



**Lahore University of Management Sciences**  
**CS678 - Topics in Internet Research**  
**Spring 2017**

Instructors	Dr. Ihsan Ayyub Qazi and Dr. Zartash Afzal Uzmi
Room No.	SBASSE 9-G14A (Ihsan), SBASSE 9-319 (Zartash)
Office Hours	TBA
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Telephone Ext	8368 (Ihsan) & 8202 (Zartash)
Class Timings	2pm-3:15pm, Tuesday/Thursday
Class Venue	TBA
Course URL	<a href="http://lms.lums.edu.pk">http://lms.lums.edu.pk</a>

Course Basics			
Credit Hours	3 credit hours		
Lecture(s)	2 per week	Duration	75 minutes per lecture

Course Distribution	
Core	None
Elective	All
Open for Student Category	All
Close for Student Category	All

COURSE DESCRIPTION
<p>CS678 is a graduate-level course on computer networking research. It involves lectures, paper reading, discussions, and a semester-long research project. CS678 will focus on the following six key areas in networking research:</p> <ul style="list-style-type: none"><li>○ Network Architecture and Principles</li><li>○ Transports, Congestion Control, and Buffer Sizing</li><li>○ Routers and Routing</li><li>○ Internet Censorship, Anonymity, and Advertising</li><li>○ Cloud Computing and Datacenter Networking</li><li>○ Wireless Networks</li><li>○ ICT for Developing Regions</li></ul> <p>For each of these areas, we will read classical research works as well as explore the state-of-the-art. Students will be required to write paper summaries and participate in class discussions. In addition, students will be expected to make presentations on assigned papers and participate in a semester-long research project.</p>

COURSE PREREQUISITE(S)
<ul style="list-style-type: none"><li>• CS382 (Net-Centric Computing) or CS471 (Computer Networks)</li></ul>

COURSE OBJECTIVES
<ul style="list-style-type: none"><li>• To become familiar with the state-of-the-art in computer networking research</li><li>• To understand how to engage in networking research</li><li>• To investigate novel ideas in computer networks through a semester-long research project</li></ul>

Learning Outcomes
<ul style="list-style-type: none"><li>• Students will have good understanding of the principles behind state-of-the-art network protocols and architectures</li><li>• Students will have gained experience in reading research papers and critically analyzing the research of others</li><li>• Students will gain experience with carrying out an independent research project</li></ul>

Grading Breakup and Policy
<ul style="list-style-type: none"><li>• Quizzes: 10%</li><li>• Attendance and Class Participation: 10%</li></ul>



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- Paper Summaries + Short Presentation(s): 10%
- Long Presentation(s): 5%
- Final Exam: 20%
- Project: 45%
  - Bi-weekly Progress Meetings: 15%
  - Project Proposal: 5%
  - Mid Project Report: 5%
  - Final Report/Presentation: 20%

### Research Project

The semester-long research project is one of the most important components of the course. The goal is to carry out novel research that by the end of the semester would be publishable in a good quality workshop or a conference. Past research projects in this course have been quite successful. Here are some papers that started out as course projects:

- Kamran Nishat, Farrukh Javed, Saim Salman, Nofel Yaseen, Ans Fida, Ihsan Ayyub Qazi, “*SlickFi: A Service Differentiation Scheme for High-Speed WLANs using Dual Radio APs*” in **ACM CoNEXT 2016**, Irvine, CA, USA December 2016
- Aqib Nisar, Aqsa Kashaf, Zartash Afzal Uzmi, Ihsan Ayyub Qazi, “*A Case for Marrying Censorship Measurements with Circumvention*” in **ACM HotNets 2015**, Philadelphia, USA, November 2015
- Hasnain Ali Pirzada, M. Raza Mahboob, Ihsan Ayyub Qazi, “*eSDN: Rethinking Datacenter Transports Using End-Host SDN Controllers*” in **ACM SIGCOMM 2015**, London, UK, August 2015 (poster paper)
- Ruwaifa Anwar, Kamran Nishat, Mohsin Ali, Zahaib Akhtar, Haseeb Niaz, and Ihsan Ayyub Qazi, “*Loss Differentiation: Moving onto High-Speed Wireless LANs*” in **IEEE INFOCOM 2014**, Toronto, Canada
- Aisha Mushtaq, Asad Khalid Ismail, Abdul Wasay, Bilal Mahmood, Ihsan Ayyub Qazi, and Zartash Afzal Uzmi, “*Rethinking Buffer Management in Data Center Networks*” in **ACM SIGCOMM 2014**, Chicago, USA August 2014 (poster paper)
- Ali Munir, Ihsan Ayyub Qazi, Zartash Afzal Uzmi, Aisha Mushtaq, Saad Naveed Ismail, M. Safdar Iqbal, and Basma Khan “*Minimizing Flow Completion Times in Data Centers*” in **IEEE INFOCOM 2013**, Turin, Italy
- Zahaib Akhtar, Kamran Nishat, Haseeb Niaz, Ruwaifa Anwar, Mohsin Ali, and Ihsan Ayyub Qazi, “*BLMon: A Loss Differentiation Scheme for 802.11n*” in **IEEE INFOCOM 2013**, Turin, Italy (poster paper)

