Swarm Intelligence Based Network Optimization

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Swarm Intelligence

Swarm intelligence (SI) based

- Biologically inspired: biological swarms like ants, bees, etc.
- Requests are delivered by sending out multiple but simple ant agents that travel the network and fetch information.

Properties:

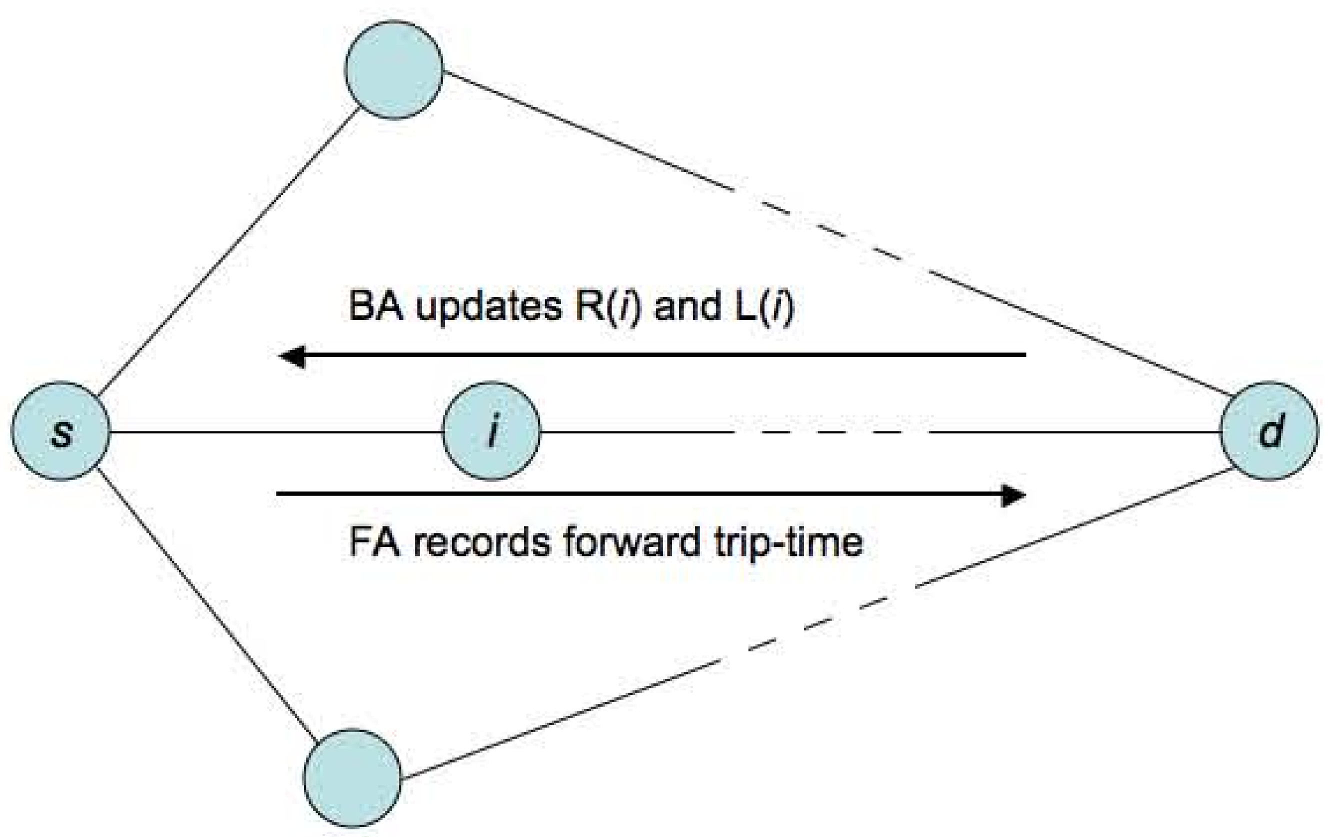
- Indirect communications between the agents (ants): (efficiency)
- Dynamic "online" optimization using local information (adaptability, scalability)

Advantages:

- Reinforce good quality paths by feedback
- Discover new sources via random exploration of the network
- SI scheme can be used both for route discovery and trust evidence discovery (leads to method for secure routing).

