

CSci551/651 Syllabus—FA2024, Monday/Wednesday Section

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August 12, 2024

Class meets Monday and Wednesday, 10am to 11:50pm, beginning Monday August 26 and ending Wednesday December 4, with a final exam on Monday December 16 at 8am. There will be no class on September 2 (Labor day) nor on November 27 (Thanksgiving recess). We will have **two short midterms** at 10am September 23 and 10am October 28. The date and time of the final is Monday, 2024-12-16, 8am–10am.

All students are expected to confirm they can make both the midterm and final exams—we do not offer alternative dates.

All classes will be hybrid in-person and online via DEN’s web videoconferencing. DEN prefers Cisco WebEx as the platform and we will use that. I have an interactive lecture style and will do my best to adapt it to online class—I *strongly encourage* students to attend class synchronously and be prepared to comment during class to get the most out of class.

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

2024-07-05: no changes yet

2024-08-08: moved [Demers89a] forward one week.

2024-08-12: moved the TCP papers forward to week 3.

Obtaining class papers: All class papers are available from the CSci551/651 Moodle site (described below) in PDF format. Because they are copyrighted they are available only for classroom use. The Moodle site is only available to students with class-specific accounts.

To get a Moodle account, go to <http://www.isi.edu/~johnh/cs651.html> and follow the instructions, or e-mail the professor or TA.

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

A good option for handling the paper is to get some kind of an e-reader. Several class members and the professor did that last year. You need something that can display 8.5×11 inch PDF files comfortably. Tables work well for this—the iPad is common (I previously used the iAnnotate PDF reader and note-taker), and Android tablets also work well (I currently use the Xodo PDF Reader and annotator). The reMarkable e-ink tablet is beautiful and light, although I’m not as fond of their proprietary annotations. In 2024 there are some new fast-update e-ink readers that look promising—if you try one, please let me know what you think. In 2024 the Kindle script might be worth trying, but some reports are that it’s PDF management and annotations mechanisms are limited.

Printing out the papers is also tried and true, and note taking with pencils works well. If you print the papers out, I *strongly* encouraged you to use a double-sided printer. You will need a 3-inch binder if you keep them that way. (If you have to pay for printing, you may find it cheaper to get together with other students to print one copy and photocopy additional ones. Please do so safely during the pandemic.)

Some of the papers were scanned. These tend to have large (2–5MB) PDF files, and may look slightly fuzzy when printed. Some of the papers may not display well in Acrobat on the screen, but they all should

look reasonable when printed.

In SP2005 we tried making hardcopies of the papers available to students. Unfortunately, USC requires that we charge for these (to recover the duplication costs), and the copyright owners (ACM, IEEE, etc.) insist that if there is *any* charge, then they must get a copyright fee. The total fee for the entire paper set was well over \$250, and it was still more than \$100 even if the optional papers were eliminated. For this reason I do not plan to make hardcopies available.

In this syllabus, “new” indicates papers that are new since my section of CSci651 or CSci551 from FA2022. (There will be other variations between my section and sections taught by other professors.)

Class Pace: We will usually go over three or four papers or so per week, and occasionally 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 is 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

Class Week 1 (Aug. 26 and Aug. 28):

Project A assigned August 25, due September 10.

Primary: Tips for reading papers: [Hanson99a]

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

Another viewpoint of paper reading [Jamin03a]

P2. [Jamin03a] Sugih Jamin. Paper reading and writing check lists. web page <http://irl.eecs.umich.edu/jamin/courses/eecs589/papers/checklist.html>, November 2003.

What to look for in systems papers: [Levin83a]

P3. [Levin83a] Roy Levin and David D. Redell. An evaluation of the ninth SOSP submissions, or how (and how not) to write a good systems paper. *ACM Operating Systems Review*, 17(3):35–40, July 1983.

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, data marshalling, packet formats and encoding.

2 Design principles

Class Week 2 (Sep. 2 and Sep. 4):

No class Sept. 2 due to Labor Day, a USC holiday.

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.

Naming: [Saltzer82a]

- P6. [Saltzer82a] Jermome H. Saltzer. On the naming and binding of network destinations. In *International Symposium on Local Computer Networks*, pages 311–317, April 1982.

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]

- S1. [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 Transport protocols, Congestion Control

(Usually we do transport protocols later in the semester, but they relate to the class project so we’re doing them earlier this time.)

