NANO-COMMUNICATIONS: AN OVERVIEW

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REFERENCES


http://www.ece.gatech.edu/research/labs/bwn/NANOS/
Development of Nano-Machines

Man-made

Bottom-up

Nature

Bio-hybrid

NANOMACHINES

Nano-electronics

Micro-electronics

Computers

Nano-robots

Micro-robots

Robots

Molecules

Cell organelles

Cells

Bacteria

Insects

Humans

Scale

nm

μm

mm

m
Nano-Machine Networking

- Nano-machines can be interconnected to execute more complex tasks in a distributed manner.

- Resulting nano-networks are envisaged to expand the capabilities and applications of single nano-machines, both in terms of complexity and...
Why can’t we use traditional communication mechanisms for Nanonetworks?

Communication Paradigms

- Electromagnetic Waves
- Acoustic Communication
- Nano-mechanical Communication
- Molecular Communication
A Possible Solution: Molecular Communication

Defined as the transmission and reception of information encoded in molecules

A new and interdisciplinary field that spans nano, ece, cs, bio, physics, chemistry, medicine, and information technologies
EXAMPLE: NANO-NETWORK FOR INTRABODY

Intra-body Interconnected Nanonetworks

Single Nanonetwork
## Nanonetworks vs Traditional Communication Networks

<table>
<thead>
<tr>
<th>Features</th>
<th>Traditional</th>
<th>Molecular</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier:</td>
<td>Electromagnetic waves</td>
<td>Molecules</td>
</tr>
<tr>
<td>Signal type:</td>
<td>Electronic, optical, mechanical</td>
<td>Chemical</td>
</tr>
<tr>
<td>Propagation speed:</td>
<td>Sound or light</td>
<td>Extremely low</td>
</tr>
<tr>
<td>Medium conditions:</td>
<td>Wired: almost immune, Wireless: affect communication</td>
<td>Affect communication</td>
</tr>
<tr>
<td>Noise:</td>
<td>Electromagnetic field and signals</td>
<td>Particles and molecules in medium</td>
</tr>
<tr>
<td>Other features:</td>
<td>High energy consumption</td>
<td>Low energy consumption</td>
</tr>
</tbody>
</table>
Nanonetworks vs Traditional Communication Networks

Traditional communication

Molecular communication
Molecular Communication

- Short Range (nm to µm)
  - Wired
  - Molecular Motors
    - Ion Signaling (e.g., calcium, sodium, potassium, chlorine)
  - Wireless

- Medium Range (µm to mm)
  - Wireless
  - Flagellated Bacteria
  - Catalytic Nanomotors

- Long Range (mm to m)
  - Wired
  - Axons
  - Capillaries
  - Wireless
  - Pheromones
  - Light Transduction
  - Pollen/Spores
Short-Range Communication

- Molecular Motors (Wired)
- Calcium Ions (Wireless)
Short-Range Communication using Molecular Motors

Features:

Communication
Range: nm - mm

Medium: Aqueous environment with necessary molecules at biologically appropriate conditions

Carrier: Molecular Motors
What is a Molecular Motor?

- Is a protein or a protein complex that transforms chemical energy into mechanical work at a molecular scale
- Has the ability to move molecules
**Molecular Motors:**

* Found in eukaryotic cells in living organisms

* Molecular motors travel or move along molecular rails called microtubules

* Movement created by molecular motors can be used to transport information molecules
Short-Range Communication using Molecular Motors
Encapsulation of information:

Information can be encapsulated in vesicles.

A vesicle is a fluid or an air-filled cavity that can store or digest cell products.
Short-Range Communication using Molecular Motors

**Encoding**
Select the right molecules that represent information

**Transmission**
Attach the information packet to the molecular motor

**Propagation**
Microtubules (molecular rails) restrict the movement to themselves

**Reception**
Information molecules are detached from molecular motors

**Decoding**
Receiver nano-sensor invokes the desired reaction according to the received information
Short-Range Communication using Ion Signaling

Features:

- **Communication Range**: nm - mm
- **Medium**: Aqueous environment with necessary molecules at biologically appropriate conditions
- **Carrier**: Calcium Ions ($\text{Ca}^{2+}$)
Short-Range Communication using Calcium Signaling

Two different deployment scenarios

Direct Access

Exchange of information among cells located next to each other

Indirect Access

Cells deployed separately without any physical contact
Short-Range Communication using Calcium Signaling

Direct Access: $\text{Ca}^{2+}$ signal travel through gates
Short-Range Communication using Calcium Signaling

- **Gap Junctions:** Biological gates that allow different molecules and ions to pass freely between cells (membranes).
Short-Range Communication using Calcium Signaling

- **Indirect Access:**
  - Transmitter nano-machine release information molecules to the medium.
  - Generate a Ca$^{2+}$ at the receiver nano-machine.
Short-Range Communication using Calcium Signaling

