



Next-Generation Internet

Architectures and Protocols

Edited by Byrav Ramamurthy,
George N. Rouskas and
Krishna Moorthy Sivalingam

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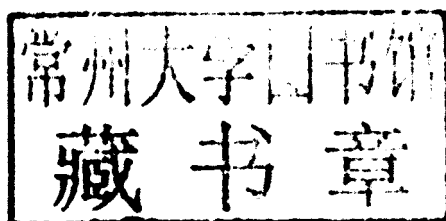
Next-Generation Internet Architectures and Protocols

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Next-Generation Internet

With ever-increasing demands on capacity, quality of service, speed, and reliability, current Internet systems are under strain and under review. Combining contributions from experts in the field, this book captures the most recent and innovative designs, architectures, protocols, and mechanisms that will enable researchers to successfully build the next-generation Internet. A broad perspective is provided, with topics including innovations at the physical/transmission layer in wired and wireless media, as well as the support for new switching and routing paradigms at the device and subsystem layer. The proposed alternatives to TCP and UDP at the data transport layer for emerging environments are also covered, as are the novel models and theoretical foundations proposed for understanding network complexity. Finally, new approaches for pricing and network economics are discussed, making this ideal for students, researchers, and practitioners who need to know about designing, constructing, and operating the next-generation Internet.

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To my mother, Mrs. Lalitha Ramamurthy – BR
To Magdalini and Alexander – GNR
To my family – KMS

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Preface

The field of computer networking has evolved significantly over the past four decades since the development of ARPANET, the first large-scale computer network. The Internet has become a part and parcel of everyday life virtually worldwide, and its influence on various fields is well recognized. The TCP/IP protocol suite and packet switching constitute the core dominating Internet technologies today. However, this paradigm is facing challenges as we move to next-generation networking applications including multimedia transmissions (IPTV systems), social networking, peer-to-peer networking and so on. The serious limitations of the current Internet include its inability to provide Quality of Service, reliable communication over periodically disconnected networks, and high bandwidth for high-speed mobile devices.

Hence, there is an urgent question as to whether the Internet's entire architecture should be redesigned, from the bottom up, based on what we have learned about computer networking in the past four decades. This is often referred to as the "clean slate" approach to Internet design. In 2005, the US National Science Foundation (www.nsf.gov) started a research program called Future Internet Network Design (FIND) to focus the research community's attention on such activities. Similar funding activities are taking place in Europe (FIRE: Future Internet Research and Experimentation), Asia, and other regions across the globe. This book is an attempt to capture some of the pioneering efforts in designing the next-generation Internet. The book is intended to serve as a starting point for researchers, engineers, students, and practitioners who wish to understand and contribute to the innovative architectures and protocols for the next-generation Internet.

Book organization

The book is divided into four parts that examine several aspects of next generation networks in depth.

Part I, titled "Enabling technologies," consists of five chapters that describe the technological innovations which are enabling the design and development of next-generation networks.

Chapter 1, "Optical switching fabrics for terabit packet switches," describes photonic technologies to realize subsystems inside high-speed packet switches

and routers. The proposed architectures using optical interconnections remain fully compatible with current network infrastructures. For these architectures, the authors conduct scalability analysis and cost analysis of implementations based on currently available components.

Chapter 2, “Broadband access networks: current and future directions,” describes Long-Reach Passive Optical Network (LR-PON) technology which brings the high capacity of optical fiber closer to the user. The authors propose and investigate the Wireless-Optical Broadband Access Network (WOBAN) which integrates the optical and wireless access technologies.

Chapter 3, “The optical control plane and a novel unified control plane architecture for IP/WDM networks,” provides an overview of current protocols utilized for the control plane in optical networks. The authors also propose and investigate a new unified control plane architecture for IP-over-WDM networks that manages both routers and optical switches.

Chapter 4, “Cognitive routing protocols and architecture,” describes the operation of wireless networks in which cognitive techniques are becoming increasingly common. The authors present cognitive routing protocols and their corresponding protocol architectures. In particular, the authors propose and investigate the mobility-aware routing protocol (MARP) for cognitive wireless networks.

Chapter 5, “Grid networking,” describes Grid networks which are enabling the large-scale sharing of computing, storage, communication and other Grid resources across the world. Grid networks based on optical circuit switching (OCS) and optical burst switching (OBS) technologies are discussed. The authors describe approaches for resource scheduling in Grid networks.

Part II, titled “Network architectures,” consists of five chapters that propose and investigate new architectural features for next-generation networks.