Class Week 3 (Sep. 9 and Sep. 11):

Project B assigned Sep. 9, due October 15.

Primary:

TCP and congestion control: [Jacobson88a]

- P8. [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]

- P9.** [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.

Class Week 4 (Sep. 16 and Sep. 18): **TCP modeling and next generation**

Bottleneck Bandwidth and Round-trip TCP [Cardwell17a]

- P10.** [Cardwell17a] Neal Cardwell, Yuchung Cheng, C. Stephen Gunn, Soheil Hassas Yeganeh, and Van Jacobson. BBR: Congestion-based congestion control. *Communications of the ACM*, 60(2):58–66, February 2017.

Supplemental:

An early academic paper on TCP, prompting the 2004 Turing Award for its authors: [Cerf74a]

- S2.** [Cerf74a] Vint Cerf and Robert Kahn. A protocol for packet network interconnection. *IEEE Transactions on Communications*, COM-22(5):637–648, May 1974.

Modeling TCP: [Padhye98a]

- S3.** [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.

TCP extensions for a datacenter: [Alizadeh10a]

- S4.** [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.

4 Unicast Routing

Class Week 5 (Sep. 23):

Short Midterm 1 will be the first 35 minutes of September 23.

Primary:

Review of unicast and distance vector 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.

Routing security:

[Goldberg14a]

- P13.** [Goldberg14a] Sharon Goldberg. Why is it taking so long to secure Internet routing? *Communications of the ACM*, 57(10):56–63, October 2014.

Supplemental:

Additional background about BGP: [Balakrishnan08a]

- S5.** [Balakrishnan08a] Hari Balakrishnan. Interdomain internet routing. web page <http://stellar.mit.edu/S/course/6/sp08/6.829/courseMaterial/topics/topic4/lectureNotes/noname/noname>, Spring 2008.

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.

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.

NEW: Google’s peering approach (Espresso) [Yap17a]

- S8.** [Yap17a] Kok-Kiong Yap, Murtaza Motiwala, Jeremy Rahe, Steve Padgett, Matthew Holiman, Gary Baldus, Marcus Hines, Taeun Kim, Ashok Narayanan, Ankur Jain, Victor Lin, Colin Rice, Brian Rogan, Arjun Singh, Bert Tanaka, Manish Verma, Puneet Sood, Mukarram Tariq, Matt Tierney, Dzevad Trumic, Vytautas Valancius, Calvin Ying, Mahesh Kallahalla, Bikash Koley, and Amin Vahdat. Taking the edge off with Espresso: Scale, reliability and programmability for global Internet peering. In *Proceedings of the ACM SIGCOMM Conference*, pages 432–445, Los Angeles, CA, USA, August 2017. ACM.

Class Week 6 (Sep. 30 and Oct. 2): **Network measurement: outages, topology, traffic**

Primary:

Network topology: [Oliveira08a]

- P14.** [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.

Edge-network outages: [Quan13c]

- P15.** [Quan13c] Lin Quan, John Heidemann, and Yuri Pradkin. Trinocular: Understanding Internet reliability through adaptive probing. In *Proceedings of the ACM SIGCOMM Conference*, pages 255–266, Hong Kong, China, August 2013. ACM.

This is your network on Covid: [Boettger20a]

- P16.** [Boettger20a] Timm Böttger, Ghida Ibrahim, and Ben Vallis. How the Internet reacted to Covid-19—a perspective from Facebook’s edge network. In *Proceedings of the ACM Internet Measurement Conference*, pages 34–41, Pittsburgh, PA, USA, October 2020. ACM.

Supplemental:

Congestion in the network: [Dhamdhere18a]

- S9.** [Dhamdhere18a] Amogh Dhamdhere, David D. Clark, Alexander Gamero-Garrido, Matthew Luckie, Ricky K. P. Mok, Gautam Akiwate, Kabir Gogia, Vaibhav Bajpai, Alex C. Snoeren, and kc claffy. Inferring persistent interdomain congestion. In *Proceedings of the ACM SIGCOMM Conference*, pages 1–15, Budapest, Hungary, August 2018. ACM.

Routing outages, results, and causes: [Wang06b]

- S10.** [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.

