

Aaron Schulman

Research Interests

Embedded systems, Wireless communication, Security, Networking, Measurement

Education

- 2007–2013 **Ph.D. Computer Science**, *University of Maryland*, College Park
Dissertation: Observing and Improving The Reliability of Internet Last-mile Links
Advisor: Neil Spring
- 2007 - 2010 **M.S. Computer Science**, *University of Maryland*, College Park
- 2003 - 2007 **B.S. Computer Science**, *University of Maryland*, College Park

Awards

- **NSF CAREER Award 2023**
- **Best Paper Award** for ZLeaks (ACNS 2022)
- **IETF Applied Networking Research Prize** for Trufflehunter (awarded to my student Audrey Randall)
- **ACM SIGCOMM Doctoral Dissertation Award**
- **Larry S. Davis Doctoral Dissertation Award**, University of Maryland
- **Outstanding graduate student**–UMD College of Computer Mathematical & Natural Sciences
Awarded by the CMNS Board of Visitors to one student out of the ten departments in the college
- **Best of team projects**–Intel International Science and Engineering Fair 2003

Grants

- **\$712,000 - NSF PI** – “CAREER: Protecting Critical Infrastructure Against Wireless Attacks”
- **\$1,100,000 - NSF Co-PI** – “SII-NRDZ: SweepSpace: Enabling Autonomous Fine-Grained Spatial Spectrum Sensing and Sharing”
- **\$600,000 - NSF Co-PI** – “ CCRI: SpecScape: Enabling a Global Spectrum Observatory through Mobile, Wide-band Spectrum Sensing Kits and a Software Ecosystem”
- **\$805,000 - NSF Co-PI** – “CNS Core: Medium: Collaborative Research: Strategies for Large-Scale IPv6”
- **\$73,000 - Amateur Radio Digital Communications** – “Automated Capture and Decoding on Modest Wideband SDRs”
- **\$70,000 - Google Faculty Research Award (shared with Stefan Savage)** – “Passive Network Analysis for Security Analysis and Assessment”
- **\$100,000 - Qualcomm Innovation Fellowship**
Students: Yeswanth Guddeti and Hadi Givenchain (co-advised with Bharadia)
- **\$99,000 - Google Faculty Research Award** – “Scalable and Precise Smartphone Power Monitoring”

Publications

Conferences

Raghav Subbaraman, Kevin Mills, Aaron Schulman, and Dinesh Bharadia. Crescendo: Towards real-time, wide-band, high-fidelity spectrum sensing systems. In *MobiCom*, 2023. 24% acceptance.

Moein Khazraee, Alex Forencich, George C. Papen, Alex C. Snoeren, and Aaron Schulman. Rosebud: Making FPGA-accelerated middlebox development more pleasant. In *ASPLOS*, 2023. 21% acceptance.

Alexander Marder, Zesen Zhang, Ricky Mok, Ramakrishna Padmanabhan, Bradley Huffaker, Matthew Luckie, Alberto Dainotti, kc claffy, Alex C. Snoeren, and **A. Schulman**. Access denied: Assessing physical risks to Internet access networks. In *USENIX Security*, 2023.

Audrey Randall, Wes Hardaker Stefan Savage, Geoffrey M. Voelker, and Aaron Schulman. The challenges of blockchain-based naming systems for malware defenders. In *eCrime (Symposium on Electronic Crime Research)*, 2022. 47% acceptance.

Audrey Randall, Pete Snyder, Alisha Ukani, Alex C. Snoeren, Geoffrey M. Voelker, Stefan Savage, and **A. Schulman**. Measuring UID smuggling in the wild. In *IMC (Internet Measurement Conference)*, 2022. 26% acceptance.

Narmeen Shafqat, Daniel J. Dubois, David Choffnes, **A. Schulman**, Dinesh Bharadia, and Aanjhan Ranganathan. ZLeaks: Passive inference attacks on Zigbee based smart homes. In *Applied Cryptography and Network Security ACNS*, 2022. 24% acceptance
Best Paper Award.

