Network Reconfiguration for Wireless Sensor Networks using UML/MARTE Profile

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Abstract: The required autonomy and the growth of the complexity of wireless sensor networks (WSNs) systems give the reconfiguration a big importance. Thus, the integration of reconfiguration scenarios (node level or network level reconfiguration) in the development cycle of WSNs system is required to offer an efficient reaction to environment variability. In this direction, existing model based design approaches of reconfigurable WSNs are limited to the design of behavioral reconfiguration techniques which bring adjustment of the system's parameters or update some functionalities. However, network reconfiguration which presents an important ability of networked systems for dealing with the network disconnectivity and power consumption, is still under-explored. In this context, we propose a high level model based design of WSNs applications using the UML/MARTE standard to specify network reconfiguration semantics. We define a new package named «NW_ Reconfiguration». A case study on water distribution network is proposed to evaluate our proposed design approach.

1 INTRODUCTION

A WSN (Mottola and Picco, 2011) consists of a large number of tiny, battery powered sensor nodes that integrate sensing, data processing and wireless communication capabilities. WSNs have many different application domains such as health monitoring (Al Ameen et al., 2012), building monitoring (Benatia et al., 2014), environmental monitoring (de Lima et al., 2010), etc. Despite of many different abilities, sensor nodes are prone to failure in some cases due to their limited energy resources. A WSN application needs to modify its behavior and its architecture in order to response to the environment requirements and manage restricted resources. Reconfiguration is one of the interesting topics in WSNs. Systems can evolve by either behavioral or architectural reconfiguration. In this context, reconfiguration approach in WSNs applications has two different scenarios. The first scenario is the node level based reconfiguration corresponding to the behavioral reconfiguration. The second scenario is the network level based reconfiguration corresponding to the architectural reconfiguration. Network level based reconfiguration is one of the important required process during the deployment since WSNs applications are often deployed in inaccessible locations that require human intervention to reestablish the network operating. Thus, reconfiguration requires to be considered in the development cycle of WSNs system with different scenarios (node level and network level) at different abstraction levels. To cope with the growth of the design complexity of WSNs systems, designers have resorted to several design methods. The most popular paradigm is the Model Driven Engineering (MDE) (Schmidt, 2006) which permits the modeling of the behavioral and the structural of the system and the specification of the non functional properties such as time constraints and energy. In particular, the Unified Modeling Language (UML) profiles allow the addition of semantics details in first steps of the design process. It presents an attractive solution to support the whole life cycle co-design of complex embedded systems with a real time constraints and performance issues. In this context, the Modeling and Analysis of Real Time and Embedded systems (MARTE) (Group, 2011) profile offers a rich support for the analysis and specification of embedded systems. Proposed reconfiguration models based on MARTE profile are limited to defining

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specifications of the behavioral reconfiguration scenario which consists in adjusting system's parameters or updating functionalities. Indeed, there is an absence of explicit semantics in MARTE to support the network level based reconfiguration. Since this reconfiguration scenario is not supported by MARTE profile, we need new extensions in order to cover this lack and provide more efficient design. In our work, we focus only on the architectural reconfiguration which consists in modifying the topology such as adding or removing components or connections.We aim to offer a high level model based on the UML/MARTE standard for modeling the specifications of this important reconfiguration scenario required in a WSNs application. The rest of paper is structured as follows. In Section 2, we review some related works that address reconfigurability in complex embedded systems. In Section3, we give an overview about modeling concepts of MARTE standard for reconfigurable WSNs systems. In section 4, we describe the adopted network reconfiguration design strategy. In Section 5, we present in details our proposed package to specify network reconfiguration in WSNs. As a proof of concept we consider, in Section 6, a case study about reconfigurable water distribution networks. Finally, Section 7 concludes the paper and presents future works.

