need to develop techniques that can monitor, measure, and manage in real time delay and response time for CMM services, in particular interactive, and gaming/rendering applications. The reliability and latency tradeoff of TCP and UDP protocols need to be examined in the context of different CMM applications, and may have to be customized depending on the application requirements. Also, we need to develop video adaptation techniques which focus on latency and response time, as opposed to packet loss, since the downlink delay will be dominated by video transmitted from the cloud to the mobile devices.

For example, to support the highly interactive, low response time requirement of cloud mobile gaming, we proposed a variation of TCP protocol to ensure highly reliable but low latency uplink transmission of gaming commands from mobile devices, and downlink delay aware video bit rate adaptation and video buffering techniques, with significant improvement in user experience [10]. We believe similar approaches can be developed for other delay-sensitive CMM applications to ensure meeting response time requirement and user experience.

B. Network and Device Aware Scalable CMM Applications

CMM applications will need to seamlessly support heterogeneous wireless networks and devices to enable an important benefit: ubiquitous, and consistently high, user experience of mobile media applications. To enable this, CMM applications need to be scalable and adaptive to different wireless networks and conditions, and device capabilities like screen resolution, interfaces, and processing, and battery status.

Content scaling techniques, like web and video transrating and transcoding, can be used to address network bandwidth constraints and device capabilities. However, the above techniques will need to be made significantly more efficient to handle the massive concurrency that is expected for CMM applications, and to ensure low latency and response time critical for CMM applications, through a combination of developing and providing appropriate cloud architectures, and developing efficient real-time transcoding and transrating algorithms that can best map to such cloud architectures.

Recently, scalable video coding (SVC) [11] has been developed to enable bit rate, spatial, and temporal scaling of video to network and device capabilities. Techniques have also been developed to make SVC more efficient for wireless networks [12]. SVC techniques can be useful for developing scalable CMM applications; however, their impact on cloud service cost and latency/response time needs to be investigated.

For cloud rendering applications, scalable rendering techniques need to be developed, which are aware of wireless network conditions, cloud computing costs, and device capabilities. Our research has demonstrated the feasibility of developing adaptive rendering techniques, which can adjust to varying network conditions, as well as being able to scale down significantly as needed network bandwidth and computing costs [13]. We need to extend such scalable rendering techniques to address device scalability, like enabled by SVC.

And finally, the prohibitive operating cost and scalability concern of some of the rich CMM services will need to be addressed, using a combination of innovative CMM-friendly cloud architectures, more efficient transcoding and rendering techniques, and scalable applications as described above.

C. Cloud QoE Modeling and Measurment

As discussed in Section IIIA, the user experience associated with CMM services can be severely affected by wireless network factors. Moreover, if scalable CMM applications are deployed, content scaling may adversely affect user experience, while at the same time being able to positively address network and device constraints, and thereby improve user experience. To ensure proper understanding of effects of different network, video and rendering parameters on cloud user experience, and optimal use of scalable CMM applications, we need to develop techniques to model and measure cloud user experience.

D. Wireless Cloud: Extending Cloud to Wireless Networks

Since many of the challenges for CMM applications are due to the limited capacity and associated latency and user experience concerns of wireless networks, we propose development of wireless cloud, bringing the benefits of cloud computing and storage to the operator core networks (CN) and radio access networks (RAN). In wireless cloud, use of CN and RAN resources can be potentially virtualized to enable more efficient sharing, and deployment of new CMM services using network APIs (like GSMA's OneAPI [4]). The problem of network delay can be potentially addressed by supplementing nodeBs and eNodeBs in the RAN with video caches, such that each requested video does not have to be fetched from the Internet cloud storages/CDNs, thereby also easing the congestion in the CNs and RAN backhauls. The challenges of response time faced by CMM applications like cloud rendering and cloud gaming can be potentially eased by adding suitable computing capabilities to CNs and RANs, such that some of the rendering and video processing tasks can be performed in the wireless cloud closer to the edge.

To ensure optimal usage of the wireless cloud resources and enable scalability of concurrent CMM users, new wireless cloud scheduling techniques need to be developed, which can simultaneously consider the computing and storage resources in the wireless cloud, together with the network availabilities for each CMM client, including the availability of Femto and WiFi networks to offload CMM traffic. The above approaches have the potential of not only reducing delay and enhancing user experience, but also ease capacity concern of wireless networks.

V. CONCLUSION

In this paper, we have analyzed the prospects of Cloud Mobile Media services, which may make possible new media experiences and applications from mobile devices. We have discussed the challenges that need to be addressed to make CMM applications successful, and suggested new technology directions that look promising to address the CMM challenges.

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