# NANO-COMMUNICATIONS: AN OVERVIEW


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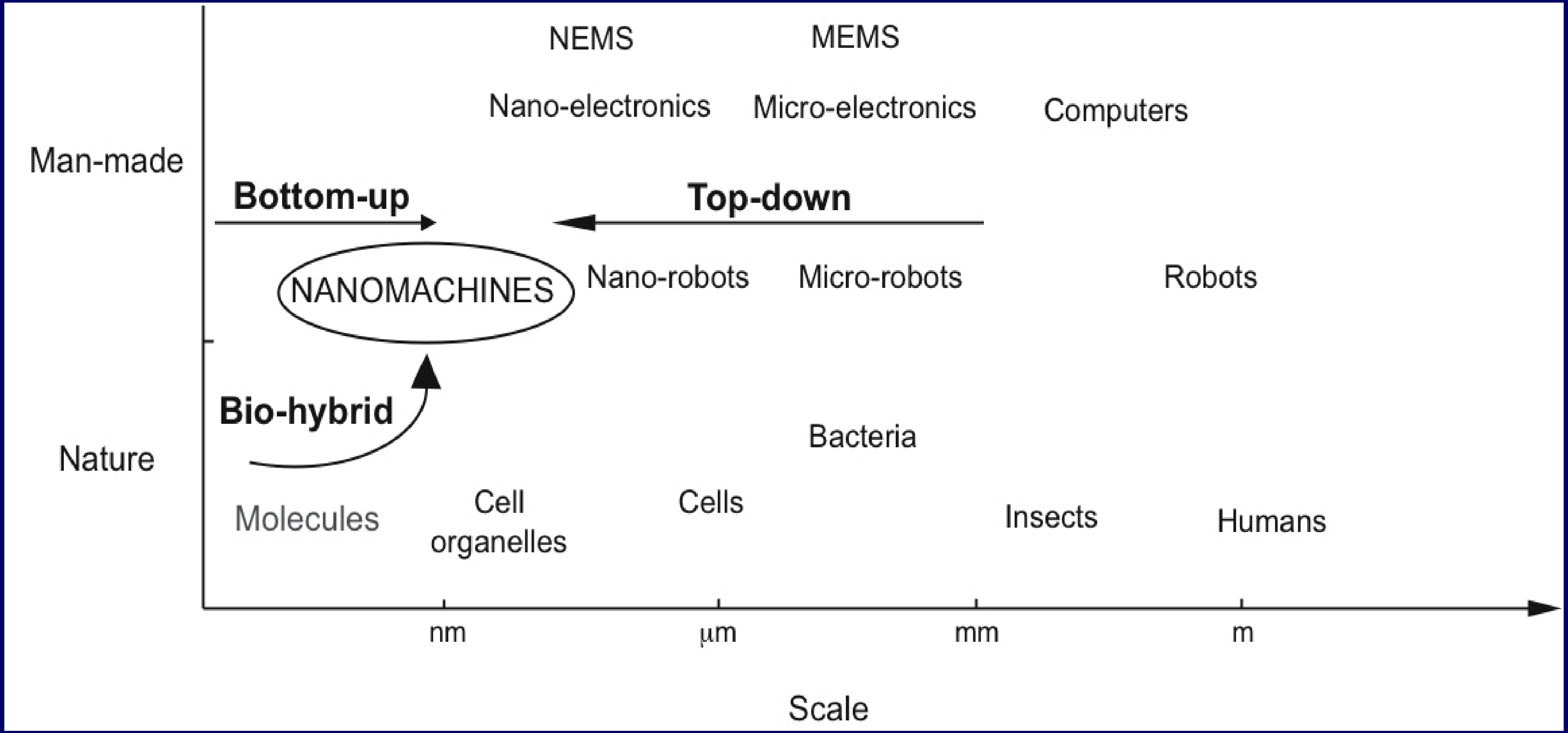
# REFERENCES


I.F. Akyildiz, F. Brunetti, and C. Blazquez, "NanoNetworking: A New Communication Paradigm", Computer Networks Journal, (Elsevier), June 2008.


http://www.ece.gatech.edu/research/labs/bwn/NANOS/

# Development of Nano-Machines



# 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

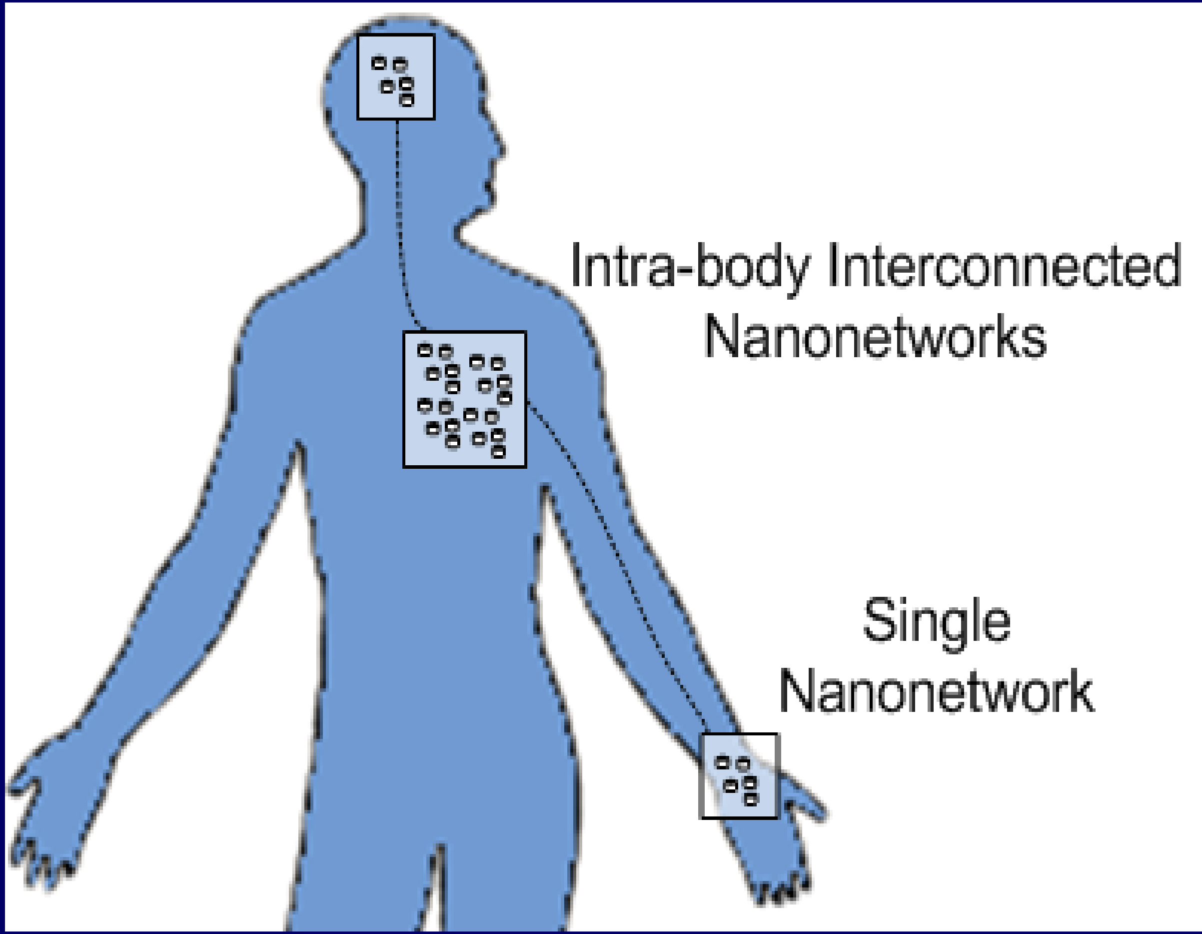
- Electromagnetic Waves
- Acoustic Communication
- Nano-mechanical Communication
- Molecular Communication