Hadi Givvehchian, Nishant Bhaskar, Eliana Rodriguez Herrera, Héctor Rodrigo López Soto, Christian Dameff, Dinesh Bharadia, and **A. Schulman**. Evaluating physical-layer BLE location tracking attacks on mobile devices. In *IEEE S&P (IEEE Symposium on Security and Privacy)*, 2022. 15% acceptance.

Zesen Zhang, Alexander Marder, Ricky Mok, Bradley Huffaker, Matthew Luckie, K.C. Claffy, and **A. Schulman**. Inferring regional access network topologies: Methods and applications. In *IMC (Internet Measurement Conference)*, 2021. 28% acceptance.

Audrey Randall, Enze Liu, Ramakrishna Padmanabhan, Gautam Akiwate, Geoffrey M. Voelker, Stefan Savage, and **A. Schulman**. Home is where the hijacking is: Understanding DNS interception by residential routers. In *IMC (Internet Measurement Conference)*, 2021. 28% acceptance.

Dhananjay Jagtap, Alexander Yen, Huanlei Wu, **A. Schulman**, and Pat Pannuto. Federated infrastructure: Use, patterns, and insights from “the people’s network”. In *IMC (Internet Measurement Conference)*, 2021. 28% acceptance.

A. Randall, E. Liu, G. Akiwate, R. Padmanabhan, G. M. Voelker, S. Savage, and **A. Schulman**. Trufflehunter: Cache sniffing rare domains at large public DNS resolvers. In *IMC (Internet Measurement Conference)*, 2020. 24% acceptance

Awarded IETF Applied Networking Research Prize (ANRP).

L. F. DeKoven, A. Randall, A. Mirian, G. Akiwate, A. Blume, L. K. Saul, **A. Schulman**, G. M. Voelker, and S. Savage. Measuring security practices and how they impact security. In *IMC (Internet Measurement Conference)*, 2019. 19% acceptance

Selected to appear as an ACM CACM Research Highlight.

S. Crow, B. Farinholt, B. Johannesmeyer, K. Koscher, S. Checkoway, S. Savage, **A. Schulman**, A. C. Snoeren, and K. Levchenko. A software-reconfigurable federated avionics testbed. In *CSET (Cyber Security Experimentation and Test)*, 2019. 31% acceptance.

R. Padmanabhan, **A. Schulman**, D. Levin, and N. Spring. Residential links under the weather. In *ACM SIGCOMM*, 2019. 15% acceptance.

N. Bhaskar, M. Bland, K. Levchenko, and **A. Schulman**. Please pay inside: Evaluating bluetooth-based detection of gas pump skimmers. In *USENIX Security*, 2019. 19% acceptance.

M. Khazraee, Y. Guddeti, S. Crow, A. C. Snoeren, K. Levchenko, D. Bharadia, and **A. Schulman**. SparSDR: Sparsity-proportional backhaul and compute for SDRs. In *ACM MobiSys (Conference on Mobile Systems, Applications, and Services)*, 2019. 23% acceptance.

R. Padmanabhan, **A. Schulman**, A. Dainotti, D. Levin, and N. Spring. How to find correlated Internet failures. In *PAM (Passive and Active Measurement Conference)*, 2019. 27% acceptance.

Y. Guddeti, R. Subbaraman, M. Khazraee, **A. Schulman**, and D. Bharadia. SweepSense: Sensing 5 GHz in 5 milliseconds with low-cost SDRs. In *USENIX NSDI (Networked Systems Design and Implementation)*, 2019. 11% acceptance

Selected to appear in ACM SIGMOBILE's GetMobile.

A. Balasingam, M. Bansal, R. Misra, K. Nagaraj, R. Tandra, S. Katti, and **A. Schulman**. Detecting if LTE is the bottleneck with BurstTracker. In *ACM MobiCom (Conference on Mobile Computing and Networking)*, 2019. 19% acceptance.

