June 25–30, 2016
Singapore

Association for
Computing Machinery

Advancing Computing as a Science & Profession

MobiSys'16

Proceedings of the 14th Annual International Conference on Mobile Systems, Applications, and Services

Sponsored by:

ACM SIGMOBILE

In-cooperation with:

ACM SIGOPS

Supported by:

Singapore Exhibition & Convention Bureau, National Science Foundation, Singapore Management University, Hewlett Packard Enterprise, Facebook, Google, IBM Reserarch, LARC, Microsoft, Naver, TATA Consultancy Services, and VISA Research

Association for
Computing Machinery

Advancing Computing as a Science & Profession

The Association for Computing Machinery
2 Penn Plaza, Suite 701
New York, New York 10121-0701

Notice to Past Authors of ACM-Published Articles

ACM intends to create a complete electronic archive of all articles and/or other material previously published by ACM. If you have written a work that has been previously published by ACM in any journal or conference proceedings prior to 1978, or any SIG Newsletter at any time, and you do NOT want this work to appear in the ACM Digital Library, please inform permissions@acm.org, stating the title of the work, the author(s), and where and when published.

ISBN: 978-1-4503-4269-8

Additional copies may be ordered prepaid from:

ACM Order Department
PO Box 30777
New York, NY 10087-0777, USA

Phone: 1-800-342-6626 (USA and Canada)
+1-212-626-0500 (Global)
Fax: +1-212-944-1318
E-mail: acmhelp@acm.org
Hours of Operation: 8:30 am – 4:30 pm ET

Printed in the USA .

General Chairs' Welcome

We take great pleasure, as general chairs, to welcome you to Singapore to attend the 14th International Conference on Mobile Systems, Applications, and Services -- MobiSys'16. MobiSys has, since its inception in 2003, been the premier venue for world-leading research in mobile systems.

We are delighted that the steering committee, led by Victor Bahl, agreed to let us bring the conference to Singapore this year. This is the first time the conference has come to South Asia and we are deeply honoured to be chosen to do so, especially as this edition coincides with the 20th anniversary of ACM SIGMOBILE.

Running a successful conference, first and foremost, requires a stellar program of excellent research papers. We are delighted that the program committee, led by Sharad Agarwal and Cecilia Mascolo as program committee chairs, has done a fantastic job in selecting 31 excellent papers from a submission pool of 197 submissions. We are also very grateful to Sharad and Cecilia for their constant and excellent help in improving all aspects of the MobiSys program, which also includes a special session to honor some luminaries who are proud recipients of SIGMOBILE's first "Test of Time" paper awards.

This year's edition of MobiSys continues the tradition of having multiple workshops, which allow our community to explore emerging and evolving topics in smaller, focused interactions. Our workshops chairs, Nicholas Lane, Eduardo Cuervo and Yunxin Liu, deserve special credit for coordinating 8 different workshops (including our first Women's workshop), spread across 2 days.

For this iteration of MobiSys, we are delighted to introduce two innovations. First, we developed a mobile application, for both iOS and Android, to improve the engagement with and between MobiSys attendees. This conference app uses location and sensing technologies to intelligently provide attendees with games, quizzes, program information, and the ability to chat with fellow attendees. We would like to thank Ignatius Tan and his entire engineering team comprising Ritesh Kumar, Tran Anh Quan, Tieu Thi Thanh Chau, William Tan, Le Hai Son, Huynh Quang Trung, Aniket Pujara, John Lee, Jeena Sebastian, and Prakhar Vishnoi for developing, testing, deploying, and maintaining the conference application. In addition, we would like to thank Sharad Agarwal, Stefan Sariou, and Alec Wolman for helping us integrate the Microsoft Research Embedded Social Software Development Kit into the app. We would also like to thank all our internal and external testers for their feedback that helped to improve the app.

