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Selected Topics of Mobile Multimedia Communication Services

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Selected Topics of Mobile Multimedia Communication Services

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Abstract

Due to the recent advancements in the related fields of technologies, mobile multimedia communication is possible with acceptable quality nowadays. Designing suitable multimedia communication services is the next step to both best utilize the advancements and enable effective and increasing use of multimedia in mobile communication. Designing interworkable services is an option to both provide flexibility and complement the services. This dissertation first provides an overview of different mobile multimedia communication services to depict a panoramic view about the subject. Then, it analyzes three potential mobile multimedia communication services of different types, carefully selected based on the context of this dissertation, to lay the foundation for the description that follows. These services are circuit-switched multimedia telephony, Multimedia Messaging Service (MMS), and streaming.

MMS has been defined as the solution for mobile multimedia messaging to overcome the known limitations of other existing messaging systems. On the other hand, streaming has been enhanced significantly to make it useful and effective in mobile communication. As the research questions of the dissertation are mostly about MMS and streaming, these are thoroughly analyzed focusing on different related aspects of standardization, implementation, and relevant published research works to find their suitability in the available infrastructures and markets. MMS is also compared with other popular messaging systems – SMS, e-mail and IM. Based on the comparative study, MMS has many advantages.

Beside identifying the advantages of MMS, this dissertation also points out couple of its limitations – an inability to handle a message requiring more storage space than available in a terminal, and long retrieval time for a large message. The store-and-forward working principle of MMS requires the storage of the whole message in a terminal before it can be rendered. As MMS has been lately positioned to carry different bandwidth-hungry media with reasonable quality and length, an MMS message can easily become too large for the available storage space of a terminal. Moreover, long retrieval time of a large message can frustratingly keep a user waiting before it is rendered.

The limitations are not visible as such in a real-time service, as it does not require storing the whole content before rendering. Interworking with such a service can be used to remove the limitations of MMS. As MMS works in multiple hops between the peer-ends, the interworking should be in terms of using a real-time service within selected hops of MMS transmission, where the limitations are critical. This dissertation considers different important factors to find the optimum scope (extent) of the interworking - using a real-time service in the last hop of MMS transmission to retrieve a message by the recipient terminal. Streaming is found suitable in the dissertation to interwork with MMS to remove the limitations, while circuit-switched multimedia telephony did not appear suitable.

The dissertation also finds the solution for the optimum interworking. First, a conceptual framework is designed. Then, three complete implementation solutions are introduced based on the conceptual framework. The solutions are consistent with the basic architecture and the working principles of both MMS and streaming. Here, consistency is important for both preserving user experience and avoiding fragmentation. All these solutions are compared with each other, indicating that none of the solutions has complete advantages over the others. One of the solutions is standardized in the 3rd Generation Partnership Project (3GPP) and the Open Mobile Alliance (OMA), while two solutions have been granted and published as patents. The dissertation also shows a general and flexible end-to-end architecture to accommodate the solutions in different deployment situations. The architecture considers different practical factors like person-to-person messaging, involvement of a content

provider and multiple service providers, load balancing and scalability, agreement between a content provider and a service provider, and the use of existing networks for the interworking.

MMS has been lately equipped with a new feature - transporting application data. As for example, a chess application in a terminal can use MMS to transport the information about each move on chess-board by remotely located players. This dissertation proposes a few enhancements for the feature to make it more effective. It provides a solution for this feature to be both backward compatible with the MMS solution not supporting this feature, and forward compatible so that a future application can start using the available MMS solution for transporting its data at any time. Compatibility is important not only for smooth deployment of the feature, but also for the future growth of applications, and thus the use of MMS. The solution is partially standardized in the 3GPP and the OMA, while it has been also lately granted and published as a patent. The format of the data communication between MMS and an application is not standardized. As a common format can be helpful in developing applications independently, this dissertation proposes the use of XML (Extensible Markup Language) in this regard. As the extent of data communication between MMS and an application in a terminal is also not defined, this dissertation also shows several examples of XML document to indicate what data should be communicated between an application and MMS.

Preface

The work for this dissertation has been carried out in Nokia Corporation, Tampere, Finland, where I got the chance to work with different mobile multimedia communication services. I started with circuit-switched multimedia telephony in 1998, and continued with the development of MMS, which was quite a challenge, as we started from the scratch. Though, we adopted different available technologies for MMS, it was not easy due to the involvement of different interest groups. Later, I worked with many other messaging, rich-communication, and personal information related services. I am grateful to Nokia Corporation for promoting my doctoral studies, and providing me the opportunity and facility for publishing the required papers. I also acknowledge the contribution, consideration and cooperation of my superiors and colleagues in Nokia Corporation in this regard.

I would like to express my profound gratitude for my supervisor Professor Jarmo Harju of Tampere University of Technology for his confident support, friendly guidance, and valuable comments. His encouragement and assessment provided me confidence and realistic hope. I also thank Dr. Petri Jarske of Nokia Corporation for guiding me for a while.

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Many of my friends and relatives helped me sincerely in many different ways during the whole period of my studies. Such continuous help kept the environs steady and stable, making it much easier for me. I am sorry not to list their names, as I am afraid of missing someone in the process. I am taking this chance to acknowledge and appreciate all the helps I enjoyed from my well wishers.

I learnt the value of education and got continuous support in all possible forms from my parents Mrs. Hazera Mostafa and Mr. Golam Mostafa. I tried to summon-up their words of inspiration in critical situation, when I was almost giving up; and it helped. I would not be able to come this far if my father was not successful in convincing me for taking this path. My sister Nazlee Ferdousi and brother Monir-E-Mostafa also helped me a lot in becoming myself, which provided me the right platform for my higher studies.

I have been overwhelmingly touched by the love and affection I got from my wife Selina Sharmin. When I felt down in this long and bumpy journey, she always stood by me with her emotional support and effective cooperation, and ensured that my moral remains high and I am not derailed. The birth of our twins Mimin Odri Mostafa and Simin Ratri Mostafa (in the middle of the study) and their growth provided me the invaluable feelings of achievement and the appropriate tempo to carry on with my studies. Dramatically, our next child is due almost at the same time when I am planning to defend my doctoral dissertation; and I feel very lucky as each is making me keen for the other.

Tampere, April 2009

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List of Publications

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[P1] Miraj-E-Mostafa, *MMS – the Modern Wireless Solution for Multimedia Messaging*, Proceedings of the 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2002), Lisbon, Portugal, vol. 5 of 5, pp. 2466-2472, Sep. 2002.

[P2] Miraj-E-Mostafa, *Interworking between MMS and Streaming*, Proceedings of the IASTED International Conference on Communication Systems and Networks (CSN 2002), Malaga, Spain, pp. 376-383, Sep. 2002.

[P3] Miraj-E-Mostafa, *Implementation Solutions for the Interworking between MMS and Streaming*, International Journal for Communication Systems, vol. 16, issue 10, pp. 877-892, Nov. 2003.

[P4] Miraj-E-Mostafa, *Improved Implementation Solution and General Mobile Network Architecture for the Interworking between MMS and Streaming*, International Journal for Communication Systems, vol. 19, issue 3, pp. 335-357, Apr. 2006.

[P5] Miraj-E-Mostafa, *Transporting Data between Wireless Applications Using a Messaging System - MMS*, Wireless Communications and Mobile Computing, vol. 7, issue 6, pp. 729-740, Aug. 2007.

List of Abbreviations

2G	2nd Generation
3G	3rd Generation
3GPP	3rd Generation Partnership Project
3GPP2	3rd Generation Partnership Project 2
AAC	Advanced Audio Coding
Ack	Acknowledgement
ACM	Address Complete Message
AKA	Authentication and Key Agreement
AMR	Adaptive Multi-Rate
AMR-NB	AMR Narrow Band
AMR-WB	AMR Wide Band
AMR-WB+	Extended AMR-WB
ANM	Answer Message
API	Application Programming Interface
APP	Atom Publishing Protocol
ARIB	Association of Radio Industries and Businesses
ARQ	Automatic Repeat Request
ATIS	Alliance for Telecommunications Industry Solutions
AVC	Advanced Video Coding
AVP	Audio/Video Profile
BCIE	Bearer Capability Information Element
BS	Bearer Service
BSC	Base Station Controller
BTS	Base Transceiver Station
CAB	Converged Address Book
CCSA	China Communications Standards Association
CCSRL	Control Channel Segmentation and Reassembly Layer
CC/PP	Composite Capabilities/Preference Profile
CDG	CDMA Development Group
CDMA	Code Division Multiple Access
CMF	Compact Multimedia Format
Codec	Coder/decoder
CPG	Call Progress
CPM	Converged IP Messaging
CS	Circuit-Switched
DIMS	Dynamic and Interactive Multimedia Scenes
DLS	Downloadable Sounds
DM	Device Management
DRM	Digital Rights Management
DS	Data Synchronization
DTD	Document Type Definition
DVB-H	Digital Video Broadcast - Handheld
ECMA	European Computer Manufacturers Association
EDGE	Enhanced Data Rates for GSM Evolution
EGPRS	Enhanced GPRS
EMN	E-Mail Notification

EMS	Enhanced Messaging Service
ENUM	Electronic Numbering
ERELD	Enabler Release Definition
ETSI	European Telecommunications Standards Institute
EVRC	Enhanced Variable Rate Codec
EXIF	Exchangeable Image File Format
E.g.	For example
E-mail	Electronic Mail
FEC	Forward Error Correction
GCF	Global Certification Forum
GERAN	GSM EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GIF	Graphics Interchange Format
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
GSMA	GSM Association
GSMNA	GSM North America
HE AAC	High Efficiency AAC
HLR	Home Location Register
HSCSD	High Speed Circuit Switched Data
HTML	Hyper Text Markup Language
HTTP	Hyper Text Transfer Protocol
IAM	Initial Address Message
IANA	Internet Assigned Numbers Authority
IEC	International Electrotechnical Commission
IEE	Institution of Electrical Engineers
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IM	Instant Messaging
IMAP	Internet Message Access Protocol
IMPS	Instant Messaging and Presence Service
IMS	IP Multimedia Core Network Subsystem
IMSI	International Mobile Subscriber Identity
IMT-2000	International Mobile Telecommunications-2000
Infotainment	Information and Entertainment
IOP	Interoperability
IP	Internet Protocol
IPR	Intellectual Property Rights
IPSec	Internet Protocol Security
IPv6	Internet Protocol version 6
ISDN	Integrated Services Digital Network
ISO	International Standards Organization
ISUP	ISDN User Part
IS-95	Interim Standard 95
ITC	Information Transfer Capability
ITU	International Telecommunications Union
ITU-T	ITU – Telecommunications Standardization Sector
IWF	Interworking Function
I/O	Input Output
JCP	Java Community Process
JFIF	JPEG File Interchange Format

JIS	Japanese Industrial Standards
JPEG	Joint Picture Expert Group
kbps	kilo bits per second
Kbytes	Kilobytes
LAPM	Link Access Procedure for Modems
LBS	Location-based Services
LC	Low Complexity
LIF	Location Interoperability Forum
MBMS	Multimedia Broadcast Multicast Service
MDM	Mobile Device Management
MGIF	Mobile Gaming Interoperability Forum
MIDI	Musical Instrument Digital Interface
MIME	Multipurpose Internet Mail Extensions
MIP	Minimum Interoperability Profile
MM	Multimedia Message
MMD	Multimedia Domain
MMS	Multimedia Messaging Service
MMSC	MMS Center
MMS R/S	MMS Relay/Server
MMS-IOP	Multimedia Messaging Interoperability Process
MMTel	IMS Multimedia Telephony
MobAd	Mobile Advertisement
MOS	Mean Opinion Score
MPEG	Motion Picture Experts Group
MS	Mobile Station
MSC	Mobile-service Switching Center
MSISDN	Mobile Subscriber Integrated Services Digital Network Number Mobile Station International Subscriber Directory Number
MSRP	Message Session Relay Protocol
MSS	Multimedia Streaming Service
MWIF	Mobile Wireless Internet Forum
M-IMAP	Mobile-IMAP
NAB	Network Address Book
NSRP	Numbered SRP Response Frames
OMA	Open Mobile Alliance
ORA	Other Rate Adaption
PC	Personal Computer
PDU	Protocol Data Unit
PIM	Personal Information Manager/Management
PLMN	Public Land Mobile Network
PNG	Portable Network Graphics
PoC	Push-to-talk over Cellular
pp.	pages
PSS	Packet-switched Streaming Service
PSTN	Public Switched Telephone Network
PTT	Push-to-talk over Cellular
QoE	Quality of Experience
QoS	Quality of Service
RADIUS	Remote Authentication Dial in User Service
RCS	Rich Communication Suite
RDF	Resource Description Framework

RDI	Restricted Digital Information
RFC	Request for Comment
RNC	Radio Network Controller
RSS	Rich Site Summary
	RDF Site Summary
	Really Simple Syndication
RTCP	Real-time Transport Control Protocol
RTDF	Recommended Technical Framework Document
RTP	Real-time Transport Protocol
RTSP	Real-time Streaming Protocol
R/S	Relay/Server
SDP	Session Description Protocol
SGSN	Service GPRS Support Node
SIM	Subscriber Identity Module
SIMPLE	SIP for Instant Messaging and Presence Leveraged Extensions
SIP	Session Initiation Protocol
SMIL	Synchronized Multimedia Integration Language
SMS	Short Message Service
SMTP	Simple Mail Transfer Protocol
SMV	Selectable Mode Vocoder
SOAP	Simple Object Access Protocol
SP-MIDI	Scalable Polyphony MIDI
SRP	Simple Retransmission Protocol
STD	Standard
SVG	Scalable Vector Graphics
SyncML	Synchronization Markup Language
TCP	Transport Control Protocol
TIA	Telecommunications Industry Association
TR	Technical Report
TS	Technical Specification
TTA	Telecommunications Technology Association
TTC	Telecommunications Technology Committee
TV	Television
UA	User Agent
UAProf	UA Profile
UDI	Unrestricted Digital Information
UDP	User Datagram Protocol
UICC	Universal Integrated Circuit Card
UMS	Unified Messaging System
UMTS	Universal Mobile Telecommunications System
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
USIM	Universal Subscriber Identity Module
US-ASCII	American Standard Code for Information Interchange
UTF-8	Unicode Transformation Format (the 8-bit form)
UTF-16	Unicode Transformation Format (the 16-bit form)
UTRAN	Universal Terrestrial Radio Access Network
VAS	Value Added Service
VASP	Value Added Service Provider
ver.	version
VMR-WB	Variable Rate Multimode Wide Band

VoIP	Voice over IP
vol.	volume
W3C	World Wide Web Consortium
WAP	Wireless Application Protocol
WBMP	Wireless Application Protocol Bitmap Format (Wireless Bitmap)
WCDMA	Wideband Code Division Multiple Access
WMF	Wireless Multimedia Forum
WSP	Wireless Session Protocol
WV	Wireless Village
XCAP	XML Configuration Access Protocol
XDM	XML Document Management
XMF	Extensible Music Format
XML	Extensible Markup Language
XHTML	Extensible Hypertext Markup Language
XQuery	XML Query

Chapter 1 Introduction

As multimedia provides more information, brings additional choices, enables interaction, and resembles real-life situation, it is naturally a preferred communication option among users. All these advantages of multimedia communication come at the cost of additional resources in different components of end-to-end communication for the following example purposes – capturing, processing, transmission capacity and quality, storage, and rendering. On the other hand, mobile environment is by nature a relatively more error-prone medium, and mobile terminals are usually limited in terms of size (limited input, output, and storage facility), available computational power, processing ability, and handling complexity. Therefore, mobile communication is taking more time to accommodate multimedia than the Internet took, and only the recent advancements in the related fields of technologies made it possible to have multimedia in mobile communication with reasonable quality. As for example, significant advancements have been achieved recently in processors, multimedia computing power, memory, signal processing, communication technologies, compression technologies, capabilities of both mobile terminals and networks, multimedia codecs, and other related fields [1] [2] [3]. There have been numerous efforts to make all these possible, and [4], [5], and [6] describe just a few in this regard in terms of audio and video codec, software, hardware, and system architecture points of view. The evolution path of mobile networks, with the support for increasing bandwidth and other capabilities, are available in [7], [8], [9], [10], [11], and [12]; while the former reference also describes the developments of different multimedia capabilities in a mobile terminal, like display, imaging and processing capabilities. Based on all these advancements and market demand, mobile multimedia is expected to be the future for the evolving broadband mobile network [13].

Motivated by both the technical advancements and market expectations, different mobile communication related standards development bodies started defining mobile multimedia communication services. Multimedia telephony for circuit-switched mobile networks is the first of this kind. Multimedia telephony is also known as videophone, video telephony, and visual telephone. Other multimedia communication services followed, and Multimedia Messaging Service (MMS) and streaming are two promising examples in this regard [13]. The trend in the leading mobile markets indicates that the demand of multimedia services is growing with the continuous growth of the data rates in the mobile networks [14], as evolving broadband mobile network can increasingly satisfy the demand of multimedia, and thus meet the user expectation. Hence, services like multimedia telephony, streaming, and MMS are important from mobile multimedia communication point of view [14]. These services are exposed to the users in terms of one or more applications. Some of these services are sometimes addressed as application, as a service can have a dedicated application to interact with users. Both the terms are used in this dissertation depending on the perspective. Moreover, these multimedia communication services are mostly addressed as multimedia services for brevity from now onwards, as multimedia services not requiring network communication are beyond the scope of this dissertation.

1.1 Motivation

Mobile communication is already a very popular means of communication among different types of users all over the world, and its popularity and scope are increasing day by day. Though mobile communication lags behind the Internet in terms of accommodating multimedia, it has enjoyed tremendous growth lately [15], and the growth of mobile communication surpluses the growth of the Internet in terms of penetration [9]. The growth of mobile subscription is significant only in the emerging markets nowadays, as the growth in this regard has been almost saturated in many advanced markets. Mobile communication started enjoying growth in terms of its use and scope, as it is a global trend to introduce new services in mobile communication. The popularity of mobile communication has been so far mainly driven by non-multimedia services. Voice communication is by far the mostly used service in mobile communication. Short Message Service (SMS) [16] is another widely used service in mobile communication. As users are naturally attracted and interested for multimedia, and it is possible to have multimedia in mobile communication with reasonable quality, it is expected that multimedia would be increasingly used in mobile communication. A subjective study among 1700 mobile users indicates that multimedia is already significantly used in the mobile domain [17].

Multimedia telephony is a conversation service like voice communication, but with additional media like video, audio, and optionally data. Though it sounds simple and natural evolution of voice communication, multimedia telephony is a very demanding service, as it requires end-to-end real-time transmission with negligible latency and jitter [18]. However, small display in a mobile terminal allows low-bit-rate version of multimedia telephony service to provide reasonable quality in mobile communication.

Human beings started using messaging systems for communication purposes long time back. Postal service and facsimile are examples of early messaging systems widely used all over the world. As a message is not digital in these systems, they do not fit within the modern definition of a messaging system [19]. Only digital messaging systems are considered here. A messaging service is less resource-hungry, as the transmission usually takes place in the background using the best available resources. Based on a consumer study, messaging services are considered highly innovative among the users of different segments [3]. Beside the conventional use of a messaging system, it can be also used for transporting content for different purposes. Internet brought a new dimension in messaging by providing means to have a message in the digital form end-to-end. It introduced some widely used messaging systems, like electronic mail (e-mail) and Instant Messaging (IM). Mobile communication also introduced commercially successful messaging system like SMS [20] [21], though an SMS message is very limited in terms of size and type of content [1] [22] [23]. MMS is a natural evolution of SMS, and it is designed based on the positive aspects of the existing equivalent messaging systems. As a result, the expected market potential for MMS has been high from the beginning [7] [13] [24]. MMS is a very important service for both the operators and the vendors [20]. MMS is one key element in the development of new content types, applications, and services in the mobile communications [7]. Camera phone was introduced to promote the use of MMS in terms of sharing images. Camera phone is very common in the markets nowadays, but the use of MMS has not grown accordingly [25]. The expectation of MMS does not match with its present market situation [10] [26], though the use of MMS is significant compared to other mobile data service [27] and has been growing lately. An in-depth study about the use of a camera phone indicates that MMS needs improvements [25]. The studies also reveal some technical and non-technical reasons hindering the anticipated growth of MMS.

Another major type of multimedia service is streaming, which is in between conversational service and messaging service in terms of resource requirement. The use of streaming started in the Internet, and nowadays it is widely used there. Though streaming is relatively new in mobile communication, both quantitative and qualitative analysis provide positive results for having streaming in mobile communication. Moreover, streaming, with less memory requirement and delay, can better exploit the mobile environment, if designed properly. As different types of services have different strengths and weaknesses, effective and optimum interworking between them can be used to hide a weakness.

1.2 Research Questions

Identifying specific research questions is important pre-requisite for carrying out a research scientifically. Besides, research questions play important role in finding the right research method [28]. The key research questions of this dissertation are outlined below.

Research question 1: Evaluate the scope and relationship of important related mobile multimedia services. In order to have a wide view, it is important to point out different relevant mobile multimedia services, and classify those in terms of various reasonable factors. It is also important to identify and focus on selected services and evaluate those considering some relevant aspects in detail. Such evaluation would not only provide in-depth view about multimedia services in mobile communication, it would also help positioning the services. Besides, similarities and dissimilarities among these services would help in better understanding the scope of the services. As answer to this question provides the basis for the dissertation, the mobile multimedia services picked in this evaluation should be based on the research questions. As for example, as the first defined multimedia service, circuit-switched multimedia telephony deserves a special attention. Due to the reason mentioned in Section 1.1, MMS is a key service for this dissertation. Streaming is another service of importance for this dissertation, as it is positioned to complement the service of MMS for the delivery of content. Generally, personal communication services with the ability of carrying a variety of contents are mostly considered; hence mass-media type of services (such as broadcast/multicast services) and less communications oriented multimedia services (such as browsing) are not considered in the evaluation.

Research question 2: Detailed and extensive conceptual evaluation of MMS. Based on the situation of MMS, outlined in Section 1.1, a detailed evaluation of MMS can only reveal its suitability in mobile communication. It is important to understand if the features and functionalities of MMS can fulfill the user expectations and market demand. It is equally important to know how the underlying technologies match with the conventional and evolving mobile infrastructures. Comparison of MMS with other existing and widely used messaging systems is also important in this regard. Messaging systems based on open standards are within the scope here. Beside finding the suitability of MMS, another intention of the question is to find the limitations of MMS. All possible aspects should be considered in this regard, like design and working principle, end-to-end architecture of MMS, and characteristics of mobile environment. While searching for limitations, user expectations should also be taken into account. As for example, a user may not be satisfied with the content of inferior quality and/or limited size, as she might be used to enjoying high quality content in the Internet and home domain. Moreover, MMS should be able to carry multimedia content of reasonable quality without significant delay in the delivery or retrieval.

Research question 3: Build solutions to overcome the identified limitations of MMS and evaluate those. The identification of any limitation would make it possible to adjust MMS for its better acceptance. The dissertation also aims to provide solutions to overcome the identified limitations of MMS. It is important that the solution is consistent with the existing framework and working principles of related services, to avoid unexpected user experience. The consistency is also important to avoid market fragmentation. In case there are multiple solutions for the same limitation, the solutions should be evaluated to find out respective pros and cons, to be able to compare those. It is also important to have a general and flexible end-to-end architecture, which can accommodate the solutions in different deployment situations. Important factors to consider in designing the architecture are minimal impact on the existing infrastructure, expectations from different stakeholders like network operator, content provider, and vendors, load balancing and scalability in related network servers.

Research question 4: Enhancing MMS to transport application data in a harmonized way. Even without any limitation, MMS may not be used significantly in the market, if it fails to meet various needs. As for example, the use of MMS can be reasonably enhanced, if it can be used as a transport of data for other applications. Though MMS has been lately positioned to act as such a transport, it is not properly functional without some enhancements. As for example, this new use of MMS must be backward and forward compatible, so that the existing and future deployments of MMS have no impact on each other. Moreover, the standards do not define the format and extent of data communication between MMS and the application. Such definition of data communication would allow independent development and deployment of an application in mobile communication, enabling increasing use of MMS. This dissertation aims to address these issues in terms of providing required solutions.

As the title of the dissertation suggests, only a few topics about mobile multimedia communications are selected here, based on the research questions stated above. The main topics of the dissertation are

- overview of different related mobile multimedia services to the need of the dissertation,
- detailed and extensive analysis about MMS considering all important aspects,
- building solutions to overcome the identified limitations of MMS and comparing those, and
- enhancing MMS to transport application data effectively in a co-ordinated manner.

The driving forces for picking up the specific questions are described in Section 1.1 above, while other topics of mobile multimedia are beyond the scope of this dissertation.

1.3 Research Methodology

A research method refers to a set and sequence of steps for carrying out a research for a single study, while research approach is a general expression for the similar research methods [28]. Both the terms are used here depending on the context. Finding the right research method is essential for carrying out a research scientifically; and understanding different research methods can ensure the right selection in this regard. Järvinen lately published his taxonomy of research approaches [28]. He summarized other popular classifications, and justified his taxonomy, which is shown in Figure 1. Järvinen considered research approach in the taxonomy to minimize the number of alternatives [29]. On the top, research approaches are divided into two classes - studying reality, and mathematical approaches, which is mostly about symbol systems not having any direct reference to objects in reality. Based on research question, the approaches studying reality is again divided into two classes – researches stressing what is reality, and researches stressing utility of innovation. The former is further divided into methods for theoretical development (i.e., conceptual-analytical approaches), and empirical research approaches, which is again divided into theory testing (theory, model or framework guiding a research), and theory creating (developing a new theory) approaches. The approaches for innovation can either be building innovation or evaluating innovation. In summary, research approaches can be enumerated to 1) mathematical approaches, 2) conceptual analytical approaches, 3) theory-testing approaches, 4) theory creating approaches, 5) building innovations, and 6) evaluation of innovations.

Many attempts have been made for classifying research approaches and methods. Couple of attempts worth mentioning in this regard are March and Smith's framework [30] and Henver et al.'s framework [31]. These frameworks do not consider all the approaches listed in the Järvinen's taxonomy (e.g., mathematical approach). However, both the frameworks have many research approaches available in the Järvinen's taxonomy (e.g., approaches numbered 3, 4, 5, and 6 above), though different terms are used in the frameworks to address some approaches.

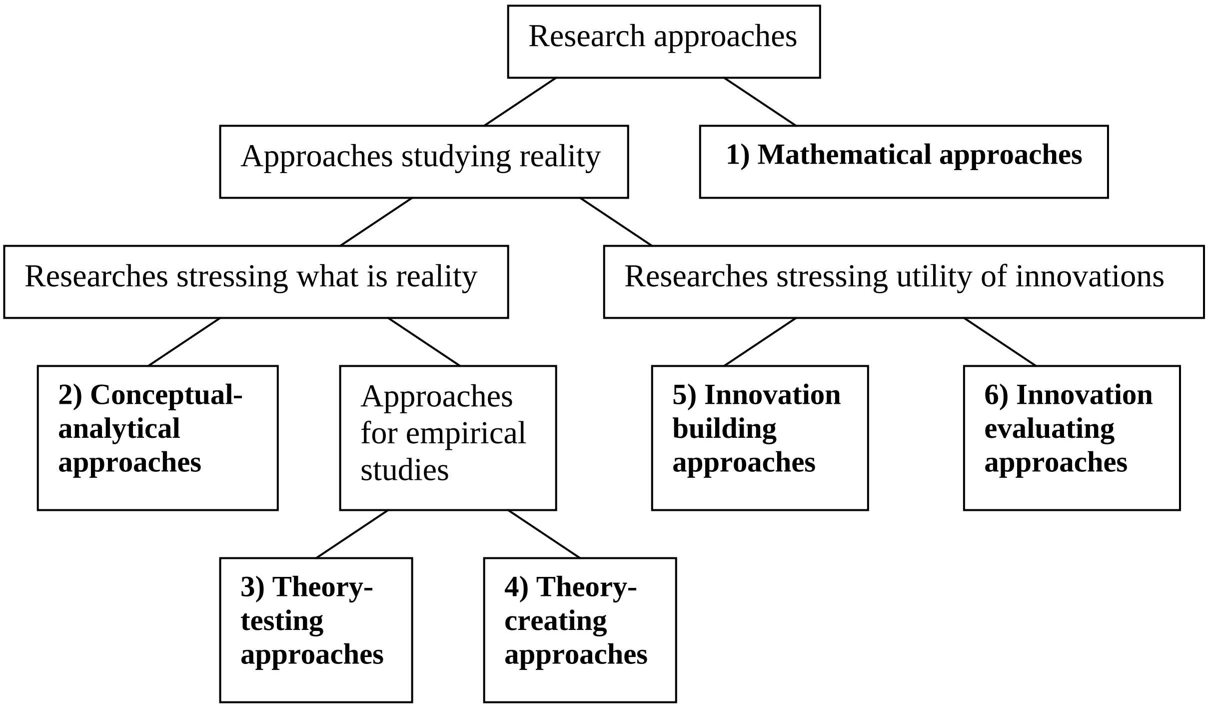

Figure 1: Järvinen's taxonomy of research approaches [28].

Research can be divided to basic and applied research. Basic research is about reality, mostly corresponding to natural science (including physical, biological, social and behavioral domain) [30]; and approaches numbered 2, 3 and 4 are suitable for this type of research. As for example, research about physics is usually considered as empirical testing theory approach, where the intention is to model reality for making it predictable. On the other hand, sociology and psychology are also empirical science, but usually create theories to understand the world [29]. On the other hand, applied research usually applies the knowledge of basic research, and usually corresponds to design science. Design science aims to build artifact or innovation that serves human purpose, and the innovations are usually also evaluated. Possible evaluation methods in this regard are – observational, analytical, experimental, testing, and descriptive [31]. Research approaches numbered 5 and 6 are usually applicable for design science. A research method having both building and evaluating innovation in the same process is called action research [28].

Based on the research questions outlined in Section 1.2, the main research method of the dissertation is approaches for innovation. More specifically, research questions 1 and 2 use the method 6 – evaluation of innovation. On the other hand, research question 3 and 4 use the method 5 – building innovation. As these two questions also involve evaluation to certain extent, action research can be considered as the research method for the questions. For evaluation, descriptive and analytical methods are mostly used.

1.4 Structure of the Dissertation

Chapter 2 first provides an overview of different mobile multimedia services, and then focuses on three different mobile multimedia services - circuit-switched multimedia telephony, MMS, and streaming - to the need of this dissertation. A couple of noted limitations, visible in MMS, are described in Chapter 3. To overcome the limitations, an idea about interworking between MMS and streaming is introduced in the same chapter. Beside finding the optimum interworking between MMS and streaming, the chapter also provides a conceptual solution for the interworking in terms of architectural framework. Chapter 4 describes three implementation solutions for the interworking in detail. A comparative study among the solutions is available in the same chapter. The chapter also presents a general and flexible end-to-end architecture that can accommodate the interworking solutions in different practical situations. Chapter 5 is about a different feature of MMS - transporting application data. Beside describing the standardized functionality briefly, the chapter proposes some enhancements for the feature. Chapter 6 describes the publications, which are the basis of this dissertation. Chapter 7 concludes the paper by outlining the main findings of the dissertation.

Chapter 2 Background and Fundamentals of Mobile Multimedia

The need to have true multimedia communication has been one of the main reasons for evolving and enhancing mobile communication [32]. This chapter first provides an overview of mobile multimedia services by positioning different important multimedia services in terms of both various service classes and different critical factors of communication in Section 2.1. Then, this chapter describes three mobile multimedia services of interest for this study – circuit-switched multimedia telephony, MMS, and streaming. Beside describing the technical details of the services from the respective specifications, this chapter also outlines related research and development works. As the first defined mobile multimedia service [33], circuit-switched multimedia telephony is described first in Section 2.2. MMS and streaming are described elaborately in Sections 2.3 and 2.4 respectively to provide the basis for the discussion in the following chapters. The term streaming is mostly used to mean multimedia wireless streaming in this dissertation for brevity. For both MMS and streaming, this chapter also outlines future evolution trends. Browsing and broadcasting are also potential mobile multimedia services. Multiple solutions are available for broadcasting, e.g., Digital Video Broadcast – Handheld (DVB-H), Multimedia Broadcast Multicast Service (MBMS). Though mobile television (TV) is the most appealing service for both the solutions, other services can also be offered (e.g., download). DVB-H is a standardized broadcasting service for handheld mobile terminals, requiring new network. On the other hand, MBMS can utilize existing mobile networks. MBMS has been lately standardized to provide two service categories - broadcast (like TV, radio) and multicast (community based) services [14] and [34]. It is a point-to-multipoint downlink bearer service for delivering multimedia data over the packet-switched domain [35]. Browsing and broadcasting are not described in this chapter, as those are beyond the scope of this study due to the reasons stated in Chapter 1.

2.1 Positioning Different Mobile Multimedia Services

Wireless transmission of information dates over 100 years back, and since then it has evolved through providing services like telegraphy and broadcasting TV and radio. Lately, it took two different paths for further evolution – mobile communication (also known as cellular communication) and data communication over the Internet (also known as wireless communication) [1]. Mobile communication started its journey by providing simple voice communications in its first generation. In the 2nd generation (2G), mobile communication became digitized. In the 3rd generation (3G), there are significant trends of converging mobile communication with the Internet. Convergence is expected in different levels, e.g., terminals, network, services and applications, and corporate [9]. Moreover, tremendous growth in mobile communication is also playing significant role in the growth of data communication in mobile domain [15].

Mobile service is a service provided to a user of a mobile device that has radio interface for communication. A mobile service has a special characteristic of providing the service in a device any where at any time. Thus, a mobile service is distinguished for its spatial and temporal component of service usage [36]. A mobile service can be offered locally from a device without requiring communication over the radio interface (e.g., clock, music player). Such services are also addressed as offline services, as they do not need network connection [10]. These services do not need much standardization, and are not focus of this dissertation. On the other hand, services requiring network communication are addressed as mobile communication services (also known as online services [10]), which are mostly considered in this study.

Traditionally, communication networks are of three types – telecommunication, broadcast, and Internet. Typically, a telecommunication network provides a dedicated voice communication type of services. Such services are usually interactive, but do not provide open access to external content and service resources. In broadcast services, audio-visual content is broadcast over a dedicated network. Such services require unidirectional delivery of information with almost no interaction. On the other hand, Internet is much more open, providing access for external resources. Moreover, Internet services provide multi-directional interaction. Due to technical advancements, nowadays mobile services tend to exhibit characteristics from conventional telecommunication, broadcast, and Internet services [37].

2.1.1 Different Approaches to Classify Mobile Multimedia Services

Digitization and convergence have been playing significant role in the evolution of mobile services, resulting in many different mobile services in the market. Different criteria have been used to classify these different mobile services. Such classifications typically originate from end-user, terminal, network, and academic research [36]. The same reference also mentions about three streams of literature with regard to mobile service classification: technical/business perspective, end-user perspective, and softer research perspective (e.g., context or ways of implementing a service). Some exemplary approaches for classifying mobile multimedia services are briefly outlined below.

Based on Quality of Service (QoS) classes, mobile services can be classified into four different classes – conversational, streaming, interactive, and background [38]. The main factor for this classification is the delay sensitivity of a service. Both conversational (e.g., voice communication, multimedia telephony) and streaming service use real-time traffic flow, while the former is more delay sensitive than the latter. Interactive and background services are even less delay sensitive, but require better error rate. The main difference between interactive (e.g., Web browsing) and background (e.g., SMS, e-mail, download) services - the former is used by interactive applications, while the traffic flow in the latter case takes place in the background requiring less priority than the former. QoS is also pointed out as an important factor for mobile services of 3G mobile communication system in [32], which outlines following potential service types in the evolving mobile networks – data, multimedia-rich Web content, media streaming services, conversational video and high quality audio services. These services can be deployed separately, or in any suitable combinations.

Reference [15] presents taxonomy of data centric mobile application based on the challenges and optimization techniques – streaming, mobile commerce, pervasive gaming, two-way database, and Web browsing. Reference [11] outlines six service categories based on market studies – mobile Internet access, mobile Intranet/Extranet access, customized infotainment (information and entertainment), MMS, location-based services, and rich voice. Eight different service areas are pointed out in [39] – corporate Voice over IP (VoIP), mobile VoIP, mobile broadband, multi play services (combination of multiple services offered uniformly across one or more access technologies), M2M communication services (data communication between machines using communication networks and standardized means), mobile broadcast, personal area network services, and mobile payment services. Based on a study, the report [39] concluded that the first five service areas are interesting from heterogeneous network service point of view, while mobile VoIP, multi play and specific M2M communication services are the most interesting in this regard.

Reference [9] has identified following service paradigms – mobile messaging, mobile game over SMS and Wireless Application Protocol (WAP), mobile video services (either person-to-person or broadcast), information service (e.g., news, sport, traffic, weather, stock), transaction service (retail service, financial service, payment), and location-based services. Reference [12] describes different key enabling services including SMS, Enhanced Messaging Service (EMS), MMS, and Wireless IM. The reference also categorizes mobile services into two top-level categories – business and customer market oriented services. Examples of the former category are Intranet access, Internet browsing, mobile office, vertical application, e-mail access, and machine-to-machine; while examples of the latter category are messaging, games and entertainment, banking/finance, location-based services, Internet access, information services, remote diagnostics, mobile advertising, public services, personal health and security. Reference [10] classifies services into person-to-person services (e.g., voice communication, VoIP), non-person-to-person multimedia services (e.g., games, navigation), and packet data services (e.g., Web browsing). The classes overlap with each other (e.g., MMS belongs to both person-to-person and packet data service classes).

According to [1], 3G mobile communication system is expected to provide following services – high-quality voice, messaging (SMS, MMS, chat), streaming multimedia (music, video, film, TV), and Internet access (Web, e-mail). Reference [7] points out three different modes of interaction in mobile services: browsing (including streaming) – near real-time access to information, rich call – real-time voice/video communication augmented by sharing file/image/object), and messaging (non-real-time data communication like SMS/MMS, IM, chat, newsgroup, e-mail [40]). Reference [14] describes a few standardized mobile video applications – circuit-switched multimedia telephony, Packet-switched Streaming Service (PSS), MMS, and MBMS. According to [41], communication can be grouped into four paradigms – live conversational, store-and-forward messaging, broadcast/multicast, and on-demand and interactive. Reference [42] analyzed about 7000 mobile applications, and classified those in following nine categories – browsing, configuration, games, infotainment, messaging, multimedia, Personal Information Manager (PIM), productivity, and utility.

Most of the above classifications of mobile services and applications are part of additional research works, and the classifications make most sense in the context of that particular work. Though, such classifications provide useful overview, these are sometimes based on approximation and assumption made about a service. Moreover, due to the evolution towards convergence, the boundary between classes in many classifications of mobile services is not obvious nowadays. Rather, there is a tendency of diminishing border line in many classifications due to the advancement in technologies.

