

**X.media.publishing** 

**Springer-Verlag Berlin Heidelberg GmbH**

Ralf Steinmetz Klara Nahrstedt

# Multimedia Systems

With 172 Figures



Springer

Ralf Steinmetz  
Technische Universität Darmstadt  
KOM  
Merckstr. 25  
64238 Darmstadt, Germany  
ralf.steinmetz@kom.tu-darmstadt.de

Klara Nahrstedt  
University of Illinois  
Department of Computer Science  
1304 West Springfield Avenue  
Urbana, IL 61801  
klara@cs.uiuc.edu

ISSN 1612-1449  
ISBN 978-3-642-07412-7      ISBN 978-3-662-08878-4 (eBook)  
DOI 10.1007/978-3-662-08878-4

Library of Congress Cataloging-in-Publication-Data applied for

Bibliographic information published by Die Deutsche Bibliothek  
Die Deutsche Bibliothek lists this publication in the Deutsche  
Nationalbibliografie; detailed bibliographic data is available in the  
Internet at <<http://dnb.ddb.de>>.

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German copyright law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer-Verlag Berlin Heidelberg GmbH.

Violations are liable for prosecution under the German Copyright Law.  
springeronline.com

© Springer-Verlag Berlin Heidelberg 2004  
Originally published by Springer-Verlag Berlin Heidelberg New York in 2004  
Softcover reprint of the hardcover 1st edition 2004

The use of general descriptive names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Cover design: KünkelLopka, Heidelberg  
Typesetting: Camera-ready by the authors  
Printed on acid-free paper      33/3142GF – 543210

---

# Preface

**M**ultimedia Applications and Systems are an increasingly common part of our everyday lives—emerging mobile terminals which can display pictures and video data, DVD players in the home, downloadable games, streaming in the Internet, radio stations on the World Wide Web—are just a few examples. These applications and systems are becoming an integral part of our heterogeneous computing and communication environment. Over the last decade, we have experienced an explosive growth of multimedia computing, communication, and applications (World Wide Web, conferencing, digital entertainment, etc.) which provide not just text and images but also video, audio, and other continuous media. In the future, all computers and networks will contain multimedia devices. They will also require appropriate processing and communication support to provide seamless and ubiquitous services and protocols for the relevant multimedia applications.

This book is one of three closely related volumes which aim to cover the whole area of multimedia technology and its applications: The first volume (*Ralf Steinmetz, Klara Nahrstedt, “Multimedia Fundamentals Volume 1: Media Coding and Content Processing”, Prentice-Hall, 2002*) deals mainly with the fundamentals of media per se, and covers media-specific considerations such as individual media characteristics, media processing, and optical storage, content analysis, and processing. It includes coding, compression, and a detailed discussion of optical storage. The third volume (*Ralf Steinmetz, Klara Nahrstedt, “Multimedia Applications”, Springer-Verlag 2004*) discusses multimedia database and document issues, programming of multimedia applications, multimedia security, human-computer interfaces, multimedia learning,

design and different types of applications. Taken together, our three books are intended to be the standard reference books on “multimedia fundamentals”.

Do the individual volumes contain sufficient information which readers might need to make the most out of reading this book?

The present volume can be read (and understood) without detailed knowledge of media coding and content processing. However, a basic grasp of the notion of compression would certainly be very useful. Furthermore, it is of crucial importance that the readers have an introductory background in the areas of operating systems and networking systems.

