Combining *SysML* and *Modelica* to Verify the Wireless Sensor Networks Energy Consumption

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Abstract: Wireless Sensor Networks (WSN) have large industrial applications. However, the modelisation is still a very complex task in view of the nature of these networks, namely because they are distributed, embedded and have strong interactions between the hardware and software parts. In addition, industrials use semi-formal methods to design their systems and validate behaviours by simulation. In this context, in order to improve the checking of the WSN properties, we propose a Model Driven Architecture (MDA) approach for modeling and checking of properties like energy consumption. This approach combines the advantages of *SysML* and *Modelica* languages. It is described mainly by two steps. At first, we offer a model transformation by taking into account static, dynamic and requirement diagrams of *SysML* in order to specify their corresponding *Modelica* model. In the second step, we carried out the virtual verification of WSN energy consumption. This approach is implemented inside Topcased platform and illustrated through a crossroads monitoring system which aims the verification of energy consumption.

1 CONTEXT AND MOTIVATION

During the last decade, WSN have been a major success in the scientific and the industrial communities for their broad application fields. However, this kind of networks is mainly used in the observation of physical phenomena in a restricted environment. They are characterized by a simple deployment and a low production cost. Furthermore, the WSN industry actors should develop the modeling methods of these networks in order to maintain the competitiveness of their products. In addition, modeling WSN is equivalent to modeling distributed and embedded system at the same time. Moreover, the formal methods are generally used in the modeling of critical systems that require rigorous verifications. These methods require good skills in mathematics. As a result, industrials have widely adopted semi-formal methods to design WSN applications. These methods are based mainly on semi-formal language (text or graphic) for which is defined a precise syntax and a relatively weak semantics. Besides, semi-formal languages are easy to understand and provide a rich structuring mechanism allowing the reduction of the design time and cost. However, in order to improve the checking of the WSN properties which is done generally by simulation, we propose an MDA approach to design and to check the WSN properties. Our approach is based on the *SysML* language which will be extended to an executable language namely *Modelica* (Modelica, 2009). Considering the *Modelica* characteristics, we propose a virtual verification of properties which are deduced from the *SysML* requirement diagram. This approach includes the benefits of the *SysML* modeling and the possibility to simulate and to verify the modeled system with *Modelica*. *SysML* and *Modelica* are two complementary languages, their joint use offers the very expressive, formal language for differential algebraic equations and discrete events of *Modelica* with the very expressive *SysML* constructs for requirements, structural decomposition, logical behavior and traceabilty of requirements.
We focused our work on the study the WSN energy consumption which is heavily dependent on the type of node. These nodes are designed in the aim to maximize their life expectancy. In (Halgamuge et al., 2009), the authors proposed an energy consumption model for WSN. The major feature of this model is the accuracy in estimating the energy consumption. Therefore, this model aims to estimate the overall lifetime of the WSN accurately. For these reasons, we adopted this energy consumption model in our study.
This paper is structured as follows: first we provide the existing works relating to the WSN modeling.

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Then, we give brief introductions to WSN, *SysML* and *Modelica* languages. After that, we explain our approach to design and to verify the WSN energy consumption property. Finally, we conclude and give some future works.

2 RELATED WORKS

In the literature, we found several works on the modeling and the verification of the WSN properties. For example, E. Cheong and al. (Cheong et al., 2006) developed a Framework that provides a graphical environment for the WSN applications modeling and simulation using mainly TinyOS. Another similar work done with Simulink was proposed by M. M. R. Mozumdar and al. (Mozumdar et al., 2008). They developed a Framework which provides the ability to make performance analysis of the designed system through simulation and it also allows the code generation which is compatible with TinyOS. S. Villa and al. (S. Villa, 2011) proposed an approach for modeling WSN using UML and SystemC. They defined two UML profiles, namely the UML-SystemC profile which includes the SystemC specific concepts and the UML-Marte profile which allows hardware-software modeling (co-design). Then they have designed a Framework that enables the model transformation between the UML model and the SystemC model. The verification of SoC properties is done by the simulation.

Our WSN modeling approach is based on the MDA standard. It allows a semi-formal modeling with the *SysML* language which will be extended by the *Modelica* in order to verify WSN properties. In other words, we offer the possibility to design clear models, to allow also the simulation and the virtual verification of designed system properties.

3 PRELIMINARIES

3.1 Wireless Sensor Networks

The WSN modeling is influenced by many factors, which include fault tolerance, scalability, production costs, operating environment, sensor network topology, hardware constraints, transmission media and power consumption. These factors are important because they serve to direct the design of the WSN protocols and algorithms. In addition, they can be used to compare different WSN architectures. Moreover, the prospects of the WSN applications are promising but the challenges that they present are not less numerous and not less complex, neither. Among the crucial issues, which represent the WSN non-functional properties, we can mention the energy consumption, the automatic configuration, the communication security.

3.2 *SysML* Language

SysML (SysML1.3, 2012) has been proposed by the Object Management Group (OMG) , together with the International Council on Systems Engineering (INCOSE) (INCOSE, 2012) and the AP233 consortium (AP2, 2012) with the aim to define a general purpose modeling language for systems engineering. It is based on the actual standard for software engineering, the Unified Modeling Language (*UML*) (UML2.4, 2011) version 2.4, with some extensions. It replaces the class concept in modeling by blocks for a vocabulary more suited to the Systems Engineering (SE). A block includes any software, hardware, data and processes concepts.