NEW Flow-level rerouting with Proactive ReRoute at Google: [Wetherall23a]

- S11.** [Wetherall23a] David Wetherall, Abdul Kabbani, Van Jacobson, Jim Winget, Yuchung Cheng, Morrey, Charles B., Uma Moravapalle, Phillipa Gill, Steven Knight, and Amin Vahdat. Improving network availability with protective ReRoute. In *Proceedings of the ACM SIGCOMM Conference*, pages 684–695, New York, NY, USA, September 2023. ACM.

Class Week 7 (Oct. 7 and Oct. 9): TCP follow-up. XCP and other transport protocols. Queue management. Fair queueing.

Primary:

(This next paper is about Active Queue Management, and it’s pulled forward from next week to even out the workload.) Active queue management, such as fair queueing: [Demers89a]

- P17.** [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.

Early drop with CoDel: [Nichols12a]

- P18.** [Nichols12a] Kathleen Nichols and Van Jacobson. Controlling queue delay. *Communications of the ACM*, 55(7):42–50, July 2012.

XCP and non-TCP congestion control: [Katabi02a]

- P19.** [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.

Supplemental:

QUIC, an replacement for TCP that avoids head-of-line blocking [Langley17a]

- S12.** [Langley17a] Adam Langley, Alistair Riddoch, Alyssa Wilk, Antonio Vicente, Charles Krasic, Dan Zhang, Fan Yang, Fedor Kouranov, Ian Swett, Janardhan Iyengar, Jeff Bailey, Jeremy Dorfman, Jim Roskind, Joanna Kulik, Patrik Westin, Raman Tanneti, Robbie Shade, Ryan Hamilton, Victor Vasiliev, Wan-Teh Chang, and Zhongyi Shi. The QUIC transport protocol: Design and internet-scale deployment. In *Proceedings of the ACM SIGCOMM Conference*, pages 183–196, Los Angeles, CA, USA, August 2017. ACM.

Congestion control by exhaustive computer search: [Winstein13a]

- S13.** [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.

5 Wireless and Mobile Networking

Class Week 8 (Oct. 14 and Oct. 16):

Project C assigned Oct. 14, due Nov. 19.

Primary:

Non-IP routing in sensor networks: [Intanagonwivat00a]

- P20.** [Intanagonwivat00a] Chalermek Intanagonwivat, Ramesh Govindan, and Deborah Estrin. Directed diffusion: A scalable and robust communication paradigm for sensor networks. In *Proceedings of the ACM International Conference on Mobile Computing and Networking*, pages 56–67, Boston, MA, USA, August 2000. ACM.

Mobile (cellular) networks: 4G LTE performance: [Huang13a]

- P21.** [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.

5G mobile networks: [Narayanan21a]

- P22.** [Narayanan21a] Arvind Narayanan, Xumiao Zhang, Ruiyang Zhu, Ahmad Hassan, Shuwei Jin, Xiao Zhu, Xiaoxuan Zhang, Denis Rybkin, Zhengxuan Yang, Z. Morley Mao, Feng Qian, and Zhi-Li Zhang. A variegated look at 5G in the wild: Performance, power, and QoE implications. In *Proceedings of the ACM SIGCOMM Conference*, pages 610–626, Virtual, August 2021. ACM.

Supplemental:

MAC protocols: [Bharghavan94a]

- S14.** [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.

Wireless propagation characteristics: [Aguayo04a]

- S15.** [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.

More about 5G performance: [Hassan22a]

- S16.** [Hassan22a] Ahmad Hassan, Arvind Narayanan, Anlan Zhang, Wei Ye, Ruiyang Zhu, Shuwei Jin, Jason Carpenter, Z. Morley Mao, Feng Qian, and Zhi-Li Zhang. Vivisecting mobility management in 5g cellular networks. In *Proceedings of the ACM SIGCOMM Conference*, pages 86–100, Amsterdam, Netherlands, August 2022. ACM.

Polymorphic radios: [Rostami18a]

- S17.** [Rostami18a] Mohammad Rostami, Jeremy Gummesson, Ali Kiaghadi, and Deepak Ganesan. Polymorphic radios: A new design paradigm for ultra-low power communication. In *Proceedings of the ACM SIGCOMM Conference*, pages 446–460, Budapest, Hungary, August 2018. ACM.