### Project Proposal

The project proposal is due on Monday, February 6<sup>th</sup> in the form of a written document (**max 2 pages**). The proposal should at least have the following sections:

- **Introduction**
  - What is the problem you plan to address? Why is it important to solve?
- **Related Work**
  - What are the most related works? (analyze prior works and cite related papers)
- **Proposed Approach**
  - What is your proposal and how does it differ from prior work?
- **Timeline and Division of Work**
  - Mention a timeline and a division (if there are 2 or more members in the project) of the project tasks

Students will also be expected to deliver a 10-min presentation on the proposal on Friday, February 10<sup>th</sup>.

### Paper Summaries

A short written summary (**max 1/2-page**) of each assigned paper will be due by 8am on the day of the class. The summaries will be expected to cover the following points:

1. What is the problem?
2. What is the solution's main idea?
3. What are the strengths and limitations of the proposed approach?
4. Does the paper (or do you) identify any fundamental/hard trade-offs?

Students will be given bonus points for answering the following question: **a suggestion for extending or building on the paper for future work**. All paper summaries will be submitted on LMS. We will be using piazza this semester for paper discussions. You can sign up for the class at the following URL: <https://piazza.com/lums.edu.pk/spring2017/cs678>

### Bi-weekly Progress Meetings

The purpose of these meetings is to ensure that (a) the research projects are on track and (b) to strategize in case there are any bottlenecks. Students will be expected to submit a list of milestones/tasks achieved (as bullet points) as well as a list of tasks to be carried out in the next two weeks (maximum 5 bullet points can be submitted). These need to be submitted on LMS.

### Mid-Project Report



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Students will be expected to submit a **1-page** mid-project report on the milestones achieved, challenges faced and how you overcame them, and a list of future tasks to be carried out and a plan for the execution of the tasks.

### Final Report

The final report should be structured as a conference/workshop paper and should include (a) description of the problem, (b) problem motivation, (c) your solution/idea, (d) discussion of related works, (e) evaluation of your solution, and (f) a conclusion. We strongly suggest that you write your final report using LaTeX. It is the de-facto tool in which most CS/EE research papers are written. While it has a small start-up cost, it is much easier to collaboratively write research papers using LaTeX than using Word. Here is a sample LaTeX paper (<http://www.cs.cmu.edu/~dga/15-744/S07/sample.tar.gz>) and a MS Word template (sample file: <http://conferences.sigcomm.org/sigcomm/2016/doc/word-acm-10pt-on-12pt-7.0x9.25.doc>) for ACM SIG proceedings).

### Source Code Control

You are required to use GitHub, version control platform for performing source code control for your project as well as for the paper/report you are writing. Please share a link of your public repository by the project proposal deadline.

### Long Presentations

Students will be expected to deliver one or more long presentations (**maximum 15mins, no more than 10 slides**) in the course. We will assign papers to the students randomly. In some circumstances, two students may be assigned to make a joint presentation. It will be expected that the presenters will be prepared to answer any related questions.

### Short Presentations

Students will be expected to present a short (oral) summary of the paper at the start of a class. Students will be chosen *randomly* for this purpose.