Chapter 6, “Host identity protocol (HIP): an overview,” describes a set of protocols that enhance the original Internet architecture by injecting a name space between the IP layer and the transport protocols. This name space consists of cryptographic identifiers that are used to identify application endpoints, thus decoupling names from locators (IP addresses).

Chapter 7, “Contract switching for managing inter-domain dynamics,” introduces contract switching as a new paradigm for allowing economic considerations and flexibilities that are not possible with the current Internet architecture. Specifically, contract switching allows users to indicate their value choices at sufficient granularity, and providers to manage the risks involved in investments for implementing and deploying new QoS technologies.

Chapter 8, “PHAROS: an architecture for next-generation core optical networks,” presents the Petabit/s Highly-Agile Robust Optical System (PHAROS), an architectural framework for future core optical networks. PHAROS, which is designed as part of the DARPA core optical networks (CORONET) program, envisions a highly dynamic network with support for both wavelength and IP services, very fast service setup and teardown, resiliency to multiple

concurrent network failures, and efficient use of capacity reserved for protected services.

Chapter 9, “Customizable in-network services,” proposes the deployment of custom processing functionality within the network as a means for enhancing the ability of the Internet architecture to adapt to novel protocols and communication paradigms. The chapter describes a network service architecture that provides suitable abstractions for specifying data path functions from an end-user perspective, and discusses technical challenges related to routing and service composition along the path.

Chapter 10, “Architectural support for continuing Internet evolution and innovation,” argues that, while the current Internet architecture houses an effective design, it is not in itself effective in enabling evolution. To achieve the latter goal, it introduces the SILO architecture, a meta-design framework within which the system design can change and evolve. SILO generalizes the protocol layering concept by providing each flow with a customizable arrangement of fine-grain, reusable services, provides support for cross-layer interactions through explicit control interfaces, and decouples policy from mechanism to allow each to evolve independently.

Part III, titled “Protocols and practice,” deals with different aspects of routing layer protocols and sensor network infrastructures.

Chapter 11, titled “Separating Routing Policy from Mechanism in the Network Layer”, describes a network layer design that uses a flat endpoint identifier space and also separates routing functionality from forwarding, addressing, and other network layer functions. This design is being studied as part of the Postmodern Internet Architecture (PoMo) project, a collaborative research project between the University of Kentucky, the University of Maryland, and the University of Kansas. The chapter also presents results from experimental evaluations, using a tunneling service that runs on top of the current Internet protocols.

Chapter 12, titled “Multi-path BGP: motivations and solutions,” discusses the motivation for using multi-path routing in the next generation Internet, in the context of the widely-used Border Gateway Protocol (BGP) routing protocol. The chapter then presents a set of proposed mechanisms that can interoperate with the existing BGP infrastructure. Solutions for both intra-domain and inter-domain multi-path routing are presented. These mechanisms are being implemented as part of the ongoing TRILOGY testbed, a research and development project funded by the European Commission.

Chapter 13, titled “Explicit congestion control: charging, fairness, and admission management,” presents theoretical results on explicit congestion control mechanisms. These are a promising alternative to the currently used implicit congestion control mechanism of TCP. Examples of protocols using explicit congestion control are eXplicit Control Protocol (XCP) and the Rate Control Protocol (RCP). This chapter presents a proportionally fair rate control protocol and an admission management algorithm that deals with

the tradeoff between maximizing resource utilization and admission of burst arrivals.

Chapter 14, titled “KanseiGenie: software infrastructure for resource management and programmability of wireless sensor network fabrics,” presents a software framework that allows a community of users to develop applications based on a network of deployed wireless sensor nodes. The framework allows the sensor nodes to be shared by multiple applications, using slicing and virtualization of the nodes’ resources. This project has been implemented as part of the NSF GENI initiative and promises to change the way in which sensor networks will operate in the future.

Finally, **Part IV**, titled “Theory and models”, deals with theoretical foundations and models, as applicable to next generation Internet protocol design.

Chapter 15, “Theories for buffering and scheduling in Internet switches,” presents interesting theoretical results on the use of small buffer sizes in the design of next generation routers/switches. It presents results on the interactions between a router’s buffer size and TCP’s congestion control mechanisms, and results on queueing theory based analysis on the fluctuation of traffic arrivals at a router. Based on these results, an active queue management mechanism is presented.

Chapter 16, “Stochastic network utility maximization and wireless scheduling,” discusses network utility maximization (NUM) as a refinement of the layering as optimization decomposition principle that is applicable to dynamic network environments. The chapter provides a taxonomy of this research area, surveys the key results obtained over the last few years, and discusses open issues. It also highlights recent progress in the area of wireless scheduling, one of the most challenging modules in deriving protocol stacks for wireless networks.