6 Characterizing Network Traffic

Class Week 9 (Oct. 21 and Oct. 23):

Primary:

Self-similarity in LAN traffic: [Leland94a]

- P23. [Leland94a]** W.E. Leland, M.S. Taqqu, W. Willinger, and D.V. Wilson. On the self-similar nature of Ethernet traffic (extended version). *ACM/IEEE Transactions on Networking*, 2(1):1–15, February 1994.

And in WAN and web traffic: [Crovella97a]

- P24. [Crovella97a]** Mark E. Crovella and Azer Bestavros. Self-similarity in world wide web traffic: evidence and possible causes. *ACM/IEEE Transactions on Networking*, 5(6):835–846, December 1997.

Changes to the network topology: [Labovitz10c]

- P25. [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.

Supplemental:

Packet-level network dynamics: [Paxson99b]

- S18. [Paxson99b]** Vern Paxson. End-to-end Internet packet dynamics. *ACM/IEEE Transactions on Networking*, 7(3):277–292, June 1999.

Economics and availability of broadband: [Paul23a]

- S19. [Paul23a]** Udit Paul, Vinothini Gunasekaran, Jiamo Liu, Tejas N. Narechania, Arpit Gupta, and Elizabeth Belding. Decoding the divide: Analyzing disparities in broadband plans offered by major US ISPs. In *Proceedings of the ACM SIGCOMM Conference*, pages 578–591, New York, NY, USA, September 2023. ACM.

7 Cloud Computing and In the Cloud

Class Week 10 (Oct. 28 and Oct. 30):

Short Midterm 2 will be the first 35 minutes of October 28.

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.

Building large-scale services [Fox97a]

- P26. [Fox97a]** Armando Fox, Steven D. Gribble, Yatin Chawathe, Eric A. Brewer, and Paul Gauthier. Cluster-based scalable network services. In *Proceedings of the 16th Symposium on Operating Systems Principles*, pages 78–91, St. Malo, France, October 1997. ACM.

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

- P27.** [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.

Performance out of the cloud: [Dean13a]

- P28.** [Dean13a] Jeffrey Dean and Luiz André Barroso. The tail at scale. *Communications of the ACM*, 56(2):74–80, February 2013.

Supplemental: NEW: SDN in the cloud: [Ferguson21a]

- S20.** [Ferguson21a] Andrew D. Ferguson, Steve Gribble, Chi-Yao Hong, Charles Killian, Waqar Mohsin, Henrik Muehe, Joon Ong, Leon Poutievski, Arjun Singh, Lorenzo Vicisano, Richard Alimi, Shawn Shuoshuo Chen, Mike Conley, Subhasree Mandal, Karthik Nagaraj, Kondapa Naidu Bollineni, Min Zhu Amr Sabaa, Shidong Zhang, and Amin Vahdat. Orion: Google’s software-defined networking control plane. In *Proceedings of the 18th USENIX Symposium on Network Systems Design and Implementation*, pages 83–98, Virtual Location, April 2021. USENIX.

8 Data Center Networks and Software Defined Networking

What’s the right network to run the apps from the last class?

Class Week 11 (Nov. 4 and Nov. 6):

Running an enterprise network (Ethane, a parent of OpenFlow): [Casado09a]

- S21.** [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.

P4, generalizing OpenFlow: [Bosshart14a]

- S22.** [Bosshart14a] Pat Bosshart, Dan Daly, Glen Gibb, Martin Izzard, Nick McKeown, Jennifer Rexford, Cole Schlesinger, Dan Talayco, Amin Vahdat, George Varghese, and David Walker. P4: Programming protocol-independent packet processors. *ACM Computer Communication Review*, 44(3):88–95, July 2014.

Optimizing a datacenter network: [Greenberg09a]

- S23.** [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.

Getting the data out of the datacenter: [Schlinker17a]

- S24.** [Schlinker17a] Brandon Schlinker, Hyojeong Kim, Timothy Cui, Ethan Katz-Bassett, Harsha V. Madhyastha, Italo Cunha, James Quinn, Saif Hasan, Petr Lapukhov, and Hongyi Zeng. Engineering egress with Edge Fabric: Steering oceans of content to the world. In *Proceedings of the ACM SIGCOMM Conference*, pages 418–431, Los Angeles, CA, USA, August 2017. ACM.