Encoding

Information is encoded in Ca$^{2+}$

Transmission

Involves the signaling initiation

Signal Propagation

Propagation of the Ca$^{2+}$ waves

Reception

Receiver perceives the Ca$^{2+}$ concentration

Decoding

Receiver nano-sensor reacts to the Ca$^{2+}$ concentration
**Molecular Motors:**

- Molecular motors velocity is 500 nm/s
- They detach from the microtubule and diffuse away when they have moved distances in the order of 1 µm
- Development of a proper network infrastructure of microtubules is required
- Molecular motors move in a unidirectional way through the microtubules

→ very long communication delays!
Problems of Short Range Molecular Communication

- Calcium Signaling

- Very high delays for longer (more than few µm) distances
Medium Range Molecular Communication

- *Escherichia coli* (*E. coli*) has between 4 and 10 flagella, which are moved by rotary motors, fuelled by chemical compounds.
- *E. coli* bacteria is approximately 2 µm long and 1 µm in diameter.
Medium-Range Communication using Flagellated Bacteria

- Information is expressed as a set of DNA base pairs, the DNA packet, which is inserted in a plasmid.

Encoding

Transmission

Propagation

Reception

Decoding

DNA packet is introduced inside the bacteria's cytoplasm, using:
- Plasmids
- Bacteriophages
- Bacterial Artificial Chromosomes (BACs)

- Bacteria sense gradients of attractant particles.
- They move towards the direction and finds more attractants (chemotaxis).
- The receiver releases attractants so the bacteria can reach it.

DNA packet is extracted from the plasmid using:
- Restriction endonucleases enzymes
**Medium Range Molecular Communication: Catalytic Nanomotors (Nanorods)**

- Au/Ni/Au/Ni/Pt striped nanorods are catalytic nanomotors
- 1.3 µm long and 400 nm on diameter
- Externally directed by applying magnetic fields.

→ We propose to use them as a carrier to transport the DNA information among nano-sensors
- Information is expressed as a set of DNA base pairs, the DNA packet, which is inserted into a plasmid.

- **Encoding**: DNA packet is inserted into a plasmid.
- **Transmission**: Magnetic Fields guide the nanorod to the receiver.
- **Propagation**: DNA packet is extracted from the plasmid using restriction endonucleases enzymes.
- **Reception**: Nanorods are introduced in a solution of AEDP.
- **Decoding**: AEDP binds with the Nickel segments.
- **Nanorods** are introduced in a solution of AEDP.
- **AEDP** binds with the Nickel segments.
- **DNA packets (plasmids)** are attached to nanorods.
- **CaCl₂** solution is used in order to compress and immobilize the plasmid.
Long-Range Communication using Pheromones

Features:

- Communication Range: mm - m
- Medium: Wet and dry
- Carrier:
  - Pheromones
  - Light Transduction
  - Pollen & Spores
  - Axons & Capillaries
Long-Range Communication using Pheromones

Communication Features:

Micro-system
Encoder
TX Nano-machine

Scale
nano
micro

Pheromones (the message)

Micro-system
Receptors
RX Nano-machine
Long-Range Communication using Pheromones

**Encoding**
Selection of the specific pheromones to transmit the information and produce the reaction at the intended receiver

**Transmission**
Releasing the pheromones through liquids or gases

**Signal Propagation**
Pheromones are diffused into the medium

**Reception**
Pheromones bind to the Receptor

**Decoding**
Interpretation of the information (Different pheromones trigger different reactions)
Long Range Molecular Communication: Light Transduction

→ the conversion between molecular and optical signals
Long Range Molecular Communication: Light Transduction: Conversion

- Molecular signal conversion to optical information
  - Fluorescent proteins
  - MOLED’s (Molecular organic LED)

- Optical information conversion to molecular signal
  - Molecular Switch
  - Molecular Wire
Research Challenges in Nano-Sensor Networks

- Development of nano-machines (sensors), testbeds and simulation tools
- Information Theoretical Approach
- Architectures and Communication Protocols
Molecule Diffusion Communication: Exchange of information encoded in the concentration variations of molecules.
Derivation of **DELAY** and **ATTENUATION**

as functions of the **frequency** and the transmission range

- Non-linear attenuation with respect to the frequency
- Distortion due to delay dispersion
HOW ABOUT Electro-Magnetics???
FUTURE INTERNET AFTER NEXT (FIAN)
Carbon Nanotubes and Graphene Nanoribbons can be used to build EM nano-transceivers:

- Nano-antennas can be developed using a single nanotube or nanoribbon (e.g., a nano-dipole).
- A single mechanically resonating nanotube can implement a fully operational radio (i.e., a nano-radio).
Nano-Electromagnetic Communications


- Frequency band, transmission range, energy constraints: everything needs to be determined.

- At this scale, novel information encoding techniques in light of quantum information theory can be further investigated.