### Class Participation (CP)

Students will be expected to participate actively in the class in the form of questions, critique of the paper, new ideas, etc. Grading of CP will also include attendance as a component.

### Policies

- All deadlines are hard
- All assigned work must be done individually (unless specified otherwise)
- Re-grading can be requested within 2 days after grade reporting

### Examination Detail

Midterm Exam	Yes/No: <b>No</b>
Final Exam	Yes/No: <b>Yes</b> Duration: <b>3 hours</b>

	Session	Author(s)	Date	Lead Instructor
1	<b>[Introduction]</b> Introduction & Overview of Networking Research  <i>"How to Read a Paper"</i> in ACM SIGCOMM CCR 2007 <i>"How to build research network systems in your spare time"</i> in ACM SIGCOMM CCR 2010  <b>[Optional]</b> <i>"Forty Data Communications Research Questions"</i> in ACM SIGCOMM CCR 2011 ( <i>useful for research projects</i> )	S. Keshav R. Mahajan  Craig Partridge	24 <sup>th</sup> Jan, 2017	Zartash Afzal Uzmi Ihsan Ayyub Qazi

## Network Architecture and Principles

### Internet Architecture, Software-Defined Networking (SDN), and Network Functions Virtualization (NFV)

2	<b>[Internet Architecture]</b> <i>"The Design Philosophy of the DARPA Internet Protocols"</i> in ACM SIGCOMM 1988  <b>[Optional]</b> <i>"End-to-end Arguments in System Design"</i> in ACM Transactions on Computer Systems <b>[Optional]</b> <i>"Towards an Active Network Architecture"</i> in Computer Communication Review, April 1996	Clarke et al.  Saltzer et al. Tennenhouse et al.	26 <sup>th</sup> Jan, 2017	Ihsan Ayyub Qazi
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3	<p>[<a href="#">Programmable Control Planes: SDN</a>]  <a href="#">[Video]</a> “<i>The future of networking and the past of protocols</i>”, talk by Scott Shenker at the Open Networking Summit, 2011</p> <p>“<i>OpenFlow: Enabling Innovation in Campus Networks</i>” in ACM SIGCOMM CCR 2008 (focus on Section 2 and onwards)</p> <p>[Optional] “<i>The Road to SDN: An intellectual history of programmable networks</i>” in ACM Queue 2013  [Optional] “<i>Onix: A Distributed Control Platform for Large-scale Production Networks</i>” in OSDI 2010  <a href="#">[Slides]</a> “<i>Software-defined networking</i>”, IEEE INFOCOM 2009</p>	<p>Scott Shenker</p> <p>McKeown et al.</p> <p>Feamster et al.</p> <p>Koponen et al.</p> <p>Nick McKeown</p>	31 <sup>st</sup> Jan, 2017	Zartash Afzal Uzmi
4	<p>[<a href="#">SDN Use Case: Middleboxes</a>]  “<i>SIMPLE-fying Middlebox Policy Enforcement Using SDN</i>” in ACM SIGCOMM 2013.</p> <p>[Optional] “<i>OpenNF: Enabling Innovation in Network Function Control</i>” in ACM SIGCOMM 2014</p>	<p>Zafar Ayyub Qazi et al.</p> <p>Aaron Gember-Jacobson et al.</p>	2 <sup>nd</sup> Feb, 2017	Ihsan Ayyub Qazi
5	<p>[<a href="#">Programmable Data Planes</a>]  “<i>Millions of Little Minions: Using Packets for Low Latency Network Programming and Visibility</i>” in ACM SIGCOMM 2014</p> <p>“<i>Programming Protocol-Independent Packet Processors</i>” in ACM SIGCOMM CCR 2014 (just skim through the paper)</p> <p>[More on P4] <a href="#">Barefoot P4 overview</a>, Watch <a href="#">See How P4 Works</a>  [Optional] “<i>Network Functions Virtualization</i>”-White Paper, 2012</p>	<p>Jeyakumar et al.</p> <p>Bosshart et al.</p> <p>Casado et al.</p>	7 <sup>th</sup> Feb, 2017	Zartash Afzal Uzmi
