

Architecting Reconfigurable Applications for Sensor Networks: an Active Rule-based Approach

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Abstract. This paper presented an approach for modeling and implementing the architecture of sensor networks reconfigurable applications using an active rule-based model. Considering the adaptability and flexibility of sensor networks applications, the active rule-based model was defined based on a service resource model by combining both the semantic context and the service description. The analysis indicated that the active decision system provided reconfiguration management and non-predefined dynamic reconfiguration management for sensor networks application. The results imply that active rule can easily be constructed, while ensuring good reconfigurability.

Introduction

With the development of sensor node technology and the increasing popularity of sensor network application, application of sensor network with the characteristic of high adaptability and more flexibility, has become more and more important. Compared with traditional communication network which is relatively stable in application, application of sensor network changes with the change of environment. In addition, sensor network has the following characteristics, such as wide coverage, a large number of nodes, high density of nodes, and the autonomy between nodes to complete application[1,2]. The protocols and softwares vary greatly from node to node in sensor networks, which requires adaptive protocols and softwares to meet the needs of different nodes with different roles and locations[3,4]. Therefore, application of sensor network has the characteristics of variability and unpredictability. However, the design characteristics of sensor network can not meet the variability of applications, mainly in the following reasons. First, the storage capacity of node is limited, all possible applications can not be deployed to nodes at once. Second, the computing power of node is limited, it is impossible to deploy complex software to adapt to environmental changes. Third, the software of sensor network is closely related to application, we can not design a single software to meet most of possible requirements. In view of the above analysis, the feasible method to solve the contradiction between the application requirements and the limited resources is as follows. With the change of application requirements of sensor node, a new application code is constantly deployed dynamically.

Grichi et al. propose a zone-based multi-agent architecture for reconfigurable wireless sensor networks(WSNs) where a communication protocol is well-defined to optimize distributed reconfigurations[5]. Balani et al. present an architecture that supports flexible software reconfiguration of sensor networks. The architecture contains two core components - SOS operating system and the dynamic virtual machine[6]. Pinto et al. propose a self-protection solution for WSNs based on the combination of the INTER-TRUST security framework and the FamiWare middleware (a DSPL approach to automatically configure and reconfigure instances of a middleware for WSNs)[7]. Hughes et al. introduce a graph-based approach to specifying the reconfiguration of software resources that may be distributed across multiple sensor networks. This approach requires application developers to specify only high-level reconfiguration graphs[8]. Tompkins et al. propose node management layer which can wirelessly reconfigure heterogeneous nodes when only a few parameters need to be

changed. This reconfiguration can simply rectify node-management tasks like sensor drift in a node[9]. Thoelen et al. propose a run-time reconfigurable component model which provides a mechanism to manage the dynamism of sensor network environments. The model allows for efficient compatibility checking and facilitates the run-time discovery and use of third-party component services[10].

The above researches effectively improve the efficiency of application development for sensor networks, but a key problem is how to provide high level abstraction in order to solve problem of the application system reconfiguration. This paper proposes an active rule-based approach for designing and developing a reconfigurable sensor networks application. Our approach supports the following features:

- (1) Integrated reconfigurable architecture with reconfiguration nodes.
- (2) Active rule-based reconfiguration management of service resources.
- (3) Active decision system of sensor networks reconfiguration architecture.

Reconfigurable Application Architecture

In the reconfigurable application model, sensor nodes are divided into two categories: code nodes and reconfiguration nodes. Among them, code node has the function of storing and managing code, and users can upload new application code to code nodes through sensor network. Reconfiguration node is a sensor node with a code execution engine and application support components, it's used to reconstruct a local application by executing new application code issued by code node. Fig. 1 shows the reconfigurable application architecture which includes reconfiguration decision-making layer, reconfiguration-execution layer and publish layer.

