19th USENIX Symposium on Networked Systems
Design and Implementation (NSDI ’22)
April 4–6, 2022
Renton, WA, USA

Monday, April 4

Cluster Resource Management

Efficient Scheduling Policies for Microsecond-Scale Tasks
Sarah McClure and Amy Ousterhout, UC Berkeley; Scott Shenker, UC Berkeley, ICSI; Sylvia Ratnasamy, UC Berkeley

A Case for Task Sampling based Learning for Cluster Job Scheduling
Akshay Jajoo, Nokia Bell Labs; Y. Charlie Hu and Xiaojun Lin, Purdue University; Nan Deng, Google

Starlight: Fast Container Provisioning on the Edge and over the WAN
Jun Lin Chen, Daniyal Liaqat, Moshe Gabel, and Eyal de Lara, University of Toronto

Transport Layer - Part 1

PowerTCP: Pushing the Performance Limits of Datacenter Networks
Vamsi Addanki, TU Berlin and University of Vienna; Oliver Michel, Princeton University and University of Vienna; Stefan Schmid, TU Berlin and University of Vienna

RDMA is Turing complete, we just did not know it yet!
Waleed Reda, Université catholique de Louvain and KTH Royal Institute of Technology; Marco Canini, KAUST; Dejan Kostić, KTH Royal Institute of Technology; Simon Peter, University of Washington

FlexTOE: Flexible TCP Offload with Fine-Grained Parallelism
Rajath Shashidhara, University of Washington; Tim Stamler, UT Austin; Antoine Kaufmann, MPI-SWS; Simon Peter, University of Washington

Video Streaming

Swift: Adaptive Video Streaming with Layered Neural Codecs
Mallesham Dasari, Kumara Kahatapitiya, Samir R. Das, Aruna Balasubramanian, and Dimitris Samaras, Stony Brook University

Ekya: Continuous Learning of Video Analytics Models on Edge Compute Servers
Romil Bhardwaj, Microsoft and UC Berkeley; Zhengxu Xia, University of Chicago; Ganesh Ananthanarayan, Microsoft; Junchen Jiang, University of Chicago; Yuanchao Shu, Nikolaos Karianakis, Kevin Hsieh, and Paramvir Bahl, Microsoft; Ion Stoica, UC Berkeley

YuZu: Neural-Enhanced Volumetric Video Streaming
Anlan Zhang and Chendong Wang, University of Minnesota, Twin Cities; Bo Han, George Mason University; Feng Qian, University of Minnesota, Twin Cities

Programmable Switches - Part 1

NetVRM: Virtual Register Memory for Programmable Networks
Hang Zhu, Johns Hopkins University; Tao Wang, New York University; Yi Hong, Johns Hopkins University; Dan R. K. Ports, Microsoft Research; Anirudh Sivaraman, New York University; Xin Jin, Peking University

SwiSh: Distributed Shared State Abstractions for Programmable Switches
Lior Zeno, Technion; Dan R. K. Ports, Jacob Nelson, and Duehyeok Kim, Microsoft Research; Shir Landau Feibish, The Open University of Israel; Idit Keidar, Arik Rinberg, Alon Ravelbach, Igor De-Paula, and Mark Silberstein, Technion

Modular Switch Programming Under Resource Constraints
Mary Hogan, Princeton University; Shir Landau-Feibish, The Open University of Israel; Mina Tahmasbi Arashloo, Cornell University; Jennifer Rexford and David Walker, Princeton University
Security and Privacy

Privid: Practical, Privacy-Preserving Video Analytics Queries ................................. 209
Frank Cangialosi, MIT CSAIL; Neil Agarwal, Princeton University; Venkat Arun, MIT CSAIL; Junchen Jiang, University of Chicago; Srinivas Narayana and Anand Sarwate, Rutgers University; Ravi Netravali, Princeton University

Spectrum: High-Bandwidth Anonymous Broadcast .................................................. 229
Zachary Newman, Sacha Servan-Schreiber, and Srinivas Devadas, MIT CSAIL

