

CSci551 Syllabus—SP2015, Friday Section

Minlan Yu

February 28, 2015

Class meets Fridays, 3pm to 5:50pm, beginning Jan 6 and ending May 1. We do not have classes during Spring break. The date and time of the final is Friday, May 8, 2-4pm.

Changes: This syllabus may be updated over the semester. The most recent version can always be found at piazza.

2015-1-1: no changes yet.

Obtaining these papers: All of these papers are available from the CSci551 piazza in PDF format. Because they are copyrighted they are available only for classroom use.

Please register on Piazza, and go to <https://piazza.com/class/i1qta967iq25zc> or search cask551–Yu on piazza.

The *primary* source of content for the class is these papers, so you will want to download and read them. Downloaded they take up about 95MB storage.

Office hours Minlan Yu: 2-3pm Fri Omid Alipourfard: 3-4pm Wed Rui Miao: 5-6pm Tue

Class Pace: We will usually go over two or three papers per day, although sometimes more. The syllabus is designed to be slightly front-loaded, with the intent that we will run a paper or two (or sometimes a full class) behind for part of the semester.

Primary and Supplemental Papers: There are two groups of papers. We will discuss *primary* papers in class. The concepts and details from primary papers are fair game in exams. On the other hand, *supplemental* will not be discussed in class, and you are not required to know details from those papers for exams (although the concepts might, since they are networking papers). You are encouraged to read the supplemental papers if you're interested in an area. (Supplemental papers will also appear on homework 1.)

I am happy to take questions about either primary or supplemental papers in class or office hours.

Other class activities: This syllabus lists exams and papers. You should also expect a class project, typically in three parts (A, B and C), and several homework assignments (often 4, but at least 3 and no more than 6). Dates for these will be given as the semester progresses.

Please note that the class dates are when you are expected to have read the papers. At times during the semester we will probably be behind a couple of papers, but you are encouraged to stay with this syllabus for reading.

1 Reference and background

Supplemental:

All of the textbooks are *optional*. Peterson and Davies and Keshav provide an overview of some of the topics we talk about. They provide helpful background and are generally broader and more consistent in their coverage of networking, but less deep on the subjects we cover in class.

General background about networking: [Peterson00a]

S1. [Peterson00a] Larry L. Peterson and Bruce S. Davie. *Computer Networks: A Systems Approach*. Morgan Kaufmann Publishers, 2000.

Sockets programming (useful for the project): [Stevens03a]

S2. [Stevens03a] W. Richard Stevens, Bill Fenner, and Andrew M. Rudoff. *Unix Network Programming: Volume 1: Networking APIs, Sockets*. Prentice-Hall, third edition edition, 2003.

(The Stevens *TCP/IP Illustrated* books are also excellent references relating the RFCs to the BSD code, but are less useful for class.)

Class 1 (Jan. 16):

Primary: Tips for reading papers: [Hanson99a, Keshav07]

P1. [Hanson99a] Michael J. Hanson. Efficient reading of papers in science. Brochure of unknown origin, revised 1999 by Dylan J. McNamee, 1989.

P2. [Keshav07] S. Keshav. How to read a paper. *SIGCOMM Comput. Commun. Rev.*, 37(3):83–84, July 2007.

Another viewpoint of paper reading [Jamin03a]

P3. [Jamin03a] Sugih Jamin. Paper reading and writing check lists. web page <http://irl.eecs.umich.edu/jamin/courses/eecs589/papers/checklist.html>, November 2003.

Finding and judging new ideas: [Heilmeier92a]

P4. [Heilmeier92a] George H. Heilmeier. Some reflections on innovation and invention. *The Bridge*, 22:12–16, Winter 1992.

No paper, but we will review and discuss: General networking, network addressing.

