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Organization: GA Tech Res Corp - GIT

Submitted By:

Xu, Jun - Principal Investigator

Title:

CAREER: Fundamental Lower Bound and Tradeoff Problems in Networking

Project Participants

Senior Personnel

Name: Xu, Jun
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Graduate Student

Name: Kumar, Abhishek
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Zhao, Qi
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: zhao, haiquan
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Hua, Nan
Worked for more than 160 Hours: Yes
Contribution to Project:

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Other Collaborators or Contacts

Prof. Xingxing Yu, School of Mathematics at GA Tech.

Prof. Richard Lipton, College of Computing at GA Tech

Prof. Ellen Zegura, College of Computing at GA Tech

Prof. Bill Lin, ECE, University of California, San Diego

Prof. Mitsunori Ogihara, CS, University of Miami

Prof. Hui Zhang, CS, CMU

Activities and Findings

Research and Education Activities:

The research proposed in this project is theoretical in nature. I have been working very closely with my Ph.D. students Abhishek Kumar and Qi Zhao, trying to solve some long-standing open problems concerning the fundamental tradeoffs and lower bounds in computer networking, using paper, pencil, and creative thinking.

I have worked with Prof. Mitsunori Ogihara to establish the lower bound on the amount of communication needed to perform some single-node or distributed data streaming operations such as single-node entropy estimation and distributed iceberg detection.

I am currently working Prof. Bill Lin of UCSD to try to establish some lower bounds on the amount of information exchange (in terms of bits or number of rounds) in order to achieve high throughput and low delay in switching algorithms. We will also try to establish such lower bounds when we assume that traffic arrival process conforms to some weak constraints (e.g., traffic pattern changing not very fast, or entropy rate no larger than a certain value with high probability).

Since 2008--2009 is a no-cost extension year with limited funding left, we were not able to carry out significant new research activities other than sending students to conferences to present their papers.

Findings:

I solved several well-known and long-standing open problems concerning lower bounds and tradeoffs in networking. My first result (Sigcomm'02) concerns the minimum computational complexity needed for packet scheduling algorithms to provide a tight delay bound. It has been a long-standing open conjecture in networking research community that there is a minimum computational complexity cost to pay (usually $\Omega(log n)$ where n is the number of sessions) for packet scheduling algorithms to achieve tight {\it delay bounds} (a type of QoS guarantee). We prove that the lower bound computational complexity of any scheduling algorithm that guarantees $O(1)$ delay bound is indeed $\Omega(log_2 n)$ per packet. We also discover that the complexity lower bound remains surprisingly the same even if the delay bound is relaxed to $O(n^a)$ for $0<a<1$. This implies that the delay-complexity tradeoff curve is ``flat'' in the ``interval'' $[O(1), O(n))$. We also extend this result to the context of end-to-end delay bounds.

The first result has led me to solve another open problem concerning the minimum complexity of tracking GPS clock, an essential function in perfect packet scheduling algorithms such as WFQ and WF^2Q. My result (Infocom'04) debunks a long-held misconception that this complexity is $\Omega(N)$ per packet, which is cited in many papers and even textbooks. I showed that there is in fact an $O(\log N)$ algorithm and proved that $\Omega(\log N)$ is also the lower bound. These two results have generated considerable impact in a short period of time. They have ended the search for scheduling algorithms that would provide better delay-complexity tradeoffs and have been used for proving the optimality of several scheduling algorithms (e.g., UCSD's Stratified Round Robin). They have also been adapted (by Prof. Anderson and Jeffay at UNC) to the systems area for establishing the complexity lower bounds of CPU scheduling algorithms.

The third open problem I solved (Infocom'03) concerns the fundamental tradeoff between routing table size and network diameter in structured P2P networks. This result has inspired studies on other related tradeoff issues (e.g., by Dr. Dwarkadas of Rochester) in P2P networks. It has also led my research team to design Ulysses (ICNP'03), one of the first protocols to achieve the optimal tradeoff, and has inspired some competing protocols designed by others.

I have already established new proofs to two lower bound results in distributed computing: a minimum of $f+1$ and $f+2$ rounds for reaching consensus and uniform consensus respectively when at most f fail-stop faults can happen. Here the computation model is synchronous message passing. Both proofs are based on a novel oracle argument. These two induction proofs are uniﬁed in the following sense: the induction steps are the same and only the initial step (f=0) needs to be proved separately. The techniques used in the proof offer new insights into the lower bound results in distributed computing. The best proofs to these two problems are both over 20 pages long and both claim that the other proof can not 'carry over'. Our unified proof to both problems, on the other hand, is only 7 pages long.