Donar: Anonymous VoIP over Tor .............................................................................. 249
Yérom-David Bromberg, Quentin Dufour, and Davide Frey, Univ. Rennes - Inria - CNRS - IRISA; Etienne Rivière, UCLouvain

Network Troubleshooting and Debugging

Closed-loop Network Performance Monitoring and Diagnosis with SpiderMon .................. 267
Weitao Wang and Xinyu Crystal Wu, Rice University; Praveen Tammana, Indian Institute of Technology Hyderabad; Ang Chen and T. S. Eugene Ng, Rice University

Collie: Finding Performance Anomalies in RDMA Subsystems ........................................ 287
Xinhao Kong, Duke University and ByteDance Inc.; Yibo Zhu, Huaping Zhou, Zhuo Jiang, Jianxi Ye, and Chuanxiong Guo, ByteDance Inc.; Danyang Zhuo, Duke University

SCALE: Automatically Finding RFC Compliance Bugs in DNS Nameservers ..................... 307
Siva Kesava Reddy Kakarla, University of California, Los Angeles; Ryan Beckett, Microsoft; Todd Millstein, University of California, Los Angeles, and Intentionet; George Varghese, University of California, Los Angeles

Operational Track - Part 1

Decentralized cloud wide-area network traffic engineering with BlastShield .................. 325
Umesh Krishnaswamy, Rachee Singh, Nikolaj Bjørner, and Himanshu Raj, Microsoft

Detecting Ephemeral Optical Events with OpTel ......................................................... 339
Congcong Miao and Minggang Chen, Tencent; Arpit Gupta, UC Santa Barbara; Zili Meng, Lianjin Ye, and Jingyu Xiao, Tsinghua University; Jie Chen, Zekun He, and Xulong Luo, Tencent; Jilong Wang, Tsinghua University, BNRist, and Peng Cheng Laboratory; Heng Yu, Tsinghua University

Bluebird: High-performance SDN for Bare-metal Cloud Services .................................... 355
Manikandan Arumugam, Arista; Deepak Bansal, Microsoft; Navdeep Bhatia, Arista; James Boerner, Microsoft; Simon Capper, Arista; Changhoon Kim, Intel; Sarah McClure, Neeraj Motwani, and Ranga Narasimhan, Microsoft; Urvish Panchal, Arista; Tommaso Pimpo, Microsoft; Ariff Premji, Arista; Pranjal Shrivastava and Rishabh Tewari, Microsoft

Cetus: Releasing P4 Programmers from the Chore of Trial and Error Compiling .................. 371
Yifan Li, Tsinghua University and Alibaba Group; Jiaqi Gao, Ennan Zhai, Mengqi Liu, Kun Liu, and Hongqiang Harry Liu, Alibaba Group

Wireless - Part 1

Exploiting Digital Micro-Mirror Devices for Ambient Light Communication ...................... 387
Talia Xu, Miguel Chávez Tapia, and Marco Züñiga, Technical University Delft

Whisper: IoT in the TV White Space Spectrum .............................................................. 401
Tusher Chakraborty and Heping Shi, Microsoft; Zerina Kapetanovic, University of Washington; Bodhi Priyantha, Microsoft; Deepak Vasisht, UIUC; Binh Vu, Parag Pandit, Prasad Pillai, Yaswant Chabria, Andrew Nelson, Michael Daum, and Ranveer Chandra, Microsoft

Learning to Communicate Effectively Between Battery-free Devices ............................... 419
Kai Geissdoerfer and Marco Zimmerling, TU Dresden

Saiyan: Design and Implementation of a Low-power Demodulator for LoRa Backscatter Systems .............................................................. 437
Xiu Zhang Guo, Tsinghua University; Longfei Shangguan, University of Pittsburgh & Microsoft; Yuan He, Tsinghua University; Nan Jing, Yanshan University; Jiacheng Zhang, Haotian Jiang, and Yunhao Liu, Tsinghua University
Tuesday, April 5

Reliable Distributed Systems

**Graham: Synchronizing Clocks by Leveraging Local Clock Properties** .................................................. 453
Ali Najafi, *Meta*; Michael Wei, *VMware Research*

