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Networks for Pervasive Services

Six ways to upgrade the internet

Springer

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To Maria, Dikeos and Marina

Foreword

When I began working for Peter Kirstein's group at the University College London (UCL) in 1980 the department had already been part of the embryo Internet for seven years. The first "local area networks" were being deployed, and it was becoming clear that the future would consist of many networks, using a variety of technologies, all of which would need to interwork. Accordingly the Internet community adopted an architecture (designed by Robert Kahn and Vint Cerf) in which all networks must implement a common "internet protocol" (IP) to carry packets of data across and between networks. *Networks* were connected to their neighbours by computers termed "gateways" (we now call them "routers"). IP did not attempt to correct any errors that might arise; that was left to the "hosts"—the computers attached to the networks that were the sources and sinks of data. Hosts implemented a protocol called the "transmission control protocol" (TCP), which arranged for the re-transmission of any packets that did not arrive intact.

Back in 1980 routers were based on refrigerator-sized "mini-computers" which cost tens of thousands of pounds (hundreds of thousands of euros in today's terms). Connecting a computer to a LAN cost more than £1,000. However, by the time Antonio Liotta joined us at UCL in 1995 things were very different; costs had plummeted, personal computers were widespread and the Internet now comprised thousands of networks and millions of hosts. The applications that generated the bulk of the traffic though—file transfer, email and the burgeoning world wide web—still matched the requirements that had inspired the development of the TCP all those years before. Underlying TCP is the assumption of a client–server model; the server computer has something the client wants and the TCP delivers it complete and error free with high probability. TCP achieves this by trading timeliness for reliability. That is fine for applications like email—no one cares much if an email message is delayed for a few seconds provided it arrives intact. However, it was clear to Antonio and others researching in the late 1990s that new applications were on the horizon, many of which would not fit the TCP client–server model at all well. Some, such as streaming audio and video, would not tolerate TCP-induced delays. Others were abandoning the asymmetric client–server model in favour of a more egalitarian "peer-to-peer" approach typified by file-sharing applications such as Napster. Yet another development, exemplified by Antonio's own research, turned the client–server model on its head by moving the servers ("agents") around the network in order to complete a task in the most efficient way.

Today those anticipated developments have arrived with a vengeance. Traditional TCP-based applications now form just a small minority of Internet traffic, perhaps no more than 15%, and most of that is world wide web. Streaming applications comprise around 10% and much of the rest is peer-to-peer file sharing—mostly of videos. (Things change so rapidly that in 12 months time these estimates will all likely be wrong!) Just as the applications have changed, so have the devices on which they run. The number of mobile phones in the world already vastly exceeds the number of networked computers and, increasingly, these phones themselves are on the Internet. Not only will there be hundreds of millions of them but they will move about! Mobility brings its own set of problems: wireless connections are subject to rapid changes in transmission speeds and error rates; an IP address is no longer a reliable clue as to where in the world a host is located.

Plainly the Internet has already adapted somewhat to support today's applications and host mobility. However, the adaptations have often been piece-meal, and stresses and strains sometimes appear. Researchers today must not only look at how better to adapt the Internet to today's applications but must also anticipate the huge changes that are, inevitably, around the corner. The authors of this book have, between them, accumulated many years researching novel techniques for optimising novel technologies within the Internet. They are well placed to understand the problems that must be solved and what solutions might be feasible. They begin by describing the key features of the Internet as it has evolved and the problems that must be addressed if it is to become flexible enough to support today's applications and mobility. They then look at what further adaptations may be needed within the Internet of the future. They do not make the mistake of claiming to know precisely what will be needed. Rather, they have used their knowledge to identify, as their subtitle makes clear, *Six ways to upgrade the Internet*. They explain these upgrades with the aid of carefully chosen examples and illustrations. The result is a book that will be of great benefit to students who wish to progress from an understanding of what the Internet is now towards an understanding of the motivations and techniques that will drive its future.

London, January 2011

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Preface

Through the eyes of billions of Internet users, we have learned how the ease of communication can ignite phenomenal innovation. It is fascinating to witness the new habits and social phenomena created by the Web. However, what happens behind the scenes of our digital ecosystem? It is the network that moves our data around, handles the peak-hour traffic and strives to smoothly deliver the audio-video streams. Networks play a vital role in sustaining the unrelenting evolution of the most demanding Web systems.