3.3 *Modelica* Language

The *Modelica* is an object-oriented modeling language that allows the modeling of physical systems which can be complex and heterogeneous. It can be considered as a multidisciplinary modeling language (Fritzson and Bunus, 2002). The *Modelica* is an open language which is developed and promoted by the *Modelica* Association. The *Modelica* models are described mathematically in acausal way through differential equations, algebraic equations and discrete equations. The *Modelica* solvers contain very effective algorithms for solving equation systems which allow the handling of complex models that are described by thousands of equations.

4 OUR APPROACH

We propose to transform the *SysML* models to an executable models in *Modelica*. The adopted methodology is constituted of following steps. In the first stage, the modeler designs the WSN application with the *SysML* language. In the next phase, the designer is invited to run a check of his model in order to refine it when there are problems reported by the analyzer. Among the problems identified by the analyzer, we list, the undefined elements (initialization, typing, etc.) which are generally due to forgetfulness and the model elements which are not considered by the model transformation (*SysML* model to *Modelica* model) rules. The objective of this analysis is to ensure that the generated code at the end of the transformation process is executable by the OpenModelica compiler. After this check, we can undertake the third step that defines the transformation from the *SysML* model to the *Modelica* model. The file resulting from this transformation is in XMI (XML Metadata Interchange) format conformed to the proposed *Modelica* meta-model. For the last step, we transform the *Modelica* model to the *Modelica* code. The input file of this transformation (model to text) is the XMI file resulting from the last transformation (*SysML* model to *Modelica* model) and the output file is the *Modelica* code.

4.1 The Case Study

We present an example for the motorized traffic density in urban areas. It requires the establishment of signaling traffic laws to improve the safety and the fluidity. The toughest traffic problems are at the road intersection. In fact, the passage priority associated to eventual changing direction could create bottlenecks. The solution adopted by traffic operators to regulate circulation is signalized system(tricolor and bicolor lights). The traffic lights installed at the intersection are used to adjust the vehicle movements. They are managed by a system that synchronizes the color changes of the different junction lights. The traffic-light colors are managed by a controller which depends on the number of cars waiting to cross the junction. The duration of a cycle lights (yellow - red - green) and the time of each phase is defined by the traffic center of the city. This center supervizes all streets intersections.

4.2 Transformation Rules from *SysML* to *Modelica*

In the literature, we found several attempts to define correspondences between the *SysML* (or UML2) and the *Modelica* languages (Paredis and Johnson, 2008), (Paredis et al., 2010). These works are based on the MDA standard, that describes an approach to make model transformations. The main work is (SysMLToModelica, 2012), there is ongoing work by the OMG on standardization of the model transformation *SysML* to *Modelica*. Our approach takes into account the requirement, structural and behavioural diagrams. The requirement diagram describes functional and non-functional requirements as well as the traceability of these with the elements of the model. Structural diagram allows is used to describe the structure of the target model and the parametric diagram allows us to consider the mathematical models which represent the behaviour of the real system. Finally, state machine diagrams are used to describe the behaviour of each component of the system under study. The below table 1 provides a list of correspondences between the elements of the *SysML* and the *Modelica* metamodels.

Table 1: Transformation rules from *SysML* to *Modelica*.

Elements of *SysML* model	Elements of *Modelica* model
package, block, abstract-block	package, block, partial-class
flow-specification, value-type	connector, type
flow-property, flow-port	property, connector
connector flux(x,y)	equation connect(x,y)
constraint property	equation
state machine guard	’when’ statement guard
operation without a value to return	instruction block of ’when’ statement
operation with a value to return	function
requirement	boolean expression (invariant or safety constraint)

5 VERIFICATION WITH *Modelica*

5.1 Virtual Verification

The *Modelica* language enables simulation and verification through the tests. In this context, the seminal work is presented by W. Schamai and al. (Schamai et al., 2011) which shows an approach to verify the properties of *Modelica* model. This approach relies on the MBSE (Model Based Systems Engineering). This model will be executed and checked against the system requirements in the early stages of the development cycle. Furthermore, in the MBSE approach requirements are connected with model elements which allows traceability.

5.2 Energy Consumption Verification

In our approach, we rely on the *SysML* requirement diagrams. The designer selects a checkable requirements by linking them with boolean expression (constraint) that represents invariant or safety constraint of system. To ensure traceability, the designer must connect each checkable requirement with one or more blocks that will satisfy this requirement. In this way, we ensure the reusability and the traceability of requirements. During the simulation of our system, we adopted a random scenario of execution. The number of vehicles on each lane will be randomly generated every five seconds. After these steps, we specified a simulation time which must be greater than the WSN desired lifetime in the order to analyze all the critical durations of time (minimal WSN lifetime). Otherwise, after ”19.22” hours of the simulation, the requirement that expresses the WSN desired lifetime is violated.

6 CONCLUSIONS AND FUTURE WORKS

This work illustrates an approach to design and to verify the WSN energy consumption property using the MDA standard. This approach combines the benefits of the *SysML* and the *Modelica* languages. We proposed a model transformation from the *SysML* model to the *Modelica* model taking into account the static diagrams, dynamic diagrams and also the requirement diagram of the *SysML* in order to specify the matching *Modelica* model. In addition, we have done virtual verification and requirement tracing. These operations are allowed by the mapping between the *SysML* requirements and the *Modelica* properties (constraints). We also indicate that our methodology is implemented in the *TopCased* environment.
The next phase of this work is to introduce sequence and activity diagrams in the action descriptions of the state machine. The purpose of this step is to provide opportunities for designers who do not master the *Modelica* programming to work with our Framework. Furthermore, we intend to validate our model transformation from *SysML* to *Modelica* by unit testing and/or formal proofs.

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