

SLIM: Service Location and Invocation Middleware for Mobile Wireless Sensor and Actuator Networks

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ABSTRACT

One of the main obstacles to the adoption of Wireless Sensor Networks (WSNs) outside the research community is the lack of high level mechanisms to easily program them. This problem affects distributed applications in general, and it has been replied by the Software Engineering community, which recently embraced Service Oriented Programming (SOP) as a powerful abstraction to ease development of distributed applications in traditional networking scenarios. In this paper, the authors move from these two observations to propose SLIM: a middleware to support service oriented programming in mobile Wireless Sensor and Actuator Networks (WSANs). The presence of actuators into the network, and the capability of SLIM to support efficient multicast invocation within an advanced protocol explicitly tailored to mobile scenarios, make it a good candidate to ease development of complex monitoring and controlling applications. In the paper the authors describe SLIM in detail and show how its performance easily exceeds traditional approaches to service invocation in mobile ad-hoc networks.

Keywords: Middleware, Service Invocation, Service Location, Service Oriented Programming, Wireless Sensor and Actuator Networks

INTRODUCTION

After an initial period of research and experimentation, *Wireless Sensor Networks* (WSNs) (Sohraby, Minoli, & Znati, 2007) and their siblings: *Wireless Sensor and Actuator Networks* (WSANs) (Akyildiz & Kasimoglu, 2004) are entering a more mature phase, with several commercial companies offering products to support a wide range of application domains

concerned with monitoring and control. On the other hand, to hold the promise of bridging the gap between the physical and the virtual world, WSANs have still to overcome a major limitation: the difficulty of developing applications on top of a given WSAN platform.

Indeed, usually WSAN programming has to be carried out in a very low-level, system-dependent way. This requires programmers to have a strong technical background in several domains, from system to network, while also resulting in very long development and testing

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phases: something that is currently limiting the adoption of WSAAN technology.

To overcome this limitation, the research community proposed various approaches to raise the level of abstraction for WSAAN programming (Picco & Mottola, in press) but none of them has been widely adopted. Meanwhile, the Software Engineering community is proposing Service Oriented Programming (SOP) as a powerful approach to ease development of complex distributed applications. While others have already proposed using SOP in WSAANs (see our section on related works), to the best of our knowledge none has offered a complete and integrated solution to bring the SOP world into the tiny scale of WSAANs. In this paper we fill this gap by presenting SLIM: a middleware infrastructure to support service-oriented programming in *mobile WSAANs*.

Issues in Mobile WSAANs

Several applications of WSAANs involve monitoring and controlling mobile entities like people, animals, or goods, through access and control points that can be also mobile, like PDAs in the hands of operators. This brings the need of considering mobility as a key aspect of a sensor network: an aspect such important because it has a great impact on the communication and coordination layers. Indeed, as the research on Mobile Ad-Hoc Networks (MANETs) shows, the communication layer of a mobile application has to include effective mechanisms to cope with unreliable links and routes. Similarly, ad-hoc coordination mechanisms are required to cope with nodes that may quickly become unreachable due to network partitions, while other nodes may appear as they approach the coordination area. Even the application layer is impacted by mobility, as the location, and more in general the *context* of nodes, becomes an important issue to consider in choosing which nodes to contact.

SLIM addresses these issues by adopting an advanced routing protocol explicitly designed to manage unreliable links and dynamic group

membership, while it decouples the service matching policy from the communication layer, allowing applications to choose and install into the middleware the matching component that better fits their needs (e.g., one including contextual information as part of service descriptions).

SLIM also provides an efficient, peer-to-peer service discovery protocol fitting the needs of a mobile network in which nodes (including a registry) may easily become unreachable. It also covers the typical needs of a network designed for sensing, by providing two forms of invocation: unicast and multicast. The former allows service consumers to get data from a single sensor or to send a command to an actuator, while the latter allows to invoke all the services that satisfy a given query at once, e.g., to gather the data produced by a set of sensors in a single step.

Organization of the Presentation

In the remainder of the paper we describe SLIM in details. In particular, the SLIM architecture and API is the topic of the next section, then we describe the routing protocol behind SLIM, while in section "Evaluation" we discuss SLIM performances and compare them with those attainable with more classical solutions for SOP. Finally, the "Related Work" section surveys other research results related with SLIM, while in the last section we draw some conclusions and describe our future research plans.

THE SLIM ARCHITECTURE

The reference scenario for SLIM (see Figure 1) is that of a *Wireless Sensor and Actuator Network* (WSAAN), composed of a set of nodes, including fixed or mobile sensor nodes, fixed or mobile actuators, PDAs in the hand of operators, and gateways toward a traditional network (a LAN or the Internet). In a SOP style, every node may act as a *service provider*, a *service consumer*, or both. Service providers offer one or more *services* to consumers, each described through a *service descriptor*. Service consum-

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