Chuan Wu

PRESENT Associate Professor

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RESEARCH INTERESTS Modeling, analysis, design and implementation of cloud computing systems, online and mobile social networks, peer-to-peer networks and wire-

less networks.

EDUCATION University of Toronto, Toronto, Ontario, Canada, September 2004 — July

Edward S. Rogers Sr. Department of Electrical and Computer Engineering

♦ **Ph.D.**, Electrical and Computer Engineering, July 2008

▷ Dissertation: "Large-Scale Peer-to-Peer Streaming: Modeling, Measurements, and Optimizing Solutions"

▷ Advisor: Prof. Baochun Li

→ Thesis Committee: Alberto Leon-Garcia, Ben Liang, Jianwen Zhu

Tsinghua University, Beijing, China, September 2000 — July 2002 *Department of Computer Science and Technology*

♦ M.Engr., Computer Science and Technology, July 2002

▷ Dissertation: "Research on Content-based Video Analysis/Retrieval Technologies"

> Advisor: Prof. Yuzhuo Zhong

Tsinghua University, Beijing, China, September 1996 — July 2000 *Department of Computer Science and Technology*

♦ **B.Engr.**, Computer Science and Technology, July 2000

Professional Experience The University of Hong Kong, Department of Computer Science, Hong Kong

Associate Professor July 2014 — Present

Assistant Professor September 2008 — June 2014

Key member of the Strategic Research Theme (SRT) on Computation and Information, August 2013 — Present

Key member of the Strategic Research Theme (SRT) on Information Technology, September 2008 — July 2013

Research focuses on:

- ▷ Pricing, resource scheduling and data migration issues in cloud computing systems.
- ▶ Measurement, performance modeling and design of online and mobile social networks/applications.
- > Optimal design of cross-layer protocols in multi-hop wireless networks.

University of Toronto, Edward S. Rogers Sr. Department of Electrical and Computer Engineering, Toronto, Ontario, Canada

Ph.D. Research Assistant

September 2004 — July 2008

Research focused on:

- ▷ Extensive measurement and statistical analysis of a large-scale real-world P2P streaming application, involving millions of users over a period of time of more than one year.
- ▷ Practical application of a wide variety of theories (optimization, game theory, graph theory, statistics and coding) in analyzing, designing, and optimizing distributed algorithms for peer-to-peer applications.

i-Sprint Innovations Pte Ltd, Singapore

Software Engineer

January 2003 — August 2004

Main responsibilities include the design and development of the company's core software products on Enterprise Single Sign-On and administrative access control systems.

Sun Engineering and Research Institute (Sun Microsystems (China) Co. Ltd.), Beijing, China

Research Intern

October 2002 — January 2003

Participated in the design and development of Evolution email and calendar software on the Sun Solaris operating system.

Tsinghua University, Department of Computer Science and Technology, Beijing, China

M.Engr. Research Assistant

September 2000 — July 2002

Research on content-based video data analysis and retrieval, including video feature extraction, semantic indexing, and video shot classification and retrieval.

3 C. Wu

Microsoft Research Asia, Beijing, China

Research Intern

June 2001 — December 2001

Research on semantic analysis of MPEG sports videos for sports event detection.

Tsinghua University, Department of Computer Science and Technology, Beijing, China

Undergraduate Research Assistant

August 1999 — July 2000

Participated in SOPCA (Software Platform of Connecting Appliance), a large national project on ubiquitous computing.

PUBLICATIONS

♦ Book Chapter:

[B1] Linquan Zhang, **Chuan Wu**, Zongpeng Li, Chuanxiong Guo, Minghua Chen, Francis C.M. Lau. "Moving Big Data to the Cloud: Online Cost-Minimizing Algorithms", to appear in *Networking for Big Data*, CRC Press-Taylor & Francis Group, USA.

♦ Journal Publications:

- [J1] **Chuan Wu**, Yufei Ma, Yuwen He, Yuzhuo Zhong, Hongjiang Zhang. "Event Recognition by Semantic Inference in Sports Videos", in *Elsevier Journal of Tsinghua Science and Technology*, Vol. 43, No. 4, pp. 507-510, April 2003.
- [J2] **Chuan Wu**, Baochun Li. "Diverse: Application-Layer Service Differentiation in Peer-to-Peer Communications," in *IEEE Journal on Selected Areas in Communications, Special Issue on Peer-to-Peer Communications and Applications*, Vol. 25, No. 1, pp. 222-234, January 2007.
- [J3] **Chuan Wu**, Baochun Li, Shuqiao Zhao. "Characterizing Peer-to-Peer Streaming Flows," in *IEEE Journal on Selected Areas in Communications, Special Issue on Advances in Peer-to-Peer Streaming Systems*, Vol. 25, No. 9, pp. 1612-1626, December 2007.
- [J4] **Chuan Wu**, Baochun Li. "rStream: Resilient and Optimal Peer-to-Peer Streaming with Rateless Codes," in *IEEE Transactions on Parallel and Distributed Systems*, Vol. 19, No. 1, pp. 77-92, January 2008.
- [J5] **Chuan Wu**, Baochun Li, Zongpeng Li. "Dynamic Bandwidth Auctions in Multioverlay P2P Streaming with Network Coding," in *IEEE Transactions on Parallel and Distributed Systems*, Vol. 19, No. 6, pp. 806-820, June 2008.
- [J6] **Chuan Wu**, Baochun Li, Shuqiao Zhao. "Exploring Large-Scale Peer-to-Peer Live Streaming Topologies," in *ACM Transactions on Multimedia Computing, Communications and Applications*, Vol. 4, Issue 3, No. 19, August 2008.