Y. Liu, W. Tome, L. Zhang, D. Choffnes, D. Levin, B. Maggs, A. Mislove, **A. Schulman**, and C. Wilson. An end-to-end measurement of certificate revocation in the web's PKI. In *ACM IMC (Internet Measurement Conference)*, 2015. 33% acceptance.

R. Padmanabhan, P. Owen, **A. Schulman**, and N. Spring. Timeouts: Beware surprisingly high delay. In *ACM IMC (Internet Measurement Conference)*, 2015. 33% acceptance.

Y. Michalevsky, G. Nakibly, **A. Schulman**, and D. Boneh. PowerSpy: Location tracking using mobile device power analysis. In *USENIX Security*, 2015. 15% acceptance.

M. Bansal, **A. Schulman**, and S. Katti. Atomix: A framework for deploying signal processing applications on wireless infrastructure. In *USENIX NSDI (Networked Systems Design and Implementation)*, 2015. 20% acceptance.

A. Schulman, D. Levin, and N. Spring. RevCast: Fast, private certificate revocation over FM radio. In *ACM CCS (Conference on Computer and Communication Security)*, 2014. 20% acceptance.

L. Zhang, D. Choffnes, T. Dumitras, D. Levin, A. Mislove, **A. Schulman**, and C. Wilson. Analysis of SSL certificate reissues and revocations in the wake of Heartbleed. In *ACM IMC (Internet*

Measurement Conference), 2014. 23% acceptance.

Selected to appear as an ACM CACM Research Highlight.

A. Schulman and N. Spring. Pingin' in the rain. In *ACM IMC (Internet Measurement Conference) - Short Paper*, 2011. 13% acceptance.

A. Schulman, N. Spring, V. Navda, R. Ramjee, P. Deshpande, C. Grunewald, V. N. Padmanabhan, and K. Jain. Bartendr: A practical approach to energy-aware cellular data scheduling. In *ACM MobiCom (Conference on Mobile Computing and Networking)*, 2010. 14% acceptance.

B. Han, **A. Schulman**, N. Spring, B. Bhattacharjee, F. Gringoli, L. Nava, L. Ji, S. Lee, and R. Miller. Maranello: Practical partial packet recovery for 802.11. In *USENIX NSDI (Networked Systems Design and Implementation)*, 2010. 17% acceptance.

A. Schulman, D. Levin, and N. Spring. On the fidelity of 802.11 packet traces. In *PAM (Passive and Active Measurement Conference)*, 2008. 32% acceptance.

Journals

Z. Foo, D. Devescery, M. Ghaed, I. Lee, A. Madhavan, Y. Park, A. Rao, Z. Renner, N. Roberts, **A. Schulman**, V. Vinay, M. Wieckowski, D. Yoon, C. Schmidt, T. Schmid, P. Dutta, P. Chen, and D. Blaauw. A low-cost audio computer for information dissemination among illiterate people groups. *IEEE Transactions on Circuits and Systems I: Regular Papers*, 2013.

Workshops

D. Levin, **A. Schulman**, K. Lacurts, N. Spring, and B. Bhattacharjee. Making currency inexpensive with iOwe. In *NetEcon (Workshop on the Economics of Networks, Systems, and Computation)*, 2011. 35% acceptance.

R. Blue, C. Dunne, A. Fuchs, K. King, and **A. Schulman**. Visualizing real-time network resource usage (NetGrok). In *VizSEC (Workshop on Visualization for Cyber Security)*, 2008. 72% acceptance.

Demos

A. Schulman, T. Schmid, P. Dutta, and N. Spring. Phone power monitoring with BattOr. In *ACM MobiCom (Conference on Mobile Computing and Networking)*, 2011.

B. Aggarwal, P. Chitnis, A. Dey, K. Jain, V. Navda, V. Padmanabhan, R. Ramjee, **A. Schulman**, and N. Spring. Stratus: Energy-efficient mobile communication using cloud support. In *ACM SIGCOMM*, 2010. 33% Acceptance.

