Challenges to Reliable Data Transport over Heterogeneous Wireless Networks

by

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B. Tech. (Indian Institute of Technology, Madras) 1993
M.S. (University of California, Berkeley) 1995

A dissertation submitted in partial satisfaction of the
requirements for the degree of
Doctor of Philosophy

in

Computer Science

in the

GRADUATE DIVISION

of the

UNIVERSITY of CALIFORNIA at BERKELEY

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1998

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Date

Date

University of California at Berkeley

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Abstract

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The Transmission Control Protocol (TCP) is the de facto standard for reliable data transmission in the Internet today. While TCP has been tuned to work well over traditional wired networks, its performance over wireless networks is much worse. This performance degradation results from several effects:

- The preponderance of channel error-induced packet losses compared to congestion-induced losses.
- Asymmetric effects and latency variation due to adverse interactions between media-access protocols and TCP.
- Small TCP transmission windows due to low wireless channel bandwidths.

While TCP adapts well to network congestion, it does not adequately handle the vagaries of wireless media. In this thesis, we address these challenges in detail and design solutions to them. These solutions incorporate link-layer techniques as well as enhancements to TCP at the sender and receiver.

The adverse effects of wireless bit-errors on TCP performance arise primarily because TCP misinterprets wireless losses as being due to congestion. We present the design and implementation of a novel protocol, called the Berkeley Snoop Protocol, that exploits cross-layer protocol optimizations to improve performance. In addition, we design a mechanism called Explicit Loss Notification that can successfully distinguish between congestion and channel error-induced packet losses to substantially enhance end-to-end performance. These mechanisms have been demonstrated to provide performance improvements between 100% and 2000% across a range of bit-error rates in various cellular topologies in a Lucent WaveLAN-based wireless LAN, for data transfer to and from mobile hosts and when wireless transit links are present.

Asymmetric networks pose a challenge to feedback-based protocols like TCP, because the characteristics of the reverse path used for acknowledgments (ACKs) have the potential to seriously affect forward performance. We classify asymmetry with respect to TCP performance into several categories, such as bandwidth asymmetry, latency asymmetry, loss-rate asymmetry, etc. We design several end-to-end and transport-aware link-layer solutions, such as ACK filtering, TCP sender adaptation and ACK reconstruction to obtain significantly better performance over such networks. These techniques lead to performance improvements for Internet access over packet radio networks such as Metricom's Ricochet network and for bandwidth-asymmetric networks such as Hybrid's wireless cable network.

Low channel bandwidths are common in many wireless networks as well as on many Internet paths today. This, and the short connections common in many Web transfers, lead to TCP windows being very small. This greatly affects its data-driven loss recovery mechanism and causes a large number of timeouts. In addition to implementing and evaluating the performance of TCP Selective Acknowledgments, we analyze data from packet-level traces of the Web server of the Atlanta Olympic Games to motivate enhancements to TCP's loss recovery mechanism. Our enhancements lead to an Enhanced Recovery scheme for TCP that greatly reduces the number of timeouts when windows are small.

In this research, we learn some general lessons about protocol design for heterogeneous networks. Specifically, we demonstrate the significant performance benefits of cross-layer protocol optimizations, of soft-state agents in the network infrastructure, and the advantages of data-driven loss recovery over timer-driven ones for better performance.

Today, wireless data networks are not widely deployed in the Internet despite the availability of a wide range of wireless technologies: one of the main reasons for this is their poor price-to-performance ratio for reliable data transfers. We believe (and hope!) that by significantly improving end-to-end TCP performance by up to an order of magnitude in some cases, our solutions will accelerate the widespread deployment and adoption of wireless data networks and make them an integral part of the Internet infrastructure of the future.

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Professor Randy H. Katz, Chair

To my great-grandmother, Seethalakshmi,

my grandmother, Janaki,

and my parents, Radha and Balakrishnan

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Acknowledgments

It has been almost five years since I started my graduate education at Berkeley, and when I sit back and think about the number of people who influenced me and helped me complete this dissertation, I am overwhelmed! There is no doubt that this would have been impossible without their help. I hope that I can remember everyone who helped me through this difficult yet rewarding process.

First and foremost, I would like to thank my advisor, Professor Randy Katz, for taking me on as a student about four years ago, even though he knew little about me at the time. It was an extraordinary piece of good fortune that led to my becoming his student. He has been an ideal advisor in every respect, both in terms of technical advice on my research and in terms of professional advice. My choice of career path has been greatly influenced by Randy and I hope that I can live up to his high standards.

