1. Introduction

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The term "Peer-to-Peer" has drawn much attention in the last few years; particularly for applications providing file-sharing, but distributed computing and Internet-based telephony have also been successfully implemented. Within these applications the Peer-to-Peer concept is mainly used to share files, i.e., the exchange of diverse media data, like music, films, and programs. The growth in the usage of these applications is enormous and even more rapid than that of the World Wide Web. Also, much of the attention focused on early Peer-to-Peer systems concerned copyright issues of shared content.

But, the concept of Peer-to-Peer architectures offers many other interesting and significant research avenues as the research community has repeatedly pointed out. Due to its main design principle of being completely decentralized and self-organizing - as opposed to the Internet's traditional Client-Server paradigm - the Peer-to-Peer concept emerges as a major design pattern for future applications, system components, and infrastructural services, particularly with regard to scalability and resilience.

The perspective of the Peer-to-Peer concept offers new challenges, e.g., building scalable and resilient distributed systems and a fast deployment of new services. Based on the decentralized Peer-to-Peer approach, new Internet services can be deployed on demand and without spending time-consuming efforts in the process of product placement for the appropriate market, community, or company.

1.1   Why We Wrote This Book

In recent years, the scientific community developed different approaches for Peer-to-Peer-based applications, identified new application scenarios, and improved the scientific advancements of the Peer-to-Peer paradigm. Many researchers have already revealed interesting possibilities and opportunities for the Peer-to-Peer idea.

But, from our point of view, something important is missing: *A fundamental overview of all facets of research in the area of Peer-to-Peer systems and applications.* Also, adequate teaching material for classes and lectures on Peer-to-Peer systems and applications, covering the whole field, is not currently available.

Thus, the editors of this book have followed certain objectives with the writing and editing of this book:

− *Overview of the Peer-to-Peer Research Area:*
  Although research on Peer-to-Peer systems and applications is very young, the Peer-to-Peer concept has already proven to be applicable and useful in many cases. With this book, we want to give a broad overview of the broad range of applications of the Peer-to-Peer paradigm. In addition to a definition of the term "Peer-to-Peer" and a discussion of fundamental mechanisms we want to show all the different facets of Peer-to-Peer research and its applications. These manifold facets are also nicely reflected by the structure of the book and its ten parts.
− *Common Understanding of the Peer-to-Peer Paradigm:*
  After providing a good overview of the research field, our second objective is to define our notion of the "Peer-to-Peer paradigm". In the past, many things were called "Peer-to-Peer" – yet were often not even slightly related to it – and most people only associated "Peer-to-Peer" with popular file-sharing applications and not with the promising advantages and possibilities the paradigm can offer in a variety of other scenarios.
− *Compendium and Continuing Knowledge Base for Teaching:*
  There does not yet exist in the literature a good overview of Peer-to-Peer systems which is also useful for teaching purposes. Thus, the third intention of this book is to provide a common basis for teaching, with material for lectures, seminars, and labs. The knowledge of many experts has been assembled for this book, each in their own specific research area. Thus, teachers can choose from a wide range of chapters on all aspects of Peer-to-Peer systems and applications, and therefore, can design the syllabus for their classes with individual accents. In addition to this text book, electronic slides are available on the companion website.

The idea to write and edit this book arose from a sequence of international and German activities and events that fostered the idea (1) to coordinate and to support research in the area of Peer-to-Peer systems and applications and (2) to establish a highly webbed research community. Among these events have been the KuVS Hot Topics Meeting (GI/ITG KuVS Fachgespräch) "Quality in Peer-to-Peer-Systems" (TU Darmstadt, September 2003) [197], the Dagstuhl Seminar "Peer-to-Peer Systems" (March 2004) [149] and the GI/ITG Workshop "Peer-to-Peer Systems and Applications" (Kaiserslautern, March 2005) [244]. In the course of these events, a scientific community of researchers, mostly from German-speaking countries, but also from elsewhere, in particular the U.S., formed in the area of Peer-to-Peer systems and applications.

1.2   Structure and Contents

This book consists of thirty-two chapters on aspects of Peer-to-Peer systems and applications, grouped into ten parts, each dealing with a major sub-topic. These parts will now be introduced to give a brief overview of each thematic aspect.

Part I: Peer-to-Peer: Notion, Areas, History and Future
Chapter 2 elaborates on our definition of the Peer-to-Peer paradigm and gives a brief overview of the basic Peer-to-Peer concepts. Chapter 3 follows with a journey through the evolution of early Peer-to-Peer systems and Chapter 4 concludes Part I with an overview of Peer-to-Peer application areas.

