

Summary Report for the First NSF Workshop on Mobile Community Measurement Infrastructure

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1. INTRODUCTION

Flexible measurement infrastructure support for experimentation are critical for enabling and supporting research work with strong experimental components to help validate ideas and evaluate the design in practice. Mobile computing research work must be evaluated in as realistic network settings as possible to help researchers understand how various factors such as signal strength, network load affect the performance and energy metrics of interest. Currently, there is no environment that enables network visibility from an end-to-end perspective of the cellular network protocol stack: from the end-device all the way to the network server traversing through various network elements. The lack of such an integrated measurement infrastructure greatly hinders the innovation in this important research field.

In November, 2014, we held the first NSF workshop on Mobile Community Measurement Infrastructure. The goal was to identify the key requirements for designing and developing a mobile community measurement infrastructure to support cutting-edge research in mobile computing, going beyond the current research interests to support experimentation in next-generation mobile networks such as 5G. Today's mobile systems are deployed with ad-hoc measurements providing limited visibility into network behavior; however, we need integrated, cross-layer scalable, and flexible measurement infrastructure to enable transformative and bold research endeavors. In particular, most commercially deployed mobile network infrastructure are completely closed to researchers, making it difficult to experiment with or understand the impact of today's systems or future technologies. We argue that measurements for mobile wireless networks must be designed from ground up, rather than as an after-thought after the protocol and infrastructures have been built and deployed.

A goal of this report is to continue the conversation on how the community will conduct measurement in an effective, sustainable, and collaborative manner. Our workshop mission aligns with previous and concurrent workshops, namely AIMS 2014 [1] and the NSF Workshop on Future Research Infrastructure held jointly with this workshop. However, our mission is more focused on

measurement and monitoring support, instead of infrastructure development in general. In fact, the each critical part of infrastructure should support measurement effectively, to enable real-time debugging and diagnosis, in order to evolve the wireless network for future application and user demands.

2. ISSUES AND CHALLENGES

The workshop focused on four high-level topics: (1) measurements and application needs, (2) testbeds, (3) operational challenges, and (4) data collection and privacy. Based on presentations, discussions, and feedback from participants, we identified the following key challenges that need to be addressed in these areas.

2.1 Measurements and Application Needs

An important challenge for any measurement infrastructure is understanding what measurements to make and how they will benefit applications. We discussed a variety of current and future measurements and applications, and identified the following key challenges.

- **What data to collect?** From fine-grained, low-level measurements to application-layer QoE metrics, the range of potential data to collect is vast. There are common challenges across all measurement domains, including coverage across time and locations, efficiency of measurements, availability of measurement data, how to use the data once it is gathered, how to crowdsource measurements, what applications will benefit, and how to support infrastructures that benefit the most amount of research.
- **Openness and ground truth:** A key challenge highlighted by participants is openness and ground truth: we need access to mobile systems and platforms, representative datasets for user/device populations, and infrastructure support for measurement.

Other key challenges include privacy, incentives for supporting/reporting measurements and covering higher-frequency spectrum.

2.2 Testbeds

The following issues came up when discussing existing testbeds for mobile measurement.

- **Limited scope:** most of the focus of testbed is on network protocols, very little on layer 2. There is a lack of a focus on end-to-end measurement with more common focus on link layer measurements by most carriers. Testbed and measuring tools are available but there are few studies to address user experience with new and evolving wireless technologies.
- **Scalability, diversity, and standardization:** Achieving large-scale measurement infrastructure is difficult, and hampered by the diversity of measurement environments and lack of standards.
- **Data completeness:** Using crowd-sourced mobile measurement data, one can end up with large datasets from sparse users. An alternative approach is drive testing (hired companies). For both, it is hard to extrapolate inside buildings. An important question is how much data is enough in order to make claims to generalize the findings from the data.
- **Data analytics:** Large amounts of data needs thoughtful analysis to reveal deep insights or patterns. Further, there are privacy and quality concerns; e.g., if the data are from users, how do we know users truthfully report them?
- **Testbed usability:** Testbeds are usually created with a target application in mind. As a result, they are carefully tuned to the PI’s research needs. Adapting the testbed for shared use is often surprisingly difficult and creates in sub-optimal results. There is also concern that we are sometimes replicating or performing work that might be done better by industry, so partnership with industry can be helpful.

From the feedback we collected, we also identified key questions that we should ask for designing testbeds:

- **Testbed purpose:** What is the purpose of a testbed, How can it be broadened to support the maximum number of projects.
- **Data collection:** What is the structure that would best benefit industry, government, and academia to build integrated testbed or collect measurement data? How to deal with the noise, privacy concerns, and incentives when collecting crowdsourcing data?
- **Integration with existing testbeds:** How can we best utilize existing testbeds? What new infrastructure is needed to perform exciting measurements?
- **Industry involvement:** What is the main challenges the Wireless industry facing, do Academic studies provide good feedback to the industry?

2.3 Operational Challenges

The workshop featured a panel discussion from representatives of mobile wireless providers, to help understand operational challenges. We summarize the key issues and challenges identified in this panel here.