# 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



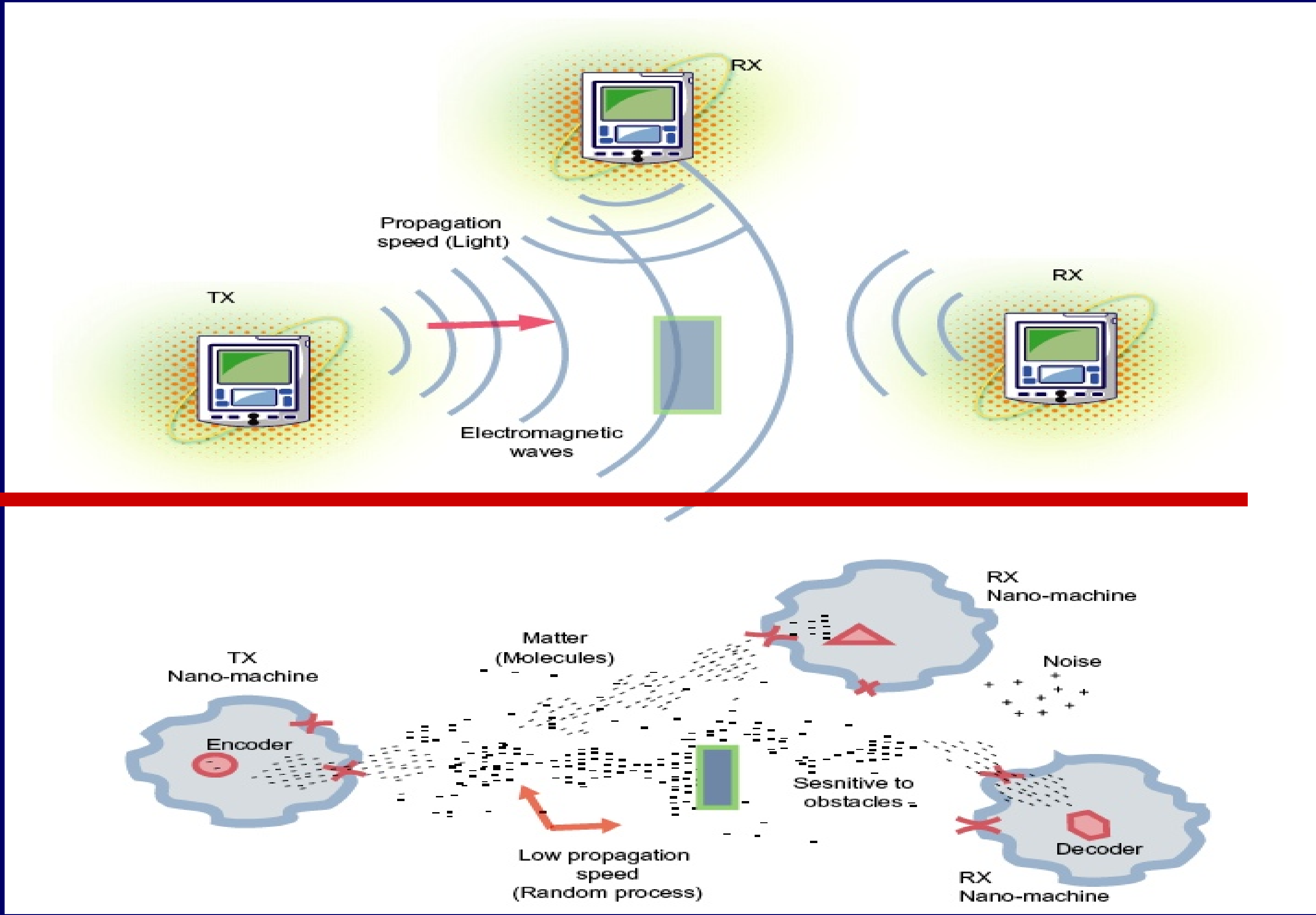
# Nanonetworks vs Traditional Communication Networks

| Features | Traditional | Molecular |
|---|---|---|
| Carrier: | Electromagnetic waves | Molecules |
| Signal type: | Electronic, optical, mechanical | Chemical |
| Propagation speed: | Sound or light | Extremely low |
| Medium conditions: | Wired: almost immune<br>Wireless: affect communication | Affect communication |
| Noise: | Electromagnetic field and signals | Particles and molecules in medium |
| Other features: | High energy consumption | Low energy consumption |

# Nanonetworks vs Traditional Communication Networks

Traditional communication

Molecular communication



# Molecular Communication

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

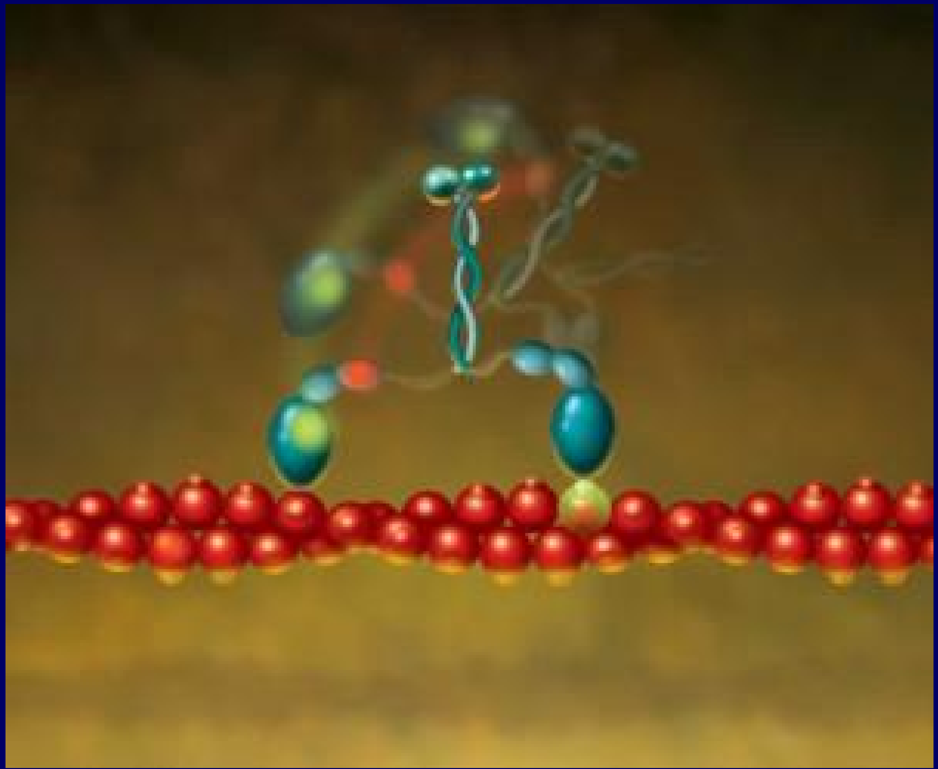
## Features:

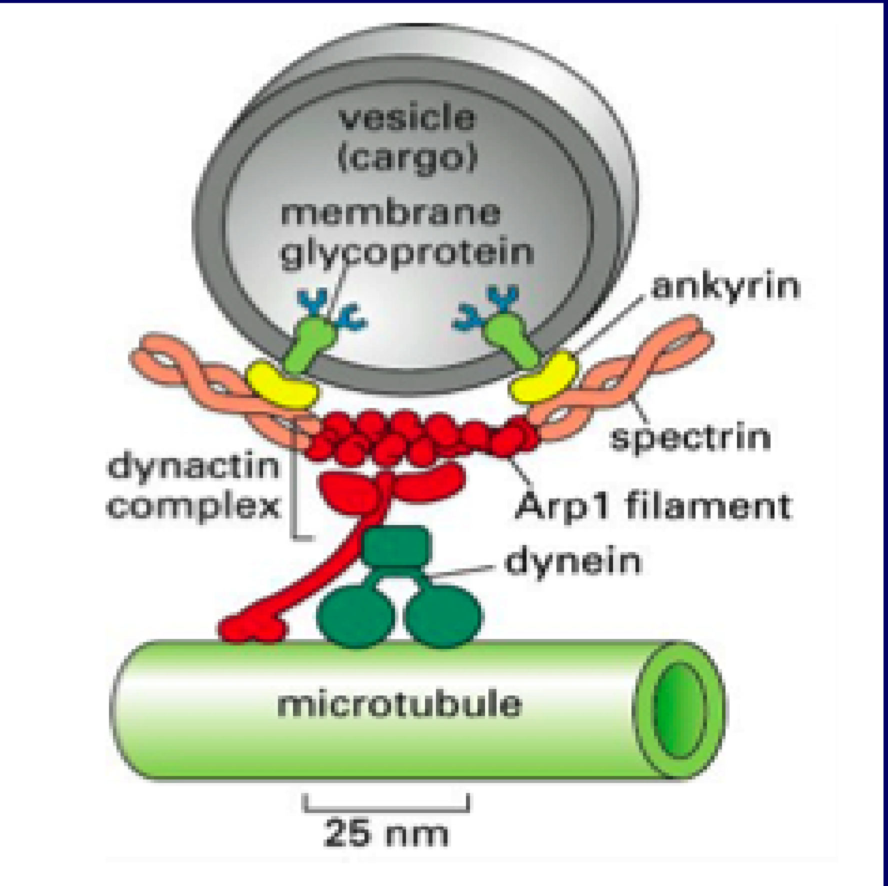
- **Communication Range** → nm - mm
- **Medium** → Aqueous environment with necessary molecules at biologically appropriate conditions
- **Carrier** → Molecular Motors

# 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





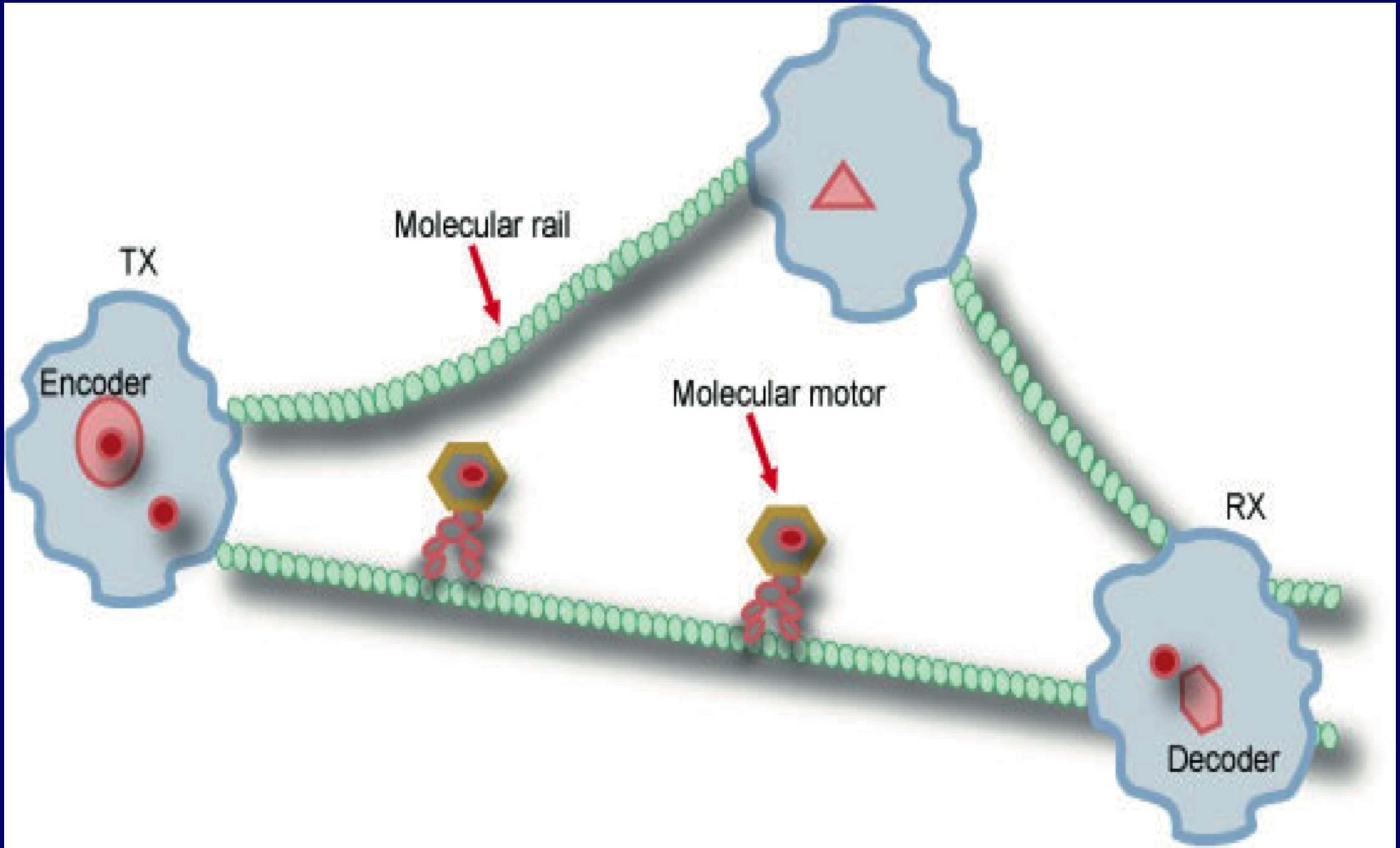

## Molecular Motors:

* 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

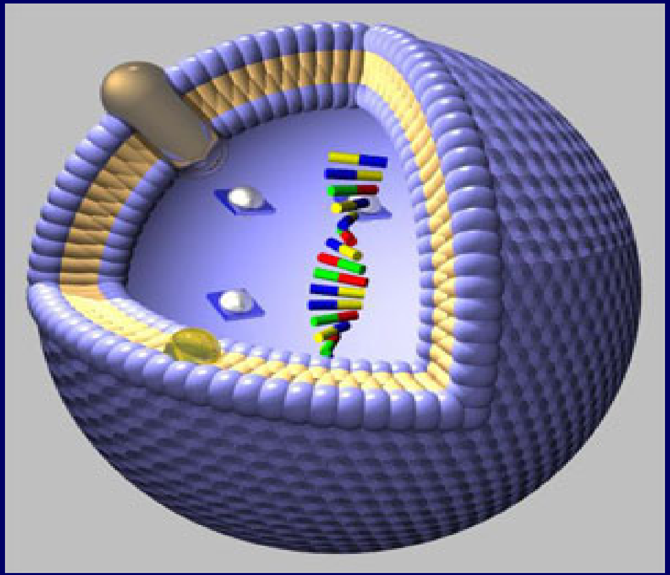
# Short-Range Communication using Molecular Motors



# 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** → **Transmission** → **Propagation** → **Reception** → **Decoding**