- [J7] Xuanjia Qiu, Wei Huang, **Chuan Wu**, Francis C.M. Lau, Xiaola Lin. "InstantLeap: an Architecture for Fast Neighbor Discovery in Large-scale P2P VoD Streaming," in *Springer Multimedia Systems Journal*, vol. 16, No. 3, pp. 183-198, Springer-Verlag, June 2010.
- [J8] **Chuan Wu**, Baochun Li, Shuqiao Zhao. "On Dynamic Server Provisioning in Multichannel P2P Live Streaming," in *IEEE/ACM Transactions on Networking*, vol. 19, No. 5, pp. 1317-1330, October 2011.
- [J9] Zhi Wang, Chuan Wu, Lifeng Sun, Shiqiang Yang, "Strategies of Collaboration in Multi-Swarm Peer-to-Peer Content Distribution," in *Elsevier Journal of Tsinghua Science and Technology*, Vol. 17, No. 1, pp. 29-39, February 2012.
- [J10] **Chuan Wu**, Baochun Li, Shuqiao Zhao. "Diagnosing Network-wide P2P Live Streaming Inefficiencies," in *ACM Transactions on Multimedia Computing, Communications and Applications*, Vol. 8s, Issue 1, No. 13, February 2012.
- [J11] **Chuan Wu**, Zongpeng Li, <u>Xuanjia Qiu</u>, Francis C.M. Lau, "Auction-based P2P VoD Streaming: Incentives and Optimal Scheduling," in *ACM Transactions on Multimedia Computing, Communications and Applications*, Vol. 8s, Issue 1, No. 14, February 2012.
- [J12] Jian Zhao, **Chuan Wu**. "Characterizing Locality-aware P2P Streaming," in *Journal of Communications*, Vol. 7, No. 3, pp. 222-231, March 2012.
- [J13] Xingwei Wang, Jiajia Sun, Hongxing Li, **Chuan Wu**, Min Huang. "A Reverse Auction Based Allocation Mechanism in the Cloud Computing Environment", in Applied Mathematics & Information Sciences, vol. 7, pp. 75-84, February 2013.
- [J14] Zhi Wang, Chuan Wu, Lifeng Sun, Shiqiang Yang. "Peer-Assisted Social Media Streaming With Social Reciprocity," in *IEEE Transactions on Network and Service Management*, vol. 10, No. 1, pp. 84-94, March 2013.
- [J15] Zhizhong Zhang, **Chuan Wu**, David W.L. Cheung. "A Survey on Cloud Interoperability: Taxonomies, Standards, and Practice," in *ACM SIG-METRICS Performance Evaluation Review*, vol. 40, No. 4, pp. 13-22, March 2013.
- [J16] Yu Wu, Zhizhong Zhang, **Chuan Wu**, Zongpeng Li, Francis C.M. Lau. "CloudMoV: Cloud-based Mobile Social TV," in *IEEE Transactions on Multimedia*, *Special Issue on Cloud-Based Mobile Media Infrastructure, Services and Applications*, vol. 15, No. 4, pp. 821-832, June 2013.
- [J17] Ruiting Zhou, Zongpeng Li, Chuan Wu, Carey Williamson. "Signal Alignment: Enabling Physical Layer Network Coding for MIMO Networking," in *IEEE Transactions on Wireless Communications*, vol. 12, No. 6,

- pp. 3012-3023, June 2013.
- [J18] Hongxing Li, Chuan Wu, Dongxiao Yu, Qiang-Sheng Hua, Francis C.M. Lau. "Aggregation Latency-Energy Tradeoff in Wireless Sensor Networks with Successive Interference Cancellation," in *IEEE Transactions on Parallel and Distributed Systems*, vol. 24, No. 11, pp. 2160-2170, November 2013.

5

- [J19] Linquan Zhang, Chuan Wu, Zongpeng Li, Chuanxiong Guo, Minghua Chen, Francis C.M. Lau. "Moving Big Data to the Cloud: An Online Cost-Minimizing Approach," in *IEEE Journal on Selected Areas in Communications, Special Issue on Networking Challenges in Cloud Computing Systems and Applications*, vol. 31, No. 12, pp. 2710-2721, December 2013.
- [J20] <u>Hongxing Li</u>, Qiangsheng Hua, **Chuan Wu**, Francis C.M. Lau. "Latency-Minimizing Data Aggregation in Wireless Sensor Networks under Physical Interference Model," in *Elsevier Ad Hoc Networks Journal*, vol. 12, pp. 52-68, January 2014.
- [J21] Tang Xiahou, Zongpeng Li, **Chuan Wu**, Jiaqing Huang. "A Geometric Perspective to Multiple-Unicast Network Coding," in *IEEE Transactions on Information Theory*, vol. 60, No. 5, pp. 2884 2895, May 2014.
- [J22] Wei Huang, **Chuan Wu**, Zongpeng Li, Francis C.M. Lau. "The Performance and Locality Tradeoff in BitTorrent-like File Sharing Systems," in *Springer Peer-to-Peer Networking and Applications Journal*, vol. 7, no. 4, pp. 469 484, December 2014.
- [J23] <u>Jian Zhao</u>, **Chuan Wu**, Xiaojun Lin. "Locality-aware Streaming in Hybrid P2P-Cloud CDN Systems", in *Springer Peer-to-Peer Networking and Applications Journal*, *Special Issue on P2P Cloud Systems*, vol. 8, no. 2, pp. 320-335, March 2015.
- [J24] Zhi Wang, Lifeng Sun, **Chuan Wu**, Shiqiang Yang. "Enhancing Internet-scale Video Service Deployment Using Microblog-based Prediction", in *IEEE Transactions on Parallel and Distributed Systems*, vol. 26, no. 3, pp. 775 785, March 2015.
- [J25] Yu Wu, Chuan Wu, Bo Li, Linquan Zhang, Zongpeng Li, Francis C.M. Lau. "Scaling Social Media Applications into Geo-Distributed Clouds," to appear in *IEEE/ACM Transactions on Networking*.
- [J26] Can Zhao, Xiaojun Lin, **Chuan Wu**. "The Streaming Capacity of Sparsely-Connected P2P Systems with Distributed Control", to appear in *IEEE/ACM Transactions on Networking*.
- [J27] Xuanjia Qiu, Hongxing Li, Chuan Wu, Zongpeng Li, Francis C.M. Lau. "Cost-Minimizing Dynamic Migration of Content Distribution Services into Hybrid Clouds", to appear in *IEEE Transactions on Parallel and*

Distributed Systems.

[J28] Yu Wu, Zhizhong Zhang, **Chuan Wu**, Chuanxiong Guo, Zongpeng Li, Francis C.M. Lau. "Orchestrating Bulk Data Transfers across Geo-Distributed Datacenters", to appear in *IEEE Transactions on Cloud Computing*.