- **Difficulties of instrumentation to support mea-**

urement: There is a limited ability to perform instrumentation, e.g., phones, base stations. There are clear tradeoffs between active monitoring and passive measurement: monitoring baseband information requires more energy, as waking up the phone for measurement can be expensive. In general, companies are not interested in altruistic investment to make access to data easier, and it is unclear how to convince them to invest in instrumentation.

- **Virtualization-imposed challenges and network complexity:** virtualization has its own challenges (following a bad experience report, hard to know what happened at the time). It is hard to look at CPU path for all packets due to slow down of the network. It is important to design measurement from scratch in this network.
- **Lack of data sharing:** Carriers, device manufacturers and chipset providers do not often share data or make their interface for collecting data openly accessible. This is detrimental to improving performance or diagnosing faults.
- **Innovation in areas controlled by industry:** There is a need for infrastructure allowing us to innovate in areas currently controlled by cellular providers. It also helps to have standardized virtual platform be implemented for a range of measurements and also adapt to specific network characteristics.
- **Realistic data and infrastructure:** it is important to recruit real users to use experimental infrastructure to provide realistic workloads and use cases. As concrete action items, the research community can build our data archive and create benchmark at least for use by the research community. Another focus can be to develop experimental infrastructure and open testbeds facilitating research in this area.

2.4 Data Collection and Privacy

An important challenge for mobile wireless measurement is that the data collected can potentially reveal significant information about users, whether doing was intentional or not. We identified the following challenges for collecting data and maintaining privacy/security.

- **Standardized mechanisms for allowing policy-based access to data.** Picking a data-sharing models can be challenging and models tend to be one of: anonymize everything and share with everyone, no sharing, or share it with anyone who signs NDAs. A key open challenge is that we are not lawyers and legal implications can vary by jurisdiction.
- **Incentives for industry to share data.** Government agencies can fund industry/academia collaborations that require open datasets. Another solution is to collect some “case study” or “benchmark” data from industry. While not necessarily broadly representative, it can be used for benchmarking—similar

to the Netflix challenge (but hopefully without the privacy problems). We also discussed the utility of data sets with mobility, both for understanding human mobility and for mobile simulations and evaluations. In this context, industry has more data, as well as data processing technology, but getting data from industry is difficult.

- **A norm for data privacy/security accepted by the community.** There is much confusion in the community around IRBs, ethical standards and privacy — examples of which vary according to where you are and who you ask. One participant suggested that the community needs to develop a set of community 'norms' for ethical mobile measurement when human subjects are involved. The NSF and ACM could perhaps support the community in developing and disseminating these norms among research institutions and their IRBs, and brokering connections to relevant international organizations.

Another challenge is improving IRB domain expertise so they are more effective/efficient in reviewing studies from CS. Last, a key challenge is that data privacy and access is a moving target.

3. RECOMMENDATIONS AND FUTURE DIRECTIONS

It is clear that mobile community measurement infrastructure is a broad area with many challenges to address across many disciplines and layers of the networking stack. We heard a wide range of talks about research efforts that were interesting individually, but there was a clear need for focus, communication, coordination, and collaboration across different research, industry, and governmental groups.

Through discussions and survey feedback, the following common themes emerged for recommendations to make progress toward sustainable, innovative mobile community measurement infrastructure:

- NSF funding of long-lived infrastructure to host collaborative testbeds for mobile measurement. There needs to be a program that funds long-term development and maintenance of measurement infrastructure as a service to the research community.
- We recommend that researchers should work with vendors, service providers and government advocates to ensure measurements are integrated into wireless systems. There is a need for open and innovated testbeds, including low-layer tools for performing measurements, systems/architectures to simplify measurement collection and techniques to use/combine the measurements effectively. Last, we need better instrumentation to understand the performance difference for new and current spectrum uses.
- Incentives for researchers and industry to work to-

gether and share data. This can in part be solved by government policies/programs providing “carrots” or “sticks” to encourage cooperation. Of course, it is also incumbent on researchers and industry to find mutually beneficial projects on which to collaborate.

- Instrumentation across all layers of the wireless stack, from spectrum to PHY to application layer, and we need to identify how to combine measurements across layers to address problems in today’s wireless networks and to inform future network designs.
- Address data privacy/security issues in the mobile environment, particularly due to the increased risk for leaks of subjects’ personally identifiable information (PII). We should develop community standards for gathering, securing, and sharing such data, and ensure that these policies are compliant with jurisdictional restrictions. We should develop ways to “reward” those who comply with community standards for sharing data, to encourage the practice.
- We should improve IRBs, *e.g.*, creating a technology-focused IRB, and look into to how social scientists (*e.g.*, Census Bureau) deals with similar issues we are facing in the wireless measurement domain. Another participant suggested that we should establish best practices and policies for data sharing.
- More research and policy effort should be devoted to making testbeds and datasets truly open and accessible. It is important to work closely with industry to not duplicate their efforts and instead focus on challenges that lead to addressing more forward-looking aspects of the network design across different layers for next-generation mobile networks.
- Better communication between research groups, industry, policy makers, and pertinent government agencies. Many participants were unaware of salient testbeds, measurement approaches, and government initiatives presented at the meeting. We suggest future workshops that focus on bringing together more focused groups of participants who share stronger interests, and use these meetings to build a community around critical mobile measurement infrastructure.

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4. REFERENCES

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