Chapter 17, “Network coding in bi-directed and peer-to-peer networks,” examines the application of network coding principles to bi-directed and peer-to-peer (P2P) networks. With the increasing use of P2P networks, it is essential to study how well network coding can be useful in such networks. The chapter discusses fundamental limitations of network coding for such networks and derives performance bounds. For P2P networks, the chapter presents practical network coding mechanisms for peer-assisted media streaming and peer-assisted content distribution.

Chapter 18, “Network economics: neutrality, competition, and service differentiation,” argues that the current Internet is not living up to its full potential because it delivers insufficient or inconsistent service quality for many applications of growing importance. The author explores how pricing can help expose hidden externalities and better align individual and system-wide objectives by structuring payments between content providers, ISPs, and users, to create the right incentives. The role of service differentiation in remedying problems that arise when users have heterogeneous requirements or utility functions is also examined.

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Contents

<i>Contributors</i>	page xvi
<i>Preface</i>	xix

Part I Enabling technologies 1

1 Optical switching fabrics for terabit packet switches 3

Davide Cuda, Roberto Gaudino, Guido A. Gavilanes Castillo, and Fabio Neri

1.1	Optical switching fabrics	5
1.1.1	Wavelength-selective (WS) architecture	7
1.1.2	Wavelength-routing (WR) architecture	8
1.1.3	Plane-switching (PS) architecture	9
1.2	Modeling optical devices	10
1.2.1	Physical model	11
1.2.2	Device characterization	12
1.2.3	Multi-plane-specific issues	15
1.3	Scalability analysis	16
1.4	Cost analysis	18
1.5	Results	21
1.5.1	Scalability of the aggregate switching bandwidth	21
1.5.2	CAPEX estimation	23
1.6	Conclusions	24

<i>References</i>	25
-------------------	----

2 Broadband access networks: current and future directions 27

Abu (Sayeem) Reaz, Lei Shi, and Biswanath Mukherjee

2.1	Introduction	27
2.1.1	Current broadband access solutions	27
2.1.2	Passive Optical Network (PON)	28
2.1.3	Extending the reach: Long-Reach PON (LR-PON)	30
2.2	Technologies and demonstrations	32
2.2.1	Enabling technologies	32
2.2.2	Demonstrations of LR-PON	33

2.3	Research challenges in LR-PON	34
2.3.1	Low-cost devices: colorless ONU	34
2.3.2	Resource allocation: DBA with Multi-Thread Polling	34
2.3.3	Traffic management: behavior-aware user assignment	35
2.4	Reaching the end-users: Wireless-Optical Broadband Access Network (WOBAN)	36
2.4.1	WOBAN architecture	36
2.4.2	Motivation of WOBAN	37
2.4.3	Research challenges in WOBAN	38
2.5	Conclusion	39
	<i>References</i>	39
3	The optical control plane and a novel unified control plane architecture for IP/WDM networks	42
	Georgios Ellinas, Antonis Hadjiantonis, Ahmad Khalil, Neophytos Antoniadou, and Mohamed A. Ali	
3.1	Introduction	42
3.2	Overview of optical control plane design	43
3.2.1	Link Management Protocol	44
3.2.2	GMPLS routing protocol	44
3.2.3	GMPLS signaling protocol	46
3.3	IP-over-WDM networking architecture	47
3.3.1	The overlay model	48
3.3.2	The peer and augmented models	48
3.4	A new approach to optical control plane design: an optical layer-based unified control plane architecture	49
3.4.1	Node architecture for the unified control plane	50
3.4.2	Optical layer-based provisioning	51
3.5	Conclusions	68
	<i>References</i>	68
4	Cognitive routing protocols and architecture	72
	Suyang Ju and Joseph B. Evans	
4.1	Introduction	72
4.2	Mobility-aware routing protocol	73
4.2.1	Background	73
4.2.2	Approach	74
4.2.3	Benefits	77
4.2.4	Protocol architecture	78
4.3	Spectrum-aware routing protocol	79
4.3.1	Background	79
4.3.2	Approach	80