2 Design principles

Class 2 (Jan. 23):

Primary: The Internet architecture: [Clark88a]

P5. [Clark88a] David D. Clark. The design philosophy of the DARPA internet protocols. In *Proceedings of the 1988 Symposium on Communications Architectures and Protocols*, pages 106–114. ACM, August 1988.

and see the commented version: Clark13a.pdf

TCP/IP: [Cerf74a]

- P6.** [Cerf74a] Vint Cerf and Robert Kahn. A protocol for packet network interconnection. *IEEE Transactions on Communications*, COM-22(5):637–648, May 1974.

The end-to-end argument: [Saltzer81a]

- P7.** [Saltzer81a] J. H. Saltzer, D. P. Reed, and D. D. Clark. End-to-end arguments in system design. *Proceedings of the 2nd International Conference on Distributed Computing Systems*, pages 509–512, April 1981.

Supplemental:

How “tussles” affect network architecture: [Clark02a]

- S3.** [Clark02a] David D. Clark, John Wroclawski, Karen Sollins, and Robert Braden. Tussle in cyberspace: Defining tomorrow’s internet. In *Proceedings of the ACM SIGCOMM Conference*, pages 347–356, Pittsburgh, PA, USA, August 2002. ACM.

3 Software-Defined Networking

Minlan is away. TA will give the lecture. Tutorial on Mininet.

Class 3 (Jan. 30):

Managing an enterprise network (OpenFlow Origins): [Casado09a]

- P8.** [Casado09a] Martin Casado, Michael J. Freedman, Justin Pettit, Jianying Luo, Natasha Gude, Nick McKeown, and Scott Shenker. Rethinking enterprise network control. *ACM/IEEE Transactions on Networking*, 17(4):1270–1283, August 2009.

Class 4 (Feb. 6):

Naming: [Saltzer82a]

- P9.** [Saltzer82a] Jermome H. Saltzer. On the naming and binding of network destinations. In *International Symposium on Local Computer Networks*, pages 311–317, April 1982.

FastPass [Perry14a]

- P10.** [Perry14a] Jonathan Perry, Amy Ousterhout, Hari Balakrishnan, Devavrat Shah, and Hans Fugal. Fastpass: A centralized “zero-queue” datacenter network. In *SIGCOMM*, 2014.

Supplemental:

Information-centric networking: [Jacobson12a]

- S4.** [Jacobson12a] Van Jacobson, Diana K. Smetters, James D. Thornton, Michael Plass, Nick Briggs, and Rebecca Braynard. Networking named content. *Communications of the ACM*, 55(1):117–124, January 2012.

Programming SDNs: [Foster13a]

- S5.** [Foster13a] Nate Foster, Michael J. Freedman, Arjun Guha, Rob Harrison, Naga Praveen Katta, Christopher Monsanto, Joshua Reich, Mark Reitblatt, Jennifer Rexford, Cole Schlesinger, Alec Story, and David Walker. Languages for software-defined networks. *IEEE Communications Magazine*, 51(2):128–134, February 2013.

4 Interdomain Routing

Class 5 (Feb. 13):

Primary:

Review of routing. (Will use class notes, plus please review your EE450 work.)

BGP introduction: [Caesar05a]

- P11.** [Caesar05a] Matthew Caesar and Jennifer Rexford. BGP routing policies in ISP networks. *IEEE Network Magazine*, 19(6):5–11, November 2005.

Routing stability and oscillation (plus a taste of queueing theory): [Shaikh00a]

- P12.** [Shaikh00a] Aman Shaikh, Lampros Kalampoukas, Rohit Dube, and Anujan Varma. Routing stability in congested networks: Experimentation and analysis. In *Proceedings of the ACM SIGCOMM Conference*, pages 163–174, Stockholm, Sweden, August 2000. ACM.

Supplemental:

Synchronization problems in routing (but also applies much wider): [Floyd94b]

- S6.** [Floyd94b] S. Floyd and V. Jacobson. The synchronization of periodic routing messages. *ACM/IEEE Transactions on Networking*, 2(2):122–136, April 1994.