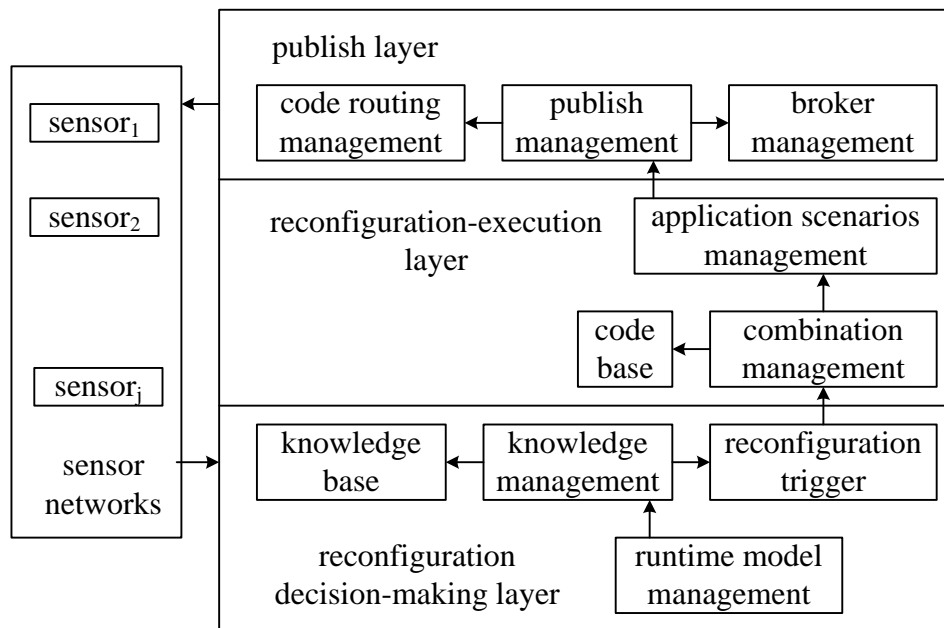


Figure 1. Reconfigurable application architecture

The reconfiguration decision-making layer includes runtime model management, knowledge base, knowledge management and reconfiguration trigger. The runtime model management shields the heterogeneity of different types of sensor device management interfaces, transmits the data collected in a unified standard format to the knowledge management, and supports automatic data synchronization with sensor devices. The knowledge base stores predefined domain knowledge. In this framework, the relationships between environmental status and sensor devices that perform distributed sensing and acting tasks are abstracted into knowledge. General knowledge about reconfigurable application is represented as active rules. The knowledge management carries on reasoning to the current environmental data collected by sensor devices, obtains the relevant conclusions of the current

environmental change, and transmits the conclusions to the reconfiguration trigger. The reconfiguration trigger checks the conclusion of the environmental changes obtained by the knowledge manager whether to match the application running on current node or not, and then judges whether to reconstruct and how to reconstruct the application. If an application needs to be reconstructed, the reconfiguration trigger sends a request message to combination management module in the reconfiguration-execution layer.

The reconfiguration-execution layer includes combination management, application scenarios management and code base. The combination management is responsible for code management; that is, according to code request messages, it retrieves and extracts the codes that meet the requirements to establish a combination model. According to the demand of reconfiguration, the application scenarios management implements the mapping from the combination model to the application scenario model. The code base stores the user defined codes or the codes which are generated by the application scenarios management. The code on code node can be migrated to reconfiguration node through multi-hop communication.

The publish layer includes code routing management, publish management and broker management. Considering the characteristics of push mode and pull mode, the code routing management can achieve the goal of saving energy consumption in the process of code transmission in large scale sensor networks. In cluster-based sensor networks, cluster-head nodes are used to obtain codes from sink nodes, and nodes in clusters use push mode to distribute codes. The publish management has adaptive capacity. According to the position of the node in sensor network, as well as the change of node's own condition, it can adjust the code transmission mode. The broker management is an application reconfiguration mechanism to with environmentally adaptive capacity. It is characterized by that sensor nodes can actively request code transmission according to the changes of the surrounding environment, and do not have to wait for sink-nodes to distribute codes.

Active Rule Model

Service Resources. In sensor networks, there are a lot of resource constrained embedded devices, such as sensor nodes, embedded gateways and so on. Due to the constraints of computing power, energy storage and other factors, it is not suitable for using Web based SOAP services to encapsulate these service entities. As a result, many of the current sensor applications are based on the Restful service architecture to build services of sensor networks. In this paper, we also use the Restful service architecture to build service entities in sensor networks. As the service resources in sensor networks are mainly composed of sensor devices with sensing capabilities, the contexts of service resources determine the availability of services. This context includes the spatial and temporal characteristics of service resources, as well as the current states of sensors. In addition to context information, it is also needed to understand some of the self-describing information about resources, that is, the meta-information about resources. Based on the resource meta information, sensor network application system can automatically understand the service type, the service interface, and the specific meaning of message delivered by service.