- **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 ($Ca^{2+}$) |

# Two different deployment scenarios

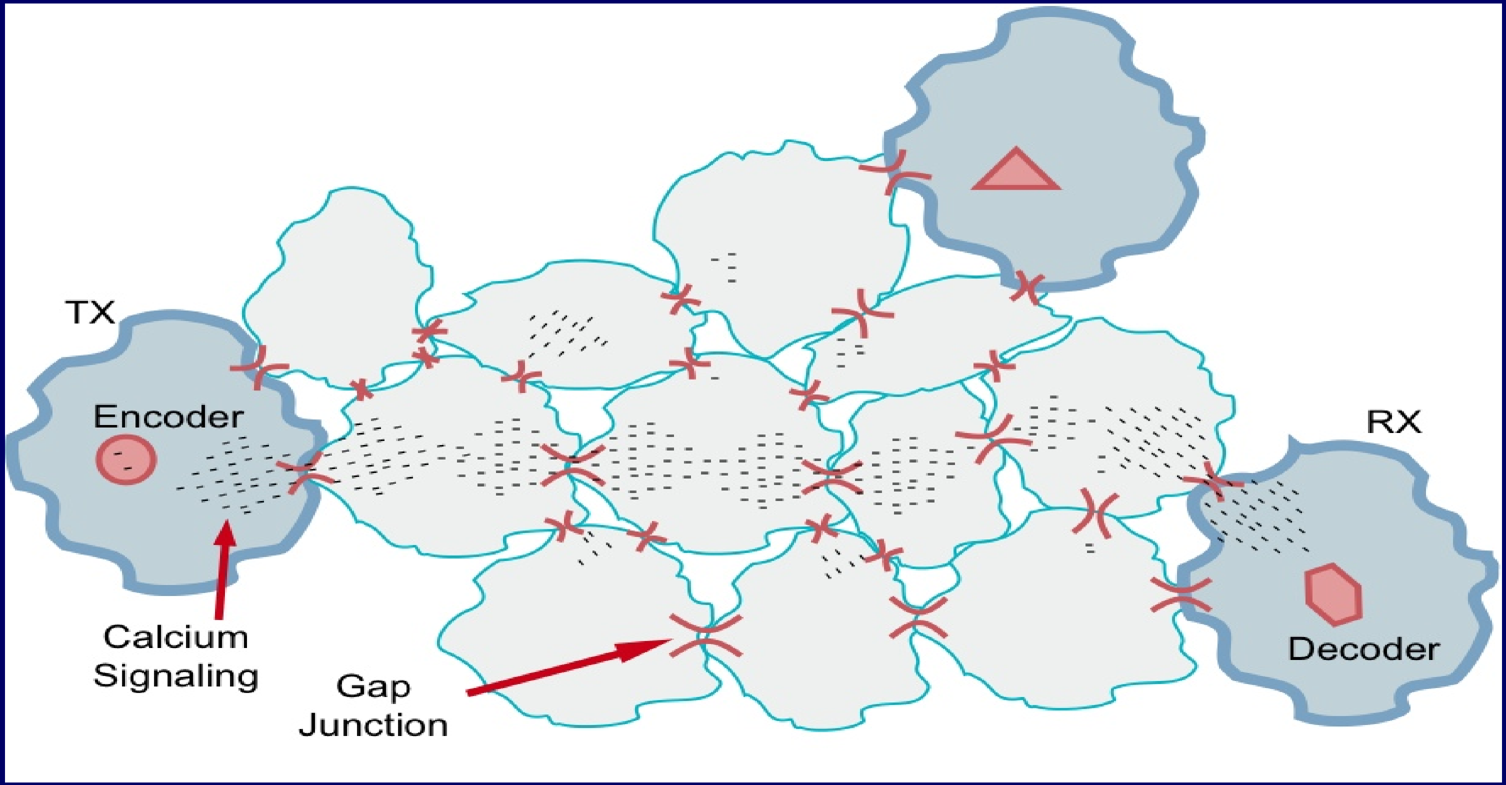
## Direct Access

Exchange of information among cells located next to each other

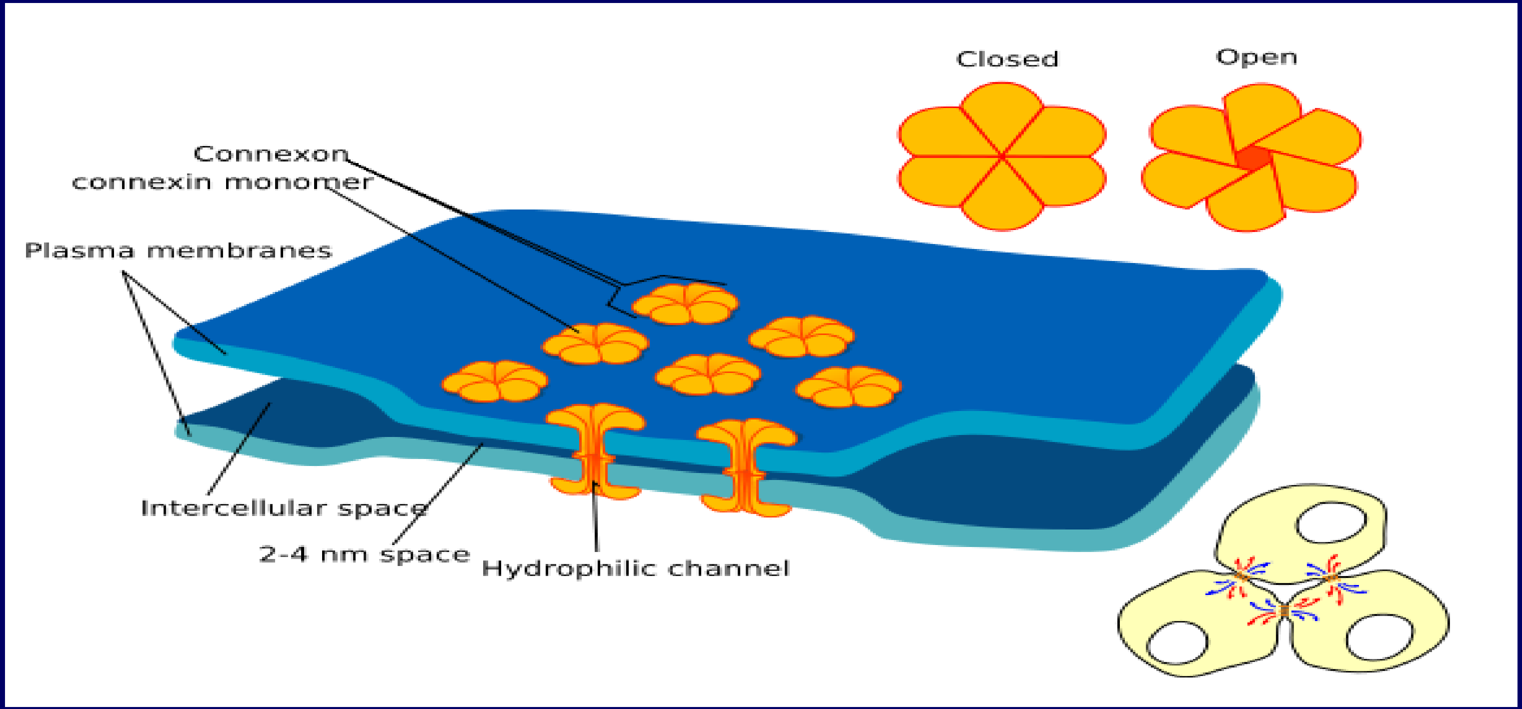
## Indirect Access

Cells deployed separately without any physical contact

# Direct Access: $Ca^{2+}$signal travel through gates

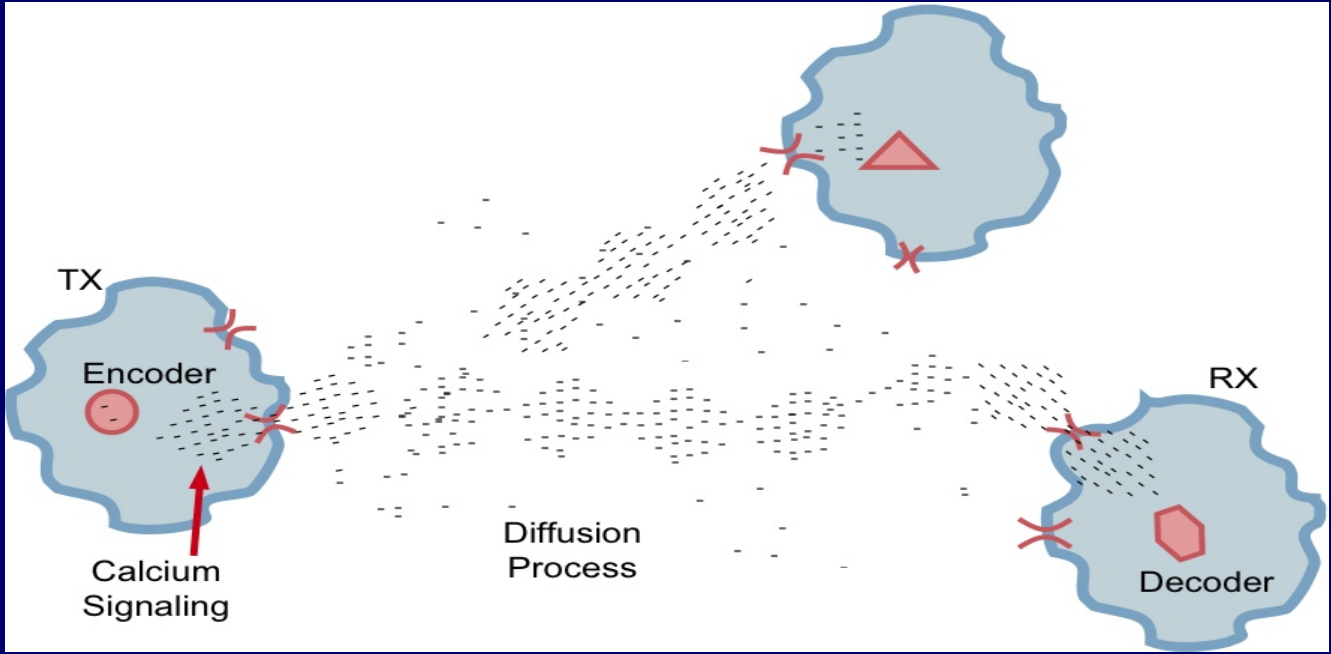


- **Gap Junctions:** Biological gates that allow different molecules and ions to pass freely between cells (membranes).



## – Indirect Access:

- Transmitter nano-machine release information molecules to the the medium.
- Generate a $Ca^{2+}$ at the receiver nano-machine.