Press

- Study on the effectiveness of BLE physical-layer identification featured in:
 - "Widespread Vulnerability Identified in Phones and Bluetooth Devices", *IEEE Spectrum*, Oct. 2021
 - "Latest Bluetooth vulnerability could leave your location enabled", *Android Police*, Oct. 2021
 - "Your iPhone can be tracked via Bluetooth - and you might not be able to stop it", *Tom's Guide*, Oct. 2021
 - "How your phone, laptop, or watch can be tracked by their Bluetooth transmissions", *The Register*, Oct. 2021
- Study on how we can observe usage of rare domain names in large DNS resolvers:

- "Trufflehunter: A New Tool to Sniff Out DNS Usage", *RIPE/APNIC Blogs*, Mar. 2021
- Study on Bluetooth-based credit card skimmer detection featured in:
 - "Thieves have been stealing credit card info at gas pumps. Now there's an app to foil them.", *NPR Marketplace*, Sep. 2019
 - "UC San Diego Develops App To Curb Card Skimmers At Gas Stations", *KPBS*, Aug. 2019
 - "Meet Bluetana, the Scourge of Pump Skimmers", *Krebs on Security*, Aug. 2019
 - Also covered in: *Engadget*, *Gizmodo*, *Techcrunch*, *FastCompany*, and *PetrolWorld*
- Heartbleed revocation study featured in:
 - "Sysadmins disposed of Heartbleed certs, but forgot to flush" *The Register*, Nov. 2014
 - "UMD Cyber Experts Discover Lapses in Heartbleed Bug Fix" *UMD Now*, Nov. 2014
- PowerSpy featured in:
 - "Battery power alone can be used to track Android phones" *BBC*, Feb. 2015
 - "Cell Phone Surveillance, What Androids Reveal, Silicon Valley Gender Discrimination" *KQED TV Interview*, Feb. 2015
 - Several radio interviews: *BBC World Service* and *KSL Broadcasting*
- NetGrok featured in: McRee, Russ "Security Visualization Tools" *Linux Magazine*, Sep. 2009
- ThunderPing featured in: "Tracking Internet Outages in Sandy's Wake" *IEEE Spectrum*, Nov. 2012

Research Experience

2016–Present **Assistant Professor**, *UC San Diego*

Leading a team of graduate students to build and deploy large-scale measurement systems to observe fundamental properties of the infrastructure in our connected world. The data from these systems informs engineers, regulators, and law enforcement about how they can improve the efficiency, reliability, and security of our infrastructure.

2013–2016 **Postdoctoral Scholar**, *Stanford University*, Mentor: Sachin Katti

Leading a research agenda that addresses the growing concern that we are reaching the limits of the efficiency of software developed for abstract computing hardware.

2007–2013 **Research Assistant**, *University of Maryland*, Advisor: Neil Spring

Designed, implemented, and evaluated systems to defend the following thesis: By building on existing infrastructure, it is possible to (1) observe the reliability of Internet last-mile links across different weather conditions and link types; (2) improve the energy efficiency of cellular Internet last-mile links; and (3) provide an incrementally deployable, energy-efficient Internet last-mile downlink that is highly resilient to weather-related failures.

2010–2012 **Visiting Research Student**, *University of Michigan*, Mentor: Prabal Dutta

Learned about various aspects of embedded systems development, including: circuit design, analog circuit design, and firmware programming. These skills enabled me to (1) create BattOr—the first portable smartphone power monitor, (2) create the FM RDS receiver hardware that I used to evaluate the reliability of revoking certificates over FM broadcasts, (3) teach the embedded systems courses at Stanford and Maryland.

2009 **Research Intern**, *Microsoft Research India*, Mentors: Navda, Ramjee, and Padmanabhan
 Researched and designed a system for energy-aware cellular data scheduling. My work from this internship was published in MobiCom and patented by Microsoft.

2008 **Research Intern**, *Microsoft Research*, Mentor: Galen Hunt

Researched and implemented a system that removes the need for synchronizing application data between PCs and mobile devices; without modifying existing PC and mobile applications.