6	<p>[<a href="#">Network Functions Virtualization (NFV)</a>]  “<i>NetVM: High Performance and Flexible Networking Using Virtualization on Commodity Platforms</i>” in NSDI 2014</p> <p>[Optional] “<i>FreeFlow: High Performance Container Networking</i>” in ACM HotNets 2016  [Optional] “<i>netmap: a novel framework for fast packet I/O</i>” in USENIX ATC 2012  [Optional] “<i>The Click modular router</i>” in SOSP 1999  [DPDK] <a href="#">DPDK quick start</a></p>	<p>Hwang et al.</p> <p>Yu et al.</p> <p>Rizzo et al.</p> <p>Kohler et al.</p>	9 <sup>th</sup> Feb, 2017	Ihsan Ayyub Qazi
<b>Transports, Congestion Control, and Buffer Sizing</b>				
7	<p>[<a href="#">Resource Sharing with TCP</a>]  “<i>Congestion Avoidance and Control</i>” in ACM SIGCOMM 1988</p> <p>“<i>Sizing Router Buffers</i>” in ACM SIGCOMM 2004</p> <p>[Optional] “<i>Analysis of the Increase and Decrease Algorithms for Congestion Avoidance in Computer Networks</i>”, Computer Networks and ISDN Systems, 1989  [Optional] “<i>Rethinking Buffer Management in Data Center Networks</i>” in ACM SIGCOMM 2014 (poster)</p>	<p>Jacobson et al.</p> <p>Appenzeller et al.</p> <p>Chiu et al.</p> <p>Aisha Mushtaq et al.</p>	14 <sup>th</sup> Feb, 2017	Zartash Afzal Uzmi
8	<p>[<a href="#">Beyond TCP: Network Assisted Congestion Control</a>]  “<i>Congestion control for high bandwidth-delay product networks</i>” in ACM SIGCOMM, 2002  + <b>Discussion: Network Utility Maximization Framework</b></p> <p>[Optional] “<i>Processor Sharing Flows in the Internet</i>” in IWQoS 2005  [Optional] “<i>Congestion Control With Multipacket Feedback</i>” in IEEE/ACM Transactions on Networking, 2012</p>	<p>Katabi et al.</p> <p>Dukkipati et al. Ihsan Qazi et al.</p>	16 <sup>th</sup> Feb, 2017	Ihsan Ayyub Qazi
9	<p>[<a href="#">Congestion Control via Machine Learning</a>]  “<i>TCP ex Machina: Computer-Generated Congestion Control</i>” in ACM SIGCOMM 2013  + <b>Discussion: Scheduling, Isolation, and Fairness</b></p> <p>[Optional] “<i>Resource Management with Deep Reinforcement Learning</i>” in ACM HotNets 2016</p>	<p>Winstein et al.</p> <p>Mao et al.</p>	21 <sup>st</sup> Feb, 2017	Ihsan Ayyub Qazi



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### Routers and Routing

10	<p>[Routers]  <a href="#">“IP Router Architectures: An Overview”</a> in International Journal of Communication Systems, 2001</p> <p>[Optional] <a href="#">“Issues and Trends in Router Design”</a> in IEEE Communications Magazine, 1998</p> <p>[Optional] <a href="#">“Tree Bitmap”</a></p>	<p>James Aweya</p> <p>S. Keshav &amp; R. Sharma  Eatherton et al.</p>	23 <sup>rd</sup> Feb, 2017	Zartash Afzal Uzmi
11	<p>[Routing]  <a href="#">“Interdomain Internet Routing”</a>, Notes (includes a tutorial on IXP)</p>	Balakrishnan et al.	28 <sup>th</sup> Feb, 2017	Zartash Afzal Uzmi
12	<p>[Internet Exchange]  <a href="#">“iSDX: An Industrial-Scale Software Defined Internet Exchange Point”</a> in NSDI 2016</p> <p>[Optional] <a href="#">“SDX: A Software Defined Internet Exchange”</a> in ACM SIGCOMM 2014</p> <p>[Optional] <a href="#">“Anatomy of a large European IXP”</a> in ACM SIGCOMM 2012</p>	<p>Gupta et al.</p> <p>Gupta et al.</p> <p>Ager et al.</p>	2 <sup>nd</sup> Mar, 2017	Ihsan Ayyub Qazi
13	<p>[Secure Routing]  <a href="#">“Why Is It Taking So Long to Secure Internet Routing?”</a> in ACM Queue 2014</p> <p>[Optional] <a href="#">“A Survey of BGP Security Issues and Solutions”</a> in Proceedings of the IEEE</p>	<p>Goldberg et al.</p> <p>Butler et al.</p>	7 <sup>th</sup> Mar, 2017	Zartash Afzal Uzmi

