Nature Inspired Techniques in communication networks

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A. Based on Lotka-Volterra (L-V) model
A. An Ecosystem View (L-V model)

- **Autonomous Network**
  - nodes initiate traffic flows
  - flows interact with each other
  - flows compete for available resources located at each node (e.g., buffer, bandwidth)
  - Goal: co-existence of flows

- **Ecosystem**
  - species live in nature
  - species interact with each other & non-living parts of their surroundings
  - compete for resources (e.g., food, water)
  - Result: co-existence of species
A. An Ecosystem View (L-V model)

Focus: small neighborhood (sub-ecosystem)

- CN-initiated flows compete for PN’s available resources (e.g., available buffer space)
- Each CN **self-regulates** and **adapts** the rate of its traffic flow to meet their needs for survival (**co-existence**)

Approach: rate adaptation of flows originating from each source node in order to avoid (or prevent) congestion based on relay node’s available buffer capacity.
Lotka-Volterra competition model

- Population dynamics modeled with simple balance equation
  - Describes how overall population changes from time to time as result of species interactions with resources, competitors, enemies, etc.
  - Examples: competition models, prey-predator models

- Generalized Lotka-Volterra competition model for $n$ species

  $$dx_i/dt = x_i \left[ r_i - \beta_i x_i - \left( \sum_{j=1}^{n} \alpha_{ij} x_j \right) x_i \right], \quad x_i(0) > 0, \quad i = 1, \ldots, n$$

  - $x_i(t)$: biomass (population size) of species $i$ at time $t$ \textbf{number of packets sent by each children node $i$}
  - $r_i$: constant intrinsic growth rate of species $i$ in the absence of all other species
  - $\beta_i$: intra-specific competition coefficient (competitive effects among individuals of species $i$)
  - $\alpha_{ij}$: the inter-specific competition coefficient (competitive effects of species $j$ on growth of species $i$)
  - $K_i$: is the carrying capacity of species (maximum number of individuals that can be sustained by the biotope in the absence of all other species competing for the same resource) \textbf{resource capacity}
Equilibria and Stability Analysis

- Equilibria of the generalised Lotka-Volterra model
  \[ \frac{dx_i}{dt} = rx_i \left\{ 1 - \frac{\beta x_i}{K} - \frac{a}{K} \sum_{j=1, j \neq i}^{n} x_j \right\} = 0, \forall i \in [1,n] \]
- Coexistence non-negative equilibrium solution \( x_i^* = x^* \)
  \[ x_i = \frac{K}{\alpha(n-1) + \beta}, i = 1,\ldots,n \]
- Stability of equilibrium coexistence solution
  - all flows (species) co-exist (survive) when \( \alpha < \beta \)
  - inter-specific competition is weaker than intra-specific competition
Preliminary Results - getting a feel

- Example: $K = 8KB$ (buffer capacity at each node), $\alpha = 1$
  - $x_i(t)$ are evaluated every 1 sec (decision period $T = 1$ second)

\[ \beta = 1.2, \quad r = 0.5 \]

\[ n = 1: N^* = \frac{8192}{1 \times (1-1) + 1.2} \approx 6826 \]

\[ n = 2: N^* = \frac{8192}{1 \times (2-1) + 1.2} \approx 3724 \]

\[ n = 3: N^* = \frac{8192}{1 \times (3-1) + 1.2} \approx 2560 \]

\[ n = 4: N^* = \frac{8192}{1 \times (4-1) + 1.2} \approx 1950 \]

- Scalability
  - as # of CNs scales up, rates of active CNs decrease
  - graceful performance degradation

- Adaptation
  - each CN self-adapts its sending rate
  - responsiveness

- Fairness
  - PN’s buffer capacity is fairly shared among active CNs

Instantaneous number of packets sent from each CN

CN–Children Node  PN–Parent Node