2 RELATED WORKS

In this section, we give an overview about existing reconfiguration approaches in WSNs. Many works (Vidal et al., 2011), (Quadri et al., 2009), (Krichen et al., 2011), (Cherif et al., 2011), (Said et al., 2013), (Vidal et al., 2010) have been carried out to the modeling of embedded systems and particularly reconfigurable ones. Most of the proposed approaches were interested in dynamic and partial reconfiguration. For example, a SoC co-design methodology based on MARTE standard is introduced in (Quadri et al., 2009). The reconfiguration behavior is defined using the specific control semantics under GASPARD (Gamatié et al., 2008) framework. The reconfigurable system is described by a mode automata which is composed of a state graph and a mode switch component.The state graph describes the behavior of the system via state based technique where states are connected with transitions. A mode switch component is constituted of a set of modes. It enhances a switch functionality which defines the following execution mode. In this work, the developed model is transformed from model level specifications to an executable FPGA platform. This work introduces the modeling of hardware reconfiguration. In (Krichen et al., 2011), authors proposed a model based approach which deals with the reconfiguration issues for Distributed Real time Embedded (DRE) systems. They introduced a solution for reconfiguring DRE systems using a non predefined number of configurations. A set of mode structures are used to model the reconfigurable DRE. Mode structures are connected with transitions. Each transition presents a reconfiguration activity. Each node structure has various instances named modes. Every mode has a configuration. The proposed configuration approach describes a configuration by a number of structured components, relations between them and their allocation on the execution platforms. This work has addressed the design of software reconfiguration in embedded systems. In (Said et al., 2013), authors proposed a model based design of adaptive real time embedded systems which supplies the MARTE standard with new semantics to model application fine-grain reconfiguration. This work adds extensions to MARTE profile in order to support fine grain adaptation. The proposed meta model describes the behavior and structure of a reconfigurable software resource. The reconfiguration behavior consists in a switch between a set of modes within mode transitions. A mode can be composed of multiple Elementary Modes connected by Elementary Mode Transitions. Each elementary mode is described by an output quality level and a configuration parameter.

All the reviewed works have proposed high level approaches to deal with the behavioral reconfiguration. Although most of embedded systems, in particular WSNs systems, have already adopted reconfiguration techniques in their design, there still a great need for a WSN system to integrate the architectural reconfiguration. Indeed, the architectural reconfiguration modeling using MARTE profile is not tackled in literature. There is no details about network reconfiguration specifications in WSN applications. MARTE standard offers only features to define the behavioral reconfiguraions of embedded systems. What makes our work different is that we aim at defining new package based on MARTE profile to support architectural reconfiguration in WSN applications.

3 PRELIMINARIES

In this section, we describe possible reconfiguration scenarios in WSNs application. We present then the UML/MARTE profile capabilities to specify the reconfiguration for embedded systems.

3.1 Reconfiguration Scenarios in WSNs

WSNs applications require the deployment of hundreds or thousands of sensor nodes in remote locations that are often inaccessible. In order to achieve its operating and connectivity, a wireless network system refers to two different reconfiguration scenarios (Rajasekaran et al., 2014); node level based reconfiguration and network level based reconfiguration.

3.1.1 Node Level based Reconfiguration

The dynamic reconfiguration at node level is a required process in WSNs applications. A sensor node adapts its behavior to environment constraints and recovers from broken network links. In this scenario, the hardware reconfiguration and software reprogramming are exploited. Hardware reconfiguration focuses on updating hardware platforms of sensor nodes and reprogramming reconfiguration concentrates on software update, application layer and operating systems. In (Eronu et al., 2013), authors survey existing reconfiguration approaches in WSN applications.

3.1.2 Network Level based Reconfiguration

Network level based reconfiguration is one of the important required process during the deployment. It consists in modifying the topology such as removing or adding elements or connections. Most of WSNs are deployed in unmanageable environments where the human intervention is required to reconfigure the network. That's why the network reconfiguration is required to maintain the network topology, avoid the network dis-connectivity, increase the network's longevity and manage limited resources more efficiently. In (Alam et al., 2014), authors proposed a network reconfiguration technique in order to achieve the topological control in the network. In the present paper, we are concerned with the present reconfiguration scenario.