### Internet Censorship, Anonymity, and Advertising

14	<p>[Censorship]  <a href="#">“Characterizing Web Censorship Worldwide: Another Look at the OpenNet Initiative Data”</a> in Transactions on Web 2015 (just read the abstract, section-1, and section-3)</p> <p><a href="#">“A Look at the Consequences of Internet Censorship Through an ISP Lens”</a> in ACM IMC 2014</p> <p>[Optional] <a href="#">“SoK: Towards Grounding Censorship Circumvention in Empiricism”</a></p> <p>[Optional] <a href="#">“Tools and Technology of Internet Filtering”</a></p> <p>[Optional] <a href="#">“Tor: The Second-Generation Onion Router”</a> in USENIX Security Symposium 2004</p> <p>[Optional] <a href="#">“Pakistan hijacks YouTube”</a> - Dyn Research</p>	<p>Gill et al.</p> <p>Khattak et al.</p> <p>Tschantz et al.</p>	9 <sup>th</sup> March, 2017	Ihsan Ayyub Qazi
15	<p>[Measuring Internet Censorship]  <a href="#">“Encore: Lightweight Measurement of Web Censorship with Cross-Origin Requests”</a> in ACM SIGCOMM 2015 (just read the abstract and the introduction)</p> <p><a href="#">“A Case for Marrying Censorship Measurements with Circumvention”</a> in ACM HotNets 2015</p> <p>[Optional] <a href="#">“Can Censorship Measurements Be Safe(r)?”</a> in ACM HotNets 2015</p> <p>[Optional] <a href="#">“OONI: Open observatory of network interference”</a> in FOCI 2012</p> <p>[OONI] <a href="https://ooni.torproject.org/">https://ooni.torproject.org/</a></p> <p>[OpenNet Initiative] <a href="https://opennet.net/">https://opennet.net/</a></p> <p>[Optional] <a href="#">“Internet censorship detection: A survey”</a> in Computer Networks 2015.</p>	<p>S. Burnett et al.</p> <p>Aqib Nisar, Aqsa Kashaf, et al.</p> <p>B. Jones et al.</p> <p>Filasto et al.</p> <p>Aceto et al.</p>	14 <sup>th</sup> March, 2017	Zartash Afzal Uzmi
16	<p>[Censorship Resistance &amp; Anonymity]  <a href="#">“LASTor: A Low-Latency AS-Aware Tor Client”</a> in IEEE/ACM Transactions on Networking 2014</p> <p>[Optional] <a href="#">“Examining How the Great Firewall Discovers Hidden Circumvention Servers”</a> in ACM IMC 2015</p> <p>[Optional] <a href="#">“Blocking-resistant communication through domain fronting”</a> in PETS 2015</p>	<p>Akhoondi et al.</p> <p>R. Ensafi et al.</p> <p>Fifield et al.</p>	16 <sup>th</sup> March, 2017	Ihsan Ayyub Qazi



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	<p>[Optional] “Evading Censorship with Browser-Based Proxies” in PETS 2012</p> <p>[Optional] “Do You See What I See? Differential Treatment of Anonymous Users” in NDSS 2016</p> <p>[Optional] “Towards Efficient Traffic-analysis Resistant Anonymity Networks” in ACM SIGCOMM 2013</p>	<p>Fifield et al.</p> <p>Khattak et al.</p> <p>Blond et al.</p>		
17	<p>[Privacy and Advertising]</p> <p>“Tracing Information Flows Between Ad Exchanges Using Retargeted Ads” in USENIX Security’16</p> <p>[Optional] “Follow the Money” in ACM IMC 2013</p> <p>[Optional] “Privad: Practical Privacy in Online Advertising” in NSDI 2011</p> <p>[Optional] “Private-by-Design Advertising Meets the Real World” in ACM CCS 2014</p> <p>[Optional] “Web Identity Translator” in ACM HotNets 2015</p>	<p>Bashir et al.</p> <p>Gill et al.</p> <p>Guha et al.</p> <p>Reznichenko et al.</p> <p>Papaodyssefs et al.</p>	28 <sup>th</sup> March, 2017	Zartash Afzal Uzmi