6

♦ Conference Papers:

- [C1] **Chuan Wu**, Yuwen He, Li Zhao, Yuzhuo Zhong. "Motion Feature Extraction Scheme for Content-based Video Retrieval", in the Proceeding of *SPIE Storage and Retrieval for Media Databases* 2002, Vol. 4676, pp. 296-305, San Jose, California, January 23-25, 2002.
- [C2] **Chuan Wu**, Yufei Ma, Hongjiang Zhang, Yuzhuo Zhong. "Events Recognition by Semantic Inference for Sports Video", in the Proceeding of the *IEEE International Conference on Multimedia and Expo 2002 (IEEE ICME 2002)*, pp. 805-808, Lausanne, Switzerland, August 26-29, 2002.
- [C3] **Chuan Wu**, Baochun Li. "rStream: Resilient Peer-to-Peer Streaming with Rateless Codes," in the Proceedings of *ACM Multimedia* 2005, pp. 307-310, Singapore, November 6-12, 2005.
- [C4] **Chuan Wu**, Baochun Li. "Optimal Peer Selection for Minimum-Delay Peer-to-Peer Streaming with Rateless Codes," in the Proceedings of *ACM Workshop on Advances in Peer-to-Peer Multimedia Streaming (P2PMMS 2005)*, in conjunction with *ACM Multimedia 2005*, pp. 69-78, Singapore, November 6-12, 2005.
- [C5] **Chuan Wu**, Baochun Li. "Echelon: Peer-to-Peer Network Diagnosis with Network Coding," in the Proceedings of the *Fourteenth IEEE International Workshop on Quality of Service (IEEE IWQoS 2006)*, pp. 20-29, Yale University, New Haven, Connecticut, June 19-21, 2006.
- [C6] **Chuan Wu**, Baochun Li. "Strategies of Conflict in Coexisting Streaming Overlays," in the Proceedings of *IEEE INFOCOM 2007*, pp. 481-489, Anchorage, Alaska, May 6-12, 2007.
- [C7] **Chuan Wu**, Baochun Li. "Optimal Rate Allocation in Overlay Content Distribution," in the Proceedings of *IFIP Networking 2007, also Lecture Notes in Computer Science, Springer*, vol. 4479, pp. 678-690, Atlanta, Georgia, May 14-18, 2007.
- [C8] **Chuan Wu**, Baochun Li. "Outburst: Efficient Overlay Content Distribution with Rateless Codes," in the Proceedings of *IFIP Networking 2007, also Lecture Notes in Computer Science*, Springer, vol. 4479, pp. 1208-1216, Atlanta, Georgia, May 14-18, 2007.
- [C9] Chuan Wu, Baochun Li, Shuqiao Zhao. "Magellan: Charting Large-Scale Peer-to-Peer Live Streaming Topologies," in the Proceedings of the

- 27th IEEE International Conference on Distributed Computing Systems (IEEE ICDCS 2007), pp. 62-69, Toronto, Ontario, Canada, June 25-29, 2007.
- [C10] **Chuan Wu**, Baochun Li. "On Meeting P2P Streaming Bandwidth Demand with Limited Supplies," in the Proceedings of the *Fifteenth Annual SPIE/ACM International Conference on Multimedia Computing and Networking (MMCN 2008)*, Vol. 6818, pp. 68180C-1—68180C-12, San Jose, California, January 30-31, 2008.
- [C11] **Chuan Wu**, Baochun Li, Shuqiao Zhao. "Multi-channel Live P2P Streaming: Refocusing on Servers," in the Proceedings of *IEEE INFOCOM* 2008, pp. 1355-1363, Phoenix, Arizona, April 14-17, 2008.
- [C12] Zimu Liu, **Chuan Wu**, Baochun Li, Shuqiao Zhao. "Distilling Superior Peers in Large-Scale P2P Streaming Systems," in the Proceedings of *IEEE INFOCOM* 2009, pp. 82-90, Rio de Janeiro, Brazil, April 19-25, 2009.
- [C13] **Chuan Wu**, Baochun Li, Shuqiao Zhao. "Diagnosing Network-wide P2P Live Streaming Inefficiencies," in the Proceedings of *IEEE INFOCOM* 2009 Mini-Conference, pp. 2731-2735, Rio de Janeiro, Brazil, April 19-25, 2009.
- [C14] Zimu Liu, **Chuan Wu**, Baochun Li, Shuqiao Zhao. "Why Are Peers Less Stable in Unpopular P2P Streaming Channels?" in the Proceedings of *IFIP Networking* 2009, also Lecture Notes in Computer Science, Springer, vol. 5550, pp. 274-286, Aachen, Germany, May 11-15, 2009.
- [C15] Xuanjia Qiu, **Chuan Wu**, Xiaola Lin, Francis C.M. Lau, "InstantLeap: Fast Neighbor Discovery in P2P VoD Streaming," in the Proceedings of the 19th International Workshop on Network and Operating Systems Support for Digital Audio and Video (NOSSDAV 2009), pp. 19-24, Williamsburg, Virginia, June 3-5, 2009.
- [C16] Zimu Liu, **Chuan Wu**, Baochun Li, Shuqiao Zhao. "UUSee: Large-Scale Operational On-Demand Streaming with Random Network Coding," in the Proceedings of *IEEE INFOCOM 2010*, pp. 2070-2078, San Diego, California, March 15-19, 2010.
- [C17] Wei Huang, **Chuan Wu**, Francis C.M. Lau. "The Performance and Locality Tradeoff in BitTorrent-like P2P File-Sharing Systems," in the Proceedings of *IEEE International Conference on Communications (IEEE ICC 2010)*, Cape Town, South Africa, May 23-27, 2010.
- [C18] Shun-Yun Hu, **Chuan Wu**, Eliya Buyukkaya, Chien-Hao Chien, Tzu-Hao Lin, Maha Abdallah, Jehn-Ruey Jiang, Kuan-Ta Chen. "A Spatial Publish Subscribe Overlay for Massively Multiuser Virtual Environments," in the Proceedings of the 2010 International Conference on Electronics and Information Engineering (ICEIE 2010), pp. V2-314 V2-318, Kyoto, Japan, August 1-3, 2010.