2.1.2 Mobile Multimedia Services in terms of Critical Communication Factors

Different mobile data services are depicted in a two-dimensional diagram in Figure 1 of [42]. The horizontal dimension is communication versus content, while the vertical dimension is interactive versus background traffic. This technical approach provides useful way to discriminate different services. The mobile communication trend of moving from communication-oriented services towards more content-oriented services is also visible from the figure. Moreover, the dimensions of the figure resemble significantly with the criteria used in some other above-mentioned classifications [32], [38], and [41]. The figure [42] only covers data services. Some interesting and useful services are not covered in the figure. Moreover, the terms communication and content are not clear, especially because the terms can overlap in greater context (as a communication service carries content as well). Clarification about the terms interactive and background may also help in understanding the logic.

Figure 2 attempts to position wider range of services. For clarity, personal communication is used as a dimension in-stead of communication. Personal communication mostly refers to person-to-person communication, while content means transporting content. The services positioned in the right hand side of the figure mostly provide means for personal communications, while the services on the left hand sides are not typically used for personal communications. Within each side, a service that can transport wider range of contents is positioned more to the left side. On the other hand, interactive mostly means on-demand here, while a user or a recipient of a background service has not much control over the communication of the service. A service providing more means for controlling communication and/or content transport is positioned more to the upper side.

Some of the services have characteristics of both communication and content (e.g., MMS). Similarly, a service can be designed to be interactive, or work in the background. In such cases, the major use of the service is considered to position it in the figure. Moreover, the positions of the services are not exact; rather it is more approximate to provide an overall picture about different important mobile services.

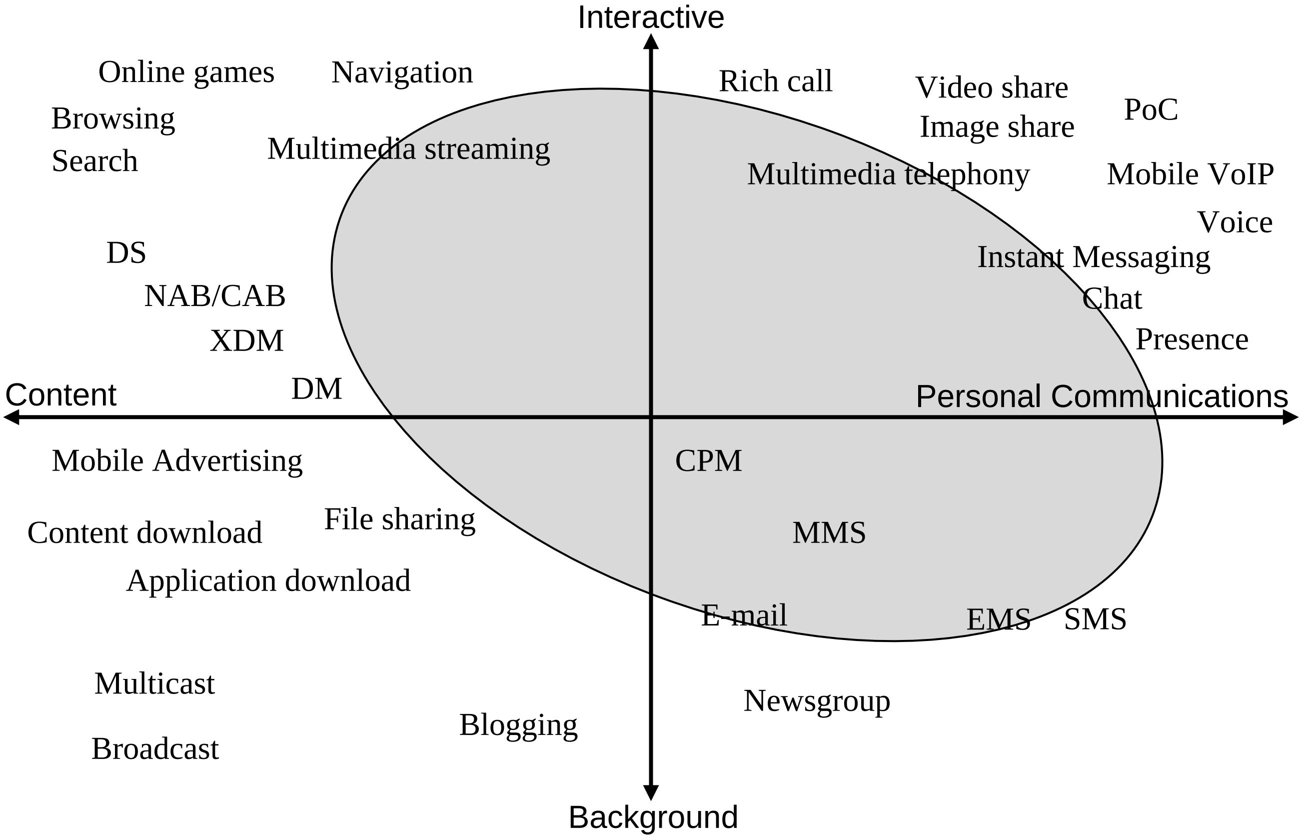

Figure 2: Positioning different mobile services in terms of critical factors of communications.

As already indicated in Section 1.2, the personal communication services having the means of delivering a variety of contents are mostly considered for evaluation in this dissertation. The shaded region in the figure roughly indicates the focus area in this regard. Many services in the figure are self-explanatory, and some are already outlined above. A few services, being or lately defined, which are not outlined above are briefly clarified below.

Both video and image share services are described in GSM Association (GSMA) specifications [43] [44] [45]. Video share service enriches an already established voice call by allowing a user to create and stream video (either live or pre-captured) to another user in near real-time. Typically, video is transmitted through packet-switched connection over IP Multimedia Core Network Subsystem (IMS) core infrastructure, while the voice call is over circuit-switched connection. Video share is different from multimedia or video telephony, mainly as it does not synchronize video with the audio. The IMS is defined by the 3rd Generation Partnership Project (3GPP)[1], based on Session Initiation Protocol (SIP) infrastructure to harmonize services, and it is further described in Section 2.2 and Sub-section 2.2.2.

Similarly, image share service allows users to share images (stored or just captured) between them over packet-switched connection established over IMS core system with ongoing circuit-switched voice call. In practice, a session is set up using SIP and image is transferred using Message Session Relay Protocol (MSRP) [46].

Presence is a network-based service for publishing, storing and distributing presence information, so that one can follow selected presence information of a person of interest based on authorization policy set by the owner of the information. Presence information can be about personal information (e.g., mood, activity, status, and icon), information about ability and willingness to communicate using different services, and device information (e.g., network access technology, geographical location). Historically, Presence service is coupled with IM service. The Presence services offered in the Internet are mostly proprietary, while the Internet Engineering Task Force (IETF)[2] and the Open Mobile Alliance (OMA)[3] standardized multiple solutions for Presence service, e.g., Instant Messaging and Presence Service (IMPS) defined by the OMA, SIP for Instant Messaging and Presence Leveraged Extensions (SIMPLE) Presence based on SIP defined by the IETF and the OMA.

Push-to-talk over Cellular (PoC), also known as PTT, is a walkie-talkie type communication service in mobile communication among the members of pre-defined or ad-hoc group. Though, there is proprietary solution, PoC mostly refers to the solution defined by the OMA. It started with simple voice communication, and new features and functionalities (e.g., sharing video) have been gradually included in the new versions of the PoC standards.

Document management allows storing a document in network, so that it can be accessed and manipulated from different devices. The OMA has defined XML Document Management (XDM) for managing XML documents. The XDM also includes many related features like search, subscription for changes in a document (synchronization), and delegation. Different protocols are used by the

[1] The 3GPP was established in 1998 as a collaboration agreement among different standards development organizations (ARIB, CCSA, ETSI, ATIS, TTA, and TTC). It defines UMTS, a 3G solution for the ITU's IMT-2000 project, based on WCDMA technology. UMTS is the 3G mobile system based on evolved GSM. Another scope of the 3GPP is to maintain and develop GSM technology, including GPRS and EDGE.

[2] The IETF is an open global community working for the evolution of Internet architecture and smooth operation of the Internet.

[3] The OMA is a global industry forum to develop open standards for different services in mobile networks, independent of the access technologies. It was formed in June 2002 by consolidating different forums - WAP Forum, LIF, SyncML Initiative, MMS-IOP, Wireless Village, MGIF, and MWIF. Beside defining technical specifications for the services, the OMA also works for achieving interoperability among different implementations, service providers, operators, geographies and networks, by defining test specifications and conducting tests. The general understanding is – OMA works in the service level, while the 3GPP and the 3GPP2 work in the access technology and bearer level.

XDM for different purposes, e.g., XML Configuration Access Protocol (XCAP) for document manipulation, SIP for subscription for changes in a document, and XQuery for search.

Based on a network-based storage of address book, Network Address Book (NAB) provides contact management service, so that contacts can be accessed, manipulated and synchronized from any device or access. Lately, the service started becoming available in the market based on proprietary solution. The OMA has very lately started defining the service in terms of Converged Address Book (CAB), not only to bring harmony among different implementations and deployments, but also to have additional features and functionalities.

Synchronization is a service that enables synchronization of information. There are many proprietary solutions for the service, while the Data Synchronization (DS) solution defined by the OMA is the most dominant standard solution in this regard. It is also known as Synchronization Markup Language (SyncML) in the industry due to historical reason.

The OMA has defined Device Management (DM) to provide the means for managing distributed mobile devices remotely, mainly for automatic and systematic provisioning of a device and services/application within the device. The scope of DM also includes additional features like delivery of device capabilities and configuration information, device diagnostics, performance and fault management. The DM is also known as Mobile Device Management (MDM).

Besides, OMA is also defining a service called CPM. The intention here is to improve user experience by bringing consistency in communication. Availability of different messaging solutions with almost similar capabilities may not only jeopardize user experience, but can also fragment markets. Moreover, behavior of messaging clients should be consistent across the service provider domains to boost growth. In CPM, IP-based infrastructure is used in converging different communication technologies and services (e.g., SMS, MMS, IM, e-mail, PoC). Though the name applies, the scope of CPM is not really limited to messaging, as it considers some non-messaging services like PoC, VoIP, multimedia telephony to build consistent user experience.

While advertisement is very common in almost all communications, mobile advertisement has been also making its way. It is a form of advertising via mobile phones. So far, different mobile messaging solutions (e.g., SMS, MMS) have been mostly used in mobile advertisement. Lately, the OMA has started defining a solution in this regard in terms of Mobile Advertisement (MobAd).

2.1.3 Positioning Multimedia Telephony, MMS and Streaming

Before focusing on multimedia telephony, streaming, and MMS individually in the following sections, they are briefly compared in terms of their paradigm and other key aspects in this sub-section. From the QoS class point of view these services belong to conversational, streaming, and background classes respectively [38]. All these services handle multimedia in wireless infrastructure. A multimedia service usually requires close and interactive integration of different media types. The term codec is associated with a single media type, providing means for encoding digital data or signal of a media type for transmission, storage, compression or encryption, and decoding it for viewing, editing, or any other processing. A proper matching between a codec and network characteristics enhances the quality of the associated service. Moreover, the type of a service can also influence the selection of a media codec for the service.

Multimedia telephony is a personal communication service, providing limited means for interaction to users in terms of controlling media. It works end-to-end in real-time to provide conversational service, like conventional voice communication. Streaming is also a real-time interactive service, as it provides means for extensive control over the streaming media. It is more a content-oriented service, as streaming is usually used to stream content from a server in network to a terminal. MMS is a personal communication service working end-to-end but in the background, based on store-and-forward approach, where content is temporarily stored in the network before it is finally delivered to a recipient. However, with the latest development, MMS can also be used to transmit content, as discussed later. Moreover, MMS can be designed to work as the transport of interactive applications, as described in Chapter 5.

Multimedia telephony and streaming are delay sensitive, while MMS is not [47]. Though both multimedia telephony and streaming work in real-time, the nature of transmission in streaming is different from the same in multimedia telephony. Media channels are usually opened at the beginning of a call and media characteristics are mostly unchanged during a call in a multimedia telephony solution for circuit-switched network, which may not be the case in streaming, where media characteristics can change in a streaming session. However, a media channel is more dynamic in a multimedia solution for packet domain.

Encoding of a media takes place in real-time in multimedia telephony, while media can be pre-encoded in streaming. The transmission of media in multimedia telephony is bi-directional (duplex), but streaming mostly handles media transmission in only one direction (simplex). Multimedia telephony is more complex and demanding than streaming. Both delay and buffering are low in multimedia telephony, while streaming usually can tolerate longer delay, and thus, requires larger buffering. Consequently, error concealment technologies are also different in the services [18]. Due to these reasons, multimedia telephony is not suitable for providing messaging and streaming service. Some enhancements are proposed in the multimedia telephony to support conventional multimedia messaging and streaming services [18]. On the other hand, MMS is very sensitive to error-rate, while both multimedia telephony and streaming can tolerate errors upto certain extent.

2.2 Mobile Multimedia Telephony

Briefly specking, multimedia telephony provides real-time audiovisual communication between connected end-users. The service can be enriched by providing means to share objects like text, file, image, audio or video clip. Here, the focus is on mobile multimedia telephony, and the term multimedia telephony is mostly used to address mobile multimedia telephony for brevity. Based on the underlying infrastructure, two types of multimedia telephony services are defined:

1) Circuit-switched (CS) multimedia telephony that operates over CS networks and
2) Multimedia telephony that works in packet domain

CS multimedia telephony was the first multimedia service defined by the 3GPP during the late nineties as part of release-99 (also known as release-3). It has been widely implemented and deployed. CS multimedia telephony is mostly considered in this dissertation, and it is described in Sub-section 2.2.1 in terms of different related key aspects like standardization and specifications, protocols, codecs, architecture, call control, and information flow. The 3GPP uses the term release to provide stable platform for developers, enabling the scope for additional features in a parallel release. 3GPP release is equivalent to the term version used in the OMA.

On the other hand, the standardization for multimedia telephony in packet domain started later when IMS and Multimedia Domain (MMD) were stable from standardization point of view. IMS is the 3GPP-defined SIP-based network infrastructure for providing converged mobile multimedia services over the Internet Protocol, while MMD is the equivalent infrastructure defined by the 3rd Generation

Partnership Project 2 (3GPP2)[4]. Two multimedia telephony services have been defined for packet domain:

A. Multimedia telephony for IMS, known as MMTel and
B. Multimedia telephony for MMD, known as Packet Switched Video Telephony

Multimedia telephony in IMS/MMD can be considered as enhancement of VoIP with multimedia support. As SIP over IP is used to access the network, it has potential to provide converged multimedia service. However, multimedia telephony service for packet domain is not matured from implementation and deployment points of view. The first version of MMTel standards (i.e., release-7) has been frozen, and the works for the latter versions (release-8 and release-9) started in the 3GPP. The work in the 3GPP2 in this regard is lagging further behind. As the multimedia telephony for the packet domain is not within the scope of this dissertation, it is very briefly described in terms of its standards and service description in Sub-section 2.2.2 for the sake of completeness. Both IMS and MMD are also described briefly in the same sub-section.

2.2.1 Circuit-Switched (CS) Multimedia Telephony

The term multimedia telephony is mostly used to address CS multimedia telephony for brevity. Multimedia telephony application was defined as 3G-324M (also known as 3GPP-324M), based on the International Telecommunications Union – Telecommunications Standardization Sector (ITU-T)[5] Recommendation (standard) H.324 [48], by the 3GPP. Later, the 3GPP2 also defined the same application. Multimedia telephony is described generally in [49], while [50] describes it from interworking point of view. Beside other mobile multimedia applications, multimedia telephony is also described in [14], in terms of standardization and error-control technology. Reference [51] outlines different involved protocols and media codecs of 3G-324M. 3G-324M and its component technologies are also discussed in [18], [33], [47], [52], and [53], from its standards point of view. Reference [33] also outlines possible uses of 3G-324M. 3G-324M is also described in [54] and [55] from an implementation point of view.

2.2.1.1 Terminal Requirements (Codecs and Protocols)

The ITU-T defined H.324 [48] as real-time multimedia telephony application for low bit-rate circuit-switched network. In fact, H.324-based multimedia telephony requires a set of protocols for different purposes, as for example H.223 [56] as the multiplexing protocol, H.245 [57] as the control protocol, and specific media codec for different media types. H.223 is packet-based, and each packet contains the information about a set of logical channels, while each logical channel represents a single media, information, or control channel. It provides error resilience and transmission service according to the type of information (e.g., QoS, framing). Multiple features - synchronization, error detection, Forward Error Correction (FEC), Automatic Repeat-Request (ARQ) and data duplication - are combined in the H.223 to make it error resilient. H.223 has two-layer structure – adaptation layer and multiplexing layer. The multiplexing layer exchanges data with the end-points, while adaptation layer mostly handles error detection and error correction. There can be different types of adaptation layer,

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[4] The 3GPP2 is a 3G telecommunications specifications-setting project focusing on North American and Asian interest. It is a collaboration of five different standards development organizations - ARIB, CCSA, TIA, TTA, and TTC. It is like a sister project of 3GPP, but concentrates on CDMA technology (i.e., cdma2000, the 3G evolution of cdmaOne, also known as IS-95).

[5] The ITU (International Telecommunications Union), founded in 1865, is an agency of United Nations for information and communication technologies. ITU-T, established in 1993, is one of the three sections of ITU. The main function of ITU-T is to provide global telecommunication standards by studying technical, operating, and tarrif questions. The outcomes of the studies are published as ITU-T Recommendations (standards).

depending on the type of information being handled. H.245 [57] is used as in-band control protocol to determine master/slave, exchange capability (e.g., supported media codec, codec-setting), transmit multiplexing table, and open/close a logical channel for the agreed media. H.245 messages are carried on a dedicated logical channel.

The H.324 was extended in the Annex C [48] to work in mobile environment, and the extended mode of the operation is known as H.324/M. The main improvement in the extension is the introduction of different levels of robustness against errors in the multiplexing protocol (H.223) [56] and segmentation and numbering of frames in the control protocol (H.245) [57]. It defines procedure for level set-up and dynamic change between levels. Some enhancements were also made in video codec (H.263) and H.245. New operational modes were introduced in the H.263 to improve the performance in error-prone situations. Additional audio and video codecs, suitable for wireless transmission, became available, and support for the codecs was added in the H.245. Moreover, the Annex H of H.324 standard defines mobile multilink operation for H.324 communication, so that higher bit rate is achieved by having H.324 operation over different physical connection.

The circuit-switched part of the Global System for Mobile communication (GSM) based 2G and 3G mobile networks was enriched for this type of application with the gradual introduction of High Speed Circuit Switched Data (HSCSD), modulation scheme Enhanced Data rates for GSM Evolution (EDGE), and radio access mechanism Wideband Code Division Multiple Access (WCDMA). The positive results of the simulations of the H.324-based implementations over circuit-switched GSM data connection [58], HSCSD and WCDMA [59] convinced the 3GPP to modify both the existing multimedia telephony application and the GSM-based circuit-switched mobile network to make these friendly to each other. The 3GPP adopted a new variation of H.324/M, named 3G-324M, as the multimedia telephony solution for circuit-switched mobile network. 3G-324M also includes mobile multilink operation defined in the Annex H. The application level changes in 3G-324M over H.324/M are mainly in terms of terminal requirements. The main differences between H.324 and 3G-324M in terms of required media codec and multiplexing and control protocol are outlined in [52] and [53]. 3G-324M defines a minimum set of media codecs for different media types for interoperability. The 3GPP also worked on call control of 3G-324M to enrich user experience of the application, briefly discussed in Sub-section 2.2.1.2. The 3GPP technical specifications [60] and [61] define 3G-324M in terms of general overview and the modifications on top of H.324/M respectively. Different related ITU-T specifications [48], [56], and [57] allow significant freedom in terminal implementation. As such freedom may challenge interoperability, the 3GPP has defined a guideline document for a terminal implementation [62]. Similar set of protocols were adopted by the 3GPP2 as its circuit-switched multimedia telephony solution [63]. In the 3GPP2 specification, only Annex C [48] is required, but not the Annex H [48] like in the 3GPP. Some supported media codecs in the 3GPP2 in this regard also differ from the same in the 3GPP. As for example, required video codec for video in the 3GPP2 is MPEG-4 Simple Profile Level 0 and H.263 baseline, while MPEG-4 Simple Scalable Profile Level 0 and H.263 Profile 3 and 4 are optional video codecs. There is no mandatory speech codec, and 13k, Adaptive Multi-Rate (AMR), Enhanced Variable Rate Codec (EVRC), and Selectable Mode Vocoder (SMV) are optionally required speech codec in the 3GPP2. The codec requirements for video and speech in the 3GPP are outlined below.

Figure 3 shows the detail architecture of a 3G-324M terminal. The minimum requirements for a 3G-324M terminal are a wireless interface, two improved lower layers of multiplexing protocol (H.223) and version 3 or later of control and system protocol (H.245). H.223 was extended to work in different higher levels (0-3) with increasing error-robustness suitable for functioning in error-prone mobile networks. The 3G-324M requires implementation of level 1 and 2, as described in Annex A and B of H.223 Recommendation [56], on top of the basic level 0. The main characteristics of these levels are different organizations of flags and headers in the multiplexed frames and, thus, wider scope for resynchronization. H.245 version 3 has support for these different working levels of H.223. Thus, the levels could be negotiated and agreed during session establishment or even during the active call depending on the error-situation in the connection. Moreover, a 3G-324M terminal is required to support at least 32 kbps at the multiplexer to wireless network interface. On the other hand, the support for video, audio/speech, data, and multilink components are optional for a 3G-324M terminal, marked with dotted line in the figure. The mandatory requirements for a terminal are shown with continuous line. Support for certain codec or protocol is conditional, meaning mandatory if that media type is supported. The optional codecs and protocols are shown within a square bracket [49] [50].

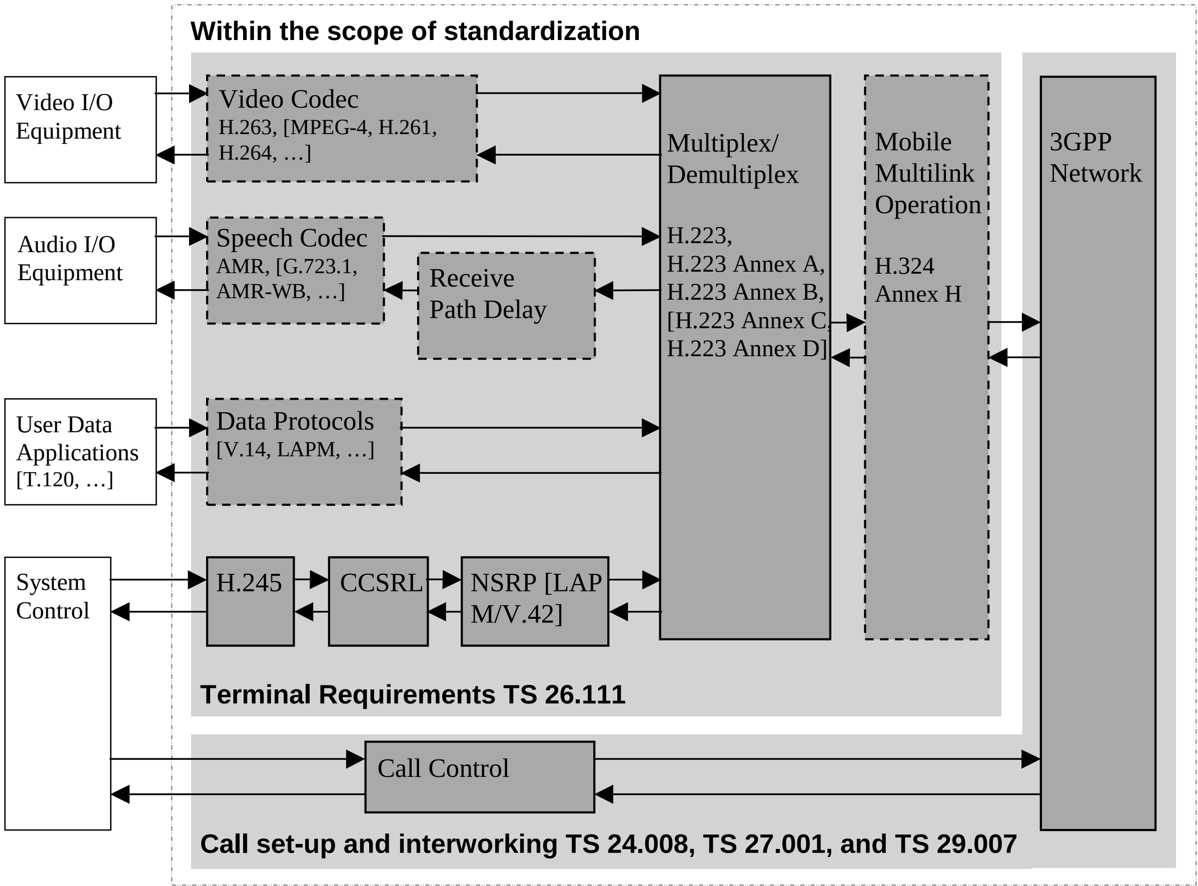

Figure 3: Architecture of a 3G-324M terminal [60].

If audio communication is supported, a 3G-324M terminal must support AMR audio codec. H.245 version 6 supports the audio codec. Support for audio codecs G.723.1 and AMR Wide Band (AMR-WB) are not mandatory, but recommended. AMR is an adaptive multi-rate speech codec, containing the scope for error concealment. It is designed for mobile operation and is mandatory for the 3G-voice call. Therefore, the scope for using the same implementation of AMR audio codec for both voice and multimedia telephony in mobile terminal brought it ahead of G.723.1 in 3G-324M audio requirements. A 3G-324M terminal must support H.263 video codec, if the terminal supports video communication. The support for video codecs MPEG-4 Visual Simple Profile, H.261, and H.264 (MPEG-4 Advanced Video Coding - AVC) is optional in this regard. Error resilience and high efficiency make MPEG-4 visual codec suitable for 3G-324M terminals. It allows also different visual input formats, having many variations within it, and [61] defines some requirements of MPEG-4 for a 3G-324M terminal, if it supports the codec. In a conventional video decoder, the exact position (macro block) of an error is not available in a video slice. Either some macro blocks are wrongly decoded, or some macro blocks are unnecessarily concealed. In the former case, erroneous macro blocks can be noticeable, making it unpleasant to a user. In the latter case, video quality is dropped. The information from the demultiplexer (H.223) can be used in the video decoder to detect the exact macro block, where error occurred in a 3G-324M implementation [64]. Such cross-layer decoder design utilizes the loss characteristics of WCDMA channels, provided by the demultiplexer. So, the video decoder can only conceal the victim macro blocks. An error resilient video coding technique is proposed in [47] to limit error propagation in low-bit-rate video coding, like in 3G-324M. The technique first detects error using intra-macro blocks data hiding. Then, the corrupted macro block data is concealed by temporary predictive error concealment technique.

ITU-T standard T.120 is an example user data application for a 3G-324 terminal. It allows multimedia data conferencing (e.g., data and image transfer), sharing whiteboard, and sharing applications. Real-time text conversation protocol T.140 is another example of possible data application in a 3G-324M terminal. These data applications may need support for specific data protocol. More about standardization and terminal requirements are available in [49].

Though hardware implementation of a codec is better in terms of processing speed and power consumption, software implementation is more flexible and suitable for multimedia application. An implementation of MPEG-4 video for 3G-324M is described in [65]. The implementation takes advantage by partitioning the functionality of the codec between software and hardware. Reference [66] proposes MPEG-4 video codec architecture for 3G-324M.

2.2.1.2 Call Control

The terminal requirements, as described in Sub-section 2.2.1.1, are important, but not enough. Network level adjustments were also required to set up a 3G-324M call. This aspect is defined as call control by the 3GPP in different specifications [67], [68], [69], and [70]. Call set-up and interworking are two core issues of call control. A call is established using the services provided by networks, depending on the requirements of the call. These services could be of different types, e.g., bearer service, teleservice. A bearer service provides means for the transmission of information between different reference nodes in networks. Bearer service is defined for different types of call by a set of parameters assigned with specific values. In call control signaling, these parameters and their corresponding values are known as fields and codepoints respectively. All these bearer-specific fields, in out-of-band approach of signaling used in digital networks, are described under bigger group, known as Bearer Capability Information Element (BCIE). BCIE is carried as part of different call control signaling messages to address required definite service definition. On the other hand, teleservice provides means for information transmission between terminating equipments; hence a specific teleservice needs agreement about terminal capabilities, like codecs, on top of the agreement about different field-values of BCIE for establishing a specific call.

Synchronous Transparent Bearer Service (BS 30 T) for multimedia [71] is assigned to carry 3G-324M calls over mobile networks. Out-of-band indication about a 3G-324M call during call set-up is very important to allow enough time for the peer-end to invoke the application and also, if required, for the network to invoke Interworking Function (IWF). IWF is required while interworking with network having different transmission and signaling characteristics. A teleservice like characteristic is imposed on service requirements for a 3G-324M call on top of all the requirements for the agreed bearer service, as other types of call can also use the bearer service in future. The multiplex protocol H.223 and control protocol H.245 are two mandatory lower level protocols for all the H.324-based applications. These two protocols together uniquely point the group of applications; hence a new codepoint "H.223 & H.245" was defined in the existing field Other Rate Adaption (ORA) of BCIE of call set-up signaling messages [67] and [68]. This application specific indication in call set-up signaling lets the network and the other end know about the 3G-324M call.

A 3G-324M call in a mobile network is also defined to interwork with the corresponding call parties in Integrated Services Digital Network (ISDN) and Public Switched Telephone Network (PSTN). Therefore, a 3G-324M call should be possible over both digital and analogue connection. End-to-end digital connection between the two ends will establish Unrestricted Digital Information (UDI) or Restricted Digital Information (RDI) connection in between. Involvement of analogue PSTN circuit in any part of the connection in a call would require modem connection. Analogue 28.8 or 33.6 kbps modem connection fulfils the requirement in this regard. A Mobile-service Switching Center (MSC) requires V.34 [72] modem in its IWF, and the V.34 modem must be capable of indicating and understanding in-band H.324 specific codepoint as mentioned in V.8 [73] to establish a modem connection for a 3G-324M call.

Different messages are sent between different involving nodes both in forward and backward directions while setting up a call. Call control protocol and messages used in the mobile network are specified in 3GPP specification [68]. ISDN circuits usually work as transit network for inter-MSC mobile-to-mobile call. Signaling in ISDN network is based on Signaling System Number 7, known as ISDN User Part (ISUP) [74], [75], [76], and [77]. Figure 4 shows the end-to-end information flow for call set-up signaling messages between different involving nodes for general inter-MSC mobile-to-mobile call. The calling Mobile Station (MS) sets "UDI"/“RDI” in the Information Transfer Capability (ITC) field of BCIE in the *Setup* message. The BCIE also includes "H.223 & H.245" in the ORA field. The requirements of Synchronous Transparent Bearer Service is reflected by selecting codepoints for other different fields of BCIE in the SETUP message, as described in the 3GPP specifications [68] [71]. The information is mapped to and carried by ISUP *Initial Address Message* (*IAM*) over transit ISDN circuit and then mapped back to the *Setup* in the MSC of the terminating mobile network. The *Setup* message is then sent to the called MS over the radio interface. The called MS knows the type of the call from the ORA field and starts invoking the application. At the same time, it acknowledges by sending back the *Call Confirmed* message, which is mapped to ISUP *Address Complete Message* (*ACM*) and conveyed back over the transit network. The called MS sends alerting and answering information in backward direction using the *Alerting* and *Connect* message over the radio interface of the mobile network. The ISUP *Call Progress* (*CPG*) and *Answer Message* (*ANM*) carry corresponding information over the transit network respectively. The same information is again mapped back to *Alerting* and *Connect* respectively and sent to the calling MS from the originating MSC. Successful reception of *Connect* issues *Connect Ack* in the forward direction as shown in the figure, and eventually results in a 3G-324M logical channel between the ends.

A user can also request to toggle between UDI/RDI 3G-324M and speech mode during an active call [67]. More about the 3G-324M call control in general and signaling is available in [49].

The interworking of 3G-324M with ISDN is relatively straightforward, as signaling used in the ISDN and mobile network are equivalent, and thus could be easily mapped to each other. However, interworking with the PSTN is not straightforward, mainly due to analogue access and lack of out-of-band signaling in PSTN. The interworking of 3G-324M with H.324 terminal in PSTN is described in detail in [50] for both mobile-to-PSTN and PSTN-to-mobile call. For the PSTN-to-mobile call, both multi-numbering and single numbering scheme of a mobile terminal is explained. If setting up a 3G-324M call does not succeed due to failure in modem handshaking while establishing a call with PSTN end, a fallback approach to set-up a speech call is also defined in [68] and [70].

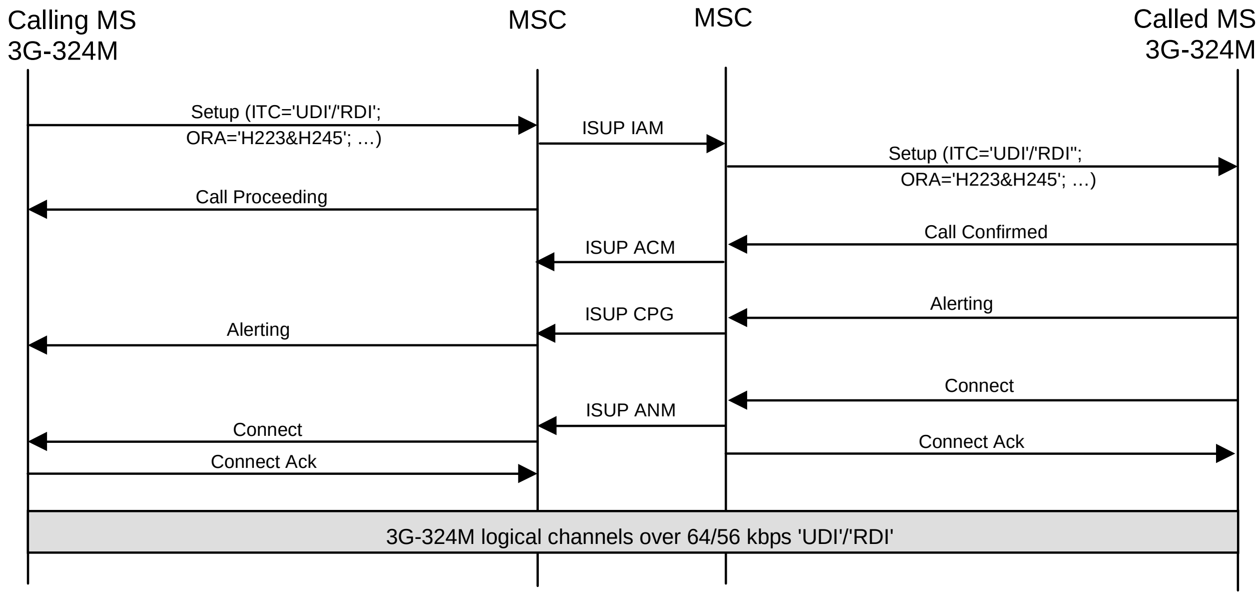

Figure 4: Call set-up signaling sequence for a mobile-to-mobile 3G-324M call [49] and [67].

The interworking with PSTN requires invoking of the IWF in the MSC, so that modem connection is achieved at the PSTN access. The signaling is in-band in the PSTN-end, while it is out-of-band in the mobile end. As the bearer service for the interworking case is different from the bearer service required for mobile-to-mobile or mobile-to-ISDN call, it is important to know the involvement of a PSTN end as soon as possible at the beginning of a call not only to select the right bearer service, but also to invoke IWF. Reference [78] introduces a noble way of understanding the involvement of a PSTN end, so that interworking with PSTN is faster and effective.

2.2.2 Multimedia Telephony in Packet Domain

The 3GPP has defined a platform, known as IMS, for providing different multimedia services over the Internet protocols in mobile communication [79], [80], [81], and [82]. The IMS is based on different IETF protocols, e.g., SIP. It utilizes packet-based wireless access mechanism like General Packet Radio Service (GPRS) core network with GSM EDGE Radio Access Network (GERAN) or Universal Terrestrial Radio Access Network (UTRAN) radio access networks. One of the main intentions behind the IMS was to combine the Internet and mobile communication by providing different types of services on top of harmonized and converged packet-based platform. The 3GPP2 also defined a solution for All-IP Network in the 3G cdma2000 network in terms of IP MMD [83] [84], which is equivalent to the IMS defined by the 3GPP. In many ways, MMD mostly follows IMS, though there are definite distinctions. The main differences are of course in terms of supported wireless packet networks and access technologies. Supported mandatory media codecs are also different not only to allow better match of a codec with the access technology, but also due to historical reason. Moreover, IMS and MMD have some technical differences, e.g., Internet Protocol Security (IPSec), Internet Protocol version 6 (IPv6), and Authentication and Key Agreement (AKA) authentication are required for IMS, but optional in MMD.

European Telecommunications Standards Institute (ETSI)[6] and its working group Telecoms and Internet Converged Services and Protocols for Advanced Networks (TISPAN)[7] took initiative in 2004 to define multimedia telephony over packet domain for fixed network. The ETSI/TISPAN endorsed 3GPP-defined IMS as the underlying infrastructure for the service. The 3GPP took a similar initiative in 2005 to have a service in mobile communication to provide means for real-time bidirectional transmission of speech, video and optionally other types of data. The initiatives from ETSI/TISPAN and 3GPP converged to produce a single multimedia telephony service – MMTel. At the beginning, the 3GPP created a report [85] to make an analysis about the service. A requirement specification [86], based on the report, was prepared to guide the technical works. The main technical specification for MMTel over IMS is 3GPP Technical Specification (TS) 24.173 [87], which has been approved as part of 3GPP release-7. The 3GPP is also analyzing the interworking between the multimedia telephony services in circuit-switched network and IMS [88]. Based on the analysis, the principles of interworking between different types of call including multimedia telephony between IMS and circuit-switched networks are defined in 3GPP TS 29.163 [89]. MMTel service has two parts – basic communication part and optional supplementary services part. In other words, the basic service of multimedia communication between users can be enriched with different optional supplementary services.

The basic communication part is realized by a single SIP session. The media capabilities within the SIP session include Real-time Transport Protocol (RTP) based transmission of voice, video, and text, as well as MSRP-based transfer of texts, arbitrary files, and sharing of media files of predefined formats. Over all media handling, including both RTP-based and MSRP-based media codecs and formats, is defined for interoperability [90]. In contrast with circuit-switched multimedia telephony, the use of media can be dynamic in MMTel, so that a media component can be added or removed during a session. The protocol for MMTel allows both simplex and duplex transmission of media between end-points. Example use cases enabled by the basic communication are – traditional voice call (possible to have with the peer-end in a CS network), voice call with unidirectional or bidirectional video, voice call with file sharing, voice call with video and text communication (chat), voice call with video and text communication (chat) and file sharing, text communication (chat), file sharing.

The supplementary service part consists of a set of specified supplementary services, which are fully standardized to ensure interoperability. The behavior of the supplementary services follows the same in CS voice call to maintain consistency in user experience. SIP is used for enabling the supplementary services, while XCAP is used to configure the supplementary services. Examples of supplementary services are – originating identification presentation, originating identification restriction, terminating identification presentation, terminating identification restriction, communication hold, conference calling, communication diversion, communication barring (both incoming and outgoing), communication transfer, message waiting indication.

