Molecular Communication: Simulation of a Molecular Motor Communication System

Michael Moore, Akihiro Enomoto, Tadashi Nakano, Tatsuya Suda
Department of Computer Science
Donald Bren School of Information and Computer Sciences
University of California, Irvine, Irvine, CA 92697-3425
Web: http://bolero.ics.uci.edu/mc/index.html
Email: mikemo@ics.uci.edu
Outline

- Nanomachine communication
  - Nanomachines
  - Nano-Scale biological communication
- Molecular communication
  - Example systems
  - Applications
- My Simulation Work
Molecular Communication

- Communication paradigm for biological nanomachines
  - Molecules as information carriers

Nanomachines: nano-scale or molecular scale objects that are capable of performing simple tasks

Figure: “Protonic Nanomachin Project”, Prof. Namba at Osaka University: http://www.npn.jst.go.jp/index.html
What are Nanomachines?

- **Cellular components/cells**
  - **Dynein**
    - Molecular motors that walk along microtubule in a cell
  - **Bacterium**
    - Swims toward the chemicals (e.g., food) using flagellum

Figures: Alberts, Molecular Biology of the Cell
What are Nanomachines?

- Molecules such as enzymes
  - Function as logic gates
    - If both substrate and effector exist, product produced
    - If no effector or no substrate, substrate remains unchanged

![Diagram of AND gate with substrate (S), effector (C), product (P), enzyme (E), and effector (C)]
Nano-Scale Communication in Bio World

- Within a cell (vesicles transported by molecular motors)

- Plasma-membrane
- Microtubule
- Nucleus
- Centrosome

A vesicle transported by a kinesin motor toward the periphery of the cell

A vesicle transported by a dynein motor toward the center of the cell
Molecular Motors

- Kinesin
  - Consumes ATP energy to move along microtubule
  - Binds cargo according to...

Motor Procession Along a Microtubule

http://www.embl-heidelberg.de/CellBiophys/LocalProbes/motorproteins/kinesin.html
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Simplest Molecular Communication System: An Example

1. Encoding

Senders (nanomachines)

Information Source

Information molecules (Proteins, ions, DNAs, etc)
Simplest Molecular Communication System: An Example

1. Encoding

Senders (nanomachines)

2. Sending

Information Source

Information molecules (Proteins, ions, DNAs, etc)
Simplest Molecular Communication System: An Example

1. Encoding

Senders (nanomachines)

Information Source

2. Sending

3. Propagation (directional)

Information molecules (Proteins, ions, DNAs, etc)
Simplest Molecular Communication System: An Example

1. **Encoding**
   - Senders (nanomachines)
   - Information Source

2. **Sending**
   - Information molecules (Proteins, ions, DNAs, etc)

3. **Propagation** (directional)

4. **Receiving** (selective)
   - Receivers (nanomachines)
Simplest Molecular Communication System: An Example

1. Encoding

2. Sending

3. Propagation (directional)

4. Receiving (selective)

5. Decoding

Senders (nanomachines)

Information Source

Receivers (nanomachines)

Information Sink

Information molecules (Proteins, ions, DNAs, etc)
Simplest Molecular Communication System: An Example

1. Encoding
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Senders (nanomachines)

Information Source

Information molecules (Proteins, ions, DNAs, etc)

Receivers (nanomachines)

Information Sink

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Components

- Senders/receivers = biological nanomachines
- Communication carrier = molecules (e.g., proteins, ions, DNA sequences)
- Communication distance = nano/micro scale
- A receiver (chemically/physically) reacts to incoming molecules
Application: Body Sensor Networks

- Soft nanomachines that are bio-friendly are embedded into a body
  - Interact with each other
  - Interact directly with cells
  - Self-replicating, self healing

- Applications
  - Medical treatment and health monitoring
  - Enhancing various capabilities
    - Sense of smell, hearing capacities
Application: New Ways of Problem Solving

- Program simple behavior rules into biological nanomachines
- Solving large scale problems (e.g., a maze) through collaboration and communication

Nanomachines communicate using molecular motors.

Molecules are transported by molecular motors that walk over a network of rail molecules.
- Self organizing creation of a rail molecule network

- Nanomachine
- Seed of rail molecules (e.g., γ-tubulin)
- CAP molecule
- Rail molecule
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My research: Simulation of Uni-cast Molecular Communication

> Uni-cast

- Simplest communication
- One sender transmits to one receiver
- E.g. sender encodes “1” and receiver decodes a “1”
Uni-cast Communication

- Compare propagation approaches

Sender: S
Receiver: R
Microtubule: +
Multi-bit Communication Model

- Signal
  - Probability to receive a “1”

- Noise
  - Causes error when receiving a 0

- Significant Parameters
  - Distance, time between sending events, number of information molecules

![Diagram showing sending and noise for next sending with signal and time for receiving annotations.]
Other Simulations Performed

- Broadcast communication
- Microtubule topologies
  - Length, number of microtubules
  - Receiver location on microtubules
- Optimize information rate in terms of
  - Decay of information molecules
  - Number of information molecules sent/received
Future Work

- Communication using Molecules
  - Reliability, Dynamics
- General molecular communications
  - Applications
  - Theoretical information limits
  - Higher-layer networking