- [C19] Hongxing Li, Qiangsheng Hua, **Chuan Wu**, Francis C.M. Lau. "Minimum-Latency Aggregation Scheduling in Wireless Sensor Networks under Physical Interference Model," in the Proceedings of the 13th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems (ACM MSWiM 2010), pp. 360-367, Bodrum, Turkey, October 17-21, 2010.
- [C20] Zhi Wang, **Chuan Wu**, Lifeng Sun, Shiqiang Yang. "Strategies of Collaboration in Multi-channel P2P VoD Streaming," in the Proceedings of *IEEE Globecom 2010*, Miami, Florida, December 6-10, 2010.
- [C21] Jin Wang, Jianping Wang, **Chuan Wu**, Kejie Lu, Naijie Gu. "Anonymous Communication with Network Coding against Traffic Analysis Attack," in the Proceedings of *IEEE INFOCOM 2011*, pp. 1008-1016, Shanghai, China, April 10-15, 2011.
- [C22] Ajay Gopinathan, Zongpeng Li, **Chuan Wu**. "Strategyproof Auctions for Balancing Social Welfare and Fairness in Secondary Spectrum Markets," in the Proceedings of *IEEE INFOCOM 2011*, pp. 3020-3028, Shanghai, China, April 10-15, 2011.
- [C23] Can Zhao, Xiaojun Lin, **Chuan Wu**. "The Streaming Capacity of Sparsely-Connected P2P Systems with Distributed Control," in the Proceedings of *IEEE INFOCOM 2011*, pp. 1449-1457, Shanghai, China, April 10-15, 2011.
- [C24] Chenguang Kong, Chuan Wu, Victor O.K. Li. "SMS: Collaborative Streaming in Mobile Social Networks," in the Proceedings of *IFIP Networking 2011*, also Lecture Notes in Computer Science, Springer, vol. 6641, pp. 275-287, Valencia, Spain, May 9-13, 2011.
- [C25] Zhi Wang, **Chuan Wu**, Lifeng Sun, Shiqiang Yang. "Peer-Assisted Online Games with Social Reciprocity," in the Proceedings of the *ACM/IEEE International Workshop on Quality of Service (ACM/IEEE IWQoS 2011)*, San Jose, California, USA, June 6-7, 2011.
- [C26] Yu Wu, Chuan Wu, Bo Li, Xuanjia Qiu, Francis C.M. Lau. "CloudMedia: When Cloud on Demand Meets Video on Demand," in the Proceedings of the 31st International Conference on Distributed Computing Systems (IEEE ICDCS 2011), pp. 268-277, Minneapolis, Minnesota, USA, June 20-24, 2011.
- [C27] Hongxing Li, Wei Huang, **Chuan Wu**, Zongpeng Li, Francis C.M. Lau. "Utility-Maximizing Data Dissemination in Socially Selfish Cognitive Radio Networks," in the Proceedings of the 8th IEEE International Conference on Mobile Ad-hoc and Sensor Systems (IEEE MASS 2011), pp. 212-221, Valencia, Spain, October 17-21, 2011.
- [C28] Ruiting Zhou, Zongpeng Li, **Chuan Wu**, Carey Williamson. "Physical Layer Network Coding with Signal Alignment for MIMO Wireless Networks," in the Proceedings of the 8th IEEE International Conference on Mobile

Ad-hoc and Sensor Systems (IEEE MASS 2011), pp. 530-539, Valencia, Spain, October 17-21, 2011.

9

- [C29] <u>Yu Wu</u>, **Chuan Wu**, Bo Li, <u>Linquan Zhang</u>, Zongpeng Li, Francis C.M. Lau. "Scaling Social Media Applications into Geo-Distributed Clouds," in the Proceedings of *IEEE INFOCOM 2012*, pp. 684-692, Orlando, Florida, USA, March 25-30, 2012.
- [C30] Hongxing Li, Chuan Wu, Zongpeng Li, Wei Huang, Francis C.M. Lau. "Stochastic Optimal Multirate Multicast in Socially Selfish Wireless Networks," in the Proceedings of *IEEE INFOCOM 2012*, pp. 172-180, Orlando, Florida, USA, March 25-30, 2012.
- [C31] Xuanjia Qiu, Hongxing Li, Chuan Wu, Zongpeng Li, Francis C.M. Lau. "Cost-Minimizing Dynamic Migration of Content Distribution Services into Hybrid Clouds," in the Proceedings of *IEEE INFOCOM* 2012 Mini-Conference, pp. 2853-2857, Orlando, Florida, USA, March 25-30, 2012.
- [C32] Zhi Wang, Lifeng Sun, **Chuan Wu**, Shiqiang Yang. "Guiding Internet-Scale Video Service Deployment Using Microblog-based Prediction," in the Proceedings of *IEEE INFOCOM 2012* Mini-Conference, pp. 3183-3187, Orlando, Florida, USA, March 25-30, 2012.
- [C33] Xuanjia Qiu, Hongxing Li, **Chuan Wu**, Zongpeng Li, Francis C.M. Lau. "Dynamic Scaling of VoD Services into Hybrid Clouds with Cost Minimization and QoS Guarantee," in the Proceedings of *the 19th International Packet Video Workshop (PV 2012)*, pp. 137-142, Munich, Germany, May 10-11, 2012.
- [C34] Xingwei Wang, Jiajia Sun, Min Huang, **Chuan Wu**, Xueyi Wang. "A Resource Auction based Allocation Mechanism in the Cloud Computing Environment," in the Proceedings of the 26th IEEE International Parallel & Distributed Processing Symposium (IPDPS) Workshops, pp. 2111-2115, Shanghai, China, May 21, 2012.
- [C35] Hongxian Sun, **Chuan Wu**. "Epidemic Forwarding in Mobile Social Networks," in the Proceedings of *IEEE International Conference on Communications (IEEE ICC 2012)*, pp. 1421-1425, Ottawa, Canada, June 10-15, 2012.
- [C36] Xuanjia Qiu, Wei Huang, Chuan Wu, Zongpeng Li, Francis C.M. Lau. "Exploring the Sustainability of Credit-incentivized Peer-to-Peer Content Distribution," in the Proceedings of the Fourth International Workshop on Hot Topics in Peer-to-Peer Computing and Online Social Networking (HotPOST), in conjunction with IEEE ICDCS 2012, pp. 118-126, Maucau, China, June 18, 2012 [Best Paper Award]
- [C37] Tang Xiahou, **Chuan Wu**, Jiaqing Huang, Zongpeng Li. "A Geometric Framework for Investigating the Multiple Unicast Network," in the Pro-