Ant Routing Algorithms

- **Features:**
  - Probabilistic routing of packets
  - Adaptive, distributed routing :
    - Ant (probe) packets collect network statistics.
    - Information in ant packets is used to update routing tables (routing probabilities)
- **Operations:**
  - Two types of ant packets: Forward Ant (FA) and Backward Ant (BA)
  - FA records IDs of nodes visited and per-hop delays it encountered
  - FA generates BA when it reaches destination d.
  - BA retraces path back to the source s along priority queues.
  - BA updates Routing Table $R(i)$ and Network Statistics Table $L(i)$ at each node i it passes.



Problem Formulation

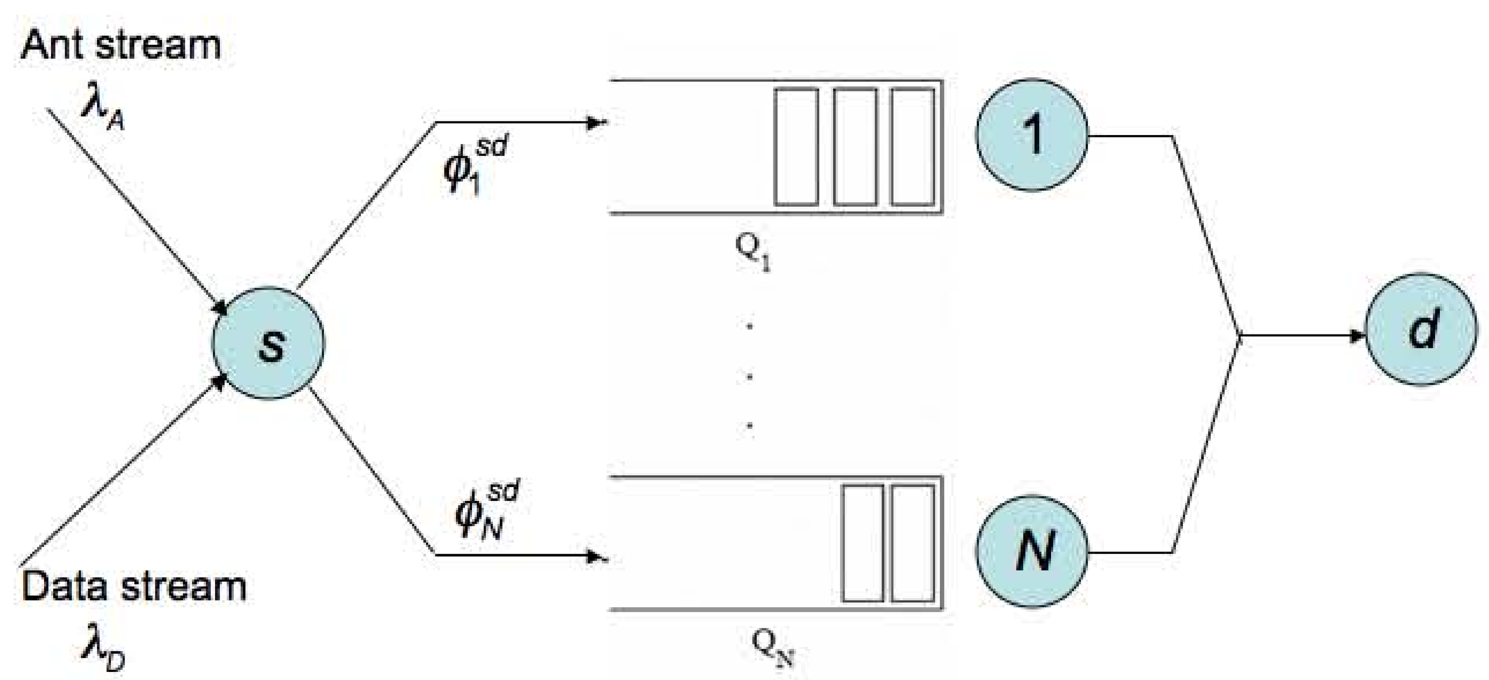
Ant Routing Scheme (Bean and Costa `05)

- Mean delay table $L(i)$:
  - X_i^{sd}: exponential averaging estimator for delay on path from s to d via i
- Routing table $R(i)$:
  - ϕ_i^{sd}: probabilities of forwarding packets to node i, $\phi_i^{sd} \propto \left[X_i^{sd}\right]^{-\beta}$
  - $\left[X_i^{sd}\right]^{-1}$: interpreted as 'pheromone content' on outgoing link (s, i)

