On attractant scheduling in networks based on bacterial communication

Yunlong Gao,
Sriram Lakshmanan,
Raghupathy Sivakumar

Georgia Institute of Technology
Background

Nanotechnology is the study of manipulating matter at the atomic and molecular scales.

- nanomachine performs very simple tasks
- Nanonetwork expands capabilities of single nanomachines.
- Several potential applications
Motivation

- Traditional communication technologies are not directly applicable in nanonetworks

- Common natural phenomenon of molecular communication networks with multiple Transmitter-Receiver (T-R) pairs

- Limited number of attractants for bacteria
Network Architecture

- Transmitter
- Receiver
- Information Carrier
- Message
- Medium
Bacterial Communication

- Chemotaxis
  - Attractant Properties
- Communication Process
Problem Description

- Total system delay with multiple T-R pairs:
  \[ D = \sum_{i=0}^{n} t_i(x_{Ti}, x_{Ri}, y_{Ti}, y_{Ri}, m, N) \]

  - \( m \): number of attractants
  - \( N \): required number of packets
  - \( n \): number of receivers
Discussion of Two-Link Topology

Case I

Case II

Case III

Case IV
System Delay and Packet Loss Analysis

- For Case I and II, the delay for a single packet is:
  \[ D = T_p(d_1) + T_p(d_2) + 2T_c \]

- Empirical equation for \( T_p(d) \) is:
  \[ T_p(d) = 1.82d^2 + 4.49d + 0.17 \]

- The Packet Loss is 0.
For case III, assume:

\[ P \propto U(d) = \frac{1}{1000} \frac{Q}{4D\pi d} \]

Therefore, the system delay is:

\[ D = \max_i \{ T_p(d_i) \} + \frac{T_c}{P_1} + \frac{T_c}{P_2}, \quad i = 1, 2 \]

where \( P_1 = \frac{d_2^2}{d_1^2 + d_2^2}, \quad P_2 = \frac{d_1^2}{d_1^2 + d_2^2} \).

The packet loss is:

\[ L = \frac{d_1^4 + d_2^4}{(d_1^2 + d_2^2)^2} \]
For case IV, modeling the two states as follows:

- Running: move with constant velocity and drift with the angular derivation of 1.12 \( \text{rad} \).
- Tumbling: stop and change its direction:
  \[
  \theta_{t+1} = \theta_t + \gamma
  \]
  where the p.d.f. of \( \gamma \) is subject to:
  \[
  f(\gamma) = \begin{cases} 
  \frac{1}{4} \cos \frac{\gamma}{2}, & |\gamma| \leq \pi \\
  0, & |\gamma| > \pi
  \end{cases}
  \]

- Exponential Distribution
System Delay and Packet Loss Analysis

Illustration of Successful Reach to the Destination

Illustration of Failing Reach to the Destination

Staring Point

Destination
For case IV, $D = T_p(d) + 4T_c$, and $L = \frac{1}{2}$. 
Network with Same-Distance Receivers

- One transmitter transmitting data to different receivers with same the distance:
  \[ D = m \cdot T_p(d) + \sum_{i=1}^{m} m_i^2 \cdot T_c \]

- Tradeoff between the propagation delay and the fixed delay.

Insight 1: allocating the attractants equally among the receivers.
Simulation Result

System delay with less than 12 receivers

System delay with more than 12 receivers

Optimal Number
Network with Different-Distance Receivers

- One transmitter transmitting data to receivers with different distances:

\[ D = T(\text{Propagation}) + T(\text{Fixed}) \]

\[ T(\text{Fixed}) = \sum_{i=1}^{m} m_i^2 \cdot T_c \]
Network with Different-Distance Receivers

- Insight 2: *Partitioning the n links into m groups after rearranging the receivers in the decreasing order of distances*

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**Two-tier Comparison Algorithm**

1. Initiate $D=0$, $D_{sys} = []$;
2. while $m \leq 12$
3. do{
4. if $m \leq n$
5. $D_{sys}(m) =$ the minimum system delay for each partition under the constraints of $m$;
6. else break;
7. end if
8. $m++$
9. }
10. $D = \min(D_{sys}(m))$
Conclusion Remarks

- Network Delay and Packet Loss for two-link topology

- Modeling of the movement pattern of E. coli under no concentration gradient

- Insights for attractant scheduling

- Extent to scheduling with multiple T-R pairs
Questions?

Thank you for listening!

Yunlong Gao
Shanghai Jiao Tong University
dg.gaoyunlong@gmail.com