- ceedings of the 2012 IEEE International Symposium on Network Coding (Net-Cod 2012), pp. 37-42, Cambridge, Massachusetts, USA, June 29-30, 2012.
- [C38] Zongpeng Li, **Chuan Wu**. "Space Information Flow: Multiple Unicast," in the Proceedings of the 2012 IEEE International Symposium on Information Theory (ISIT 2012), Cambridge, Massachusetts, USA, July 1-6, 2012.
- [C39] Ruiting Zhou, Zongpeng Li, **Chuan Wu**, Carey Williamson. "Buddy Routing: A Routing Paradigm for NanoNets Based on Physical Layer Network Coding," in the Proceedings of the IEEE International Conference on Computer Communication Networks (ICCCN 2012), Munich, Germany, July 30-August 2, 2012.
- [C40] Qiang-Sheng Hua, Haisheng Tan, Yuexuan Wang, Hongxing Li, Dongxiao Yu, Francis C.M. Lau, **Chuan Wu**. "Computing Capacity and Connectivity in Cognitive Radio Ad-Hoc Networks," in the Proceedings of 2012 International Symposium on Pervasive Systems, Algorithms, and Networks (IS-PAN), pp. 9-16, San Marcos, Texas, December 13-15, 2012.
- [C41] Hongxing Li, **Chuan Wu**, Zongpeng Li, Francis C.M. Lau. "Socially-optimal Multi-hop Secondary Communication under Arbitrary Primary User Mechanisms," in the Proceedings of *IEEE INFOCOM 2013*, pp. 1765-1773, Turin, Italy, April 14-19, 2013.
- [C42] Can Zhao, Jian Zhao, Xiaojun Lin, **Chuan Wu**. "Capacity of P2P On-Demand Streaming with Simple, Robust and Decentralized Control," in the Proceedings of *IEEE INFOCOM 2013*, pp. 2797-2805, Turin, Italy, April 14-19, 2013.
- [C43] Linquan Zhang, **Chuan Wu**, Zongpeng Li, Chuanxiong Guo, Minghua Chen, Francis C.M. Lau. "Moving Big Data to the Cloud," in the Proceedings of *IEEE INFOCOM 2013* Mini-Conference, pp. 405-409, Turin, Italy, April 14-19, 2013.
- [C44] Hongxing Li, **Chuan Wu**, Zongpeng Li, Francis C.M. Lau. "Profit-Maximizing Virtual Machine Trading in a Federation of Selfish Clouds," in the Proceedings of *IEEE INFOCOM 2013* Mini-Conference, pp. 25-29, Turin, Italy, April 14-19, 2013.
- [C45] Wei Deng, Fangming Liu, Hai Jin, **Chuan Wu**, Xue Liu. "MultiGreen: Cost-Minimizing Multi-source Datacenter Power Supply with Online Control," in the Proceedings of the Fourth ACM International Conference on Future Energy Systems (ACM e-Energy), pp. 149-160, Berkley, California, USA, May 22-24, 2013.
- [C46] Xuanjia Qiu, Wai Leong Yeow, **Chuan Wu**, Francis C.M. Lau. "Cost-Minimizing Preemptive Scheduling of MapReduce Workloads on Hybrid Clouds," in the Proceedings of the *ACM/IEEE International Symposium on Quality of Service (ACM/IEEE IWQoS 2013)*, Montreal, Canada, June 3-4,

2013.

- [C47] Tang Xiahou, Zongpeng Li, **Chuan Wu**. "Information Multicast in (Pseudo-)Planar Networks: Efficient Network Coding over Small Finite Fields," in the Proceedings of the 2013 IEEE International Symposium on Network Coding (NetCod 2013), Calgary, Canada, June 7-9, 2013.
- [C48] Wei Deng, Fangming Liu, Hai Jin, **Chuan Wu**. "SmartDPSS: Cost-Minimizing Multi-source Power Supply for Datacenters with Arbitrary Demand," in the Proceedings of *the 33rd International Conference on Distributed Computing Systems* (*ICDCS 2013*), pp. 420-429, Philadelphia, USA, July 8-11, 2013.
- [C49] Ming He, Zongpeng Li, **Chuan Wu**, Xunrui Yin. "On Uniform Matroidal Networks," in the Proceedings of the 2013 IEEE International Symposium on Information Theory (ISIT 2013), Istanbul, Turkey, July 7-12, 2013.
- [C50] Yu Wu, Chuan Wu, Bo Li, Francis C.M. Lau. "vSkyConf: Cloudassisted Multi-party Mobile Video Conferencing," in the Proceedings of the Second Mobile Cloud Computing (MCC) Workshop, in conjunction with ACM SIGCOMM 2013, pp. 33-38, Hong Kong, August 12, 2013.
- [C51] Jian Zhao, Hongxing Li, **Chuan Wu**, Zongpeng Li, Zhizhong Zhang, Francis C.M. Lau. "Dynamic Pricing and Profit Maximization for the Cloud with Geo-distributed Data Centers," in the Proceedings of *IEEE INFOCOM* 2014, pp. 118-126, Toronto, Canada, April 27-May 2, 2014.
- [C52] Zhi Wang, Lifeng Sun, **Chuan Wu**, Wenwu Zhu, Shiqiang Yang. "Joint Online Transcoding and Geo-distributed Delivery for Dynamic Adaptive Streaming," in the Proceedings of *IEEE INFOCOM* 2014, pp. 91-99, Toronto, Canada, April 27-May 2, 2014.
- [C53] Linquan Zhang, Zongpeng Li, **Chuan Wu**. "Dynamic Resource Provisioning in Cloud Computing: A Randomized Auction Approach," in the Proceedings of *IEEE INFOCOM 2014*, pp. 433-441, Toronto, Canada, April 27-May 2, 2014.
- [C54] Linquan Zhang, Zongpeng Li, **Chuan Wu**, Minghua Chen. "Online Algorithms for Uploading Deferrable Big Data to The Cloud," in the Proceedings of *IEEE INFOCOM 2014*, pp. 2022-2030, Toronto, Canada, April 27-May 2, 2014.
- [C55] Weijie Shi, **Chuan Wu**, Zongpeng Li. "RSMOA: A Revenue and Social Welfare Maximizing Online Auction for Dynamic Cloud Resource Provisioning," in the Proceedings of the *ACM/IEEE International Symposium on Quality of Service (ACM/IEEE IWQoS 2014)*, pp. 166-175, Hong Kong, May 26-27, 2014.
- [C56] Shengkai Shi, Zhi Wang, Chuan Wu, Xiaojun Lin. "Characterizing