Service

- **Program committee member:**
 - **2023:** MobiCom, Performance
 - **2022:** MobiSys, NSDI (heavy), RAID
 - **2021:** SIGCOMM, PAM, IMC
 - **2020:** NSDI (heavy), SIGCOMM, PAM
 - **2019:** IMC
 - **2018:** SIGCOMM, CoNeXT
 - **2017:** HotNets, IMC
 - **2016:** MobiSys (light), HotNets, HotMobile
 - **2015:** INFOCOM
 - **2014:** SIGCOMM Posters, TMA
 - **2011:** ACM S3, MobiSys PhD Forum
- **NSF Panel member:**
 - **2023:** Secure and Trustworthy Cyberspace (SaTC)
 - **2021:** Secure and Trustworthy Cyberspace (SaTC)
- **Program committee chair:** ACM S3 2012
- **Job Event Chair:** MobiCom 2019
- **Corporate sponsorship chair:** MobiCom 2014
- **Judge:** Intel ISEF 2014
- **Organizer:** Syschat weekly paper discussions 2009-2010
- **Data set collector:** 802.11 traces collected at SIGCOMM 2008

Teaching Experience

- Spring **Lead, CSE123: Computer Networks**, UC San Diego
- 2019–2022 This course provides an introduction to the concepts, principles, and practice of computer communication networks with examples from existing architectures, protocols, and standards. Topics include layering and the OSI model; switching; local, metropolitan, and wide area networks; datagrams and virtual circuits; routing and congestion control; and internetworking (a.k.a. The Internet).
- Winter **Lead, CSE190: Wireless Embedded Systems**, UC San Diego
- 2019–2021 This course teaches students about how an embedded system works from the ground up. The lectures focus on the key enabling components of embedded systems, including: Clocks, GPIO, Interrupts, Busses, Amplifiers, Regulators, Power supplies, ADC/DAC, DMA, Storage, and Wireless communication. The goal of the class is to familiarize the students with these components so that they feel comfortable working on a team that is building a device that incorporates a wireless embedded system. The students iteratively designed and built a privacy-enabled “lost my keys” device that waits until the lost item is motionless for an extended period of time, then it begins to beacon over Bluetooth Low Energy to a nearby smartphone.
- Fall 2021 **Lead, CSE291: Internet Infrastructure**, UC San Diego
- This course teaches students the latest research on the infrastructure behind the Internet. Topics will include wireless Internet access links that provide high performance in increasingly challenging environments, including: 5G mobile, rural ISPs, and Low Earth Orbit satellite networks. Also, large-scale wireline Internet infrastructure, including: metropolitan and long-distance fiber, Fiber-To-The-Home, and Fiber-To-The-Node (e.g., DOCSIS).

