Robert Bauer
Department of Mathematics, University of Illinois at Urbana-Champaign
e-mail: rbauer13@illinois.edu

A queueing theory model for the dynamics of microtubules and microfilaments

Dynamic features of microtubules and microfilaments are essential to cell division, cell motility, and other cellular processes. ATP-bound monomeric actin and GTP-bound tubulin polymerize to actin filaments and microtubules, respectively. After assembly into polymers, nucleotide hydrolysis occurs, which can lead to a change in the on- and off-rates at the polymer ends. A simple stochastic model of such a polymer from nucleation until complete depolymerization is presented. The model assumes that there is a sharp boundary between the "newer" part of the polymer containing only ATP-bound actin—the ATP cap (GTP cap in the case of tubulin), and the "older" part, where all nucleotides have undergone hydrolysis. The ATP cap and GTP cap are modeled as a single-server queue with reneging, where the server rate (rate of nucleotide hydrolysis) plus the reneging rate (off-rate at plus end of filament) exceeds the arrival rate (on-rate at plus end of filament). Coupled to this queue is another single server queue that describes the length of the entire filament and whose arrival and reneging rate switch between two regimes depending on whether the ATP cap has disappeared (first server empty) or not. The model exhibits dynamic instability and treadmilling for proper choice of hydrolysis rate and on/off-rates at polymer ends. Analytic expressions for the distribution of the life time and length of polymers together with Monte Carlo simulations are presented and their fit to experimental data discussed.