- Cascade Dynamics in A Microblogging System," in the Proceedings of *IEEE International Conference on Communications (IEEE ICC 2014)*, Sydney, Australia, June 10-14, 2014.
- [C57] Weijie Shi, Linquan Zhang, **Chuan Wu**, Zongpeng Li, Francis C.M. Lau. "An Online Auction Framework for Dynamic Resource Provisioning in Cloud Computing," in the Proceedings of *ACM SIGMETRICS* 2014, pp. 71-83, Austin, Texas, USA, June 16-20, 2014.
- [C58] Linquan Zhang, Zongpeng Li, **Chuan Wu**. "Randomized Auction Design for Electricity Markets between Grids and Microgrids," in the Proceedings of *ACM SIGMETRICS 2014*, pp. 99-110, Austin, Texas, USA, June 16-20, 2014.
- [C59] Xuanjia Qiu, Chuan Wu, Hongxing Li, Zongpeng Li, Francis C.M. Lau. "Federated Private Clouds via Broker's Marketplace: A Stackelberg-Game Perspective," in the Proceedings of the 7th IEEE International Conference on Cloud Computing (IEEE Cloud 2014), Alaska, USA, June 27-July 2, 2014
- [C60] Haoming Fu, Zongpeng Li, **Chuan Wu**, Xiaowen Chu. "Core-Selecting Auctions for Dynamically Allocating Heterogeneous VMs in Cloud Computing," in the Proceedings of the 7th IEEE International Conference on Cloud Computing (IEEE Cloud 2014), Alaska, USA, June 27-July 2, 2014
- [C61] Jian Zhao, Chuan Wu. "Socially-optimal ISP-aware P2P Content Distribution via a Primal-Dual Approach," in the Proceedings of the Sixth International Workshop on Hot Topics in Peer-to-Peer Computing and Online Social Networking (HotPOST), in conjunction with IEEE ICDCS 2014, Madrid, Spain, June 30, 2014
- [C62] Xiaoxi Zhang, **Chuan Wu**, Zongpeng Li, Francis C.M. Lau. "A Truthful $(1-\epsilon)$ -Optimal Mechanism for On-demand Cloud Resource Provisioning," to appear in the Proceedings of *IEEE INFOCOM 2015*, Hong Kong, China, April 26-May 1, 2015.
- [C63] Linquan Zhang, Shaolei Ren, **Chuan Wu**, Zongpeng Li. "A Truthful Incentive Mechanism for Emergency Demand Response in Colocation Data Centers," to appear in the Proceedings of *IEEE INFOCOM 2015*, Hong Kong, China, April 26-May 1, 2015.
- [C64] Hongxing Li, **Chuan Wu**, Zongpeng Li. "Socially-Optimal Online Spectrum Auctions for Secondary Wireless Communication," to appear in the Proceedings of *IEEE INFOCOM 2015*, Hong Kong, China, April 26-May 1, 2015.
- [C65] Ruiting Zhou, Zongpeng Li, **Chuan Wu**. "An Online Procurement Auction for Power Demand Response in Storage-Assisted Smart Grids," to appear in the Proceedings of *IEEE INFOCOM 2015*, Hong Kong, China,

April 26-May 1, 2015.

[C66] Jingpu Duan, Zhi Wang, Chuan Wu. "Responsive Multipath TCP in SDN-based Datacenters," to appear in the Proceedings of IEEE International Conference on Communications (IEEE ICC 2015), London, UK, June 8-12, 2015.

[C67] Xiaoxi Zhang, Zhiyi Huang, Chuan Wu, Zongpeng Li, Francis C.M. Lau. "Online Auctions in IaaS Clouds: Welfare and Profit Maximization with Server Costs," to appear in the Proceedings of ACM SIGMETRICS 2015, Oregon, Portland, USA, June 15-19, 2015.

[C68] Linquan Zhang, Zongpeng Li, Chuan Wu, Shaolei Ren. "Online Electricity Cost Saving Algorithms for Co-Location Data Centers," to appear in the Proceedings of ACM SIGMETRICS 2015 (poster paper), Oregon, Portland, USA, June 15-19, 2015.

INVITED TALKS [S1] "Optimal Peer Selection for Minimum-Delay Peer-to-Peer Streaming AND LECTURES with Rateless Codes," half-hour presentation, ACM Workshop on Advances in Peer-to-Peer Multimedia Streaming (P2PMMS 2005), in conjunction with ACM Multimedia 2005, Singapore, November 11, 2005.

> [S2] "Echelon: Peer-to-Peer Network Diagnosis with Network Coding," half-hour presentation, the 14th IEEE International Workshop on Quality of Service (IEEE IWQoS 2006), Yale University, New Haven, Connecticut, June 19, 2006.

> [S3] "Strategies of Conflict in Coexisting Streaming Overlays," half-hour presentation, IEEE INFOCOM 2007, Anchorage, Alaska, May 8, 2007.

> [S4] "Large-Scale Peer-to-Peer Streaming: Measurements and Optimizing Solutions," one-hour invited talk, Department of Computing, the Hong Kong Polytechnic University, Hong Kong, January 9, 2008.

> [S5] "Large-Scale Peer-to-Peer Streaming: Measurements and Optimizing Solutions," one-hour invited talk, Department of Computer Science, the University of Hong Kong, Hong Kong, February 20, 2008.

> [S6] "Large-Scale Peer-to-Peer Streaming: Measurements and Optimizing Solutions," one-hour invited talk, Department of Computer Science, National *University of Singapore*, Singapore, March 5, 2008.

> [S7] "Multi-channel Live P2P Streaming: Refocusing on Servers," half-hour presentation, IEEE INFOCOM 2008, Phoenix, Arizona, April 16, 2008.

> [S8] "Large-Scale Peer-to-Peer Streaming: Measurements and Optimizing Solutions," one-hour invited talk, Department of Information Engineering, The Chinese University of Hong Kong, December, 2008.