**IA-CCF: Individual Accountability for Permissioned Ledgers** ................................................................. 467

**DispersedLedger: High-Throughput Byzantine Consensus on Variable Bandwidth Networks** ..................... 493
Lei Yang, Seo Jin Park, and Mohammad Alizadeh, *MIT CSAIL*; Sreeram Kannan, *University of Washington*; David Tse, *Stanford University*

Raising the Bar for Programmable Hardware

**Re-architecting Traffic Analysis with Neural Network Interface Cards** ...................................................... 513

**Elixir: A High-performance and Low-cost Approach to Managing Hardware/Software Hybrid Flow Tables** .... 535
Yanshu Wang and Dan Li, *Tsinghua University*; Yuanwei Lu, *Tencent*; Jianping Wu, Hua Shao, and Yutian Wang, *Tsinghua University*

**Gearbox: A Hierarchical Packet Scheduler for Approximate Weighted Fair Queuing** ............................... 551
Peixuan Gao and Anthony Dalleggio, *New York University*; Yang Xu, *Fudan University*; H. Jonathan Chao, *New York University*

Testing and Verification

**Performance Interfaces for Network Functions** .............................................................................................. 567
Rishabh Iyer, Katerina Argyraki, and George Candea, *EPFL*

**Automated Verification of Network Function Binaries** ................................................................................. 585
Solal Pirelli, *EPFL*; Akvilė Valentukonytė, *Citrix Systems*; Katerina Argyraki and George Candea, *EPFL*

**Differential Network Analysis** ..................................................................................................................... 601
Peng Zhang, *Xi’an Jiaotong University*; Aaron Gember-Jacobson, *Colgate University*; Yueshang Zuo, Yuhao Huang, Xu Liu, and Hao Li, *Xi’an Jiaotong University*

**KATRA: Realtime Verification for Multilayer Networks** .............................................................................. 617

Programmable Switches - Part 2

**Enabling In-situ Programmability in Network Data Plane: From Architecture to Language** ...................... 635
Yong Feng and Zhikang Chen, *Tsinghua University*; Haoyu Song, *Futurewei Technologies*; Wenquan Xu, Jiahao Li, Zijian Zhang, Tong Yun, Ying Wan, and Bin Liu, *Tsinghua University*

**Runtime Programmable Switches** ................................................................................................................. 651
Jiarong Xing and Kuo-Feng Hsu, *Rice University*; Matty Kadosh, Alan Lo, and Yonatan Piasetzky, *Nvidia*; Arvind Krishnamurthy, *University of Washington*; Ang Chen, *Rice University*

**IMap: Fast and Scalable In-Network Scanning with Programmable Switches** ......................................... 667
Guanyu Li, *Tsinghua University*; Menghao Zhang, *Tsinghua University*; KuaiShou Technology; Cheng Guo, Han Bao, and Mingwei Xu, *Tsinghua University*; Hongxin Hu, *University at Buffalo, SUNY*; Fenghua Li, *Tsinghua University*

**Unlocking the Power of Inline Floating-Point Operations on Programmable Switches** .............................. 683
Sketch-based Telemetry
Dynamic Scheduling of Approximate Telemetry Queries ................................. 701
Chris Misa, Walt O’Connor, Ramakrishnan Durairajan, and Reza Rejaie, University of Oregon; Walter Willinger, NIKSUN, Inc.

HeteroSketch: Coordinating Network-wide Monitoring in Heterogeneous and Dynamic Networks ............ 719
Anup Agarwal, Carnegie Mellon University; Zaoxing Liu, Boston University; Srinivasan Seshan, Carnegie Mellon University

SketchLib: Enabling Efficient Sketch-based Monitoring on Programmable Switches ......................... 743
Hun Namkung, Carnegie Mellon University; Zaoxing Liu, Boston University; Daehyeok Kim, Carnegie Mellon University and Microsoft; Vyas Sekar and Peter Steenkiste, Carnegie Mellon University

