Dependable Sensor and Actuator Networks

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Omnipresent networked sensor and actuator systems intended to improve our daily live will only become acceptable to society if they are dependable and trustworthy. To date, it is not possible to accurately predict important aspects such as latency of data collection, robustness against faults, and lifetime. Moreover, systems are not robust against changes in the system and its environment during operation. To achieve dependable systems, we need integrated progress along four lines of working: integral system-level modeling, robust system architectures and deployments, run-time adaptation techniques to cope with dynamic changes and unforeseen circumstances, and design support targeting robustness and dynamic adaptation.

THE CHALLENGE

Many industrial and academic research roadmaps (e.g., [1,4]) predict a future with omnipresent sensors and actuators to assist humans in their daily living and to improve a wide range of activities such as transport and logistics, medical care, agriculture, environmental monitoring, and security. Communication between devices occurs typically through wireless networks, and devices are often battery powered. Before deploying such a wireless sensor and actuator network, it is important to know that its functional behavior is correct, i.e., that it is doing what it is designed for. At least as important though is that extra-functional aspects such as latency and reliability of data collection and network lifetime are as expected, and that the system is robust against faults, changes, and unforeseen circumstances. **With today's technology, however, it is not possible to accurately predict system-level aspects of networked sensor and actuator systems**. The main reasons are:

- The fluctuating quality of wireless communication and the lack of practical system-level radio channel models to predict this fluctuating behavior in the presence of objects (buildings, furniture within buildings, humans, cars) and interference sources (other sources of radio communication, weather).
- The lack of accurate energy models for many system components. This makes it impossible to accurately predict system properties like the network lifetime.
- The scale of the systems that may consist of large numbers of communicating devices. This leads to scalability problems for larger systems in typical verification and simulation approaches.
- The highly dynamic nature of the systems and their behavior, both due to fluctuating external interference sources like objects moving through the network and due to changes in the system itself, like node mobility, node failures, system updates, etc.

Developing networked sensor and actuator systems that are robust against faults, dynamic changes, and unforeseen circumstances is in fact a challenge in itself. To maintain proper service levels and optimize extra-functional aspects like reliability and network lifetime, it is important that a system can adapt to the dynamic environment in which it operates and to changes in the system itself. Today's design trajectories do not pay sufficient attention to these dynamic aspects.

THE SOLUTION

It is unlikely that in the near future the research community will be able to develop models that accurately predict all aspects of the envisioned wireless sensor and actuator networks. Moreover, these networks and their environments will always be dynamic in nature. Therefore, alongside the development of improved models and analysis techniques, the community should focus on developing robust systems, run-time adaptation techniques, and design support targeting robustness and run-time adaptation. Systems can be made robust by built-in redundancy in sensors, including duplicate sensors and complementary sensors (allowing sensor fusion), redundancy in actuators, and in communication infrastructure. Network topology, protocol stacks, operating systems and middleware functionality should all be designed with robustness in mind. A good example of a very robust means of communication and data dissemination is gossip-based networking [3]. Run-time adaptation techniques, including on-line learning, that monitor and optimize system performance during operation are needed to maintain service quality (see e.g. [2] for an illustrative example) and further contribute to robustness. Such techniques can compensate to some extent for design-time prediction inaccuracies, and they provide robustness in case of failures, system changes, unforeseen circumstances, and changing environmental conditions. Modeling and analysis research should therefore focus on supporting the design of robust system architectures and deployments and reliable run-time adaptation techniques. Design trajectories should treat robustness and dynamic adaptation as first-class citizens, for example by targeting multiple operating points of the system with different quality and resource usage characteristics and mechanisms to switch between operating points. System developers should keep in mind that their designs lead to predictable behavior, that can be captured by accurate models. Protocols and run-time adaptation techniques should be verified whenever possible. **Only joint progress in predictive modeling and analysis, robust system architectures and deployments, reliable run-time adaptation, and appropriate design support will lead to the level of dependability that is required to make omnipresent sensor and actuator networks a reality.**

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