Situation-Aware Adaptive Service Provisioning for Wireless Sensor Networks

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Abstract

Wireless sensor networks (WSNs) present a challenging programming environment because of their limited resources, heterogeneity, and highly dynamic nature. Service-oriented computing can simplify application development by hiding platform-specific capabilities behind services. These services are dynamically discovered and used at run-time, enabling applications to be platform-independent and adapt to network dynamics. While service-oriented computing is widely used on the Internet, adopting it to WSNs is non-trivial due to the extremely limited resources available. The selection of which service provider to use and how to adapt as providers change significantly impacts application and network performance. This paper describes how service provisioning in WSNs can adapt to application and network dynamics. Several strategies for achieving higher energy efficiency and more predictable quality of service are presented.

1 Introduction

Wireless sensor networks (WSNs) consist of a multitude of tiny embedded devices that are capable of sensing the environment and communication via a wireless ad hoc network. They encompass a wide range of nodes that vary in terms of computational and sensing ability, and are exposed to the harsh natural environment resulting in high turnover rates among nodes. New programming models are necessary to simplify WSN application development and increase overall network utility.

In the past, we developed Agilla [4], the first working system to bring the mobile agent and tuple space programming models into WSNs. Mobile agents enable flexibility by allowing applications to control the distribution of their code within a WSN. Tuple spaces facilitate this by offering a decoupled style of communication in which the sender and receiver need not be spatially or temporally collocated. Agilla proved useful in numerous applications ranging from wildfire detection and mapping [3], to cargo container tracking and monitoring [7], to robot navigation assistance [1]. To support wide-area sensing applications spanning multiple WSNs and the Internet, we have used it in a system called Agimone [6], a unified middleware for IP and WSNs, and created a multi-resolution location directory service (MLDS) [2] for monitoring agent location over multiple WSNs connected by IP networks.

Developing applications using Agilla and Agimone revealed that, while mobile agents and tuple spaces address network dynamics, they do not handle network heterogeneity. For a variety of reasons, WSNs tend to evolve into heterogeneous networks consisting of devices that exhibit a wide range of computational ability, memory, and sensor types. Because of this, a WSN application cannot be written assuming, for example, that a certain type of sensor will be available. To meet the challenges of network heterogeneity, we develop a flexible service-oriented programming model and middleware for WSNs.

SOC provides a framework for service consumers to dynamically discover and invoke services that reside in the surrounding environment. This is highly suitable for enabling applications to handle network heterogeneity. Specifically, the set of all WSN node capabilities can be divided into those that are platform-independent (i.e., common to all platforms) and platform-dependent (i.e., unique to specific platforms). Applications can be written using only platform-independent capabilities, platform-dependent capabilities can be exposed as services. When an application needs to access a platform-specific capability, it is dynamically bound to a service that provides the capability. By enabling applications to be platform-independent, application development is simplified. To realize the benefits of SOC in WSNs, we developed Servilla [5], the first middleware for enabling service provisioning among processes *within* a WSN.

While Servilla overcomes many of the challenges of WSNs, WSNs exhibit many properties that are not characteristic of networks that have traditionally been used with SOC. Chief among these is that WSNs are highly dynamic, resource constrained, and can consist of a multitude of nodes all providing similar services. The selection of which service to use and how to adapt as services change can have a significant impact on the quality-of-service provided to the application and the health and longevity of the WSN. For example, imagine a soldier walking through a field instrumented with a WSN. The soldier is carrying a PDA that forms a wireless ad hoc network with the sensor network for detecting hazards. At any point in time, the PDA may be exposed to a multitude of services that are able to detect various but similar types of hazards. The challenge is how the PDA can intelligently select among these services to best inform the soldier.

2 Research Directions

Adaptive Service Matching. The problem of how to intelligently map consumers to services and how to adapt this mapping based on changing network conditions to achieve certain levels of quality of service can be approached from two directions. The first is from the consumer's perspective. The consumer can proactively discover all services within range and rank them according to certain attributes such as power efficiency, residue energy, and reliability. Of course, the question then becomes what is the metric for ranking services and how can it consider both the demands of the application and the network. The second approach is from the provider's perspective. In certain situations, the consumer may not be the best entity to make the decision on service mapping because the consumer is inherently selfish and will not consider the needs of other applications. In this case, the providers can collaborate to determine how consumer demands can best be met. In this approach, a provider can even detect how well it is serving the consumer and proactively try to find a replacement when it notices that its quality-of-service dips below a certain threshold.

Reliable Provisioning. When a consumer invokes a service, it expects that the service operation is successful. One common way to achieve reliability is through redundancy. In that is, perhaps a consumer can invoke multiple services simultaneously to better the chance of getting a result. Such a technique may also be used to determine correctness by comparing the results of multiple simultaneously invoked providers. For example, if the consumer wants to know the temperature, it can invoke five temperature-sensing services around it and take the average or majority vote to determine what is the most accurate temperature. Of course, invoking multiple providers consumes more energy. The cost-benefit ratio of such a technique must be carefully evaluated to determine whether the higher confidence in correct service invocation is worth, for example, the higher energy costs and lower network lifetime.

Service Merging. In situations where there are many consumers, a single provider may be accessed simultaneously by multiple consumers. In this case, the provider can adapt by merging multiple invocations to save energy. For example, if one consumer invokes a temperature sensor at 1Hz, and another invokes the same service at 2Hz, the provider can detect this and obtain the 1Hz invocation by filtering the 2Hz invocations. This can potentially save a significant amount of energy by reducing the number of times the sensor needs to be accessed.

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