Large-scale Distributed RFID Infrastructures for Pervasive Computing

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Introduction

The future of large-scale pervasive computing undoubtedly involves a plethora of devices with various form factors and functionalities, interacting on many levels in concert. In this paper, we argue that simple devices like passive UHF RFID tags, will nonetheless have significant impact in pervasive computing. We provide our vision of a simple, distributed, and scalable infrastructure, and a sampling of application domains. We provide technical challenges that we believe are practical and within our grasp. Finally, we argue why this RFID vision will continue to advance pervasive computing as a whole.

RFID Everywhere

We do not limit our vision to a particular technology. But passive RFID tags currently are representative of our vision. They are small and can be affixed or printed onto a variety of materials. They are battery less and contain increasingly large storage spaces. They are very inexpensive and can have a long lifetime. We envision that the cost of a tag will be absorbed into the cost of the object it is associated with. In other words, every physical object that is not a device, such as a table, a cup, or a piece of clothing, could one day become a connected storage device by default of RFID.

The "Internet of Things" predicts that all of these everyday-tagged objects will be networked together, allowing for easy inventorying and tracking. We see broader application domains for this distributed tag infrastructure. We mention only three (that are not necessarily independent) in the interest of space. 1) Tags will serve as a fully distributed, potentially mobile, scalable storage system. We envision active devices equipped with RFID interrogators reading from and writing to groups of tags allowing for robust and secure information storage in a large dynamic space-time range. 2) Currently, much of pervasive computing is centered around people. In the future, RFID will push this granularity even finer to extend to physical real-world objects. Mark Weiser in his famous 1991 Scientific American article remarked that a technology should disappear once it matures and that ubiquitous computing is about bringing computation into the real physical world. We envision that RFID will hide these intricate software mechanisms from users that shape their physical lives. Instead of users interacting with each other using personal devices, objects will interact with each other (within the context of a mesh of active devices and networks), ultimately to the benefit of users. 3) Tagged objects will not only interact with each other, they will be self-aware and context-aware, on many space-time scales. Both as their storage capacity and number increase and the computational power of devices activating these tags increase, we envision distributed computing at the level of objects themselves.

Research Directions

We present two broad challenges and consequent research directions in regards to distributed RFID infrastructures for scalable pervasive computing systems. 1) The first challenge is the heterogeneous nature of pervasive computing itself. Devices, network infrastructures, and the software gluing them all together are vastly different in variety. This very richness makes pervasive computing highly desirable and powerful. But to the system designer, this heterogeneity presents many challenges of design and integration. RFID only adds to the complexity when we bring well-defined computing ontologies to the infinite physical world. One possible research strategy is to design vertically, and then to generalize horizontally. That is, to define small, closed systems, such as tagging retail clothing for automated consumer experiences.

Once this has been implemented, to expand to other arenas, such as tagging food items in a grocery store. The problem here is that we seek pervasive computing systems that scale in both space and time. The physical world cannot be fully categorized and the systems fully defined a priori. We therefore envision research that leverages ideas from areas such as artificial intelligence and data mining to allow RFID infrastructures to evolve and learn on their own. In particular, even though RFID tags are passive, they can still be self-aware and context-aware. We envision active devices storing code onto tags, dynamically running the code depending on varied situations. In this way, we can build flexible and intelligent RFID infrastructures. 2) Another research challenge is system assurance. How can we design RFID infrastructures to be robust from both natural Byzantine failures and intended attacks from malicious parties. RFID offers exciting solutions since its very design is distributed in nature. We can scale the redundancy of a system to hedge the required acceptable level of a risk by scaling the deployment of tags. Since tags individually have asymptotically zero cost, we can design with great precision. We need research to characterize these very notions of scaling. For example, consider a smart building where tags are placed in the walls, floors, furniture, and even carried by people inside. As users interact with the building, active devices can correspondingly scan tags, and the building become self-aware. As more tags are added, we expect the building to learn even faster. In an example scenario, a highly confidential document can be digitally chopped into multiple pieces, sent through the local network, and stored into tags throughout the building. Alternatively, the tags in a building could reliably record every visitor to the building, making a historical database of its use.

A Natural Evolution in Pervasive Computing

We argue that our vision of distributed RFID infrastructures will continue to advance pervasive computing, because it follows from a natural evolution. Mark Weiser predicted that computing devices can have different form factors, adapting to the needs of the user in his/her physical environment. Today, we increasingly see this reality, as keyboard-based computers, smart phones, and very recently, touch-based tablet computers have become commonplace. But ultimately, we do not only interact with screens, but individual physical objects in a multi-modal fashion. Therefore, we believe that distributed RFID infrastructures are the next logical step as we computerize the physical world.

Advances in artificial intelligence in large-scale networks using large repositories of information have resulted in technologies and trends such as web search, location-based services, and social networking. These are all focused on the individual. We must push further to the next scale of physical granularity in the advancement of pervasive computing. That is, we believe this research should be continued in a similar vein, but at the level of physical objects through RFID infrastructures.

Author Backgrounds

Victor K.Y. Wu is a PhD candidate at the University of Illinois at Urbana-Champaign. With Professor Campbell, he has designed, deployed, and investigated distributed RFID systems for a variety of applications.

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