Rare-event Splitting for Efficient Simulation of Cascading Blackouts

New Approaches for Rare-Event Simulation and Decision Making

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Abstract

The objective of this talk is to efficiently estimate rare-event blackout probabilities via simulation. Standard Monte-Carlo simulation may be computationally intractable when the events of interest are extremely rare. For example, to simulate an event that occurs with probability 10^{-9} requires 10^9 simulation runs to observe one event, on average. To estimate the probability with a 1% relative error (that is, where the standard deviation of the estimator is 1% of the rare-event probability) requires 10^{13} simulation runs. If one can conduct 1,000 simulation runs per second, this would take over 30 years to simulate.

We have developed a variant of a rare-event simulation technique known as splitting. The basic idea of splitting is to create separate copies (splits) of the simulation whenever it gets close to the rare event. This tends to allocate more computing time towards “promising” simulation runs. A standard approach is to simply use an equal number of runs at all levels. We formulate the problem of determining the number of runs as an optimization problem that minimizes the variance of an estimator subject to a constraint on the total computing budget available. We derive a solution that is asymptotically optimal as the computing budget goes to infinity. We further extend the idea to the problem of choosing among a number of different mitigation strategies to most efficiently find the one that yields the lowest rare-event probability.

This talk investigates the application of these splitting techniques to simulate blackouts in a power grid. The cascading failure model used in this talk is similar to, and inspired by, a number of models in the literature in which the intermediate failures of transmission lines are treated as instantaneous events. Following the failure of one line (or a set of lines), the power flow is recalculated and the subsequent failures of the remaining working lines are determined probabilistically as some function of the resulting power flows. With multiple simulation replications, the model can be used to estimate the probability of a large blackout, defined as an event where the number of failed lines or the amount of load shed exceeds some threshold.

We investigate theoretical properties of some simple grid structures in order to effectively choose various parameters and functions associated with the splitting method. These include the choice of the level function and the number and locations of the levels. Then we apply the method to a variety of more complicated networks. Numerical experiments show significant efficiency gains for the networks and model considered in this talk.