Dependability Evaluation of Wireless Sensor Networks: a Hybrid Simulation Tool

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1 Rationale

Wireless Sensor Networks (WSNs) [1] represent one of the most interesting research areas, with profound impact on technological development. Several applications are being proposed, such as target tracking [2], environmental monitoring (e.g., detection of fires in forests [1]), and structural monitoring of civil engineering structures [3]. The recent scientific production on WSNs is shifting more and more its attention on dependability modeling and evaluation. These studies are growing in number due to the novel, emerging scenarios where dependability requirements play a key role for the fulfillment of the application mission. For example, the monitoring of a civil engineering structure requires the reliable delivery of a significant amount of measurements to correctly perform alarm signaling [4]. Therefore, dependability evaluation of WSNs is gaining popularity since it could help to reduce risks and money losses, by forecasting the dependability of a WSN before the deployment. Despite the recent effort on WSN dependability evaluation, most of the existing works, such as [5, 6], do not consider the actual network behavior (e.g., routing and traffic load) when simulating the failure modes of the network. For instance, a node closer to the sink node is more likely to fail than other nodes, due to the greater solicitation it is subjected to. The failure of such a node would in turn require the change of the traffic load of other nodes, due to routes reorganization. As another example, a failure of a node may induce a partition of the network into two or more subsets, involving a large set of nodes to be unavailable, i.e., isolated, since they are no more able to deliver data to the sink node. In addition, these works stems from strong assumptions on network topology (e.g., random topology, which is most often unrealistic) and on power consumption (e.g., infinite energy). Finally, proposed failure models do not relate to the hardware/software platforms, to the sensing hardware being used, and to the workload which runs on the nodes. Different power consumptions and failure rates could be indeed experienced when varying the underlying platforms and computational load, making node and network lifetime dependent on these aspects.

To face all the above mentioned issues, we developed a simulation tool which is hybrid, in the sense that it is composed of two simulators: i) a behavioral WSN simulator which takes into account all the parameters related to the evolution of the WSN, including the workload program, the topology, and the routing algorithm, and ii) a Stochastic Activity Networks (SAN, we adopted Mōbius tool¹) simulator able to reproduce the failure behavior and to perform dependability analysis. The latter gathers parameters form the execution of the former thanks to a inter-model interface that dynamically drives the simulation of the SAN failure model. Using a behavioral simulator combined with a SAN failure model help us to prevent the failure model of being too specific for a particular considered network. In other terms, the approach decouples the failure model from the network behavior, allowing the same failure model to be used for evaluating networks with different behaviors. At the same time, dependability evaluation performed with the SAN model is more realistic, since it encompasses all network/application related parameters which varies during WSN execution.

2 Tool Description

The driving idea behind the proposed hybrid tool is sketched in Figure 1: a behavioral WSN simulator (i.e., TOSSIM²) is used to configure the real testbed scenario, in terms of number of nodes, network topology, routing algorithm being adopted, workload program being running on each node, battery consumption model, and signal propagation model. Simulation results are then provided to an external library (Network/Traffic Model in the figure) according to a defined inter-model interface. Subsequently, the failure

¹http://www.mobius.uiuc.edu
²http://www.cs.berkeley.edu/pal/research/tossim.html
model is simulated via Möbius. During the simulation, the library feeds the failure model and interacts with it. More in detail, we developed the library so as to offer the following facilities to the failure model simulation: i) provision of all the model parameters needed to initialize every individual node, such as adopted hardware/sensing platform along with its parametric failure rates, initial energy of the battery, traffic and computational load figures; ii) provision and dynamic update of the current network topology in terms of a weighted connectivity graph those weights represent the quality of the radio links. The dynamic update of the network topology is performed every time the SAN simulation signals a node failure, and it is necessary since the topology (and, consequently, the failure behavior) actually changes in the presence of node failures. The update is performed by computing the actual routing algorithm adopted on the simulated network.

The SAN that models the failure behavior of the WSN has been conceived as the composition (replicate/join) of individual node failure models (FMs), plus the external Network/Traffic Model for the network behavior. The FM of an individual node is in turn composed of four SAN sub-models: i) sensor board FM, modeling hardware failures due to the sensor board, such as stuck-at-N, null readings, and out-of-scale readings, ii) power supply FM, which takes into account power-off failures due to natural or abnormal energy exhaustion, and reset failures, due to anomalous current requests, iii) isolation FM, modeling the isolation of a single node caused by the failure of all its neighbors which are forwards to the sink node, and iv) radio board FM, which models packet loss failures that can occur between a node and its neighboring nodes. Every failure sub-model uses several parameters provided by the behavioral model via the external library, as summarized in Table 1.

At the end of the failure model simulation, the tool is capable of providing several dependability measures, defined as reward variables in the Möbius tool. Examples are per-node availability and reliability, network availability and reliability, maintainability, isolation probability, and network coverage (i.e., the percentage of the total number of nodes that are still connected to the sink).

### Table 1. Behavioral parameters used by failure sub-models.

<table>
<thead>
<tr>
<th>Failure Model</th>
<th>Behavioral Model-related parameters</th>
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</thead>
<tbody>
<tr>
<td>Sensor Board</td>
<td>Hardware failure rates, measurement load</td>
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<tr>
<td>Power Supply</td>
<td>Computation &amp; traffic load</td>
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<tr>
<td>Isolation</td>
<td>Topology &amp; routing tables</td>
</tr>
<tr>
<td>Radio Board</td>
<td>Topology &amp; routing tables, traffic load</td>
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3 Conclusions and Future Work

This paper presented the driving ideas behind a hybrid simulation tool for the dependability evaluation of WSNs. The tool aims at quantifying the failure behavior of a WSN starting from its real use: the tool essentially requests as input the application program (the workload) that runs on the real network, and the actual network topology. Then, it produces as output coarse-grained and fine-grained dependability figures, such as the network coverage and the per-node availability. For instance, this last measure can be used to pinpoint potential dependability bottlenecks in the network, hence suggesting to change the topology or the workload. The same considerations apply during the design phase of a WSN. The tool can be successfully adopted to validate design choices and to improve WSN algorithms and deployment strategies from a dependability point of view, prior to install the real WSN in the production environment. We are in the process of performing several reality checks on the proposed tool to validate the approach. The idea is to compare the dependability figures obtained with the tool with those we obtain from related work, real testbeds and industrial installations.

4 Availability

The interested reader can find the current release of the tool available at http://www.mobilab.unina.it/resources.html.

References


