Apoorva Jindal

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Research Interests

The focus of my research is to build next generation wireless networks, which will be more application-driven, and support much higher data rates using multi-hop technologies. To this end, I will design and implement protocols which achieve high data rates with guaranteed reliability at low cost in wireless multi-hop networks, and use these protocols to implement the important applications.

Education

- M.S and Ph.D in Electrical Engineering — Fall 2003 - Fall 2008
  UNIVERSITY OF SOUTHERN CALIFORNIA — Los Angeles, CA
  Thesis Title: IEEE 802.11 is good enough to build wireless multi-hop networks.
  GPA: 4.0/4.0.

- B.Tech. in Electrical Engineering — Fall 1998 - Spring 2002
  INDIAN INSTITUTE OF TECHNOLOGY (IIT) KANPUR — Kanpur, India
  B.Tech Project Title: A novel scheme for capacity enhancement in DS-CDMA systems.
  GPA: 9.3/10.0.

Ph.D. Dissertation

Title: "IEEE 802.11 is good enough to build wireless multi-hop networks."
Advisor: Professor Konstantinos Psounis.
Thesis Committee: Professor Ramesh Govindan and Professor Bhaskar Krishnamachari.

Researchers have proposed two different approaches to schedule transmissions in wireless multi-hop networks. The first approach is to use collision-free distributed approximations to optimal scheduling (as implementing optimal scheduling itself is an NP-hard problem). However, it is not clear if these distributed approximations can be implemented with a low overhead in terms of control messages exchanged. The second approach uses CSMA-CA based random access scheduling, like IEEE 802.11. The advantage is its low overhead and low cost. However, a common misconception is that existing random access schemes yield unfair and inefficient rates in wireless multi-hop networks. This misconception is based on works which study IEEE 802.11-scheduled multi-hop networks with TCP or in saturation conditions, both of which grossly under-utilize the capacity that IEEE 802.11 provides, or use topologies which cannot occur in practice due to physical layer limitations.

In my Ph.D. dissertation, I have formally shown that IEEE 802.11 yields exceptionally good performance in the context of wireless multi-hop networks. Specifically, I have established that IEEE 802.11 achieves more than 30% of the optimal throughput in practical topologies, and attains more than 55% of the optimal throughput on average. Considering that the state-of-the-art distributed approximations to optimal scheduling achieve lower worst case bounds than the above, IEEE 802.11 is surprisingly efficient. To ensure that the complexity does not get shifted to the transport layer, I have proposed a novel distributed rate control scheme which achieves near-optimal rates. The scheme, labeled WCP-CAP, provides explicit and precise feedback-based rate control, similar to XCP and RCP in wired networks.

Research Experience

I have worked on a variety of research projects varying from theoretical works on deriving fundamental performance limits and modeling to pure systems like implementing rate control schemes for wireless mesh networks and developing location based services for cell phones.

- Research Assistant, Networked Systems Performance and Design Lab — January'04-December'08
  DEPARTMENT OF ELECTRICAL ENGINEERING, USC — Los Angeles, CA
  - ***Achievable Rate Region of IEEE 802.11-scheduled Multi-hop Networks:*** A central question in the study of wireless multi-hop networks is the following. Given an arbitrary multi-hop topology and a collection of source-destination pairs, what is the achievable rate region of this arbitrary multi-hop network? I have characterized this region with IEEE 802.11 scheduling. (Other researchers have studied this problem with optimal scheduling.)
  - ***IEEE 802.11 vs Optimal Scheduling in Wireless Multi-hop networks:*** I have formally shown that IEEE 802.11 achieves the same degree of performance as achieved with current state-of-the-art distributed approximations to optimal scheduling in wireless multi-hop networks. This result motivates making CSMA-CA based random access schemes the de-facto standard for scheduling in multi-hop networks.
  - ***Congestion Control in Wireless Mesh Networks:*** Achieving fair and efficient rates over CSMA-CA based random access schedulers requires the transport protocol to be aware of the existing complex interference. With this in mind, I (along with my collaborators) have proposed neighborhood-centric congestion control schemes for arbitrary mesh topologies. We have designed, analyzed and implemented both AIMD-based schemes and explicit rate notification schemes.
  - ***Study of Fundamental Mobility Properties Required to Analyze Mobility-assisted Routing:*** I have derived closed form expressions for the following three fundamental mobility properties for the commonly used mobility models: (i) the meeting time, (ii) the inter-meeting time, and (iii) the contact duration. These three mobility properties are required to analyze mobility-assisted routing schemes.
  - ***Contention-Aware Performance Analysis of Mobility-assisted Routing Schemes for Delay Tolerant Networks (DTNs):*** I have proposed a general framework to model contention in DTNs which can be used with any mobility and channel model, and can be used to derive expected delay expressions for any mobility-assisted routing scheme. I then used these delay expressions to design more efficient mobility-assisted routing schemes for DTNs.
  - ***Modeling Spatially Correlated Sensor Network Data:*** Researchers have designed a large number of sensor network protocols and algorithms that attempt to exploit spatial correlations present in sensor network data. To carefully study the performance of these algorithms and obtain guidelines for designing more efficient algorithms, I have derived a simple and accurate model of spatially correlated sensor network data. I have validated the model by statistically comparing synthetic and experimental data.

