Chapter 5

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ABSTRACT
Recent years have witnessed a proliferation of routing algorithms for Wireless Sensor Networks (WSNs), hence complicating the choice of the proper algorithm to be used for a given application. Simulation frameworks represent a viable solution to anticipate crucial choices, however existing solutions do not encompass the impact of changes (e.g., route updates, node crashes) on the nodes behavior and vice-versa. This article proposes a novel adaptive modeling approach to master the complexity of the thorough simulation of routing algorithms for WSN. Experimental results are provided showing the effectiveness of the proposed approach at managing changes, and dealing with detailed aspects, during the simulation and comparison of several routing algorithms.

INTRODUCTION
The evolution and diffusion of Wireless Sensor Networks (WSNs) (Akyildiz et al., 2002) has been accompanied by an impressive number of research results on routing algorithms. Routing is a fundamental function of WSNs, due to their wireless ad-hoc nature. WSN nodes exploit routing facilities to coordinate each other and to deliver sensed data to “sink” nodes (which are responsible for gathering sensed data from sensor nodes). Routing is also fundamental to adapt to the changes experienced in the network, e.g., to reconfigure the paths to the sink in the face of nodes or channel malfunction.

The availability of a large number of classes of routing algorithms makes it possible to address a large variety of problems, depending on the particular class of application where the WSN is to be applied. On the other hand, this complicates

DOI: 10.4018/978-1-4666-0255-7.ch005
the choice of a proper class of routing algorithms, able to fulfill the requirements of a given application. WSNs are indeed highly dynamic and complex systems, subject to frequent and sudden changes induced by the surrounding environment or by the behavior of single nodes. The choice a routing algorithm is hence not trivial, due to the presence of several variable and inter-dependent factors. For instance, a reliable routing algorithm, while preserving a high percentage of correctly delivered packets, may have a negative impact on the lifetime of sensor nodes, due to packet retransmissions.

Simulation frameworks represent a viable solution to anticipate crucial choices, mitigating the risk of adopting the wrong solution. Several simulation frameworks for WSNs have been proposed, as reported in next section. However, most of the existing approaches stem from strong simplifying assumptions, for instance, on the failure behavior (e.g., only packet loss) and on power consumption (e.g., infinite energy). Commonly adopted models do not encompass the impact of changes (e.g., route updates, node crashes) on the nodes behavior and vice-versa. In addition, existing simulation frameworks are typically difficult to use. Users have to specify the behavior of sensor nodes, and in some cases they have to implement routing algorithms explicitly.

We claim that, to make feasible the thorough and realistic simulation of routing algorithms for WSNs, change management has to be taken into account. Changes can be induced at runtime due to several factors, such as the network topology, the workload, the energy profile, the wireless propagation profile, the per-node failure behavior, and the routing algorithm per se. All above factors are inter-dependent. The workload, included the use of aggregation/fusion algorithms, impacts on the number of packets sent on the network, on which path depends on the routing algorithm, on the topology, and on the wireless propagation profile (packets can be lost). The energy profile is in turn affected by the workload, and by the particular battery technology. All above factors impact on the failure behavior, e.g., a node can fails due to battery exhaustion. Then node failures can induce changes in the topology, and hence in the workload and in the routing algorithms, and so on. Clearly, such high degree of inter-dependence complicates the modeling and simulation task, by exponentially increasing the number of state combinations.

This article proposes an adaptive modeling approach, able to master the complexity of the routing algorithms simulation through change management. According to this approach, the WSN, and its sub-components and functions (included routing) can be modeled as a set of simple and adaptive simulation models: each model has to adapt itself to changes induced on the network by other models. Change is managed by an external adaptation engine, which intercepts changes from simulation model and propagates them to other models. The use of an external engine decouples simulation models, hence achieving higher modularity and simplifying the structure of models, while taking into account all needed details.

More in detail, in this article we adopt the Stochastic Activity Networks (SAN) formalism (Sanders et al., 1992) to model routing algorithms for WSNs. Instead of developing unnecessarily complex and large detailed SAN models for every possible class of routing algorithms (also accounting for fine grain components like topology, per-node energy profile, workload profile, etc.), we opted for a parametric model able to simulate a number of families of routing algorithms. By means of the adaptation engine, this model is interfaced with other simple parametric sub-models, in charge of simulating other aspects of the network (e.g., the failure behavior of nodes, the energy profile). Every sub-model is able to modify its behavior at execution time according to changes occurring in other sub-models. The adaptation engine is in charge of handling changes on behalf of the SAN models, specializing the behavior and values for model parameters after changes.