4.3.3	Benefits	83
4.3.4	Protocol architecture	84
4.4	Conclusion	84

<i>References</i>	85
-------------------	----

5 **Grid networking** 88

Anusha Ravula and Byrav Ramamurthy

5.1	Introduction	88
5.2	The Grid	89
5.2.1	Grid Computing	89
5.2.2	Lambda Grid networks	90
5.3	Cloud Computing	91
5.4	Resources	92
5.4.1	Grid network resources	92
5.4.2	Optical network testbeds and projects	92
5.4.3	Computational resources	94
5.4.4	Other resources	95
5.5	Scheduling	95
5.6	Optical Circuit Switching and Optical Burst Switching	98
5.6.1	Studies on OCS-based Grids	98
5.6.2	Studies on OBS-based Grids	100
5.7	Conclusion	101

<i>References</i>	102
-------------------	-----

Part II Network architectures 105

6 **Host identity protocol (HIP): an overview** 107

Pekka Nikander, Andrei Gurtov, and Thomas R. Henderson

6.1	Introduction	107
6.2	Fundamental problems in the Internet today	108
6.2.1	Loss of universal connectivity	109
6.2.2	Poor support for mobility and multi-homing	109
6.2.3	Unwanted traffic	109
6.2.4	Lack of authentication, privacy, and accountability	110
6.3	The HIP architecture and base exchange	110
6.3.1	Basics	111
6.3.2	HITs and LSIs	112
6.3.3	Protocols and packet formats	113
6.3.4	Detailed layering	117
6.3.5	Functional model	118
6.3.6	Potential drawbacks	120

6.4	Mobility, multi-homing, and connectivity	121
6.4.1	HIP-based basic mobility and multi-homing	121
6.4.2	Facilitating rendezvous	122
6.4.3	Mobility between addressing realms and through NATs	123
6.4.4	Subnetwork mobility	124
6.4.5	Application-level mobility	126
6.5	Privacy, accountability, and unwanted traffic	126
6.5.1	Privacy and accountability	126
6.5.2	Reducing unwanted traffic	127
6.6	Current status of HIP	129
6.7	Summary	131
	<i>References</i>	131
7	Contract-switching for managing inter-domain dynamics	136
	Murat Yuksel, Aparna Gupta, Koushik Kar, and Shiv Kalyanaraman	
7.1	Contract-switching paradigm	137
7.2	Architectural issues	138
7.2.1	Dynamic contracting over peering points	139
7.2.2	Contract routing	139
7.3	A contract link: bailouts and forwards	143
7.3.1	Bailout forward contract (BFC)	144
7.3.2	Formalization for pricing a bailout forward contract (BFC)	144
7.3.3	Bailout forward contract (BFC) performance evaluation	147
7.4	Summary	152
	<i>References</i>	153
8	PHAROS: an architecture for next-generation core optical networks	154
	Ilia Baldine, Alden W. Jackson, John Jacob, Will E. Leland, John H. Lowry, Walker C. Milliken, Partha P. Pal, Subramanian Ramanathan, Kristin Rauschenbach, Cesar A. Santivanez, and Daniel M. Wood	
8.1	Introduction	154
8.2	Background	157
8.3	PHAROS architecture: an overview	157
8.4	Resource allocation	161
8.4.1	Resource management strategies	161
8.4.2	Protection	164
8.4.3	Playbooks	166
8.4.4	Sub-lambda grooming	168
8.5	Signaling system	169
8.5.1	Control plane operation	171
8.5.2	Failure notification	172

8.6	Core node implementation	173
8.7	Performance analysis	175
8.8	Concluding remarks	176

<i>References</i>	177
-------------------	-----

9 Customizable in-network services 179

Tilman Wolf

9.1	Background	179
9.1.1	Internet architecture	179
9.1.2	Next-generation Internet	180
9.1.3	Data path programmability	180
9.1.4	Technical challenges	181
9.1.5	In-network processing solutions	181
9.2	Network services	182
9.2.1	Concepts	182
9.2.2	System architecture	184
9.3	End-system interface and service specification	186
9.3.1	Service pipeline	186
9.3.2	Service composition	187
9.4	Routing and service placement	188
9.4.1	Problem statement	188
9.4.2	Centralized routing and placement	189
9.4.3	Distributed routing and placement	190
9.5	Runtime resource management	191
9.5.1	Workload and system model	191
9.5.2	Resource management problem	192
9.5.3	Task duplication	192
9.5.4	Task mapping	193
9.6	Summary	194

<i>References</i>	194
-------------------	-----

10 Architectural support for continuing Internet evolution and innovation 197

Rudra Dutta and Ilia Baldine

10.1	Toward a new Internet architecture	197
10.2	The problems with the current architecture	199
10.3	SILO architecture: design for change	201
10.4	Prior related work	206
10.5	Prototype and case studies	207