5 Internet Topology

Primary:

Routing outages, results, and causes: [Wang06b]

- P13.** [Wang06b] Feng Wang, Zhuoqing Morley Mao, Jia Wang, Lixin Gao, and Randy Bush. A measurement study on the impact of routing events on end-to-end Internet path performance. In *Proceedings of the ACM SIGCOMM Conference*, pages 375–386, Pisa, Italy, August 2006. ACM.

Path inflation: [Spring03a]

- P14.** [Spring03a] Neil Spring, Ratul Mahajan, and Thomas Anderson. Quantifying the causes of path inflation. In *Proceedings of the ACM SIGCOMM Conference*, pages 113–124, Karlsruhe, Germany, August 2003. ACM.

Network topology: [Oliveira08a]

- P15.** [Oliveira08a] Ricardo V. Oliveira, Dan Pei, Walter Willinger, Beichuan Zhang, and Lixia Zhang. In search of the elusive ground truth: the Internet’s AS-level connectivity structure. In *Proceedings of the ACM SIGMETRICS*, pages 217–228. ACM, June 2008.

Class 6 (Feb. 20):

Measuring ISP topologies: [Spring02a]

- P16.** [Spring02a] Neil Spring, Ratul Mahajan, and David Wetherall. Measuring isp topologies with rocketfuel. In *ACM SIGCOMM Computer Communication Review*, volume 32, pages 133–145. ACM, 2002.

Supplemental:

Routing hierarchy and policy: [Gao01b]

- S7.** [Gao01b] Lixin Gao. On inferring autonomous system relationships in the Internet. *ACM/IEEE Transactions on Networking*, 9(6):733–745, December 2001.

Delay-tolerant networking: [Fall08a]

- S8.** [Fall08a] Kevin Fall and Stephen Farrell. DTN: An architectural retrospective. *IEEE Journal of Selected Areas in Communication*, 26(5):828–837, June 2008.

Classic cases where policy choices in peerings result in oscillations: [Griffin99a]

- S9.** [Griffin99a] Timothy G. Griffin and Gordon Wilfong. An analysis of BGP convergence properties. In *Proceedings of the ACM SIGCOMM Conference*, pages 277–288, Cambridge, MA, USA, September 1999. ACM.

6 Internet Traffic

Primary:

Packet-level network dynamics: [Paxson99b]

- P17.** [Paxson99b] Vern Paxson. End-to-end Internet packet dynamics. *ACM/IEEE Transactions on Networking*, 7(3):277–292, June 1999.

Changes to the network traffic mix: [Labovitz10c]

- P18.** [Labovitz10c] Craig Labovitz, Scott Iekel-Johnson, Danny McPherson, Jon Oberheide, and Farnam Jahanian. Internet inter-domain traffic. In *Proceedings of the ACM SIGCOMM Conference*, pages 75–86, New Delhi, India, August 2010. ACM.

7 Transport protocols, Congestion Control, and Queue Management

Class 7 (Feb. 27):

Primary: TCP and congestion control: [Jacobson88a]

- P19.** [Jacobson88a] Van Jacobson. Congestion avoidance and control. In *Proceedings of the ACM SIGCOMM Conference*, pages 314–329, Stanford, California, USA, August 1988. ACM.

Congestion control from first principles: [Ramakrishnan90a]

- P20.** [Ramakrishnan90a] K. K. Ramakrishnan and Raj Jain. A binary feedback scheme for congestion avoidance in computer networks. *ACM Transactions on Computer Systems*, 8(2):158–181, May 1990.

Modeling TCP: [Padhye98a]

- P21.** [Padhye98a] J. Padhye, V. Firoiu, D. Towsley, and J. Kurose. Modelling TCP throughput: A simple model and its empirical validation. In *Proceedings of the ACM SIGCOMM Conference*, pages 303–314, Vancouver, Canada, September 1998. ACM.

Supplemental:
[Cerf74a]

[Cerf74a] see above.

