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Tutorial on Importance Sampling Methods for Communication Networks

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Overview

Computer simulation is widely used for analyzing the performance of telecommunication systems, computer networks, and protocols. However, many important measures of performance in communication networks are defined in terms of rare event probabilities. Two examples are cell loss probability and maximum cell delay variation in asynchronous transfer mode (ATM) networks. Obtaining accurate estimates of such rare event probabilities using Monte Carlo simulation can require execution times that are too long to be useful.

The issue of reducing execution time while simultaneously retaining the ease and flexibility of the Monte Carlo simulation technique has been a topic of investigation for a number of years. Techniques based on importance sampling (IS) have shown great promise for many different classes of communication networks.

However, many network engineers are dissuaded in practice by the apparent mathematical complexity of the technique. Despite its tremendous potential, IS has thus gained limited acceptance and applicability by practitioners. In this tutorial we set out to encourage engineers to use IS and thus enable the community to benefit from its implementation.

We outline the theoretical foundations of IS and show its applications to the design and analysis of broadband networks. We first give a general description of importance sampling as a variance reduction technique, we discuss issues of efficiency and optimality, and how it can be applied in the communication network context.

Next we describe individual element biasing (e.g, sources, servers) versus global element biasing/modification. We then turn to the issue of how much each element should be biased by discussing tuning/optimization techniques that have been used in network simulation. Furthermore, we describe modification of parameters based on effective and decoupling bandwidths.

Finally, we present application examples that demonstrate how IS is applied to a number of different communication networks.

Intended Audience

Network Engineers
Simulation Engineers
Graduate students in Electrical, Systems and Computer Engineering

Pre-requisites

Knowledge of the basic concepts in
- Probability Theory
- Statistics
- Simulation

Duration Four (4) hours

Outline

Introduction
- Large simulation run times for analysis of communication networks
- Simulation of rare events
- Requirement for variance reduction techniques

Part I: Theory

1. Derivation of IS Estimators
    - Fundamentals
    - Optimal IS estimators and effective bandwidths
    - Steady-state estimation and regenerative simulation
    - Dynamic IS

2. Properties of IS Estimators
    - Variance reduction
    - Efficiency/Optimality
    - Over-biasing

Part II: Techniques

3. Global versus individual biasing
4. Stochastic optimization
    - Mean Field Annealing
    - Stochastic Gradients
5. Effective and decoupling bandwidths
6. Conditional IS
7. RESTART/DPR

Part III: Applications

8. Fast Simulation of Intree Networks
   - An algorithm for simulating intree networks
   - Simulation setup
   - Example topology: Intree network
   - Results
9. Fast Simulation of Non-Intree Networks
   - Decoupling bandwidths
   - An algorithm for simulating non-intree networks
   - Simulation setup
   - Example topology: Non-intree network
   - Results
10. Other examples

Biographical Note

Michael Devetsikiotis was born in Thessaloniki, Greece, in 1964. He received the Diploma degree in Electrical Engineering from the Aristotle University of Thessaloniki, Thessaloniki, Greece, in 1988, and the M.Sc. and Ph.D. degrees in Electrical Engineering from North Carolina State University, Raleigh, in 1990 and 1993, respectively. In October 1993 he joined the Broadband Networks Laboratory at Carleton University, Ottawa, Canada, as a Research Associate and became an Adjunct Professor in April 1995. He has been an Assistant Professor in the Department of Systems and Computer Engineering, Carleton University, since July 1996. His research work has been in the areas of telecommunication systems modeling, performance evaluation, and efficient simulation; traffic characterization and management; and optimization techniques applied to the analysis and design of communication systems. His present focus is on the performance and nonlinear behavior of broadband communication networks as they become larger in size, and more complex in topology and traffic. He currently serves as the secretary of the IEEE Communication Society committee on communication systems integration and modeling (CSIM), and as an Associate Editor for the ACM Transactions on Modeling and Computer Simulation (TOMACS).