Generalizing Window Flow Control in Bivariate Network Calculus to Enable Leftover Service in the Loop

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ABSTRACT

With the works of Cruz [8, 9, 7] the theory of network calculus emerged. As methodology it has grown to capture more complex queueing systems, including a wide variety of scheduling disciplines and topologies (see [6]); furthermore, this theory has been extended into stochastic versions that effectively capture random effects like the statistical multiplexing gain [10] or arrivals and service as stochastic processes (e.g. [1]). Many of the original, deterministic results of network calculus have been carried over to these extensions – known today as Stochastic Network Calculus (SNC).

The results for window flow controlled systems (WFC systems), however, eluded a corresponding stochastic analysis ever since. This has been marked as an open and challenging problem for over a decade [5]. Only recently, progress towards a stochastic analysis of WFC systems has been made [5, 2, 11, 3].

We briefly sketch the mechanics of the stochastic extension of network calculus: The event one is interested in (e.g., a delay bound) is first analyzed for sample paths satisfying certain conditions on the arrival and service processes. This first step is a logical implication, which takes place inside the space of possible sample paths. The probability of the event happening is then bounded by the probability of the conditions being fulfilled – the second step. That second step usually invokes bounds on the processes' tails or moment-generating functions. This two step procedure is characteristic for SNC [6].

The main contribution of the recent results towards window flow controlled systems [11, 3] are related to the second step. Regarding the first step, results of (deterministic) bivariate network calculus [4] are re-used. This paper shows that the existing available results for the first step are not sufficient to analyze window flow controlled systems in the presence of crossflows, i.e., in the highly relevant case of multiple flows sharing the network. Indeed, the first step of SNC, using deterministic arguments, must be developed further to cover such scenarios. We address this by formulating a general result about WFC systems within the notation of σ-additive operators. With this theorem we achieve two goals: First, we have a single formulation for WFC systems and are able to recover previous results as special cases. Second, and more importantly, we cover a wide variety of systems, including those with crossflows. As such this paper provides a missing piece for the further research towards the stochastic analysis of window flow controlled systems.

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