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Research interests

My current research interests lie at the confluence of my expertise, **information and communication theory**, and the fields of circuits, signal-processing, and control. I seek fundamental results applicable to technological applications of current interest, with current focus on **gigabit wireless communication** and **cyber-physical systems**.

Education

- Research engineer/Postdoc, Electrical Engg. UC Berkeley. (Aug 2010 – present)
  Focus area: *"Theoretical underpinnings of green radios and cyber-physical systems"*
- Graduate student, Electrical Engg. UC Berkeley (Aug. 2005 – Dec. 2010)
  GPA: 3.915/4.0, Dissertation topic: *"Implicit communication: Actions can speak more clearly than words."*
- Master of Technology in Electrical Engineering, IIT Kanpur (2003-2005)
  CPI : 10.0/10, Ranked 1^{st} in the department. Dissertation topic: *"Fundamental bounds on the rate of LDPC codes"*
- Bachelor of Technology, Electrical Engineering, IIT Kanpur (1999-2003).
  CPI : 9.1/10, in major 9.5/10.

Awards and Scholarships

- Best student paper award at IEEE Conference on Decision and Control (CDC), Atlanta, GA, 2010 for the paper *"Is Witsenhausen's counterexample a relevant toy?"* coauthored with Anant Sahai.
- Finalist for the best student paper award at IEEE International Symposium on Information Theory (ISIT) 2010.
- *"Vodafone Fellowship"* for 2005-06, and 2006-07 by Dept. of EECS, UC Berkeley.
- *"Microsoft Award for Innovation"* at *IEEE Computer Society International Design Competition (CSIDC) 2002.*
- *"Best Project Award"* by IIT Kanpur, Technical Arts project: "Wire Straightener"(2002).
- *National Talent Search Scholarship* (Govt. of India. '97-'03) and *State Science Talent Search Scholarship* (Govt. of Rajasthan) in recognition of science talent. Represented Rajasthan in *Indian National Physics Olympiad* (1998).

Service

- Volunteered for teaching Math 50, elementary mathematics, at San Quentin State Prison, California (2008–09).
- Co-chair for session on "Stochastic Control" for IEEE Conference on Decision and Control (CDC) 2010.
- Student co-organizer of Net/Comm/DSP Seminar, UC Berkeley (2007–present).
- Co-founder and organizer of EE Graduate Student Seminar, UC Berkeley (2008–09).
- Coordinator of Ham and amateur radio club, IIT Kanpur (2002–04).
- Reviewer for (journals) IEEE Trans. on Information Theory, IEEE Journal on Selected areas in Communications, IEEE Trans. on Communications, Systems and Control letters. For (conferences) IEEE International Symposium on Information Theory (ISIT), IEEE Conference on Decision and Control (CDC), IEEE Communication Theory Workshop (CTW), IEEE Information Theory Workshop (ITW), American Control Conference (ACC).

Teaching and guidance record

- Guiding an undergraduate student, Karthik Ganesan, for simulating my joint design of green codes/decoders by testing them in Cadence ('10-'11).
- Helped design course project for EE 141 — an implementation of LDPC decoders — for Digital Integrated Circuits (EE 141), taught by Prof. Jan Rabaey (Spring '10).

- Teaching assistant for EE120 — Signals and Systems, UC Berkeley (Fall 2007).
- Teaching assistant for EE40 – Electronic circuits lab, Spring 2005, IIT Kanpur, India.
- Tutor for Math 50, elementary mathematics, at San Quentin State Prison, California (2008-09).
- Instructor of a 3 day course on LDPC codes at the Defense Research and Dev. Organization, Dehradun, India.
- TA for Electronics circuits lab., IIT Kanpur (2004-05).

Industry experience

- "Active Interference Cancelation for OFDM systems"
  — with Stephan ten Brink, Wionics Research, Realtek, Irvine, USA, Summer, 2007.
- "Sensor motes for traffic monitoring"
  — at the California Center for Innovative Transportation, Berkeley, CA, USA, Summer, 2006.
- "CDMA for car phones"
  — with Ganesh Murthy, Daimler-Chrysler Research Center, Bangalore, India, Summer, 2002.