3.2 MARTE Capabilities for Reconfiguration Modeling

This sub section gives an overview about UML/-MARTE profile capabilities related to reconfiguration issues in the modeling of embedded systems. MARTE profile is promoted by the the Object Management Group (OMG). This profile supports the modeling, specification and analyzing of real time embedded systems. MARTE consists of three principal packages. Foundation package represents the foundational concepts for embedded systems modeling. It offers the description of basic real time features such as time constraints, non functional properties (NFPs) and other resources. The second package, the MARTE design model package, presents hardware and software specifications. The third package is the MARTE analysis model package which provides annotations for generic basis of quantitative performance and schedulability analysis. MARTE introduces some concepts to design reconfigurable systems. It defines in the Foundation package the Core Elements profile which contains the Causality sub package that permits the description of the dynamic behavioral modeling of embedded systems. This profile defines the dynamic behavioral reconfiguration in terms of modes and transitions between these modes. A mode is characterized by a particular configuration. A transition represents an event which applies the switch between different modes. The dynamics between modes is described using state machines composed of a set of modes and modes transitions. The current MARTE proposition for reconfigurable system design is illustrated in Figure 1. MARTE standard presents only concepts for the behavioral reconfiguration of embedded systems, however, it still lacks explicit support for the architectural reconfiguration modeling of networked systems. In the rest of paper, we propose a new package called «NW_Reconfiguration» package based on UML/MARTE for the modeling of architectural reconfiguration applied in WSNs applications.

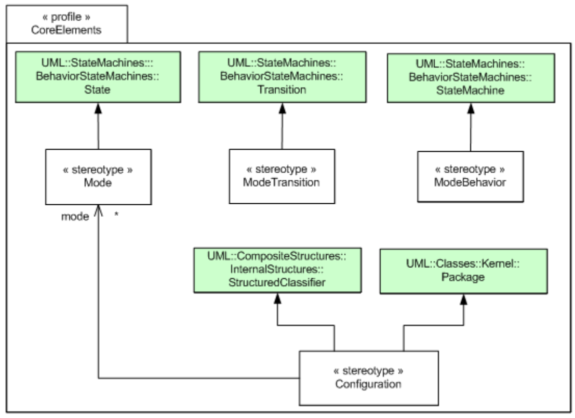

Figure 1: MARTE capabilities for modes and configuration modeling.

4 PROPOSED DESIGN METHODOLOGY

Designing an autonomous and efficient WSN architecture with satisfying the application constraints is a complex process. Dynamic network configuration is a great need for WSN design. In this context, we adopt a promising approach that enables the network reconfiguration with kept of the network connectivity and reduces the network's power consumption. This technique divides the network into a set of sub network areas (SNAs). The proposed approach offers an easier way to debug network problems where SNAs are totally independents so any problem in each SNA can easily be isolated and resolved. It enables also the application of different topologies in each SNA which reduces the energy consumption.This methodology can be expressed in two steps. In the first step, we begin by the network formation. The network is composed of three types of nodes: a single base station (BS), routers and end devices. After the identification of the BS and different nodes in the network by their IDs, the BS station identifies, first, the router which must have the lowest Received Signal Strength Indication (RSSI) value and the greater battery level and others nodes will be considered as end points after a determined time. Second, this router identifies the next router and their associated end points in the highest level of the same SNA based on the same algorithm. Two topologies can be described; the tree topology for the connection between BS and routers and the star topology for the connection between routers and end points. The second phase, is the dynamic network reconfiguration in which an automatic self reconfiguration done if any change occurs in the physical topology of the network. This reconfiguration technique depends on two major parameters: the RSSI value and the battery level of nodes. The RSSI value specifies the strength of the received signal. Its value decreases with the increase in distance between the receiver and the sender. Battery level describes the remaining energy enables the continuity of the node's operations. Any modifications in these two parameters could affect in the assignment of different task (router or end device) to that considered mote. The network also can detect presence of any new mote in its coverage area and assign its role based on the two mentioned parameters. Likewise, the remove of any node from the network needs a dynamic reconfiguration and a replacement of the removed node.

5 THE PROPOSED «NW_ RECONFIGURATION» PACKAGE

In this section, we give a description of the new proposed network reconfiguration package. The structure of the «NW_ Reconfiguration» package is shown in Figure 2. Within this proposed package, reconfiguration properties and network features are declaratively