I thank Professors Bob Brodersen and Paul Wright for serving on my qualifying exam and dissertation committees. I had a great time working on the Infopad project under Bob's supervision and learnt a lot from my extended association with Infopad. Paul taught one of the most interesting courses that I took, on intelligent manufacturing systems, which broadened my outlook and taught me what *real* engineers do!

I benefited greatly from the technical and career advice given to me by Deborah Estrin, Sally Floyd, Steven McCanne, Vern Paxson, K. K. Ramakrishnan and Srinivasan Seshan. I am grateful to them for this and look forward to interacting with them in the future.

I am grateful to Darrell Long, Patrick Mantey and Eric Rosen of U.C. Santa Cruz for continuous access to the Reinas wireless network. They were very tolerant users of the Snoop protocol and suffered through crashes and downtimes until several bugs were ironed out. I hope that this software continues to serve them well. I would also like to thank numerous members of the wireless and network research communities who downloaded the implementations of Snoop and TCP SACK, installed them (sometimes porting them to other systems), and sent me useful feedback. My work would have been impossible without *ns*, and I thank the members of the VINT project for the splendid simulation testbed.

The Bureaucracy at Berkeley can make life difficult for graduate students, but I had no trouble with Sproul Hall due to the tremendous efforts of Kathryn Crabtree. Her friendly attitude, approachability and sense of humor made it easy to get all administrative problems solved. Terry Lessard-Smith and Bob Miller were wonderful project administrators, responding promptly to my frequent requests for equipment and other goodies. I thank them for their efforts and more importantly, for their warm friendship.

My research was primarily supported by DARPA under contract DAAB07-95-C-D154 and by a Segasoft research grant from the Okawa Foundation. It was also supported by grants or equipment from Hughes Aircraft Corp., Hybrid Networks Inc., Metricom Inc. and the California MICRO program.

I am grateful to Mike Ritter, Mike Cunningham (Metricom Inc.) and Ed Moura (Hybrid Inc.) for helping in the installation of substantial infrastructure for my experimental work. I sincerely thank Ken Lutz, Brian Shiratsuki and Keith Sklower who helped run our testbed.

The Daedalus research group set the stage for this dissertation and the numerous discussions I had with its members greatly improved the quality of my work. I thank its members, past and present—Elan Amir, Tom Henderson, Todd Hodes, Dan Jiang, Giao Nguyen, Venkat Padmanabhan, Srini Seshan, Mark Stemm, Helen Wang and Tao Ye, and the members of the sister Glomop research group—Eric Brewer, Yatin Chawathe, Armando Fox and Steve Gribble—for an intense and fun intellectual environment. My collaborators in this group—Srini, Venkat, Elan and Mark—had an enormous impact in shaping my thinking about networking, systems, and on the contents of this thesis.

One of the distinguishing features of many Berkeley research groups is the semi-annual retreats and Randy's Daedalus group was no exception to this. These retreats, at Tahoe and Monterey, helped shape our research agenda and check our research progress. I got several suggestions and comments from the participants at these retreats over the past three years. In particular, B.R. Badrinath, Mary Baker, J.J. Garcia-Luna, Akhtar Jameel, Barry Leiner, Reiner Ludwig, Kevin Mills, Mike Ritter, Rob Ruth and Subir Varma offered useful suggestions and criticism on my work.

The stimulating atmosphere in 443 Soda with Elan, Venkat, Mark and Todd, and its logical extensions to Srini at IBM and Giao and Tom in 473 made it a pleasure to work there every day. The scope of discussions and arguments we had there over the past four years taught me a number of things that are sure to serve me well. Elan, in particular, has taught me a thing or two about being productive and simultaneously having fun; I admire (and hope to replicate!) his work ethic and his resolve to get things done efficiently.

There's more to life than just one's work. I was fortunate to have been part of a wonderful cricket team (Berkeley Cricket Club), have regular racquetball partners (Mark, Andrew Swan, and Srini), and have friends like Andrew, Mark and Ketan Patel introduce me to the vicissitudes of golf.

Srini Seshan played a major part in my graduate career. Over the years, he has listened patiently to numerous ideas, good and bad, and questions I have had and has given me extremely useful and incisive comments in return. I look forward to continue working with him and further developing our friendship.

I owe a special debt of gratitude to my parents and family. They have, more than anyone else, been the reason I have been able to get this far. Words cannot express my gratitude to my parents, my sister Hamsa, my grandmother and great-grandmother who give me their support and love from across the seas. They instilled in me the value of hard work and taught me how to overcome life's disappointments. My wife, Suchitra Raman, gives me her selfless support and love that make me want to excel. I am grateful to her for enriching my life.