Prof. Mitsunori Ogihara and I, together with our graduate students, have established the lower bound on the minimum amount of memory needed to computing the entropy of a data stream, using reduction techniques from the communication complexity theory. This result is a theorem in one of my Sigmetrics'06 papers.

Training and Development:

Both students (Abhishek and Qi) are now able to produce high-quality publications mostly by themselves after working with me for a couple of years. When they first came to GA Tech in 2002, they had little idea about what research is.

Abhishek graduated in late 2005, did a start-up company with his co-advisor Prof. Ellen Zegura on his data streaming work during my sabbatical year (2006 -- 2007), and joined Google as a member of technical staff. He is one of the best network phd graduates of his year and could have easily obtained a faculty position in top 20 schools, but unfortunately he has never wanted to become a faculty.

Qi graduated in late 2007 and joined AT&T Labs-Research as a researcher. He is also one of the best network phd graduates of his year nationwide. Internally, he received our college's most prestigious award for phd students, the graduate researcher award, in 2007. Since his graduation, he has been a successful independent researcher, publishing Sigcomm and Sigmetrics papers with his colleagues.

Haiquan's research skills and networking domain knowledge have also significantly improved. He came to Georgia Tech with strong mathematical background, but with little or no knowledge in computer networking. I am glad to see that he is catching up and can now deal with network systems issues with ease, which are often challenging for students with strong mathematical skills. Since he is the only US citizen among the phd students of our networking group, his success will help boost domestic phd production and brainpower development.

Outreach Activities:

I have been giving seminar talks on this subject (lower bounds and tradeoffs ...) at many organizations (e.g., UNC).

Journal Publications

Jun Xu and Richard Lipton, "On Fundamental Tradeoffs between Delay Bounds and Computational Complexity in Packet Scheduling Algorithms", IEEE/ACM Transaction on Networking, p. 15, vol. 13, (2005). Published,

Jun Xu, Abhishek Kumar, and Xingxing Yu, "On the Fundamental Tradeoffs between Routing Table Size and Network Diameter in Peer-to-Peer Networks", IEEE Journal on Selected Areas in Communications, p. 151, vol. 22, (2004). Published,

Abhishek Kumar, Shashi Merugu, Jun Xu, Ellen Zegura, and Xingxing Yu
, "Ulysses: A Robust, Low-Diameter, Low-Latency Peer-to-peer Network", European Transactions on Telecommunications, special issue on Peer-to-Peer Networks, p. 571, vol. 15, (2004). Published,

Qi Zhao and Jun Xu, "On the Computational Complexity of Maintaining GPS Clock in Packet Scheduling", Proc. of IEEE Infocom 2004, p. 1, vol. 1, (2004). Published,

Jun Xu, "A Unified Proof of Minimum Time Complexity for Reaching Consensus and Uniform Consensus -- An Oracle-based Approach", IEEE 21st Symposium on Reliable Distributed Systems (SRDS 2002), p. , vol. , (2002). Published,

Ashwin Lall, Vyas Sekar, Mitsunori Ogihara, Jun Xu and Hui Zhang, "Data Streaming Algorithms for Estimating Entropy of Network Traffic", Proc. of ACM SIGMETRICS 2006/IFIP Performance 2006, p. , vol. , (2006). Published,

Books or Other One-time Publications

Web/Internet Site

Other Specific Products

Contributions

Contributions within Discipline:

My findings solved several long-standing and/or well-known open problems in the networking area. See 'findings' section for details.

Contributions to Other Disciplines:

In the course of my work, I have explored and applied techniques from computational complexity theory. I believe that creative ways of applying theoretical computer science (TCS) techniques to networking is a contribution to TCS.

Contributions to Human Resource Development:

The two graduate students have been very successful in their graduate study. One (Abhishek) is going to receive the Ph.D. degree this year and the other (Qi) expects to finish Ph.D. in one to two years. Last but not the least, this award significantly helps me develop my own research skills.

Contributions to Resources for Research and Education:

Georgia Tech has matched this CAREER award with 20K in computing equipment funding, which I have used to purchase a few computing servers for the whole networking and telecommunications group at College of Computing, Georgia Tech. Numerous phd students (not just mine) have run simulations on these servers over the past several years.

Contributions Beyond Science and Engineering:

Conference Proceedings

Categories for which nothing is reported:

Organizational Partners

Any Book

Any Web/Internet Site

Any Product

Contributions: To Any Beyond Science and Engineering

Any Conference