In this book, we emphasize multimedia systems and networking to provide fundamental understanding what are the underlying concepts, mechanisms and frameworks that multimedia applications stand on. Chapter 2 on quality of service provides the basic definitions and concepts (1) to explain quality differentiation and quality-aware resource management, and (2) to present one of the most fundamental building blocks of multimedia systems. Chapter 3 on multimedia operating systems touches upon fundamentals in processor soft-real-time scheduling, based on earliest deadline first and rate-monotonic scheduling policies, as well as in memory and device management. Chapter 4 continues the discussion of multimedia operating systems and presents media servers, one of the most researched domains in multimedia operating systems. Topics range from multimedia file structure, file placement, overall storage organization, to disk management, disk scheduling, and caching policies. Chapter 5 describes basic concepts for multimedia transmission at the physical and Medium Access Control layers, presenting past and existing networking technologies (e.g., Gigabit Ethernet, ATM) that embed appropriate algorithms, protocols and services for multimedia communication. Chapter 6 on multimedia communication is the core chapter for multimedia-enabled protocols executing at the network IP and transport layers. The readers will find discussion on existing protocols, that have been modified to assist in multimedia communication such as the TCP protocol, as well as on new protocols such as IPv6 and RTP protocols. Chapter 7 continues the discussion of multimedia-enabling concepts in the protocol stack and presents group communication services and protocols at the session layer. Chapter 8 is the glue of the whole book because it describes the synchronization concepts and mechanisms across the whole multimedia system architecture. It ties together synchronization mechanisms at the operating system and network levels with synchronization mechanisms at the application and user levels to deliver the overall goal of a multimedia system—the best perceptual quality of multimedia data to the user.

Overall, the book covers a wide scope of multimedia system and networking concepts, due to its intended purpose of serving as a reference, or as an introductory book in an undergraduate multimedia systems class. It evolved from the third edition of

our book on multimedia technology, published in German in 2000 [Ste00]. (Figures from this book have been reused with the permission of Springer-Verlag). However, several sections of the English text depart from the corresponding material in the German edition. The present volume can be used by computer professionals who are interested in multimedia systems, or by instructors as a textbook for introductory multimedia courses in computer science and related disciplines.

To help instructors use this book, additional material is available on our Web site: <http://www.kom.tu-darmstadt.de/mm-book/>. Please enter `mm_book` and `mm_docs` for user name and password, respectively.

Many people have helped us to prepare this book: R. Ackermann, M. Bräuer, D. Dimitriu, J. Dittmann, A. El Saddik, M. Farber, S. Fischer, J. Geißler, N. Georganas, C. Griwodz, T. Hollmer, T. Kamps, T. Kunkelmann, J. Liang, A. Mauthe, A. Meissner, K. Reichenberger, J. Schmitt, K. Schork-Jakobi, C. Seeberg, A. Steinacker, N. Streitz, P. Tandler, H. Thimm, D. Tietze, M. Wessner, L. Wolf. Thank you!

However, we would especially like to thank Ivica Rimac for his outstanding dedication to this project.

Last but not least, we would like to thank our families for their support, love, and patience.

*Ralf Steinmetz*  
Darmstadt, Germany  
[www.kom.tu-darmstadt.de](http://www.kom.tu-darmstadt.de)

*Klara Nahrstedt*  
Urbana, IL, USA  
[cairo.cs.uiuc.edu](http://cairo.cs.uiuc.edu)

---

# Contents

|                                                          |          |
|----------------------------------------------------------|----------|
| <b>Preface.....</b>                                      | <b>v</b> |
| <b>1 Introduction .....</b>                              | <b>1</b> |
| 1.1 Interdisciplinary Aspects of Multimedia .....        | 2        |
| 1.2 Contents of This Book .....                          | 4        |
| 1.3 Organization of This Book .....                      | 4        |
| 1.3.1 Quality of Service.....                            | 5        |
| 1.3.2 Multimedia Operating Systems .....                 | 6        |
| 1.3.3 Multimedia Networking and Communication.....       | 6        |
| 1.3.4 Synchronization.....                               | 6        |
| 1.4 Further Reading About Multimedia.....                | 7        |
| <b>2 Quality of Service .....</b>                        | <b>9</b> |
| 2.1 Requirements and Constraint.....                     | 10       |
| 2.1.1 The Notion of “Real-Time” .....                    | 10       |
| 2.1.2 Deadlines .....                                    | 11       |
| 2.1.3 Characteristics of Real-Time Systems .....         | 11       |
| 2.1.4 Real-time Requirements on Multimedia Systems ..... | 13       |
| 2.1.5 Service and Protocol Requirements .....            | 14       |
| 2.1.6 Processing and Communication Constraints.....      | 15       |