- [S9] "P2P VoD Streaming: Fast Neighbor Discovery and Indexing Overlay Design," one-hour invited talk, Department of Computer Science and Engineering, Hong Kong University of Science and Technology, May, 2009.
- [S10] "Large-Scale Peer-to-Peer Streaming: Measurements and Optimizing Solutions," one-hour invited talk, *The Hong Kong Applied Science and Technology Research Institute (ASTRI)*, June, 2009.
- [S11] "Introduction to Convex Optimization: Optimal Rate Control in Communication Networks", one-hour invited lecture, *Winter School, Institute of Theoretical Computer Science and Communications, The Chinese University of Hong Kong*, January, 2010.
- [S12] "Characterizing the Performance and Locality Tradeoff in BitTorrent-like P2P Systems," one-hour invited talk, Department of Computer Science, City University of Hong Kong, March, 2010.
- [S13] "Strategyproof Auctions for Balancing Social Welfare and Fairness in Secondary Spectrum Markets," half-hour presentation, *IEEE INFOCOM* 2011, Shanghai, China, April 14, 2011.
- [S14] "CloudMedia: When Cloud on Demand Meets Video on Demand," half-hour presentation, *IEEE ICDCS 2011*, Minneapolis, Minnesota, USA, June 21, 2011.
- [S15] "CloudMedia: When Cloud on Demand Meets Video on Demand," one-hour invited talk, *Institute for Infocomm Research* (*I2R*), Singapore, August 16, 2011.
- [S16] "CloudMedia: When Cloud on Demand Meets Video on Demand," one-hour invited talk, *Department of Computer Science, Northeastern University*, Shenyang, China, September 19, 2011.
- [S17] "Dynamic, Optimal Migration of Content Distribution Applications into Geo-distributed Clouds," one-hour invited talk, *Shenzhen Institutes of Advanced Technology*, Shenzhen, China, March 21, 2012.
- [S18] "Exploring the Sustainability of Credit-incentivized Peer-to-Peer Content Distribution," half-hour presentation, *HotPOST'12 in conjunction with IEEE ICDCS 2012*, Maucau, China, June 18, 2012.
- [S19] "An Online Auction Framework for Dynamic Resource Provisioning in Cloud Computing," one-hour invited talk, *Fudan University*, Shanghai, China, May 6, 2014.
- [S20] "Cloud CDN + Cloud Economics," half-an-hour invited talk, *Tsinghua Shenzhen Graduate School*, Shenzhen, China, September 20, 2014.

Prizes and AWARDS

- ♦ Distinguished Member of TPC, IEEE INFOCOM 2015.
- ♦ Prolific Reviewer for IEEE Transactions on Parallel and Distributed Systems, 2012.
- ♦ Best Paper Award in the 4th International Workshop on Hot Topics in Peer-to-Peer Computing and Online Social Networking (HotPOST'12), in conjunction with IEEE ICDCS 2012.
- ♦ IEEE Outstanding Leadership Award (in appreciation for contribution as Publication Chair of the International Conference on Cloud and Service Computing, December 12-14, 2011, Hong Kong).
- ♦ University of Toronto Fellowship, 2004 2008.
- ♦ Outstanding Master Thesis, Tsinghua University, 2004.
- ♦ Tsinghua University Excellent Graduate Scholarship, 2001.
- ♦ Outstanding Graduate, Tsinghua University, 2000.
- ♦ Tsinghua University Social Work Scholarship for Excellence in Social Work Ability, 1999.
- ♦ Tsinghua-Legend Scholarship for Outstanding Undergraduate Students,
- \Diamond Tsinghua University First-Class Scholarship (awarded to the top 5\% undergraduate students), 1998.
- ♦ Tsinghua University Excellent Undergraduate Student Scholarship, 1997.
- ♦ Tsinghua-Haolaixi Scholarship for Outstanding Undergraduate Students, 1996.

TEACHING ACTIVITIES

- ♦ CSIS0322/COMP3322 Modern Technologies on World Wide Web: Spring 2015, Fall 2013, Fall 2012
- ♦ CSIS0234B Computer and Communication Networks (CE & Double): Spring 2012, Spring 2011, Spring 2010, Spring 2009
- ♦ COMP9602 Convex Optimization: Spring 2015, Spring 2014, Fall 2011, Fall 2010, Fall 2009
- ♦ CSIS7304 The Wireless Internet and Mobile Computing: Spring 2009

DEPARTMENTAL \Diamond Faculty of Engineering, Board of the: member since 2008

AND UNIVERSITY♦ OBL Workgroup: member, 2014 — present

SERVICES

- ♦ Exchange Students Coordinator: 2012 present
- ♦ Programme Committee for MSc(CompSc): member, 2011 present
- ♦ Departmental Research Postgraduate Committee: member, 2009 present
- ♦ Programme Committee for the Computer Engineering Course: member, 2009 — present
- ♦ Admissions Committee: member, 2009 present
- ♦ China Programme Development Committee: Deputy Chair, 2009 2012
- ♦ Mainland UG Student Recruitment Committee: Deputy Chair, 2009 —
- ♦ Mainland Exchange Students Coordinator: 2009 2012

♦ Committee on Advanced Undergraduate Training: member, 2009 — 2011

16

♦ Served as interviewer in the University's mainland undergraduate interview trips to Beijing and Xi'an, in January and June 2010, respectively

♦ External Examiner on Ph.D. Thesis Committee:

Mr. Yuan, Yi, "Efficient Big Data System in the Cloud: Resource Provisioning and Scheduling", Department of Computing, The Hong Kong Polytechnic University, 2014.

♦ Internal Examiner on Ph.D. Thesis Committees:

Mr. Zhao, Haojie, "Auction-based Resource Allocation in Selfish Networks", EEE, The University of Hong Kong, 2014.

Mr. Chen, Fei, "Linear Programming Techniques for Algorithms with Applications in Economics", CS, The University of Hong Kong, 2014.

Mr. Yu, Dongxiao, "Distributed Algorithmic Studies in Wireless Ad Hoc Networks", CS, The University of Hong Kong, 2014.

Ms. Guo, Dingding, "On the Efficiency of Resource Utilization in Strategic Peer-to-Peer Systems", EEE, The University of Hong Kong, 2014.

Mr. Zhai, Ke, "Budget-Sensitive Testing and Analysis Strategies and Their Applications to Concurrent and Service-based Systems", CS, The University of Hong Kong, 2014.

Mr. Di, Sheng, "Optimal Divisible Resource Allocation for Self-Organizing Cloud", CS, The University of Hong Kong, 2011.

Mr. Ma, Ka Kui, "Lightweight Task Mobility Support for Elastic Cloud Computing", CS, The University of Hong Kong, 2011.

Mr. Tan, Haisheng, "Minimizing Interference in Wireless Sensor Networks", CS, The University of Hong Kong, 2011.

Mr. Mei, Lijun, "XML-Manipulating Techniques for the Testing and Analysis of XML-Manipulating Services", CS, The University of Hong Kong, 2010.