# Short-Range Communication using Calcium Signaling

Encoding → Transmission → Signal Propagation → Reception → Decoding

- **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

# Problems of Short Range Molecular Communication

## – Molecular Motors:

- Molecular motors velocity is 500 nm/s
- They detach of 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 !

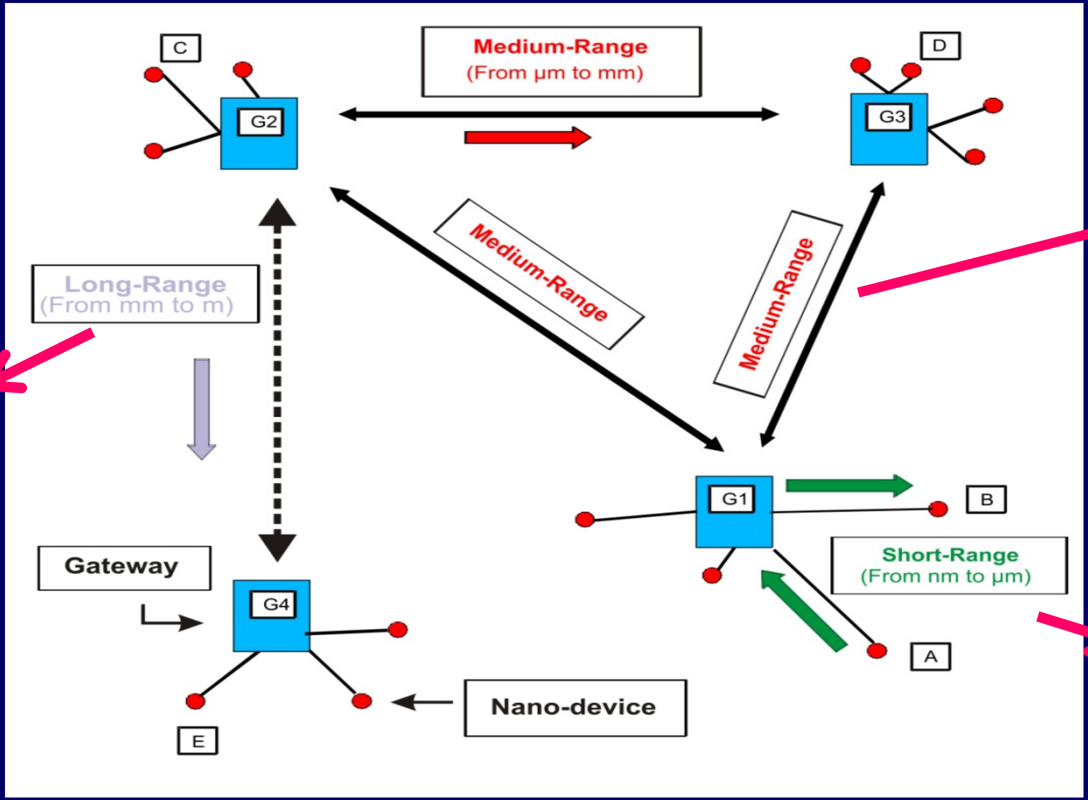
## – Calcium Signaling

- Very high delays for longer (more than few μm) distances

# Medium Range Molecular Communication

M. Gregori and I. F. Akyildiz, "A New NanoNetwork Architecture using Flagellated Bacteria and Catalytic Nanomotors," submitted for journal publication, March 200

- Pheromones
- Pheromones
- Light transduction
- Pollen & Spores
- Axons & capillaries