Transport Layer - Part 2
An edge-queued datagram service for all datacenter traffic ........................................ 761
Vladimir Olteanu, Correct Networks and University Politehnica of Bucharest; Haggai Eran, Technion and NVIDIA; Dragos Dumitrescu, Correct Networks and University Politehnica of Bucharest; Adrian Popa and Cristi Baciu, Correct Networks; Mark Silberstein, Technion; Georgios Nikolaidis, Intel; Mark Handley, UCL and Correct Networks; Costin Raiciu, Correct Networks and University Politehnica of Bucharest

Backpressure Flow Control ................................................................. 779
Preetesh Goyal, MIT CSAIL; Preey Shah, IIT Bombay; Kevin Zhao, University of Washington; Georgios Nikolaidis, Intel, Barefoot Switch Division; Mohammad Alizadeh, MIT CSAIL; Thomas E. Anderson, University of Washington

Packet Order Matters! Improving Application Performance by Deliberately Delaying Packets ............... 807
Hamid Ghasemirahni, Tom Barbette, Georgios P. Katsikas, and Alireza Farshin, KTH Royal Institute of Technology; Amir Roozbeh, KTH Royal Institute of Technology and Ericsson Research; Massimo Girondi, Marco Chiesa, Gerald Q. Maguire Jr., and Dejan Kostić, KTH Royal Institute of Technology

Troubleshooting
Buffer-based End-to-end Request Event Monitoring in the Cloud ......................................... 829
Kaihui Gao, Tsinghua University and Alibaba Group; Chen Sun, Alibaba Group; Shuai Wang and Dan Li, Tsinghua University; Yu Zhou, Hongqiang Harry Liu, Lingjun Zhu, and Ming Zhang, Alibaba Group

Characterizing Physical-Layer Transmission Errors in Cable Broadband Networks ...................... 845
Jiyao Hu, Zhenyu Zhou, and Xiaowei Yang, Duke University

How to diagnose nanosecond network latencies in rich end-host stacks .................................... 861
Roni Haecki, ETH Zurich; Radhika Niranjan Mysore, Lalith Suresh, Gerd Zellweger, Bo Gan, Timothy Merrifield, and Sujata Banerjee, VMware; Timothy Roscoe, ETH Zurich

Wireless - Part 2
CurvingLoRa to Boost LoRa Network Throughput via Concurrent Transmission ....................... 879
Chenning Li, Michigan State University; Xiuze Huo, Tsinghua University; Longfei Shangguan, University of Pittsburgh & Microsoft; Zhichao Cao, Michigan State University; Kyle Jamieson, Princeton University

PLatter: On the Feasibility of Building-scale Power Line Backscatter .................................. 897
Junbo Zhang, Carnegie Mellon University; Elahe Soltanaghai, University of Illinois at Urbana-Champaign; Artur Balanuta, Reese Grimsley, Swarun Kumar, and Anthony Rowe, Carnegie Mellon University

Passive DSSS: Empowering the Downlink Communication for Backscatter Systems ..................... 913
Songfan Li, Hui Zheng, Chong Zhang, Yihang Song, Shen Yang, Minghua Chen, and Li Lu, University of Electronic Science and Technology of China (UESTC); Mo Li, Nanyang Technological University (NTU)
Wednesday, April 6

Operational Track - Part 2

Check-N-Run: a Checkpointing System for Training Deep Learning Recommendation Models ......................... 929
Assaf Eisenman, Kiran Kumar Matam, Steven Ingram, Dheevatsa Mudigere, Raghuraman Krishnamoorthi, Krishnakumar Nair, and Misha Smelyanskiy, Facebook; Murali Annavaram, Facebook and USC

MLaaS in the Wild: Workload Analysis and Scheduling in Large-Scale Heterogeneous GPU Clusters ........ 945
Qizhen Weng, Hong Kong University of Science and Technology and Alibaba Group; Wencong Xiao, Alibaba Group; Yinghao Yu, Alibaba Group and Hong Kong University of Science and Technology; Wei Wang, Hong Kong University of Science and Technology; Cheng Wang, Jian He, Yong Li, Liping Zhang, Wei Lin, and Yu Ding, Alibaba Group