---

|          |                                                 |           |
|----------|-------------------------------------------------|-----------|
| 2.2      | Quality of Service Concepts .....               | 16        |
| 2.2.1    | Quality Layering .....                          | 16        |
| 2.2.2    | Service Objects.....                            | 17        |
| 2.2.3    | QoS Specification.....                          | 18        |
| 2.2.4    | QoS Parameter Values and Service Classes.....   | 22        |
| 2.2.5    | Quality-Aware Service Model.....                | 24        |
| 2.3      | Resources .....                                 | 25        |
| 2.3.1    | Resource Management .....                       | 26        |
| 2.3.2    | Requirements on Resource Management .....       | 28        |
| 2.3.3    | Model for Continuous Streams .....              | 29        |
| 2.4      | Establishment Phase .....                       | 34        |
| 2.4.1    | QoS Negotiation .....                           | 34        |
| 2.4.2    | QoS Translation.....                            | 40        |
| 2.4.3    | QoS Scaling.....                                | 43        |
| 2.4.4    | QoS Routing .....                               | 45        |
| 2.4.5    | Admission Control .....                         | 50        |
| 2.4.6    | Reservation.....                                | 52        |
| 2.5      | Run-time Phase of Multimedia Call .....         | 58        |
| 2.5.1    | Traffic Shaping.....                            | 59        |
| 2.5.2    | Rate Control .....                              | 62        |
| 2.5.3    | Error Control .....                             | 65        |
| 2.5.4    | QoS and Resource Monitoring .....               | 69        |
| 2.5.5    | QoS Renegotiation and Adaptation.....           | 70        |
| 2.6      | QoS Management Architectures.....               | 74        |
| 2.7      | Closing Remarks.....                            | 76        |
| <b>3</b> | <b>Multimedia Operating Systems.....</b>        | <b>77</b> |
| 3.1      | Process Management .....                        | 78        |
| 3.1.1    | Real-Time Processing Requirements .....         | 79        |
| 3.1.2    | Traditional Real-Time Scheduling .....          | 80        |
| 3.1.3    | Real-time Scheduling: System Model.....         | 81        |
| 3.1.4    | Soft-Real-Time Scheduling Concepts .....        | 83        |
| 3.1.5    | Scheduling Policies .....                       | 94        |
| 3.1.6    | Prototype Operating Systems: Case Studies ..... | 103       |

---

|          |                                                      |            |
|----------|------------------------------------------------------|------------|
| 3.2      | Interprocess Communication and Synchronization ..... | 108        |
| 3.3      | Memory Management.....                               | 109        |
| 3.3.1    | Reservation Concept for Memory Management .....      | 110        |
| 3.3.2    | Buffer Management Techniques .....                   | 111        |
| 3.3.3    | Buffer Management for Client/Server Systems .....    | 113        |
| 3.4      | Device Management .....                              | 116        |
| 3.5      | System Architecture.....                             | 119        |
| 3.5.1    | UNIX-based Systems .....                             | 122        |
| 3.5.2    | QuickTime.....                                       | 123        |
| 3.5.3    | Windows Multimedia Extensions .....                  | 125        |
| 3.5.4    | OS/2 Multimedia Presentation Manager/2 .....         | 127        |
| 3.6      | Concluding Remarks .....                             | 129        |
| <b>4</b> | <b>Media Server .....</b>                            | <b>131</b> |
| 4.1      | Architecture .....                                   | 132        |
| 4.2      | Storage Devices .....                                | 135        |
| 4.2.1    | Disk Layout .....                                    | 135        |
| 4.2.2    | Zone Bit Recording .....                             | 137        |
| 4.2.3    | File Structure .....                                 | 139        |
| 4.3      | Disk Controller .....                                | 140        |
| 4.3.1    | Data Placement.....                                  | 140        |
| 4.3.2    | Reorganization .....                                 | 146        |
| 4.4      | Storage Management .....                             | 148        |
| 4.4.1    | Disk Management .....                                | 149        |
| 4.4.2    | Traditional Disk Scheduling.....                     | 151        |
| 4.4.3    | Multimedia Disk Scheduling.....                      | 155        |
| 4.4.4    | Admission Control .....                              | 163        |
| 4.4.5    | Replication .....                                    | 165        |
| 4.4.6    | Supporting Heterogeneous Disks .....                 | 168        |
| 4.5      | File Systems.....                                    | 170        |
| 4.5.1    | Traditional File Systems.....                        | 170        |
| 4.5.2    | Multimedia File Systems.....                         | 173        |
| 4.5.3    | Example Multimedia File Systems .....                | 174        |
| 4.6      | Memory Management.....                               | 180        |
| 4.6.1    | Interval Caching Policy .....                        | 181        |