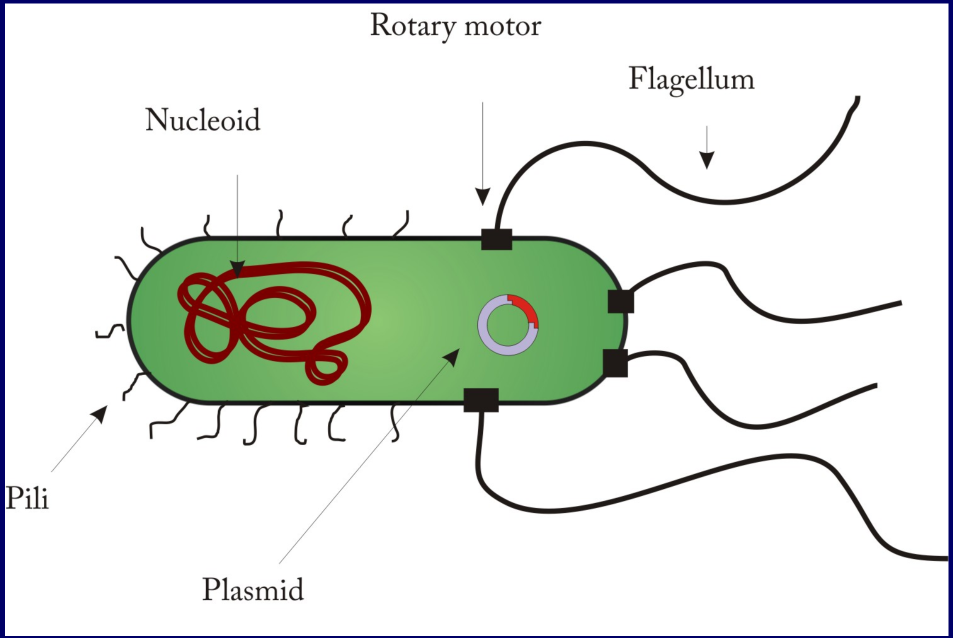

- Flagellated bacteria
- Catalytic nanomotors

Ion Signaling

Molecular Motors

# Medium Range Molecular Communication: Flagellated Bacteria

- *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**

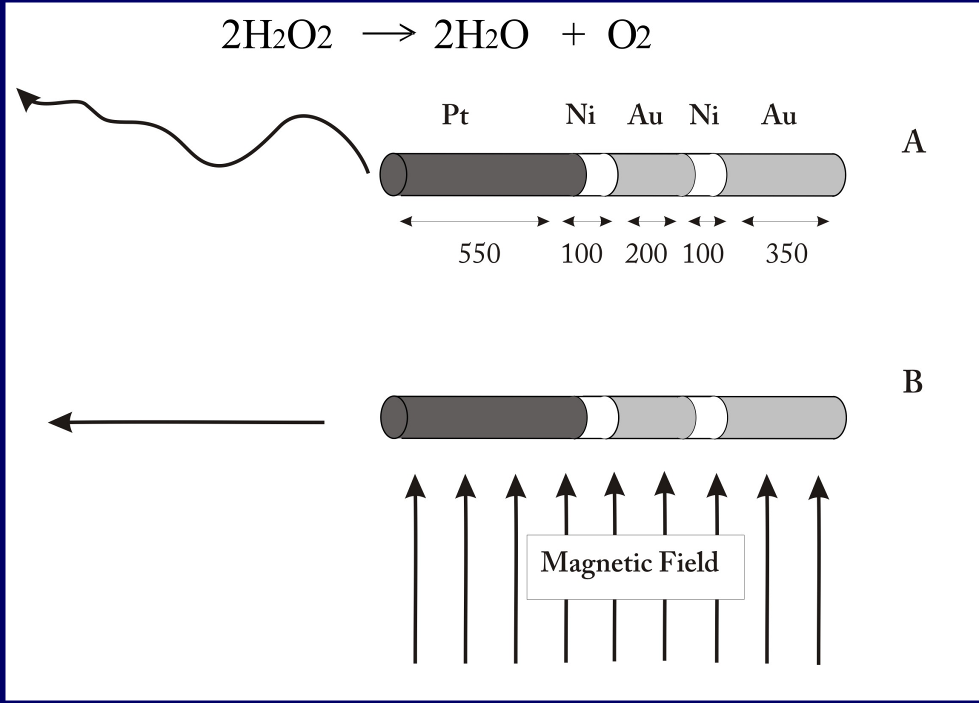
DNA packet is introduced inside the bacteria's cytoplasm, using:
- *Plasmids*
- *Bacteriophages*
- *Bacterial Artificial Chromosomes* (BACs)

- 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

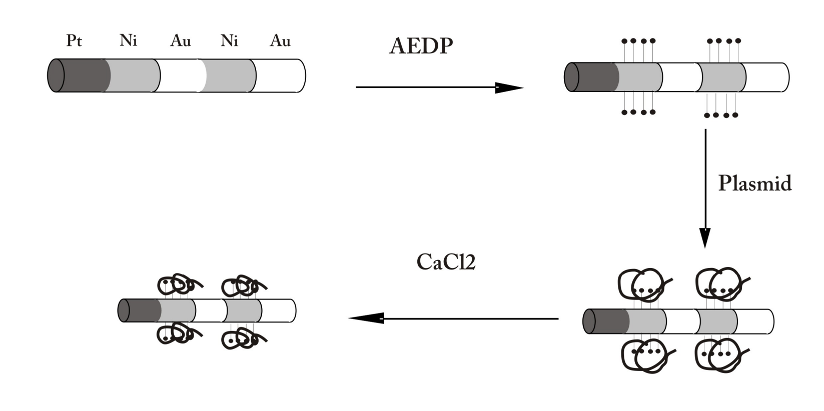
# Medium-Range Communication using Catalytic Nanomotors

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

Encoding → Transmission → Propagation → Reception → Decoding

- Nanorods are introduced in a solution of AEDP
- AEDP binds with the Nickel segments
- DNA packets (plasmids) are attached to nanorods
- $CaCl_2$ solution is used in order to compress and immobilize the plasmid

- Magnetic Fields guide the nanorod to the receiver




DNA packet is extracted from the plasmid using:

- *Restriction endonucleases enzymes*

# Long-Range Communication using Pheromones

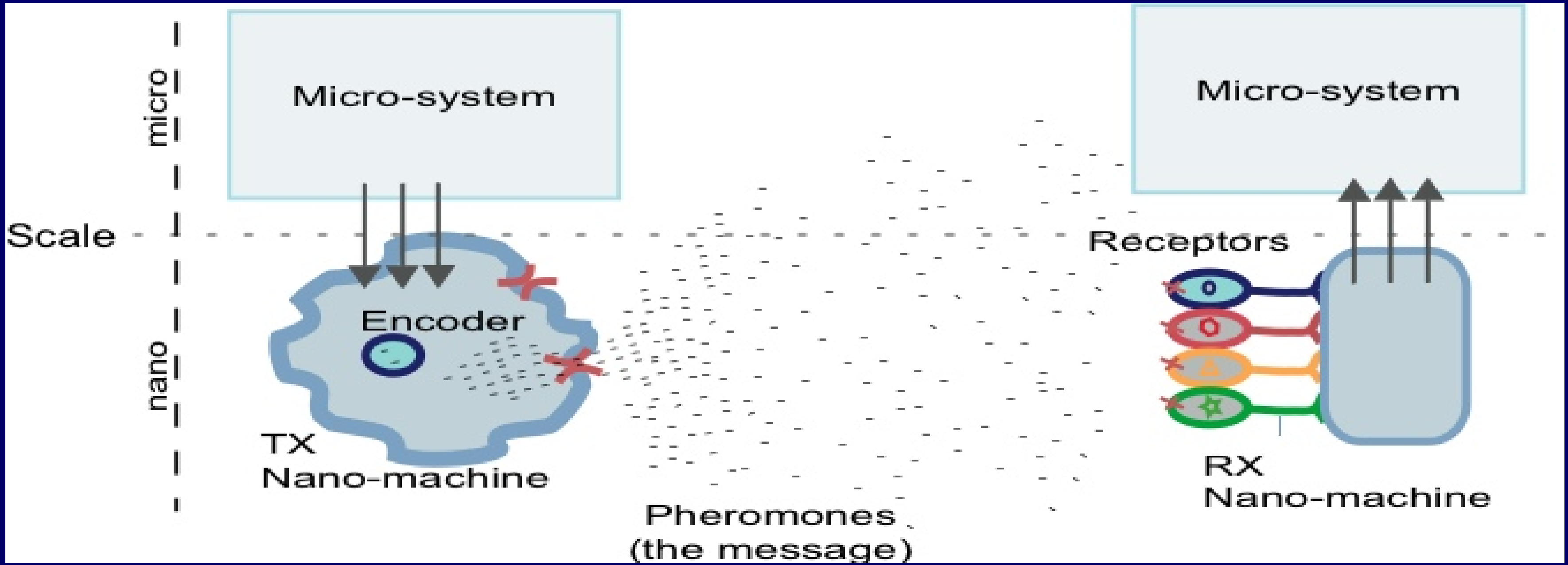
L. Parcerisa and I.F. Akyildiz, "Molecular Communication Options for Long Range Nanonetworks", submitted for publication, May 2009.