The 3GPP2 has also defined a solution for multimedia conversational service over a packet-based network, and named it Packet-Switched Video Telephony. The involved specifications are – S.R0106 [91] and C.S0055 [92].

[6] The ETSI is a non-profit standardization organization responsible for producing global standards for information and communication technologies, including fixed, mobile, radio, converged, broadcast and Internet technologies. It is recognized by the European Commission. The initial activities started in 1982 under different name, and the ETSI was formally created in 1988.

[7] The TISPAN is a standardization technical committee under the ETSI, focusing on fixed networks and Internet convergence. It was formed in 2003 by combining ETSI bodies Telecommunications and Internet Protocol Harmonization Over Networks (TIPHON) and Services and Protocols for Advanced Networks (SPAN).

2.3 Mobile Messaging

Messaging is a method of communication between two ends, where information to be communicated is transmitted in terms of a message. In other words, messaging includes the methods and processes for exchanging information (structured or unstructured) between source and destination [93]. Only digital messaging systems are considered here, and the term messaging is used in this dissertation to address digital messaging for brevity. Messaging is the forerunner data-service in mobile communication. Mobile messaging started with SMS, and it has been a significant money-making service in mobile communication. After SMS, different types of messaging started becoming available in mobile communication, and Sub-section 2.3.1 outlines various messaging types relevant for mobile communication. As SMS was a great success, MMS was designed with the same fundamental working principle, but with the ability to carry true multimedia contents. MMS is described in detail in Sub-section 2.3.2. With the continuous development of technologies, mobile devices and networks are evolving, and so is mobile messaging. Possible future evolution for mobile messaging is outlined in Sub-section 2.3.3. MMS is compared with other important mobile messaging services in Sub-section 2.3.4.

2.3.1 Types of Messaging

Quite many messaging systems are available nowadays (e.g., paging, SMS, chat, e-mail, voice mail, IM, MMS), and those are different from each other in terms of various aspects like uses, scope, supported media and size, transport protocols, and delivery mechanisms. Messaging systems can be classified based on these different aspects. As for example, messaging services can be named according to allowed content – text messages that carry texts, picture messages that carry image, audio messages that carry audio clip, video messages that carry video clip. Most of these are commercial names of services. Commercial messaging services usually have message classes/types based on service provider’s interest.

A messaging service can be either asynchronous or synchronous, depending on the relationship between a message and its response. Messages are sent spontaneously in asynchronous messaging, where a sender does not care much if the recipient is listening, and if there would be a response. It is a loosely coupled communication model. Examples of asynchronous messaging services are e-mail, SMS, and MMS. On the other hand, the sender of a message waits for its response in synchronous messaging. Chat is an example of synchronous messaging service. However, examples of a messaging solution cannot be tightly coupled with this approach of classification, as SMS or MMS can be designed to provide transport for synchronous messaging application.

Reference [93] defines three categories of messaging – store-and-forward, publish-and-subscribe, and remote procedure call. In store-and-forward messaging, a message is first constructed in a commonly understood format by both the sender and the recipient, and then transmitted based on store–and-forward fashion. In publish-and-subscribe messaging, a specific message is delivered to a group of recipients who have subscribed or registered themselves to receive it. Remote procedure call extends the messaging to inter-application communication, so that a remote application is called to perform a specific task, and the called application returns the result to the calling application.

Reference [94] mentions about two kinds of messaging – point-to-point and publish-and-subscribe. A point-to-point messaging service has one originator and one recipient of a message; while, publish-and-subscribe messaging service resembles a broadcast or multicast service, where the copy of the same message is distributed among multiple recipients who have subscribed to the message.

The 3GPP has classified different messaging systems in the following main types [20] [95]:

Immediate Messaging: A message is delivered immediately in real-time or near real-time in this messaging type. A message may not be delivered, if it is not possible to deliver it right away due to any reason, e.g., the recipient is not available, connection or network failure. It is expected that some other means would be used to know the availability (e.g., ability, willingness) of a recipient prior sending a message. Presence is an example service which can be used for this purpose. IM is one example of this messaging type.

Deferred Delivery Messaging: In this messaging type, a message is delivered as soon as it is possible to deliver it. The messaging system needs to preserve a message at least until it is delivered or expired. This type of messaging is also known as store-and-forward messaging. As a sender relies on the messaging service to deliver a message, usually no other means is required to know the availability of a recipient. Examples of this type of messaging type are SMS, MMS, and e-mail. In SMS and MMS, a message is usually pushed to a recipient; while an e-mail is usually pulled. Push e-mail systems (where a new e-mail or its notification is pushed to recipient terminal) are deployed based on proprietary solution. The work is going on in the OMA and the IETF to define standard solution for push e-mail. Push e-mail is further described in Sub-section 2.3.3.

Session-based Messaging: This messaging type is similar to the Immediate Messaging type in terms of message delivery. However, the senders and the recipients join a messaging session (e.g., chat room) for message submission and delivery. A message is usually sent immediately to all or selected participants of a session.

This 3GPP classification provides a guideline for grouping and designing a messaging system, and the 3GPP does not require a messaging system to conform any such messaging type. Some of the messaging systems can be deployed to provide different types of services [40]. It is possible and practical to have a messaging system as a solution for multiple messaging types, as described more elaborately later. Due to the advancements in the related technologies, the distinction between the messaging types is diminishing day-by-day [41].

2.3.2 Multimedia Messaging Service – MMS

Though MMS is positioned as store-and-forward service, it can provide almost instant service. MMS was defined not only to provide the multimedia messaging solution to mobile communication by removing the limitations of other available messaging systems, but also to interwork with other similar messaging systems. Reference [7] discusses about different mobile multimedia applications and services (e.g., browsing, streaming, rich call, mobile messaging), however the focus is on MMS. MMS is described in detail in [96], [97], and [98], while it is also discussed in [23], [99], [100], and [101]. Reference [100] extends MMS to interwork with the Internet. However, the later versions (also known as release) of MMS specifications defined solutions for the same purpose. Reference [102] makes a thorough analysis over MMS from interoperability point of view. Important aspects of interoperability, like terminal capability negotiation and content adaptation, also come under focus in [103]. MMS is also described in [104] in terms of its architecture, standardization, and different possible contents in terms of media types and allowed size. Reference [40] also describes MMS as a solution to mobile messaging in the 3G. Beside pointing out the expectation of MMS, it also points out some problems of mobile messaging. The key problems pointed out are user interface, content adaptation, multiple technologies, interoperability, and billing. Based on more capable device and 3G networks, the reference proposes integration of mobile messaging – an MMS-based integrated messaging for intelligent routing among different systems. MMS is also described and analyzed in [14] in terms of its working principles, standards, and error protection technology. Reference [2] reports about the development of an MMS system. The system works in a server-based mailbox approach, requiring logging in to access messages form a server. It also describes a couple of commercially deployed MMS solutions.

Reference [105] describes MMS from the interworking with IMS-based IM service point of view. The proposed interworking model is based on a gateway that translates a message between the systems. Reference [22] describes MMS in terms of a delivery platform of different content and services.

An implementation of MMS, as embedded image transmission system, is described in [106]. The implementation can be used in video watch field (e.g., home safeguard control system) for the surveillance of any place covered by a GPRS network. Multimedia messaging is a power-hungry service, and may become a critical factor in a mobile terminal. Reference [107] makes an analysis to find some ways how MMS can be designed to consume less power

MMS is also analyzed in detail in [P1], [P2], [P3], [P4] and [P5] from both implementation and standardization points of view. Different aspects of MMS come under focus in the analysis. The summary of the analysis, the recent developments in terms of standardization, and the related key research activities are described below in different sub-sections to provide an in-depth view about MMS.

2.3.2.1 History, Standardization, and Specifications

The standardization works for MMS started in the 3GPP and the WAP Forum[8] in 1999. After the initial confusion about scope, responsibility and objectives, both the organizations agreed to share the works to provide unique end-to-end solution for MMS. The agreement was not easy due to different factors, like positioning MMS among the other available messaging systems, procedural and legal issues involved in the organizations, and the involvements of different interest groups. According to the agreement, the WAP Forum would provide the solution for the terminal interface of MMS, while the 3GPP would provide the solution for different network interfaces of MMS.

In 2000, the 3GPP approved its first version (known as release) of MMS specifications in terms of release-99 MMS, which provided the model and basis for MMS service. The corresponding work in the WAP Forum (known as MMS 1.0) became stable in 2000, but final approval took place in 2001 due to procedural reason. The 3GPP had two main specifications for the release-99 MMS – TS 22.140 [108] and TS 23.140 [109]. The scope of the TS 22.140 is functional requirements, while the TS 23.140 defines architecture, functions, and technical solutions, based on the requirements in the TS 22.140. Specifically, the TS 23.140 defines

- functional capabilities and requirements of different involved entities,
- service behavior for different features and functionalities,
- information flow in all the interfaces in terms of abstract message of application protocol, and
- transport protocol, messages (Protocol Data Unit - PDU), headers, and mapping for the network interfaces.

The specification suit for MMS 1.0, defined by the WAP Forum, includes three specifications – WAP 205 (architecture) [110], WAP 206 (transactions) [111], and WAP 209 (encapsulation of

[8] The WAP Forum, founded in 1997, developed global open standards for wireless information and telephony services on digital mobile phones and other wireless terminals. It was consolidated to the OMA in 2002, and does no longer exist as an independent organization.

messages) [112]. All these specifications provide solutions in terms of transport protocol, messages, headers, and mapping for the terminal interface.

Since the approval of the first MMS version, the 3GPP continued the work to enhance MMS, and approved the second version of MMS (known as release-4 MMS) in 2001. The release-4 enhanced the end-to-end architecture, identifying different interfaces – MM1 for the terminal interface, MM3 for the interface for interworking between MMS and other messaging services (e.g., SMS, e-mail), MM4 for the MMS interface between different network/service providers, MM7 for the interface with value added service/content providers [113]. The WAP Forum also continued its work to align its MMS with the release-4 MMS, and brought stability to its second version of MMS (known as MMS 1.1) in 2002. In the mean time, the WAP Forum consolidated to the OMA. MMS Conformance Document [114], a document initially developed by the industry to bring end-to-end conformance, consistency and interoperability, was also included in the MMS 1.1 specification suit. The other existing MMS specifications were renamed to conform to OMA [115], [116], and [117]. Due to all these consolidation process and the new OMA working procedure related to interoperability, MMS 1.1 was finally approved by the OMA in 2004.

The 3GPP continued to enhance MMS with increasing features, and finished its third version (known as release-5 MMS) in 2002. In the release-5, the 3GPP included a specification to define the MMS-specific media types, codecs, file format, and media synchronization and presentation format – TS 26.140 [118]. Previously, these media-specific definitions belonged to the TS 23.140, which was also updated for the release-5 [119]. While working with the procedural issues related to MMS 1.1, the work for MMS 1.2 (the MMS version corresponding to release-5), already started in 2002 in the WAP Forum. The MMS 1.2 [120] was approved in the OMA in 2005.

Due to market demand, the 3GPP worked further to enrich MMS, and the fourth version of its MMS (known as release-6 MMS) was frozen in 2004. The main specifications for the release-6 MMS are TS 22.140 [121], TS 23.140 [122], and TS 26.140 [123]. The OMA also followed the work for the corresponding version – MMS 1.3. The MMS 1.3 has been technically stable since the end of 2005, but it is not finally approved yet due to the required testing and interoperability processes, which sometimes require correction in the specifications. The main specifications included in MMS 1.3 are – MMS Architecture [124], MMS Client Transactions [125], MMS Encapsulation Protocol [126], and MMS Conformance Document [127]. The features and functionalities of different MMS versions (releases) are outlined in Sub-section 2.3.2.5.

The MMS standardization activities started late in the 3GPP2. After lot of discussion, the 3GPP2 agreed to align its MMS with the MMS defined by the 3GPP. Beside the alignment, the 3GPP2 also decided to develop some additional protocol solutions for different interfaces. In many cases, the 3GPP2 followed the agreement in the 3GPP. The 3GPP2 published its first suit of MMS specification for the Code Division Multiple Access (CDMA) market in 2003 – known as the initial release 0 [128]. The 3GPP2 published follow-up versions of MMS gradually – release A [129], B [130], and C [131], roughly corresponding to MMS 1.1, 1.2, and 1.3 respectively. Beside what is defined in the OMA and the 3GPP, the 3GPP2 has two additional solutions for the terminal interface [132] [133], and a solution for the interface to interwork with e-mail [134]. Media requirements for the 3GPP2 MMS [135] are also different from the same in the 3GPP MMS due to suitability of media with the corresponding access technologies, licensing status of a codec, and historical reason.

Beside the standardization organizations, many industry forums became involved with the MMS standardization process in terms of e.g., testing, certification, providing contributions, requirements, and guidelines. Some examples worth mentioning in this regard are Multimedia Messaging Interoperability Process (MMS-IOP) (consolidated to the OMA in 2002), CDMA Development

Group (CDG), Global Certification Forum (GCF), GSMA, GSM North America (GSMNA), Fixed line MMS Forum.

2.3.2.2 End-to-end Architecture

Both the 3GPP and the OMA defined end-to-end architecture for MMS, shown in Figure 5 and Figure 6 respectively. Though the architectures look different from each other at the first look, they are very close to each other. The main difference is - they choose different names for the same entity or interface. A simplified architecture is available in Figure 1 of [P1], Figure 2 of [P2] and Figure 3 of [P3], which are updated in Figure 1 of [P4] and Figure 1 of [P5]. The simplified architecture is shown here in Figure 7 below for easy tracking. The names used in the simplified architecture are also simplified, and these simplified names are used throughout this dissertation for consistency and simplicity. A brief description about different important entities and interfaces, and the mapping between the simplified architecture and the architectures defined by the 3GPP and the OMA are provided below. Some of the entities and interfaces are beyond the scope of this dissertation, and not discussed here.

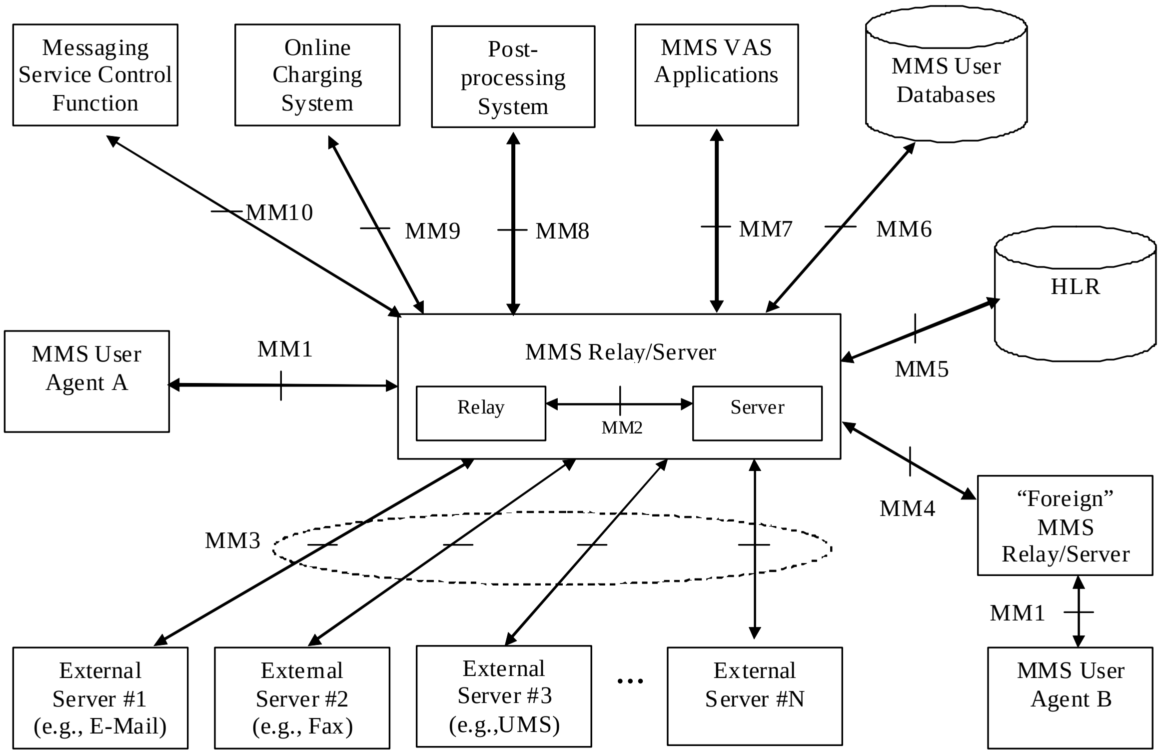

Figure 5: The 3GPP view of MMS end-to-end architecture [122].

The most important entities in the architecture are MMS User Agent (MMS UA) and MMS Relay/Server (MMS R/S), known as MMS Client and MMS Proxy Relay in the OMA architecture respectively. MMS R/S is the combination of two logical entities – MMS Server and MMS Relay. It is also known as MMS Center (MMSC) commercially. MMS UA provides means for user interaction, so that a user can compose, send, retrieve, view, and perform other controlling functions. An MMS UA interacts with an MMS R/S over the terminal-interface, known as MM1 and MMS_M in the 3GPP and OMA respectively, for transporting and controlling purposes. Application and the related application interface MMS_A, shown in the OMA architecture in Figure 6, are described at the end of this sub-section. According to the OMA solution, Hyper Text Transfer Protocol (HTTP) or Wireless Session Protocol (WSP) can be used across the terminal-interface. HTTP is more popular solution, while WSP remains as a solution due to historical reason. The 3GPP2 has defined more solutions for the interface, based on Mobile-IMAP (M-IMAP) [132] and SIP [133]. M-IMAP is an adaptation of Internet Message Access Protocol version 4 rev 1 (IMAP4). However, these solutions mostly focus on basic MMS functionalities, and are not updated to meet the enhancements of the later versions of MMS.

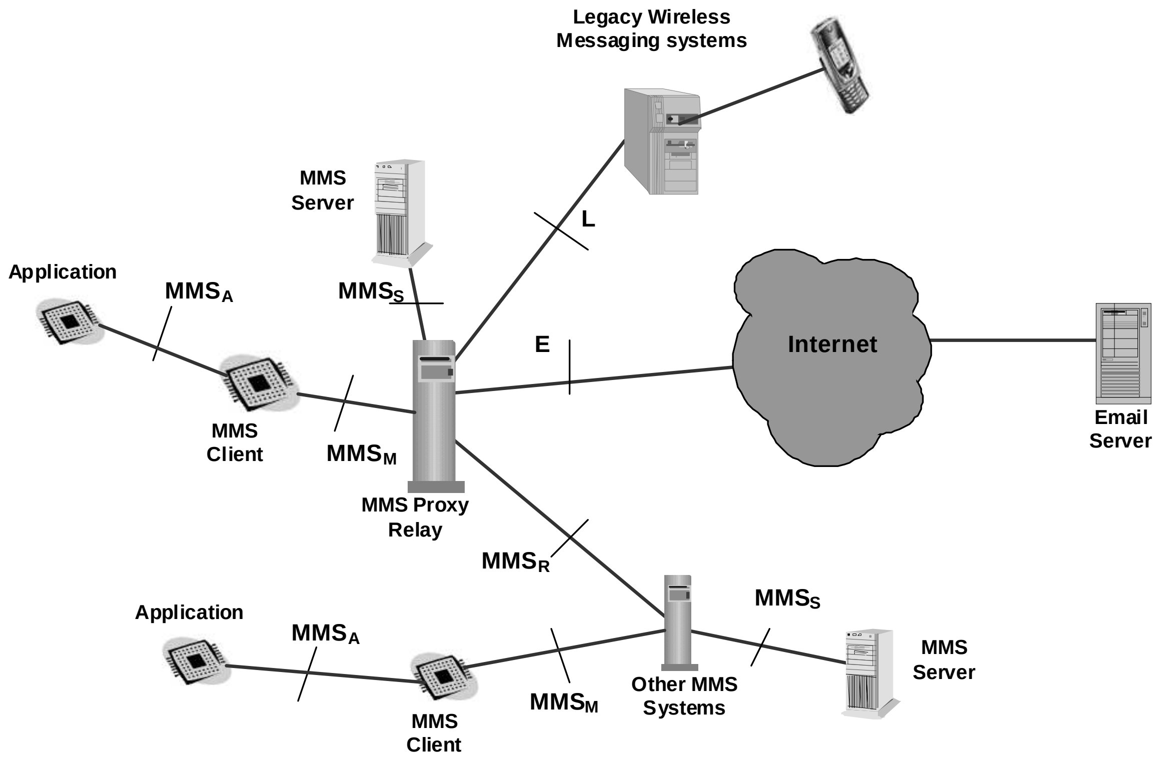

Figure 6: The OMA view of MMS end-to-end architecture [124].

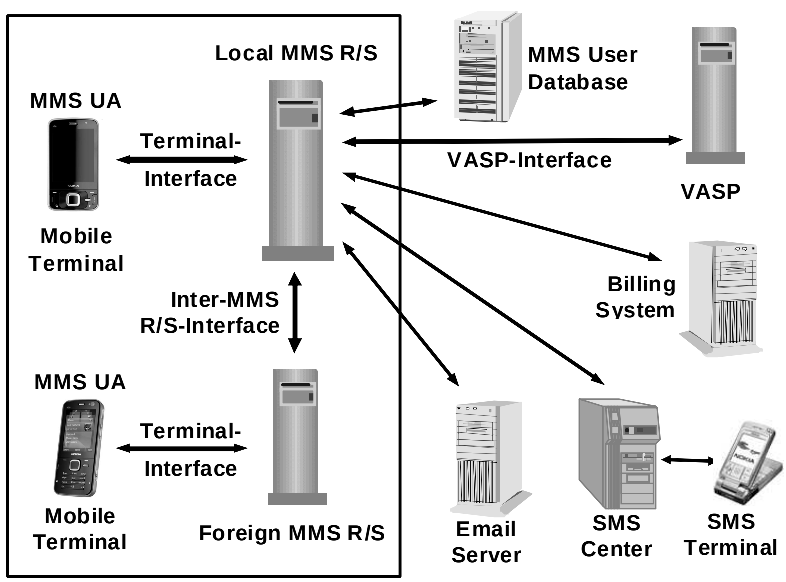

Figure 7: Simplified MMS architecture [P4] and [P5].

An MMS R/S is the central network entity that controls the whole service. Typically, it is owned by a network operator or service provider. MMS R/S has many responsibilities, like storage, address resolution, routing, collecting charging information, content adaptation, conversion of message format, interworking, generation and routing of delivery reports, routing read report, and controlling the messages to/from a content provider. An MMS R/S controls the function by interacting with other MMS entities (e.g., MMS User Database, Billing System – shown as Post-processing System and Online Charging System in the 3GPP architecture in Figure 5) in the local environment. As the OMA architecture is more terminal-centric, it does not show these interfaces. MMS User Database provides user information about, e.g., subscription and configuration. An MMS R/S interacts with the MMS R/Ss of foreign environment across inter-MMS R/S-interface, known as MM4 and MMS_R in the 3GPP and the OMA architecture respectively. This interface is used to route MMS message between different network operators or service providers. The only solution provided for the interface is based on Simple Mail Transfer Protocol (SMTP), defined by the 3GPP. An MMS R/S also interacts with other messaging systems (e.g., SMS, e-mail) to provide interworking. The interface for such interaction is shown as L and E in the OMA architecture, while it is collectively addressed as MM3 in the 3GPP architecture. An MMS R/S uses the VASP-interface (MM7 interface in the 3GPP architecture) to interact with a VASP (MMS VAS Application in the 3GPP architecture), which provides value added service/content to users. The only solution provided for the interface is Simple Object Access Protocol (SOAP) over HTTP, as defined by the 3GPP. This interface is not shown in the OMA architecture. In the early releases, MMS was limited without the definition of MM3 and MM7 interfaces, respectively [100].

Application has been lately included in the MMS architecture [124]. Application is defined as a system entity that can interact with MMS to transport its data to its peer application. More specifically, one or more applications interact with either an MMS UA or a VASP across the application-interface (MMS_A). The interaction of an application with an MMS UA is mostly mentioned in this dissertation (assuming that an application resides on top of an MMS UA in a terminal) for brevity, while similar interaction can take place between an application and VASP, if an application is in a value added server. Application and the application-interface are used for the MMS feature of transporting application data, which is described in Sub-section 2.3.2.5.

Reference [23] developed a mathematical model for evaluating an MMS system. The expressions for important performance parameters like message loss, message delay, and expiry probability were derived. An algorithm to find temporary storage size in an MMS R/S for a given set of system parameter is also presented. A simulation of the proposed solution shows example of system response to different parameters like load, message expiry, and service rate.

2.3.2.3 Message Structure and Encoding

MMS message structure and encoding across different important interfaces are briefly described below.

<u>Terminal Interface</u>

MMS uses different messages for transporting and controlling purposes. It does not have separate user plane or control plane, as the same message can be used for both transporting and controlling purposes. An MMS message uses Multipurpose Internet Mail Extensions (MIME) format to combine information elements (also known as headers) and multimedia elements, forming top-level MMS headers and MMS message body inside an MMS message respectively. The information elements carry control information and information about content, while multimedia elements contain multimedia content and content-specific headers. Each multimedia content is described by the content-type header of the corresponding body part. On the other hand, the typical values for the content-type header in the top-level MMS header is multipart/related or multipart/mixed, if the multimedia contents within the message are dependent or independent respectively; while other values are also allowed. The OMA has defined binary coding for the information elements and their values to make efficient use of the radio interface. The multimedia elements are also binary coded before transmission for the same reason. An MMS message having both information elements and multimedia elements are addressed as multimedia message (MM) in this dissertation. The structure of an example multimedia message is shown in Figure 8.

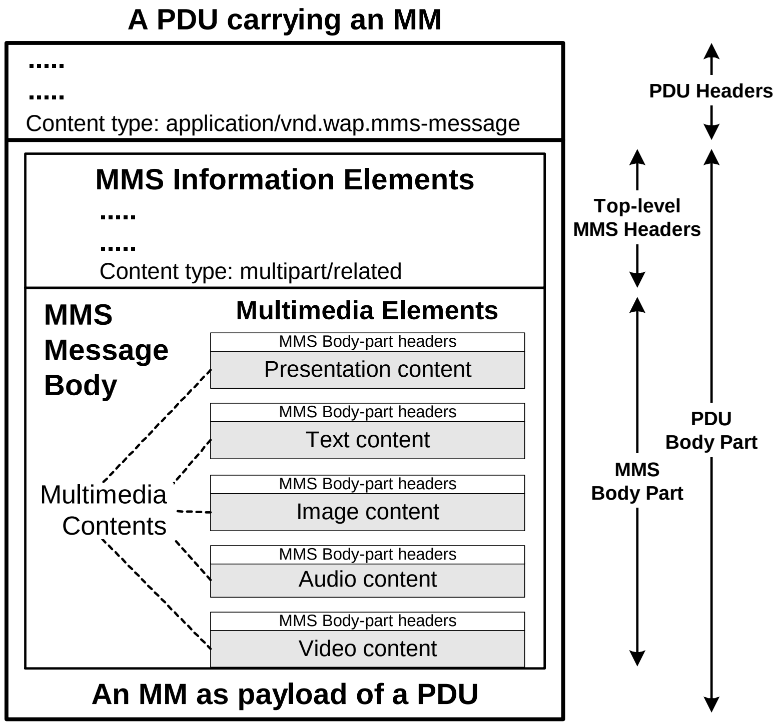

Figure 8: The structure of an example MMS Message [P5].

An MMS message is carried as the payload of the PDU of transport protocol (e.g., HTTP across the terminal-interface). The OMA has defined and registered the media type application/vnd.wap.mms-message, which is used as the content-type header of the PDU that carries an MMS message. Figure 3 of [P1] and Figure 4 of [P3] also show simplified structure of a multimedia message; however there is an error in the figures. The value of the content-type header is mistakenly shown as application/vnd.wap.mms-message in the figures, while the right value should be multipart/related instead.

The possible media types and formats that can be carried as multimedia content within a multimedia message are described in Sub-section 2.3.2.4. An example MMS message is shown below (without the encapsulation of the transport PDU) in text format to better understand the structure and format.

An example MMS message, with related contents text, image and video, in text format:

```
X-Mms-Message-Type: m-send-req
X-Mms-Transaction-ID: abcdefghijk
X-Mms-MMS-Version: 1.3
From: +358601234567
To: +358701111111/Type=PLMN
Subject: greetings
X-Mms-Priority: Normal
X-Mms-Delivery-Report: Yes
Content-Type: multipart/related;
                boundary=”54321”;
                start=”<950100xyz@abc.com>”;
                type=“application/smil”

--54321
Content-Type: application/smil;
                 name=”greetings.smil”
Content-Transfer-Encoding: binary
Content-ID: <950100xyz@abc.com>

… smil content …

--54321
Content-Type: text/plain;
                 name=”greetings.txt”
Content-Transfer-Encoding: binary
Content-ID: <950101xyz@abc.com>

… text content …

--54321
Content-Type: image/jpeg;
                 name=”greetings.jpg”
Content-Transfer-Encoding: binary
Content-ID: <950102xyz@abc.com>

… jpeg content …

--54321
Content-Type: video/H263-2000;
                 name=”greetings.3gp”
Content-Transfer-Encoding: binary
Content-ID: <950104xyz@abc.com>

… video content …

--54321--
```

The example MMS message, shown above, is used to submit different related multimedia contents (text, image, and video) to network for delivery to a specific recipient identified by the top-level MMS header `To`. The presentation content (`Content-Type: application/smil`) defines the temporal and spatial information for rendering the multimedia contents within the message. More about different types of multimedia message and possible media content within a message are described in Sub-sections 2.3.2.6 and 2.3.2.4 respectively.

Inter-MMS R/S-Interface

MMS message is included within a single SMTP mail message across the inter-MMS R/S-interface. An SMTP mail message is MIME formatted. If an MMS message includes content, the `content-type` header has appropriate value to identify the content (e.g., `multipart/related`, `multipart/mixed`). If the message does not include any media content, the `content-type` header has `text/plain` as its value. The MMS information elements (top-level MMS headers) are included in the SMTP mail message as header fields. Some MMS information elements are mapped to the appropriate Standard (STD) 11 headers [136], while the "X-" extensions mechanism is used with an "X-MMS-" prefix for other MMS information elements. More about message structure, format, and encoding of MMS message across the inter-MMS R/S-interface is available in the 3GPP TS 23.140 [122].

VASP-Interface

Messages across the VASP-interface is formatted based on SOAP 1.1. Each SOAP message has two main parts – SOAP envelope and SOAP attachment. SOAP envelope is an Extensible Markup Language (XML) document having two main elements – `<header>` and `<body>`, while SOAP attachment includes content of an MMS message. MMS information elements (top-level MMS headers) are carried in terms of SOAP envelope within the two main elements. The SOAP message also follows the MIME encoding. The whole SOAP message is the payload of the transport PDU, in this case HTTP *Post* request. The `content-type` of the PDU is either `multipart/related` or `text/xml`, depending on if the message includes SOAP attachment or not. SOAP envelope is always the first part of the MIME message, indicated by the `start` parameter of the `content-type` header. The MIME part of SOAP attachment has appropriate value for the `content-type` header to identify content.

The response message is carried in an HTTP response PDU. In this case, SOAP envelope is encapsulated within an HTTP response, having `text/xml` as the content-type. The response can carry status of the request in three levels:

- HTTP level - in terms of HTTP response code (e.g., 200 ok, 403 server not found),
- SOAP level - in terms of SOAP fault, and
- MMS level - in terms of MMS information element within the SOAP envelope.

Further detail about message structure, format and encoding, including examples in terms of figures and textual format, are available in the 3GPP TS 23.140 [122].

2.3.2.4 Media Types and Formats

The capabilities of different mobile terminals vary significantly. As for example, media capabilities of different terminals can vary due to the differences in the hardware (e.g., screen size, memory, processing power, ability for capturing and displaying a media) and software used. Moreover, media capabilities of a terminal also depend on its business focus, price, and royalty fee of a media codec. On the other hand, a user expects that a multimedia message is presented in the recipient terminal as submitted, requiring harmony among different MMS-capable mobile terminals in terms of media capabilities. Therefore, the 3GPP and the 3GPP2 defined minimum set of media codecs for different media types for MMS, depending mostly on Intellectual Property Rights (IPR) situation, royalty fee, availability of open standard, and the suitability with the respective access technology [123] [135].

However, the minimum sets defined by both the 3GPP and the 3GPP2 still provide flexibility to some extent, as there are multiple codecs for different demanding media types, and some codecs are optional. As such flexibility may not be suitable for the end-to-end interoperability, the OMA has defined another minimum set with more restrictions [127]. The minimum set defined by the OMA is mostly a subset of the minimum set defined by the 3GPP and the 3GPP2. In fact, the OMA has two different minimum set – one for the 3GPP networks and the other for the 3GPP2 networks. Beside defining the media codec and format, the minimum set also includes specific version of codec and format, and additional MMS-specific rules to ensure interoperability.

Due to the continuous development in the related technologies, a terminal can support increasing number of media types and formats day-by-day. Consequently, the minimum sets of codec for MMS have been also evolving with each new version of MMS specifications. MMS started with less demanding media types like texts and graphics, and gradually more demanding media (e.g., image, speech, audio, video) have been gradually included [137]. Moreover, different media have been evolving with higher quality (e.g., higher resolution, bandwidth, sampling rate, length). Reference [40] also predicted that the support for very rich media (e.g., video) may not be there at the early phase of the MMS deployment. According to [2], mobile video is expected to grow gradually, and generate reasonable revenue in 2009.

For related multimedia contents within a message, the expression of temporal and spatial synchronization among the contents is important for consistent user experience. While temporal synchronization refers to temporal relationship between media, and spatial synchronization refers to spatial arrangement (layout) and relationship of media on a specific output (e.g., display screen). Such synchronization can be expressed within a multimedia element of the message. Such an element is addressed as presentation element in this dissertation. The element provides means for automated rendering of a multimedia message, requiring less user interaction. As the idea of having consistent presentation element has been missing from multimedia messaging [138], MMS incorporates the mechanism by defining suitable formats for the presentation element. Moreover, MMS specifications also define file format for different codecs, as it is an important component for transporting and storing both dynamic and static media contents.

Table 1 shows the minimum set of media codec and format for different media types and presentation format, according to the latest version of MMS specifications in the OMA [127], the 3GPP [123], and the 3GPP2 [135]. Reference [1] also outlines the minimum set of codec defined in the early version of MMS specifications for certain media types.

Synchronized Multimedia Integration Language (SMIL) is suitable format for presentation, as it provides extended capabilities, such as timing of multimedia objects and synchronization. MMS SMIL is sort of a SMIL profile defined at the beginning [127]. Only a few basic SMIL elements are included in the MMS SMIL, as capabilities of a mobile terminal were very limited at that time. As terminal capabilities have been evolving, a new mobile terminal can support more complex elements of SMIL. The 3GPP has defined another enriched profile of SMIL, and named it 3GPP SMIL Language Profile, which is also known as 3GPP SMIL. As it was originally defined for the streaming service defined by the 3GPP (known as PSS), it is also known as 3GPP PSS SMIL Language Profile or PSS SMIL in brief. PSS and 3GPP SMIL are described in Section 2.4 and Sub-section 2.4.1 respectively. The corresponding profile defined by the 3GPP2 is 3GPP2 SMIL. 3GPP2 SMIL is the superset of 3GPP PSS SMIL, and includes a few additional modules. However, 3GPP2 SMIL and 3GPP PSS SMIL are interoperable.

A subset of Extensible Hypertext Markup Language (XHTML) Mobile Profile is defined by the OMA to use it only for rich text (e.g., bold, italic, underline, number-list, bullet-list). Beside the rich text capability, XHTML Mobile Profile can also be used as a presentation element in terms of spatial synchronization. XHTML Mobile Profile is a subset of XHTML 1.1 but a superset of XHTML Basic.

Table 1: Minimum set of media in MMS, according to the latest version of MMS specifications.

Media type / Presentation	OMA [127]	3GPP [123]	3GPP2 [135]
Plain text	US-ASCII, UTF-8, UTF-16	US-ASCII, ISO-8859-1, UTF-8, Shift_JIS	US-ASCII, ISO-8859-1, UTF-8, GSM 7-bit default alphabet, Shift_JIS
Rich text	XHTML Mobile Profile		Text in SMIL, XHTML profile in 3GPP2 SMIL
Still image	Baseline JPEG	Baseline JPEG, Progressive JPEG	Baseline JPEG, Progressive JPEG
File format for still image	JFIF, EXIF	JFIF, EXIF	JFIF
Bitmap graphics	GIF87a, GIF89a, WBMP, PNG (3GPP2)	GIF87a, GIF89a, PNG	GIF87a, GIF89a, PNG
Vector graphics	SVG-Tiny	SVG Tiny and ECMAScript	SVG-Tiny, SVG-BASIC
Speech audio	AMR-NB, 13K (3GPP2)	AMR-NB, AMR-WB	EVRC, 13K, AMR-NB, VMR-WB
Synthetic audio	SP-MIDI, General MIDI Level 1 (3GPP2)	SP-MIDI	SP-MIDI, General MIDI Level 1
File format for synthetic audio		Mobile DLS instrument, Mobile XMF content	
Audio	Enhanced AAC+	Enhanced AAC+, Extended AMR-WB, MPEG-4 AAC Low Complexity, MPEG-4 AAC Long Term Prediction	MPEG-4 AAC Profile Level 2, MPEG-4 HE AAC Profile Level 3
Video	H.263, MPEG4, (3GPP2) 13K (associated audio) (3GPP2) AMR (associated audio)	H.263 profile 0 level 45, H.263 Profile 3 Level 45, MPEG-4 Visual Simple Profile Level 0b, H.264 (AVC) Baseline Profile Level 1b	H.263 profile 0 level 45, MPEG-4 Visual Simple Profile, H.264 Baseline Profile Level 1b, H.263 Profile 3 Level 45,
File format for dynamic media	3GPP (3GPP) 3GPP2 (3GPP2)	3GPP file format ("3GP") [139]	3GPP2 file format (".3g2")
Personal Information Management (PIM)	vCard 2.1 MIP [140], vCalendar 1.0 MIP [140]	vObject MIP (vCard 2.1 MIP [140], vCalendar 1.0 MIP [140], and vBookmark 1.0 MIP) [140]	
Timed text		3GPP Timed Text format [141]	3GPP Timed Text
Presentation	MMS SMIL, 3GPP PSS SMIL (3GPP), 3GPP2 SMIL (3GPP2) CMF (3GPP2)	3GPP SMIL [142], XHTML Mobile Profile	3GPP2 SMIL, CMF

Note: a codec/format marked with 3GPP or 3GPP2 in parenthesis means that the codec/format is required only for the implementation complying to the 3GPP or 3GPP2 network respectively. The other codecs/formats in the column under "OMA" apply for both the 3GPP and 3GPP2 compliance.

H.264/MPEG-4 AVC is a compression efficient video codec lately designed jointly by the International Standards Organization (ISO)[9] and the ITU. Based on a subjective test on the codec for MMS, frame rate of 10 frames per second and bit rate below 64 kbps are sufficient to provide good quality for a video clip with less motion, while 15 frames per second is sufficient for sports video [143]. Reference [137] described a method for implementing typical speech codecs for MMS solution, where compression and processing power are critical issues.