Evolvable Network Telemetry at Facebook ................................................................. 961
Yang Zhou, Harvard University; Ying Zhang, Facebook; Minlan Yu, Harvard University; Guangyu Wang, Dexter Cao, Eric Sung, and Starsky Wong, Facebook

Edge IoT Applications

SwarmMap: Scaling Up Real-time Collaborative Visual SLAM at the Edge................................. 977
Jingao Xu, Hao Cao, and Zheng Yang, Tsinghua University; Longfei Shangguan, University of Pittsburgh & Microsoft; Jialin Zhang, Xiaowu He, and Yunhao Liu, Tsinghua University

In-Network Velocity Control of Industrial Robot Arms ....................................................... 995
Sándor Laki and Csaba Györgyi, ELTE Eötvös Loránd University, Budapest, Hungary; József Pető, Budapest University of Technology and Economics, Budapest, Hungary; Péter Vörös, ELTE Eötvös Loránd University, Budapest, Hungary; Géza Szabó, Ericsson Research, Budapest, Hungary

Enabling IoT Self-Localization Using Ambient 5G Signals .................................................. 1011
Suraj Jog, Junfeng Guan, and Sohrab Madani, University of Illinois at Urbana Champaign; Ruochen Lu, University of Texas at Austin; Songbin Gong, Deepak Vasisht, and Haitham Hassanieh, University of Illinois at Urbana Champaign

Cloud Scale Services

Accelerating Collective Communication in Data Parallel Training across Deep Learning Frameworks .... 1027
Joshua Romero, NVIDIA, Inc.; Junqi Yin, Noumane Laanait, Bing Xie, and M. Todd Young, Oak Ridge National Laboratory; Sean Treichler, NVIDIA, Inc.; Vitalii Starchenko and Albina Borisevich, Oak Ridge National Laboratory; Alex Sergeev, Carbon Robotics; Michael Matheson, Oak Ridge National Laboratory

Cocktail: A Multidimensional Optimization for Model Serving in Cloud ................................ 1041

Data-Parallel Actors: A Programming Model for Scalable Query Serving Systems .................... 1059
Peter Kraft, Fiodar Kazhamiaka, Peter Bailis, and Matei Zaharia, Stanford University

Orca: Server-assisted Multicast for Datacenter Networks .................................................... 1075
Khaled Diab, Parham Yassini, and Mohamed Hefeeda, Simon Fraser University

ISPs and CDNs

Yeti: Stateless and Generalized Multicast Forwarding ......................................................... 1093
Khaled Diab and Mohamed Hefeeda, Simon Fraser University

cISP: A Speed-of-Light Internet Service Provider ............................................................... 1115
Debopam Bhattacharjee, ETH Zürich; Waqar Aqeel, Duke University; Sangeetha Abdu Jyothi, UC Irvine and VMware Research; Ilker Nadi Bozkurt, Duke University; William Sentosa, UIUC; Muhammad Tirmazi, Harvard University; Anthony Aguirre, UC Santa Cruz; Balakrishnan Chandrasekaran, VU Amsterdam; P. Brighten Godfrey, UIUC and VMware; Gregory Laughlin, Yale University; Bruce Maggs, Duke University and Emerald Technologies; Ankit Singla, ETH Zürich

Configanator: A Data-driven Approach to Improving CDN Performance .............................. 1135
Usama Naseer and Theophilus A. Benson, Brown University
C2DN: How to Harness Erasure Codes at the Edge for Efficient Content Delivery .......................... 1159
Juncheng Yang, Carnegie Mellon University; Anirudh Sabnis, University of Massachusetts, Amherst; Daniel S. Berger, Microsoft Research and University of Washington; K. V. Rashmi, Carnegie Mellon University; Ramesh K. Sitaraman, University of Massachusetts, Amherst, and Akamai Technologies

Cloud Scale Resource Management
Optimizing Network Provisioning through Cooperation ................................. 1179
Harsha Sharma, Parth Thakkar, Sagar Bharadwaj, Rajnipta Bhagwan, Venkata N. Padmanabhan, Yogesh Bansal, Vijay Kumar, and Kathleen Voelbel, Microsoft