**Features:**

- **Communication Range** → mm - m
- **Medium** → Wet and dry
- **Carrier** →
  - Pheromones
  - Light Transduction
  - Pollen & Spores
  - Axons & Capillaries

# Long-Range Communication using Pheromones

## Communication Features:

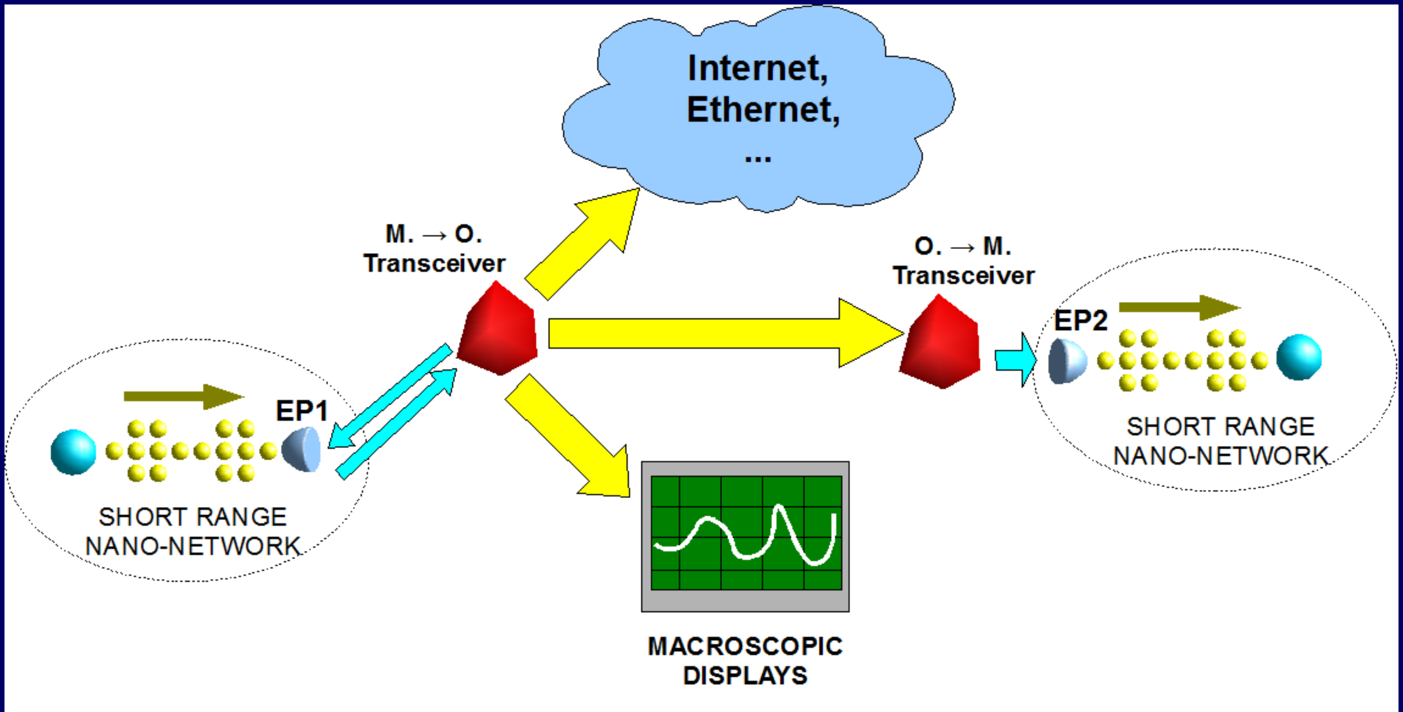



# Long-Range Communication using Pheromones

| Encoding | Transmission | Signal Propagation | Reception | Decoding |
| --- | --- | --- | --- | --- |
| Selection of the specific pheromones to transmit the information and produce the reaction at the intended receiver | Releasing the pheromones through liquids or gases | Pheremones are diffused into the medium | Pheremones bind to the Receptor | Interpretation of the information (Different pheremones trigger different reactions) |

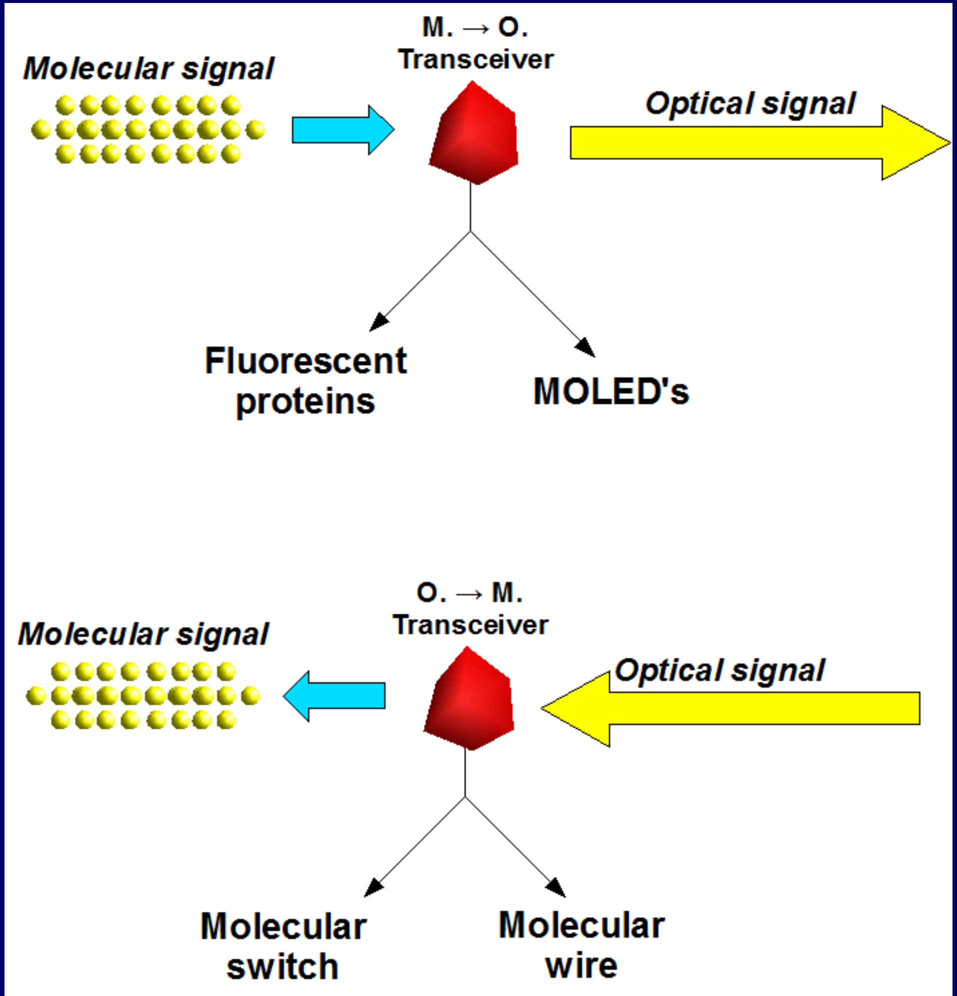
# Long Range Molecular Communication: Light Transduction

→ 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



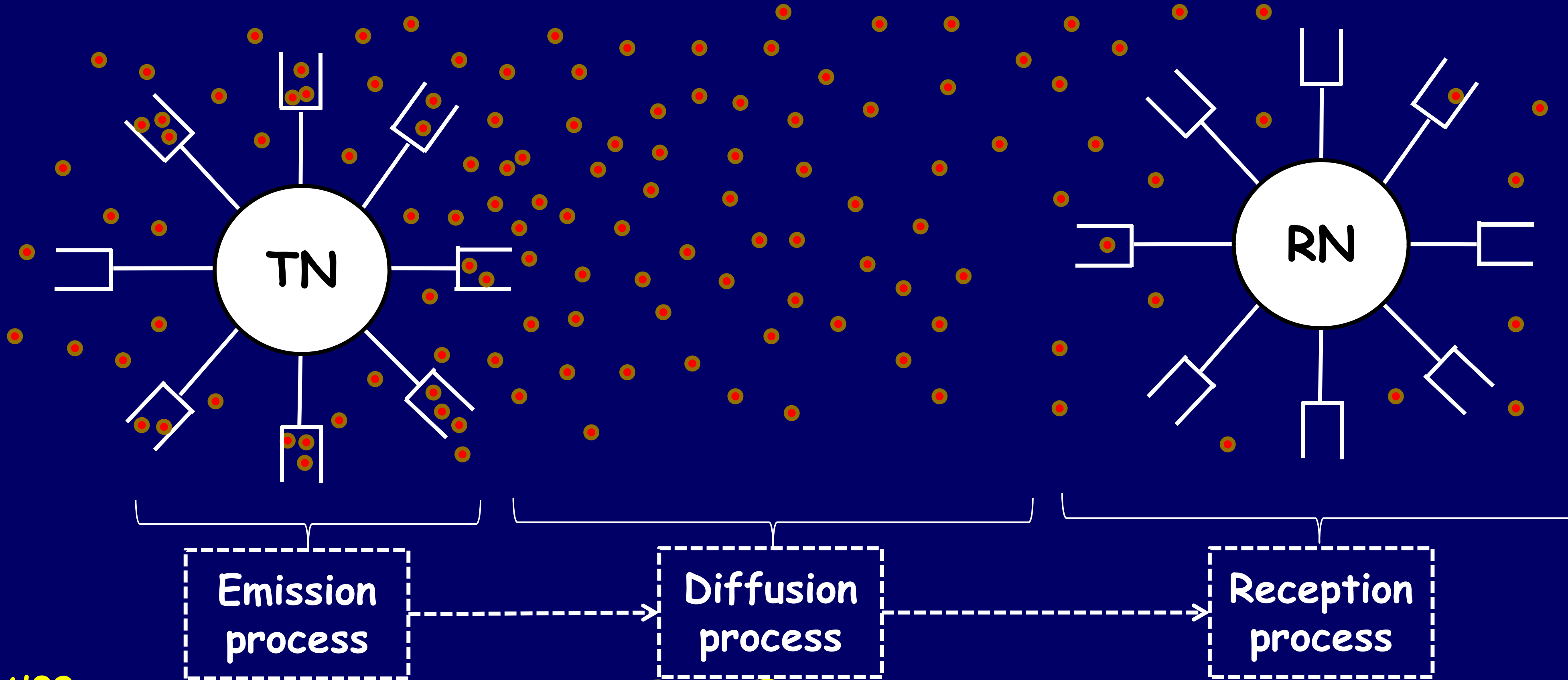
# Research Challenges in Nano-Sensor Networks