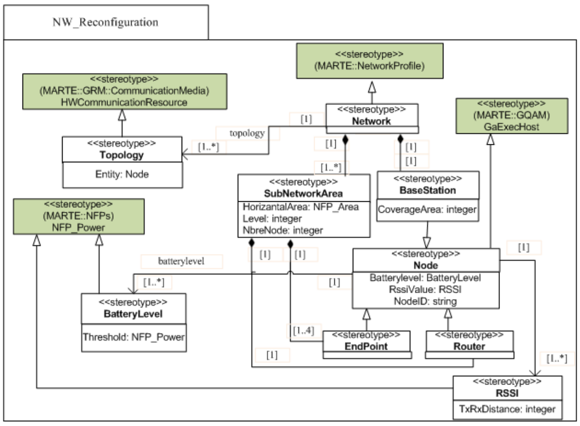

Figure 2: The NW_Reconfiguration package overview.

specified. We define a number of stereotypes to relate Network reconfiguration elements based on the UML/MARTE profile. Data types from MARTE Non Functional Properties (NFPs) are used to represent some attributes. The stereotype «GaExecHost» from the GQAM sub profile and the stereotype «HwCommunicationResource» from GRM sub profile are used to specify others semantics of classes. We detail the modeling of different features for the network reconfiguration in the next sub sections.

5.1 «Network» stereotype

It extends the semantics of the «Network» profile proposed in (Ebeid et al., 2015).

Generalization:

- MARTE::NW.

Associations:

- Topology: Topology [2], specifies topologies of the connection between BS and routers, and the connection between routers and EndDevices.
- sna: SubNetworkArea [1..*], the network is composed of a set of SNAs.
- BS: BaseStation[1], the network contains only one base station.

Attributes:

- None.

Semantics:

- A network is composed of one Base Station (BS) and a set of sub network area (SNA) containing a definite number of nodes. It is characterized by its topology which defines the relations between nodes.

5.2 «SubNetworkArea» Stereotype

Generalization:

- None.

Associations:

- Topology: Topology [2], specifies topologies of BS and routers, and routers and EndDevices.
- endpoint: EndPoint [1..4], each SNA contains four end devices which are connected to the router.
- router: Router [1], only one router exists in each SNA.

Attributes:

- HorizentalArea: NFP_Area, Each SNA has a definite horizontal area.
- Level: integer, the SNA is composed of a set of vertical down levels.
- NbreNode: integer, each SNA contains a determine number of nodes

Semantics:

- A sub network area is the environment that groups a set of nodes. Each SNA has a determined width and a set of levels which each level consists of 5 nodes one of each acts a router and others are end devices.

5.3 «BaseStation» Stereotype

It inherits attributes and implementation of Node class.

Generalization:

- MARTE::GQAM::GaExecHost::Node.

Associations:

- None.

Attributes:

- CoverageArea: integer, the coverage area of the base station

Semantics:

- One base station is considered in the network, which is fixed and can be replaced by any other node at run time. It is responsible for network initiation, determines the first router of every SNA, receives data from nodes and transmits data to the attached system.

5.4 «Topology» Stereotype

It inherits attributes and implementation of HwCommunicationResource from GRM MARTE subprofile.

Generalization:

- MARTE:: GRM:: CommunicationMedia:: HwCommunicationResource

Associations:

- None.

Attributes:

- Entity: Node, describes the function of the node in the network topology (parent node, central hub)

Semantics:

- Two possible topologies can exist in the network. The tree topology for the connection between BS and routers, and the star topology for the connection between router and End Devices.

5.5 «Node» Stereotype

It inherits attributes and implementation of GaExecHost from GQAM MARTE sub profile.

Generalization:

- MARTE::GQAM::GaExecHost

Associations:

- batteryLevel: BatteryLevel[1..*], indicates the remaining energy in each sensor node.
- rssi: RSSI[1..], indicates the received srenght signal indicator.

Attributes:

- Batterylevel: BatteryLevel, the remaining energy in the battery.
- RSSIValue: RSSI, received srenght signal indicator.
- NodeId: integer, the ID of each node in the network.

Semantics:

- A node represents physical processing device capable of storing and executing program code. Each node is defined in the network by an ID. This class presents an attribute to define the battery level and an attribute to calculate the RSSI value. They are the two major parameters used to achieve the dynamic reconfiguration of the network.

5.6 «BatteryLevel» Stereotype

Generalization:

- MARTE::NFPs::NFP_Power

Associations:

- None.

Attributes:

- Threshold: NFP_Power, the minimal level of energy remaining in the node. This attribute enables the reconfiguration of the network when the battery level of a considered node is lower than its value.