According to the above analysis, we provide two kinds of information to describe services of sensor networks. They are the semantic context of service resources and the semantic meta information of service resources, where the semantic context mainly describes the states of service resources, including the temporal and spatial state, as well as energy state; the semantic meta information describes some attribute information related to services. By combining both the semantic context and the service description, we can realize the semantic information query to all kinds of service resources, and complete with service discovery, matching, and combination through reasoning.

Active Rule. We adopt the rules based on active mechanism to describe the semantic meaning of services. The active rule consists of three parts: a service profile about a service description, a process model about a service flow, and a grounding service about a specific connection parameters of service. The process model is the main part of active rule, and describes the input-and-output parameters of

services, the preconditions of services execution and the results after running service. The input-and-output parameters of service describe the data interface for running service. The preconditions and results of service describe the final structure after execution of service and the conditions which service can be executed, they are an important basis to judge whether service meets application requirements. In order to effectively support service matching and service composition reasoning, we make a unified description of the service preconditions and running results. On the basis of description logic, active rule introduces the concept of action and adds an action set in the rule. Action can be divided into two types, atomic action and compound action. Formally, atomic action is represented as a three-tuple $A=\{pre, occ, post\}$, where pre is a set of preconditions for action execution; occ is a set of assertions that describe service's status when running action; and post is the state change after action is performed. In addition, by using action connection operators, such as sequential operator, select operator, loop operator, and test operator, atomic actions can constitute a compound action.

Based on active rules, we can describe both the precondition of orderly execution of services and the corresponding execution result as an action. Here, the precondition and result of action are respectively corresponding to the precondition and result of service. Active rule can not only describe single service in sensor network applications, but also can represent service composition. Therefore, the semantic context and the service description constitute a semantic model of reconfiguration service for sensor network application.

Active Rule Decision System

The sensor network can be regarded as a database with the capability of providing massive physical world information. Therefore, we propose an active rule decision support system based on sensor networks. Fig. 2 shows the active rule decision system(ARDS) structure which includes the following parts, such as rule interface, multi-rule processing system, knowledge base, task decomposition module for reconfiguration application and semantic modeling module for sensor network.

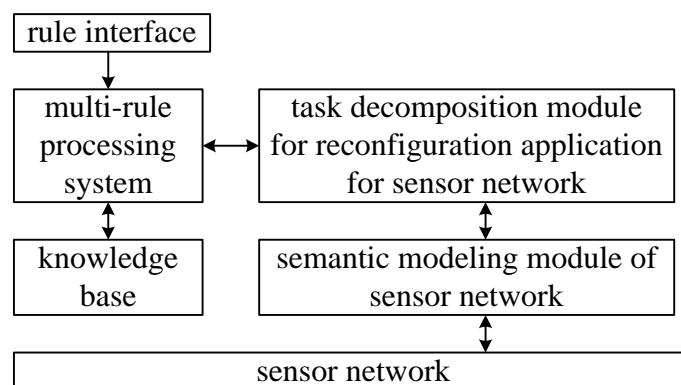


Figure 2. ARDS structure

Through the rule interface, ARDS is assigned tasks which correspond to rules, then the tasks are delivered to the multi-rule processor system. According to the knowledge in the knowledge base, the multi-rule processing system divides the abstract complex tasks into a series of sub-tasks with a low degree of coupling, then, each sub-task is assigned to a specific rule processor. When performing a task, the rule processor needs to acquire the real-time status of the physical world, and make a reasonable decision accordingly. In the form of high-level semantics, the multi-rule processing system describes the state of the environment which needs to be aware. But for the massive heterogeneous sensor network entities in sensor networks, such as the gateway, sensor node, in general, sensor network can only output sensing information by specific queries. Therefore, according to semantic model, ARDS constructs a semantic overlay network for sensor network resources. By using the ontology based resource description method, the semantic overlay network provides a unified description of individual attribute and access interface of sensor network resources, and enables the

multi-rule processing system to obtain the corresponding sensor network resources by analyzing semantic descriptions. Through semantic overlay network of sensor network, the multi-rule processing system decomposes a complex task into a series of simple tasks, and acquires the real-time sensing information needed for simple tasks.

Conclusion

In this paper, we propose an active rule-based approach to provide the architecture of sensor networks applications reconfigurability. Active rule is defined based on service resource model. We derive conclusions of dynamic reconfiguration management for sensor networks application from analysis. The results show that active decision system provides rule-based reconfiguration management, and easily be constructed.

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