An MPEG-4 video codec architecture suitable for mobile multimedia applications like MMS and streaming is proposed in [13]. With the optimized partitioning of the codec functionalities between

[9] The ISO is a network of the national standards institutes of 155 countries, on the basis of one member per country. It is a leading developer of international standards, specifying requirements for state-of-the-art products, services, processes, materials and systems, conformity assessment, and managerial and organizational practice.

software and hardware, the architecture of the codec is made suitable for mobile terminal, which is usually limited in terms of processor load and power consumption.

The 3GPP recommended MPEG4 Advanced Audio Coding (AAC) for audio codec for the early releases (release-4 and release-5) of MMS and PSS without very detail analysis. The 3GPP decided to select an advanced audio codec starting from the release-6 to meet the growing demand. Reference [144] describes the selection process. Low bit rate (12 to 32 kbps) and high bit rate (more than 24 kbps) were considered separately in the process. The low bit rate is useful for speech, music and mixed content, while high bit rate is mostly intended for high quality music. The careful selection process (that includes defining design constraints, performance requirements, test plans and selection rules, and performing subjective listening tests) indicated good performance of enhanced AAC+ (in both high and low bit rate ranges) and extended AMR-WB (in the low bit rate range) codecs. Extended AMR-WB is also known as AMR-WB+.

As mobile terminal is limited in terms of computational resources, a media codec with low complexity algorithm is suitable for mobile multimedia applications. Moreover, limited bandwidth in the wireless transmission and the increasing demand of high quality mobile service require very high compression ratio for a media codec to be suitable for multimedia application, like MMS. A low complex audio encoding method, to fulfill the requirements of MMS, is described in [145]. The encoder is a version of the extended AMR-WB audio coder, and works on open loop coding model selection algorithm. The result of the listening test indicates that the encoder is good enough for mobile application, though extended AMR-WB closed loop model selection performs better.

Coding techniques of a media can be used to improve the bandwidth efficiency of a multimedia messaging system. Layered coding, distribution of coded content in the network, and progressive download can reduce the required bandwidth for delivering a multimedia message [146]. Progressive download is beyond the scope of this dissertation, as stated in Sub-section 2.4.1, where streaming is described.

2.3.2.5 Important Features and Functionalities

At the beginning, the basic scope of MMS was person-to-person messaging. Here, a person is a user (also known as consumer). The functionality required for the scope is end-to-end transmission of multimedia contents, which mainly involves submission, routing, storage, and delivery of the contents. While the submission is relatively straightforward, the delivery is based on a push followed by a pull. After the submission, a message is temporarily stored in the network, and a notification (including the summary of a message) is pushed to the recipient first. Upon receiving the notification, the recipient pulls the contents. Moreover, the retrieval can be either immediate or delayed, depending on if the pull follows the push immediately or not. The MMS was designed with the basic functionality and some core features in its first version (i.e., OMA MMS 1.0 or 3GPP MMS release-99). As mentioned in Sub-section 2.3.2.1, MMS has been further developed gradually with incremental features for three more versions. The important features and functionalities of the MMS versions of both the OMA and the 3GPP are outlined in Table 2.

The MMS versions of the 3GPP2 is not shown in the table, as the relationship of the 3GPP2 MMS versions with the MMS versions in the OMA and the 3GPP is not straightforward as such.

The table mostly outlines the MMS developments in protocol level. Besides, MMS has been developed in terms of media capabilities, which is not shown in the table for simplicity. Sub-section 2.3.2.4 outlines the latest situation of media capabilities for MMS in the OMA, the 3GPP and the 3GPP2.

Table 2: Important MMS features and functionalities, defined in different versions of specifications.

1st MMS version (OMA MMS 1.0/3GPP MMS release-99)	Enhancements in the 2nd MMS version (OMA MMS 1.1/3GPP MMS release-4)	Enhancements in the 3rd MMS version (OMA MMS 1.2/3GPP MMS release-5)	Enhancements in the 4th MMS version (OMA MMS 1.3/3GPP MMS release-6)
• End-to-end content transmission (submission, temporary storage, notification, immediate and delayed retrieval) for person-to-person messaging • Delivery report • Read report (MMS message based) • Multiple addressing scheme – MSISDN, e-mail address • Address hiding • End-to-end message qualifier (e.g., subject, class, priority) • Validity period (the earliest and the latest time for message delivery) • UAProf-based terminal capability negotiation • Message upto 30 Kbytes • Content adaptation in the MMS R/S	• SMTP-based inter-MMS R/S-interface for the interworking between multiple operators or service providers • Forwarding a message without prior retrieval • PDU-based read report • MMS-level hook for reply and pre-paid charging • Enhancements of notification (addition of priority and subject headers) • Storage of MMS information (e.g., notification, connectivity information) on SIM • Support for streaming	• SOAP-based VASP-interface for content-to-person and person-to-service messaging • Server-based permanent storage of MMS message • Short code addressing scheme to address a VASP • RADIUS based user authentication, and ENUM and IMSI based address resolution • Further enhancements of MMS notification (size, type and name of individual elements within a message) • Storage of MMS information (e.g., notification, connectivity information) on USIM • Enhancement in the support for streaming • OMA DRM v1.0 Forward-Lock • Message upto 300 Kbytes • Enhancements in content adaptation - transcoding policy and matrices	• MMS as application data transport for application-to-application messaging • Refreshing and canceling content in a terminal • UTF-8 encoding for object name • Deletion of a message in MMS R/S • Private addressing • MMS template • Post card service • Full OMA v1.0 DRM • Message upto 600 Kbytes

The artificial limit in the MMS specification on the message size, as shown in Table 2, is not only to have interoperability, consistency, and control over traffic, but also to avoid long transmission time. However, MMS specifications also allow a message without any limit on the size and media in a message. For such a message, there is no guarantee for end-to-end delivery without content adaptation in the MMS R/S. MMS is designed with so many features that it is expected that those will be deployed in phased approach. As for example, simple and core features (e.g., end-to-end content transmission, delivery report) are naturally deployed at the early stage, while complex and additional features (e.g., read report, support for streaming) are likely to be deployed later [2] [40].

The most of the key features and functionalities outlined in Table 2 are described in [P1] and [P2], while the rest can be found from different MMS specifications. Only the features that are directly related with this dissertation are described below. The support for steaming in MMS is not described here, as it is elaborately described in Chapters 3 and 4.

Terminal Capability Negotiation and Content Adaptation

Terminal capability negotiation is used to adapt content in accordance with the recipient terminal capabilities and transcoding policy and matrices. Terminal capabilities [125] can vary in terms of different aspects like screen size (resolution), message size, and media types and formats. Technological advancement has significant contribution in having disparity between mobile terminals [102]. Beside variation of terminal capabilities, other possible reasons for content adaptation are user (both originating and recipient) settings/preferences, network status (e.g., load), operator setting, variation in the native codec of mobile access technologies, patent and licensing status of a codec [103]. Network characteristics (e.g., bandwidth, delay, jitter) and user preferences can vary significantly, requiring content adaptation [147]. The standard terminal capability negotiation in MMS is based on UA Profile (UAProf) [125]. In practice, actual terminal capabilities are usually stored in a Profile Server. Typically, the recipient MMS UA includes a reference of the terminal capabilities, stored in the Profile Server, in the message sent to the associated MMS R/S as a request to retrieve an MMS message. The MMS R/S fetches the terminal capabilities from the Profile Server based on the reference, and adapts content of the message accordingly, before providing the message to the recipient MMS UA. The routing via the own MMS R/S ensures interoperability between networks, as an MMS R/S can adapt the message, if required [102].

However, without proper design, content adaptation can cause some problems. As for example, automated down-sampling from a high resolution image to low resolution image is a lossy process, and may have negative impacts like poor visualization, wrong subject selection, violation of legal constraints (e.g., copyright, digital rights) [148]. Moreover, different supported codecs by different terminals make it difficult to transcode content [138]. As content adaptation can be complex and difficult [102], MMS specification [127] defines transcoding metrics for identified needs. Terminal capability negotiation can be dynamic, where the recipient MMS UA includes the capabilities dynamically in the message sent to the MMS R/S as a request to retrieve an MMS message. Both terminal capability negotiation and content adaptation are described in [102] and [103]. Reference [103] proposes some enhancements in the content adaptation in MMS – e.g., caching content, language translation, and network profile (for maintaining a list of network-preferred codec).

Reference [147] makes an analysis over video structuring method, and proposes improvement in content adaptation on a video clip by providing metadata about a clip and segmenting and producing a representative key-frame index. Content adaptation in MMS also comes under focus in [149], which proposes an architecture for content adaptation in the network. It proposes an extension to MMS network architecture that allows user-tailored delivery by considering aspects like sender's preferences, recipient's setting and state, and network information.

Content-to-Person and Person-to-Service Messaging

SOAP-based VASP interface enables MMS to provide content-to-person and person-to-service messaging services consistently. In both content-to-person and person-to-service messaging, an MMS UA needs to be equipped with the logic for handling the content of a message.

Content-to-person messaging provides means to a content provider for distributing contents in terms of a message to users. It is also known as application-to-person messaging [20]. This form of messaging has many practical uses, like distributing news clip, advertisements, weather forecast, information about share price or traffic, music, highlights of a sports or games [40]. The implementation of sending advertisement of a shopping center, to inform its customers about new movies and music, in terms of an MMS message is described in [150].

Person-to-service messaging allows a user to request for a service. One such use of MMS has been postcard service. In this service, a user captures an image of her interest, and sends it as an MMS message to a service provider. The service provider then prints out the image in a postcard format, and sends it as a conventional post card to the address mentioned in the message using the postal service. Another example of person-to-service messaging is home surveillance, where a user sends an MMS message to the surveillance system to activate different detectors (e.g., infrared sensor, gas detector, and camera). In response, an MMS message, which includes the detected information in terms of multimedia content, is sent back to the user [150].

Application-to-Application Messaging (MMS as a Transport of Application Data)

The dissertation proposes enhancements to this feature in Chapter 5. The level of description for this feature is more detailed here to better understand the proposed enhancements later. This feature enables MMS to transport data between top-level peer applications. As MMS is also addressed as an application sometimes, the term "top-level" is used to mean any application over MMS UA in the communication layer. However, the term is not used any more for brevity. The logic of handling the contents of a message resides in the target application in this case. As for example, if two users are using their mobile phones to play chess remotely, the chess application in the terminal can use MMS to convey the information about each move on the chess board to the peer end. Reference [151] describes one more example, where MMS is used as the transport for museum guide service. In practice, there can be many more examples of applications that can use MMS as the transport. These and some other examples are further described in Section 5.2.

As an application can reside on a VASP, the VASP-interface can be also used for application-to-application messaging. However, MMS just provides transport, and neither MMS R/S and nor MMS UA is supposed to perform any content adaptation of a message that carries application data. Therefore, the message that carries application data should be somehow easily distinguishable by an MMS R/S and an MMS UA. Moreover, the recipient MMS UA should be able to know from the information within the message about the specific destination application for the message, so that it can forward the content of the message to the right application. The 3GPP has defined three top-level MMS headers to serve these purposes. The presence of any of these headers in a message indicates that it contains application data.

The first header identifies the recipient application, allowing quick handover of the content of the message to the right application by the recipient MMS UA. The second header identifies the originating application, so that the recipient application can easily send a response to the originating application. This second header is useful when the originating application has different identification than the recipient application. As for example, different application developers can develop applications that can communicate.

The identity of an application, used as the value of the first two headers, must be unique. The uniqueness can be achieved in two different alternative ways. A rule is defined to generate unique identity for an application [152]. Here, the uniqueness is achieved by combining top-level globally unique part (e.g., name of manufacturer or application developer) and locally unique part. As for example, if an application developer has unique global identity (based on its registration or name), and the application developer maintains local identity of all the applications developed by them; the combination of these two identities is expected to be globally unique. Alternatively, the registration of a new MIME type for an application in the Internet Assigned Numbers Authority (IANA) can provide unique identification. The former approach of having an unique identity for an application is expected to be fast, and thus, helpful in the quick deployment of an application.

The third header is defined with bit wider scope, so that it could be used for different purposes depending on the need of an application. A user of an application can communicate with multiple users of the same application at the same time (e.g., a user is playing chess with multiple users at the same time), Moreover, a user of an application can communicate with another user of the same application in multiple channels at the same time (e.g., a user is playing multiple chess games with another user). The third header can be used to distinguish the channel or thread of the communication, as in all these cases both first and second headers can have identical values. The third header can also potentially be used for security purposes, so that it carries credential to authenticate the peer application. Such use of the header can be used to protect any misuse of the feature (e.g., spamming, sending harmful data).

2.3.2.6 End-to-End Information Flow and Transport

In MMS, the end-to-end information flow takes place in multiple hops (store-and-forward) in terms of a message, which is also known as PDU. Figure 5 of [P3] shows an example of end-to-end information flow for the whole chain of content delivery between two users. The same figure is shown as Figure 9 here for easy tracking. The name of the messages used in the 3GPP and the OMA are different. The names of the messages used in the figure are simplified to make those self explanatory. As for example, the name of the message for submitting multimedia content for delivery is M-Send.req and MM1_submit.REQ in the OMA and the 3GPP respectively, while the name used for the same message in the figure is MM Submit.

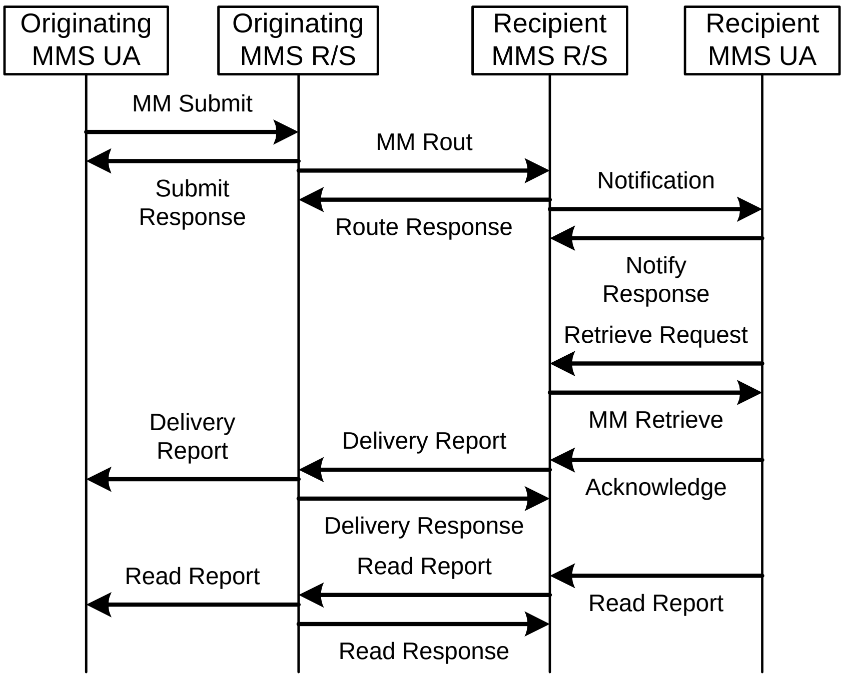

Figure 9: Example information flow in MMS for the whole chain of multimedia content delivery between users (i.e., person-to-person messaging) [P3].

Multiple transport protocols are defined to carry these messages across the terminal-interface. The OMA defined the binding of the messages with both WSP and HTTP protocols, while the 3GPP2 defined the similar bindings with the M-IMAP and SIP protocols. The 3GPP has defined the binding of the messages across the inter-MMS-R/S-interface with the SMTP protocol, which is the only solution for the interface. Table 3 outlines the binding of different MMS messages used in the figure with transport PDU [122] and [125]. Only HTTP is considered here as the transport protocol across the terminal-interface, as it is the most popular protocol solution (in terms of deployment) for the interface.

Table 3: Binding of MMS messages with transport PDU.

MMS Message	**Interface**	**Transport PDU**
MM Submit	Terminal	HTTP Post
Submit Response	Terminal	HTTP 200 OK
MM Route	Inter-MMS-R/S	SMTP mail
Route Response	Inter-MMS-R/S	SMTP mail
Notification	Terminal	WAP Push
Notify Response	Terminal	HTTP Post
Retrieve Request	Terminal	HTTP Get
MM Retrieve	Terminal	HTTP 200 OK
Acknowledge	Terminal	HTTP Post
Delivery Report	Inter-MMS-R/S	SMTP mail
Delivery Response	Inter-MMS-R/S	SMTP mail
Delivery Report	Terminal	WAP Push
Read Report (recipient)	Terminal	HTTP Post
Read Report	Inter-MMS-R/S	SMTP mail
Read Response	Inter-MMS-R/S	SMTP mail
Read Report (originating)	Terminal	WAP Push

The figure is generalized to cover both immediate and delayed retrieval. However, for the immediate retrieval case, the messages Notify Response and Retrieve Request are merged to make efficient use of the radio resource. The end-to-end information flow and related processes in different entities are described in detail in Chapter VI of [P1].

Beside the end-to-end content delivery between users, MMS has been designed to carry contents from a VASP (content provider) to a user, described as content-to-person messaging in Sub-section 2.3.2.5. The end-to-end information flow for such content delivery is described in Chapter 2 of [P4]. The only solution for the VASP-interface is SOAP over HTTP, defined by the 3GPP. The request message across the VASP-interface is transmitted in an HTTP *Post* request, while the response message across the VASP-interface is transmitted in the HTTP response.

2.3.3 Evolution of Messaging in Mobile Communication

Mobile messaging started with text-messaging system SMS [153] and [154], and it has been evolving since then. SMS was extended to EMS to support simple multimedia [22], [97], and [153], though the content size and type allowed in EMS are still very limited by the transport of the messaging system. Then, MMS appeared as a big step in the mobile messaging, as it introduced multimedia in true sense. MMS itself has evolved with many features and functions for multiple versions, as described in Sub-sections 2.3.2.1 and 2.3.2.5. Though, the standardization of MMS is still active in the OMA, not much developments is expected in MMS specifications. The MMS evolution is expected mostly in terms of deployment, as many standardized MMS features are yet to be introduced in the markets. As for example, [7] predicted future development of MMS in terms of newer contents, services, and use of streaming. Moreover, evolution is also expected in terms of usability and user interface. As for example, MMS and other equivalent messaging systems (e.g., SMS) are expected to be integrated in a terminal both in terms of message creation, viewing, and storage, so that a user would not require to know different messaging systems. Rather, the appropriate messaging system would be selected in the background to deliver any message upon it is created by a user.

Besides, mobile messaging has been developing in a different track to deliver a message instantly (known as IM), followed by the popularity of such services in the Internet. As a message is usually delivered instantly, the service of Presence is used by the originator to know the availability and willingness of a recipient. The most of the IM services in the Internet are based on proprietary solutions. Some key vendors of mobile communication formed a standardization body called Wireless Village (WV), and defined a solution of IM and Presence for mobile communication. The solution is known as WV 1.0. The WV was later consolidated to the OMA, and the OMA continued the work and defined a few more versions of the solution with additional features and functions in terms of IMPS (e.g., IMPS 1.1, IMPS 1.2, and IMPS 1.3).

The 3GPP also took an initiative to define messaging solutions over the Internet protocol for all different types of messaging, outlined in Section 2.3.1. As MMS works end-to-end over the Internet protocol, it was accepted as the solution for the deferred delivery type of messaging. The work mainly focused on immediate and session-based services. Later on, the work continued in the OMA, based on the understanding that OMA would focus on the bearer agnostic aspects, like defining services. As a result, the OMA has stabilized another solution of instant messaging called SIP SIMPLE IM 1.0 [155], which is based on SIP and its extension developed by the SIMPLE group in the IETF. SIP SIMPLE IM is defined to use the service of OMA-defined SIP SIMPLE Presence to know the ability and willingness of a recipient. The OMA took an initiative to provide an interworking solution between IMPS and SIP SIMPLE IM, though it did not get much momentum.

Besides, the 3GPP has defined SIP-based IMS [79], [80], [81], and [82] as the platform to provide different IP services. IMS can be considered as a SIP profile providing more control in the network than the IETF-defined SIP. This network-centric approach is suitable for the conventional mobile communication, where billing, authentication, and security are very critical issues. SIP SIMPLE IM is defined in a way that it can work smoothly over IMS. A few key operators and vendors took an initiative to define a profile of mostly IMS-based services in terms of Rich Communication Suite (RCS) to both enable quick deployment of services and enhance user experience in terms of phonebook, messaging, and rich communication. Lately, the initiative became part of the GSMA. The RCS is a bundled service (including SMS, MMS, SIP SIMPLE Presence, XDM, SIP SIMPLE IM, Video/Image/File Share) with specific configuration, features and functions for each service.

SIP-based messaging (e.g., SIP SIMPLE IM) are considered by some as the converged solution of mobile messaging in the long run [41] and [156]. However, it is difficult to justify such prediction, as MMS and other systems defined before are yet to be fully exploited. Moreover, it also depends on the market acceptance of IMS. As IMS is just being deployed discretely by a few operators only in the saturated markets, it is too early to predict about IMS and IMS-based services.

Some enhancements of MMS by blending it with IMS are proposed in [41]. One enhancement is message notification and delivery based on user rule. The choice in this regard can be MMS, SMS, e-mail, or voice mail, determined by static (e.g., day of time, device) and/or dynamic (e.g., roaming, access technology) rule set by a user. Another enhancement is Presence-based MMS, where the Presence information of a recipient is used when sending an MMS message. There are other examples of blending MMS with IMS.

Due to the noted limitation of e-mail (requiring continuous access to check new e-mails), the concept of push e-mail has been introduced in mobile communication. Push e-mail is sometimes addressed as mobile e-mail. In push e-mail, a newly received e-mail or a notification about it is pushed to the recipient client. Push e-mail is not a specific solution, rather there are quite many solutions of push e-mail. While many of the deployed solutions of push e-mail are proprietary (which are not mentioned here), some push e-mail solutions have also been standardized. The OMA defined E-mail

Notification (EMN) [157], which can be used in push e-mail. The EMN is mainly about sending a notification to a terminal, when there is a new e-mail. The notification contains mailbox address, timestamp, and optionally preferred protocol.

Post Office Protocol version 3 (POP3) [158] and IMAP4 [159] have been used in traditional e-mail for accessing mailbox, requiring polling to know about any new e-mail. IMAP command IDLE [160] enables having a persistent session between a client and a server, allowing the server to inform the client about any new e-mail immediately. The IETF has been working for various other extensions of IMAP to make it effective in mobile communication in Lemonade working group, which aims to enhance Internet e-mail to support diverse service environments. M-IMAP has been defined by the 3GPP2 as a protocol solution for MMS [132]. Though M-IMAP has some enhancements, still it uses other solutions for notification; hence M-IAMP is not really a push e-mail solution.

The OMA has defined a synchronization solution, known as DS, which can be used to synchronize data. As OMA DS version 1.2 includes support for synchronizing e-mails between a client and a server when there is new e-mail, it can be also used as a solution for push e-mail. Besides, Web or WAP based e-mail access can also provides the feeling of push e-mail by sending an instant message when there is a new e-mail. However, such services are mostly based on proprietary solutions.

Lately, the OMA is also discussing to have an end-to-end push e-mail solution for mobile communication. It is not expected that a new solution would be defined, rather endorsement of a solution already defined or being defined somewhere else (e.g., the Lemonade profile defined in the IETF, the DS solution defined by the OMA) is a likely outcome of the discussion.

Very lately, there is an initiative in the OMA to combine all different messaging solutions in terms of CPM, so that a user is not bothered by either multiple options or different involved technologies. It is too early to comment about the work, as the related standardization work is not yet matured.

A data format used for providing frequently updated or time critical content (e.g., blog, wiki, news) is called web feed, which is also known as news feed and syndicated feed. Typically, a user subscribes for changes in web content, and gets a notification in terms of a web feed when there is an update in the subscribed content. The notification may contain only the changed content and/or metadata. It resembles the publish-and-subscribe type of messaging outlined in Sub-section 2.3.1. Nowadays, it is possible to publish content and follow the contents published by others from a mobile terminal.

RSS and Atom are the two main web feed formats. RSS is an XML-based family of web feed formats, which are not completely compatible with each other. As for example, it refers to different formats – Rich Site Summary, RDF Site Summary, Really Simple Syndication. Atom is a relatively new effort to overcome the limitations of RSS. It consists of couple of IETF standards - an XML-based web feed, known as Atom syndication or publishing format; and an HTTP-based protocol for managing web content, known as Atom Publishing Protocol (APP). Atom syndication or publishing format is precise and machine parsable, suitable for displaying, filtering, remixing and archiving information, Though RSS has more foot-print in the market, Atom is anticipated to take over in the future. It is questionable if RSS and Atom are messaging solutions. They are briefly mentioned here, as their core operation resembles a specific type of messaging.

Messaging got a new dimension with the introduction of web-based social networking and blogging services. Address book is inherent part of some of these services, providing launching pad for different kinds of communications. Some of these services (e.g., Facebook, LinkedIn, Plaxo) became very popular lately. They usually provide free-access to website, where people form virtual community by exchanging messages, files, images, audiovisual clips, and what not. A few of these services have been designed or configured for mobile domain, e.g., Twitter, Jaiku. Beside social networking, these services provide means for micro-blogging - multimedia blogging that allows sending brief text updates or micromedia such as photos or audio clip for publication.

Twitter is a service that allows exchanging brief texts among the users of interest. The service can be configured for mobile communication, so that one can use SMS for updating her status. Beside SMS, a user can get the updates via Twitter website, RSS, e-mail, or some other similar application.

Jaiku is somehow similar to Twitter. From the software component point of view, it consists of a website, a mobile website, and a client application. It is compatible with mobile domain through its mobile client on a Nokia S60 (former Series 60) platform. The S60 is a software platform over Symbian operating system for mobile phones. One critical difference between Jaiku and other similar services like Twitter is Lifestream, which allows sharing users' online activities using other programs.

There are some other social networking services that allow access from mobile device, like Pownce, Youmeo, Plurk. All these services are mostly based on proprietary solution, driven by specific business model and/or local/social need. These services are not described further here.

2.3.4 Comparison of MMS with other Popular and Evolving Messaging Solutions

SMS, IM, and e-mail are widely used messaging systems. SMS is mostly used in mobile communication; while IM and e-mail evolved from Internet. Lately, e-mail has been introduced in mobile communication, and started growing especially in the enterprise sector. IM has also been introduced in the mobile communication, and it is still early to predict about its future in mobile communication. These messaging systems have been designed with specific intention, and thus, historically they have different perception. These mostly non-technical historical differences among these messages are summarized in Table 4. The same messaging systems are positioned in terms of two important factors in Figure 10, where the horizontal line corresponds to delivery time, and the vertical line corresponds to increasing versatility of allowed content within a message in terms of both content type and size.

The differences stated in Table 4 may not be obvious in all the implementations and deployments, as only predominant use case is considered here. Moreover, due to the advancements in technologies, all these messaging systems have been evolving, and the boundary lines between the systems are diminishing. As for example,

- IM nowadays can also carry multimedia contents,
- it is possible to send IM to a recipient who is not available (off-line),
- SMS, MMS, or e-mail can also carry time-critical content,
- SMS, MMS, or e-mail can be archived based on discussion thread in an implementation, and
- e-mail can be delivered immediately with push e-mail solution.

SMS, e-mail, and MMS are mostly standardized. Moreover, these messaging systems work in store-and-forward approach. Therefore, it is reasonable and possible to make in-depth comparison among SMS, e-mail, and MMS, considering different technical aspects. Such detail comparison is available in [P2] and [P3]. The summary of the comparison is shown in Table 5. As described in Sub-section 2.3.3, push e-mail is a natural evolution of traditional e-mail systems for mobile communication. As it is similar to traditional e-mail in many aspects, a separate column is not created for push e-mail, rather the push e-mail specific enhancements are mentioned within a parenthesis under the e-mail column when appropriate.

Table 4: Comparison among SMS, IM, MMS, and e-mail, mostly based on historical user perception

Basis of comparison	**SMS**	**IM**	**MMS**	**E-mail**
Typical content of a message	Texts	Mostly texts	Multimedia content optimized for mobile transfer	Multimedia content and object of virtually any type
Time-criticality of the content of a message	Typically, content is not time-critical	Typically, content is time-critical	Typically, content is not time-critical	Typically, content is not time-critical
Delivery of a message	Immediate (best effort)	Immediate (online)	Immediate (best effort) and scheduled	Relatively slow, as multiple steps and proactive access are required
Availability of the recipient of a message	Availability of the recipient is not needed	Recipient is expected to be available (online)	Availability of recipient is not needed	Availability of recipient is not needed
Dependency on Presence service	It is not dependent on Presence service	Typically, it is bundled with Presence, so that availability of a recipient is known before sending a message	It is not dependent on Presence service	It is not dependent on Presence service
Network storage	Storage of a message might be required, if the recipient is not available right away	Typically, storage is not required, as recipient is mostly available	Storage of a message might be required, if the recipient is not available right away, or in case of scheduled delivery	Storage of a message is required, as it is accessed by the recipient for retrieval
Content consumption	Consumed at once (hardly archived)	Discussion (depicted in a thread)	Consumed at once (hardly archived)	Usually archived
Message component	One entity comprising limited texts	One entity comprising mostly texts and emoticons	Usually one entity – presentation format links all contents	Texts and attachments
Business case	Person-to-person mobile text messaging	Text-based conversation in Internet community	Person-to-person mobile multimedia messaging	Person-to-person over Internet/Intranet and mobile enterprise community
Communication model	Loosely coupled (once a message is sent, typically the sender does neither care much about delivery time nor immediate response)	Interactive (a sender expects immediate delivery and quick response)	Loosely coupled (once a message is sent, typically the sender does neither care much about delivery time nor immediate response)	Loosely coupled (once a message is sent, typically the sender does neither care much about delivery time nor immediate response)
Standardization	Standardized in 3GPP, and latter in 3GPP2	Internet IM services are mostly proprietary. Lately, IETF and OMA defined different solutions for IM for the Internet and mobile communication respectively.	Standardized in the 3GPP and the OMA, and latter in the 3GPP2	The basic protocols and encoding/format are standardized in IETF. Lately, IETF and OMA started working to define push e-mail, though proprietary solutions of push e-mail have already been deployed

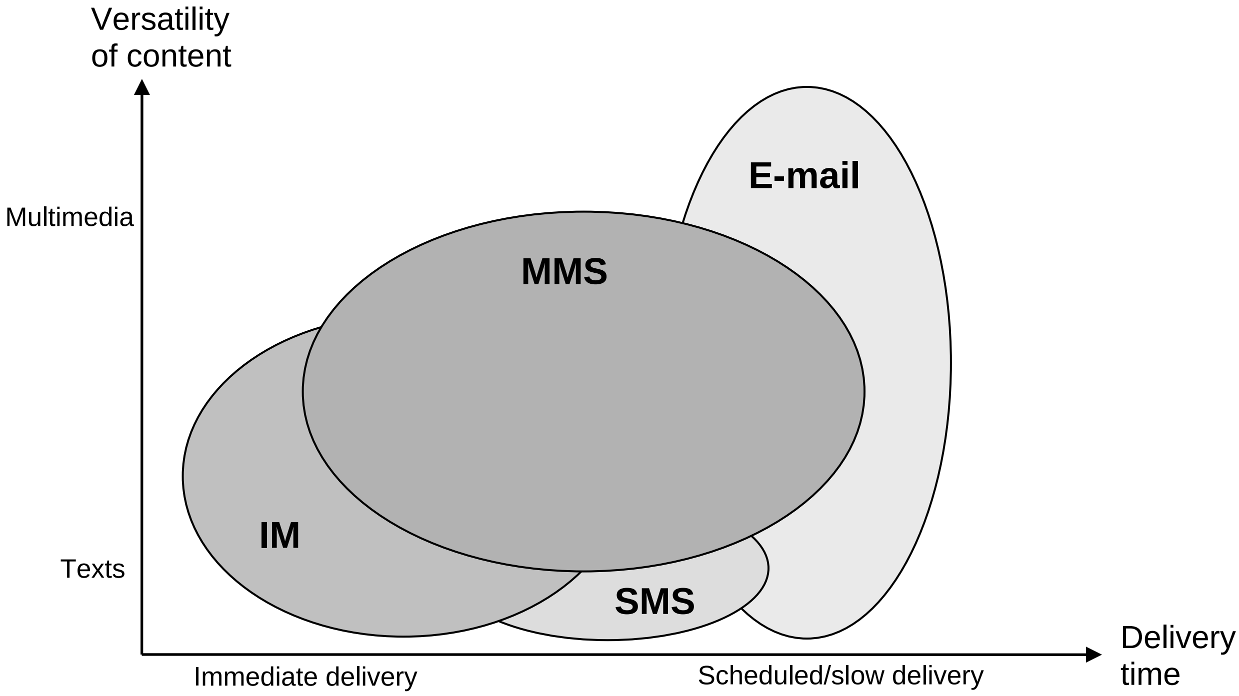

Figure 10: SMS, IM, MMS, and e-mail in terms of versatility of content and delivery time.

As MMS was designed later, it is natural that it overcomes the shortcomings and limitation of SMS and e-mail. It is also apparent from the comparison that MMS has more restrictive approach than e-mail; hence MMS can work efficiently in the mobile environment, which has more control and restriction compared to the Internet.

RSS and Atom are mostly used to get automatic update about selected web content, as briefly mentioned in Sub-section 2.3.3. They work like an automated e-mail program. However, they are not compared with MMS here, as they have limited scope and purpose different from those of MMS.

Messaging is one of the key aspects in the mobile social networking services, like Twitter and Jaiku. These are more like exchanging text or instant messages with other users of interest. In other words, it can be positioned somehow between e-mail and IM, allowing controlled distribution of short messages. However, these are not end-to-end services like other mobile messaging solutions (e.g., SMS, MMS). Rather, messages are mostly published on a website. The social networking services also resemble Presence service, as one can exchange present status dynamically in terms of media like texts and image. Moreover, some of these services provide address book services. In summary, they are mixture of many different services, from user experience point of view. Anyway it is difficult to compare conventional messaging systems with these solutions of social networking, as there are quite many services available with significant variation. Moreover, it also does not make much sense to make detail comparison here, as these social networking solutions are not compliant to any standards, while this dissertation focuses on standardized services.

Table 5: Detail technical comparison among SMS, e-mail, and MMS.

Basis of comparison	SMS	(Push) E-mail	MMS
Protocol in higher layer	SMS has dedicated protocol in all the layers. A message is transmitted over a dedicated signaling channel of mobile communication.	E-mail has dedicated session layer protocol.	MMS is designed to work with multiple protocols in the session layer, though HTTP is mostly used.
Dependency on lower (e.g., transport) layer protocol		From application layer, e-mail is independent of any protocol used for transport. However, transport protocol becomes obvious due to link between the session layer protocol and transport protocol.	In the transport level, MMS is bearer-independent, though the chosen session layer protocol may have link to a transport protocol.
Number of protocols	Single protocol for sending and receiving a message.	E-mail requires different protocols for sending and receiving a message. (Depending on solution, push e-mail may use the same protocol for both sending and receiving a message.)	Though MMS has solution based on multiple session layer protocols, only one protocol is used both for sending and receiving a message in an implementation.
Allowed size of content within a message	Allowed size of content in a message is limited by the transport mechanism.	Transport mechanism does not put any limit on the size of content of an e-mail. (Depending on the protocol solution, the notification in push-email may have limitation in terms of allowed bytes.)	Transport mechanism does not put any limit on the size of content of a multimedia message, though there is an artificial limit on the size to ensure interoperability.
Allowed media types within a message	Allowed media (only text) is limited in SMS by the transport mechanism. SMS is enhanced to EMS to carry some less demanding media (e.g., formatted texts, pictures, animations, PIM) in terms of concatenated messages.	Transport mechanism does not put any limit on the media type of contents in an e-mail. (Depending on the protocol solution, the notification in push-email may have limitation in terms of allowed media.)	Transport mechanism does not put any limit on the media type of contents in MMS, though there is a minimum set of codecs for different media types in the MMS specification to ensure interoperability.
Text-based format or binary encoded	SMS message is binary encoded before transmission.	The e-mail protocols are text-based.	MMS message is binary encoded before transmission.
Delivery mechanism	An SMS message is pushed to the recipient, not requiring any check-up for a new message.	Requires regular access to check for new e-mail. (Such client-initiated poll/pull is not required in push e-mail, as new e-mail is either pushed or notified automatically.)	An indication about a new message is pushed to the recipient, not requiring regular check-up for a new message.
Number of round-trips for the end-to-end delivery of a message	Sending a message does not require multiple round-trips.	Sending an e-mail may take multiple round-trips in the session layer protocol for sending different information. (Depending on solution, push e-mail may not take multiple round-trips as such for sending an e-mail)	Sending of a multimedia message requires the transmission of only one message in the session layer protocol.

Table 5: Detail technical comparison among SMS, e-mail, and MMS (continued).

Basis of comparison	SMS	(Push) E-mail	MMS
Authentication mechanism	It uses the authentication used for mobile communication (RADIUS), not requiring any user interaction.	It does not rely on the underlying network for authentication, and a user needs to interact to provide credential each time she wants to access e-mail system. (Depending on solution, push e-mail may not require frequent access.)	It uses the authentication used for mobile communication (RADIUS), not requiring any user interaction.
Supported addressing schemes	Addressing is based on MSISDN, though e-mail address can also be used based on implementation.	Supports only e-mail address.	Supports multiple addressing schemes – MSISDN, e-mail address, and short code.
Ability to interwork with other messaging systems	SMS does not interwork with other messaging system, though work has been going on for supporting SMS over IMS-based IP connectivity access [161] and [162].	It does not inherently interwork with other messaging system.	MMS can interwork with other messaging systems (SMS, e-mail).
Need/availability of terminal capability negotiation	It does not require terminal capability negotiation.	It does not have means for terminal capability negotiation.	It provides means for terminal capability negotiation to improve interoperability.
Need/ability to perform content adaptation	It does not require content adaptation.	E-mail does not inherently have means for content adaptation.	MMS has means for network-based content adaptation based on terminal capability negotiation and other factors to improve user experience.
Rendering (presentation) of a message	Scene description format is not required, as only texts are allowed within an SMS message.	Typically the presentation of an e-mail is not described, due to significant variation of both available format and terminals.	As a format of scene description and synchronization is defined for MMS, rendering of a message can be easily and consistently described, requiring less user interaction while rendering.

2.4 Streaming

Streaming provides a means of presenting data in a synchronized and systematic manner to a user at the same time it is being transmitted. Multimedia streaming is the streaming of multiple media. With the developments of related technologies in mobile communication, wireless streaming is nowadays a reality. Objective studies show that streaming is possible with reasonable quality both in the 2G and the 3G mobile communications [32], [163], [164], [165], and [166]. Subjective test on audiovisual streaming content also shows positive results [32] and [167]. Streaming is analyzed in [P2], [P3], and [P4] from mobile communication point of view. The summary of the analysis, the recent developments in standards and specifications, and the related key research activities are described in Sub-sections 2.4.1, 2.4.2, and 2.4.3.