Second, we wanted to greatly increase the number of student attendees at MobiSys, with a special emphasis on students from our regional neighborhood and various parts of Asia. To do this, we created a special symposium called the Asian Students' Symposium on Emerging Technologies (ASSET) that will run from June 23-June 25th, right before the main conference. ASSET was designed to help students with their research and presentation skills, allow them the opportunity to present and discuss research with distinguished researchers, and to increase and improve their peer networks. We would like to humbly thank Youngki Lee, JeongGil Ko, Tadashi Okoshi, and Jie Xiong for helping us to organise ASSET. In addition, we would like to thank Suman Banerjee, Romit Roy Chowdhury, Nigel Davis, and Lin Zhong for generously volunteering their time and agreeing to be speakers at ASSET.

In addition to ASSET, we also increased the demo and poster session to a two day event with up to 150 presenters. This allowed many additional students to present their work at MobiSys. We

would like to thank Landon Cox, Yutaka Arakawa, Xia Zhou, and Robert LiKamwa for managing the expanded demo/poster session.

This year, we have been fortunate to receive amazing sponsorship support from academic, governmental, and industrial sources. This allowed us to sponsor at least 80 students to attend MobiSys -- students that otherwise would not have been able to attend. We would first like to thank our main sponsors, the ACM and ACM SIGMOBILE for making this conference possible. In addition, we would like to thank Singapore Tourism Board (STB), Suntec Convention Centre, LiveLabs Urban Lifestyle Innovation Platform (LiveLabs), Information Technology Research Academy (ITRA), National Science Foundation (NSF), Hewlett Packard Enterprises, Facebook, Google, Microsoft Research, Visa Research, Living Analytics Research Centre (LARC), School of Information Systems at Singapore Management University (SIS), IBM Research, Tata Consultancy Services (TCS), and Naver Labs for their generous support that made these student scholarships possible. We also would like to thank Pei Zhang, Vinayak Naik, and Christos Efstratiou for managing the entire scholarship application process in a very competent and seamless way.

Running all of these events requires an entire team of 'heroes'--unsung volunteers who help manage the chaos and madness that every conference like ours must face. We would like to extend our heartfelt thanks to our entire local arrangements team, led by Youngki Lee, and ably assisted by our colleagues, Huang Sipei and Luar Shu Hui. Special thanks also to our colleagues Jonathan Wang (Finance) and Kazae Quek (Registration), who have gone well beyond their nominal designations and helped out in so many different ways. This team of battle-hardened veteran is being helped by so many enthusiastic student volunteers, ably coordinated by Mun Choon Chan, Salil Kanhere and Azeem Khan. We owe all of them a big thanks for making MobiSys a seamless and enjoyable experience for all our guests.

The reason that most people know about the events taking place at MobiSys is because of the publicity efforts and the website. In this regard, we are very grateful to our publicity chairs Moustafa Youssef, and Tamer Nadeem for sending out numerous publicity emails. In addition, we would like to thank Tadashi Okoshi for his amazing social media publicity efforts that created engaging publicity channels that was not utilised heavily previously. We also want to express our sincere thanks to Kasthuri Jayarajah and Inseok Hwang for being amazing webmasters who were willing and able to update the website as soon as changes were required -- which was quite frequently at some points in time.

Finally, we would like to thank everyone, including our volunteers and especially the authors who submitted paper, poster, and demo submissions for making MobiSys a very successful event. On behalf of the entire organising team, we would like to welcome you to Singapore and we hope that you have an amazing experience here!

Archan Misra & Rajesh Krishna Balan
MobiSys'16 General Chairs
Singapore Management University

Message from the Program Chairs

It is our great pleasure to bring you the proceedings for the 14th ACM Conference on Mobile Systems, Applications, and Services (ACM MobiSys 2016). We hope you enjoy this technical material behind the conference that attracts a diverse set of attendees from both academia and industry and is a leading venue for publications and idea exchange on mobile systems. ACM MobiSys 2016 has a highly selective, single-track program featuring research related to mobile systems and applications. It is an ideal venue to address research challenges facing the design, development, deployment, use, and fundamental limits of these systems.