## Cloud Computing and Datacenter Networking

### Overview, Cloud Abstractions, and Datacenter (DC) Topologies

18	<p>[Overview]</p> <p>“A Guided Tour through Data-center Networking” in Communications of ACM, 2012</p> <p>“A View of Cloud Computing” in Communications of ACM, 2010 (skim through)</p> <p>[Optional] “Inside the Social Network’s (Datacenter) Network” in ACM SIGCOMM 2015</p> <p>[Optional] “Achieving Rapid Response Times in Large Online Services” Talk by Jeff Dean, Google Fellow</p> <p>[Optional] “The Tail at Scale” in Communications of the ACM 2013</p> <p>[Optional] “Network Traffic Characteristics of Data Centers in the Wild” in IMC 2010 (skim through)</p>	<p>Abts et al.</p> <p>Armbrust et al.</p> <p>Roy et al.</p> <p>Dean et al.</p> <p>Benson et al.</p>	30 <sup>th</sup> March, 2017	Ihsan Ayyub Qazi
19	<p>[Cloud Abstractions]</p> <p>“MapReduce: Simplified Data Processing on Large Clusters” in OSDI 2004</p> <p>[Optional] (Spark) “Resilient Distributed Datasets: A Fault-Tolerant Abstraction for In-Memory Cluster Computing” in NSDI 2012</p> <p>[Optional] “Making Sense of Performance in Data Analytics Frameworks” in NSDI 2015</p> <p>[Optional] “TensorFlow: A System for Large-Scale Machine Learning” in OSDI 2016.</p>	<p>Dean et al.</p> <p>Zaharia et al.</p> <p>Ousterhout et al.</p> <p>Abadi et al.</p>	4 <sup>th</sup> April, 2017	Zartash Afzal Uzmi
20	<p>[Cloud Abstractions]</p> <p>“TAO: Facebook’s Distributed Data Store for the Social Graph” in USENIX ATC</p> <p>[Optional] “Scaling Memcache at Facebook” in NSDI 2013</p> <p>[Blog: New Facebook DC Network]</p> <p><a href="https://code.facebook.com/posts/360346274145943/introducing-data-center-fabric-the-next-generation-facebook-data-center-network/">https://code.facebook.com/posts/360346274145943/introducing-data-center-fabric-the-next-generation-facebook-data-center-network/</a></p>	<p>Bronson et al.</p> <p>Muralidhar et al.</p>	6 <sup>th</sup> April, 2017	Ihsan Ayyub Qazi