Different commercial solutions (e.g., QuickTime, RealPlayer, Windows Media Player) for streaming became available in the Internet. With the advancements of related different technologies, such solutions are also becoming available in mobile communications. These commercial solutions are not typically compliant to the standards, as they are mostly driven by business model and market need.

They are not the focus of this study either. Still, they are very briefly outlined in Sub-section 2.4.4 for the sake of completeness.

2.4.1 Standardization and Specifications

The emergence of open standards for streaming systems helps achieving interoperability among different solutions. Reference [51] provides an overview of streaming solutions for mobile communications, related multimedia technologies, and involved standardization works. The focus of the discussion here are the streaming framework defined by the 3GPP and the 3GPP2, and the involved IETF protocols.

The IETF has defined a number of core protocols for streaming. As streaming works between a client and a server, the IETF defined Real-time Streaming Protocol (RTSP) [168] for a client to control the operations of a server. The RTSP provides a means to a client to set up a session and control the real-time transmission of one or more synchronized media stored in one or more servers. A set of multimedia streams, simultaneously transmitted and presented, is known as a presentation; and the multimedia streams within a presentation are described by a presentation description. Presentation description, which is also known as session description, includes all the information required for session establishment. The IETF has defined Session Description Protocol (SDP) [169] as a format of the presentation description. As RTSP is more a higher layer protocol, it requires suitable protocol in the lower layer for the effective transmission of real-time data. RTP [170], defined by the IETF, is one such protocol that can be used by the RTSP. The RTP has a control protocol, known as Real-time Transport Control Protocol (RTCP) [170], which can be used for getting feedback about the data transmission and information about the participants of an active session.

The 3GPP took the above-mentioned IETF protocols as the basis for defining streaming for the IP-based packet-switched networks in mobile communications, know as Packet-switched Streaming Service (PSS). Beside the conventional streaming, the PSS also defines progressive download, where content is delivered over HTTP based on one or more HTTP *Get* requests. Progressive download, being an extremely simplified form of streaming without control mechanism, is not studied further here.

The PSS is described in different publications [8], [14], [163], [164], [165], [166], [171], [172], and [173]. Network architecture, involved transport protocols, and signaling related to PSS come under focus in [163]. The PSS is described in [164] in terms of its feasibility in GPRS network. The study also reveals optimal network setting to support streaming. Reference [165] describes PSS with respect to EGPRS – the Enhanced GPRS due to the introduction of EDGE technology. It describes different aspects of both EGPRS (modulation scheme, layers, protection schemes, QoS) and PSS (e.g., evolution, protocols, signaling). A study about PSS in the 3G network is described in [166], indicating the improvement of its performance due to the additional capabilities of the 3G networks. Reference [171] describes PSS from architecture and protocol stack points of view. The description about PSS in [172] mostly focuses on involved protocols, end-to-end information flow, and the support for QoS. Reference [8] describes PSS from architecture, involved media types/formats, and protocols points of view. Different aspects of PSS (e.g., evolution, specifications, protocols, signaling) are described in [173].

The 3GPP first defined the basic streaming service in its first version in terms of PSS release-4, and then enhanced the service with additional features and functionalities in the following versions – release-5, release-6, and release-7. Only major features of different PSS versions are outlined below.

The PSS release-4 allows limited capability exchange in terms of SDP. The supported media codec for the PSS release-4 are

- AMR NB and AMR WB for speech,
- MPEG-4 AAC Low Complexity (AAC-LC) for audio, and
- H.263 (Profile 0 Level 10 and Profile 3 Level 10) and MPEG-4 Visual Simple Profile Level 0 for video.

A profile of SMIL is also defined for scene description (presentation) in terms of PSS4 SMIL. It is a subset of the SMIL 2.0 Language Profile, but a superset of the SMIL 2.0 Basic Language Profile. Though it was defined for streaming at the beginning, the extended profile was later defined for MMS, as mentioned before. The profile was later extended, as described below; and all these profiles are collectively addressed as 3GPP SMIL or PSS SMIL.

The main specifications for the PSS release-4 are TS 26.233 [174] and TS 26.234 [175]. The TS 26.233 contains general description in terms of usage scenarios, over-all end-to-end service and architecture concept, and functional components; while the TS 26.234 defines the protocols and codecs.

The release-5 of the 3GPP PSS has enriched the basic service with new media types and formats, and mechanism for capability exchange [166] and [173]. A profile of Resource Description Framework (RDF) document that follows Composite Capabilities/Preference Profile (CC/PP) framework and CC/PP application UAProf is defined for capability exchange. The profile includes both existing vocabularies (attributes, allowed values, and semantics) from UAProf and newly defined vocabularies for PSS. Some SDP fields are also defined as extensions. All the newly added media in the PSS release-5 are for progressive download, having HTTP over TCP/IP as the transport. The SMIL Profile is extended by including the Transition Effects Module – BasicTransitions, and the extended profile is known as PSS5 SMIL. Beside updating the existing specifications of the release-4 [176] and [177], the PSS release-5 also includes TS 22.233 [178] and Technical Report (TR) 26.937 [179]. The TS 22.233 includes the core requirements to enable different services in the application level. The TR 26.937 is not a normative specification. Rather, it characterizes PSS based on different use-cases and network conditions, and reveals optimization possibilities in the implementation level to improve performance.

The release-6 of the PSS introduced significant enhancements in terms of functionalities like adaptive streaming and RTP retransmission [173]. Adaptive streaming, an important feature for mobile communication especially when QoS-enabled bearer is not available, allows adaptation of session bandwidth to the time-varying bandwidth of mobile network. RTP retransmission [180] allows the retransmission of a corrupted or lost RTP packet. Both adaptive streaming and RTP retransmission are further described in Sub-section 2.4.3. The PSS release-6 also allows protection and security of content and transmission by providing the means for content-level encryption and transport-level integrity protection. This security and protection mechanism is defined based on the OMA-defined Digital Rights Management (DRM) version 2 and its extensions. Capability exchange mechanism, defined in the PSS release-5, is enhanced enabling filtering between streaming and downloading static media. The following new continuous media are added for streaming in the release-6:

- Enhanced AAC+ and Extended AMR-WB for audio,
- H.264 (AVC) Baseline Profile Level 1b for video, and
- 3GPP Timed Text format for timed text.

The SMIL profile is again extended with Media Object Module MediaParameter. Moreover, systemComponent test attribute of the ContentControl module is added in the extended profile, known as 3GPP PSS6 SMIL. Beside updating the existing specifications of the PSS release-5, the PSS relase-6 defines TS 26.245 [141] for the Timed Text format and TS 26.246 [142] for the 3GPP PSS SMIL profile, which was previously defined within the TS 26.234.

Lately, the 3GPP has finalized release-7 of PSS specifications. PSS release-7 includes a procedure to enable faster start up and switching of content for a streaming session. This is achieved based on the extensions of RTSP protocol. This release also enables MBMS transmission using PSS. Moreover, the PSS release-7 also defines an additional scene description format – Dynamic and Interactive Multimedia Scenes (DIMS) - in TS 26.142 [181]. The core PSS specifications updated for the release-7 are TS 22.233 [182], TS 26.233 [183], TS 26.234 [184], TR 26.937 [185], TS 26.245[186], and TS 26.246 [187].

Release-8 of PSS has also been matured very lately. The main works of release-8 PSS have been around the use of IMS for initiating and controlling PSS and extending PSS for optimized mobile TV. Further works are planned on the same area in release-9 of PSS, which is starting in the 3GPP. The PSS extensions in release-8 and release-9 are beyond the scope of this study.

The 3GPP2 also defined streaming service, and named it Multimedia Streaming Service (MSS) [188], which is mostly compatible with the 3GPP PSS. The requirements for the MSS are listed in [189]. The major supported continuous media for MSS are

- H.263 Profile 0 Level 45, MPEG-4 Visual Simple profile Level 0b, and H.264 Baseline Profile Level 1b for video,
- EVRC and 13K for narrow-band speech,
- Variable Rate Multimode Wide Band (VMR-WB) for wide band speech,
- MPEG-4 AAC Profile Level 2 and MPEG-4 HE AAC Profile Level 2 for audio, and
- 3GPP Timed Text format for timed text

The Wireless Multimedia Forum (WMF) was formed in 2000 to form a consensus about the suitable protocol for streaming in mobile networks. The WMF provides its findings in terms of Recommended Technical Framework Document (RTDF). In 2001, the WMF joined the 3GPP2 as its market representation partner.

Both the 3GPP and the 3GPP2 adopted media codec and format defined by different standards development organizations. As for example, SMIL was defined by the World Wide Web Consortium (W3C)[10], H.263 was defined by the ITU-T, MPEG-4 was defined by the ISO/IEC[11]. The standardization and specifications of these codecs and formats are not elaborated here.

2.4.2 End-to-End System Architecture

Figure 11 shows the streaming architecture for mobile communication, as defined by the 3GPP. The most important entities in the architecture are Streaming Client and Media Server, which is also known as Content Server, PSS Server, or Streaming Server. A Streaming Client provides the means for user interaction for streaming purposes. Alternatively, different streaming-specific applications can be built on a Streaming Client, so that the applications provide the means of user interaction. On the other side, a Streaming Client interacts with one or more Media Server, which contains the streaming content. Radio access and mobile core network include different entities depending on the radio access technology. As for example, in case of GSM/GPRS and EGPRS networks, Base Transceiver Station (BTS) and Base Station Controller (BSC) are core entities for radio access, while

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[10] The W3C, founded in 1994, is an international consortium for developing interoperable technologies in terms of specifications, guidelines, software, and tools to lead the Web to its full potential.

[11] The IEC, founded in 1906, is a global organization for preparing and publishing international standards for all electrical, electronic, and related technologies.

Service GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN) are the core entities for mobile core network [163] [165]. In case of Universal Mobile Telecommunications System (UMTS), Radio Network Controller (RNC) and Node B are the main entities instead for radio access [190].

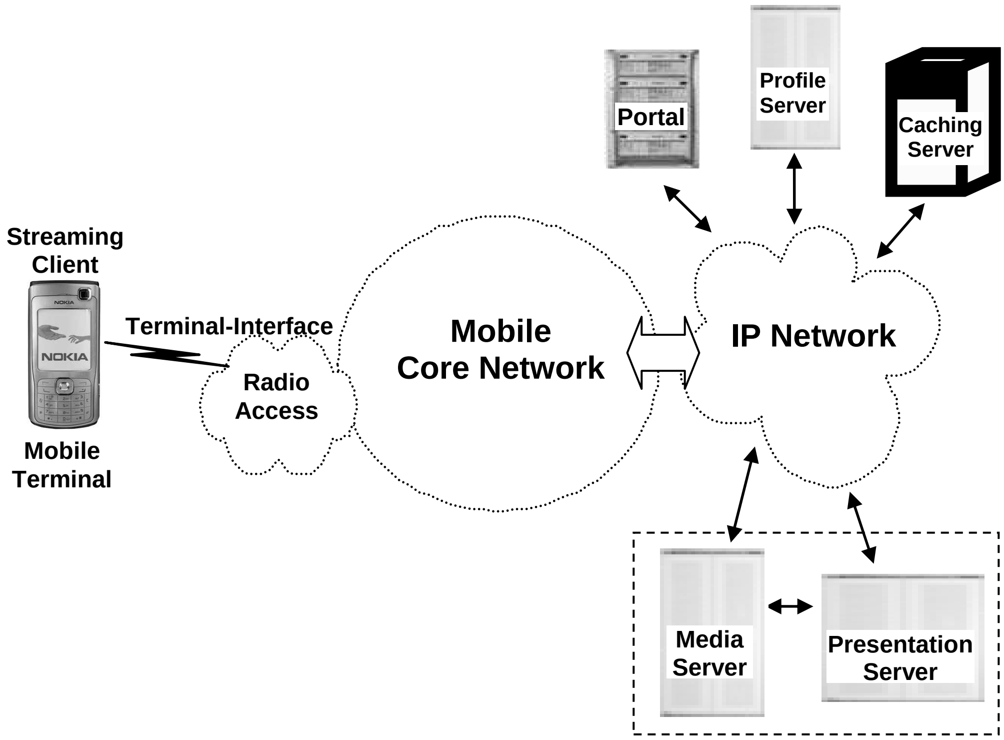

Figure 11: The streaming architecture in mobile communication, as defined by the 3GPP.

Other network entities are used to either provide additional services or improve service quality. A Presentation Server is used to handle (e.g., create, delivery) presentation description. Generally, a Portal is a server that provides useful access to the stream. As for example, a Portal could be used to provide browsing or searching facilities. A Caching Server is used for caching a stream. All these servers are logical entities. In practice, more than one of these can be combined in a physical entity in an implementation. As for example, Media Server and Presentation Server can be combined in an implementation.

Profile Server is used to store user preferences and/or device capabilities, so that the stream can be adjusted accordingly. In practice, a Profile Server can be maintained by either a terminal manufacturer, software vendor, or an operator. Typical use of the Profile Server for capability exchange and content adaptation is shown in Figure 12. A Streaming Client includes one or more references (e.g., Uniform Resource Locator - URL) to the profile of its device capabilities and/or user preferences stored in one or more Profile Servers in a PDU request (e.g., RTSP, HTTP). The use of the RTSP *Describe* message is recommended here, as it helps even to customize the presentation description according to the capabilities and preferences. Specific header is used to include the URL in the PDU request. The PDU request can also use additional header to dynamically change the preferences or capabilities stored in a Profile Server. It is possible that multiple Profile Servers are used to store different kinds of capabilities, e.g., hardware, software. Upon receiving the references, the Media Server retrieves the specific profile of device capabilities and/or user preferences from the Profile Server using suitable HTTP transaction. The Media Server then uses the profile to adapt the requested media content accordingly, if required. The adapted content is then delivered to the Streaming Client in the mobile terminal. Though both device capabilities and user preferences can be used as the basis for content adaptation, mostly device capabilities are used in practical implementations. More about the capability exchange is available in the 3GPP TS 26.234 [184].

Reference [191] makes an analysis about different design options of the architecture of a Media Server. The analysis proposes caching streaming content, modular design, and intelligent scheduler to improve the quality of streaming in different network conditions. Caching the whole or segmented media can reduce bandwidth consumption, load at the origin server, and latency seen by a client. It also provides greater fault tolerance in case the origin server is not accessible.

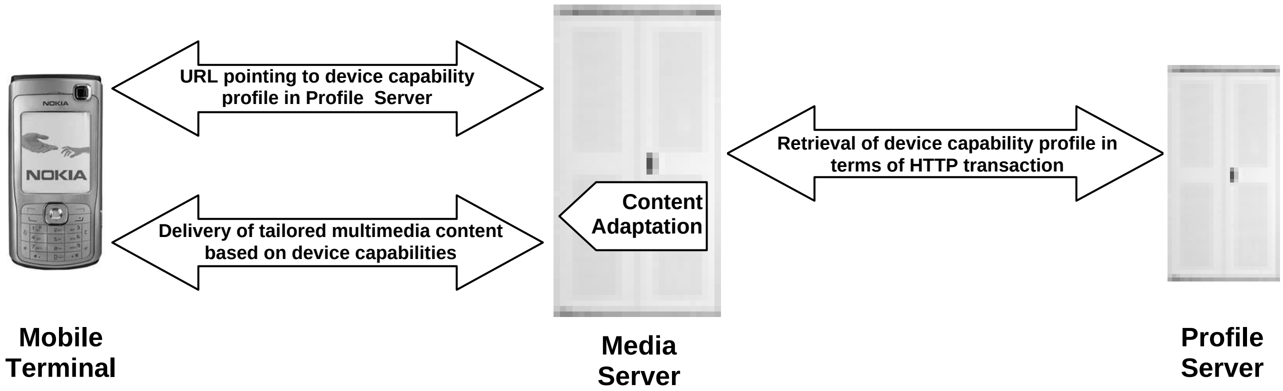

Figure 12: The use of a Profile Server for capability exchange and content adaptation in PSS.

2.4.3 Streaming Session and Information Flow

Streaming services are usually of two categories - on-demand and live information delivery. In the first category, multimedia data, stored in a Media Server, is accessed by a Streaming Client on-demand basis. In the latter category, multimedia data is provided to the Media Server as a continuous multimedia stream that is immediately transmitted to Streaming Clients. As only the on-demand streaming service is within the scope of this study, it is focused here.

Beside other functions, the RTSP can control the real-time retrieval of content to a Streaming Client from a Media Server. The important RTSP methods in terms of media retrieval are

- *Describe* (retrieve presentation description),
- *Setup* (allocates resources and starts RTSP session),
- *Play* (starts transmission of a stream),
- *Pause* (temporarily halts a stream without freeing resources), and
- *Teardown* (ceases RTSP session and releases resources)

An example of a streaming session is shown in Figure 13, where the above-mentioned RTSP methods are used. As shown in the figure, streaming consists of three different kinds of activities – session establishment, session control, and media transport. Session establishment is nothing but the invoking of a streaming session by a Streaming Client. During the session establishment, a Streaming Client obtains the presentation description. It may have two steps. In the first step, the Streaming Client obtains a reference, addressed as a URL in the figure, of the presentation description from a Portal. In the second step, the Streaming Client uses the RTSP *Describe* method to fetch the presentation description, based on the retrieved reference in the first step. The *Describe* request can carry a reference for Profile Server, where user preference and/or device capabilities are stored. If carried, the Presentation Server retrieves profile information from the Profile Server to optimize the presentation description and streaming content accordingly. This is an example of capability exchange, which is already outlined in Sub-section 2.4.2. Though the RTSP *Describe* is shown for fetching the presentation description in the figure, it is important for the context of this study to note that this is just an example, and in practice, different ways could be used for both the steps of the session establishment. Moreover, the description could be located in a Portal, or in any other server.

The operations involving session control and media transport are handled by RTSP and RTP/RTCP respectively. RTSP *Setup* is sent for setting up the streaming session. Then, the Client sends RTSP *Play* to start sending one or more streams over the IP network. The actual media stream is carried by RTP packets, as shown as RTP Audio and RTP Video in the figure, while RTCP is used in both the direction to collect feedback on the stream. As part of the session control, RTSP *Pause* or *Teardown* is used to halt or stop the streaming, respectively. The establishment and the controlling of packet radio bearers and the negotiation of the QoS of the session [184] are not shown in the figure, as these are beyond the scope of this study.

While Figure 13 describes the basic streaming service defined in the early version of PSS in the 3GPP, advanced standardized features (e.g., QoS, adaptive streaming, and RTP retransmission) and related recent research activities are briefly described now.

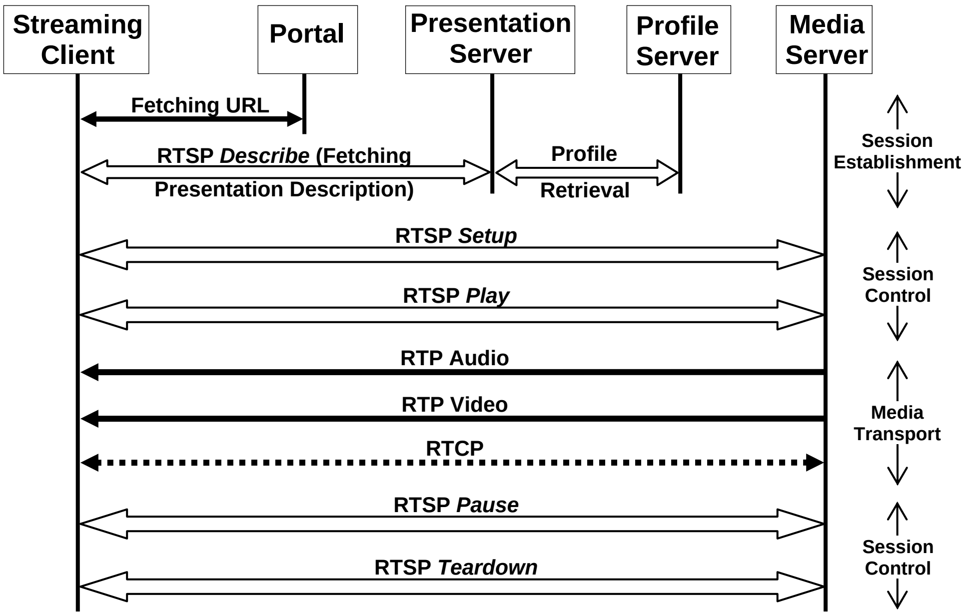

Figure 13: An example mobile streaming session and involved information flow [P4].

A subjective analysis about the influence of different encoding factors of video streaming (e.g., bandwidth, frame rate, spatial resolution) on user perception indicates that frame rate has the most influence in this regard [192]. Due to small screen size, increase in bandwidth may not have significant effect on the perception. All these factors have direct correspondence on the QoS, providing guideline about optimum values of different factors in achieving high user perceivable QoS.

The most of the currently deployed mobile networks do not support the QoS suitable for streaming service. Rather, the most only offer the basic best-effort QoS providing no guarantee of resources, like bit-rate and throughput. On the other hand, the status of mobile network changes dynamically due to the variation in load, radio network condition (e.g., fading), and mobility (e.g., base-station hand-over, wireless-channel switching); resulting in variation in the characteristics, like throughput, delay, with or without QoS. Streaming service can adapt with these varying conditions in a network, not supporting QoS suitable for streaming, by using adaptive streaming. Here, the intention is to achieve highest possible Quality of Experience (QoE) at the receiving end with the available resources, while maintaining the interruption-free playback of the media. QoE is measured, in terms of defined metrics, in the recipient end, and transmitted to the server using the RTSP and SDP based protocol extensions. A Media Server supporting the adaptive streaming keeps a number of media streams of the same content encoded at different bit-rates, and dynamically switches between the streams depending on the condition of the network. Alternative SDP is used to advertise the alternative media encodings. The details about the adaptive streaming adopted by the 3GPP for the PSS release-6 is available in [173] and [193].

The combination of the rate control, as described above, and media adaptation techniques (e.g., media interleaving, bit-stream switching, bit-stream thinning) can improve the performance of the adaptive streaming [193]. The reference also proposes a few extensions to the PSS. An experiment result shown there reveals that the adaptive streaming can improve over-all user experience in case of varying network condition or mobility (e.g., handover, roaming). However, effective end-to-end rate control is not easy to achieve. Based on the analysis in [194], network information based rate control is better than the end-to-end control in terms of number of lost packets and bandwidth usage.

A mechanism for controlling congestion for video streaming in the UMTS network is proposed in [171]. Here, the rate-control (that allows simultaneous transmission of other Internet applications) is applied on the streaming of video clip in the UMTS. In the analysis, the transmission rate of video is dynamically determined based on packet loss rate, round trip time, and packet size. The performance of the UMTS for the adaptive video streaming, beside other TCP-based data transmissions, is also examined in terms of end-to-end delay, delay in the radio access network, jitter, and throughput.

RTP retransmission [180] allows selective retransmission of lost packets depending on the importance of the packet and the possibility of playing back the packet upon retransmission. The status of the receiver buffer is checked before the retransmission to know if it is possible to decode the retransmitted packet in time. Adaptive streaming and RTP retransmission can be designed to function in coordination to enhance the performance. Adaptive streaming can indicate the availability of bandwidth required for the retransmission, and can even provide extra bandwidth, if not available [173]. This way, the additional traffic due to the retransmission is also considered to control congestion by rate adaptation.

While User Datagram Protocol (UDP) is suitable transport protocol for RTP, other transport protocols are also allowed to carry RTP packets [170]. Though UDP is the mostly used transport protocol for streaming, it has problems like vulnerability against congestion and unfair allocation of bandwidth among traffic flows. Use of TCP may overcome these limitations. Moreover, TCP provides lossless transport not requiring retransmission in the RTP level. However, use of TCP has some drawbacks. Firstly, as an end-to-end protocol TCP does not fit for multicasting. Additionally, slow start mechanism and ARQ based recovery in TCP may not allow timely delivery of content, especially in the mobile environment. Reference [195] analyses the use of TCP as the transport layer protocol for streaming video in a wireless system.

2.4.4 Commercial Streaming Solutions

2.4.4.1 QuickTime

QuickTime is a multimedia architecture that works with real-time movies, video clips, sounds, and high quality compressed images. It includes solutions for different functions like player, server, and broadcaster. Beside streaming, it provides means for different functions like encoding, decoding, editing, and transcoding. Moreover, it has plug-in architecture for supporting additional codecs. It supports various standard and non-standard audio and video codecs. QuickTime streaming server supports RTSP/RTP. The QuickTime file format acts as a container file to help transporting, storing and presenting a clip. Moreover, it supports some other file formats, e.g., MPEG-4 (.mp4) and 3GPP (.3gp), 3GPP2 (.3g2). Besides, it supports codecs adopted by the 3GPP, e.g., H.263, H.264, AAC, and AMR. With the support for audiovisual file format and codecs defined by the 3GPP and the 3GPP2, audiovisual content created by QuickTime can be transmitted and viewed in mobile domain.

2.4.4.2 RealPlayer

RealPlayer is a cross-platform media player that plays a number of standard and non-standard media formats. It is one of the first media players that can play streaming media over the Internet. The latest version of RealPlayer is also available for different platforms for mobile devices (e.g., Symbian operating system, Windows Mobile). It supports 3GPP (.3gp) file format and AMR codec as plug-ins. The same vendor also has commercial solution for media server. Beside the predominant support for proprietary transport protocol for streaming media, it supports RTSP/RTP/SDP.

2.4.4.3 Windows Media Player

Windows Media Player is another media player for playing audio, video and viewing images. It was first launched in a PC running Windows operating system. Now, it is also available in Windows Mobile based devices. The default file formats of the player are Windows Media Video (WMV), Windows Media Audio (WMA), and Advanced Systems Format (ASF). Nowadays, it also supports mobile-friendly codecs like AAC, MPEG-4, and H.264. Beside predominant support for the proprietary transport protocol, it started supporting standard format like RTSP lately.

Chapter 3 Scope of Interworking between MMS and Streaming

Traditionally, a messaging system is used between users for person-to-person messaging. As MMS is designed as a channel for providing content [148], the scope of MMS has been gradually extended to content-to-person, person-to-service, and application-to-application messaging, which are briefly described in Sub-section 2.3.2.5. Application-to-application messaging is also described elaborately in Chapter 5. As MMS can deliver different kinds of services based on these forms of messaging, it is considered to be over-all service delivery technologies [20]. Reference [22] describes an MMS-based content delivery platform, where SMS message is used to invoke the content (e.g., instantly captured picture by a Web-camera) delivery in terms of an MMS message. Successful content delivery is a challenge in mobile domain, as it requires end-to-end interoperability among servers and devices of various capabilities [22]. MMS specification [127] defines minimum set of capabilities (e.g., supported media types and formats) for a device to support harmonized content-to-person and person-to-service messaging, so that the interoperability between different implementations is achieved. Such messaging naturally involves heavier messages containing different types of media. With the integration of high resolution still image camera and video camera with a mobile terminal, handling heavy content is also required for person-to-person messaging nowadays. MMS has limitations in handling heavy content. This chapter describes the limitations, and proposes interworking between MMS and streaming as the means to overcome the limitations in principle.

3.1 Limitations in MMS

In MMS, a message is the unit of transmitting contents, and a message is transmitted in multiple hops between entities for the whole chain of content delivery from the originator to the recipient. The scenario is shown in Figure 14. Upon the submission of an MMS message by the MMS UA in the originating terminal, it is transmitted to the originating MMS R/S, and then stored temporarily there. Similarly, the message is transmitted and stored at the end of each hop until it reaches the target MMS UA in the recipient terminal. The intermediate server in the figure represents any number of servers the message may come across in between the originating MMS R/S and the recipient MMS R/S. The processes take place in sequential order as shown in the figure. This way, all the contents of a message need to be fully stored in the intermediate network entity, before the processing (e.g., billing, authentication, validity check, content adaptation, transmission) in the entity can begin. Similarly, all the contents of the message is required to be fully transmitted and stored in the recipient terminal, before it can start processing the contents (i.e., checking rights and validity, screening, adaptation, rendering, storing). If any intermediate or the recipient entity does not have enough storage space to store the whole message, the transmission fails. This way, the basic MMS has a limitation of handling a message that requires more storage space than available in any entity.

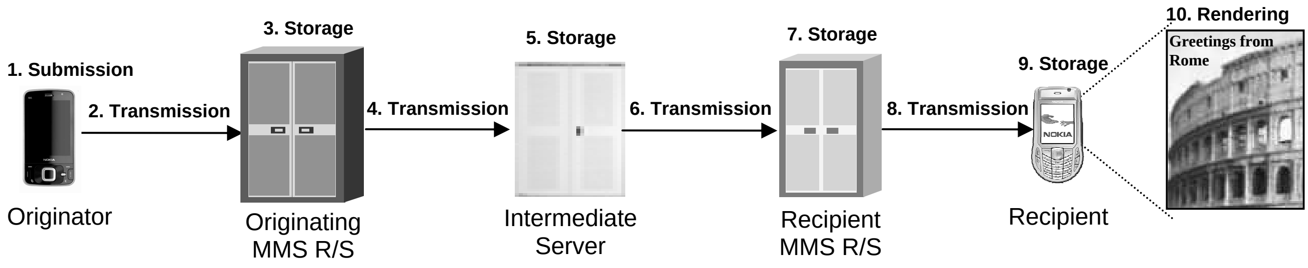

Figure 14: The scenario of sequential processes for the whole chain of content delivery in MMS.

Storage space in a mobile terminal and available bandwidth in mobile networks have been a noted concern from the beginning [137]. Low memory in a mobile terminal has been a constraint in designing MMS system [2]. Buffer overflow in MMS UA is also addressed as a vulnerability of MMS [99]. The storage constraint in a mobile terminal also emphasizes the importance of compressing data [137]. It is probable that a message (especially with dynamic content, which is naturally heavier) does not fit in the available space in a mobile terminal. Even a small message may not fit in a mobile terminal, if the most of its space is already used by other purposes. Reference [P3] analyses how many multimedia message of average size can fit in a relatively feature-rich mobile terminal.

Due to the advancements in related technologies, nowadays a mobile terminal has increasingly more space, and a feature-rich mobile terminal may have more space than considered in the above-mentioned calculation. However, due to the same reason, wireless infrastructure and mobile terminal nowadays can also support increasingly more complex media with reasonable quality. MMS has been lately positioned to carry heavier media - mega-pixel image, longer audio and video clip with higher sampling rate. Examples of possible content in an MMS message are available in Sub-section 2.3.2.4, while the exhaustive list is available in [127]. The allowed media within an MMS message has been evolving in MMS specifications. References [2], [40], and [137] also predict similar evolution path in the deployment. Allowed size of an MMS message is also increasing.

Moreover, more features are introduced in a mobile terminal (e.g., many more pre-installed applications, downloadable application like games, colorful and more interactive idle screen), requiring more space. The size of a video clip can easily grow significantly depending on its frame rate, resolution, duration, and involvement with high motion and audio. The situation of a reasonably cheaper mobile phone is even more critical in terms of storage space.

Beside the storage in a mobile terminal, bandwidth in mobile communication is also expensive [2]. Wireless access is more limited in terms of bandwidth compared to the wired access, resulting in longer retrieval time of an MMS message that contains heavy content like audiovisual clip, keeping a user waiting for long to see the message, causing poor user-experience. This long retrieval time is also addressed as delay sometimes [23]. The retrieval time of an MMS message depends on many factors like message size, access technology, traffic condition, packet loss, QoS factors (e.g., bitrates, delays). Chapter 4 of [P4] analyses the retrieval time of typical messages in different GPRS networks. Performance evaluation of an MMS system also shows similar trend – increasing retrieval time with the size of a message [2]. The calculation indicates that the retrieval takes significant time, and more importantly, the retrieval time increases significantly with the size of a message. With a 3G network, the performance in terms of retrieval time should be better. However, as already mentioned above, size of a message is also increasing. MMS specification [127] already allows the transmission of a message of 600 Kbytes in the restricted mode, and much more in free mode, while in the early days of MMS the size of a message was limited to only 30 Kbytes.

A study in different markets and all segments of users indicate that usefulness, ease of use, price, and speed of use are the most important factors about user adoption of a mobile multimedia service [3]. The multimedia services considered in the study include photo messaging, mobile e-mail, video messaging, postcard messaging, rich text messaging, and video call. Four out of these six services are based on MMS. The limitations of MMS, pointed out above, are directly linked with the fourth factor (i.e., speed of use) for adopting mobile multimedia service, while the other factors can be also linked, especially the usefulness and ease of use. Though "usefulness" and "ease of use" are subjective matter, and usually linked with the user interface, the limitations may have impact on these factors (e.g., delay, content adaptation, failure in message).

The market situation of MMS does not yet reflect the expectation. Rather, the development of MMS use has been so far poor [26] and [196]. A detailed study in [26] reveals that the main problems of MMS are different factors of user experience, like pricing, usability, network coverage, blocking, dropping, sending delays, and bit-rates. Above-mentioned limitations of MMS are directly related to the last two identified factors, while the most of the other factors are non-technical. The objective study made about MMS in [197] also indicates that the key barriers (i.e., price of both service and terminal, and interoperation among different networks) against extensive use of MMS in the market are mostly non-technical.

3.2 Need for the Interworking

Though MMS has many positive features, as described in Sub-section 2.3.2.5 and Section 2.3.4; MMS has still couple of limitations, as discussed in Section 3.1:

1) Inability to handle a message requiring more storage space than available and
2) Long retrieval time for a relatively large message.

These limitations are not usually similarly obvious in real-time communication. Real-time communication has an inherent ability of managing limited storage space and long transmission delay, as processing of the content starts before the whole content is transmitted or stored. If properly designed, interworking between MMS and a real-time transport should be able to remove the limitations of MMS. As the transmission in MMS takes place in multiple hops, the interworking means using a real-time transport to transmit the contents of an MMS message in a hop. However, the interworking solution should be consistent with the frameworks and the working principles of both MMS and a real-time transport; so that the solution is compatible with the existing solutions and user experience is preserved.

3.3 Optimum Scope of the Interworking

As interworking between MMS and a real-time transport can overcome the limitations of MMS, now the question is what would be the optimum scope (extent) of the interworking. In other words, which MMS hops require such interworking. Any alternative means for transmitting the contents of an MMS message in any hop in terms of interworking is not expected to be straightforward. It might be complex and expensive option, requiring change in the existing deployments. Real-time transport is naturally a demanding option in terms of required resources. Therefore, it is important to find the MMS hops where the limitations are mostly damaging to know the optimum interworking.

Before finding the optimum interworking, let us look at the end-to-end transmission in MMS again. A closer look reveals that the MMS transmission has three main consecutive sequences:

1) the submission of a message (upload) by an MMS UA to the originating MMS R/S,
2) the routing of the message from the originating MMS R/S to the recipient MMS R/S, and
3) the retrieval of the message (download) by the recipient MMS UA.

The scope of the interworking is already reduced in Section 3.2 to the unilateral use of a real-time transport by MMS per hop basis. Among the involved entities in the end-to-end MMS transmission, a mobile terminal is the most critical entity in terms of storage space. A mobile terminal is naturally small in size, light in weight, and cheaper in price. Moreover, the processing power and ability in a mobile terminal are limited due to limited battery life. An MMS R/S may need huge storage space for MMS message to handle many users. However, it is predictable, and more importantly an MMS R/S does not have the above-mentioned shortcomings available in a mobile terminal. Moreover, only the terminal-interfaces are exposed to expensive radio interface, making it the bottleneck for the transmission in MMS. Therefore, both the identified limitations of MMS are more critical for the content upload and download across the terminal-interfaces involving a mobile terminal.

An originating mobile terminal is naturally likely to have integrated or external device to capture audiovisual clip that the originator wants to send in terms of an MMS message. The additional device is also likely to provide sufficient space for its processing and storage in any case. Moreover, if the message is rather created from the stored content (not from the recently captured content), the mobile terminal is not supposed to have the storage problem, as the content is already stored. The user of the originating terminal has the option of making the required space free on demand before capturing any content or creating a message. However, a recipient of the message can be any mobile terminal, and it is more probable that it does not have such additional device, and thus sufficient storage space. The recipient gets the notification of a new message at any time without any early notice. It is likely that the notification is received when there is not enough space for storing the whole message.

Content upload and download should require similar transmission time for the same message, if the same wireless access technology is used across the terminal-interface at both the ends. However, the same amount of delay at the two ends may not impact user-experience equally. In the case of media upload, originating MMS R/S receives the content. While, in the case of media download, content is received by the recipient terminal, which involves user-interaction. The recipient user has to wait for the whole retrieval time to see the content, if she manually decided to retrieve a message based on an MMS Notification message.

Considering the discussions in the two last paragraphs, both the limitations are mostly visible, and thus damaging, in the hop involving content retrieval (download) from the recipient MMS R/S to the recipient MMS UA across the terminal-interface. Therefore, the unidirectional use of a real-time transport by MMS in the retrieval (download) of a message is the optimum scope of the interworking. The optimum scope is discussed in detail with figure in the Chapter 6 of [P2] and Chapter 4 of [P3].

In brief, the optimum interworking focuses on the following most likely problem – an originator, being able to handle a demanding multimedia content (e.g., audiovisual clip) in terms of storage space and transmission time, submits the content in terms of an MMS message to the network for the delivery of the same to a mobile terminal either not having enough space to retrieve the whole message, or requiring disturbingly long retrieval time.

3.4 Why Interworking with Streaming

Though, MMS works end-to-end, meaning user-to-user, an MMS message is stored after each hop. As the optimum interworking involves only the content retrieval, a real-time transport should fit architecturally within the last MMS hop. Multimedia telephony and streaming are real-time transports defined for mobile communication. Let us find out which real-time transport is suitable to interwork with MMS, based on the overview about the transports in Chapter 2.

As multimedia telephony provides conversational service between users, it also works end-to-end. Therefore, it does not fit within the MMS hop. Moreover, multimedia telephony uses circuit-switched transport, while MMS mostly uses packet-switched IP protocol for transmission nowadays; making it difficult and complex to make those interoperate. Thus, multimedia telephony is not suitable for the interworking with MMS.

On the other hand, streaming works based on client-server approach – not end-to-end as such. Both the scope and extent of the transmission in streaming fit within the MMS hop for the interworking. Moreover, streaming also uses packet-switched IP protocol for transmission. Even if streaming is used only in the last hop, MMS still covers the end-to-end content transmission, and should have the over-all control of the interworking. Providing the over-all control to MMS also better realizes the interworking, as MMS should decide if the streaming would be used. The vertical layers for the interworking are shown in Figure 5 in Chapter 5 of [P2]. References [7] and [24] also predicted about the use of streaming in MMS as a scope for the future development of MMS. PSS is picked as an example streaming solution in this dissertation to depict the details of the interworking, while any other mobile streaming solution could be used for the interworking instead.

Dynamic content, also known as continuous content, is naturally heavy, requiring more space and time for its storage and transmission respectively [191]. As dynamic content has inherent notion of time, it is suitable for streaming. On the other hand, static content (also known as discrete content) does not contain an element of time. In streaming, presentation of a content starts before the transmission finishes. It reduces the memory requirements for a mobile terminal, and removes the practical limitation on the length of any media [163] and [165]. Moreover, streaming may use better QoS profile than the profile used by MMS. Based on delay sensitivity, four different QoS classes are defined for UMTS. The QoS classes are conversational (the most sensitive), streaming, interactive, and background (the least sensitive) [198]. Even without better QoS profile, adaptive streaming can better handle the dynamic situation of mobile environment to provide consistent service in terms of both storage requirement and delay. Therefore, streaming can improve the situation for dynamic content in terms of both storage space and transmission time [199]. Streaming also provides the means of playing back, pausing, fast forwarding, and rewinding media stream at will, so that a user have the impression that the media is stored locally [163]. Streaming can be a remedy of the noted limitation of MMS, as it has the benefit of low initial delay and needs a small storage space [198]. The 3GPP defined streaming (PSS) to avoid storage problem in a terminal and reduce start-up delay [8]. A comparative study is available in Chapter 4 of [P4] between the user delay in streaming and retrieval time in normal MMS, which indicate significant improvement in streaming.

Both subjective and objective tests over streaming of different video and audiovisual clips in mobile network indicate that the streaming in mobile networks is possible with reasonable performance. As for example, subjective test over different audiovisual clips indicate that the performance can vary significantly with the selection of codec and bit-rate selected for audio and video in an audiovisual clip [167]. The study shows MOS (Mean Opinion Score) value as high as more than 4 with the right selection of codec and bit-rate, while the MOS value more than 3 is achieved with multiple combinations [167]. MOS is quantitative measure of quality of human speech, obtained from mathematical average of opinion scores in a subjective test. It can have value between 1 (worst) and 5 (best).

Detailed objective analysis about the performance of streaming in mobile communication and other related issues are available in [32], [163], [164], [165], and [166] for GPRS, EGPRS and 3G networks. Videoconferencing-capable video quality can be achieved in the real-time video streaming in GPRS network with multi-slotting [32]. Though bit-rate and delay are not guaranteed in the GPRS network, it can still support streaming if it is configured with the appropriate quality parameters [163] and [164]. Cell reselection and non-guaranteed bit-rates are critical factors in having streaming in GPRS network. Quality factors related to both signaling (e.g., connection setup delay, pause-play delay, and teardown delay) [163] and media transport (e.g., packet losses, buffering, and buffer usage) [164] are considered in the analysis. Based on evaluating and comparing quality factors (signaling delay, media bit-rate, packet loss, cell reselection, buffering, link adaptation), user experience is much better for streaming in EGPRS network than the same in GPRS network [165]. Beside evaluating the performance of streaming in WCDMA-based 3G network based on the similar quality factors, [166] also compares the streaming performance in GPRS, EGPRS, and WCDMA networks. Beside other factors, seamless cell reselection in WCDMA network is a major reason of having improved streaming performance in the WCDMA network.

A study was made to find the major sources of delay in GPRS network [200]. According to the study, sharing of resources at BTS with circuit-switched traffic (e.g., voice) is one of the major reasons of delay in streaming over GPRS network. Moreover, the load on SGSN and GGSN can vary significantly, causing variation in the traffic delay [200]. Due to the dynamic network aspects like fading and mobility, available bandwidth may become lower than the media rate (delay jitter). A play-back buffer is used in the receiver to reduce the playback interruption due to the mismatch between available bandwidth and media rate. However, playback buffer increases end-to-end delay, resulting in lower start-up time. As delay jitter and end-to-end delay are related, a study reveals that adaptive buffering depending on instantaneous network situation can improve the end-to-end delay [201]. The study proposes to adjust the playback buffer adaptively based on delay margin and delay jitter margin in the network. Moreover, there are solutions to reduce the set-up delay further in streaming [172]. One approach, named RTSP Early Setup, provides enough media information in the RTSP *Describe* to enable early activation of the secondary PDP-context. The other approach, namely SDP Template, minimizes the amount of SDP information, in case of streaming sessions of similar encoding setting, transferred over the radio interface. This can be achieved by storing the unlikely-to-change SDP fields among multiple streaming sessions in a client as a template. Both the approaches can reduce the setup delay by about 30 percent by reducing the time required by RTSP and SDP signaling exchange and negotiation – one of the main reasons of set-up delay in streaming [172].

Figure 6 of [P2] shows a simplified framework for the optimum interworking between MMS and streaming. The figure is extended to cover inter-operator case in Figure 15. The framework has three phases – media upload (including submission and routing to the recipient MMS R/S), streaming indication, and streaming. Before the streaming indication, the MMS R/S has to decide for streaming retrieval and make the content of the message available in a Media Server for the streaming retrieval. Making MMS contents available for the streaming retrieval is one type of content adaptation [23] and [103]. Thus, terminal capabilities and user setting/preference are important factors in deciding about making any MMS content available for the streaming retrieval. All these aspects would be described for different implementation solutions in the following chapter.

The framework assumes MMS and streaming as different services, supporting both the implementation options of providing dependent and independent services. If the services are independent, the MMS entities are not expected to support the streaming-specific protocols or features, and vice versa. This way, the performance is expected to be better for both the services. The framework also does not break the framework of either MMS or streaming, allowing consistency with the available implementations.

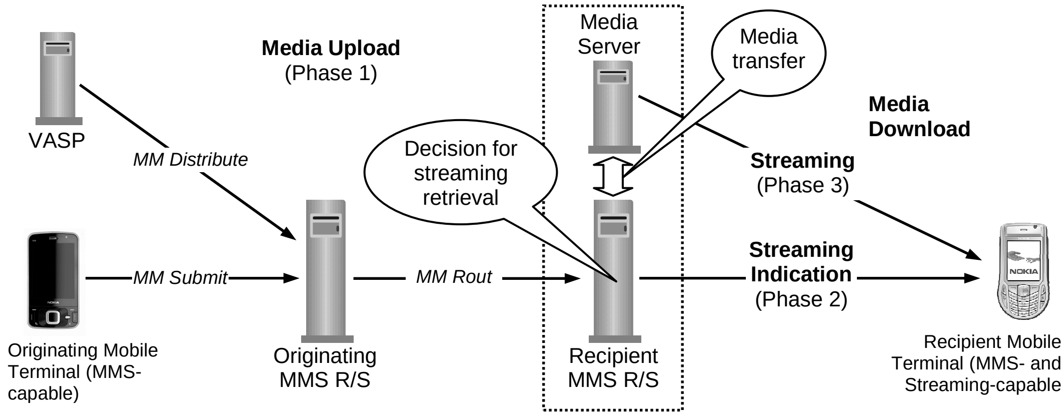

Figure 15: The framework for the optimum interworking between MMS and streaming.

A connection mechanism between streaming and MMS is proposed in the Reference [199]. However, the discussion is limited to the framework (architecture). The main criteria in the proposed framework are balancing load and retransmission. An MMS R/S is coupled with a streaming server to form the core MMS network entity - MMSC, while MMS Proxies are distributed to reduce the overload of the MMSC. MMS Proxy caches data and interacts with mobile terminal. Coordination Agent provides updated information about the state of each MMS Proxy, and informs the terminal about the suitable MMS Proxy. The work does not mention how MMS R/S and streaming server interworks to enable streaming delivery of MMS content.

Chapter 4 Implementation Solutions for the Interworking

The previous chapter points out a couple of limitations of MMS. A conceptual framework for the optimum interworking between MMS and streaming is also proposed in the same chapter to overcome the limitations. The framework provides an architectural concept, and does not go down to the implementation level. The framework has three main phases for the interworking – upload, streaming indication, and streaming retrieval. MMS and streaming are expected to be used for the upload and streaming retrieval phase respectively. On the other hand, streaming indication is the basis for the interworking, as it links MMS with streaming. References [P3] and [P4] introduce three different implementation solutions based on the framework described in the previous chapter. The solutions mainly differ from each other in terms of format, scope, and carrier of the streaming indication. All the solutions are complete in terms of end-to-end information. The solutions are also consistent with the existing standardized solutions of both MMS and streaming. Consistency is important for preserving both backward compatibility to avoid market fragmentation, and user experience to avoid breaking the continuity of the services in the market. Though, consistency is one of the core factors, many other important factors are also considered while defining the solutions. This chapter summarizes the solutions by first describing, and then comparing those. This chapter also describes a general end-to-end architecture [P4] for accommodating the solutions.

4.1 Solution 1 – Brief Streaming Indication over the MMS *Notification* Message

An MMS *Notification* message is sent to the recipient terminal to indicate that there is a new MMS message. An example of an MMS *Notification* message is shown below in text format. The example shows only the mandatory and a few commonly used optional information elements (headers). The new message is referred by a URL, as the value of the header `X-Mms-Content-Location`. Though not shown here, it is possible to indicate more information about the new message using some other optional headers, e.g., different contents in terms of media type and format and size. These additional headers are not practically used mainly to fit a *Notification* message within the limit of WAP push carrier (e.g., SMS message), so that expensive radio interface is optimally used. Some other carrier of WAP push (e.g., UDP) does not have such stringent limit, but SMS is still the most popular carrier of WAP push. The value of `X-Mms-Message-Size` header may not be the exact size of the retrieved message, due to possible content adaptation by the MMS R/S prior the retrieval.

In case of streaming, a presentation description is required, as described in Section 2.4, by a client to initiate a streaming session. The reference of a presentation description can also be expressed in terms of a URL. This solution exploits the fact that both an MMS message and a presentation description can be referred by a URL. According to this solution (solution 1), the URL, which is used as the value of `X-Mms-Content-Location` header in the *Notification* message, refers to a presentation description. It acts as the streaming indication to the recipient.

An example of an MMS *Notification* message in text format:

```
X-Mms-Message-Type: m-notification-ind
X-Mms-Transaction-ID: zyxwvutsrqponm
X-Mms-MMS-Version: 1.3
From: +358901234567/Type=PLMN
Subject: greetings
X-Mms-Delivery-Report: Yes
X-Mms-Message-Class: Personal
X-Mms-Priority: Normal
X-Mms-Message-Size: 32456
X-Mms-Expiry: Relative: 36000
X-Mms-Content-Location: http://abc.mmsc:8002/messageID
```

Solution 1 is shown in Figure 16 in terms of information flow. All the information flow prior to sending the MMS *Notification* message to the recipient is identical to the information flow of normal MMS shown in Figure 9 in Sub-section 2.3.2.6. Moreover, the solution focuses on the information flow only in the recipient terminal-interface. Therefore, the figure shows only the information flow across the recipient terminal-interface.

A recipient MMS R/S can receive an MMS message for delivery in terms of an MMS

- *MM Submit* message from an MMS UA in intra-domain person-to-person messaging,
- *MM Route* message from another MMS R/S in inter-domain person-to-person messaging, or
- *MM Distribute* [P4] message from a VASP in content-to-person messaging.

Upon receiving an MMS message, the recipient MMS R/S needs to decide if it would make the content of the message available for streaming retrieval. The response of the *MM Submit*, *MM Route*, or *MM Distribute* message is not shown in the figure for simplicity. The possible factors that can influence the decision taken in an MMS R/S are:

- support for the streaming retrieval by the recipient MMS R/S,
- support for the streaming retrieval by the recipient terminal, and
- if the content of the MMS message is streamable, i.e., dynamic content.

Moreover, user preference and service provider setting can also be considered while taking the decision. The standard way of capability negotiation in MMS can not be used by the MMS R/S to know about the support for the streaming retrieval by the recipient terminal or user preference, as the terminal capability of the recipient terminal is made available to the MMS R/S only in the *MM Retrieve* message. This solution can use proprietary way of capability negotiation, like maintaining setting (e.g., look-up table) in an MMS R/S. Alternatively, such static table can be maintained by the associated profile server, so that the MMS R/S get the capability and/or preference of the recipient from the profile server upon receiving any new message.

After deciding to make the content of the MMS message available for the streaming retrieval, the MMS R/S stores the dynamic content in the associated Media Server. Any open or proprietary protocol solution can be used to store content in the Media Server by the MMS R/S. As the normal MMS procedure of retrieving content is not available in this solution, any non-streamable (i.e., static) content, within the MMS message, can not be retrieved. Upon storing the content, the MMS R/S sends a *Notification* message to the recipient and it includes the URL for the presentation description. The URL includes

- the address of the server where the presentation description is available,
- the identification of the presentation description, and
- the access mechanism to retrieve the presentation description.

As for example, if RTSP or HTTP is used for retrieving the presentation description, `rtsp` or `http` would be used as the scheme of the URL to show the access mechanism, respectively. The figure shows RTSP *Describe* method to retrieve the presentation description. If the RTSP *Describe* request contains a reference of device capabilities, the Media Server retrieves the capabilities from the referred Profile Server, as described in Sub-section 2.4.2. The Media Server performs content adaptation based on the device capabilities, and generates a presentation description. It sends the presentation description in the response of RTSP *Describe*. After the presentation description is retrieved, the terminal can start the streaming retrieval using different RTSP methods, as shown in the figure. Different RTSP and HTTP methods are shown with double arrows in opposite direction to indicate the involvement of both request and response. Figures of other implementation solutions, shown below, also use similar convention.

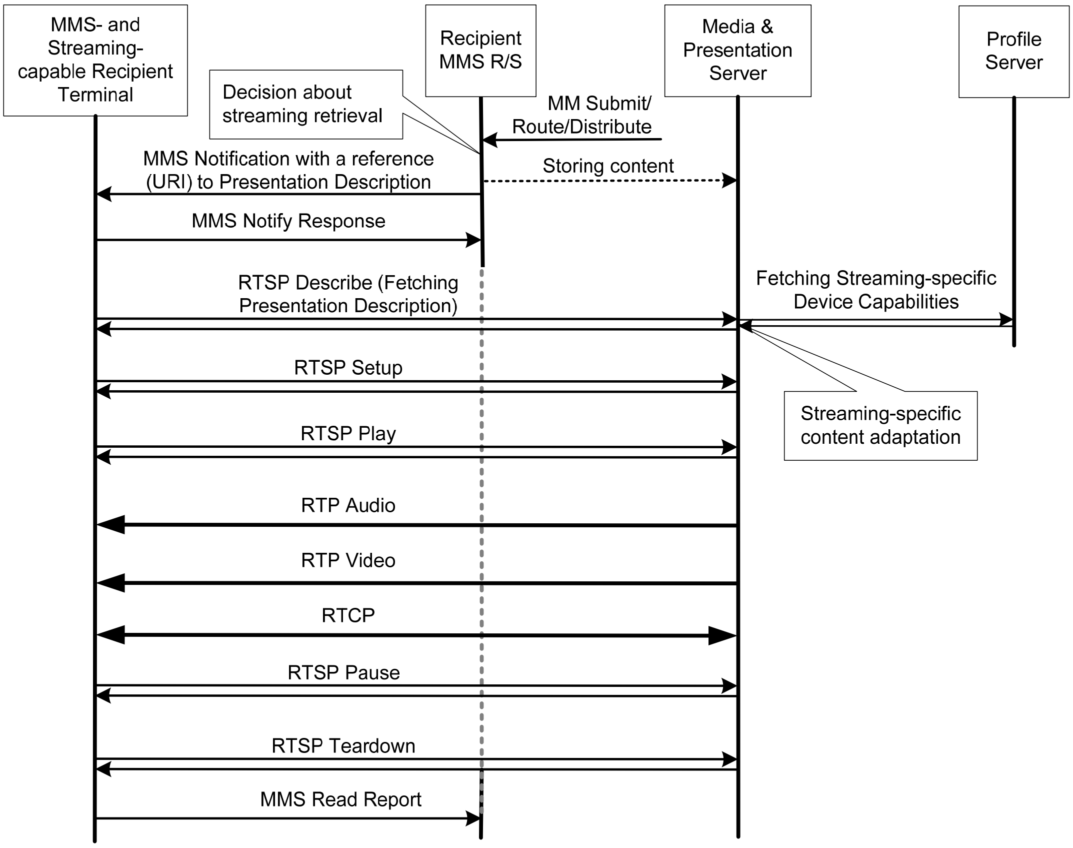

Figure 16: Information flow for the solution 1 (brief streaming indication in *Notification* message).

Some MMS messages (*Retrieve Request*, *MM Retrieve*, and *Acknowledge*) are not shown in the figure, as those are not required here. Generation of delivery report (not shown in the figure) and read report take place according to the normal MMS principles. Figure 16 assumes that the Media Server and Presentation Server are integrated, which is a likely practical case. Figures of other implementation solutions, shown below, also make similar assumption for the same reason.

4.2 Solution 2 – Detail Streaming Indication over the MMS *MM Retrieve* Message

Instead of sending the streaming indication over the MMS *Notification* message like in solution 1, it is sent over the *MM Retrieve* message in solution 2. Moreover, in contrast to solution 1 where the streaming indication is brief in terms of a URL, the streaming indication in solution 2 is more detail in terms of presentation description. This solution is depicted in Figure 17 in terms of information flow. Like in Figure 16, the focus is on the recipient terminal-interface in this figure for the same reason.

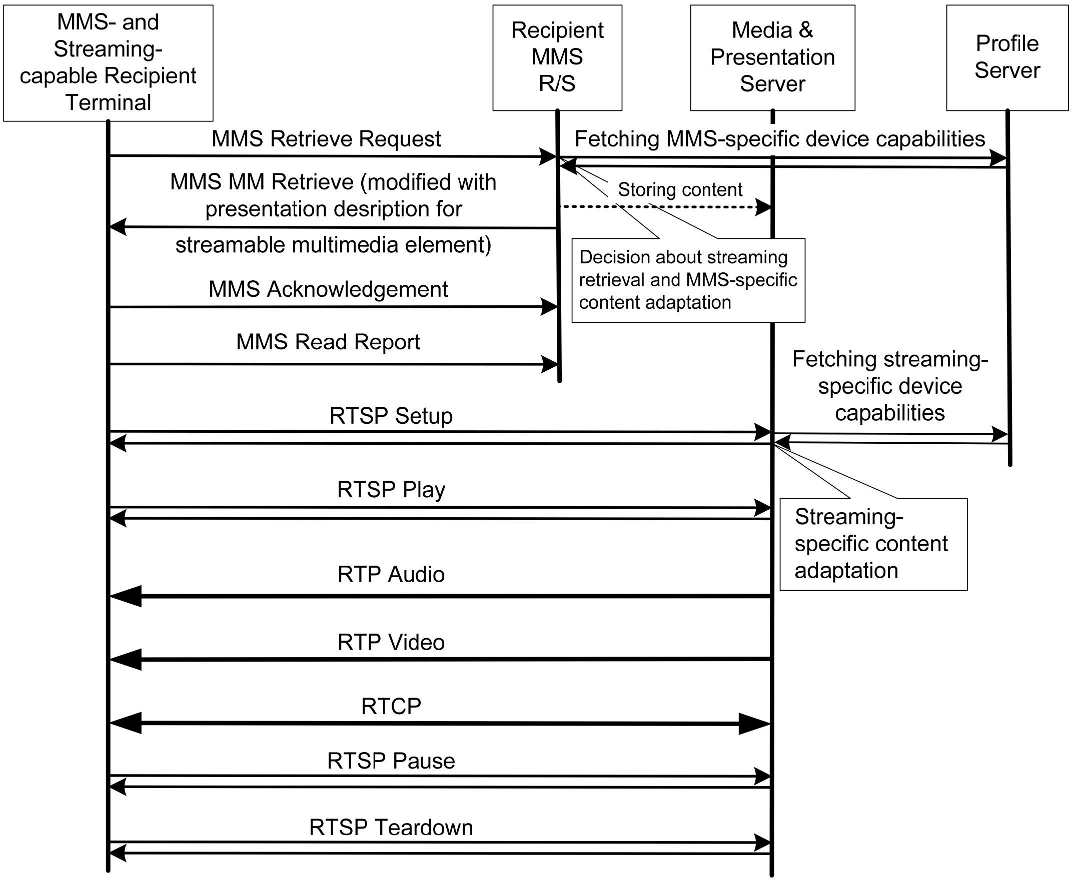

Figure 17: Information flow for the solution 2 (detail streaming indication in *MM Retrieve* message).

In solution 2, the normal information flow of MMS takes place until the recipient MMS R/S sends the MMS message to the recipient. A regular *Notification* is sent to the recipient (not shown in the figure), followed by the *Notify Response* (not shown in the figure) sent from the recipient to the MMS R/S. Then, the recipient sends a request for retrieving the message in terms of a regular *Retrieve Request* message. Upon receiving the *Retrieve Request* message, the MMS R/S decides whether the content of the message would be made available for the streaming retrieval. The decision is based on the similar factors listed for the previous solution. However, the difference is - the MMS-specific capability of the recipient terminal is known by the MMS R/S from the terminal capabilities made available in the *Retrieve Request* message – the standard procedure of capability negotiation in MMS [102] and [125].

Here, the content of a message can be made available for the streaming retrieval partially or fully. If a message contains both dynamic and static content, the dynamic content can be retrieved by streaming, while the static content can be retrieved according to the normal MMS procedure. The MMS R/S stores the streamable content of the message in the associated Media Server, and at the same time, it generates a presentation description for the content stored in the Media Server for the streaming retrieval. The MMS R/S also creates a modified MMS message by placing the presentation description in place of the content stored in the Media Server. Reference [P3] shows an example, in terms of the graphical representation of message structure, how a modified MMS message is created in this solution. The same MMS message (both before and after modification) is shown below in text format to better understand the solution. The contents of the message in this example are independent, so there is a presentation description for each streamable content. If the contents were related, only one presentation description may cover multiple streamable contents.

Modifications made in an example MMS message, with four independent contents, by the recipient MMS R/S based on solution 2 – original message is on the left hand side, and the modified message is on the right hand side:

```
X-Mms-Message-Type: m-retrieve-conf
X-Mms-Transaction-ID: abcdefghijk
X-Mms-MMS-Version: 1.3
Message-ID: 1234567890
Date: Tue, 29 Sep 2004 15:30:30 GMT
From: +358601234567
To: +358701234567/Type=PLMN
Subject: Greetings from holidays
X-Mms-Message-Class: Personal
X-Mms-Priority: Normal
X-Mms-Delivery-Report: Yes
Content-Type: multipart/mixed; boundary=54321

--54321
Content-Type: text
Content-Transfer-Encoding: binary

… text content …

--54321
Content-Type: image/jpeg
Content-Transfer-Encoding: binary

… image content …

--54321
Content-Type: audio/AMR
Content-Transfer-Encoding: binary

… audio content …

--54321
Content-Type: video/H263-2000
Content-Transfer-Encoding: binary

… video content …

--54321—
```

```
X-Mms-Message-Type: m-retrieve-conf
X-Mms-Transaction-ID: abcdefghijk
X-Mms-MMS-Version: 1.3
Message-ID: 1234567890
Date: Tue, 29 Sep 2004 15:30:30 GMT
From: +358601234567
To: +358701234567/Type=PLMN
Subject: Greetings from holidays
X-Mms-Message-Class: Personal
X-Mms-Priority: Normal
X-Mms-Delivery-Report: Yes
Content-Type: multipart/mixed; boundary=54321

--54321
Content-Type: text
Content-Transfer-Encoding: binary

… text content …

--54321
Content-Type: image/jpeg
Content-Transfer-Encoding: binary

… image content …

--54321
Content-Type: application/sdp
Content-Transfer-Encoding: binary

v=0
o=ghost 1 1 IN IP4 192.168.10.10
s=audio in MMS
i=SDP file for audio streaming in MMS
u=http://www.mediaserver.com/
e=ghost@mailserver.com
c=IN IP4 0.0.0.0
b=AS:16
t=0 0
a=range:npt=0-56.247
m=audio 0 RTP/AVP 97
b=AS:16
a=rtpmap:97 AMR/8000
a=control:rtsp://mediaserver.com/1234567890_audio.amr
a=fmtp:97 octet-align=1

--54321
Content-Type: application/sdp
Content-Transfer-Encoding: binary

v=0
o=ghost 1 1 IN IP4 192.168.10.10
s=video in MMS
i=SDP file for video streaming in MMS
u=http://www.mediaserver.com/
e=ghost@mailserver.com
c=IN IP4 0.0.0.0
b=AS:64
t=0 0
a=range:npt=0-10.235
m=video 1024 RTP/AVP 96
b=AS:64
a=rtpmap:96 H263-2000/90000
a=fmtp:96 profile=3;level=10
a=control:rtsp://mediaserver.com/1234567890_video.3gp
a=framesize:96 176-144

--54321--
```

The recipient MMS R/S sends the modified MMS message to the recipient in terms of the *MM Retrieve* message. The flow of *Acknowledge*, *Read Report*, and *Delivery Report* (not shown in Figure 17) follows the normal MMS procedure. Though *Read Report* is generated before the streaming retrieval in the figure, it can be generated before or after the streaming retrieval, depending on an implementation. As the presentation description carries all the required information to initiate the streaming session, the recipient can start the streaming session to retrieve and render the content using different RTSP methods and RTP and RTCP protocols as shown in the figure.

The RTSP *Setup* request may include the reference of device capabilities, as described in Sub-section 2.4.2. If included, the Media Server fetches the streaming-specific device capabilities from the referred Profile Server, and performs content adaptation, if required. Though, the same Profile Server stores both MMS- and streaming-specific device capabilities in Figure 17, different Profile Servers can be used in practice depending on deployment preference or need.

In this solution, a presentation description may be generated well before the streaming session. If the recipient does not invoke the streaming session for any reason, the presentation description remains useless. In case the capabilities of a terminal change in between (e.g., switching terminal, dynamic download of new codec), either the presentation description may become invalid (as it may not match with the streaming content), or the streaming content may not match with the terminal capabilities, depending on if streaming-specific content adaptation is performed or not.

4.3 Solution 3 – Brief Streaming Indication over the MMS *MM Retrieve* Message

In solution 3, the streaming indication is sent over the *MM Retrieve* message like in solution 2, but the streaming indication is brief in terms of a URL like in solution 1. Solution 3 is shown in terms of information flow in Figure 18. The information flow follows the information flow in MMS until a message is retrieved by the recipient across the recipient terminal-interface. The figure only concentrates on the interface, assuming that a message is already stored in the recipient MMS R/S.

After storing the message, the recipient MMS R/S sends a regular *Notification* message (not shown in the figure), followed by the *Notify Response* (not shown in the figure) sent by the recipient to the MMS R/S. The recipient also sends back a regular *Retrieve Request* message, when it wants to retrieve the message. Then, the MMS R/S decides whether it would make the contents of the MMS message available for the streaming retrieval, and the decision is based on the similar factors listed for the solution 1 in Section 4.1. The standard MMS capability negotiation is used, like in solution 2, by the MMS R/S to determine whether the recipient terminal supports the streaming retrieval. In this solution, content of a message can be made available for the streaming retrieval partially or fully, like in solution 2.

Upon deciding about the streaming retrieval, the MMS R/S stores the content that it decided to make available for the streaming retrieval in the associated Media Server. The MMS R/S keeps the non-streamable content (e.g., static media) of the message, and replaces each streamable content (that the MMS R/S decided to make available for the streaming retrieval) with a brief streaming indication in terms of a URL. The URL points the presentation description or directly the content. However, the URL should point presentation description to be conformant with the 3GPP PSS specification [184]. The URL includes all the information required to initiate the streaming session - access type, address of the server, and the identification of the content. In case, the URL points to the presentation description, the server addressed can be a presentation server, which generates presentation description for the content. Presentation description refers to the Media Server, where the streaming content is stored. The 3GPP has defined a specific field of SDP "`a=control:`" to refer to the Media Server [122]. In case, the URL directly points to the content, the server addressed in the URL is the Media Server. The figure assumes that the URL points to presentation description.

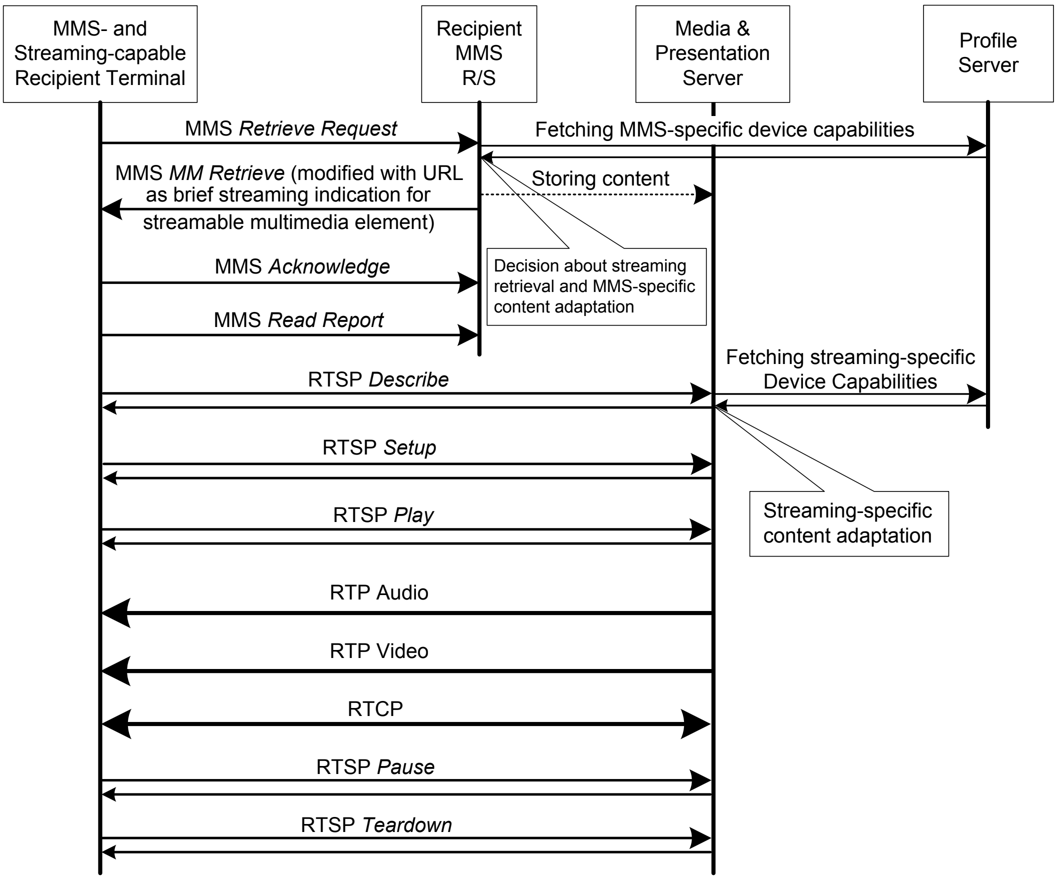

Figure 18: Information flow for the solution 3 (brief streaming indication in *MM Retrieve* message).

The IETF specification allows having a MIME object that does not include any content, rather it can only have a reference to the content stored in an external storage [202]. Such remote reference uses `external-body` as the subtype value of `content-type` header in a MIME body. A URL can be used, as a parameter of the `content-type` header, to express the reference and the mechanism for accessing the content [203]. In solution 3, the URL of a presentation description is used as the access type of an `external-body` MIME object. This empty MIME object is the multimedia element that replaces the streamable content in the message. Reference [P4] shows some examples of such MIME object, referring different types of content either in presentation server or in Media Server. The modification made, according to this solution, on the same multimedia message, used in Section 4.2 for solution 2, is shown below. Reference [P4] shows the modification, in terms of graphical representation of message structure, both for this message and another message that has related content.

The MMS R/S sends the modified MMS message to the recipient in terms of the *MM Retrieve* message. The flow of *Acknowledge*, *Read Report*, and *Delivery Report* (not shown in Figure 18) follows the normal MMS procedure. Though *Read Report* is generated before the streaming retrieval in the figure, it can be generated before or after the streaming retrieval, depending on an implementation.

After receiving the *MM Retrieve* message, the recipient activates the URL (streaming indication) to initiate the streaming retrieval. Though RTSP *Describe* is used for retrieving presentation description in the figure, HTTP *Get* is another example method that can be used for the same. RTSP *Describe* or HTTP *Get* request can include a reference for the device capabilities stored in a Profile Server. If included, the Media & Presentation Server fetches the device capabilities, and makes content adaptation accordingly, if required, as described in Sub-section 2.4.2. Though, the same Profile Server stores both MMS- and streaming-specific device capabilities in Figure 18, different Profile Servers can be used in practice depending on deployment preference or need.

Upon retrieving the presentation description, different RTSP methods and RTP and RTCP protocol are used for the actual retrieval and rendering of the content, as shown in the figure and described in Sub-section 2.4.3. If the URL in the empty multimedia element points the content directly, the retrieval of presentation description is skipped.

Modifications made in an example MMS message with four independent contents by the MMS R/S based on solution 3:

```
X-Mms-Message-Type: m-retrieve-conf
X-Mms-Transaction-ID: abcdefghijk
X-Mms-MMS-Version: 1.3
Message-ID: 1234567890
Date: Tue, 29 Sep 2004 15:30:30 GMT
From: +358601234567
To: +358701234567/Type=PLMN
Subject: Greetings from holidays
X-Mms-Message-Class: Personal
X-Mms-Priority: Normal
X-Mms-Delivery-Report: Yes
Content-Type: multipart/mixed; boundary=54321

--54321
Content-Type: text
Content-Transfer-Encoding: binary

… text content …

--54321
Content-Type: image/jpeg
Content-Transfer-Encoding: binary

… image content …

--54321
Content-Type: message/external-body; access-type=URL;
            URL="rtsp://mediaserver.com/1234567890_audio.sdp"

Content-Type: application/sdp
Content-Transfer-Encoding: binary

--54321
Content-Type: message/external-body; access-type=URL;
            URL="rtsp://mediaserver.com/1234567890_video.sdp"

Content-Type: application/sdp
Content-Transfer-Encoding: binary

--54321--
```

4.4 Comparison of the Solutions

All the three implementation solutions described above follow the existing framework and basic working principles of both MMS and streaming, as defined by the 3GPP and the OMA. As for example, the required MMS transactions take place in the right sequence, meeting all the requirements. Moreover, the solutions accommodate different streaming specific protocols, as required by the 3GPP – RTSP for the streaming control, SDP for the presentation description, and RTP and RTCP for the transport. It is possible, in all the solutions, to convey presentation description to the recipient before it can initiate the streaming session. It varies among the solutions what constitutes the streaming indication and how it is carried to the recipient. However, the streaming indication fits well within the structure of the carrier MMS messages in all the solutions.

In all these solutions, streaming and MMS are considered as different services. In a terminal, an MMS UA and a Streaming Client can work in separate module, but there should be a means of communication between those. As for example, upon receiving the streaming indication, the MMS UA should have means to invoke the Streaming Client for the streaming retrieval by handing over the streaming indication. Moreover, if the recipient is designed to generate a Read Report after the streaming retrieval, the Streaming Client should indicate to the MMS UA after the streaming session, so that the MMS UA can generate the Read Report in due time. In the implementation level, this kind of interworking can be achieved by designing a software architecture with suitable Application Programming Interface (API).

On the other hand, the MMS and streaming-specific servers in the network can belong to different physical entities. However, the servers must communicate to achieve the interworking. As for example, an MMS R/S should be able to store content, of an MMS message that it decided to make available for the streaming retrieval, to the associated Media Server. They should also have understanding in terms of generating presentation description, performing content adaptation, and knowing each other's media capabilities. It is expected that the communications in this regard are based on commonly used means in MMS and streaming. As this communication is within a service provider domain, the means for communication between MMS and streaming servers is out of scope of this study. Still, if a network provider or service provider has the servers from different vendors, it must agree with the vendors about the means to avoid any possible interoperability problem.

Though, different MMS- and streaming-specific logical entities can belong to different modules in a terminal and physical entities in the network, as mentioned in the last two paragraphs, it is also possible to couple the entities in the same module or physical entity in a terminal or networks depending on the implementation, respectively. This way, the module or entity become more complex, and the performance may deteriorate, if they are overloaded. However, the communication between different MMS and streaming entities become easier, if they are coupled. An implementation should make its own choice about the coupling of entities depending on different practical situation, as for example load, performance.

The solutions appear similar from top as described above, as they are designed to serve the same purpose. However, the solutions also differ from each other in terms of many different detail aspects. Reference [P4] makes a detailed analysis to compare the solutions both in terms of the similarities and dissimilarities. As the similarities are mostly summarized above, the dissimilarities are outlined in Table 6. Based on the comparisons in Table 6, none of the solutions has complete advantages over the others. Though, solution 3 has relatively more number of advantages, it may not be the most suitable solution for all the deployments. As the importance of a basis of comparison may vary from one practical situation to another, the suitability of a solution depends on specific deployment needs.

Table 6: Comparison of all the implementation solutions for the optimum nterworking between MMS and streaming.

Basis of comparison	Solution 1	Solution 2	Solution 3
Streaming indication	Brief streaming indication in terms of URL.	Descriptive streaming indication in terms of presentation description.	Brief streaming indication in terms of URL.
Streaming indication carrier	MMS *Notification* message.	MMS *MM Retrieve* message.	MMS *MM Retrieve* message.
Presentation description carrier	Non-MMS means (e.g., RTSP *Describe*, HTTP *Get*).	MMS *MM Retrieve* message.	Non-MMS means (e.g., RTSP *Describe*, HTTP *Get*).
Streaming requirements (protocol, content adaptation) in MMS R/S, if MMS and streaming are decoupled	An MMS R/S does not require to support any streaming requirement.	An MMS R/S requires to support the protocol of presentation description (e.g., SDP) and streaming-specific content adaptation.	An MMS R/S does not require to support any streaming requirement.
Time for generating a presentation description and its effectiveness	A presentation description is generated and delivered after streaming is invoked in a terminal - presentation description is not created unnecessarily.	A presentation description is created before the streaming is invoked. Resources in network servers and radio interface are misused for creating and delivering presentation description, if streaming is not invoked. There is a possibility of charging a user for the misuse.	A presentation description is generated and delivered after streaming is invoked in a terminal - presentation description is not created unnecessarily.
Matching of streaming content with the terminal capabilities	As a presentation description is generated just before the streaming retrieval, the streaming content always matches with the terminal capabilities.	As a presentation description might be delivered well before the streaming retrieval, the streaming content may not match with the terminal capabilities, if the terminal is changed in between and no streaming-specific content adaptation is performed. If streaming-specific content adaptation is performed, the presentation description may not match with the streaming content.	As a presentation description is generated just before the streaming retrieval, the streaming content always matches with the terminal capabilities.
Retrieval of both streamable and non-streamable content of a message	It is not possible to retrieve any non-streamable content of a multimedia message.	It is possible to retrieve both the streamable and the non-streamable contents of a multimedia message.	It is possible to retrieve both the streamable and the non-streamable contents of a multimedia message.
Retrieval of all information elements of a message	It is not possible to retrieve all the information elements of a multimedia message.	It is possible to retrieve all the information elements of a multimedia message.	It is possible to retrieve all the information elements of a multimedia message.
Use of the standard MMS terminal capability negotiation procedure	It is not possible to utilize the terminal capability negotiation procedure standardized for MMS.	It is possible to utilize the terminal capability negotiation procedure standardized for MMS.	It is possible to utilize the terminal capability negotiation procedure standardized for MMS.
Traffic performance	It requires streaming transaction for retrieving a presentation description. However, the retrieval transaction of MMS may not be required.	As MMS is used for transporting presentation description, it requires less streaming transaction.	Requires all the transactions in MMS and streaming,

4.5 Recognition of the Solutions

4.5.1 Standardization

The solution 1 was first proposed to the 3GPP for standardization to enrich MMS with a new feature. The 3GPP analyzed the solution and accepted it. Later on, the solution 2 was introduced and proposed to the 3GPP. After analyzing and comparing solution 2, the 3GPP replaced the solution 1 with the solution 2 in the specifications [122] and [183]. Changing solution did not cause backward compatibility problem, as solution 2 replaced solution 1 in the same version of 3GPP MMS (i.e., release-4) where solution 1 was accepted. Moreover, the vendors also agreed with the replacement, indicating that the feature was most probably not implemented by the time of the replacement. Later, the OMA also acknowledged the acceptance of solution 2 by the 3GPP in its specification [125]. The OMA also defined UAProf attributes for streaming-capabilities of a terminal within the scope of MMS capability negotiation [125]. The solution of the interworking between MMS and streaming is addressed as the support for streaming in the 3GPP MMS specification.