Mr. Hua, Qiangsheng, "Scheduling Wireless Links with SINR Constraints", CS, The University of Hong Kong, 2009.

Mr. Chiu, Hon Sun, "Channel Assignment and Routing in Multi-Channel Multi-Interference Wireless Networks", EEE, The University of Hong Kong, 2009.

♦ Internal Examiner on MPhil. Thesis Committee

Mr. Xin Zhang, "Gossip-based Publish-Subscribe Systems in Peer-to-Peer Networks", EEE, The University of Hong Kong, 2014. Mr. Zheming Xu, "WAVNet: Wide-Area Virtual Networks for Dynamic Provisioning of IaaS", CS, The University of Hong Kong, 2010.

♦ Secondary examiner for MSc(CompSc) project:

Mr. Zhixiong Niu, "Experimentation of SCTP", August 2014. Mr. Ti Liu, "Distributed Geo-Photo Sharing System", August 2009.

PROFESSIONAL MEMBERSHIP AND SERVICE ACTIVITIES

PROFESSIONAL \Diamond Member, the Institute of Electrical and Electronic Engineers (IEEE) and

IEEE Communications Society (ComSoc)

- ♦ Member, the Association for Computing Machinery (ACM)
- ♦ Demo/Poster Co-Chair, IEEE INFOCOM, Hong Kong, 2015.
- ♦ Demo Chair, ACM Multimedia Systems Conference (ACM MMSys), Portland, Oregon, 2015.
- Chair of Interest Group on Multimedia services and applications over Emerging Networks (MEN), IEEE Multimedia Communication Technical Committee (MMTC), 2012-2014.
- ♦ Member of the proposal review panel for Shenzhen High-tech Industrial Projects, August 2012.
- ♦ Publication Chair, the 2011 International Conference on Cloud and Service Computing (CSC2011), Hong Kong, December 12-14, 2011.
- ♦ Program Track Co-Chair ("Pervasive, Grid, P2P and Cloud Computing" track), the 6th International Conference on Frontier of Computer Science and Technology (FCST-11), Changsha, China, November 16-18, 2011.
- ♦ Poster Session Co-Chair, the 17th IEEE International Workshop on Quality of Service (IEEE IWQoS 2010), Beijing, China, June 16-18, 2010.
- Guest Editor: IEEE Transactions on Circuits and Systems for Video Technology, Special Issue on Visual Computing in the Cloud: Fundamentals and Applications
- ♦ Regularly Refereeing for Academic Journals:

IEEE Transactions on Parallel and Distributed Systems (TPDS)

IEEE/ACM Transactions on Networking (TON)

IEEE Journal on Selected Areas in Communications (JSAC)

IEEE Transactions on Multimedia (TMM)

IEEE Transactions on Mobile Computing (TMC)

IEEE Transactions on Wireless Communications (TWC)

IEEE Transactions on Circuits and Systems for Video Technology (TCSVT)

IEEE Transactions on Computers (TC)

IEEE Transactions on Communications (TCOM)

IEEE Transactions on Cloud Computing (TCC)

IEEE Transactions on Vehicular Technology (TVT)

IEEE Transactions on Network and Service Management (TNSM)

ACM transactions on Sensor Networks (TOSN)

Springer Multimedia Systems Journal

Springer Peer-to-Peer Networking and Applications Journal (PPNA)

Elsevier Journal of Computer Networks (JCN)

Elsevier Journal of Parallel and Distributed Computing (JPDC)

Elsevier Computer Networks Journal (COMNET)

Elsevier Performance Evaluation Journal (PEVA)

IEEE Network

IEEE Multimedia

18 C. Wu

IEEE Communications Magazine

IEEE Communications Letters

Journal of Information Systems Education (JISE)

Journal of Communications (JCM)

International Journal of Communication Systems (IJCS)

♦ Membership in Technical Program Committees:

IEEE INFOCOM: 2015 (awarded Distinguished Member of the 2015 IEEE INFOCOM Technical Program Committee), 2014, 2013, 2012, 2011

ACM International Conference on Multimedia (ACM Multimedia): 2014, 2012, 2011, 2009

ACM Multimedia Systems Conference (MMSys): 2013

IEEE International Conference on Distributed Computing Systems (ICDCS): 2011

IEEE International Conference on Network Protocols (ICNP): 2011

IEEE International Conference on Communications (ICC): 2015, 2014, 2013, 2012, 2011, 2010

IEEE Global Communications Conference (GLOBECOM): 2012, 2011, 2010, 2009

IEEE International Conference on Parallel and Distributed Systems (IC-PADS): 2012

IEEE International Conference on Computer Communications and Networks (ICCCN): 2011, 2010

IEEE Wireless Communications and Networking Conference (WCNC): 2013

IEEE International Conference on Mobile Ad-hoc and Sensor Networks (MSN): 2012

IEEE Consumer Communications and Networking Conference (CCNC): 2011, 2010

IEEE/CIC International Conference on Communications in China (ICCC): 2014

IFIP Networking: 2012

ACM/IEEE International Symposium on Quality of Service (ACM/IEEE IWQoS): 2014

ACM Workshop on Network and Operating Systems Support for Digital Audio and Video (NOSSDAV): 2014, 2013, 2012

IEEE International Workshop on Network Science for Communication Networks (NetSciCom): 2014

IEEE Workshop on Mobile Cloud Computing (MobiCC): 2012

IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (CCGrid): 2013

ACM International Workshop on Mobility in the Evolving Internet Architecture (MobiArch): 2014, 2012

ACM International Workshop on Hot Topics in Planet-Scale Measurement (HotPlanet): 2010

International Conference on Computing, Networking and Communications (ICNC): 2013, 2012

International Workshop on Hot Topics in Peer-to-Peer Computing and Online Social Networking (HotPOST): 2014, 2013

19 C. Wu

International Conference on Parallel Processing (ICPP): 2011 International Conference on Computer Science and its Applications (CSA): 2011

International Conference on Algorithms and Architectures for Parallel Processing (ICA3PP): 2010

International Conference on Contemporary Computing (IC3): 2010 International Conference on Parallel and Distributed Computing, Applications and Technologies (PDCAT): 2010

International ICST Conference on Scalable Information Systems (INFOSCALE): 2009

Pacific-Rim Symposium on Image and Video Technology (PSIVT): 2009