Semantics:

- A BatteryLevel is the indication of the remaining battery life to support the mote's operation.

5.7 «RSSI» Stereotype

Generalization:

- MARTE::NFPs::NFP_Power

Associations:

- None.

Attributes:

- TxRxDistance: integer, the distance between the sender and receiver nodes.

Semantics:

- RSSI value presents the power of received signal which gives information about the strength of the received signal and it decreases with the increase in distance between sender and receiver.

6 CASE STUDY

In order to illustrate our proposed approach for the modeling of network reconfiguration, we consider, in case study form, a water distribution network. Water pipeline monitoring is one of the most interesting applications in WSNs. The implementation of sensor network is a great solution for optimal water quality and quantity control and leakage management in the pipe. The architecture of the proposed water pipeline network is described in Figure 3. The water pipeline network is divided into several SNA that each SNA is composed of different levels. We present in Figure 3 only one SNA with three levels. Following our proposed approach, in the first phase, we begin by defining a state machine representing possible roles of existing nodes in the network. We define three states of the nodes: *ExistingNode*, *EndPointNode* and *RouterNode*. To do the distribution of node's role in every

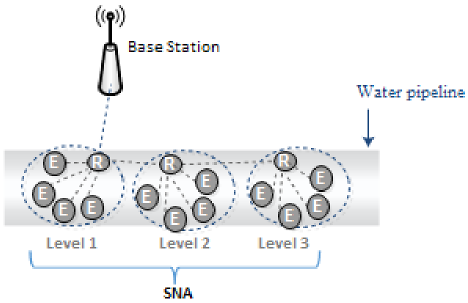

Figure 3: Water pipeline network architecture.

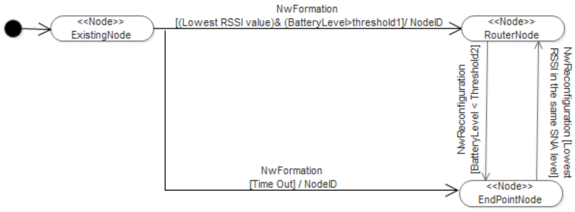

Figure 4: The state machine of network reconfiguration of existing nodes.

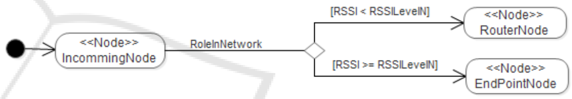

Figure 5: The state machine of the incoming node role reconfiguration.

SNA, transitions are ensured by event triggering. For example, the switch from *ExistingNode* to *RouterNode* occcurs when the node has the lowest RSSI value and the greater battery level. Existing nodes require also function reconfiguration due to the battery level reduction in order to avoid disconnectivity in the network. For example, the switch from a *RouterNode* to *EndPointNode* occurs when the battery level of the considered router becomes lower than a certain threshold and the *EndPonitNode* with the lowest RSSI value in the same level becomes the *RouterNode*. Figure 4 shows the state machine of network reconfiguration of existing nodes.

Additionally, the bring or the removal of nodes in/from the coverage area of the network requires the reconfiguration of the network and the distribution of node's functions. The incoming mote can be Router or EndPoint depending on the RSSI value. If a node is removed from the network, the BS is informed about the missing node and replaces it. If the missing node was acting as a router then another node from that level automatically becomes router to maintain the network's connectivity at all times. We present in Figure 5 the state machine describing the bring of the node.

7 CONCLUSION

The present paper presented a high level methodology for modeling the architectural reconfiguration in WSNs systems. We addressed the lack of network reconfiguration semantics in the UML/MARTE profile and we presented a new profile to specify this reconfiguration scenario in WSNs system at high abstraction levels. We gave an overview of the MARTE capabilities for the specifications of reconfigurables WSNs which shown that the present version of the MARTE standard is limited to the description of node level based reconfiguration. We then presented in details our proposed profile «NW_Reconfiguration» to characterize network reconfiguration features. The main contribution of the present work is that it supplies the MARTE profile with new semantics to design network reconfigurability in WSNs applications. We illustrate the practical use of our proposed with a water distribution network. We plan in future works to investigate the verification of Non Functional Properties (NFPs) such as energy consumption and time constraints. We also intend to integrate the proposed profile in an MDE-based approach for the development of low power WSNs.

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