Solution 3 was introduced even later. The advantages of solution 3 can be better utilized by standardizing it in place of or in addition to the already standardized solution, so that one could easily exploit those in a consistent and harmonized manner. If solution 3 is standardized, it should be simply added to the MMS specification to ensure backward compatibility with a terminal supporting the already standardized solution (i.e., solution 2). Moreover, an MMS R/S should support both solution 2 and 3 for the same reason, while a terminal should be allowed to support only one solution, as a terminal has limited resource compared to a network entity. Thus, an MMS R/S should be able to know beforehand about which solution is supported by the recipient terminal. A new UAProf attribute can be defined to indicate which solution is supported by a terminal, so that the existing capability negotiation procedure is used by an MMS R/S to solve the problem. As the existing implementation would not support such new UAProf attribute, absence of such attribute would by default indicate that a terminal supports solution 2, if any.

4.5.2 Patent

The concept of interworking between MMS and streaming and the conceptual solution in terms of framework, as described in Chapter 3, are also accepted and published as a patent [204]. The patent considers more general case, where media is also uploaded to the network repository by streaming. As for example, RTSP *Record* method can be used to upload multimedia content to a Media Server. However, streaming for uploading is not considered in this dissertation due to practical reasons mentioned in Section 3.3.

Implementation solutions 1 and 2 are also accepted and published as patent lately [205] and [206]. The scopes of the solutions in these patents are wider than described in this dissertation. As for example, multiple protocols, media types/formats, and data formats are considered in the patents, while the solutions in this dissertation focus on specific protocol, media types/formats, and data format, as required.

4.6 General Architecture

The deployment of any implementation solution for the interworking between MMS and streaming requires suitable network architecture for proper functioning. The deployment situation can vary depending on the local needs. The network architecture should be feasible and flexible, so that it can cover different practical situations to provide equally useful service. A general network architecture is depicted in [P4] to accommodate the interworking solution in different situations of mobile communication. The general architecture is shown in Figure 19, and described briefly below.

Though, it is possible that a network operator or service provider, providing MMS service to users, has more than one MMS R/S, it is assumed in the figure that one network operator or service provider has only one MMS R/S for all the users it serves, which is the most likely practical situation. The figure shows end-to-end architecture involving multiple network operators - A and B.

A network operator can deploy a Proxy MMS R/S to balance the load of its MMS R/S, so that the requests for any MMS R/S first arrives the Proxy MMS R/S. The Proxy MMS R/S either handles the request or forwards it to MMS R/S, depending on the request and/or design principle. This implementation option is shown in the figure for operator B. The arrows of Figure 19 do not implicitly shows the use of Proxy MMS R/S B for simplicity. In case of the optimum interworking, the Proxy MMS R/S B can take care of the MMS-specific activities relating to the interworking with streaming. In this case, the Proxy MMS R/S B has following responsibilities, if solution 3 is deployed:

- taking decision if the message would be retrieved by streaming,
- if decided for the streaming retrieval, storing the content in the associated Media Server,
- modifying the message by replacing the content with a streaming indicator, and
- sending the modified message to MMS R/S for the delivery of the message to the recipient.

This way, an already deployed MMS R/S can support the interworking with streaming, enabling smooth deployment of the interworking in the existing MMS infrastructure. Moreover, this functional approach of sharing the responsibility between an MMS R/S and its proxy can achieve improved performance and scalability.

The use of a caching proxy of MMS R/S can also improve traffic management and reduce delay. The proxies can be distributed in the networks [199]. This way, the load on the proxies can be optimized. However, it requires additional mechanism to rightly select an MMS Proxy for any operation (e.g., retrieval). Reference [199] proposes the use of Coordination Agent to dynamically select the MMS Proxy. Alternatively, the selection of an MMS Proxy can be based on static configuration of the entities. The proxy, if designed properly at the edge, can result in a distributed system. If the proxies are used for caching content, both bandwidth consumption and latency can be reduced, allowing less delay time [191]. Reference [101] proposes adaptive multimedia framework based on proxy to balance load and optimize traffic, as an MMS R/S faces less traffic, so less delay is observed by an MMS UA.

Though, a Media Server and MMS R/S can be integrated in a physical entity, those are shown separately in the figure. MMS R/S B and Media Server B are shown in a rectangle to show this integrated implementation option [199]. However, such converged server may become overloaded easily, as it has to support the features and provide services of both MMS and streaming.

Moreover, a dedicated presentation server could be used for managing presentation description, as shown for the operator A in the figure. Alternatively, Media Server (e.g., Media Server B in the figure) or any other server can manage presentation description.

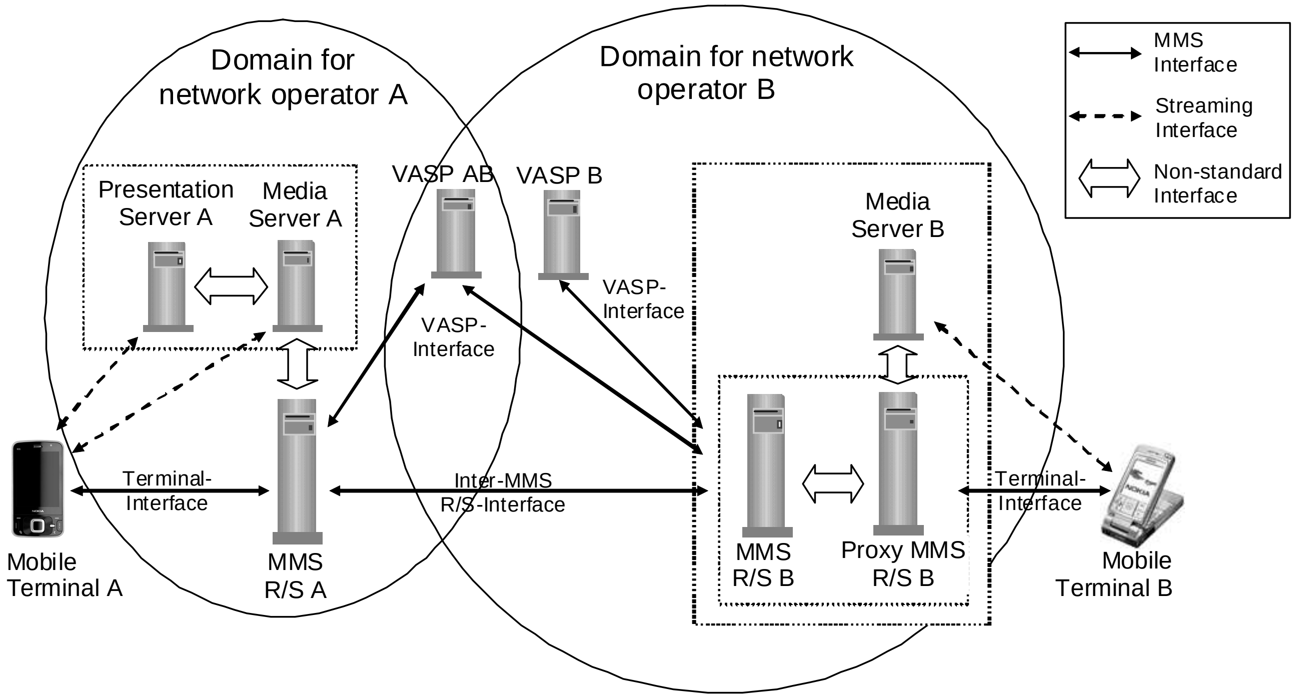

Figure 19: General network architecture to accommodate an implementation solution of the optimum interworking between MMS and streaming, providing various architectural options suitable in different practical situations.

A VASP can have individual connection (VASP-interface) with multiple network operators (MMS R/S) – VASP AB. Alternatively, a VASP can have connection with only one MMS R/S – VASP B. In the latter case, VASP provides services to the users belonging to other network operator over the inter-MMS R/S-interface across different MMS R/Ss. The former case is more useful when a VASP is providing services to different local operators (e.g., the operators within the same countries), while the latter one is useful to provide services to the users of remotely located network operators. As operators need agreements for the latter case, the approach is suitable for the friendly operators.

In summary, the general network architecture in Figure 19 covers following main aspects

- the involvement of multiple network operators,
- the use of Proxy in MMS to balance load and improve performance,
- various combinations of different MMS and streaming servers to match deployment needs,
- enable using existing infrastructure for the interworking,
- person-to-person messaging in both inter- (messaging between mobile terminal A and B) and intra-operator cases,
- content-to-person messaging (messaging from a VASP to any mobile terminal), and
- different kinds of agreements between a VASP and a network operator.

Chapter 5 MMS as a Transport for Application Data

Even with certain limitations, SMS has been used for providing different contents and services. Examples of such simple services are alerting (e.g., weather report, flight/train/bus information, news headline, lottery results, examination results, flight check-in), market campaign (e.g., feedback collection, advertisement), and real time auction [21]. Moreover, nowadays SMS is widely used for expressing opinion and interest (e.g., voting, registration). There are also growing trends of Internet services for monitoring media, alerting users, and delivering content of interest [107]. This trend provides direction for mobile communication, as the industry is heading for the harmonization of the Internet with mobile communication [9]. As a consequence MMS has evolved from person-to-person messaging to content-to-person and person-to-service messaging, described in Sub-section 2.3.2.5. In content-to-person and person-to-service messaging, MMS needs to handle the content, requiring MMS to act as the application for the additional services. Such advanced uses of MMS naturally require means for intensive user-interaction, like search, select, and customization [148]. It is very demanding for MMS to handle different services, as each service may have its own service-logic and characteristics. As there could be many value-added services, this approach of using MMS as the applications for different services can very easily overload different entities of MMS.

Rather, it is simpler and systematic, if different applications on top of MMS in a terminal handle the corresponding service; so that MMS is just used as a transport or carrier for the services, as MMS is predicted to have new role of wider data bearer for a range of other services [20]. The use of a messaging system for transporting data between applications can be considered as a new type of messaging – application-to-application messaging, where an application is the creator and the consumer of a message. Application-to-application messaging can also be considered as content-to-person and person-to-service messaging, where an application handles the service instead of the messaging UA or client. A survey found that third party application usage is a promising trend in mobile communication [27]. Application-to-application messaging is expected to help such application usage, if it requires communication. Though, the definition of a smartphone varies, having the ability of installing application is one of the common defining factors for a smartphone [42]. Increasing use of smartphone also indicates the interest for downloading applications to a mobile phone. Different aspects of using MMS for application-to-application messaging (i.e., transporting application data) are described in [P5], which is summarized in this chapter. This chapter also outlines noted research activities in this regard. As the focus is mobile communication, wireless application is mostly considered in this study, though the term application is used for brevity.

5.1 Positioning MMS for Transporting Application Data

In mobile communication, there are not many suitable options for transporting application data. Voice communication is clearly the dominant service by far in terms of traffic in the mobile communication. Beside the voice communication, the use of messaging has grown in mobile communication lately [42].

E-mail, IM, and SMS are commonly used messaging systems nowadays. Though, e-mail is very popular in the Internet, most of the deployed solutions of e-mail in mobile communication are proprietary, and the standardization works for mobile e-mail in the OMA and the IETF are not stable yet. The most of the IM solutions in the Internet are also proprietary. It is not feasible to have a new feature (like transporting application data) consistently over a non-interworking proprietary solution. Moreover, the standardized solutions of IM in the mobile communication are either not deployed much or under development. So far, the most popular mobile messaging system is SMS. The main reasons to make SMS so popular are simplicity, mobility, low price, and ability to work with any mobile terminals across any mobile network (i.e., interoperability) [20] [21]. However, it is limited in terms of both size and type of transporting data, and thus not suitable in this regard.

Transporting application data is relatively a new idea, and none of the above mentioned messaging systems was designed keeping this in mind. As enhancements are required for any conventional messaging service to support the feature, there should be scope for developing a messaging system accordingly. MMS is a relatively new messaging system, having scope for further development. It is standardized to carry data of wide variation and significant size. Moreover, it overcomes many noted limitations of both e-mail and SMS, as outlined in ´Sub-section 2.3.4. As most of the key vendors and operators are keen about MMS, MMS is commonly supported by a mobile terminal, and it is expected to increase with time even in the emerging markets [151]. The popularity of MMS is also expected to increase [103], [147], [148], and [151]. A subjective study also shows that users in general have positive view about MMS, anticipating increase in the popularity of the service [197]. Another detail study among 1700 users in U.S.A, France, England, Germany, and Finland shows that MMS is one of the leading multimedia communication services [17].

MMS is mostly used to deliver content immediately, though it works in store-and-forward fashion. Content adaptation and involvement of multiple hops are two noted reasons that can cause longer delivery time in MMS. However, Section 2.1 of [P5] indicates that these do not have much impact on the use of MMS for transporting application data. The same paper also shows experimental data in terms of retrieval delay of MMS messages of different size to show that MMS can serve as the transport for even time-sensitive data of reasonable size. As longer transmission time (especially across the radio interface) in mobile communication causes additional delay in transporting large data in MMS, any other service would have the same difficulty in handling large time-sensitive data. Moreover, MMS can interwork with streaming to reduce the retrieval time.

Considering all these, MMS has been positioned to transport application data. Both the 3GPP and the OMA have enhanced MMS with the feature of transporting application data. The standardization works in this regard are described in Section 5.3. The use of MMS in transporting application data is also addressed as application-to-application messaging in this dissertation.

5.2 Examples of Application-to-Application Messaging

This section provides examples of applications that require data transport over network. The first few examples reflect the market trend of deploying applications, while the rest are mostly collection of applications described in different referred publications as potential user of MMS for transporting data. As for example, interactive online games, camera and image management, location-based services (LBS), and download applications are briefly outlined below, as they are either already deployed or there is noted trend for their deployment in mobile communications. Requirements of these example applications on the possible transport are briefly analyzed in Sub-section 5.2.1.

With the advancements of related technologies, a mobile terminal can nowadays provide interactive gaming services for playing with remotely located users. Chess application is one such gaming service providing means to its user to play chess with a user of another terminal having the same application. The application can use MMS for transporting the information about different moves, made by the users on the chessboard, to its peer application. Many other interactive gaming services can use MMS for transporting data in the same way.

Though transmission of captured images seems inherent part of MMS, in true sense camera is an application that uses MMS for transporting data [106]. The way MMS is deployed nowadays, camera and image management are obvious applications that uses MMS as a transport for storing, retrieving, and distributing captured and received images.

Location service is another potential user of the data transport provided by MMS. Location service has the objective of providing information at the right place, and becoming popular across mobile networks [207]. Possible location-based services are emergency service (e.g., security alert, public safety), informational services (e.g., news, sports, weather, stock market, navigation), tracking services (e.g., resource monitor, person tracking), and entertainment services (e.g., locating friends, games) [207]. Usually, a location server over a VASP acts as a peer application for the location application in a terminal for providing these location-based services. MMS can transport location information between the location application and location server. Potential location data that can be transported are map, coordinate (position information) of a place of interest - also known as landmark (like gas station, restaurant, home), search result for any location service. Examples of location based MMS messaging are available in [208], where MMS messages are delivered to a user based on her location. Here, a message can carry different location-related information, like notification about a nearby event or place of interest, reminder about doing something due to proximity of the subjected place, and nearness of a person of interest.

Similarly, download application in a terminal can use MMS for downloading any content from a download server that acts as the peer application. In this case, the download application can download, as for example, a media object, a media codec, a new application, plug-in for any existing application, or virtually any content. Downloading third party application to a smartphone is already a noted trend in mobile communication [27].

Reference [151] describes another example, where MMS transports the data for a museum guide service. When a user is moving inside a museum, the service provides multimedia information (image and voice) of the exposition approached by the user. Here, the location of a user is determined by different Bluetooth-enabled devices.

Another potential use of MMS for transporting data is described in detail in [209]. The main idea is to retrieve information (e.g., template, images) from mobile sensors in terms of an MMS message. The reference defines a framework to provide web-based access to the information provided by the distributed mobile sensors. It uses XML-based control description to request for specific information from sensors.

One more example of application that requires data transport is group collaboration application in office work, where introduction update of any office activity can be achieved [210]. A form-based framework is proposed to encapsulate the right information in a structured format, so that application data can be transported over MMS in a systematic manner.

An automated service for multimedia content monitoring and alerting is described in [211]. The alert, in this regard, is generated based on user profile, and can be delivered over MMS using the application data transport feature.

The purpose of using MMS as data transport varies, and can be even sophisticated like healthcare, where increasing use of tele-presence is bringing new dimension in the whole content [212].

Applications that can be supported by MMS for transporting data are categorized in [102] – mobile-to-mobile (e.g., sending/receiving photos, voicemail, business cards), web applications to mobile (e.g., sending post card, greeting card, advertisement, news, maps), and Internet to/from mobile (sending/receiving e-mail).

These are just a few examples of application-to-application messaging, and the feature can be used for many different purposes, as there could be numerous applications in the mobile enterprise space, requiring means for transporting its data.

5.2.1 Requirements of the Example Applications on MMS

Sub-section 2.3.2.5 already points out a few requirements on MMS to enable its use as application data transport. In all the examples of application-to-application messaging in Section 5.2, data is destined for a specific application for processing (e.g., decryption, decode, storage, rendering, screening), as only the destination instance of the application knows the proper way to process data. From this respect, the important requirements on MMS are listed below.

1) There should be an easy and fast way to understand if a message contains application data.
2) The application data must be delivered to the destined application.
3) The application data must be delivered in the original form without any modification done by any intermediate entity used to transport the data (e.g., MMS UA, MMS R/S).
4) As an application can be interactive (e.g., chess game), there must be an easy and effective way to send response back to the appropriate application.
5) Maintaining multiple parallel channels of communications between the same peer-applications would be also required by some applications (e.g., downloading two separate applications from download server at the same time, playing chess games in parallel sessions).
6) There should be means to provide application-specific information (e.g., credentials to authenticate an application, if required).

As MMS has been deployed widely without supporting application-to-application messaging, it is also required that MMS solutions with and without the support for application-to-application messaging are compatible to each other; so that they can co-exist in harmony. An MMS-capable terminal, not supporting the feature, may behave unexpectedly when it receives a message containing application data. An MMS deployment, supporting this feature, should be backward compatible with the existing MMS deployments not supporting this feature. The new feature should also be forward compatible, so that an MMS UA supporting the feature can start transporting the data for any new application. Without a solution for backward and forward compatibility, the deployment of the feature would not be smooth, and the development of an application would be dependent on terminal manufacturing.

Moreover, it would be useful if the format of data communication between an application and MMS is easy to implement and commonly agreed. It would also be beneficial to have agreement about what data should be communicated between an application and MMS to ensure optimum use. Such agreements would be useful for any downloaded application that starts using MMS for its transport on the fly. Having a common agreement in this regard would also help in making an application available independent of the manufacturer of a terminal.

5.3 Related Standardization Works

The basic functionality for using MMS as the transport of application data has been already standardized in the 3GPP and the OMA. The standardization work done in this regard is mainly in terms of extending the MMS architecture to cover application and application interface, and defining three top-level MMS headers, as described in Sub-section 2.3.2.5. The standardized headers meet the demand of all six requirements listed in the first paragraph of Sub-section 5.2.1.

Figure 3 of [P5] shows different layers of communication for using MMS as the data transport between peer applications in a simplified scenario, where the terminals belong to the same MMS R/S. Figure 20 shows similar vertical interactions in both MMS UA and MMS R/S in terms of different layers to achieve data transport between peer applications residing in two different terminals belonging to different MMS R/Ss (i.e., operators).

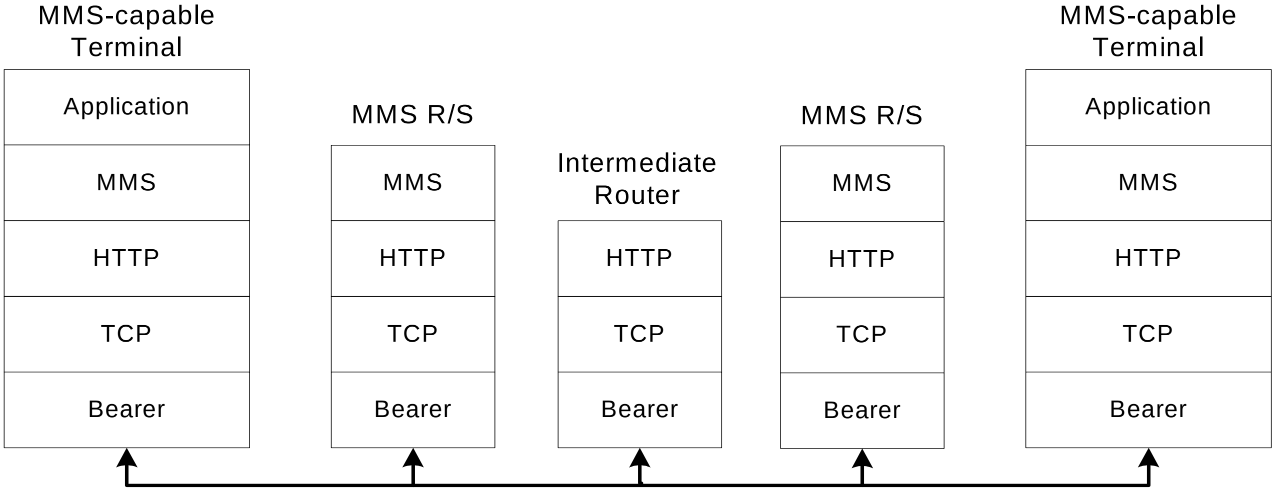

Figure 20: Different layers of communication in MMS UA and MMS R/S to achieve data transport between peer applications in multiple operator domains.

Beside the standardization works in the 3GPP and the OMA, described above, the Java Community has defined another solution to include identity of an application within an MMS message [152]. In this solution, both the identities of the originating and recipient applications are included as parameters of the MMS top-level header `content-type` (see Figure 8 in Sub-section 2.3.2.3). This solution was defined quickly for the early deployment of the feature, as it may take more time to standardize the new headers in the OMA and the 3GPP. It is expected that this quick solution would be used in the near future, when the robust solution of three-headers defined by the 3GPP and the OMA is still under development.

5.4 Compatibility Requirements and Solution

The requirements in term of backward and forward compatibility are already outlined in the second paragraph of Sub-section 5.2.1. The requirements are described further in Sub-section 5.4.1 in terms of the background problems, to emphasize the importance of compatibility. A solution of the compatibility requirement is provided in Sub-section 5.4.2. Sub-section 5.4.3 briefly indicates about the recognition of the solution by the internationally acknowledged standard development organization and patent office.

5.4.1 Problem Statement

Only the recipient application is supposed to know how to handle (e.g., storing, screening, decoding, digital rights management, adaptation, rendering) application data. In application-to-application messaging, MMS is simply a transport, and the recipient MMS UA is supposed to handover the content of a message carrying application data to the right application based on the top-level headers defined for the feature, as described in Sub-section 2.3.2.5. However, if an MMS UA does not support application-to-application messaging, it may treat a message, carrying application data, like a normal message by ignoring the newly defined headers. As handling of a received message by an MMS UA is mostly implementation-specific, there is no guarantee about what the MMS UA is going to do with the content of the message. As for example, it may present the data in an unexpected manner, causing poor user-experience. Moreover, the MMS UA may violate the legal constraints (e.g., digital rights, copyright) associated with the content. Reference [P5] provides specific example how legal constraints can be violated. Poor user experience and violation of legal constraints are just two example consequences of backward compatibility. In practice, the consequence cannot be really predicted, as the behavior of an MMS UA in this regard is not standardized, as mentioned before. This is a potential problem, as there are many MMS-capable terminals in the market not supporting the feature. Moreover, any new MMS-capable terminal not supporting the feature may also face the same problem, as supporting the feature is optional from MMS specification point of view [122], [124], [125], and [126].

Beside backward compatibility, forward compatibility can become also an issue. Say for example, an MMS-capable terminal supports application-to-application messaging. The terminal is deployed with the support for specific applications that it contained during the deployment. After its deployment, a new application can appear in the market. If the terminal is not forward compatible with the new application, it is possible to have the similar consequence described in the previous paragraph, when the terminal receives a message that carries the data for the newly deployed application.

It is not only risky to provide an MMS message with unsupported application data to a terminal, the transmission of such a message to the terminal also misuses the expensive radio interface, as the message is not going to be useful for the terminal.

5.4.2 The Solution

The possibility of mishandling an MMS message, carrying unsupported application data, can be avoided, if the message is already rejected in the network, and not delivered to the terminal. Such rejection also ensures that the radio resource is not misused due to unnecessary delivery of the message. This is the main idea behind the solution to the compatibility problems. The recipient MMS R/S, to be able to reject an MMS message safely, needs to know about both the application whose data is carried in a message and if the application is supported by the recipient of the message. The MMS R/S can easily identify the application from the top-level new header defined for the feature, described in Sub-section 2.3.2.5. However, the question is how it knows if the application is supported by the recipient.

MMS already has a standard way of capability negotiation between the recipient terminal and the recipient MMS R/S, as described in Sub-section 2.3.2.5. A recipient MMS UA indicates about its supported capabilities each time it sends a request for retrieving a new message. Example capabilities that an MMS UA can indicate are supported media types/formats, character sets, resolution, and languages. The recipient MMS R/S can adapt the message based on the terminal capabilities, before it delivers the message to the terminal. Deletion of the whole message is also a kind of adaptation in MMS. MMS uses UAProf [213] for this capability negotiation. Both the standard and non-standard, based on User-Agent header [214], way of capability negotiation in MMS are described briefly in [P5].

The solution of the compatibility problem proposes to add following two items in the list of capabilities that an MMS UA advertises:

- if the MMS UA supports the new feature of transporting application data, and
- if supported, the list of supported applications by the MMS UA.

The addition of these two items allows the MMS R/S to know if the application, whose data is carried by an MMS message, is supported by the recipient. If the recipient does not support the feature or the application, the MMS R/S can reject the incoming message. Upon rejecting the message, the MMS R/S can send an empty *MM Retrieve* message to the recipient, indicating the reason for the rejection. The reason is expressed as values for the `X-Mms-Retrieve-Status` and `X-Mms-Retrieve-Text` headers, which carry codepoint for MMS UA and human-readable texts for a user respectively [126]. Though both the standard and non-standard way of capability negotiation can be used to advertise these newly proposed capabilities, the UAProf-based standard approach is more suitable in this regard, as it provides the scope for advertising capabilities dynamically, which could be useful to indicate about the support for a new application on the fly.

Beside overcoming the possibility of misusing the radio interface, this network-based solution of the compatibility problem does not also require much from a terminal, allowing efficient use of its limited power. Moreover, it provides more control to the network operators by providing a means for forbidding the data transport for any suspicious or unknown application.

The solution described in this sub-section meets the demand of the requirements outlined in the second paragraph of Sub-section 5.2.1.

5.4.3 Recognition of the Solution (Standardization and Patent)

The solution described in Sub-section 5.4.2 was analyzed by both the 3GPP and the OMA for standardization. The solution was agreed, and became part of MMS specification in essence [122]. However, only the first item of the proposed capabilities was added in the standard [125]. The main reason for not including the second item is possible increase in complexity, processing time, and storage space in an MMS R/S for storing the lists of supported applications for all its users and checking each message against the list. As the number of supported applications by an MMS UA can grow without any limit, the time and effort required by an MMS R/S for checking the recipient application against the applications in the list may become critical.

The main idea of the standardization is - an MMS message containing application data would be discarded by the MMS R/S only if the recipient does not support the feature. If the recipient supports the feature, the MMS R/S does not check if the recipient application is supported by the recipient. Rather, it is expected that the MMS UA would discard an MMS message, if it carries data of any unsupported application. This way, the standardized solution makes a balance between the complexity in an MMS R/S in one side and complexity in a terminal and efficient use of radio resource in the other side.

The solution has been also granted and published as a patent [215]. The scope of the granted patent is much wider than the standardized solution or the solution described in Sub-section 5.4.2. As for example, the solution in the granted patent has two alternative approaches – based on one or two items in the list of capabilities. Moreover, the patented solution offers multiple options for handling a message that contains application data not supported by the recipient – reject, modify, and redirect. Besides, it indicates the use of user setting or the configuration of a service provider to select the options from the alternatives.

5.5 Application-Interface

An application can either be incorporated in a terminal during the manufacturing stage, or it can be downloaded to the terminal at any time later. In any case, if the application wants to use MMS as a transport of its data, it needs to have an agreement with the MMS UA. This process is addressed as the registration of the application to the MMS UA. During this registration process, the application makes its identification available to the MMS UA, which can use it later to compare with the recipient application of a received MMS message, carrying application data. They can agree about other issues of the application-interface during the registration process, as for example,

- the data format for the communication across the application-interface and
- the specific data for the communication.

For a downloaded application some sort of understanding about the format and data across the application-interface allow an application developer to develop an application without consulting each manufacturer of the terminals where the application would function. Neither the 3GPP nor the OMA has defined anything in this regard. The Java Community Process (JCP) has defined some APIs for the interface [152]. However, the APIs are not for any general application, as those are limited for the Java applications only.

The following two sub-sections describe a common format of application data and exact data to be communicated between an application and MMS, respectively; providing solutions to the requirements outlined in the third paragraph of Sub-section 5.2.1.

5.5.1 Format across the Application-Interface

The data format across the application-interface is expected to be simple for various reasons mentioned in [P5]. As the communication between an application and an MMS UA does not involve any network-level transport or transmission, the format does not require considering these issues. The format should be flexible and extensible, so that it can meet the demand of different present and future applications in terms of communicating diverse required information.

It is beneficial, if any already used format in MMS can be used across the application-interface, so that the existing implementation of the format can be reused. However, none of the formats, already used in MMS, is suitable for the application-interface, based on the expectations mentioned in the last paragraph.

As for example, MIME-based binary encoded format is used for an MMS message between an MMS UA and an MMS R/S [126]. The format is quite strict and rigorous, requiring more processing power in a terminal. Using the format for multiple applications across the application-interface would require the unwelcome encoding and decoding cycles for each application while both sending and receiving a message with application data. The binary-encoded MMS message carries some headers useful for transporting and controlling purposes, and using the format across the application-interface would make those available to an application unnecessarily. Moreover, the binary code is mainly used for using the radio interface effectively, and the application-interface is not involved with such interface. The format also considers the lower-level network transport and transmission aspects, which again are not involved with the application-interface. Using the format across the application-interface can also be considered as a violation of layering principle.

SMIL is another format used in MMS to convey rendering instruction for the media contents within a message. Though, it can be easily parsed, as it is based on XML, it is designed dedicatedly for presentation purpose; hence it is not extensible, and not suitable across the application-interface.

MMS also uses SOAP across the VASP-interface [122]. It is also XML-based, extensible, and designed to work over protocol like HTTP. The encoding in the SOAP is designed to meet the demand of lower-level transport protocol; hence it is more like a protocol option, and again not that suitable format across the application-interface.

XML is a general markup language defined for describing information in a consistent way. It is different from the XML-based formats, mentioned above, in different aspects. As for example, XML is not dedicated for any application or use, unlike some markup languages (e.g., SMIL, HTML). XML can be easily extended in a systematic way in terms of new elements and attributes, making it useful for any new purpose. As it is text-based, XML is simple in terms of parsing. Nowadays, XML or XML-based formats are used for so many different purposes, that it is highly likely that a terminal has to support it in any case. Therefore, XML is able to meet the expectations of the application-interface.

Now, let us see how XML can describe the specific information across the application-interface. It is expected that application data is meta-information and/or media content. When forming an MMS message with application data, the meta-information and media content would be transformed to multimedia information (header) and multimedia elements of an MMS message respectively. It is not required that media content is sent across the application-interface. Rather, referring to the content based on a local identification within a terminal is enough. Both an application and an MMS UA reside in the same terminal, and it is assumed here that both have access to a common storage in the terminal. The identification of media content can be described in terms of an element or an attribute within an XML document. Similarly, the meta-information can be described in terms of elements and attributes within an XML document. The rules for these new elements and attributes of XML are usually defined in terms of schema and/or Document Type Definition (DTD); so that an XML document is created in a consistent and inter-workable manner. Thus, XML has means to describe the application data across the application-interface. Moreover, it is easy to construct an MMS message based on the application data described in an XML document, and vice versa.

As XML meets different demands of the application-interface, it is considered as the suitable data format for the communication between an application and MMS across the application-interface.

Beside using across the application-interface, XML could also be used as a common format to describe the components of a multimedia message for other purposes. As for example, a content provider can provide an XML file as a template for messages. The templates can be stored in a terminal or in a smart card at manufacturing or subscription stage, respectively; so that a user can use it for creating a multimedia message. Moreover, an XML document can also be used to store a multimedia message in a device or a memory card that does not fully support all the functionality of an MMS UA.

If an application has limited storage space or slow access, the overhead of an XML document may appear verbose. An application in a smart card within a terminal may have such problems. Subscriber Identity Module (SIM) or Universal Subscriber Identity Module (USIM) application in a Universal Integrated Circuit Card (UICC) is an example of such application. In binary XML, the components of an XML document are binary encoded to make efficient use of storage space or transmission rate. Binary XML can be useful in this situation. The OMA (formerly WAP Forum) defined binary values for some then available components of XML [216]. As the use of XML across the application-interface requires new elements and attributes, existing binary XML definition is not enough.

5.5.2 Data across the Application-Interface

It is indicated in the previous sub-section that XML is capable of describing the data across the application-interface. As all the MMS headers are not useful in the application level, only a subset of MMS headers is communicated across the application-interface. Reference [P5] includes two example XML documents to show what MMS headers can be useful in the application level – one for related contents and the other for independent contents. The reference also describes different XML elements and mapping of the elements with the corresponding MMS headers. MMS messages created based on the example XML documents are also shown in the same reference in text format.

Data flow in terms of XML documents across the application-interface is bi-directional, if the corresponding application uses MMS for both sending and receiving data. If an application wants to send data to its peer application, it generates an XML document, which includes meta-information and reference for the media contents to be sent. The application also makes the media contents that are referred from the XML document available in a common storage within the terminal. The XML document is then communicated to the MMS UA across the application-interface. Upon receiving the XML document, the MMS UA constructs an MMS message that includes the meta-information as headers and the referred media contents as multimedia elements. The MMS message is then transported to the recipient MMS UA that resides in the terminal that also hosts the recipient application for the data. Upon receiving the message, the recipient MMS UA understands from the top-level MMS headers that the data within the message is for a specific application. It constructs a similar XML document that includes the useful headers and references of the media content within the message in terms of XML elements and attributes. It also stores the media contents in a common storage, and sends the constructed XML document to the recipient application across the application-interface, so that the data is consumed by the application as intended.

Chapter 6 Summary of the Publications

The publications are summarized sequentially at the beginning of this chapter in Section 6.1 in terms of publication date (i.e., the earliest publication is described first). The sequence matches well with the subject matter of the publications. The first publication [P1] provides basis for the rest of the publications, and provides answer to mostly research question 2 (detailed and extensive conceptual evaluation of MMS) and partially research question 1 (evaluate the scope and relationship of important related mobile multimedia services) of this dissertation. Though the first publication focuses on research question 1 and 2, the other publications also provide answer to the same questions from different perspectives. As for example, the second publication [P2] points out the limitations of MMS (research question 2). It also provides partial answer to research question 3 (build solutions to overcome the identified limitations of MMS and evaluate those) by describing a conceptual solution to overcome the limitations of MMS. The third [P3] and the fourth publications [P4] provide multiple detailed solutions to overcome the limitations, and mostly answer to research question 3. The fifth publication [P5] provides answer to research question 4 (enhancing MMS to transport application data in a harmonized way) by focusing on another feature of MMS – transporting application data. This chapter also indicates the contributions of the author for each publication in Section 6.2.

6.1 Overview of the Individual Publications

6.1.1 Publication 1 [P1]

Beside having many dedicated specifications developed by multiple standards development organizations, MMS is also defined in some specifications about other subjects. This publication provides a wide picture of MMS by summarizing all important related specifications. MMS is also briefly compared with the first standardized mobile multimedia service, i.e., circuit-switched multimedia telephony. Though, both the services deal with multimedia, they are different in terms of the services they provide. At the same time, it makes a detailed analysis (based on surveying different publications including related specifications) focusing on many different important and practical aspects to find out the feasibility of MMS in the evolving wireless infrastructure. The main aspects of MMS considered in the analysis are end-to-end network architecture involving different entities and interfaces, structure and encodings of a message, different key features and functionalities, and end-to-end information flow across different interfaces for the whole chain of content delivery. The analysis indicates that MMS is defined with not only the positive features of other existing equivalent messaging systems (e.g., SMS, e-mail), but also some new demanding features.

6.1.2 Publication 2 [P2]

This publication makes further analysis about MMS in terms of different aspects including comparing it with both e-mail and SMS. Despite identifying many advantages of MMS in the extensive analysis, it also finds a limitation in MMS – inability to handle a message requiring more storage space than available in a terminal. Being a real-time service, streaming has an ability of managing storage space efficiently. This publication proposes the interworking between MMS and streaming to overcome the limitation visible in MMS. This publication also makes a background study about wireless streaming, as defined by the 3GPP, in terms of end-to-end architecture, related protocols, and involved information flow. Based on an analysis, this publication gradually reduces the extent of the interworking to find the optimum scope of the interworking – use of streaming in retrieving an MMS message across the recipient terminal-interface. Based on the studies about both MMS and streaming, this publication presents a framework as a simplified conceptual solution for the optimum interworking. The framework splits the whole interworking activities into 3 phases – media upload, streaming indication, and streaming retrieval. The second phase (i.e., streaming indication) is the essence of the interworking, as it links MMS with streaming. Different important factors considered in the publication in defining the interworking framework are backward compatibility, complexity, practical demand, implementation flexibility, economic feasibility, and user friendliness.

6.1.3 Publication 3 [P3]

This publication continues describing the work about the interworking between MMS and streaming. It extends the conceptual solution introduced in Publication 2 [P2] to provide two concrete and detailed implementation solutions for the optimum interworking between MMS and streaming. In the first solution, the streaming indication is brief in terms of a URL and carried over the MMS *Notification* message. The streaming indication is more descriptive in terms of a presentation description, and carried over the MMS *MM Retrieve* message in the second solution. Both the solutions are designed considering different important aspects of both MMS and streaming, like framework, working principles, message structure, and information flow. The solutions are consistent and compatible with the existing solutions already deployed in the markets. The publication also compares the solutions with each other in detail in terms of different important factors like content adaptation, creation and generation of presentation description, capability negotiation, handling of non-streaming (static) content in an MMS message, and retrieval of all the headers of an MMS message. The comparison indicates that none of the solutions is completely superior than the other, though the second solution has more number of advantages. The solutions and their comparison were also studied in the 3GPP, and the second solution was accepted and included in the MMS specifications in terms of support for streaming in MMS.