Networks have to keep up with unprecedented data volumes while adapt-ing to new communication patterns or, rather, new kinds of traffic. Most applications are now *pervasive*. We expect them to be accessible everywhere, without compromise. We expect the same "look and feel," and the same quality and functionality, irrespective of any other technological constraints. Hence, many fear that the emerging breed of *pervasive applications* will soon render the Internet obsolete. As a matter of fact, a worldwide effort to reinvent the Internet is well underway by the "Future Internet" research community.

Through our active involvement in the investigation and teaching of network protocols, we have come to realize how difficult it is to grasp networking concepts that exceed the horizon of TCP/IP (i.e., the Internet protocol). When it comes to *advanced network protocols*, specialist literature abounds with creative proposals. Yet, very few protocols manage to step out of the laboratory and into the commercial world.

Perhaps our most ambitious task in writing this book was to extract a selection of remarkable ideas from the scientific literature and make them accessible to the non-specialist reader. Our book does not have the objective of embracing the *Future Internet*, though it does introduce a series of *network mechanisms* that will certainly find a place in the next-generation network. We propose six ways to upgrade the Internet and make it more *ubiquitous*, *reactive*, *proactive*, *information-driven*, *distribution-efficient* and *searchable*. In the final chapter, we offer some considerations about the Future Internet, though we have resisted the temptation to give any specific technical solutions.

This book is self-contained and is meant for anybody with an interest in the *post-Internet* era. We use the book to teach *ad hoc networks* and *P2P networks* in our *Communicating Systems* course at the Technical University Eindhoven (The Netherlands). You do not need to have a background in *computer networks* because all necessary concepts are summarized in the first two chapters. We have had to face the challenge of teaching *networking* to students who are not keen mathematicians: our efforts are reflected in this book which does not contain equations or mathematical formulations, but is enriched by examples and illustrations.

Yet, this is not another book for “dummies.” Whoever has taken a classic course in *computer networks* will find our book to be a useful tool for gaining a deeper understanding of more *advanced network mechanisms*.

We hope that scholars in the field will find inspirational ideas within these pages for their research.

January 2011

Antonio Liotta
George Exarchakos

Acknowledgments

This book has been in our mind for several years, but it started as a concrete project only after we moved to the *Technical University of Eindhoven* (The Netherlands). At TU/e we found the inspirational energy that sustained our efforts. Several improvements came after discussions with our colleagues at *Electrical Engineering* and *Computer Science* and thanks to the interactions with our *Communicating Systems* students.

Springer was instrumental in bringing the book to the light of the day. We were lucky to work with an enthusiastic publishing editor who not only championed the book but also taught us a lot of things about writing for non-specialist readers. Many thanks to Rachel Hopkins who patiently copyedited the book in astounding detail.

We are particularly grateful to Lisandro Granville for injecting great ideas into the book. Graham Knight and Raouf Boutaba were the first to provide scientific feedback on the manuscript. Alessandro Liotta helped making Chaps. 1, 3 and 10 readable to the non-technologist.

On a more personal note, we are immensely grateful to our respective partners for supporting us throughout the writing process.

Contents

Acronyms

AODV	Ad-hoc on-demand distance vector
APS	Adaptive probabilistic search
BFS	Breadth-first search
CIDR	Classless inter-domain routing
CPU	Control processing unit
CS	Client–server
CTS	Clear-to-send
DFS	Depth-first search
DHCP	Dynamic host configuration protocol
DHT	Distributed hash table
DiffServ	Differentiated services
DNS	Domain name system
DSL	Digital subscriber line
DV	Distance vector
FTTH	Fiber-to-the-home
HTL	Hops-to-live
IARP	Intrazone routing protocol
ICT	Information and communication technologies
ID	Identifier
IDS	Iterative deepening search
IERP	Interzone routing protocol
IntServ	Integrated services
IP	Internet protocol
IPTV	Internet protocol television
IS	Intelligent search
ISP	Internet service provider
KISS	Keep it simple and stupid
LAN	Local area network
LS	Link state routing
LSP	Link state packet
MACA	Multiple access with collision avoidance

MANET	Multiple ad hoc network
mBFS	Modified breadth-first search
MPR	Multipoint relays
NDP	Neighbor discovery protocol
NL	Neighbor list
NO	Network operator
OLSR	Optimized link state routing
P2P	Peer-to-peer
PC	Personal computer
PKI	Public key infrastructure
QoE	Quality of experience
QoS	Quality of service
RERR	Route error
RFIDs	Radio-frequency identification
RREP	Route reply
RREQ	Route request
RTS	Request-to-send
RW	Random walks
TC	Topology control
TCP	Transmission control protocol
TIB	Topology information base
TTL	Time-to-live
TV	Television
VoD	Video on-demand
VoIP	Voice over IP