Supplemental:

A review of 10 years of Google datacenter topologies: [Singh15a]

- S25. [Singh15a]** Arjun Singh, Joon Ong, Amit Agarwal, Glen Anderson, Ashby Armistead, Roy Bannan, Seb Boving, Gaurav Desai, Bob Felderman, Paulie Germano, Anand Kanagala, Jeff Provost, Jason Simmons, Eiichi Tada, Jim Wanderer, Urs Hoelzle, Stephen Stuart, and Amin Vahdat. Jupiter rising: A decade of Clos topologies and centralized control in Google’s datacenter network. In *Proceedings of the ACM SIGCOMM Conference*, page to appear, London, UK, August 2015. ACM.

NEW: Facebook’s data center [Roy15a]

- S26. [Roy15a]** Arjun Roy, Hongyi Zeng, Jasmeet Bagga, George Porter, and Alex C. Snoeren. Inside the social network’s (datacenter) network. In *Proceedings of the ACM SIGCOMM Conference*, pages 123–137, London, UK, August 2015. ACM.

Network virtualization in datacenters: [Koponen14a]

- S27. [Koponen14a]** Teemu Koponen, Keith Amidon, Peter Balland, Martín Casado, Anupam Chanda, Bryan Fulton, Igor Ganichev, Jesse Gross, Natasha Gude, Paul Ingram, Ethan Jackson, Andrew Lambeth, Romain Lenglet, Shih-Hao Li, Amar Padmanabhan, Justin Pettit, Ben Pfaff, Rajiv Ramanathan, Scott Shenker, Alan Shieh, Jeremy Stribling, Pankaj Thakkar, Dan Wendlandt, Alexander Yip, and Ronghua Zhang. Network virtualization in multi-tenant datacenters. In *Proceedings of the USENIX Symposium on Network Systems Design and Implementation*, pages 203–216, Seattle, WA, USA, April 2014. USENIX.

9 Network Architecture Past and Future

Class Week 12 (Nov. 11 and Nov. 13):

Primary:

Google’s use of Software Defined Networking for traffic engineering: [Jain13a]

- P29. [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*, pages 3–14, Hong Kong, China, August 2013. ACM.

Information-centric networking: [Jacobson12a]

- P30. [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.

Quality of service and admission control: [Shenker95a]

- P31. [Shenker95a]** Scott Shenker. Fundamental design issues for the future Internet. *IEEE Journal of Selected Areas in Communication*, 13(7):1176–1188, September 1995.

Supplemental:

Modern congestion control and streaming video: [Akhtar18a]

- S28. [Akhtar18a]** Zahaib Akhtar, Yun Seong Nam, Ramesh Govindan, Sanjay Rao, Jessica Chen, Ethan Katz Bassett, Bruno Martins Ribeiro, and Hui Zhang Jibin Zhan. Oboe: Auto-tuning video ABR algorithms to network conditions. In *Proceedings of the ACM SIGCOMM Conference*, pages 44–59, Budapest, Hungary, August 2018. ACM.

Traffic engineering: [Hong13a]

- S29.** [Hong13a] Chi-Yao Hong, Srikanth Kandula, Ratul Mahajan, Ming Zhang, Vijay Gill, Mohan Nanduri, and Roger Wattenhofer. Achieving high utilization with software-driven WAN. In *Proceedings of the ACM SIGCOMM Conference*, pages 15–26, Hong Kong, China, August 2013. ACM.

10 Network Security

Class Week 13 (Nov. 18 and Nov. 20):

Primary:

Spam and anti-spam: [Levchenko11a]

- P32.** [Levchenko11a] Kirill Levchenko, Andreas Pitsillidis, Neha Chachra, Brandon Enright, Márk Félegyházi, Chris Grier, Tristan Halvorson, Chris Kanich, Christian Kreibich, He Liu, Damon McCoy, Nicholas Weaver, Vern Paxson, Geoffrey M. Voelker, and Stefan Savage. Click trajectories: End-to-end analysis of the spam value chain. In *Proceedings of the IEEE Symposium on Security and Privacy*, pages 431–446, Oakland, CA, USA, May 2011. IEEE.

TLS interception: [Raman20a]

- P33.** [Raman20a] Ram Sundara Raman, Leonid Evdokimov, Eric Wurstrow, J. Alex Halderman, and Roya Ensafi. Investigating large scale HTTPS interception in Kazakhstan. In *Proceedings of the ACM Internet Measurement Conference*, pages 125–132, Pittsburgh, PA, USA, October 2020. ACM.

Onion routing (TOR): [Dingledine04a]

- P34.** [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.