6.1.4 Publication 4 [P4]

The extended work done about the interworking between MMS and streaming are described in this publication. Based on values found from calculations, this publication points out another limitation in MMS – long time for retrieving a large multimedia message. It also indicates that the optimum interworking between MMS and streaming can be also used to overcome the limitation. The third solution for the optimum interworking is introduced in this paper. In this solution, the streaming indication is in terms of a URL like in the first solution, and it is carried over the MMS *MM Retrieve* message like in the second solution. Like the previous solutions described in the Publication 3 [P3], this solution is also consistent with the existing solutions of both MMS and streaming. This new solution is also compared in detail with the previous solutions in this publication. While comparing, this publication shows examples of text-based MMS messages, where the new and previous solution are applied. The comparison indicates that the new solution has many advantages over the previous solutions, though in a few cases the previous solutions were found better. This publication also shows a general end-to-end architecture for accommodating the implementation solution of the optimum interworking. Different important factors (e.g., person-to-person messaging, content-to-person messaging, interworking between multiple operator networks, scalability and load balancing, and agreement between a content provider and a network operator) are considered in designing the architecture; so that it is flexible and feasible for different practical situations.

6.1.5 Publication 5 [P5]

The subject of this publication is the lately standardized MMS feature of transporting data between peer applications. First of all, it makes an analysis about the feasibility of using MMS for transporting application data. The analysis, backed-up by some calculations, indicates that MMS (e.g., its working principles, message structure and format, information flow, scope and status of standardization, market situation, and prospect) is suitable for the feature. Then, it makes a background study to find out what is defined for the feature in the MMS specifications defined by the OMA and the 3GPP. The study reveals that not all important aspects of the feature are standardized. This publication proposes a solution for the backward compatibility, so that a new MMS solution, supporting the feature, can be smoothly and easily deployed among the existing MMS solutions, not supporting the feature. The same solution also provides a solution for forward compatibility, so that a new application can start using any existing MMS solution, supporting the feature, for transporting its data at any time. Moreover, based on an analysis over some possible formats, this publication finds that XML is the suitable data format for the communication between an application and an MMS UA in a terminal. It also shows some example XML documents and the corresponding MMS messages in text format to indicate the mapping between different components of an XML document and an MMS message. The examples also show what data should be communicated between an application and an MMS UA.

6.2 Author's Contribution to the Publications

The author of this dissertation is the sole author of all the publications outlined above. The author contributed for all the findings and outcomes of the publications. Innovation building and evaluation of selected topics of mobile multimedia communication services are the main research contribution of the publications. Acceptance of different proposed innovation in standard and patent indicates acceptability, usefulness, and novelty of the contributions.

Standardization provides an open way of developing and managing technologies by picking the right solution from different possible proposals. The author actively participated and provided significant contribution in the standardization of MMS in the 3GPP, the WAP Forum and the OMA. Standardization activities are mostly based on study, finding and contributing solution, discussion, review, debate, and agreement. Beside finding technical solution and contributing the same on behalf of his employer, the author also reviewed the proposals from other contributors representing different key vendors and operators involved in mobile communications. He contributed solution 1 of the interworking between MMS and streaming, described in Section 4.1 and [P3] to the 3GPP, and the contribution was accepted. Later on, he contributed solution 2, described in Section 4.2 and [P3], to the 3GPP, and this was also accepted in place of solution 1. He also made significant contribution for developing the solution for the MMS feature of transporting application data. The solution of compatibility problem in this regard, described in Section 5.4.2 and [P5], was contributed to both the OMA and the 3GPP, and the solution was partially accepted in both the bodies, as outlined in Sub-section 5.4.3. The author also participated in the standardization of call control of circuit-switched multimedia telephony in the 3GPP before.

Chapter 7 Conclusions

Human beings are naturally inclined to multimedia communication for obvious reasons. With the due advancements in different fields of both multimedia and mobile communications, nowadays it is possible to have multimedia in mobile communication with reasonable quality. However, this may not be enough for a user to use multimedia in mobile communication. Suitable and useful multimedia services are required in mobile communication to meet the demand of a mobile user. Mobile multimedia service should be designed specifically considering different aspects of mobile communication, so that the shortcomings of mobile domain are not as such visible. This dissertation first provides an overview of mobile multimedia communication services by pointing out different related services and positioning them in Section 2.1. Then, this dissertation focuses on three carefully selected potential mobile multimedia services – circuit-switched multimedia telephony, MMS, and streaming in Sections 2.2, 2.3, and 2.4, respectively. Though, all these services deal with multimedia content, the type of service provided by them are different. Circuit-switched multimedia telephony, MMS, and streaming provide conversational, store-and-forward messaging, and real-time services, respectively. The discussion in Chapter 2 and referred analysis in all the publications (as outlined in Chapter 6) collectively answer to research question 1 (evaluate the scope and relationship of important related mobile multimedia services) of this dissertation.

Traditionally, human being has been using different primitive and non-digital messaging systems. With the appearance of the Internet some digital messaging systems became popular (e.g., e-mail). Mobile communications also introduced popular digital messaging system like SMS. Both, e-mail and SMS work based on store-and-forward approach. However, they cannot take the full advantages of the advancements in the mobile communications, as they have many noted limitations. MMS was designed as the solution for mobile messaging to overcome the noted limitations. This dissertation makes a detailed conceptual evaluation of MMS in Section 2.3. The evaluation includes

- assigning MMS among different types of messaging in Sub-section 2.3.1,
- in-depth description of MMS, covering all important aspects, in Sub-section 2.3.2,
- evolution of messaging in Sub-section 2.3.3, and
- comparing MMS with other important messaging solutions in Sub-section 2.3.4.

MMS is compared in detail with both e-mail and SMS in the dissertation, indicating its different advantages over both.

Mobile environment is not as friendly as wired environment for communication. Mobile terminal is also naturally limited in terms of size, handling complexity, processing power, and storage capacity. The limitations of the mobile domain are not equally visible in different types of multimedia services. This dissertation points out couple of limitations of mobile domain that are visible in MMS in Section 3.1 – handling a large message that requires more storage space than available in a mobile terminal, and long retrieval time of a large message. The discussion about MMS in Section 2.3 (as outlined in the previous paragraph) and 3.1 provide answer to research question 2 (detailed and extensive conceptual evaluation of MMS).

These limitations visible in MMS are not that way obvious in multimedia telephony and streaming services, as they work in real time, allowing rendering to start before the delivery of the whole content. Therefore, interworking of MMS with a real-time service is proposed in Section 3.2 to overcome the limitations visible in MMS.

As transmission takes place sequentially in hops in MMS, the interworking should be in terms of using a real-time service within a hop of MMS transmission. The use of a real-time service in all the hops of MMS may not be suitable, due to additional complexities and expense. Moreover, the limitations are not critical in all the hops of MMS. This dissertation finds the optimum scope (extent) of the interworking in Section 3.3 – the use of a real-time service across the recipient terminal interface for retrieving the contents of an MMS message.

The end-to-end architecture of multimedia telephony is not suitable for the optimum interworking. Moreover, multimedia telephony works over circuit-switched networks, while the transmission in MMS mostly takes place over packet-based network nowadays. Therefore, the interworking with multimedia telephony is not sensible. The architecture of streaming fits well within a hop of MMS, and the dissertation proposes the use of streaming in MMS to overcome the limitation in Section 3.4.

The dissertation first provides a conceptual solution in Section 3.4. Then, it provides three detailed implementation solutions for the optimum interworking in Sections 4.1, 4.2, and 4.3. All the solutions are consistent with the existing working principles and architecture of both MMS and streaming. The solutions are also compared in detail in Section 4.4. Based on the comparison, the third solution has more advantages, though the other solutions come out better in a few cases. The suitability of a solution in a deployment situation depends on the importance of the comparison factors in the situation. The second solution is standardized in the 3GPP in terms of support for streaming in MMS, while the first and the second solutions have been granted as patents. Section 4.6 presents a generic and flexible end-to-end architecture to accommodate the solution in different practical situations. Sections 3.2, 3.3, and 3.4 of Chapter 3 and Chapter 4 provide answer to research question 3 (build solutions to overcome the identified limitations of MMS and evaluate those).

As MMS appeared suitable, it has been lately extended in its specifications with a new feature – transporting application data, also addressed as application-to-application messaging here. This dissertation finds some practical issues with the feature, and proposes solutions to fix those in Chapter 5. First of all, this feature must be backward compatible with the existing deployed MMS solutions. A solution is proposed in this dissertation to make the feature backward compatible in Sub-section 5.4.2. The proposed solution also makes the feature forward compatible, so that any new application can start using any MMS solution supporting the feature any time. The solution is standardized partially in the 3GPP and the OMA, while it has been granted as a patent. The format and specific data for communication between any application and MMS are also not defined in MMS specifications. Clear understanding about these between an application and MMS is important to allow independent development and deployment of applications from the development of a mobile terminal. Beside enhancing the use of MMS, this should help in having more multimedia applications in mobile communications. Based on a study, this dissertation proposes the use of XML as the format in this regard in Sub-section 5.5.1. It shows some example XML files to show what data should be communicated between an application and MMS in Section 5.5.2. As a whole, Chapter 5 provides answer to research question 4 (enhancing MMS to transport application data in a harmonized way).

While analytical and descriptive methods are used in the innovation evaluating approaches of the research questions of this dissertation, use of other methods (e.g., experimental, testing) in this regard would provide complementary information, and hence they are potential scopes for future studies.

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MMS – THE MODERN WIRELESS SOLUTION FOR MULTIMEDIA MESSAGING

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Abstract - MMS provides multimedia messaging solution to contemporary and evolving wireless communications. Both SMS and Email have been widely used for messaging in wireless and fixed networks respectively, but none of these is capable enough to fulfill the present and the future demands of wireless messaging. None of the existing messaging systems can also take full advantages of the recent technological advancements in wireless communications. MMS has been designed both in 3GPP and WAP Forum to overcome the known limitations and shortcomings of the existing messaging systems. MMS utilizes the capabilities provided by WAP, GPRS and 3G, which offer efficient use of radio resources and improved connectivity. This paper makes an analysis over MMS by pointing out its features and functionalities. Architecture, message structure, encoding, information flow and transport of MMS come gradually under scrutiny in this paper both from standardization and implementation point of views to find feasibility of MMS in the target wireless infrastructure. According to the comparative study made in this paper, MMS is not only equipped with the positive features of existing messaging systems, but also with some new ones. A predictive study is also made in this paper to outline different expected MMS-based services.

Keywords – Multimedia Messaging Service (MMS), Mobile Multimedia, Standards and Protocols, Applications and Services.

I. INTRODUCTION

Multimedia Messaging Service (MMS) is a natural evolution of Short Messaging Service (SMS). SMS [1] has been very successful in the 2nd Generation (2G) of wireless communication systems. Still, SMS has both limitations and shortcomings. MMS, with richer contents and improved content creation and display capabilities, can provide much more than what SMS can provide. Email is a well-known messaging service mostly used over the fixed networks like Internet. Naturally, Email is also limited in working effectively across wireless interface. Both SMS and Email work off-the-line, meaning simultaneous end-to-end connection is not required in either case. Rather, connections are made gradually on successive hops to achieve end-to-end transmission. MMS works on store-and-forward approach. Thus, MMS resembles to both SMS and Email in terms of the basic principle of working off-the-line. Though kept similar in basic working principle, MMS is designed to overcome known limitations and shortcomings of both SMS and Email, making it suitable and effective to work over contemporary and evolving wireless infrastructure, fulfilling the market demands of wireless messaging. MMS could be used for both immediate delivery and delivery during any pre-defined time period. MMS can interoperate with Email and other messaging systems, so that an MMS-capable wireless terminal can send an MMS message to an Email account and vice versa. Thus, MMS combines mobility and totality with richer contents, and considered to be a powerful application in Wireless Application Protocol (WAP), General Packet Radio Service (GPRS) and the 3rd Generation (3G) of wireless communication. MMS is a bearer independent service, and thus, should work over the 2G infrastructures as well. An application becomes meaningful to the users when service providers provide supporting service. So, MMS is a service from service provider point of view. MMS could be used for providing other services besides messaging, which is further discussed at the end of this paper.

MMS has not been focused in any publication like this. A comparative study between MMS and other messaging systems has also been missing. This paper makes an analytical study over MMS by both pointing out its new features and functionalities and comparing it with other well known messaging systems working on the same basic principle. The paper also tries to find the association of different features of MMS with the characteristics of wireless terminals and transmission. Scope of the paper includes scrutinizing MMS in terms of architecture, message structure, encoding, information flow and transport from both standardization and implementation point of views. The paper also briefly tells about studies made about finished and ongoing MMS-related standardization works and different expected uses of MMS.

Multimedia is a relatively new technology in wireless communication. The 3rd Generation Partnership Project (3GPP), responsible for standardizing GSM-based 3rd Generation (3G) wireless communications, started working with multimedia technology in 1999. The 3GPP became involved with multimedia technology when it started defining multimedia telephony, which is also known as video telephony. Multimedia telephony is a multimedia application, which provides real-time multimedia communication between connected end-users. 3GPP already defined multimedia telephony for circuit switched wireless networks. Multimedia telephony for circuit-switched wireless networks is described in [2] and [3] in terms of terminal requirements and interworking respectively.

Performance of a simulated multimedia telephony implementation over circuit-switched Wideband Code Division Multiple Access (WCDMA) networks is described elaborately in [4]. Multimedia telephony has a fundamental similarity with MMS - both multimedia telephony and MMS deal with transmission, processing, storage and presentation of multimedia in wireless infrastructure. So, advantages and complexities of multimedia communications, as described in [2], [3] and [4], are equally applicable for both the applications. Though these are similar in fundamental sense, multimedia telephony and MMS are different based on how corresponding services are provided. Multimedia telephony is an end-to-end real-time application, making it a conversational application like conventional voice communication. MMS also provides means for end-to-end communication, but rather based on store-and-forward approach, where content is stored in the network before it is finally transmitted to a recipient. So, the transmission in MMS takes place in the background (off-the-line), making it a form of non-conversational communication.

MMS is expected to be a global service, standardized by both 3GPP and WAP Forum. WAP Forum is an active standardization body working to provide Internet communications and advanced telephony services to wireless terminals. The groups responsible for MMS, both in the 3GPP and the WAP Forum, work together to ensure alignment of the related specifications belonging to both the bodies. Section II of this paper tells more about MMS-specific standardization works. The section also introduces different MMS-related specifications. Section III describes the architecture of the MMS infrastructure. Different MMS entities and interfaces are introduced in this section. Information flow takes place in MMS in terms of messages. Main components of an MMS message are information element and multimedia element. An MMS message carrying multimedia elements is known as a multimedia message. More about information element and multimedia element is discussed in section IV in terms of message structure and encoding. The section also talks about addressing and media types in MMS.

Submission and retrieval of multimedia messages are the two most important functionalities of MMS. Retrieval of a multimedia message is based on a push followed by a pull mechanism – indication about a new message is first pushed to a recipient, and then, the recipient uses pull to retrieve the message. The retrieval is of two types – immediate retrieval and delayed retrieval. The pull operation takes place immediately after the push operation in immediate retrieval. Immediate retrieval provides the scope for instant delivery. It is considered as the default retrieving process of MMS. Considerable time gap between the push and the pull operations makes delayed retrieval different from immediate retrieval. Apart from the basic functionalities, MMS provides scope for additional functionalities, like terminal capability negotiation, content adaptation, address hiding, forwarding, support for streaming and sending reports. MMS provides scope for sending two different kinds of reports back to the originator of a multimedia message indicating the post-submission status of the message. These are delivery report and read report. Delivery report and read report indicate status of a multimedia message specific to delivery to and handling by the recipient respectively. MMS also provides hooks in the application level for implementing enhanced charging. All these functionalities are discussed further in section V. Section VI presents information flow required for the entire chain of a multimedia message delivery. The section also briefly states about transport used for the information flow in MMS. Standardization work is going on to enhance MMS for future releases. Section VII highlights the ongoing work in this regard. Finally, section VIII concludes the paper by indicating possible different MMS-based services.

II. STANDARDIZATION AND SPECIFICATIONS

As mentioned in section I, both the 3GPP and the WAP Forum are working for standardizing MMS, and thus, both of the standardizing bodies have their own MMS specifications. There are two main specifications dedicated for MMS in 3GPP – Technical Specification (TS) 22.140 [5] and TS 23.140 [6]. 22.140 [5] defines core functional requirements, while 23.140 [6] defines functional and technical description of MMS. The description, in 23.140, is based on high-level requirements defined in 22.140 [5]. The scope of 23.140 [6] includes functional capabilities of terminal and different network entities, service behavior, and information flow in the level of application protocol. It also defines and describes implementation protocol for network interfaces. 3GPP already finished the first and the second release, known as Release-99 and Release-4 respectively, of the 3GPP MMS specifications. 3GPP is now working for the third release of its MMS. On the other hand, the WAP Forum finished the work of its first release (1.0) of MMS. The MMS specification suits for the first WAP release includes three specifications – WAP 205 [7], WAP 206 [8] and WAP 209 [9]. All these specifications define the implementation solution of the terminal interface of MMS, making these complementary to 3GPP specifications in providing end-to-end implementation solution for MMS. WAP Forum is now working for its second release of MMS.

III. MMS ARCHITECTURE

Different important entities in MMS architecture are depicted in Figure 1. The two most important MMS entities are MMS User Agent (UA) and MMS Relay/Server (R/S).

An MMS UA, known as MMS Client in WAP MMS specifications, interacts with users. It resides on a terminal or any external device connected to a terminal. The MMS UA provides means for viewing, composing, sending, retrieving and other multimedia message controlling functions to users.

An MMS UA also interacts with an MMS R/S through terminal interface for both multimedia message transmission and control purposes. The MMS R/S is an MMS-specific network entity, which is under the control of an MMS service provider. Storage, address resolution, routing, collecting charging information, content adaptation, conversion of message format, interworking and generation of delivery reports are few important responsibilities of the MMS R/S. An MMS R/S consists of two separate logical entities – MMS Relay and MMS Server. Neither 3GPP nor WAP Forum specifies the interface between an MMS Relay and an MMS Server, keeping it open for implementation. The MMS R/S controls the functionalities of MMS by interacting with other MMS elements (e.g. MMS User Database) within the local MMS environment, other MMS R/Ss of foreign MMS environments, and other messaging systems (e.g. Email, SMS, Fax, Voice Mailbox). The MMS User Database contains user specific information, like subscription and configuration. MMS provides scope to interact with other messaging systems, and thus, MMS could be used for providing Unified Messaging System. Figure 1 shows interworking of MMS with SMS and Email as example. Protocols to be used in the interface between an MMS R/S and other messaging services are not MMS-specific, and thus, beyond the scope of MMS specifications.

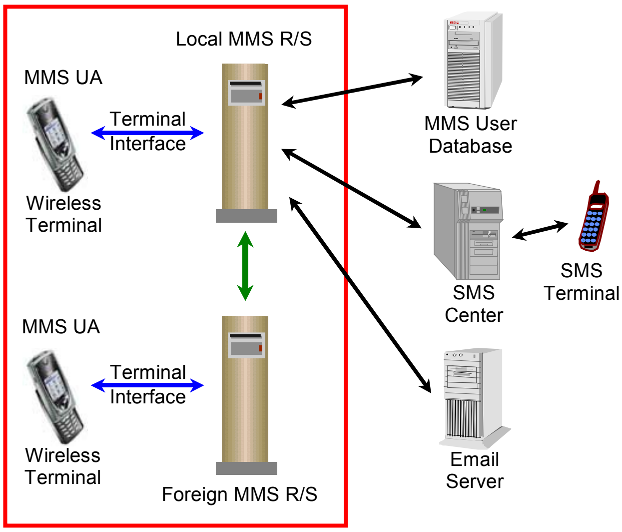

Figure 1: MMS architecture

According to the WAP MMS implementation, MMS messages that travel between an MMS UA and an MMS R/S are normally transferred through WAP Gateway. Either Wireless Session Protocol (WSP) or wireless profiled Hypertext Transfer Protocol (HTTP) is used to carry MMS messages between MMS UA and WAP Gateway, while HTTP is used between WAP Gateway and MMS R/S. WSP is a session layer protocol defined in WAP Forum to provide HTTP functionality to an interface having low-bandwidth and longer latency. Wireless profiled HTTP is a HTTP profile defined by the WAP Forum to work effectively for WAP-capable devices across wireless interface. Figure 2 shows the relationship between an MMS UA and an MMS R/S according to WAP MMS model, where terminal interface lies across wireless network and Internet. Here, WAP Gateway provides standard WAP services needed to implement MMS. These services include invoking WSP/HTTP methods, push service, over the air security, and capability negotiation. The WAP Gateway is also responsible for transcoding the transports used in either side of the WAP Gateway. The MMS R/S operates as an origin server for pull operation and push initiator for push operation, making the model consistent with WAP architecture. The WAP MMS model works over both WAP 1.x (WSP in between an MMS UA and a WAP Gateway) and WAP 2.0 (wireless profiled HTTP in between an MMS UA and a WAP Gateway) architectures. Use of wireless profiled HTTP provide means for transporting MMS messages directly between MMA UA and MMS R/S. In this case, a gateway is required in the middle only for push functionality. Moreover, a gateway in the middle could be used to provide improved performances.

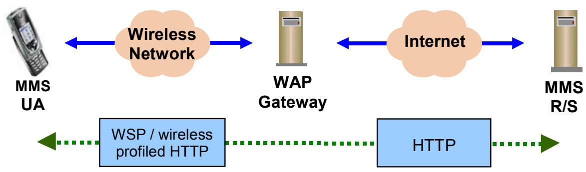

Figure 2: Interface between MMS UA and MMS R/S, according to the WAP MMS implementation.

IV. MESSAGE STRUCTURE AND ENCODING

Different types of messages are used in MMS. An MMS message may carry different information elements and various multimedia elements. Information elements consist of control information for transferring messages and information about multimedia elements to be presented to recipients. Information elements are addressed as headers in WAP MMS specifications. Some of the headers defined in WAP MMS specifications originated from standard Internet headers, while the rest is MMS specific. WAP MMS specification [9] defines binary coding of the headers and their possible values. All multimedia elements carried together in a message body are addressed as multimedia contents here. MMS uses Multipurpose Internet Mail Extension (MIME) format to combine multimedia contents with information elements. Few MMS messages carry both information elements and multimedia contents, while others are used to carry only information elements. An MMS message carrying multimedia contents is addressed as multimedia message throughout this paper, while message is used as a general term independent of its payload. Section VI discusses more about different messages used for different purposes of MMS. An example structure of an

MMS message is shown in Figure 3, where all multimedia elements are addressed together as multimedia contents. When an MMS message carries multimedia contents, application/vnd.wap.mms-message is used as the general content type for the message, as defined in [9]. Different multimedia elements are organized in the message body of a multimedia message, as shown in Figure 3. Each multimedia element is carried as a body part of the message body, and described by its media type as the value for the content type of the body part. These MMS messages are usually carried as a payload of Protocol Data Unit (PDU) of the underlying layer. Examples of content type of PDU in the underlying layer (WSP, wireless profiled HTTP, HTTP) carrying MMS message are multipart/related and multipart/mixed.

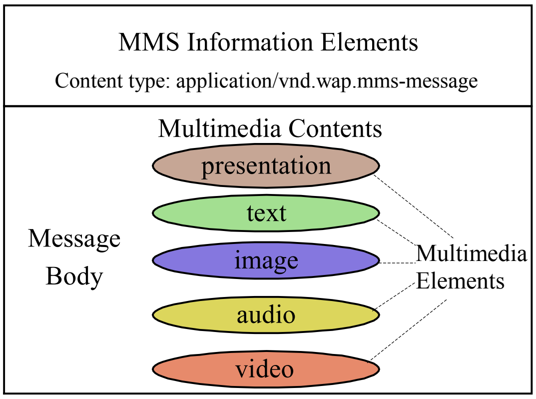

Figure 3: Example of an MMS message structure.

Information elements carry various informations depending on the type of the message carrying those. Important information carried by information elements are message type, version number, identifications, time stamp, addresses, subject, message class, priority, validity period, request for reports, request for address hiding and content type. Address specific information elements, pointing both originator and recipients of a multimedia message, are very important for MMS messages. Address is used for routing and tracking of multimedia messages and presenting before users. Default addressing scheme in MMS is MSISDN, though the use of Email address is also possible according to MMS specifications. Addressing model in MMS allows only one user in a terminal.

Optional presentation element as a part of multimedia contents, as shown in Figure 3, makes MMS much more user friendly when multimedia elements, in a message body, are related. Presentation element specifies the mechanism how a multimedia message is presented to the user. The element guides the user while viewing a multimedia message, requiring less user interaction. Synchronized Multimedia Integration Language (SMIL) is a very good example of such presentation technique to be used for the presentation of multimedia messages. The SMIL provides extended capabilities, such as timing of multimedia objects, synchronization, and animation. The media type of a single media element is identified by its appropriate MIME type, whereas the media format is indicated by its appropriate MIME subtype. Theoretically, multimedia elements may be of any content type. In order to guarantee compatibility between terminals, 3GPP specified minimum set of mandatory media formats for different media types for MMS. For example, AMR, JPEG and H.263 are such mandatory media formats for speech, image and video respectively. File format is an important component for transporting and storing dynamic multimedia elements. 3GPP also specified MP4 as a minimum requirement for supporting file format for dynamic media in MMS.

V. FEATURES AND FUNCTIONALITIES

As mentioned in section I, retrieval of a multimedia message is based on a push followed by a pull operation. The push is known as notification in MMS language. The notification, carrying a summary of a multimedia message, indicates a recipient about a new message. The recipient sends a request for retrieving the multimedia message, upon receiving the notification to initiate the pull operation. The pull operation completes when the multimedia message is sent to the recipient in response to the retrieve request. The recipient may also reject the multimedia message after receiving the notification. Besides submission and basic retrieval functionalities, MMS also provides scope for some other advanced functionalities, like address hiding, delayed retrieval, delivery report, read report, terminal capability negotiation, forwarding of multimedia messages without prior retrieval, support for streaming, and flexible charging. Few of these functionalities are mandatory requirements in MMS specifications, while others are optional. Important functionalities are briefly described below.

Address Hiding: Address hiding means hiding originator's identity (address, name) from recipients. An originator can request for such address hiding while submitting a multimedia message. If requested, the MMS R/S should not provide originator's identity to recipients. The MMS R/S is also responsible for removing originator's identity while routing a multimedia message to any unknown network entity, which is not reliable in terms of supporting address hiding. If for some special reason, like restriction in local or national legislation, address hiding is not allowed, the MMS R/S rejects any submitted multimedia message requesting address hiding. The MMS R/S is responsible for indicating the originator about such rejection.

Delayed Retrieval: Upon receiving the notification, the recipient may be able to retrieve the multimedia message at some later time before it expires. This is known as delayed retrieval in MMS. How long an MMS R/S should store the multimedia message before it is finally retrieved is an implementation issue, and thus, defined by certain service provider. The delayed retrieval should be useful for users who are roaming or when a recipient terminal is in the crisis of storage space.

Delivery Report: Delivery report is generated by the MMS R/S and sent back to the originator to indicate the status (e.g. delivered, rejected, expired) of any multimedia message in terms of delivery. The originator can request for a delivery report while submitting any multimedia message. The recipient, while retrieving the multimedia message, can deny the generation of the report. Delivery report is a mandatory functionality according to MMS specifications.

Read Report: According to this functionality, a recipient indicates the originator with the status of the multimedia message in terms of reading (handling). Read report is an optional requirement for MMS. The originator can request for a read report while submitting a multimedia message. The recipient can generate such a report depending on if a read report is requested and the functionality is supported in the recipient terminal. Considering the complexity for implementing read report and trivial use case, support for read reporting is not expected in the early commercial systems of MMS.

Terminal Capability Negotiation: It provides means for harmonizing different MMS-capable terminals. According to this functionality, a recipient indicates the capabilities of its terminal while requesting for retrieval of any multimedia message. Associated MMS R/S may adapt multimedia contents of a multimedia message to make those consistent with the received terminal capabilities before responding to the request for retrieval.

Forwarding without prior Retrieval: The recipient can also request for forwarding a multimedia message, which is still not retrieved, after receiving the notification. So, the recipient is not allowed to change multimedia contents of the multimedia message while requesting such forwarding. The functionality is not defined in the first release of MMS. So, the support for forwarding is not expected in the early commercial systems of MMS.

Support for Streaming: The support for streaming in MMS is limited only to the retrieval of streamable multimedia elements of a multimedia message. An MMS UA is not expected to execute streaming by itself. Rather, the scope is to invoke any streaming capable application in the recipient terminal to take over the responsibility of retrieving selected multimedia elements by streaming. Early systems of MMS are not expected to provide support for streaming, as general streaming is not yet operative in wireless networks.

Flexible Charging: MMS does not provide charging solution. Rather, it provides means for indicating and collecting information about different charging schemes (prepaid and reply-charging) in the application level. An originator may be able to take over the charge of sending a reply to the originator (reply charging). MMS also provides means to indicate the limit of such reply in terms of size and media type. Moreover, a prepaid user may be charged for using MMS from pre-paid credit. The MMS R/S rejects the submission and the retrieval of multimedia message, if the user has insufficient credit. The MMS R/S is responsible for indicating the user for such rejection.

VI. INFORMATION FLOW AND TRANSPORT

Flow of information in MMS is described in terms of abstract messages and PDU in the specifications of 3GPP and WAP Forum respectively. The same entity is addressed as messages in this paper. These messages are used to carry different information elements, and sometimes also multimedia elements, as mentioned in section IV. Figure 4 shows an example of information flow in terms of different MMS messages. The figure covers the whole chain of multimedia message (MM) delivery. The names of the messages used here are simplified form of what is used in MMS specifications.

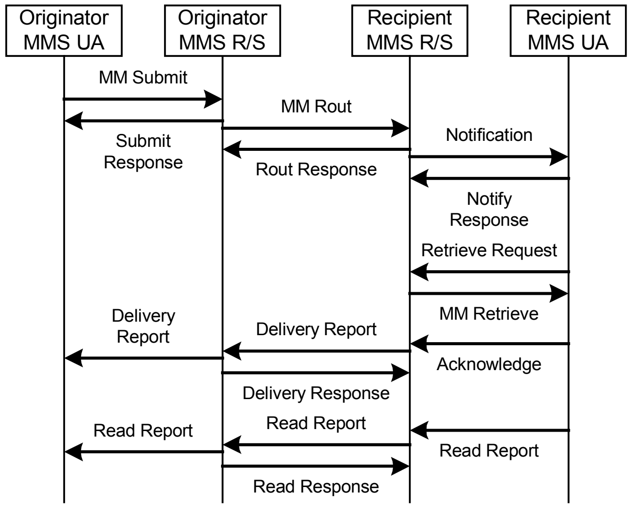

Figure 4: Example of MMS message flow for the entire chain of multimedia message (MM) delivery

An originator submits multimedia contents for delivery by sending MM Submit message to the originator MMS R/S. The message is carried over either WSP Post or HTTP Post message in the lower layer of the WAP MMS. The message includes different information elements and multimedia contents, and hence, addressed as MM. Upon receiving the MM Submit the MMS R/S evaluates it, and accepts the MM if it finds the MM valid. It may reject the MM if it finds invalid recipient address, or if the MM mismatches or contradicts with the limits defined by the service provider (e.g. too long message, service not available). The MMS R/S sends back Submit Response message to the originator indicating if the MM is accepted or rejected for delivery.

If the recipient is under the authority of a different MMS R/S (service provider), the originator MMS R/S discovers the peer MMS R/S by resolving the recipient address. It is expected that ENUM (Electronic Numbering), an Internet Engineering Task Force (IETF) global numbering solution, will be used for this purpose. It is also expected that MMS service providers may use solutions based on static tables or look-up methods as an alternative solution for the same purpose, if ENUM is not deployed by the time MMS comes to the market. MMS connectivity across different service providers is based on IETF Simple Mail Transfer Protocol (SMTP). Each MMS message is included in a single SMTP mail message. The SMTP message is organized according to MIME. An example MIME type for SMTP message to carry a multimedia message, as payload, is application/multipart. Encoding of MMS-specific values in SMTP message and header mappings between the SMTP message and corresponding messages used in the terminal interface are defined in [6]. Upon discovering the peer entity, the originator MMS R/S routs the MM by sending MM Rout message to the recipient MMS R/S. The MM Rout message could be routed to the recipient MMS R/S via intermediate network entities, which are not shown in Figure 4 for simplicity. The MM Rout mainly carries all the information received in the MM Submit. An MMS R/S can modify few selected information elements. The recipient MMS R/S responds with a Rout Response message indicating the status of the MM.

The recipient MMS R/S notifies the recipient about a new MM by sending a Notification message. The most important information element carried by a Notification is a unique message reference, which could be later used by the recipient for pointing the MM. The Notification can optionally carry few other information elements, which could be used as basis for the recipient to decide about the retrieval of the MM. The recipient responds by sending back a Notify Response message to the recipient MMS R/S. In the Notify Response message the recipient can indicate its interest for either of the following – delayed retrieval, forwarding and rejection of the MM. In case, the recipient wants to retrieve the MM immediately (described as immediate retrieval before), it does not send Notify Response message back. Rather, it sends request for retrieval as described in the following paragraph. Notification is carried over WAP Push, while Notify Response is carried over WSP/HTTP Post in the lower layer of the WAP MMS.

The recipient requests for retrieval of an MM by sending a Retrieve Request message to the MMS R/S. The message carries the message reference as received in the Notification, and optionally, indication about terminal capabilities. The MMS R/S can adapt multimedia contents of the multimedia message according to the terminal capabilities received in the Retrieve Request message. In the WAP MMS implementation the Retrieve Request message is carried over WSP/HTTP Get message in the lower layer. In response, the MMS R/S sends the MM to the recipient encapsulating it in an MM Retrieve message. The MM Retrieve message mostly carries all the information elements sent in the MM Submit message, excepting few selected elements which can be modified by the MMS R/S. Example of such exception is recipient is not provided with the address of the originator, if address hiding is requested by the originator and legislation does not deny the request. The MM Retrieve is carried over the response of WSP/HTTP Get in the lower layer of the WAP MMS implementation. The recipient acknowledges by sending back Acknowledge message to the MMS R/S upon receiving the MM Retrieve message. The Acknowledge may deny the generation of delivery report. The message is carried over WSP/HTTP Post in the lower layer of the WAP MMS.

If the originator requested for a delivery report and the recipient did not deny the generation of such a report, the MMS R/S generates a delivery report. The delivery report is sent over Delivery Report message to the originator. The message is carried over WAP Push in the lower layer of the WAP MMS implementation across the terminal interface of the originator side. The delivery report carries unique identification of the MM which the report refers to, addresses, delivery-specific status of the MM, and corresponding time. Moreover, if the originator requested for a read report and the recipient agrees for such a report, the recipient generates it. The read report carries unique identification of the MM which the report refers to, addresses, read-specific status of the MM, and corresponding time. The report could be transmitted either as an MM or messages. In case of transmission as an MM, information about read report is encapsulated as the content of the MM. In case messages are used to carry read report, Read Report messages carry the read report, as shown in Figure 4. Messages carried across terminal interface from the recipient and to the originator are carried over WSP/HTTP Post and WAP Push respectively in the lower layer of the WAP MMS implementation.

After receiving the Notification, the recipient may indicate about its intention in the Notify Response to forward the MM to new recipients. The functionality is described as forwarding without prior retrieval in section V. Two additional messages, which are not shown in Figure 4, are defined in [6] for the functionality – the first forwarding-specific message is used by an MMS UA to request the associated MMS R/S to forward an MM, while the other message is used by MMS R/S to indicate the MMS UA about the status of the request.

VII. ONGOING WORKS

Work is going on both in the 3GPP and the WAP Forum to extend and enhance the scope of MMS. Few of the active MMS issues are briefly elaborated below.

Address Resolution and Interworking: ENUM is an IETF global numbering solution. ENUM links MSISDN with the addressing scheme used in IETF (IP address) by associating MSISDN with Uniform Resource Identifier (URI). The proposal might be specified for resolving recipient MSISDN to the IP address of the recipient MMS R/S. ENUM might not be deployed in time. So, 3GPP is working to specify alternative solution for address resolution. A standardized way of address resolution would ensure better interoperability between different MMS service providers. Work about interworking with other messaging systems is also going on in the 3GPP. MIME type for SMS is under registration process, which would allow MMS to interwork with SMS. The MMS R/S is responsible for converting the format of messages while interworking with other messaging systems. This kind of external interworking is not easy to achieve through this one-way approach, as specifying or extending only the MMS is not enough in most of the cases.

Value Added Service (VAS) Application: VAS Applications is expected to provide value added services (e.g. news service, weather forecasts) to MMS users. 3GPP is now working to define an interface between the MMS R/S and the VAS Application. VAS Application is expected to work like an MMS UA with enhanced messaging functionalities, like canceling and replacing of multimedia messages. Standardized interface should allow VAS (content) providers to explore MMS to provide both on-demand and mass-messaging services.

Network-based Storage: Present MMS specifications do not mandate the storage of multimedia messages in the network after it is retrieved. Being able to store multimedia messages for longer time in networks might be useful to the users considering the situations of roaming and shortage of storage space in terminals. This extended storage facility might also be useful for users to maintain images or audio-visual clips in networks. Work is going on to extend the scope of MMS to such controllable network-based storage.

VIII. CONCLUSION

MMS is expected to continue and enhance what is already started by SMS in wireless messaging. With richer content, interactive content creation and better presentation, MMS is designed to combine images with text in a dynamic way for extensive use in end-to-end off-the-line wireless communication. MMS requires much less user interaction while viewing a message, as attached presentation mechanism guides the user in viewing multimedia messages in a systematic and synchronized manner. Integrated digital camera with MMS-capable terminals seems a good match for MMS, as it would allow the user to send images of any special moment of daily life to the person of interest very easily. Scope of MMS is also extended to audiovisual clips. Support for streaming in MMS would better fit into the uses of such dynamic media. Considering the complexity and expense involved for handling such bulky and sensitive media types, it is expected that early commercial systems of MMS would be mainly based on text, image and speech.

MMS can also be used as career of other services, like news, weather bulletin, and downloading ring-tones, animated screensavers, music and games. Sending voicemail as multimedia messages to MMS users and maintaining photo-album in the networks are other example uses of MMS as career. It is already possible to configure required network-based storage in the application layer for such services. The scope would be further improved with a standardized way of managing storage in the network as described in section VII.

Unlike Email users, MMS users do not need to take any initiative to see if there is any new message in the server. Information flow in MMS does not need that many round trips and complex authentication as required for the information flow in the conventional Email service. As mentioned before, MMS has scope to interact with other messaging system like Email. Apart from all these positive MMS characteristics, lot about the success of MMS is also depending on how easy it would be to use, how global the service would be, and how much one has to pay for the service. Fast and effective conclusion of the ongoing standardization work, as mentioned in section VII, might also prove important for the success of MMS.

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