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UNIFIED PACKET-LEVEL AND FLUID-FLOW SIMULATION OF LARGE-SCALE NETWORKS

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ABSTRACT

Mainly two very disparate approaches dominate the Modeling and Simulation (M&S) of data networks. The packet-level approach yields fine-grained results comparable to real data networks, but its complexity makes it unsuitable for the simulation of large high-speed networks. The fluid-flow approach relies on Ordinary Differential Equations approximations for faster simulation, but captures only averaged network behavior. Classically, each approach requires different knowledge and tools making network experts adhere to only one of them. We developed a DEVS-based M&S methodology and tool to define seamlessly fluid-flow and packet-level network topologies under a common formal framework. The approach helps reducing the gap between communities approaching network simulation from the algorithmic and the mathematical perspectives. As a case study, simulation models of the DAta AcQuisition network in the ATLAS experiment at CERN helped in the design, sizing and fine tuning of upgrade projects planned for 2021 and 2027.

1 INTRODUCTION AND PROBLEM DESCRIPTION

Designing and evaluating communication networks through M&S became a central tool in many engineering projects, witnessing an exponential growth in terms of bandwidth, topology size and adoption.

Our work studies the *packet-level* and the *fluid-flow* approaches for the M&S of large data networks and how to combine them under a common formalism and tool. *Packet-level* models provide fine-grained results that closely match real networks at the cost of high execution times. *Fluid-flow* models use Ordinary Differential Equations (ODEs), which are faster to simulate but represent only averaged network behavior.

Existing methods and tools for *packet-level* simulation are of a very different nature than those required to solve ODEs. A new modular and scalable approach is presented to combine the modeling and numerical solving of *fluid-flow* and *packet-level* dynamics simultaneously under a common formalism and tool.

We rely on the Discrete EVent Systems Specification (DEVS) as the underlying formalism, capable of representing discrete event, discrete time and continuous dynamics combined in a mathematically sound way. Quantized-State Systems (QSS) methods, represented as DEVS models, are used to solve ODEs.

2 PACKET-LEVEL NETWORK SIMULATION

The classical *packet-level* M&S approach represents data flows packet-by-packet. Control logic and protocols are implemented yielding results comparable to the real systems. Unfortunately, simulation time grows linearly with the number of nodes and link speeds, making them unsuitable for large high-speed networks.

A new DEVS-based methodology and a *packet-level* library were developed and used to simulate the DAta AcQuisition (DAQ) network in the ATLAS experiment at CERN (Bonaventura et al. 2016). The same simulation tool was used to systematically characterize load balancing strategies under various conditions (Bonaventura et al. 2018). New tools where developed to automatically validate results (Foguelman et al. 2016) and to generate automatically large topologies based on SDN descriptions (Laurito et al. 2017).

3 FLUID-FLOW NETWORK SIMULATION

The *fluid-flow* M&S approach represents the network dynamics through a set of ODEs, trading execution speedups for coarser-grained accuracy. Simulation execution time becomes almost independent of link speeds. Classic tools for solving ODEs require knowledge on continuous dynamic systems, are radically different from the *packet-level* simulation tools, and are far from being adopted by network experts.

A new *fluid-flow* model library allows to define graphically *fluid-flow* and *packet-level* topologies in the same way (Bonaventura and Castro 2018) using the same PowerDEVS tool. The set of ODEs gets automatically expressed by the interconnection of pre-defined blocks, yielding results with acceptable accuracy when compared to fine-grained *packet-level* simulations as shown in Figure 1.

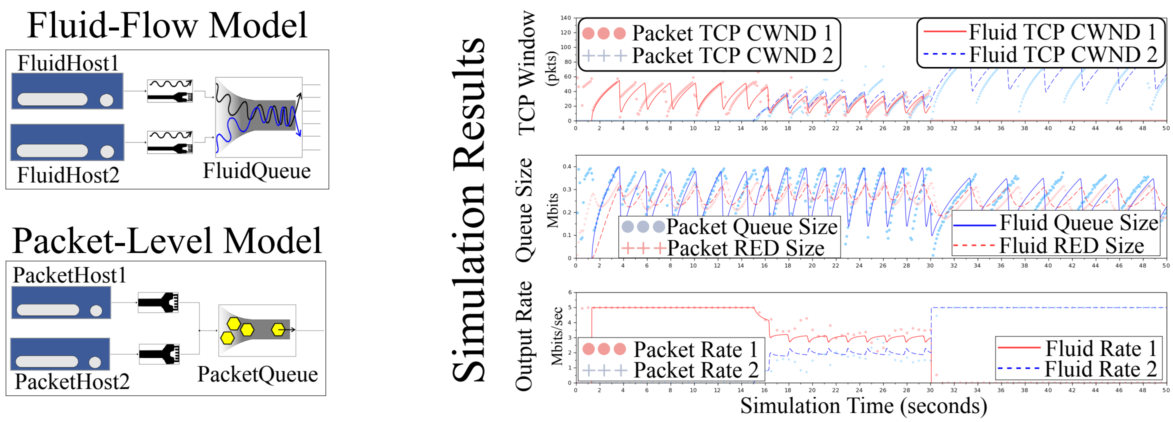

Figure 1: Fluid-Flow and Packet-level models in PowerDEVS (left). TCP protocol simulation (right).

4 CONCLUSIONS AND FUTURE WORK

The strategy of developing libraries of reusable, block-oriented and self-contained models proved successful: the visual design of network topologies can now be implemented almost indistinguishably from the network representation, be it fluid- or packet-based. Next steps include: test larger topologies/higher-speed networks and evolve towards hybrid network simulation (interacting fluid- and packet-level models).

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