Part II: Unstructured Peer-to-Peer Systems
Part II deals with all aspects of unstructured Peer-to-Peer systems. Chapter 5 gives an overview of the first and second generations of file-sharing applications. The interesting aspects of small-worlds, random graphs and scale-free networks are addressed in Chapter 6.

Part III: Structured Peer-to-Peer Systems
Part III focuses on the realm of structured Peer-to-Peer systems. First, Chapter 7 introduces the fundamental concepts of Distributed Hash Tables (DHTs) and their potential. Chapter 8 follows with an introduction to selected approaches for DHT algorithms and a discussion of their specific details. Chapter 9 provides an overview of load-balancing and reliability in DHTs. Chapter 10 concludes Part III by looking at the dynamics of self-organizing processes in structured Peer-to-Peer systems, using the example of the P-Grid system.

Part IV: Peer-to-Peer-Based Applications
Part IV presents a selection of Peer-to-Peer-based applications. Starting with end-system-based multicast in Chapter 11, the benefits of realizing services on the application-layer are shown. Chapter 12 presents the completely decentralized e-mail system ePOST running on a structured Peer-to-Peer overlay. Then, Chapters 13 and 14 discuss Peer-to-Peer issues in Grid and Web-Services applications.

Part V: Self-Organization
Part V deals with the fascinating topic of self-organization. General aspects and a characterization of self-organization is given in Chapter 15. Chapter 16 follows with a discussion of self-organization in Peer-to-Peer-based systems.

Part VI: Search and Retrieval
Part VI discusses techniques for search and (information) retrieval in widely distributed systems and addresses scalability aspects. Chapter 17 compares different search strategies and discusses scalability issues. Chapter 18 studies

basic algorithmic tasks on overlay networks. It explores both the communication and the computation needed to perform such tasks. Chapter 19 introduces schema-based Peer-to-Peer systems and relations to Semantic Web and database research. Chapter 20 continues with an survey of information retrieval techniques in Peer-to-Peer infrastructures. Chapter 21 concludes this Part by discussing the challenges of hybrid Peer-to-Peer systems.

Part VII: Peer-to-Peer Traffic and Performance Evaluation
Part VII deals with traffic and load issues of Peer-to-Peer systems and applications. Chapter 22 presents facts about the amount and effects of Peer-to-Peer traffic measured in an ISP's backbone. Chapter 23 deals with traffic characterization and performance evaluation of unstructured systems.

Part VIII: Peer-to-Peer in Mobile and Ubiquitous Environments
Part VIII discusses the emerging topics of using Peer-to-Peer techniques in mobile and ubiquitous environments. Chapter 24 evaluates the use of unstructured and structured Peer-to-Peer techniques in mobile environments. Chapter 25 presents techniques for spontaneous collaboration in mobile ad hoc networks using the Peer-to-Peer paradigm. Chapter 26 deals with epidemic data dissemination for Peer-to-Peer-based lookup services in mobile ad hoc networks. Chapter 27 concludes Part VIII by discussing the communication needs of ubiquitous computing architectures, showing that many similarities with Peer-to-Peer based systems exist, and explaining how they may be explored.

Part IX: Business Applications and Markets
Part IX addresses distributed, self-organizing markets and business applications based on Peer-to-Peer techniques. Chapter 28 discusses revenue models for Peer-to-Peer-based business applications. Chapter 29 focuses on market-managed P2P systems and discusses their requirements. Chapter 30 addresses electronic markets and discusses their Peer-to-Peer nature.

Part X: Advanced Issues
Part X deals with advanced issues concerning Peer-to-Peer-based systems and applications. Chapter 31 addresses security aspects of decentralized self-organized systems on the network and application layers. Chapter 32 addresses accounting aspects in Peer-to-Peer systems and proposes an suitable architecture for this purpose. Chapter 33 concludes with a description of the PlanetLab testbed. PlanetLab is a widely used, global platform for researchers to develop, deploy, and evaluate widely-distributed applications such as Peer-to-Peer systems.

1.3   Teaching Materials and Book Website

The authors of each chapter were asked to supply related teaching materials, in particular slides in the current PowerPoint format. All this e-learning content can be retrieved by instructors from `www.peer-to-peer.info` – the website of this book. The slides can be used without charge and adapted individually by teachers provided that this book and the origin of the material is appropriately acknowledged.

Teachers may also want to publish their modifications at the book website so that they are accessible to a wide audience. Our hope is that contributions from the community will allow the companion website to grow into a large knowledge base.

More information on accessing and using the website can be found at `www.peer-to-peer.info`. Please provide us with your comments on improvements, errors, or any other issues to be addressed in the next edition through this website. Thank you!

1.4   Acknowledgements

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