- Summer Intern, Mobile Applications Group May'06 - Aug'06
  GOOGLE INC — Mountain View, CA
  - ***Building Location-based Services for Cell phones while Respecting User Privacy:*** I have designed and implemented a location-based service which allows the user choose his/her level of privacy. Higher the privacy need, more resources will be used at the cell phone. There is no impact on the application quality. Thus, unlike prior works which trade-off privacy and application quality, I have explored an orthogonal trade-off between privacy and resource usage. A patent application based on this work has been filed.

- Summer Intern, Mobile Applications Group May'07 - Aug'07
  GOOGLE INC — Mountain View, CA

– ***Structure of the Mobile Web:*** The mobile web is defined to be the set of pages written in mark-up languages designed for, or particularly suited for, consumption on mobile wireless devices such as cell phones. I (along with my collaborators) have studied the structural properties of the mobile web graph, which is a directed graph formed by considering each page on the web to be a node, and each hyperlink an edge between nodes. We have also looked at the implications of these properties for search engines which crawl and index the mobile web.

Work Experience

- Software Engineer — July'02 - July'03
  ATRENTA PVT LTD — Noida, India
  I worked on the Predictive Analysis Tool Spyglass, which does rule checking at the RTL level and reports errors which would otherwise have been found at later stages of Design Cycle. I worked on several projects including speeding up the simulator on benchmarks by 10x by optimizing the sweep routine in synthesis, redesigning the elaborator and introducing support for mixed language in the kernel.

- Summer Intern — May'01 - July'01
  EPFL — Lausanne, Switzerland
  I wrote LabView programs to study the properties of ferro-electric thin films.

Teaching Experience

- Teaching Assistant — Fall 2004, Spring 2005, Fall 2005.
  DEPARTMENT OF ELECTRICAL ENGINEERING, USC — Los Angeles, CA
  Teaching Assistant for graduate course *Probabilistic methods in computer systems modeling*. Prepared and gave lectures for material not covered in class. Formulated questions for homework sets, quizzes and mid-term/final examinations, graded exams and interacted with students during weekly office hours.
- Teaching Assistant — Summer 2005.
  DEPARTMENT OF ELECTRICAL ENGINEERING, USC — Los Angeles, CA
  Teaching Assistant for graduate course *Introduction to Computer Networks*. Prepared and gave lectures for material not covered in class. Formulated questions for homework sets, quizzes and mid-term/final examinations, graded exams and interacted with students during weekly office hours.
- Teaching Assistant — Spring 2006.
  DEPARTMENT OF ELECTRICAL ENGINEERING, USC — Los Angeles, CA
  Teaching Assistant for graduate course *Advanced Topics in Computer Networks: Applications of Optimization Theory in Wired and Wireless Networks*. Formulated questions for homework sets, interacted with students during weekly office hours and helped them with their research projects.

Honors and Awards

- Best Graduate Teaching Assistant in Electrical Engineering at USC in 2007.
- Ranked 1 in the CENG PhD screening exam at USC in 2005.
- Best Baccalaureate Project in Electrical Engineering, IIT Kanpur.
- Tata Consultancy Services (TCS) Award for the Best Undergraduate Project in IIT Kanpur.
- Awarded with the Certificate of Excellence IIT Kanpur, 2000.
- Recipient of National Talent Search (NTSE) scholarship awarded by National Council of Education Research and Training (NCERT), New Delhi.
- Top 0.3% of the students appearing in All-India IIT Joint Entrance Examination (IIT-JEE) in 1998.

List of Publications

- Journal Articles

  J1 Apoorva Jindal and Konstantinos Psounis. IEEE 802.11 vs Optimal Scheduling in Wireless Multi-Hop Networks. Manuscript under preparation.

  J2 Sumit Rangwala, Apoorva Jindal, Ki-Young Jang, Konstantinos Psounis and Ramesh Govindan. Understanding Congestion Control in Multi-hop Wireless Mesh Networks. under submission to IEEE/ACM Transactions on Networking.

  J3 Apoorva Jindal and Konstantinos Psounis. Achievable Rate Region of Wireless Multi-hop Networks with 802.11 Scheduling. Accepted to appear in *IEEE/ACM Trans. on Networking*.