OrbWeaver: Using IDLE Cycles in Programmable Networks for Opportunistic Coordination ..................... 1195
Liangcheng Yu, University of Pennsylvania; John Sonchack, Princeton University; Vincent Liu, University of Pennsylvania

CloudCluster: Unearthing the Functional Structure of a Cloud Service .......................... 1213
Weiwu Pang, University of Southern California; Sourav Panda, University of California, Riverside; Jehangir Amjad and Christophe Diot, Google Inc.; Ramesh Govindan, University of Southern California

Data Center Network Infrastructure
Zeta: A Scalable and Robust East-West Communication Framework in Large-Scale Clouds .................... 1231
Qianyu Zhang, Gongming Zhao, and Hongli Xu, University of Science and Technology of China; Zhuolong Yu, Johns Hopkins University; Liguang Xie, Futurewei Technologies; Yangming Zhao, University of Science and Technology of China; Chunming Qiao, SUNY at Buffalo; Ying Xiong, Futurewei Technologies; Liusheng Huang, University of Science and Technology of China

Aquila: A unified, low-latency fabric for datacenter networks ............................................. 1249
Dan Gibson, Hema Harirhan, Eric Lance, Moray McLaren, Behnam Montazeri, Arjun Singh, Stephen Wang, Hassan M. G. Wassel, Zehua Wu, Sungwan Yoo, Raghuaram Balasubramanian, Prashant Chandra, Michael Cutforth, Peter Cuy, David Decotigny, Rakesh Gautam, Alex Iriza, Milo M. K. Martin, Rick Roy, Zuowei Shen, Ming Tan, Ye Tang, Monica Wong-Chan, Joe Zbiciak, and Amin Vahdat, Google

RDC: Energy-Efficient Data Center Network Congestion Relief with Topological Reconfigurability at the Edge. 1267
Weitao Wang, Rice University; Dingming Wu, Bytedance Inc.; Sushovan Das, Afsaneh Rahbar, Ang Chen, and T. S. Eugene Ng, Rice University

Multitenancy
Isolation Mechanisms for High-Speed Packet-Processing Pipelines .......................................... 1289
Tao Wang, New York University; Xiangrui Yang, National University of Defense Technology; Gianni Antichi, Queen Mary University of London; Anirudh Sivaraman and Aurojit Panda, New York University

Justitia: Software Multi-Tenancy in Hardware Kernel-Bypass Networks ..................................... 1307
Yiwen Zhang, University of Michigan; Yue Tan, University of Michigan and Princeton University; Brent Stephens, University of Illinois at Chicago; Mosharaf Chowdhury, University of Michigan

NetHint: White-Box Networking for Multi-Tenant Data Centers ............................................ 1327
Jingrong Chen, Duke University; Hong Zhang, University of California, Berkeley; Wei Zhang, Duke University; Liang Luo, University of Washington; Jeffrey Chase, Duke University; Ion Stoica, University of California, Berkeley; Danyang Zhuo, Duke University

Software Switching and Beyond
Tiara: A Scalable and Efficient Hardware Acceleration Architecture for Stateful Layer-4 Load Balancing ...... 1345
Chaoliang Zeng, Hong Kong University of Science and Technology; Layong Luo and Teng Zhang, ByteDance; Zilong Wang, Hong Kong University of Science and Technology; Luyang Li, ICT/CAS; Wenchen Han, Peking University; Nan Chen, Lebing Wan, Lichao Liu, Zhipeng Ding, Xiongfei Geng, Tao Feng, and Feng Ning, ByteDance; Kai Chen, Hong Kong University of Science and Technology; Chuanxiong Guo, ByteDance

Scaling Open vSwitch with a Computational Cache ......................................................... 1359
Alon Rashelbach, Ori Rottenstreich, and Mark Silberstein, Technion

Backdraft: a Lossless Virtual Switch that Prevents the Slow Receiver Problem ............................. 1375
Alireeze Sanaee, Queen Mary University of London; Farbod Shahinfar, Sharif University of Technology; Gianni Antichi, Queen Mary University of London; Brent E. Stephens, University of Utah