A systematic approach to constructing families of incremental topology control algorithms using graph transformation

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Abstract: In this talk, we present results on integrating support for variability modeling into a correct-by-construction development methodology for topology control algorithms, as appeared online in the Software & Systems Modeling journal in 2017 [Kl17]. A topology control algorithm reduces the size of the visible neighborhood of a node in a wireless communication network. At the same time, it must fulfill important consistency properties to ensure a high quality of service. In previous work, we proposed a constructive, model-driven methodology for designing individual topology control algorithms based on declarative graph constraints and graph transformation rules; the resulting algorithms are guaranteed to preserve the specified properties. Even though many topology control algorithms share substantial (structural) parts, few works leverage these commonalities at design time. In this work, we generalize our proposed construction methodology by modeling variability points to support the construction of families of algorithms. We show the applicability of our approach by reengineering six existing topology control algorithms and developing e-kTC, a novel energy-efficient variant of the topology control algorithm kTC. Finally, we evaluate a subset of the algorithms using a novel integration of a wireless network simulator and a graph transformation tool.

Keywords: Graph transformation; Graph constraints; Static analysis; Model-driven engineering; Wireless networks; Network simulation

1 Summary

In the communication systems domain, wireless sensor networks (WSNs) [Sa05] are a highly active research area. WSNs serve, e. g., to monitor environmental conditions using small, battery-powered sensor nodes that cooperatively transmit data to a sink node. To improve important properties (e. g., the energy consumption), a topology control (TC) algorithm inactivates redundant communication links of a WSN [Sa05]. Constructing a TC

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algorithm is a challenging task, which is carried out by highly skilled experts usually in two major steps. First, the TC algorithm is specified using a mathematically framework (e. g., graph theory), which allows us to prove the required formal properties. Then, the TC algorithm is implemented, typically in a general-purpose programming language (e. g., Java or C) for simulation or real-life evaluation purposes.

The traditional development process of TC algorithms suffers from (at least) two major shortcomings [Kl17, Sec. 1]: The first shortcoming is that a systematic mapping between the specification and the implementation is missing. This makes it difficult to verify that specification and implementation correspond to each other. To tackle this shortcoming, we proposed a model-driven development methodology that constructively integrates the required formal properties [Kl16]. We describe topologies as graph-based models, required properties as graph constraints, and possible operations of topology control algorithms as declarative graph transformation rules [HW95].

The second shortcoming is that—even though novel TC algorithms tend to build on former TC algorithms—the inherent commonalities and differences of TC algorithms are not specified systematically. This reduces reusability among and comparability of TC algorithms, especially w. r. t. the proven formal properties. In the presented article [Kl17], we generalize the constructive, model-driven methodology for designing TC algorithms using graph transformation [Kl16] to support the development of families of TC algorithms. More precisely, (i) to model commonalities and differences of TC algorithms, we extract common structural constraints and specify individual part of each TC algorithm as attribute constraints, thereby lifting all steps described in [Kl16] to algorithm families; (ii) to demonstrate that our approach is applicable, we specify six existing TC algorithms and e-kTC, a novel energy-aware TC algorithm; (iii) to support dynamic TC, we extend the constructive approach with a step that systematically derives context event handlers, which anticipate imminent constraint violations; (iv) we present a rapid evaluation environment, consisting of the graph transformation tool eMoflon and the network simulator Simonstrator.

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