---

|          |                                                                       |            |
|----------|-----------------------------------------------------------------------|------------|
| 4.6.2    | Generalized Interval Caching Policy.....                              | 181        |
| 4.6.3    | Batching .....                                                        | 181        |
| 4.6.4    | Piggybacking.....                                                     | 181        |
| 4.6.5    | Content Insertion .....                                               | 182        |
| <b>5</b> | <b>Networks.....</b>                                                  | <b>183</b> |
| 5.1      | Services, Protocols, Layers.....                                      | 183        |
| 5.1.1    | Requirements to Services and Protocols .....                          | 184        |
| 5.1.2    | The Layers of the ISO-OSI Model .....                                 | 185        |
| 5.2      | Networks.....                                                         | 188        |
| 5.2.1    | Ethernet .....                                                        | 189        |
| 5.2.2    | Gigabit Ethernet .....                                                | 191        |
| 5.2.3    | Token Ring .....                                                      | 192        |
| 5.2.4    | 100VG AnyLAN .....                                                    | 199        |
| 5.2.5    | Fiber Distributed Data Interface (FDDI).....                          | 201        |
| 5.2.6    | ATM Networks .....                                                    | 210        |
| 5.3      | Metropolitan Area Networks (MANs).....                                | 218        |
| 5.3.1    | Distributed Queue Dual Bus (DQDB).....                                | 219        |
| 5.3.2    | Orwell.....                                                           | 223        |
| 5.3.3    | MAN Connection to ATM Networks.....                                   | 224        |
| 5.4      | Wide Area Networks (WANs).....                                        | 225        |
| 5.4.1    | Traditional WANs .....                                                | 226        |
| 5.4.2    | B-ISDN over ATM.....                                                  | 228        |
| 5.5      | Closing Remarks.....                                                  | 239        |
| <b>6</b> | <b>Communication.....</b>                                             | <b>241</b> |
| 6.1      | Transport Subsystem Requirements and Constraints .....                | 241        |
| 6.1.1    | User and Application Requirements.....                                | 242        |
| 6.1.2    | Processing and Protocol Constraints .....                             | 242        |
| 6.2      | Traditional Network Protocols and Their Support for Multimedia .....  | 244        |
| 6.2.1    | Internet Protocol Version 4 (IPv4) .....                              | 244        |
| 6.2.2    | Internet Protocol Version 6 (IPv6) .....                              | 247        |
| 6.2.3    | Multicast Support .....                                               | 252        |
| 6.3      | Traditional Transport Protocols and Their Support of Multimedia ..... | 258        |
| 6.3.1    | Transmission Control Protocol (TCP).....                              | 258        |
| 6.3.2    | User Datagram Protocol (UDP) .....                                    | 263        |

---

|          |                                                                  |            |
|----------|------------------------------------------------------------------|------------|
| 6.4      | New Protocols for Support of Network Quality of Service.....     | 264        |
| 6.4.1    | Reservation Concept .....                                        | 265        |
| 6.4.2    | Early Reservation-based Protocols.....                           | 266        |
| 6.4.3    | Internet Integrated Services.....                                | 267        |
| 6.4.4    | Resource Reservation Protocol .....                              | 268        |
| 6.4.5    | Alternative Reservation Approaches.....                          | 271        |
| 6.4.6    | Internet Differentiated Services.....                            | 272        |
| 6.5      | New Protocols for Transport of Multimedia .....                  | 273        |
| 6.5.1    | Early Multimedia Transport Protocols.....                        | 273        |
| 6.5.2    | Real-time Transport Protocol (RTP) .....                         | 275        |
| 6.5.3    | Handling of Heterogeneous Requirements in Multicast Scenarios... | 282        |
| 6.5.4    | Reliable Multicast Transmission .....                            | 285        |
| 6.6      | Closing Remarks.....                                             | 286        |
| <b>7</b> | <b>Group Communication .....</b>                                 | <b>289</b> |
| 7.1      | Computer Supported Cooperative Work (CSCW) .....                 | 289        |
| 7.1.1    | Dimensions of CSCW .....                                         | 290        |
| 7.2      | Architecture .....                                               | 292        |
| 7.2.1    | Establishing Communication Relationships (Group Rendezvous) ...  | 293        |
| 7.3      | Joint Use of Applications.....                                   | 294        |
| 7.3.1    | Conferences .....                                                | 297        |
| 7.3.2    | Conference Control .....                                         | 298        |
| 7.4      | Session Management .....                                         | 301        |
| 7.4.1    | Architecture .....                                               | 301        |
| 7.4.2    | Session Control .....                                            | 303        |
| 7.5      | Internet Protocols and their Use in MBone .....                  | 305        |
| 7.5.1    | Protocols .....                                                  | 305        |
| 7.5.2    | MBone Applications .....                                         | 309        |
| 7.5.3    | Cooperation of Protocols in an MBone Session.....                | 316        |
| 7.6      | Closing Remarks.....                                             | 317        |
| <b>8</b> | <b>Synchronization .....</b>                                     | <b>319</b> |
| 8.1      | Defining "Synchronization".....                                  | 319        |
| 8.1.1    | Intra- and Inter-object Synchronization .....                    | 322        |
| 8.1.2    | Time-dependent Presentation Units .....                          | 323        |