### Datacenter Transports, Load Balancing Schemes, and Architectures

21	<p>[DC Transports]</p> <p>“Data Center TCP (DCTCP)” in ACM SIGCOMM 2010</p> <p>“Minimizing Flow Completion Times in Data Centers” in IEEE INFOCOM 2013 (just read the abstract, section I, section II-A, and section II-B)</p> <p>[Optional] “It’s Time for Low Latency” in ACM HotOS 2011</p> <p>[Optional] “Low Latency via Redundancy” in ACM CoNEXT 2013</p>	<p>Alizadeh et al.</p> <p>Munir et al.</p> <p>Rumble et al.</p> <p>Vulimiri et al.</p>	11 <sup>th</sup> April, 2017	Zartash Afzal Uzmi
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22	<p><b>[DC Transports]</b>  <a href="#">“Friends, not Foes - Synthesizing Existing Data Center Transport Strategies in PASE”</a> in ACM SIGCOMM 2014</p> <p><b>[Optional]</b> <a href="#">“pFabric: Minimal Near-Optimal Datacenter Transport”</a> in ACM SIGCOMM 2013</p> <p><b>[Optional]</b> <a href="#">“TIMELY: RTT-based Congestion Control for the Datacenter”</a> in ACM SIGCOMM 2015</p> <p><b>[Optional]</b> <a href="#">“Fastpass: A Centralized Zero-Queue Datacenter Network”</a> in ACM SIGCOMM 2014</p> <p><b>[Optional]</b> <a href="#">“Decentralized Task-Aware Scheduling for Data Center Networks”</a> in ACM SIGCOMM 2014</p> <p><b>[Optional]</b> <a href="#">“Silo: Predictable Message Latency in the Cloud”</a> in ACM SIGCOMM 2015</p>	<p>Munir et al.</p> <p>Alizadeh et al.</p> <p>Mittal et al.</p> <p>Perry et al.</p> <p>Dogar et al.</p> <p>Jang et al.</p>	13 <sup>th</sup> April, 2017	Ihsan Ayyub Qazi
23	<p><b>[DC Routing/Load Balancing]</b>  <a href="#">“CONGA: Distributed Congestion-Aware Load Balancing for Datacenters”</a> in ACM SIGCOMM 2014</p> <p><a href="#">“Micro Load Balancing in Data Centers with DRILL”</a> in ACM HotNets 2015 (just read the abstract and the introduction)</p> <p><b>[Optional]</b> <a href="#">“Load Balancing Over Symmetric Virtual Topologies”</a> in IEEE INFOCOM 2017</p> <p><b>[Optional]</b> <a href="#">“Hedera: Dynamic Flow Scheduling for Data Center Networks”</a> in NSDI 2010</p> <p><b>[Optional]</b> <a href="#">“Presto: Edge-based Load Balancing for Fast Datacenter Networks”</a> in ACM SIGCOMM 2015</p> <p><b>[Optional]</b> <a href="#">“FlowBender: Flow-level Adaptive Routing for Improved Latency and Throughput in Datacenter Networks”</a> in ACM CoNEXT 2014</p> <p><b>[Optional]</b> <a href="#">“Improving Datacenter Performance and Robustness with Multipath TCP”</a> in ACM SIGCOMM 2011</p>	<p>Alizadeh et al.</p> <p>Soudeh et al.</p> <p>Irteza et al.</p> <p>Al-Fares et al.</p> <p>He et al.</p> <p>Kabbani et al.</p> <p>Raiciu et al.</p>	18 <sup>th</sup> April, 2017	Ihsan Ayyub Qazi
24	<p><b>[DC Architectures]</b>  <a href="#">“PortLand: A Scalable Fault-Tolerant Layer 2 Data Center Network Fabric”</a> in ACM SIGCOMM 2009</p> <p><b>[Optional]</b> <a href="#">“FireFly: A Reconfigurable Wireless Datacenter Fabric using Free-Space Optics”</a> in ACM SIGCOMM 2014</p> <p><b>[Optional]</b> <a href="#">“Jellyfish: Networking Data Centers Randomly”</a> in NSDI 2012</p> <p><b>[Optional]</b> <a href="#">“VL2: A Scalable and Flexible Data Center Network”</a> in ACM SIGCOMM 2009</p> <p><b>[Optional]</b> <a href="#">“Jupiter Rising: A Decade of Clos Topologies and Centralized Control in Google’s Datacenter Network”</a> in ACM SIGCOMM 2015</p>	<p>Mysore et al.</p> <p>Hamedazimi, Zafar Qazi et al.</p> <p>Singla et al.</p> <p>Greenberg et al.</p> <p>Singh et al.</p>	20 <sup>th</sup> April, 2017	Zartash Afzal Uzmi
<b>Wireless Networking</b>				
25	<p><b>[MAC Protocols for WLANs]</b>  <a href="#">“Wireless Channel Access Protocols”</a> Notes</p> <p><a href="#">“Cross-Layer Wireless Bit Rate Adaptation”</a> in ACM SIGCOMM 2009 (just read Sections 1 and 2)</p> <p><b>[Optional]</b> <a href="#">“Loss Differentiation: Moving onto High-Speed Wireless LANs”</a> in IEEE INFOCOM 2014</p> <p><b>[Optional]</b> <a href="#">“WiFi-Nano: Reclaiming WiFi Efficiency through 800ns Slots”</a> in ACM MOBICOM 2011</p>	<p>Balabrishnan et al.</p> <p>Vutukuru et al.</p> <p>Anwar et al.</p> <p>Magistretti et al.</p>	25 <sup>th</sup> April, 2017	Ihsan Ayyub Qazi
26	<p><b>[Application QoS Differentiation]</b>  <a href="#">“SlickFi: A Service Differentiation Scheme for High-Speed WLANs”</a> in ACM CoNEXT 2016</p>	Nishat et al.	27 <sup>th</sup> April, 2017	Zartash Afzal Uzmi
27	<p><b>[Context-Aware WiFi &amp; Room-Area Networks]</b>  <a href="#">“Room-Area Networks”</a> in ACM HotNets 2015</p> <p><a href="#">“Extending Cell Tower Coverage through Drones”</a> in HotMobile 2017</p>	<p>Iannucci et al.</p> <p>Dhekne et al.</p>	2 <sup>nd</sup> May, 2017	<p>Zartash Afzal Uzmi</p> <p>Ihsan Ayyub Qazi</p>