  J4 Apoorva Jindal and Konstantinos Psounis. Contention-Aware Performance Analysis of Mobility-Assisted Routing. To appear in *IEEE Trans. on Mobile Computing*, February 2009.

  J5 Thrasyvoulos Spyropoulos, Apoorva Jindal and Konstantinos Psounis. An Analytical Study of Fundamental Mobility Properties for Encounter-based Protocols. *International Journal of Autonomous and Adaptive Communications Systems*, March 2008.

  J6 Apoorva Jindal and Konstantinos Psounis. Modeling Spatially Correlated Data in Sensor Networks. *ACM Trans. on Sensor Networks*, November 2006.

- Conference Papers

  C1 Sumit Rangwala, Apoorva Jindal, Ki-Young Jang, Konstantinos Psounis and Ramesh Govindan. Understanding Congestion Control in Multi-hop Wireless Mesh Networks. *ACM Mobicom, 2008*.

  C2 Apoorva Jindal, Chris Crutchfied, Samir Goel, Ravi Jain and Ravi Kolluri. The Mobile Web is Structurally Different. *11th IEEE Global Internet Symposium, 2008*.

  C3 Apoorva Jindal and Konstantinos Psounis. Achievable Rate Region and Optimality of Multi-hop Wireless 802.11-Scheduled Networks. *Information Theory and Applications Workshop (ITA), 2008*.

  C4 Apoorva Jindal and Konstantinos Psounis. Contention-Aware Analysis of Routing Schemes for Mobile Opportunistic Networks. *ACM Mobisys Workshop on Mobile Opportunistic Networking (MobiOpp), 2007*.

  C5 Apoorva Jindal and Konstantinos Psounis. Fundamental Mobility Properties for Realistic Performance Analysis of Intermittently Connected Mobile Networks. *IEEE PerCom Workshop on Intermittently Connected Mobile Ad Hoc Networks (ICMAN), 2007*.

  C6 Apoorva Jindal and Konstantinos Psounis. Optimizing Multi-Copy Routing Schemes for Resource Constrained Intermittently Connected Mobile Networks. *Fortieth Asilomar Conference on Signals, Systems and Computers, 2006*.

  C7 Apoorva Jindal and Konstantinos Psounis. Performance Analysis of Epidemic Routing under Contention. *IWCMC, 2006*.

  C8 Apoorva Jindal and Konstantinos Psounis. Modeling spatially-correlated data of sensor networks with irregular topologies. *IEEE SECON, 2005*.

  C9 Apoorva Jindal and Konstantinos Psounis. Modeling spatially-correlated sensor network data. *IEEE SECON, 2004*.

  C10 Apoorva Jindal and Konstantinos Psounis. A clustering method that uses lossy aggregation of data. *Extended Abstract in ACM Sensys 2004*.

  C11 Kartikeya Mehrotra, Apoorva Jindal and A.K.Chaturvedi. A novel scheme for capacity enhancement in DS-CDMA systems. *WNCG Symposium 2003*.

Talks

- "IEEE 802.11 is Good Enough to Build Wireless Multi-hop Networks", *Cisco Systems, HP Labs, Deutsche Telekom Labs and Docomo Labs*, December 2008
- "The Mobile Web is Structurally Different", *IEEE Global Internet Symposium*, March 2008.

- "Contention-Aware Analysis of Routing Schemes for Mobile Opportunistic Networks", *ACM Mobisys Workshop on Mobile Opportunistic Networking (MobiOpp)*, June 2007.
- "Fundamental Mobility Properties for Realistic Performance Analysis of Intermittently Connected Mobile Networks", *IEEE PerCom Workshop on Intermittently Connected Mobile Ad Hoc Networks (ICMAN)*, March 2007.
- "Optimizing Multi-Copy Routing Schemes for Resource Constrained Intermittently Connected Mobile Networks", *Fortieth Asilomar Conference on Signals, Systems and Computers*, October 2006.
- "Performance Analysis of Epidemic Routing under Contention", *IWCMC*, July 2006.
- "Modeling spatially-correlated data of sensor networks with irregular topologies", *IEEE SECON*, September 2005.
- "Modeling spatially-correlated sensor network data", *IEEE SECON*, October 2004.

Professional Associations

- Institute of Electrical and Electronic Engineers (IEEE).
- IEEE Communications Society.

Professional Activities

Reviewer for IEEE Transactions on Mobile Computing, ACM Transactions on Sensor Networks, Ad Hoc Networks, IEEE Infocom 2007, 2006, 2005, ACM Mobicom 2007, IFIP Networking 2007, 2006.

References

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