Research Challenges and Directions for Next-Generation Internet of Things

Outcome Report from the US-Europe Invited Workshop on Next-Generation Internet of Things, University of Southern California, Los Angeles, March 31-April 1, 2016

The USC Ming Hsieh Institute and Inria@SiliconValley organized a US-Europe Invited Workshop on Next-Generation Internet of Things at Los Angeles on March 31-April 1, 2016. The workshop was attended by about thirty leading researchers from academia, government labs, and industry from different US states and EU countries (France, Italy, Ireland, etc). Details of the workshop including the list of attendees and the program can be found on the workshop website at http://anrg.usc.edu/ngiot16/

Through interactive discussions, participants of the workshop identified the following key challenges and directions for new research efforts in the area of the Internet of Things:

1. Security and Privacy:
- Systematically identify security and privacy requirements (user, institution, or regulatory) for different IoT systems and applications.
- Develop the science of data use and sharing to ensure secure, trustworthy data is delivered to the right users with low overhead in a way that guarantees privacy across time.
- Design commissioning techniques, key management schemes, access policies, intrusion detection and response systems that are suitable for increasingly larger numbers of low power, unattended (and mobile) devices, with intermittent access to servers.

2. Reliability and Dependability:
- Develop simple and user-friendly tools for specification, coding, formal verification, testing to reduce bugs and vulnerabilities.
- Develop design and analysis tools for IoT systems that describe what they can and cannot do, what guarantees they can provide at various layers, under time-varying operating conditions.
- Inform programmers about inherent unreliability and uncertainty, including in sensing and actuation, through suitable abstractions.

3. Usability, Management, Interoperability:
- Make IoT systems really easy to deploy, even in environments where they have to interoperate with legacy devices and networks.
- Develop intuitive, effective, user-friendly interfaces and tools for human operators to gather information about network health, and to reconfigure the network as needed
- Ensure interoperability across multiple layers -- interoperability of communication (at PHY and MAC levels), applications, data between different IoT devices and networks.

4. Software Architecture:
- Create enhanced middleware and tools that enable easy specification and flexible implementation of processing at the edge and in the cloud.
- Develop architecture and optimization frameworks that determine how best to split computation (and data) across edge devices and cloud servers in a distributed / hierarchical manner, to enable both coarse and fine-grained insights from the collected sensor data
- Develop architectures that allow IoT devices to network together seamlessly and enable compute-intensive tasks and distributed storage platforms.

5. Information-Centric Networking:

- Connect event-based, publish-subscribe middleware to named data networking and other information-centric networking approaches to bridge the gap between applications and network layer in the context of IoT systems with their unique characteristics.
- Make it easy for authorized users to search through an IoT system for devices and the data they produce, while ensuring data authentication and confidentiality by securing IoT data directly.
- Enable real-time data analytics via distributed aggregation, fusion, pruning.

6. Closed-Loop Operation:

- Develop control algorithms to close the loop between sensing and actuation, including motion control and human users in the loop, even in the presence of loss and delay, and analyze their stability and efficiency.
- Provide deterministic predictable behaviors at the network level to allow developers to re-use existing body of work on closed-loop control.
- Create autonomous, self-adaptive IoT networks that monitor, self-heal and improve their own performance over time by incorporating online learning.

7. Radio Innovations:

- Design new physical and link layers using techniques such as massive MIMO, network coding, successive interference cancellation, etc. that enhance spectrum efficiency, low-power operation, and reliability.
- Develop and utilize low-cost low-power software-defined radios to spur innovations at the lower layers.
- Discover and develop new radio-based sensing capabilities.

8. Testing and Evaluation:

- Identify canonical applications that push the boundaries of capability, and provide benchmarks for evaluation.
- Develop shared / federated testbeds and code repositories that facilitate replicable evaluation of protocols and software in diverse environments.

9. Social, Economic, and Policy Issues:

- Research social acceptance of new IoT technologies, their impact on the digital divide and sustainable living, new economic opportunities and disruptions
- Identify and study new regulatory policies and economic incentives for spectrum use, data sharing, and interoperability.

10. Education:

- Develop and disseminate interdisciplinary curricula and materials about new developments as well as relevant results and techniques from existing disciplines such as communications and networking, embedded systems, control theory, machine learning, software engineering.
- Educate the next generation of developers to create software able to run with limited resources and exposed to faults.
- Encourage testbed operators to make testbeds more broadly accessible and available to students and researchers at universities.

For any questions about this document or the NGIOT16 workshop, please contact the co-organizers Bhaskar Krishnamachari (bkrishna@usc.edu) and Valerie Issarny (Valerie.Issarny@inria.fr).