Supplemental:

Denial of service attacks: [Hussain03b]

- S30.** [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]

- S31.** [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.

Multi-party TLS: [Naylor15a]

- S32.** [Naylor15a] David Naylor, Kyle Schomp, Matteo Varvello, Ilias Leontiadis, Jeremy Blackburn, Diego Lopez, Konstantina Papagiannaki, Pablo Rodriguez Rodriguez, and Peter Steenkiste. Multi-context TLS (mcTLS): Enabling secure in-network functionality in TLS. In *Proceedings of the ACM SIGCOMM Conference*, page to appear, London, UK, August 2015. ACM.

(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.

11 Peer-to-peer and Content Delivery Networks

Class Week 14 (Nov. 25 and Nov. 27):

Primary:

Efficient peer-to-peer storage: [Stoica00a]

P35. [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.

Microsoft Bing’s anycast CDN: [Calder15a]

P36. [Calder15a] Matt Calder, Ashley Flavel, Ethan Katz-Bassett, Ratul Mahajan, and Jitendra Padhye. Analyzing the performance of an anycast CDN. In *Proceedings of the ACM Internet Measurement Conference*, pages 531–537, Tokyo, Japan, October 2015. ACM.

Latency in and out of the cloud: [Jin19a]

P37. [Jin19a] Yuchen Jin, Sundararajan Renganathan, Ganesh Ananthanarayanan, Junchen Jiang, Venkata N. Padmanabhan, Manuel Schroder, Matt Calder, and Arvind Krishnamurthy. Zooming in on wide-area latencies to a global cloud provider. In *Proceedings of the ACM SIGCOMM Conference*, pages 104–116, Beijing, China, August 2019. ACM.

Supplemental:

Akamai, a modern CDN: [Schomp20a]

S33. [Schomp20a] Kyle Schomp, Onkar Bhardwaj, Eymen Kurdoglu, Mashooq Muhaimen, and Ramesh K. Sitaraman. Akamai DNS: Providing authoritative answers to the world’s queries. In *Proceedings of the ACM SIGCOMM Conference*, pages 465–478, Virtual, July 2020. ACM.

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

S34. [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]

S35. [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.

12 Privacy and Ethics

Class Week 15 (Dec. 2)

No class Nov. 24 due to the Thanksgiving holiday.

Poster Session: we will have a poster session for all people doing research projects on Nov. 25 in the second half of class. The poster session is **required attendance for CSci651 students**.

Ethics and network research: [Dittrich11a]

P38. [Dittrich11a] David Dittrich and Erin Kenneally (editors). The Menlo report: Ethical principles guiding information and communication technology research. Technical report, United States Department of Homeland Security, September 2011.

Supplemental:

Network data collection and differential privacy: [McSherry10a]

S36. [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.

13 Network Diagnosis and Alternative Architectures

Failures in Google’s networks: [Govindan16a]

P39. [Govindan16a] Ramesh Govindan, Ina Minei, Mahesh Kallahalla, Bikash Koley, and Amin Vahdat. Evolve or die: High-availability design principles drawn from google’s network infrastructure. In *Proceedings of the ACM SIGCOMM Conference*, pages 58–72, Florianopolis, Brazil, August 2016. ACM.

NEW-FA2024: A completely different type of cloud networking (balloons): [Uyeda22a]

P40. [Uyeda22a] Frank Uyeda, Marc Alvidrez, Erik Kline, Bryce Petrini, Brian Barritt, David Mandl, and Aswin Chandy Alexander. Sdn in the stratosphere: Loon’s aerospace mesh network. In *Proceedings of the ACM SIGCOMM Conference*, pages 264–280, Amsterdam, Netherlands, August 2022. ACM.

14 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: [Miao17a]

S37. [Miao17a] Rui Miao, Hongyi Zeng, Changhoon Kim, Jeongkeun Lee, and Minlan Yu. Silkroad: Making stateful layer-4 load balancing fast and cheap using switching ASICs. In *Proceedings of the ACM SIGCOMM Conference*, pages 15–28, Los Angeles, CA, USA, August 2017. ACM.

Router software (Click): [Kohler00a]

S38. [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.

RFID-inspired energy harvesting networks: [Liu13a]

S39. [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.

15 Final Exam

The final exam is **Monday, December 16, 8am–10am** (sorry, it's the University's choice of start time).