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	<p>[Optional] “Tracking Drone Orientation with Multiple GPS Receivers” in ACM MobiCom 2016</p> <p>[Optional] “Improving Wireless Network Performance Using Sensor Hints” in NSDI 2011</p>	<p>Gowda et al.</p> <p>Ravindranath et al.</p>		
28	<p>[Cellular Networks - 3G/4G/5G]</p> <p>“KLEIN: A Minimally Disruptive Design for an Elastic Cellular Core” in ACM SOSR 2016</p> <p>[Optional] “Wireless Software-defined Networks (W-SDNs) and Network Function Virtualization (NFV) for 5G Cellular Systems: An Overview and Qualitative Evaluation” in Computer Network (Elsevier) Journal</p> <p>[Optional] “Adaptive Congestion Control for Unpredictable Cellular Networks” in ACM SIGCOMM 2015</p> <p>[Optional] “SoftRAN: Software Defined Radio Access Network” in HotSDN 2013</p>	<p>Zafar Ayyub Qazi</p> <p>Akyildiz et al.</p> <p>Zaki et al.</p> <p>Gudipati et al.</p>	4 <sup>th</sup> May, 2017	Ihsan Ayyub Qazi

## ICT for Developing Regions

29	<p>[Low Cost Data Channels]</p> <p>“Hermes: Data Transmission over Unknown Voice Channels” in ACM MobiCom 2010</p> <p>[Optional] “Ripple: Communicating through Physical Vibrations wireless mobile” in NSDI 2015</p>	<p>Dhananjay et al.</p> <p>Roy et al.</p>	9 <sup>th</sup> May, 2017	Zartash Afzal Uzmi
30	<p>[Mobile Phones &amp; Services in Developing Countries]</p> <p>“A View from the Other Side: Understanding Mobile Phone Characteristics in the Developing World” in ACM IMC 2016</p> <p>“On the Free Bridge Across the Digital Divide: Assessing the Quality of Facebook’s Free Basics Service” in ACM IMC 2016</p> <p>[Optional] “Dissecting Web Latency in Ghana” in ACM IMC 2014</p> <p>[Optional] “WiLDNet: Design and Implementation of High Performance WiFi Based Long Distance Networks” in NSDI 2007</p> <p>[Optional] “On the Effectiveness of High-Speed WLAN Standards for Long Distance Communication” in IEEE INFOCOM 2014 (poster)</p> <p>[Optional] “Experiences in using WiFi for rural Internet in India” in IEEE Comm. Mag., Special Issue on New Directions in Networking Technologies in Emerging Economies, 2007.</p>	<p>Ahmad et al.</p> <p>Sen et al.</p> <p>Zaki et al.</p> <p>Patra et al.</p> <p>Nishat et al.</p> <p>Raman et al.</p>	12 <sup>th</sup> May, 2017	<p>Zartash Afzal Uzmi</p> <p>Ihsan Ayyub Qazi</p>

### Textbook(s)/Supplementary Readings

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