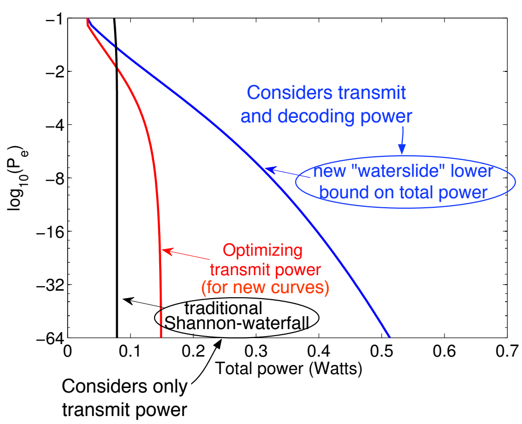
Research Summary (Preprints and MATLAB code at http://www.eecs.berkeley.edu/~pulkit/)

1. Fundamental limits on energy-efficiency of communication systems.

The goal: communication and computation The communication distances are getting smaller: from hundreds of kilometers in the 60's, to a few meters, or even smaller (e.g. 60 GHz communication). At such small distances, the required power for decoding computation can be *orders of magnitude* larger than the transmit power. How should information and communication theory adapt to this change?

A computational abstraction: In a sequence of papers, [ITW'07, ISIT '08, ISIT '09, JSAC'10 Sub.], we arrive at a "VLSI model of decoding" in order to account for power consumed in the decoding process. The model maps naturally to the fully-parallel architecture of modern-day message-passing decoders, and includes all message-passing algorithms.

A fundamental computational lower bound: In [JSAC'10 Sub.], we derive fundamental lower bounds on the required number of decoding "iterations," or time-steps, that are needed in order to attain a specified error probability P_e at a given gap from the channel capacity for *any* code/decoder in the VLSI model of decoding. These bounds show that the total number of decoding iterations *must diverge to infinity* as $P_e \to 0$, or as the rate approaches capacity (*i.e.* the transmit power approaches the Shannon limit). Results are also extended to Gaussian broadcast [ISIT '08].



A "fundamental" lower bound on total power: Shannon's "waterfall" curves illustrate that the transmit power can remain bounded even as P_e converges to zero. In [JSAC Sub '10], using our bounds on decoding complexity, we explore the behavior of **total (transmit + decoding) power** as a function of P_e. Unlike the Shannon-waterfall behavior for transmit power, we observe a **"waterslide" behavior** for total power: it must diverge to infinity as P_e converges to zero. Further, the code must operate at a gap from capacity to limit decoding power. (just as the channel capacity depends on the SNR, these bounds depend on the technology (e.g. 90 nm CMOS) and on the complexity of operations performed by the nodes.)

An "experiment" integrating teaching and research: how low can the decoding power be? To investigate the power consumption of the simplest message-passing (bit-flipping) decoders, I helped design course projects for the course on Digital Integrated Circuits (EE 141) in collaboration with Prof. Jan Rabaey (I was not a TA for the course). The results that we crowd-sourced from the 51 students' projects were interesting: for these simple decoders, the power consumed in the wires can dominate that consumed in the nodes.

Code/decoder design should depend on the desired error-probability: Inspired by the above crowd-sourcing "experiment," we derive a fundamental result [Grover, Sahai '11 *Sub.*] that shows that the decoder wire-lengths must increase as we demand lower and lower error probabilities. Our simulations of decoding power in [Ganesan, Grover '11 *in prep.*] verify this empirically: codes that minimize wire-lengths for the desired error probability can be substantially more efficient. The implications are significant: the current wireless standards (that follow the theoretical constructions) rarely propose different codes for different error-probabilities, and thus might waste decoding power.