Example

N Parallel Links Case

- Incoming traffic : Ant stream - Poisson(λ_A) , and Data stream - Poisson(λ_D)
- Lengths of ant and data packets - generally distributed with means L_A and L_D bits



Parameter Updates

Mean delay table $L(i)$:

- When an ant packet arrives at d via Q_i with new delay measurement, X_i is updated as:

$$X_i := X_i + \varepsilon(\Delta_i - X_i)$$

- Delay estimates for other queues are left unchanged:

$$X_j := X_j, j \neq i$$

Routing table R(i):

- routing probabilities are updated as :

$$\phi_i = \frac{[X_i]^{-\beta}}{\sum_{j=1}^{N}[X_j]^{-\beta}}, i \in \{1,\ldots,N\}$$

Analysis and Results

Key idea : Time-scale decomposition for $\varepsilon > 0$ small enough

- Delay estimates X_i evolve much more slowly than the delay processes Δ_i;
- With $(X_1(\cdot), \ldots, X_N(\cdot))$ fixed at $z_1, \ldots, z_N$, delay processes Δ_i converge to a stationary distribution;
- ODE approximation tracks evolution of $(X_1(\cdot), \ldots, X_N(\cdot))$.

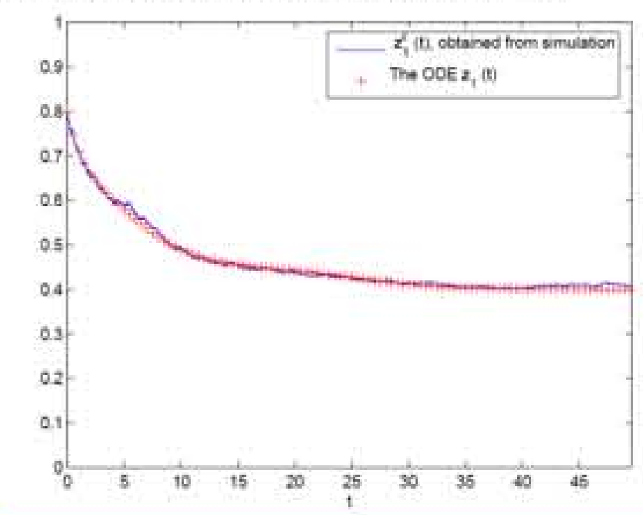
Steady-state behavior

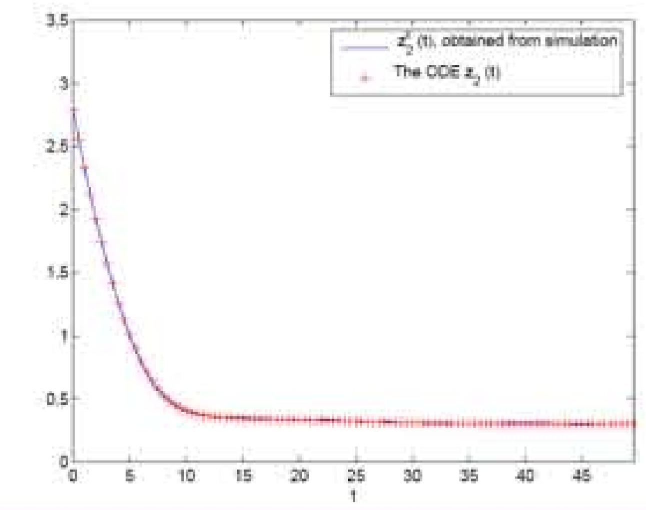
- Equilibrium points of ODE give system steady-state behavior.
- Steady state probabilities $\phi_1^*, \cdots, \phi_N^*$ are positive and satisfy the fixed-point equations
- ϕ^* is the unique global minimum for the optimization problem :

$$\text{Minimize } F(\phi_1,\ldots,\phi_N) = \sum_{j=1}^{N}\int_0^{\phi_j} u\left[D_j(u)\right]^{\beta} du,$$