|        |                                                                |     |
|--------|----------------------------------------------------------------|-----|
| 8.2    | Particularities of Synchronization in Multimedia Systems ..... | 327 |
| 8.2.1  | Overview .....                                                 | 327 |
| 8.2.2  | Requirements to Lip Synchronization .....                      | 332 |
| 8.2.3  | Requirements to Pointer Synchronization .....                  | 336 |
| 8.2.4  | Elementary Media Synchronization .....                         | 339 |
| 8.2.5  | Analysis of Existing Synchronization Mechanisms .....          | 343 |
| 8.3    | Requirements to the Presentation .....                         | 345 |
| 8.4    | Reference Elements for Synchronization .....                   | 345 |
| 8.5    | Synchronization Types .....                                    | 345 |
| 8.5.1  | Live Synchronization—Overview .....                            | 346 |
| 8.5.2  | Synthetic Synchronization—Overview .....                       | 346 |
| 8.5.3  | Variants of Live Synchronization .....                         | 346 |
| 8.5.4  | Synthetic Synchronization .....                                | 349 |
| 8.6    | System Components Involved in Synchronization .....            | 351 |
| 8.7    | A Reference Model for Multimedia Synchronization .....         | 353 |
| 8.7.1  | Existing Classification Methods .....                          | 353 |
| 8.7.2  | The Synchronization Reference Model .....                      | 354 |
| 8.7.3  | Synchronization in a Distributed Environment .....             | 359 |
| 8.7.4  | Characteristics of the Synchronization Reference Model .....   | 364 |
| 8.8    | Synchronization Specification .....                            | 366 |
| 8.8.1  | Quality of Service in the Context of Synchronization .....     | 366 |
| 8.9    | Specification Methods for Multimedia Synchronization .....     | 370 |
| 8.9.1  | Interval-based Specification .....                             | 370 |
| 8.9.2  | Axis-based Synchronization .....                               | 373 |
| 8.9.3  | Control-flow-based Specification .....                         | 376 |
| 8.9.4  | Events-based Synchronization .....                             | 382 |
| 8.9.5  | Scripts .....                                                  | 383 |
| 8.9.6  | Summary of Synchronization Specification Methods .....         | 385 |
| 8.10   | Case Studies .....                                             | 385 |
| 8.10.1 | Synchronization in MHEG .....                                  | 385 |
| 8.10.2 | HyTime .....                                                   | 388 |
| 8.10.3 | The Firefly System .....                                       | 390 |
| 8.10.4 | The MODE System .....                                          | 393 |
| 8.10.5 | Multimedia Tele-Orchestra .....                                | 397 |
| 8.10.6 | Little's Framework .....                                       | 398 |

---

|                                                    |            |
|----------------------------------------------------|------------|
| 8.10.7 ACME .....                                  | 400        |
| 8.10.8 Other Synchronization-specific Systems..... | 402        |
| 8.11 Summary and Discussion .....                  | 403        |
| <b>Bibliography .....</b>                          | <b>405</b> |
| <b>Index .....</b>                                 | <b>445</b> |