Coding in interference environments: What is the utility of coding in environments with interference? In [ISTC '10, JSAC Sub. '10], under simplifying assumptions, we show a simple fact: coding is required to support a higher *density* of links (*i.e.* simultaneous communication links per sq-meter) when interference is treated as noise.

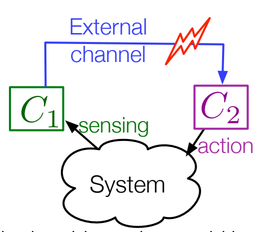
Wireless information and power transfer: For future systems, it is intriguing to consider the transfer information and power on the same channel. For Tesla's coupled inductor setup, we show [ISIT '10b] that there is a tradeoff between power-transfer and the rate of communication.

2. Control and comunication in cyber-physical systems.

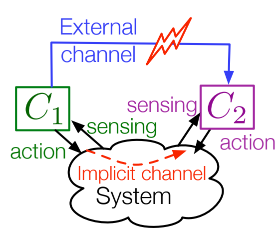
The goal: How do we connect the "cyber" — the computational/communicating/controlling agents — with the "physical?" My dissertation lays down the foundations for a theory to help answer this question.

A theory of implicit communication: The crux of this issue is captured in a deceptively simple problem called the Witsenhausen counterexample, which has been open despite more than 40 years of research effort. In my dissertation [Ph.D. Thesis], I provide the ***first provably approximately-optimal solution*** to the Witsenhausen counterexample by understanding the potential of *implicit communication* between the controllers. These approximately-optimal solutions were developed in the following sequence of results. In [CDC '08, IJSCC '10, ITW'10], we introduce a vector version of Witsenhausen's counterexample, and obtain approximately-optimal solutions for an asymptotically infinite-length version of the problem. In [ConCom '09, CDC '09, TAC '10 Sub.], we pull the results back to finite-lengths, including the original (scalar) counterexample, using techniques from large-deviation theory.

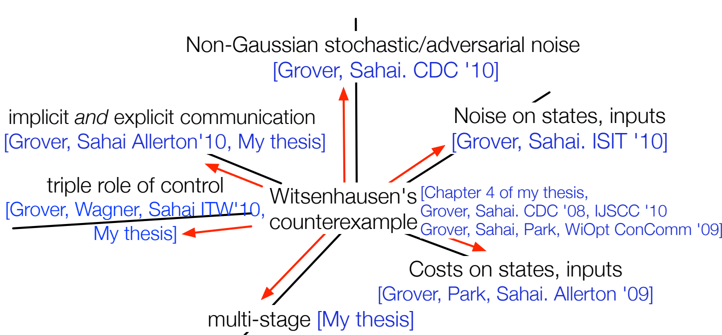
The work has received attention within Berkeley and outside and across the communities of control and communication, with the **Best Student Paper Award at IEEE Conference on Decision and Control, CDC 2010**, the **General Chairs' Recognition award for Interactive Papers** at IEEE CDC 2009, and a **finalist for the Best Student Paper Award at IEEE International Symposium on Information Theory (ISIT) 2010**.



Limited problems that could be addressed before my dissertation. These disallow for implicit communication through the system.



Problems that could be addressed using results in my dissertation.



Building a communication theory for decentralized control: In my dissertation, I argue that the Witsenhausen counterexample has been a major bottleneck in understanding the interplay of control and communication. Because the counterexample was viewed as essentially unsolvable, it forced problem formulations into corners where the obtained engineering insights could only be very limited. Our approach of using semi-deterministic models to obtain approximately-optimal strategies can be extended to understand toy problems of control under communication constraints which could not have been understood earlier. For instance, what happens when controllers can communicate implicitly as well as explicitly [Allerton '10]? How should one communicate implicitly in a dynamic setting with feedback [Ph.D. thesis]? Various extensions of the counterexample appear in [Allerton '09, ISIT '10, CDC '10].