- Development of nano-machines (sensors), testbeds and simulation tools
- Information Theoretical Approach
- Architectures and Communication Protocols

# MOLECULE DIFFUSION COMMUNICATION MODEL

M. Pierobon, and I. F. Akyildiz, ``A Physical Communication Model for Molecular Communication in Nanonetworks," *submitted for journal publication*, March 2009.

- **Molecule Diffusion Communication:** Exchange of information encoded in the concentration variations of molecules.



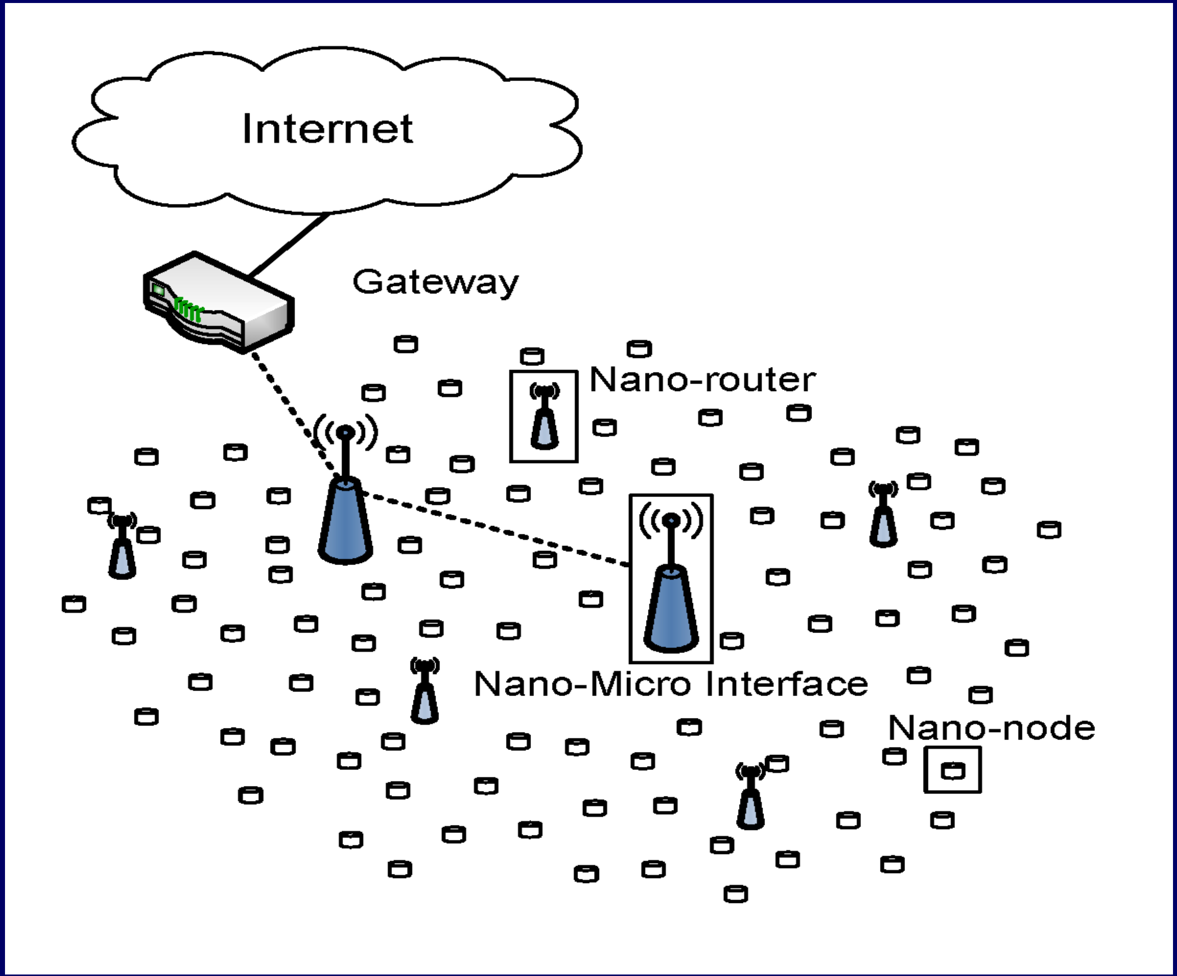
M. Pierobon, and I. F. Akyildiz, ``A Physical Communication Model for Molecular Communication in Nanonetworks,'' *submitted for journal publication*, March 2009.

# 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)



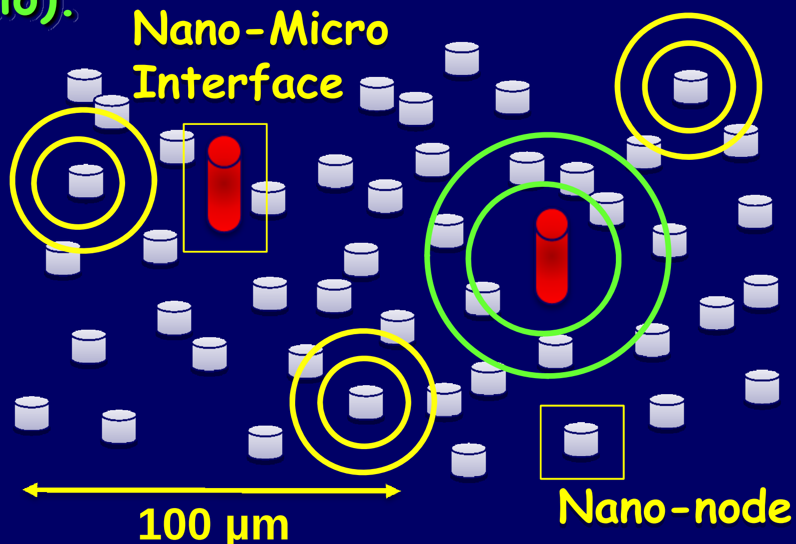
# Nano-Electromagnetic Communications

J.M. Jornet and I.F. Akyildiz, "A nano-patch antenna for electromagnetic nanocommunications in the terahertz band", submitted for publication, May 2009.

J.M. Jornet and I.F. Akyildiz, "A physical channel model for electromagnetic nanocommunications in the terahertz band", in preparation.

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).



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- 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.