Congestion control by exhaustive computer search: [Winstein13a]

S10. [Winstein13a] Keith Winstein and Hari Balakrishnan. TCP ex machina: Computer-generated congestion control. In *Proceedings of the ACM SIGCOMM Conference*, pages 123–134, Hong Kong, China, August 2013. ACM.

TCP follow-up. XCP and other transport protocols. Queue management. Fair queueing.

Primary:

Active queue management, such as fair queueing: [Demers89a]

P22. [Demers89a] Alan Demers, Srinivasan Keshav, and Scott Shenker. Analysis and simulation of a fair queueing algorithm. In *Proceedings of the ACM SIGCOMM Conference*, pages 1–12, Austin, Texas, September 1989. ACM.

Class 8 (Mar. 6):

XCP and non-TCP congestion control: [Katabi02a]

P23. [Katabi02a] Dina Katabi, Mark Handley, and Charlie Rohrs. Congestion control for high bandwidth-delay product networks. In *Proceedings of the ACM SIGCOMM Conference*, pages 89–102, Pittsburgh, PA, USA, August 2002. ACM.

TeXCP: [Kandula05a]

P24. [Kandula05a] Srikanth Kandula, Dina Katabi, Bruce Davie, and Anna Charny. Walking the Tightrope: Responsive Yet Stable Traffic Engineering. In *ACM SIGCOMM*, Philadelphia, PA, August 2005.

Multipath TCP: [Wischik11]

P25. [Wischik11] Damon Wischik, Costin Raiciu, Adam Greenhalgh, and Mark Handley. Design, implementation and evaluation of congestion control for multipath TCP. In *NSDI*, 2011.

Supplemental:

8 Midterm

Class 9 (Mar. 13):

midterm exam We will first cover papers that’s left over in the class. Answer questions you have about previous papers. The midterm exam will be the second half of the class period.

Supplemental:

9 Wireless and Mobile Networking

Primary:

MAC protocols: [Bharghavan94a]

- P26.** [Bharghavan94a] Vaduvur Bharghavan, Alan Demers, Scott Shenker, and Lixia Zhang. MACAW: A media access protocol for wireless LANs. In *Proceedings of the ACM SIGCOMM Conference*, pages 212–225, London, UK, September 1994. ACM.

Mobile (cellular) networks: [Huang13a]

- P27.** [Huang13a] Junxian Huang, Feng Qian, Yihua Guo, Yuanyuan Zhou, Qiang Xu, and Z. Morley Mao. An in-depth study of LTE: Effect of network protocol and application behavior on performance. In *Proceedings of the ACM SIGCOMM Conference*, pages 363–374, Hong Kong, China, Aug 2013. ACM.

Supplemental:

Wireless propagation characteristics: [Aguayo04a]

- S11.** [Aguayo04a] Daniel Aguayo, John Bicket, Sanjit Biswas, Glenn Judd, and Robert Morris. Link-level measurements from an 802.11b mesh network. In *Proceedings of the ACM SIGCOMM Conference*, pages 121–132, Portland, Oregon, USA, August 2004. ACM.

Wireless security: [Borisov01a]

- S12.** [Borisov01a] Nikita Borisov, Ian Goldberg, and David Wagner. Intercepting mobile communications: The insecurity of 802.11. In *Proceedings of the ACM International Conference on Mobile Computing and Networking*, pages 180–189, Rome, Italy, July 2001. ACM.

Wireless software radios: [Bahl09a]

- S13.** [Bahl09a] Paramvir Bahl, Ranveer Chandra, Thomas Moscibroda, Rohan Murty, and Matt Welsh. White space networking with Wi-Fi like connectivity. In *Proceedings of the ACM SIGCOMM Conference*, pages 27–39, Barcelona, Spain, August 2009. ACM.

10 Spring Break

Spring break and no class on Mar. 20.

11 Network Security

Class 10 (Mar. 27):

Primary:

Onion routing (TOR): [Dingledine04a]

- P28.** [Dingledine04a] Roger Dingledine, Nick Mathewson, and Paul Syverson. Tor: The second-generation onion router. In *Proceedings of the 13th USENIX Security Symposium*, pages 303–320, San Diego, CA, USA, August 2004. USENIX.

Routing security: [Lychev13a]

- P29.** [Lychev13a] Robert Lychev, Sharon Goldberg, and Michael Schapira. Bgp security in partial deployment. *SIGCOMM*, 2013.

Supplemental:

Denial of service attacks: [Hussain03b]

- S14.** [Hussain03b] Alefiya Hussain, John Heidemann, and Christos Papadopoulos. A framework for classifying denial of service attacks. In *Proceedings of the ACM SIGCOMM Conference*, pages 99–110, Karlsruhe, Germany, August 2003. ACM.

Worm propagation: [Staniford02a]

- S15.** [Staniford02a] Stuart Staniford, Vern Paxson, and Nicholas Weaver. How to Own the Internet in your spare time. *Proceedings of the 11th USENIX Security Symposium*, pages 149–167, August 2002.

End-to-end encryption: [Popa14a]

- S16.** [Popa14a] Raluca Ada Popa, Emily Stark, Jonas Helfer, Steven Valdez, Nickolai Zeldovich, M. Frans Kaashoek, and Hari Balakrishnan. Building web applications on top of encrypted data using Mylar. In *Proceedings of the 11th USENIX Symposium on Network Systems Design and Implementation*, pages 157–172, Seattle, WA, USA, April 2014. USENIX.

(Note that, in this class, we intentionally do not do the cryptographic side of network security. There is coverage of that material in CSci555, Graduate Operating Systems, and most of CSci530, Security Systems, is about that.)

Unfortunately there is not time to talk about security and network protocols in CSci551. CSci555 provides a good coverage of security from an operating systems perspective; see the papers by Voydock and Kent and Needham and Schroder there.

12 Content Delivery Networks, Distributed Hash Tables

Class 11 (Apr. 3):

Primary:

Efficient peer-to-peer storage: [Stoica00a]

- P30.** [Stoica00a] Ion Stoica, Robert Morris, David Karger, M. Frans Kaashoek, and Hari Balakrishnan. Chord: A scalable peer-to-peer lookup service for Internet applications. In *Proceedings of the ACM SIGCOMM Conference*, pages 149–160, Stockholm, Sweden, September 2000. ACM.

Akamai networks: [Nygren10a]

- P31.** [Nygren10a] Erik Nygren, Ramesh K Sitaraman, and Jennifer Sun. The akamai network: a platform for high-performance internet applications. *ACM SIGOPS Operating Systems Review*, 44(3):2–19, 2010.

Supplemental:

Freenet and anonymous peer-to-peer file sharing: [Clarke02a]

- S17.** [Clarke02a] Ian Clarke, Theodore W. Hong, Scott G. Miller, Oskar Sandberg, and Brandon Wiley. Protecting free expression online with Freenet. *IEEE Internet Computing*, 6(1):40–49, February 2002.

Privacy built over BitTorrent in OneSwarm: [Isdal10a]

Quality of service and admission control: [?]

Lighter-weight QoS: [?]

- S18.** [Isdal10a] Tomas Isdal, Michael Piatek, Arvind Krishnamurthy, and Thomas Anderson. Privacy-preserving P2P data sharing with OneSwarm. In *Proceedings of the ACM SIGCOMM Conference*, pages 111–122, New Delhi, India, August 2010. ACM.

13 Network virtualization

Class 12 (Apr. 10):

Internet Virtualization: [Anderson05a]

- P32.** [Anderson05a] Thomas Anderson, Larry Peterson, Scott Shenker, and Jonathan Turner. Overcoming the internet impasse through virtualization. *Computer*, 38(4):34–41, 2005.

Data center virtualization: [Koponen14a]

- P33.** [Koponen14a] Teemu Koponen, Keith Amidon, Peter Balland, Martín Casado, Anupam Chanda, Bryan Fulton, Igor Ganichev, Jesse Gross, Natasha Gude, Paul Ingram, et al. Network virtualization in multi-tenant datacenters. In *Networked Systems Design and Implementation*, 2014.

14 Cloud Computing

Class 13 (Apr. 17):

Primary:

While most of the class focuses on protocols that connect things, this class focuses on how one builds data services that can sit at one end of the connection, often the “inside” of the cloud. For more work in this direction, see CSci555 (graduate operating systems) and distributed computing.

Data-parallel processing with map/reduce: [Dean04a]

- P34.** [Dean04a] Jeffrey Dean and Sanjay Ghemawat. MapReduce: Simplified data processing on large clusters. In *Proceedings of the USENIX Symposium on Operating Systems Design and Implementation*, pages 137–150, San Francisco, California, USA, December 2004. USENIX.

Spark: [Zaharia12a]

- P35.** [Zaharia12a] Matei Zaharia, Mosharaf Chowdhury, Tathagata Das, Ankur Dave, Justin Ma, Murphy McCauley, Michael J Franklin, Scott Shenker, and Ion Stoica. Resilient distributed datasets: A fault-tolerant abstraction for in-memory cluster computing. In *Proceedings of the 9th USENIX conference on Networked Systems Design and Implementation*, pages 2–2. USENIX Association, 2012.

15 Data Center Networks

Class 14 (Apr. 24):

Minlan is away. TA will give the lecture.

Primary:

Topology: [Greenberg09a]

P36. [Greenberg09a] Albert Greenberg, James R. Hamilton, Navendu Jain, Srikanth Kandula, Changhoon Kim, Parantap Lahiri, David A. Maltz, and Parveen Pat. VL2: A scalable and flexible data center network. In *Proceedings of the ACM SIGCOMM Conference*, pages 51–62, Barcelona, Spain, August 2009. ACM.

Datacenter traffic: [Benson10a]

P37. [Benson10a] Theophilus Benson, Aditya Akella, and David A Maltz. Network traffic characteristics of data centers in the wild. In *Proceedings of the 10th ACM SIGCOMM conference on Internet measurement*, pages 267–280. ACM, 2010.

Datacenter TCP: [Alizadeh10a]

P38. [Alizadeh10a] Mohammad Alizadeh, Albert Greenberg, David A. Maltz, Jitendra Padhye, Parveen Patel, Balaji Prabhakar, Sudipta Sengupta, and Murari Sridharan. Data center TCP (DCTCP). In *Proceedings of the ACM SIGCOMM Conference*, New Delhi, India, August 2010. ACM.

Managing Google’s WAN: [Jain13a]

P39. [Jain13a] Sushant Jain, Alok Kumar, Joon Ong Subhasree Mandal, Leon Poutievski, Arjun Singh, Subbaiah Venkata, Jim Wanderer, Junlan Zhou, Jonathan Zolla Min Zhu, Urs Hölzle, Stephen Stuart, and Amin Vahdat. B4: Experience with a globally-deployed software defined WAN. In *Proceedings of the ACM SIGCOMM Conference*, page to appear, Hong Kong, China, August 2013. ACM.

16 Network Verification

Class 15 (May. 1):

Header-space analysis: [Kazemian12a]

P40. [Kazemian12a] Peyman Kazemian, George Varghese, and Nick McKeown. Header space analysis: Static checking for networks. In *Proceedings of the 9th USENIX Symposium on Network Systems Design and Implementation*, San Jose, CA, USA, April 2012. USENIX.

VeriFlow: [Khurshid13a]

P41. [Khurshid13a] Ahmed Khurshid, Xuan Zou, Wenxuan Zhou, Matthew Caesar, and P Godfrey. Veriflow: Verifying network-wide invariants in real time. *NSDI*, 2013.

17 Multicast Routing, Transport, and Applications

Multicast was a major push in networking in the 1990s, and it is standardized, deployed, and used in some niches. However a glut of bandwidth and technical challenges dealing with state (most protocols required per-multicast-group state in routers) means that wide-area IP multicast does not seem to have prospered. The techniques developed in multicast are interesting, worth understanding, and used by some. But as of FA2014, they are all supplemental.

Supplemental:

Multicast routing (flood-and-prune, rendezvous): (for [Deering88b], please read only sections 1–4, pages 85–103): [Deering88b]

S19. [Deering88b] Stephen E. Deering. Multicast routing in internetworks and extended LANs. In *Proceedings of the ACM SIGCOMM Conference*, pages 55–64, Stanford, CA, August 1988. ACM.

Reliable multicast and SRM: (for [Floyd97c], please read only through section 7.1, page 15)) [Floyd97c]

S20. [Floyd97c] Sally Floyd, Van Jacobson, Ching-Gung Liu, Steven McCanne, and Lixia Zhang. A reliable multicast framework for light-weight sessions and application level framing. *ACM/IEEE Transactions on Networking*, 5(6):784–803, December 1997.

File distribution and coding: [Byers98a]

S21. [Byers98a] John W. Byers, Michael Luby, Michael Mitzenmacher, and Ashutosh Rege. A digital fountain approach to reliable distribution of bulk data. In *Proceedings of the ACM SIGCOMM Conference*, pages 56–67, Vancouver, Canada, September 1998. ACM.

Multimedia: [Bolot94a]

S22. [Bolot94a] Jean-Chrysostome Bolot, Thierry Turlettil, and Ian Wakeman. Scalable feedback control for multicast video distribution in the Internet. In *Proceedings of the ACM SIGCOMM Conference*, pages 58–67, London, United Kingdom, September 1994. ACM.

18 Privacy and Ethics

Supplemental:

Network data collection and differential privacy: [McSherry10a]

S23. [McSherry10a] Frank McSherry and Ratul Mahajan. Differentially-private network trace analysis. In *Proceedings of the ACM SIGCOMM Conference*, pages 123–134, New Delhi, India, August 2010. ACM.

19 Other Topics: Hardware and Software in Routers and Devices

These are topics we cannot cover but that are considered in some similar network courses. All these materials are supplemental.

Supplemental:

Router design: [Partridge98a]

S24. [Partridge98a] Craig Partridge, Steve Kohalmi, Tracy Ma, John Mcallen, Trevor Mendez, Walter C. Milliken, Ronald Pettyjohn, John Rokosz, Joshua Seeger, Michael Sollins, Steve Storch, Philip P. Carvey, Benjamin Tober, Gregory D. Troxel, Ed Burgess, Isidro Castineyra, Tom Clarke, Lise Graham, Michael Hathaway, Phil Herman, and Allen King. A fifty gagabit per second IP router. *ACM/IEEE Transactions on Networking*, 6(3):237–248, June 1998.

Router software (Click): (NEW-FA2014) [Kohler00a]

S25. [Kohler00a] Eddie Kohler, Robert Morris, Benjie Chen, John Jannotti, and M. Frans Kaashoek. The Click modular router. *ACM Transactions on Computer Systems*, 18(3):263–297, August 2000.

Optical networking: [Mukherjee00a]

S26. [Mukherjee00a] Biswanath Mukherjee. WDM optical communication networks: Progress and challenges. *IEEE Journal of Selected Areas in Communication*, 18(10):1810–1824, October 2000.

RFID-inspired energy harvesting networks: (NEW-FA2014) [Liu13a]

S27. [Liu13a] Vincent Liu, Aaron Parks, Vamsi Talla, Shyamnath Gollakota, David Wetherall, and Joshua R. Smith. Ambient backscatter: Wireless communication out of thin air. In *Proceedings of the ACM SIGCOMM Conference*, pages 39–50, Hong Kong, China, August 2013. ACM.

20 Final Exam

The final exam is **Monday, May 8, 2pm–4pm**.