Quantile Estimation for Performance Measures in Network Simulations with CINSim

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Abstract

This paper presents the simulator CINSim. It was developed to investigate interconnection network architectures for a wide application range, like networks-on-chip or parallel computers. CINSim allows the simulation of arbitrary network topologies, various traffic distributions in time and space as well as dynamic reconfiguration of the network under investigation. Besides the estimation of mean values for several performance measures, quantiles can be observed.

1 Introduction

Packet-switched networks used to establish parallel computers or Ethernet switches consist of similar architectures. The same architectures also build the networks of multiprocessor systems and they are under investigation to be applied for networks-on-chip in complex systems-on-chip.

For all such systems, detailed performance models of the network architecture are needed to investigate and optimize the network for a given application range. Besides the observation of mean values of performance measures, quantile investigation improves the analysis of the network behavior. With the observation of several quantiles, one can draw conclusions about the underlying distributions.

The simulator CINSim (Component-based Interconnection Network Simulator) [5] supports modeling and performance evaluation of component-based interconnection networks. It is designed to provide a single simulator for different kinds of network architectures that base on atomic components such as switches and buffers. Regular network topologies can be modeled as well as irregular ones. Compared to other popular simulators like ns-2 or OMNeT++, CINSim focuses less on network protocols, but more on low level architectural details. The tool is available free of charge for non-commercial use at http://pdv.cs.tu-berlin.de/CINSim/.

2 Features

CINSim consists of two parts: a simulator core performing the simulation runs and a graphical user interface (GUI) to design and draw the network under investigation.

The GUI, as shown in Fig. 1, is based on the TimeNET GUI [3]. It is XML schema-driven and can be adapted to a wide range of target domains. It provides a comfortable editor to develop the network that will be investigated. Networks are composed by combining atomic components. Namely, switches (routers), buffers, sources (traffic generators), destinations (target buffers), and routes (links). Hierarchical modeling is supported: subnetworks can be combined to meta elements and so easily replicated to build larger models. Performance measures are defined by placing analyzer elements in the network and connecting them with relevant components. Source or destination throughput, delay or latency times and buffer queue sizes can be investigated.

The GUI also provides several dialogs to specify component, network, and simulation parameters. Every component can be parameterized individually or a global value is inherited. Such individual parameters are buffer strategies and capacities, traffic distributions in time and space and multicast distributions. Various traffic interarrival times, like heavy tailed and geometric distributions, can be chosen. A simple formula parser allows the definition of arbitrary distri-
butions. The arbitration scheme in the switches can also be selected. Several strategies, like round-robin, least-recently-used, priority-based, etc., are supported.

The desired switching scheme (store-and-forward, virtual cut-through, wormhole, etc.), several routing schemes, and the backpressure mechanism can be selected as network parameters. Simulation parameters select, whether a steady-state simulation or a finite-horizon simulation is to be performed. To automate larger evaluations, simulation series with a changing parameter can be specified.

As already mentioned, CINSim supports the modeling with hierarchical levels. The top hierarchy level allows the modeling of dynamic reconfigurations of the network. The topology, routing scheme, buffer capacities, etc. can be altered during runtime. Such a feature allows the investigation of new network architectures that take advantage of dynamic reconfigurable hardware like FPGAs.

Two reconfiguration strategies are supported in CINSim: flushing all packets from the network before reconfiguration or leaving all packets in the network during reconfiguration and subsequently rerouting remaining packets adaptively. The first strategy is much easier to implement in real systems because the hardware overhead is limited. The second strategy provides better performance but with increased complexity concerning routing logic and buffer space requirements to guarantee lossless reconfigurations.

Network models are stored in XML files. They are passed to the simulator core, which performs the actual simulation. Several pseudorandom number generators are implemented to provide stochastic events. The core observes confidence level and estimated precision for every measure independently to achieve a given accuracy. If the termination criteria for all observations are met, the simulation is stopped.

To speed up simulations, CINSim supports distributed simulations. More precisely, it incorporates the Multiple Replications in Parallel Time Streams (MRIP) [4] approach.

3 Quantile Estimation

To draw conclusions from simulation results that only contain mean values can be misleading in some cases. The mean value gives no information about extreme values and the distribution of the performance measure in question. Quantiles can be helpful to answer questions like how many packets will be delivered in time.

CINSim provides the estimation of arbitrary quantiles besides the mean value for many performance measures. The quantile estimations can be obtained in steady-state and finite-horizon simulations. With this, the detailed transient behavior of a network can also be investigated.

To reduce the memory requirements of the tool during simulation the P²-Algorithm [2] is implemented combined with a spectral analysis [1] for the quantile estimation with the corresponding confidence levels. The P²-Algorithm is tailored for non-regenerative simulations and the spectral analysis can be applied to autocorrelated observations. This approach allows distributed simulations without major modifications of the simulator.

Fig. 2 depicts several p-quantiles of the packet latency of a 16 × 16 bidirectional multistage interconnection network with 4 × 4 bidirectional switches with input buffers for two packets and a packet size of five flits (flow control digits). In this steady-state simulation, virtual cut-through switching and global backpressure scheme were applied. Uniform traffic distributions and an injection rate of 40% and 80% were assumed. The mean value of the packet latency is in the first case 9.2 and in the second 34.5. The simulation was stopped at a confidence level of 99.9% and an estimated precision of 0.1%.

This example shows, for instance, that approx. 5% of all packets have a doubled latency compared to the mean value.

References