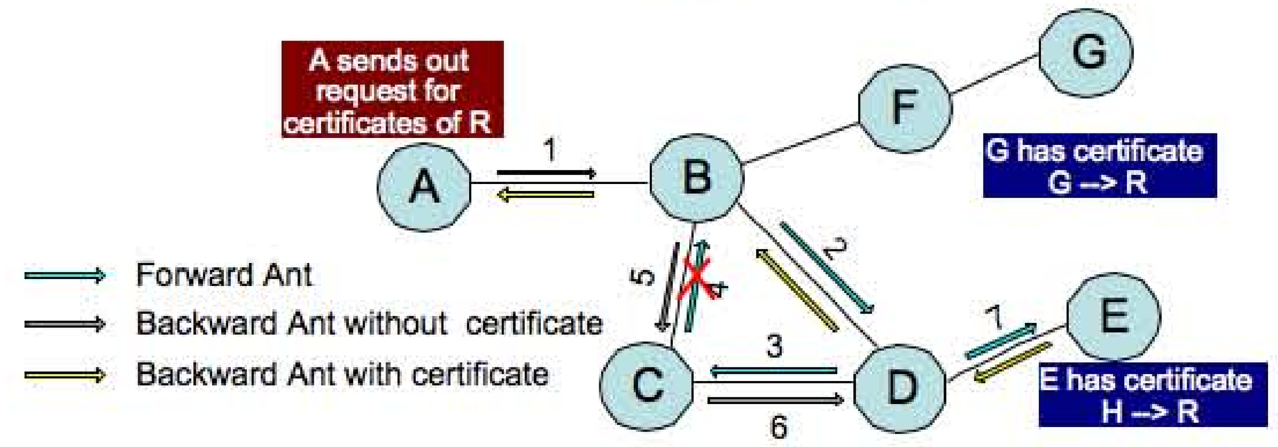
subject to the queue stability constraints and $\sum_{i=1}^{N}\phi_i = 1.$

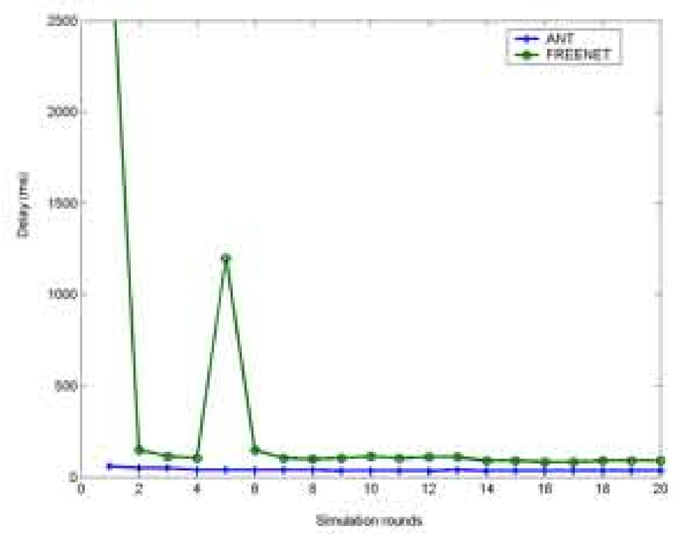
Simulation results with N=3

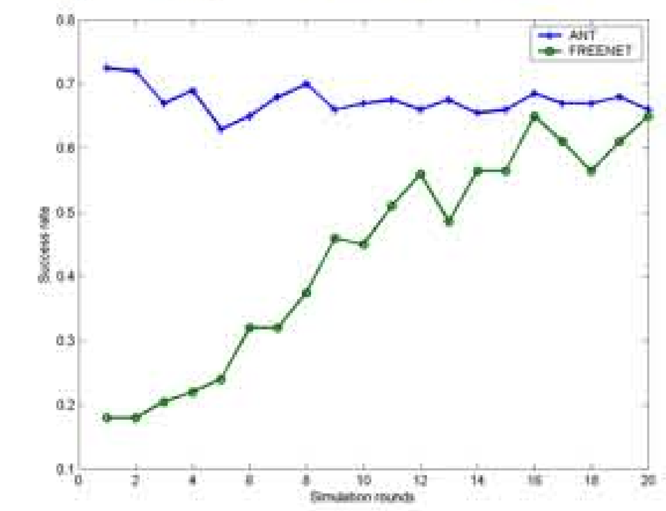




Trust Evidence Discovery







- The ant based scheme quickly finds the best solution because of randomness in the searching phase. The fast convergence property is highly desirable in mobile scenarios.
- Multiple paths are inherent for swarm intelligence. The multiple path scheme is more resilient to failures.