Challenge: Distributed Sensing Applications in Highly Heterogeneous and Multimodal Pervasive Environments

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Whitepaper

NSF Workshop on Pervasive Computing at Scale (PeCS)

Background Dr. Di Francesco has been working in the field of Wireless Sensor Networks (WSNs) for several years, with specific focus on energy-efficient mechanisms for data collection and dissemination [1]. He investigated how different sensing modalities and acquisition strategies can improve the quality of information and the energy-efficiency in WSNs [2]. He also considered urban sensing scenarios and, more generally, applications exploiting mobile elements in WSNs [3, 4]. In this context, he applied learning algorithms for improving the efficiency of data collection [5]. More recently, he started investigating privacy issues in pervasive systems, with special reference to smart environments [6].

Vision Pervasive applications have become increasingly complex. Context and situation awareness – complemented by learning and data mining algorithms – have emerged as effective abstractions to map data (which are often noisy or too abundant) to meaningful representation of states, activities, and patterns. Rich characterization of contextual information can significantly benefit from scale, which brings fine resolution and extended coverage. Since it is impractical to explicitly instrument large-scale pervasive environments, an intriguing option consists in exploiting whatever devices – sensing platforms, application-specific devices already present in the environment (such as surveillance cameras), personal communication devices (such as smartphones), and so on – are incidentally available in the environment to perform distributed applications. These devices should self-organize to collaboratively allocate and execute even multiple applications at the same time. Since nodes spontaneously interact, there is no control not only on the network architecture, but also on the specific kind (or family) of the participating devices, which are potentially highly heterogeneous. However, *heterogeneity should not be seen as a foe, but rather as a resource to federate specialized (hence efficient) devices in a pervasive infrastructure* which can exploit rich interactions by means of multimodal sensing and multi-paradigm communication.

Significance While many approaches to pervasive applications operates on top of a specific network architecture or communication paradigm, much effort has been also targeted to bridge diverse (and sometimes technically incompatible) technologies. A recent research direction relates to the field of the so-called Internet-of-Things [7]. The heterogeneity of devices is addressed in this context, however the focus is still on interconnection issues, in terms of both homogeneity of in the internetworking and the availability of standardized access to data [8]. Hence, an approach targeted at *giving value to heterogeneity (in terms of functions), while at the same time abstracting from the differences between the individual devices, is definitively a foundation of large-scale pervasive environments*. In fact, it will ease the creation and deployment of distributed applications, as well as improving the efficiency and the robustness of the system.

Handling heterogeneity requires to rethink conventional paradigms, for instance those used in the context of middleware architectures for sensing devices [9]. In fact, the following significant challenges arise.

- Heterogeneous devices imply a variety of platforms, architectures, and operating systems. A framework for heterogeneous devices should be carefully designed to meet the contrasting requirements of abstracting the functions of the nodes and providing access to the features peculiar to individual devices.
- How to obtain a distributed application suitable to pervasive environments is demanding, since the decomposition in tasks has to be aware of the heterogeneity of devices. Hence, new methodologies and tools have to be developed, with particular focus on optimizing the resource utilization.
- The large number of devices leads to scalability and reliability issues. Also here heterogeneity can help: devices can use different communication technologies, and in some cases even multiple interfaces at the same time, thus increasing the overall spectrum utilization and raw bandwidth. However, proper scheduling and routing mechanisms have to be defined.
- Due to the large scale of the pervasive environment, security threats are critical, since they might spread over the entire system very rapidly, and with very serious consequences. Hence, attacks or selfish/malicious behaviors should be prevented and controlled as much as possible from the early stages of their development.

References

[1] G. Anastasi, M. Conti, M. Di Francesco, and A. Passarella. Energy conservation in wireless sensor networks: A survey. *Ad Hoc Networks*, 7(3):537–568, May 2009.

[2] C. Alippi, G. Anastasi, M. Di Francesco, and M. Roveri. A survey on energy management in wireless sensor networks with energy-hungry sensors. *IEEE Instrumentation and Measurements Magazine*, 12(2):16–23, April 2009.

[3] G. Anastasi, M. Conti, and M. Di Francesco. Reliable and energy-efficient data collection in sparse sensor networks with mobile elements. *Performance Evaluation*, 66(12):791–810, December 2009.

[4] M. Di Francesco, S. K. Das, and G. Anastasi. Data collection in wireless sensor networks with mobile elements: A survey. *ACM Transactions on Sensor Networks*, to appear.

[5] M. Di Francesco, K. Shah, M. Kumar, and G. Anastasi. An adaptive strategy for energy-efficient data collection in sparse wireless sensor networks. In *Proceedings of the 7th European Conference on Wireless Sensor Networks (EWSN 2010)*, pages 322–337, February 2010.

[6] G. Pallapa, M. Di Francesco, and S. K. Das. Adaptive and context-aware privacy preservation schemes exploiting user interactions in smart environments. Submitted to the 9th IEEE International Conference on Pervasive Computing and Communications (PerCom 2011).

[7] Hakima Chaouchi, editor. *The Internet of Things: Connecting Objects*. Wiley-ISTE, 2010.

[8] A.P. Castellani, N. Bui, P. Casari, M. Rossi, Z. Shelby, and M. Zorzi. Architecture and protocols for the internet of things: A case study. In *Pervasive Computing and Communications Workshops (PERCOM Workshops), 2010 8th IEEE International Conference on*, pages 678–683, april 2010.

[9] Karen Henricksen and Ricky Robinson. A survey of middleware for sensor networks: state-of-the-art and future directions. In *Proceedings of the 1st International Workshop on Middleware for Sensor Networks*, MidSens '06, pages 60–65. ACM, 2006.