Our paper review process this year was highly selective. Out of 197 submissions, the technical program committee accepted only 31 for publication and presentation as full papers, yielding an acceptance rate around 15.73%. Submitted papers underwent a rigorous, multistage review process. First, we checked all submissions for compliance, general quality, and topic match. We administratively rejected those not meeting our submission criteria. We assigned 3 reviewers to papers that survived this stage from the program committee and the external review committee. At the conclusion of this stage, those papers where none of the reviewers recommended acceptance were rejected. We then assigned at least 2 additional reviewers from the program committee to papers that survived, thus totaling at least 5 reviews per paper. An online discussion phase then ensued, resulting in the PC recommending 59 papers for discussion at the PC meeting. The PC meeting was held in person in St. Augustine, FL, USA, the day before ACM HotMobile 2016. At the conclusion of the PC meeting, we tentatively accepted 31 papers to the conference. All tentatively accepted papers were assigned shepherds to help ensure that the authors produce a final manuscript that satisfactorily addresses reviewer comments. All shepherded papers were ultimately accepted to the conference.

Our program this year covers an exciting set of topics including operating systems, transport, networking, sensing, security and privacy. It also includes a poster/demo session, a panel, and keynote speakers.

Putting together the program of ACM MobiSys 2016 was a team effort. We thank the General Chairs, Professors Rajesh Krishna Balan and Archan Misra, for supporting us and forming and driving the rest of the organizing committee. We thank all authors for submitting their work to the conference. Our special thanks go out to the program committee and external review committee members for the monumental amount of work in producing over 800 reviews. We thank ACM and the other members of the organizing committee for all the logistical arrangements that made it possible to bring this program to you. Our thanks also go out to the ACM MobiSys Steering Committee for trusting us to produce the 2016 program. Last but not least, we thank the conference attendees for their patronage of the conference and for making it a successful meeting place for multiple communities and a catalyst for discussions and creative exchange.

We hope that you will find this program interesting and thought-provoking and that the conference will provide you with a valuable opportunity to share ideas with other researchers and practitioners from institutions around the world.

Sharad Agarwal, *Microsoft*

Cecilia Mascolo, *University of Cambridge*

ACM MobiSys 2016 Program Co-Chairs

Table of Contents

Session IV: Transit and Mapping

Session Chair: Robin Kravets *(University of Illinois at Urbana-Champaign)*

Session V: No More Leaks

Session Chair: Ben Greenstein *(Google)*

Session VI: Better Mobile Interfaces

Session Chair: Inseok Hwang *(IBM Research)*

Session VII: Small and Large Scale Networking

Session Chair: Xia Zhou *(Dartmouth College)*

Session VIII: App Security & Privacy

Session Chair: Landon Cox *(Duke University)*

2016 MobiSys Organization

General Chairs: Rajesh Balan *(Singapore Management University)*
Archan Misra *(Singapore Management University)*

Program Chairs: Sharad Agarwal *(Microsoft)*
Cecilia Mascolo *(University of Cambridge)*

Workshop Chairs: Nicholas Lane *(Bell Labs)*
Eduardo Cuervo *(Microsoft)*
Yunxin Liu *(Microsoft)*

Poster/Demo/Video Chairs: Landon Cox *(Duke University)*
Yutaka Arakawa *(NAIST)*
Xia Zhou *(Dartmouth College)*
Robert LiKamWa *(Rice University)*

Local Arrangements Chairs: Youngki Lee *(*Lead*) (Singapore Management University)*
Sipei Huang *(Singapore Management University)*
Shu Hui Luar *(Singapore Management University)*

Publicity Chairs: Tamer Nadeem *(Old Dominion University)*
Tadashi Okoshi *(Keio University)*
Moustafa Youssef *(Egypt-Japan University of Science and Technology)*

Publication Chair: Jie Xiong *(Singapore Management University)*

Treasurer & Registration Chairs: Jonathan Wang *(Singapore Management University)*
Kazae Quek *(Singapore Management University)*

Web Chairs: Inseok Hwang *(IBM Research)*
Kasthuri Jayarajah *(Singapore Management University)*

Student Scholarship Chairs: Christos Efstratiou *(University of Kent)*
Vinayak Naik *(IIIT Delhi)*
Pei Zhang *(Carnegie Mellon University)*