Invited talks and seminars (excluding conference paper presentations)

"Green" communications

- "Towards a theory for low-power wireless system design." To be presented at the Workshop on Information Theory and its Applications (ITA), San Diego, Feb. 2011.
- "Low-power wireless systems: A theory-practice ping-pong." Berkeley Wireless Research Center Summer Retreat, Jun. 7, 2010.
- "Green codes for Short Distance Wireless Communication." LNMIIT, Jaipur, India, Jan 17, 2007.

Decentralized control

- "Decentralized control: when actions speak." Control Seminar, University of Michigan, Jan. 7, 2010.
- "Actions can speak more clearly than words." Comm/Net Seminar, USC, Oct. 27, 2010.
- "Actions can speak more clearly than words." Electrical Engineering department, UCLA, Oct. 26, 2010.
- "Actions can speak more clearly than words." LIDS, MIT, Oct. 18, 2010.
- "Distributed Control: A New Frontier for Information Theory." ISS Seminar, Princeton University, Mar. 25, 2010.
- "Distributed Control: A New Frontier for Information Theory." Graduation day talk, Workshop on Information Theory and its Applications, San Diego, Feb. 3, 2010.
- "Understanding Implicit Communication in Distributed Control." Cymer Center for Control Systems and Dynamics, UC San Diego, Nov. 13, 2009.
- "Understanding Distributed Control Through Information Theory." UC Berkeley graduate student seminar, Berkeley, Nov 17, 2008.

Journal papers and Magazine articles

Published

[*CSM '10*] Pulkit Grover and Anant Sahai. *"Demystifying the Witsenhausen Counterexample."* IEEE Control Systems Magazine ('Ask the experts'), vol. 30, no. 6, pp. 20-24, Dec. 2010.

[*IJSCC '10*] *"Witsenhausen's counterexample as Assisted Interference Suppression."* Pulkit Grover and Anant Sahai. International Journal of Systems, Control and Communications (IJSCC), Special Issue on Information Processing and Decision Making in Distributed Control Systems, 2(1), Jan 2010,. Pages: 197-227.

[*TIT '07*] *"Upper Bounds on the Rate of LDPC Codes for a Class of Finite State Markov Channels."* Pulkit Grover and AK Chaturvedi. IEEE Trans. on Information Theory 53(2), Feb. 2007 Pages:794 - 804

In review

[*TIT '10, sub.*] *"Information embedding meets distributed control."* Pulkit Grover, Aaron Wagner and Anant Sahai. Submitted to IEEE Trans. on Information Theory, 2010.

[*TAC '10, sub.*] *"The finite-dimensional Witsenhausen counterexample."* Pulkit Grover, Se Yong Park and Anant Sahai. Submitted to IEEE Trans. on Automatic Control, 2010.

[*JSAC '10, sub.*] *"Towards a communication-theoretic understanding of system-level power consumption."* Pulkit Grover, Kristen Ann Woyach and Anant Sahai. Submitted to Journal of Selected Areas in Communication (JSAC), special issue on Energy-Efficient Wireless Communication, 2010.

Conference Papers

Published

[*CDC '10*] *"Is Witsenhausen's counterexample a relevant toy?"* Pulkit Grover and Anant Sahai. IEEE Conference on Decision and Control (CDC) 2010, Atlanta, Georgia. **Recipient of the Student Best Paper Award**.

[*ISTC'10*] *"An interference perspective on decoding power."* Pulkit Grover, Kristen Ann Woyach, Hari Palaiyanur and Anant Sahai. 6th Int. Symp. on turbo codes and iterative information processing (ISTC), Brest, France, 2010.

[*ISIT '10a*] *"Distributed signal cancelation inspired by Witsenhausen's counterexample."* Pulkit Grover and Anant Sahai. IEEE International Symposium on Information Theory (ISIT) 2010, Austin, Texas. **Finalist for Student Best Paper Award**.

[*ISIT '10b*] *"Shannon meets Tesla : wireless information and power transfer."* Pulkit Grover and Anant Sahai. IEEE International Symposium on Information Theory (ISIT) 2010, Austin, Texas.

[*ISIT '10c*] *"Information-theoretic tradeoffs on throughput and chip power consumption for decoding error-correcting codes."* Pulkit Grover, Hari Palaiyanur and Anant Sahai. IEEE International Symposium on Information Theory (ISIT) 2010, Austin, Texas.

[*ITW '10*] *"Information embedding meets distributed control."* Pulkit Grover, Aaron Wagner and Anant Sahai. IEEE Information Theory Workshop (ITW), Cairo, Egypt, 2010.

[*Allerton '09*] *"A Generalized Witsenhausen Counterexample."* Pulkit Grover, Se Yong Park and Anant Sahai. 47th Annual Allerton Conference on Communication, Control, and Computing, Monticello, Illinois, 2009.

[*ConCom '09*] *"The Finite Dimensional Witsenhausen Counterexample."* Pulkit Grover, Anant Sahai and Se Yong Park. Control over Communication channels (ConCom), Seoul, South Korea, 2009.

[*CDC '09*] *"A constant factor approximately optimal solution to the Witsenhausen counterexample."* Se Yong Park, Pulkit Grover and Anant Sahai. IEEE Conference on Decision and Control (CDC), Shanghai, China, 2009. (**Winner of the General Chairs' Recognition award for Interactive Papers**).

[*ISIT '09*] *"Time-division multiplexing for green broadcasting."* Pulkit Grover and Anant Sahai. IEEE International Symposium on Information Theory (ISIT), Seoul, South Korea, 2009.

[*CDC '08*] *"A vector version of Witsenhausen's counterexample : Towards convergence of control, communication and computation."* Pulkit Grover and Anant Sahai. IEEE Conf. on Decision and Control (CDC), Mexico, 2008.

[*ISIT '08*] *"Green Codes: Energy-Efficient Short-Range Communication."* Pulkit Grover and Anant Sahai. International Symposium on Information Theory (ISIT), Toronto, 2008.

[*DySPAN '07*] *"On the need for knowledge of the phase in exploiting known primary transmissions."* Pulkit Grover and Anant Sahai. IEEE Inter. Dynamic Spectrum Access Networks (DySPAN) symp., Dublin, Ireland, 2007.

[*ITW '07*] *"Bounds on the tradeoff between decoding complexity and rate for codes on graphs."* Pulkit Grover. IEEE Information Theory Workshop (ITW), Lake Tahoe.

[*ISIT '07*] *"Writing on Rayleigh faded dirt: a computable upper bound to the outage capacity "* Pulkit Grover and Anant Sahai. IEEE International Symposium on Information Theory (ISIT) 2007.

[*NCC '05*] *"Upper Bounds on the Rate of LDPC Codes for a class of Finite-State Markov Channels."* Pulkit Grover and Ajit Kumar Chaturvedi. National Conference on Communications (NCC) 2005.

[*ITW '04*] *"Upper Bounds on the Rate of LDPC Codes for Gilbert-Elliott Channels."* Pulkit Grover and Ajit Kumar Chaturvedi. IEEE Information Theory Workshop (ITW) 2004, San Antonio, Texas, USA.

[*Globecomm '04*] *"Geolocation Using Transmit and Receive Diversity."* Pulkit Grover, R Agarwal and Ajit Kumar Chaturvedi. IEEE Globecom 2004, November 27–December 03 2004, Dallas, Texas, USA

In preparation/under review

- [Grover, Sahai '11 *Sub.*] *"Fundamental bounds on the interconnect complexity of decoder implementations."* Pulkit Grover and Anant Sahai. Conference on Information Sciences and Systems (CISS) 2010, *Submitted.*
- [Ganesan, Grover '11 *in prep.*] *"Decoding power consumption can increase significantly with increased wire lengths: Empirical results."* Karthik Ganesan and Pulkit Grover. In preparation.

Theses

- [Ph.D. Thesis] "Actions can speak more clearly than words," UC Berkeley, December'10.
- [MS Thesis] "LDPC Codes: Bounds on the rate and some results on minimal stopping sets," IIT Kanpur, July'05.