- Winter 2021–2022 **Lead**, *CSE222A: Computer Communication Networks*, UC San Diego
 This course provides a broad understanding of exactly how the network infrastructure supports distributed applications. Topics covered in the course include: Internet routing, software-defined networking, datacenters, content distribution networks, and peer-to-peer systems. This is a research-oriented course focusing on current and classic papers from the research literature. Further, all students will work on an original research project, culminating in a project writeup and conference-style presentation. The very best of these course projects have resulted (with additional work) in publication in top conferences.
- 2017–2018 **Lead**, *CSE291: Topics in Embedded Computing and Communication*, UC San Diego
 This course is a discussion of classic and recent research that addresses the challenges introduced by the mobile platform. Specifically, it focuses on the blurry line between electrical engineering and computer science. The shift to the embedded computing platform has brought with it a host of new challenges. Embedded devices have severely constrained energy capacity, their network connectivity is exclusively provided by unreliable bandwidth-constrained wireless links, they carry a standard set of sensors that are seemingly insufficient for certain applications and also can inadvertently leak private information about their users. Also, embedded devices are notoriously difficult to secure because they lack hardware security primitives.
- Fall 2015 **Co-Lead**, *EE107: Networked Embedded Systems*, Stanford University
 I designed the first embedded systems course for EE undergraduates at Stanford. I also co-taught twice-weekly classes with Sachin Katti. The topics covered included: MMIO, GPIO, timers, interrupts, clocks, serial busses, ADC, power management, and wireless networking. The course project entailed assembling and programming a smartphone power monitor. For the final project, the students used the power monitors that they created to compare the power consumption of popular Android applications.
- Spring 2014 **Co-Lead**, *ENGR40C: Engineering Wireless Networks*, Stanford University
 I co-taught various classes on wireless communications, including compression, modulation, and demodulation. I also created live in-class demonstrations of wireless communication concepts using audio signals, including: modulation, multipath, angle-of-arrival, channel linearity, and error models.
- Fall 2012 **Co-Lead**, *CMSC498A Introduction to Embedded Systems*, University of Maryland
 I designed and taught the first embedded systems course for CS undergraduates at Maryland. I co-taught twice weekly, 75 minute classes with Bobby Bhattacharjee. The topics covered included: MMIO, GPIO, clocks, interrupts, ADC and DAC, filtering, DMA, busses, amplifiers, energy efficiency, and circuit boards. The course projects consisted of building the following systems around an ARM microcontroller: a binary clock, a sound recorder, and an audio modem.
- Fall 2008 **Graduate Teaching Assistant**, *CMSC412 Operating Systems*, University of Maryland
 Taught twice-weekly, hour-long discussions sections. Administered a semester long course project. Graded homework, projects, and the final exam. The projects consisted of adding the following features to an open source educational kernel: process listing, signals, scheduling, synchronization, paging, virtual memory, and an inodes-based file system.
- Spring 2006 **Ugrad Teaching Assistant**, *CMSC420 Data Structures*, University of Maryland
 Revised and improved the specification for a semester long project. Answered students' questions regarding the project.

Talks

- UC Irvine - Department of Computer Science Colloquium - Nov. 2019: *Measuring Widespread Problems With Our Critical Infrastructure*
- Google Faculty Summit - Networking 2019: *Residential Links Under the Weather*

- SIGCOMM 2015: *SIGCOMM Preview Session – Wireless*
- CCS 2014: *Fast, Private Certificate Revocation over FM Radio*
- CAIDA AIMS-5: *Pingin' II: Now We're Analyzin'*
- CAIDA AIMS-4: *Pingin' in the Rain*
- NANOG 54 Lightning Talk: *Pingin' in the Rain*
- IMC 2011: *Pingin' in the Rain*
- MobiCom 2010: *Bartendr: A Practical Approach to Energy-aware Cellular Data Scheduling*
- NSDI 2010: *Maranello: Practical Partial Packet Recovery for 802.11*
- PAM 2008: *On the Fidelity of 802.11 Packet Traces*

--- Professional Experience

- 2015–2018 **Co-Founder and Chief Scientist**, *Mellow Research, LLC*, Redwood City, CA
Commercializing the BattOr power monitor hardware.
- 2015–2018 **Software Engineer**, *Contractor for Google*, Mountain View, CA
Tech transfer of the BattOr power monitor research into Telemetry, Google Chrome's automated performance testing framework.
- 2008–2013 **Software Engineer**, *KEYW Corporation*, Annapolis Junction, MD
Advising the development of quick reaction software applications.
- 2007–2008 **Software Engineer**, *Northrop Grumman Mission Systems: Essex Windermere*, Annapolis, MD
Designed and implemented software and hardware for a wireless signal capture system.
- 2005–2007 **Research Fellow**, *Consortium Research Fellows Program: National Defense University*, Fort McNair, DC
Assisted in the design, implementation and presentation of an Information Assurance Laboratory used in executive briefings, presentations to foreign dignitaries and masters level coursework.

--- Patents

- US8345616: Scheduling Communications in a Mobile Device
Vishnu Navda, Ramachandran Ramjee, *Aaron Schulman*, Venkata N. Padmanabhan, Kamal Jain
- US20200326362A1: High Resolution Spectrum Monitoring (pending)
Yeswanth Reddy Guddeti, Dinesh Bharadia, Moein Khazraee, *Aaron Schulman*, Raghav Vaidyanathan Subbaraman