Student Volunteers Chairs: Mun Choon Chan *(National University of Singapore)*
Salil Kanhere *(University of New South Wales)*
Azeem Javed Khan *(Oriental Institute of Management)*

Steering Committee Chair: Victor Bahl *(Microsoft Research)*

Program Committee: Mary Baker *(HP Labs)*
Aruna Balasubramanian *(Stony Brook University)*
Geoffrey Challen *(University at Buffalo)*
Jennifer Yingying Chen *(Stevens Insitute of Technology)*
Landon Cox *(Duke University)*
Eduardo Cuervo *(Microsoft)*
Nigel Davies *(Lancaster University)*
Jakob Eriksson *(University of Illinois at Chicago)*
Jason Flinn *(University of Michigan)*
Deepak Ganesan *(University of Massachussetts)*
Ben Greenstein *(Google)*
Marco Gruteser *(Rutgers University)*
Jeremy Gummeson *(Disney)*
Polly Huang *(National Taiwan University)*
Minkyong Kim *(IBM Research)*
Robin Kravets *(University of Illinois, UC)*
Nicholas Lane *(Bell Labs)*
Youngki Lee *(Singapore Management University)*
Qin *(*Christine*)* Lv *(University of Colorado, Boulder)*
Z. Morley Mao *(University of Michigan)*
Lama Nachman *(Intel)*
Vishnu Navda *(Microsoft)*
Giovanni Pau *(UPMC - LIP6)*
Ardalan Amiri Sani *(University of California, Irvine)*
Lenin Ravindranath Sivalingam *(Microsoft)*
Junehwa Song *(KAIST)*
Jia Wang *(AT&T)*
Kamin Whitehouse *(University of Virginia)*
Ying Zhang *(HP Labs)*
Xia Zhou *(Dartmouth College)*

External Review Committee: Yuvraj Agarwal *(Carnegie Mellon University)*
Jeremy Andrus *(Apple)*
Nilanjan Banerjee *(University of Maryland)*
Alastair Beresford *(University of Cambridge)*
Jeremy Blackburn *(Telefonica Research)*
Mun Choon Chan *(National University of Singapore)*
Kuan-Ta Chen *(Academia Sinica)*
Hao-Hua Chu *(National Taiwan University)*
David Chu *(Microsoft)*
Sarah Clinch *(Lancaster University)*
Mark Corner *(University of Massachussetts Amherst)*
Nicola Dell *(Cornell Tech)*
Christos Efstratiou *(University of Kent)*
Shyam Gollakota *(University of Washington)*
Y. Charlie Hu *(Purdue University)*
Wenjun Hu *(Yale University)*
Inseok Hwang *(IBM Research)*
Puneet Jain *(HP Labs)*
Fahim Kawsar *(Bell Labs)*
David Kotz *(Dartmouth College)*
Sung-Ju Lee *(KAIST)*
Kyunghan Lee *(UNIST)*
Ilias Leontiadis *(Telefonica Research)*
Justin Manweiler *(IBM Research)*
Mahesh Marina *(University of Edinburgh)*
Richard P. Martin *(Rutgers University)*
Mirco Musolesi *(University College London)*
Tadashi Okoshi *(Keio University)*
Abhinav Pathak *(Apple)*
Matthai Philipose *(Microsoft)*
Kiran Rachuri *(Samsung Research)*
Bozidar Radunovic *(Microsoft)*
Silvia Santini *(TU Dresden)*
Stefan Saroiu *(Microsoft)*
Souvik Sen *(Google)*
Kannan Srinivasan *(The Ohio State University)*
Emmanuel Munguia Tapia *(Intel*
Sasu Tarkoma *(University of Helsinki)*
Alec Wolman *(Microsoft)*
Guoliang Xing *(Michigan State University)*

MobiSys'16 Sponsors & Supporters List

Sponsors:

Venue Partner:

Academic Partner:

Held in:

Supported by:

Platinum Supporter:

Gold Supporter:

Silver Supporter:

Bronze Supporters: