NANO-COMMUNICATIONS: AN OVERVIEW

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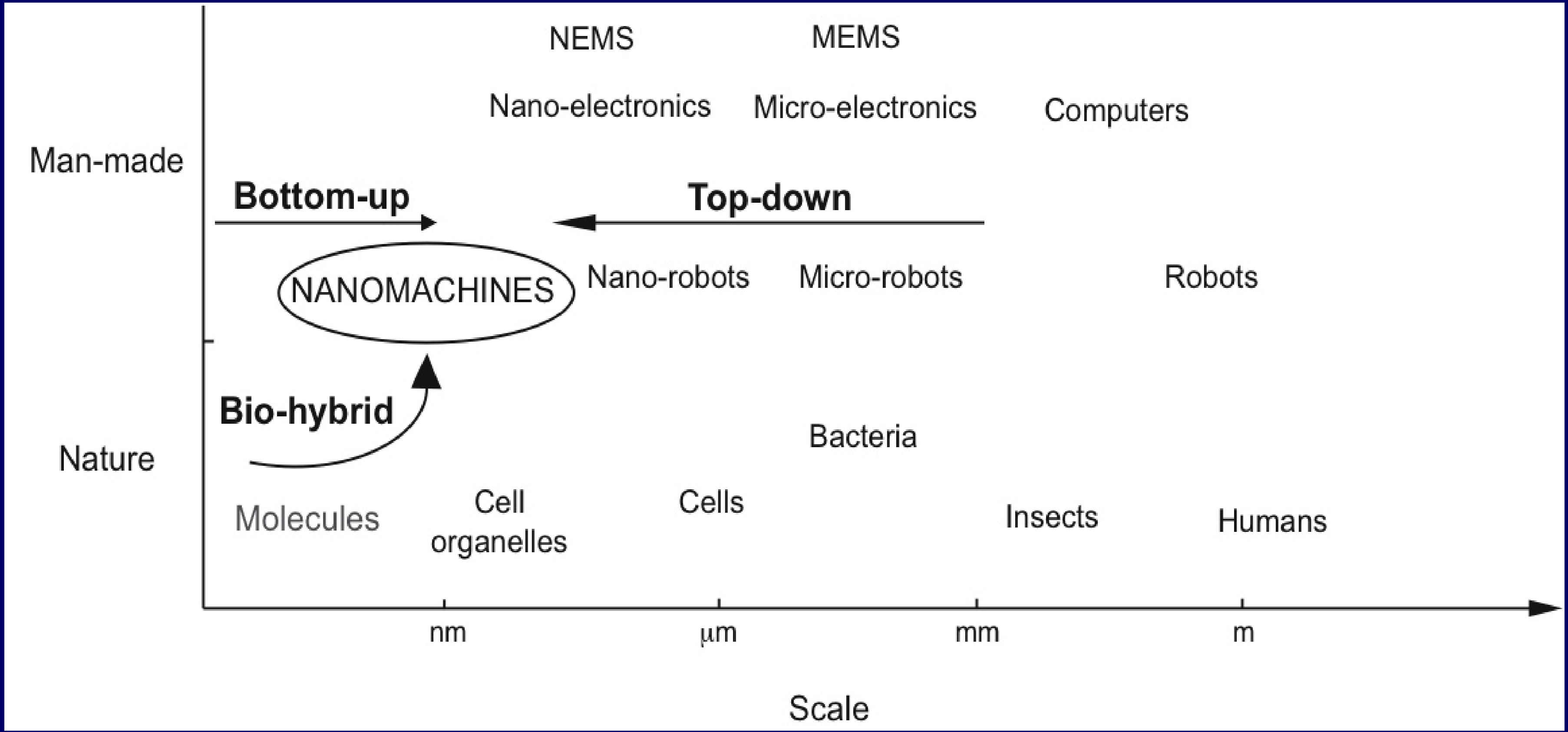
REFERENCES

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

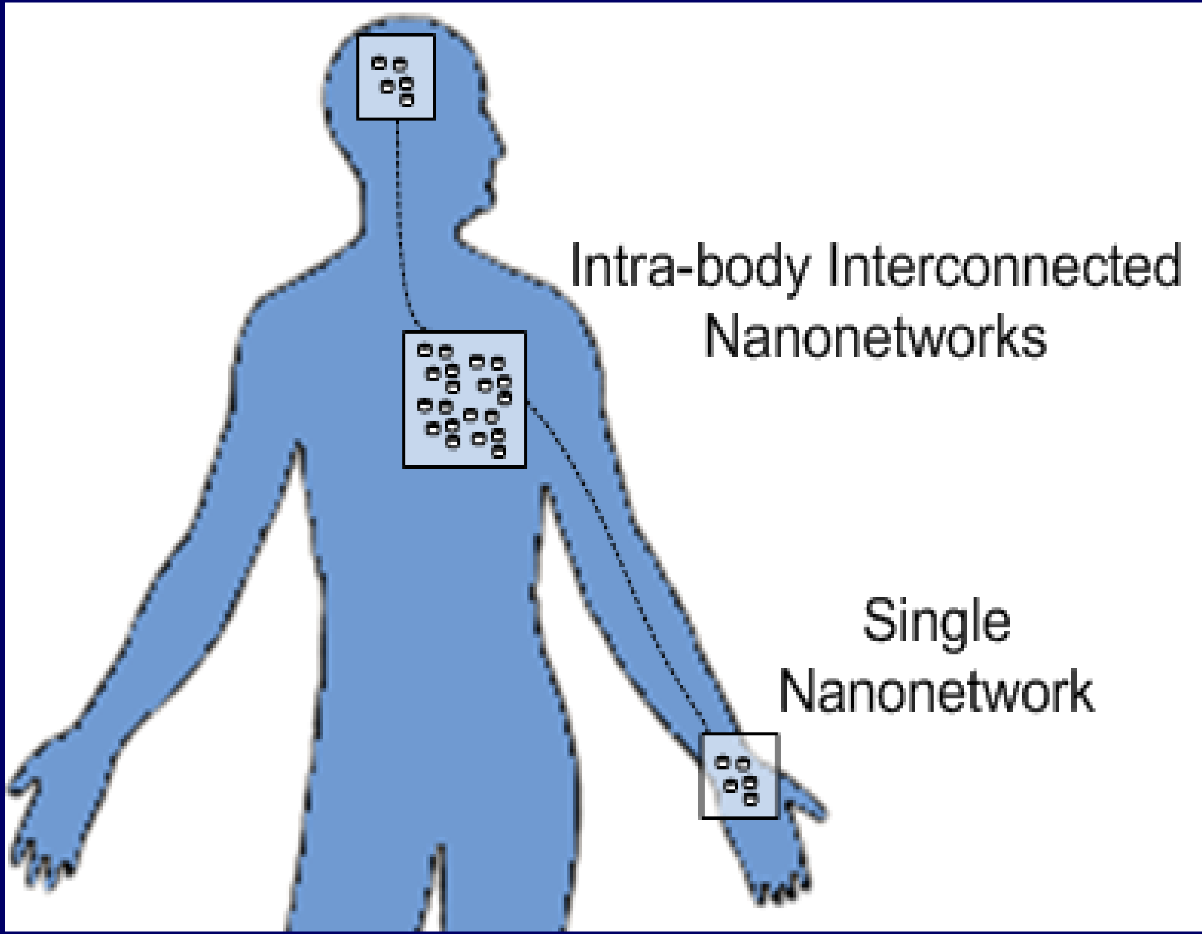
- Electromagnetic Waves
- Acoustic Communication
- Nano-mechanical Communication
- Molecular Communication

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



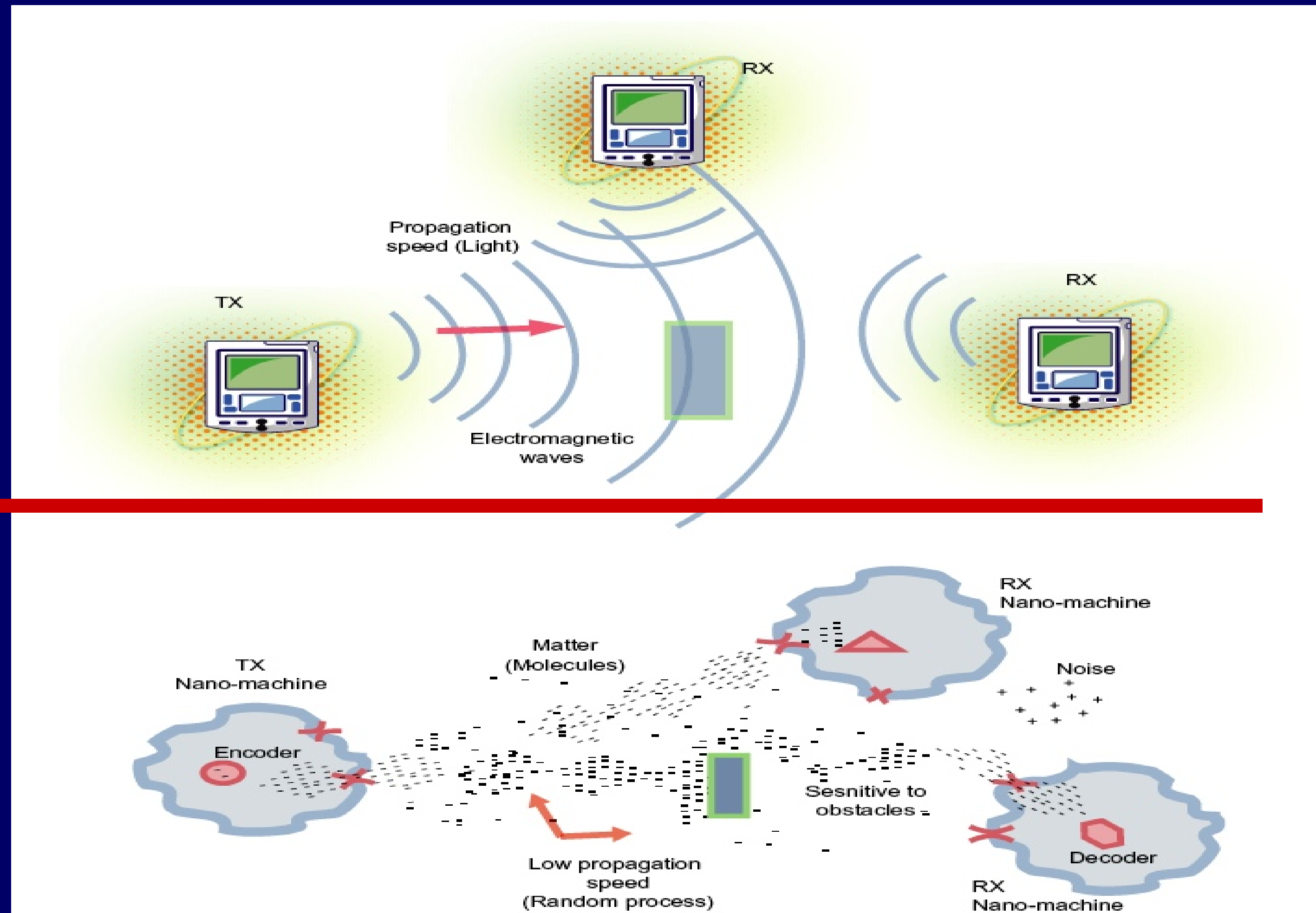
Nanonetworks vs Traditional Communication Networks

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 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

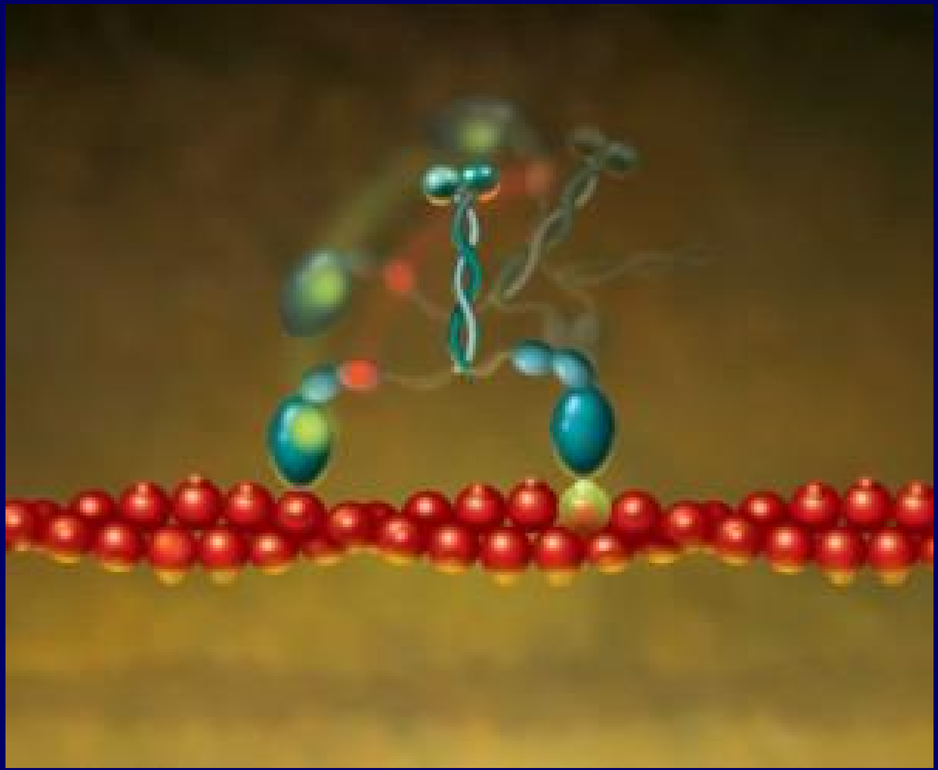
Features:

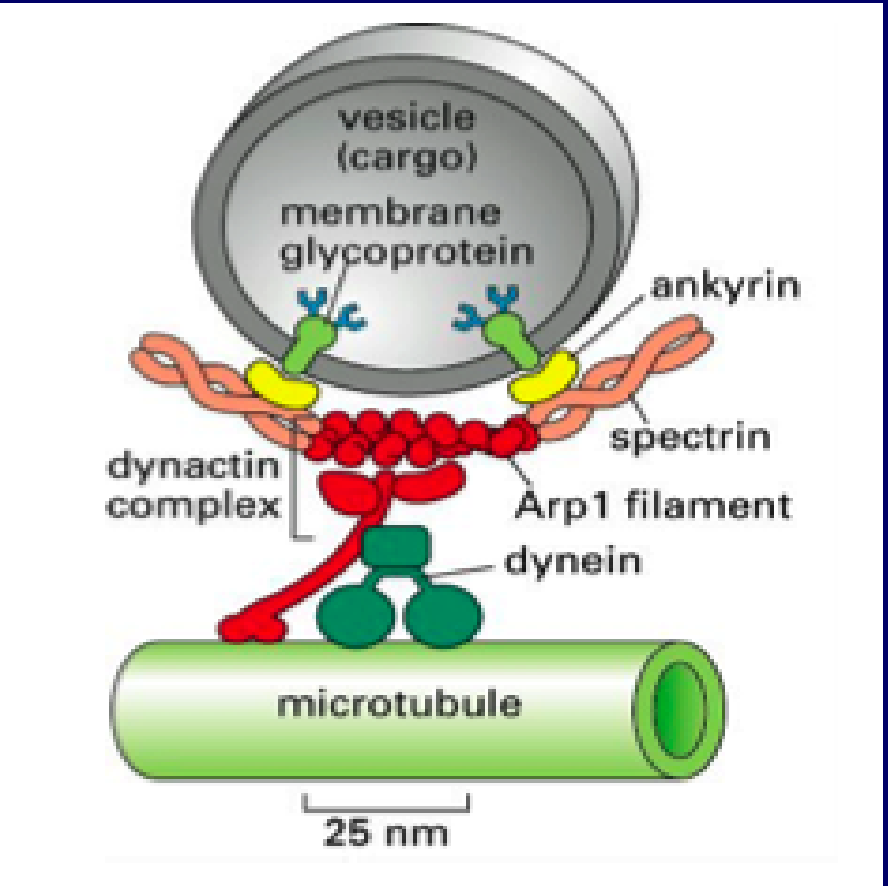
Communication Range	nm - mm
Medium	Aqueous environment with necessary molecules at biologically appropriate conditions
Carrier	Molecular Motors

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

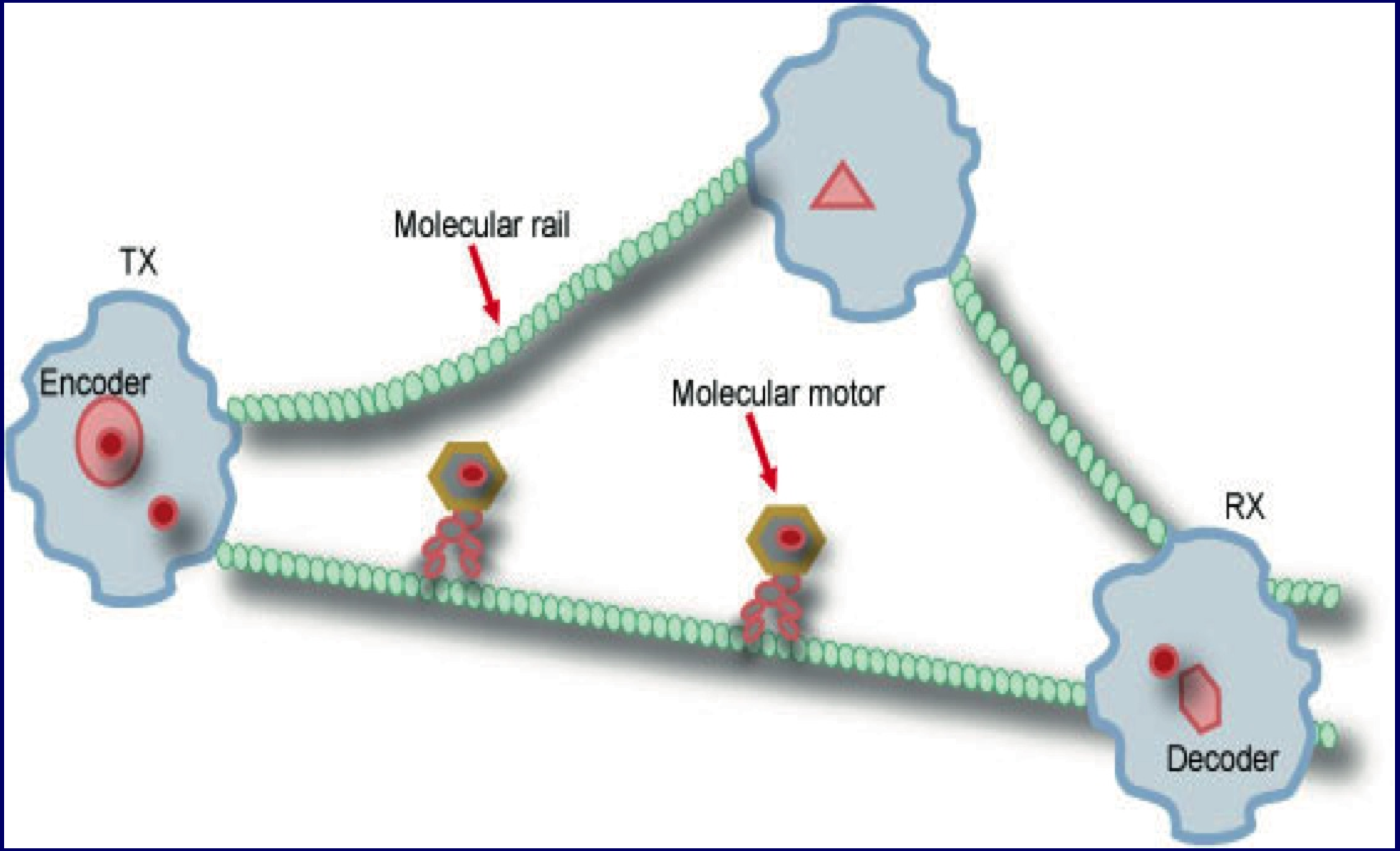




Molecular Motors:

* 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

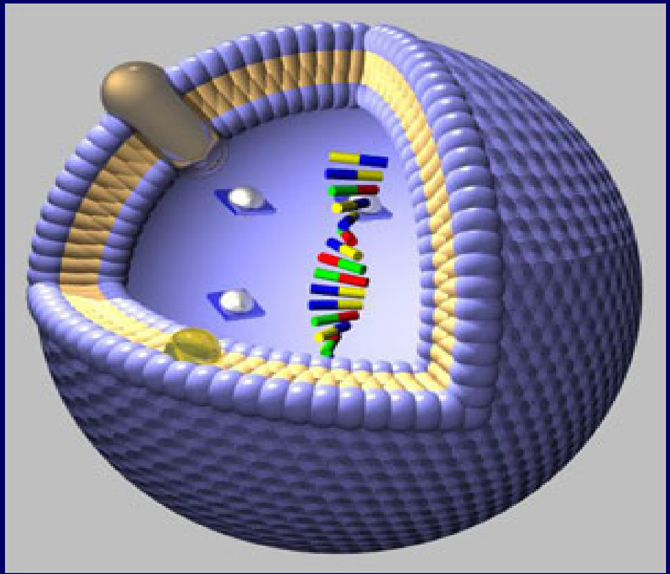
Short-Range Communication using Molecular Motors



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
Select the right molecules that represent information	Attach the information packet to the molecular motor	Microtubules (molecular rails) restrict the movement to themselves	Information molecules are detached from molecular motors	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

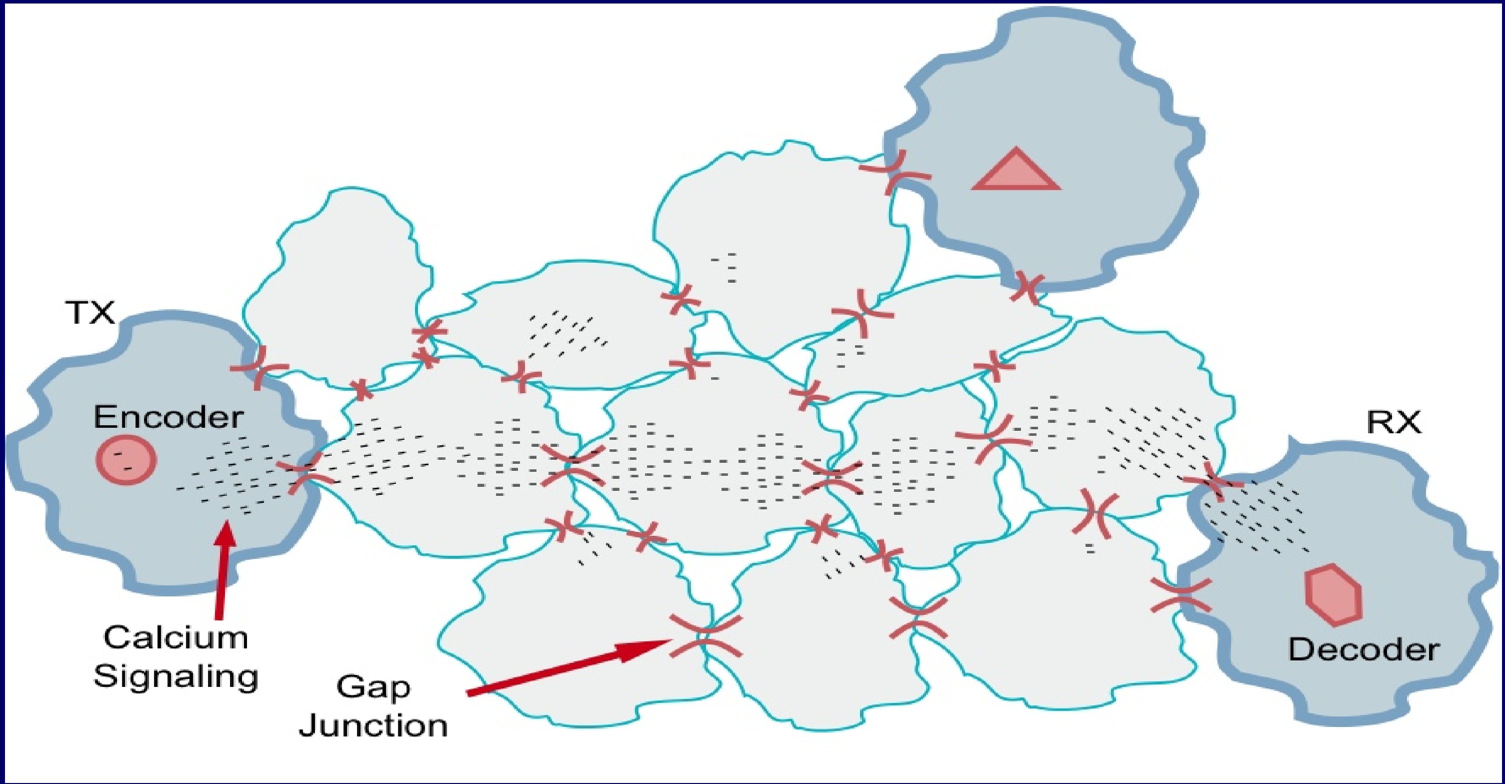
Direct Access

Exchange of information among cells located next to each other

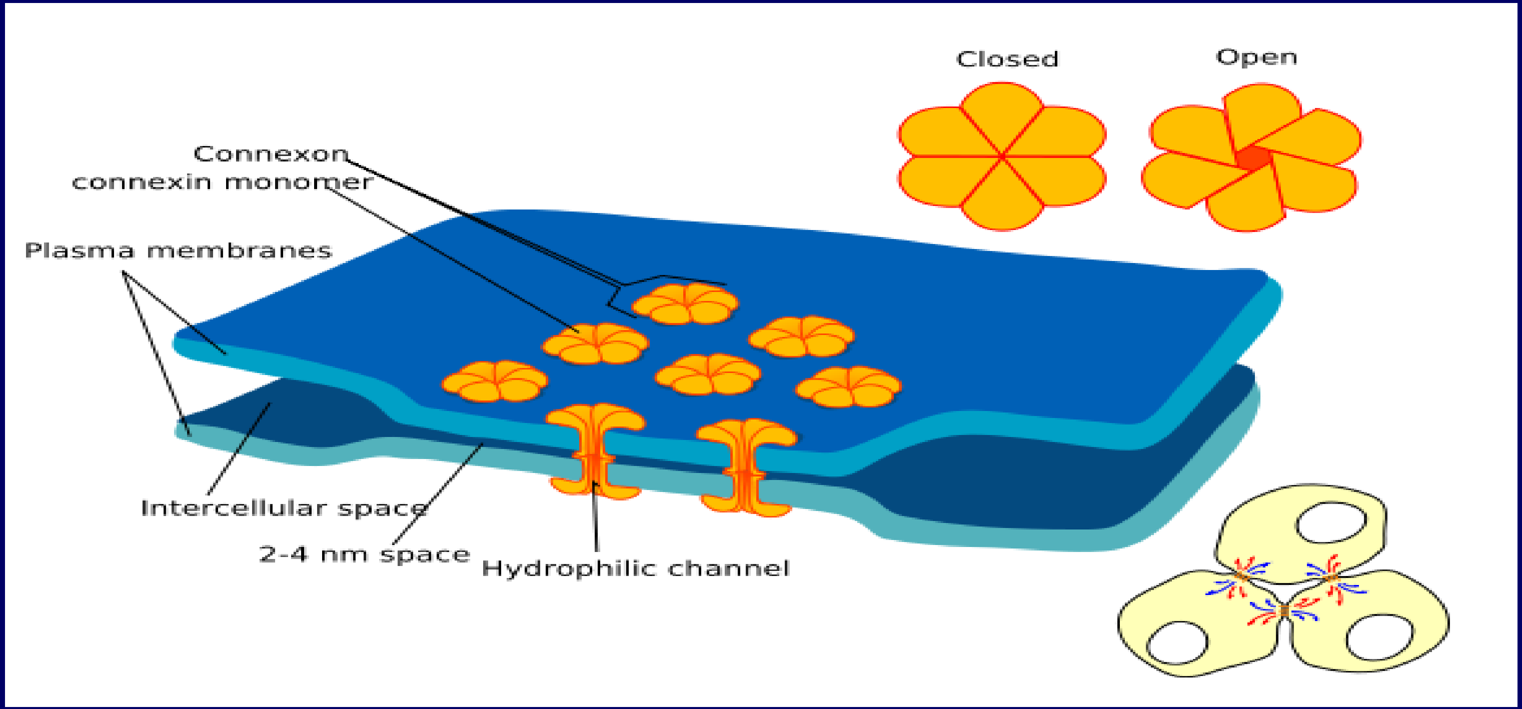
Indirect Access

Cells deployed separately without any physical contact

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

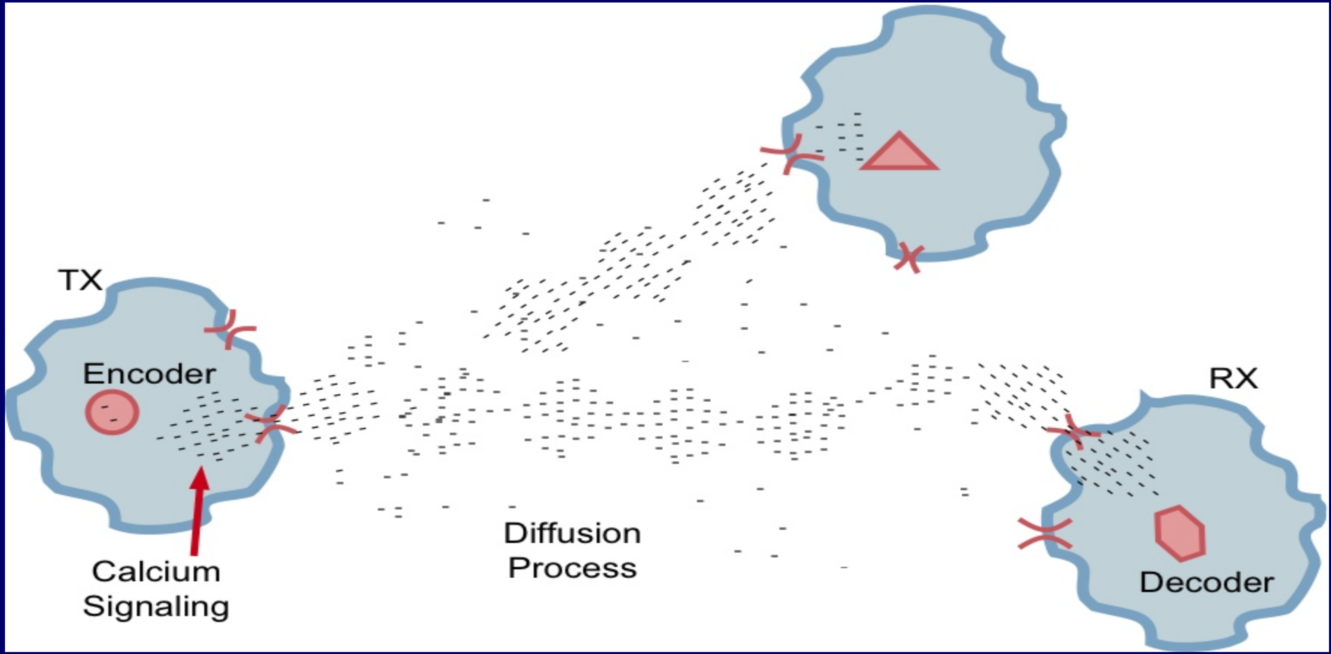


- **Gap Junctions:** Biological gates that allow different molecules and ions to pass freely between cells (membranes).



- 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 Propagatio n → 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

– 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

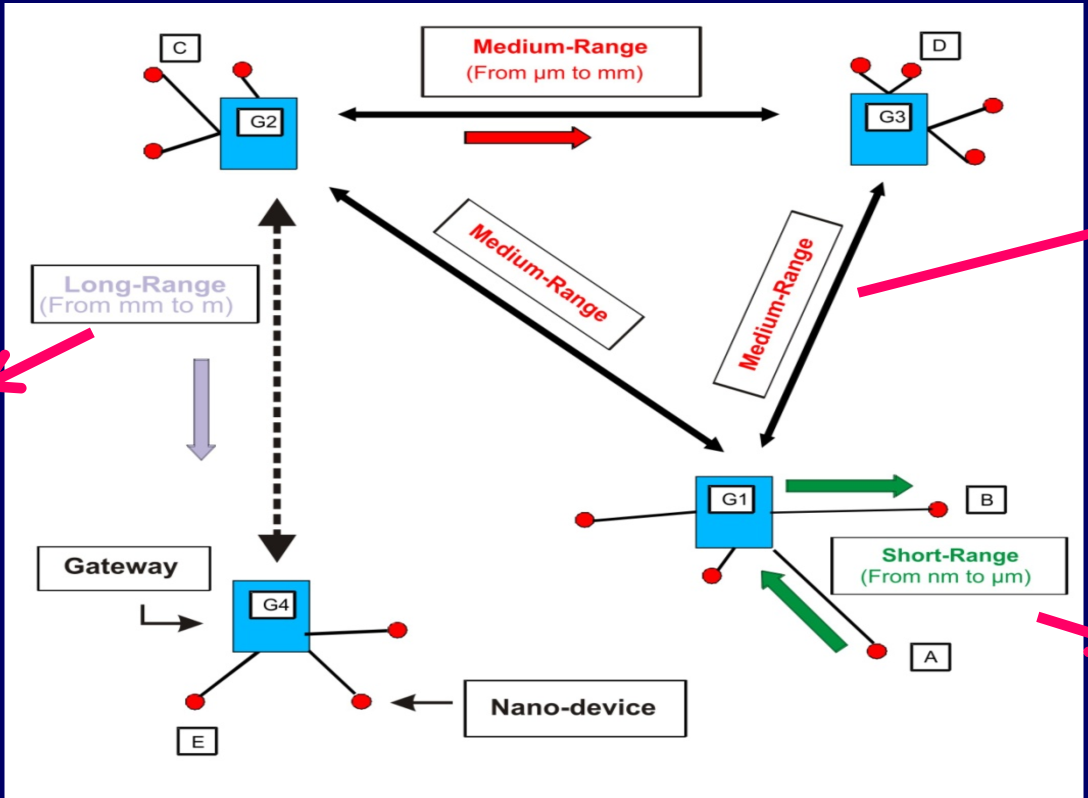
→ very long communication delays !

- 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



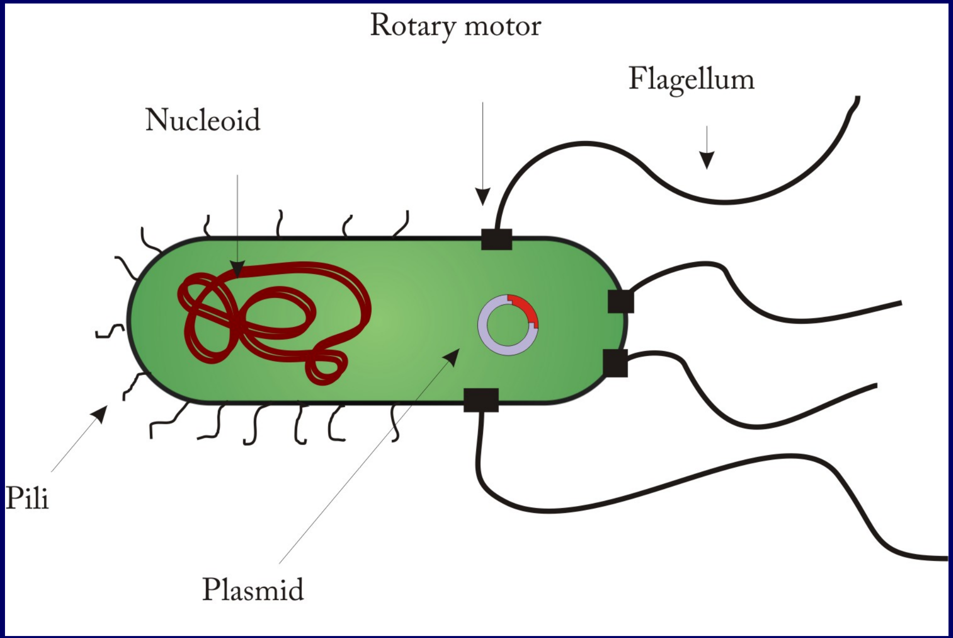
- Flagellated bacteria
- Catalytic nanomotors

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

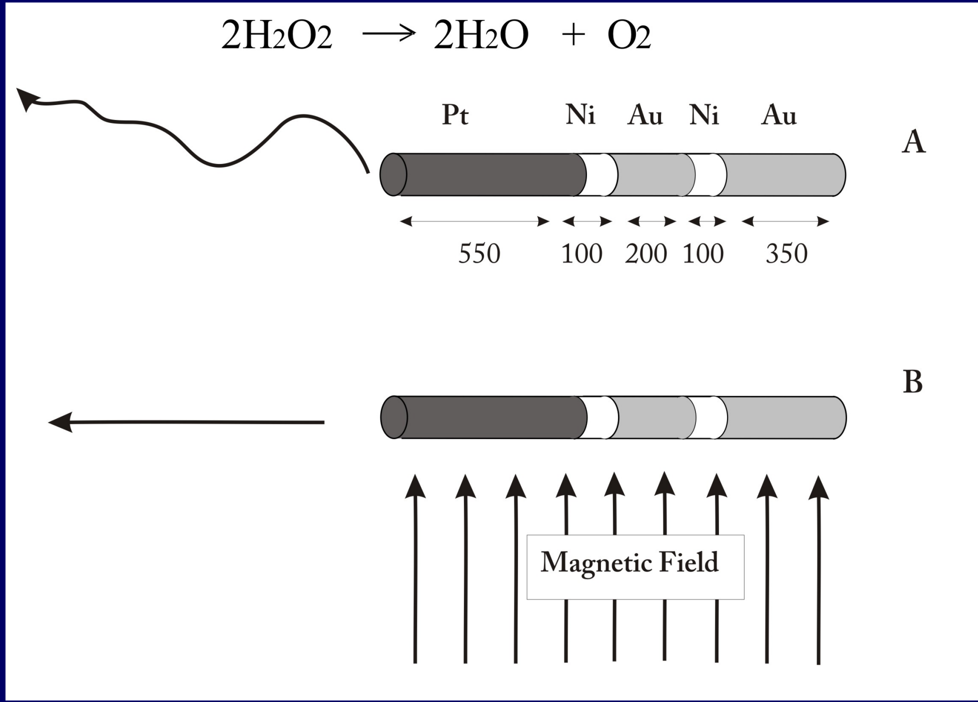
DNA packet is introduced inside the bacteria's cytoplasm, using:
- *Plasmids*
- *Bacteriophages*
- *Bacterial Artificial Chromosomes* (BACs)

- 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.

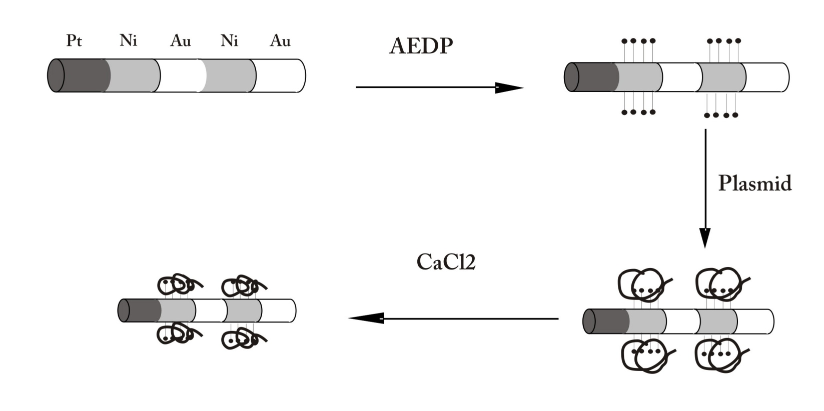
Encoding → Transmission → Propagation → Reception → Decoding

- 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*



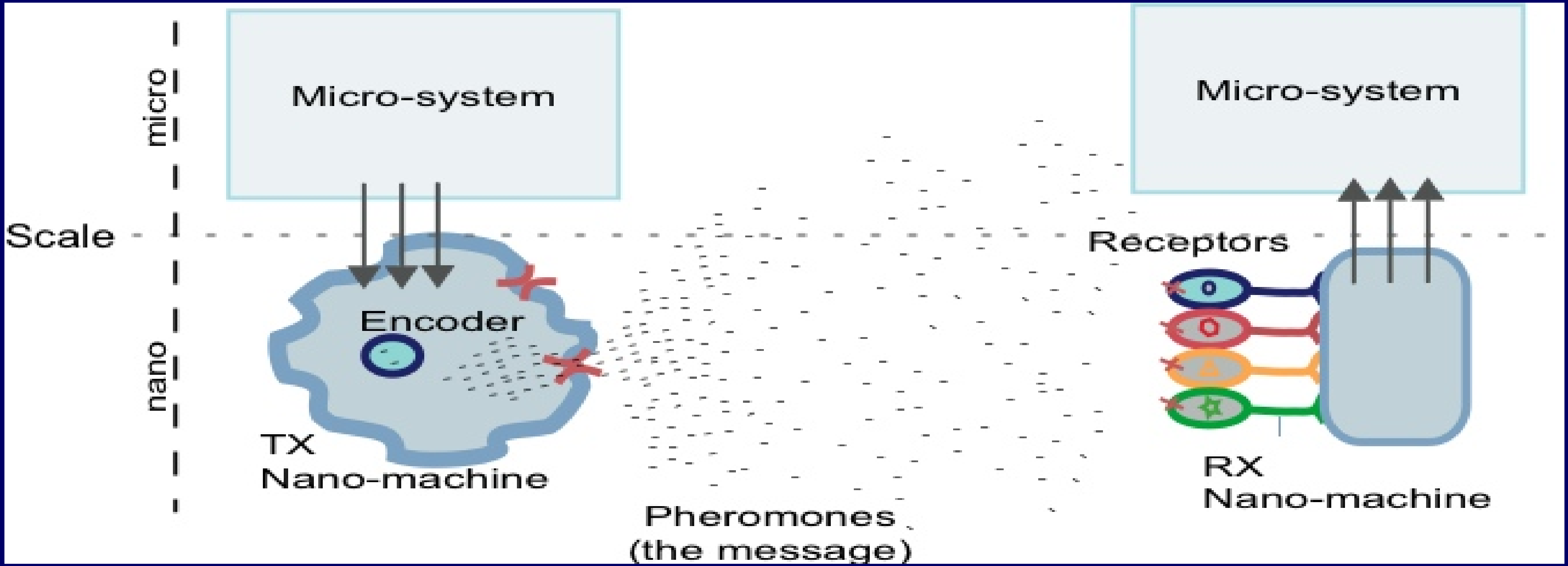
Long-Range Communication using Pheromones

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

Communication Features:



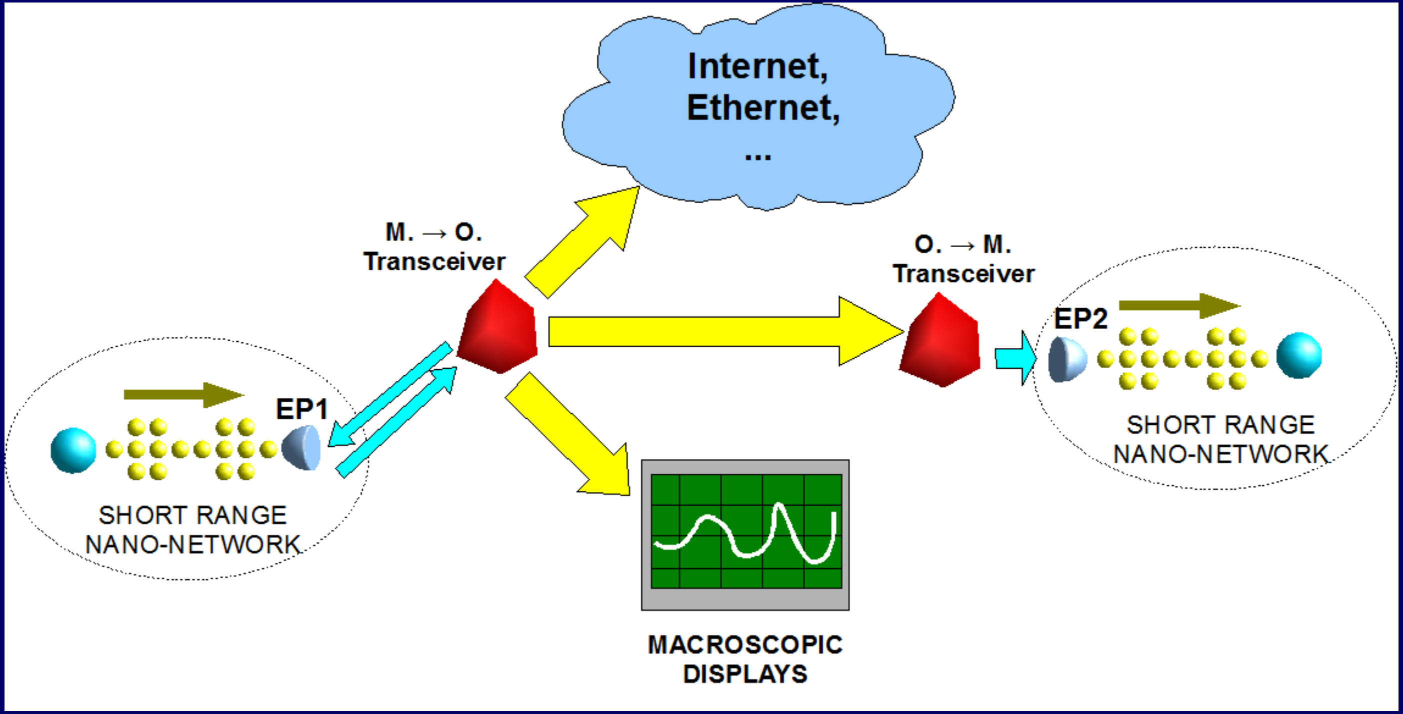
Long-Range Communication using Pheromones

Encoding → **Transmission** → **Signal Propagation** → **Reception** → **Decoding**

- **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**: Pheremones are diffused into the medium
- **Reception**: Pheremones bind to the Receptor
- **Decoding**: Interpretation of the information (Different pheremones trigger different reactions)

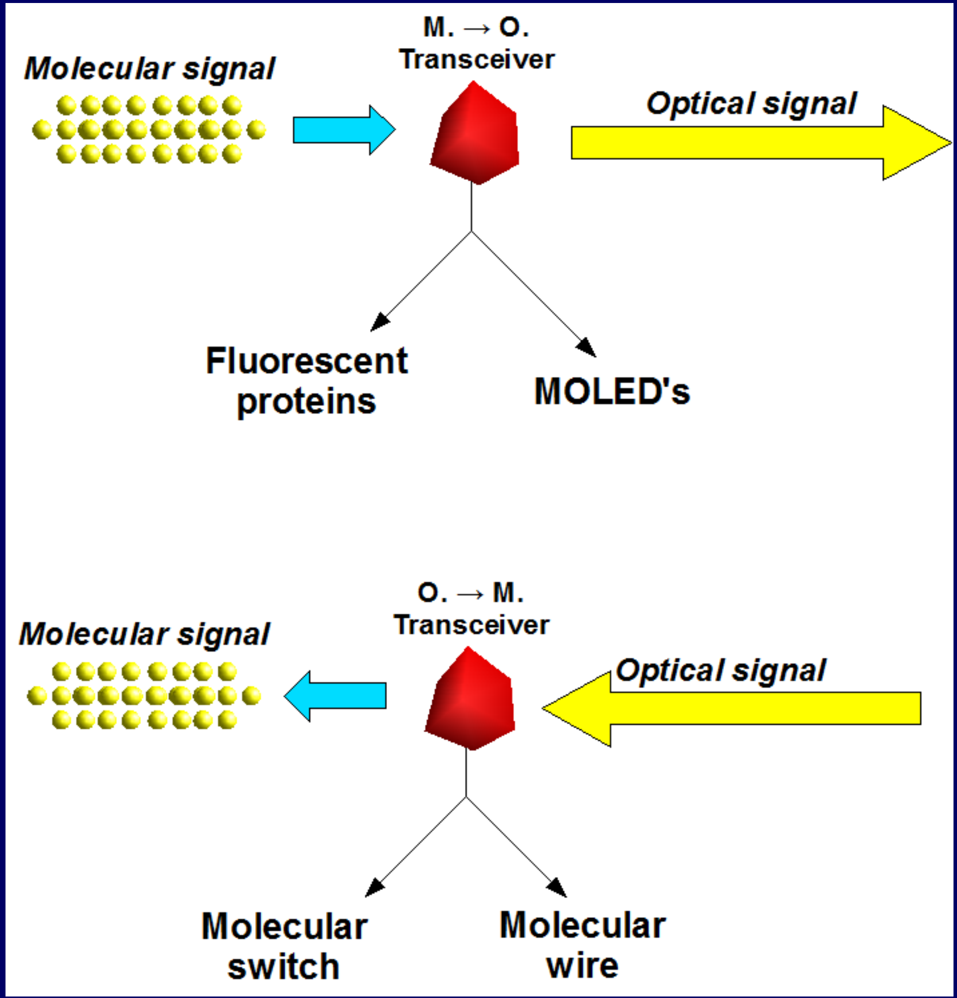
Long Range Molecular Communication: Light Transduction

→ 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

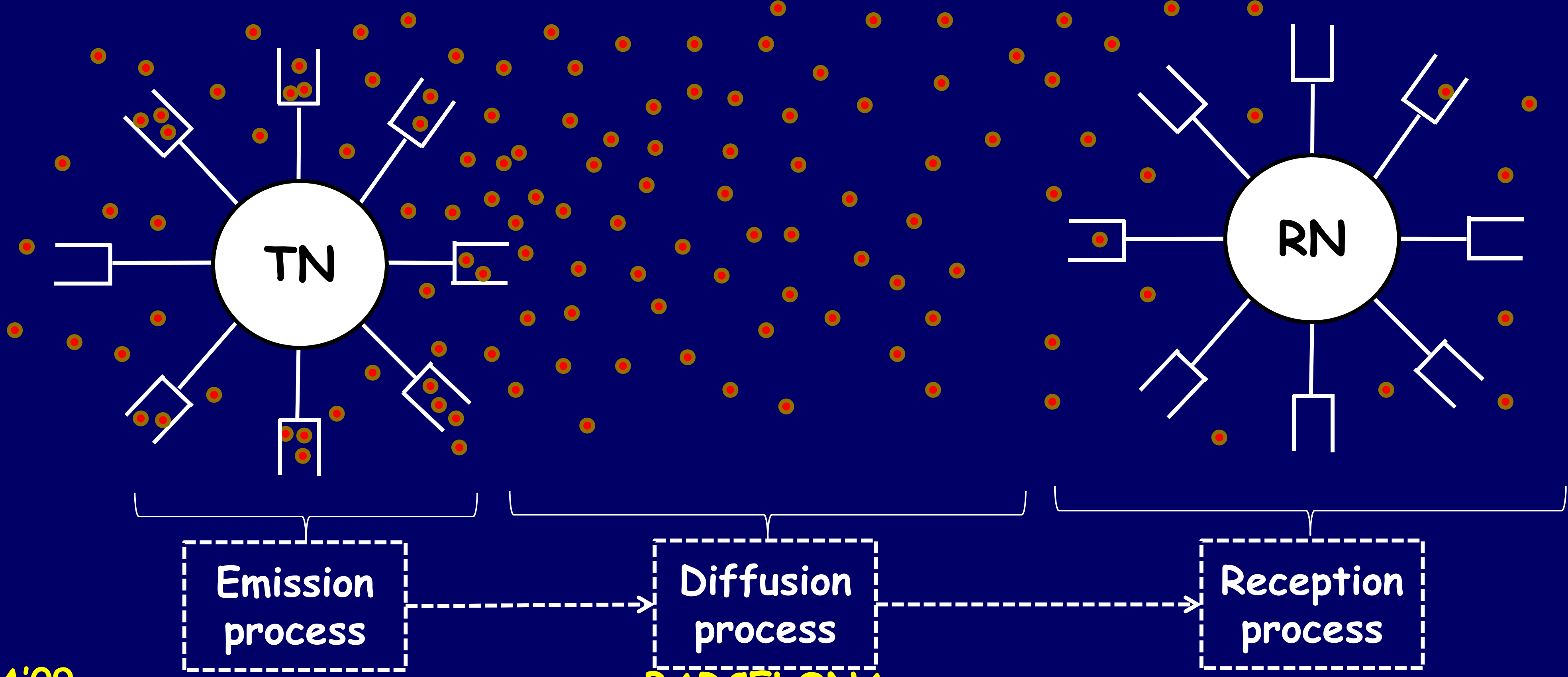
Information Theoretical Approach

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.



OBJECTIVE OF THE PHYSICAL COMMUNICATION MODEL

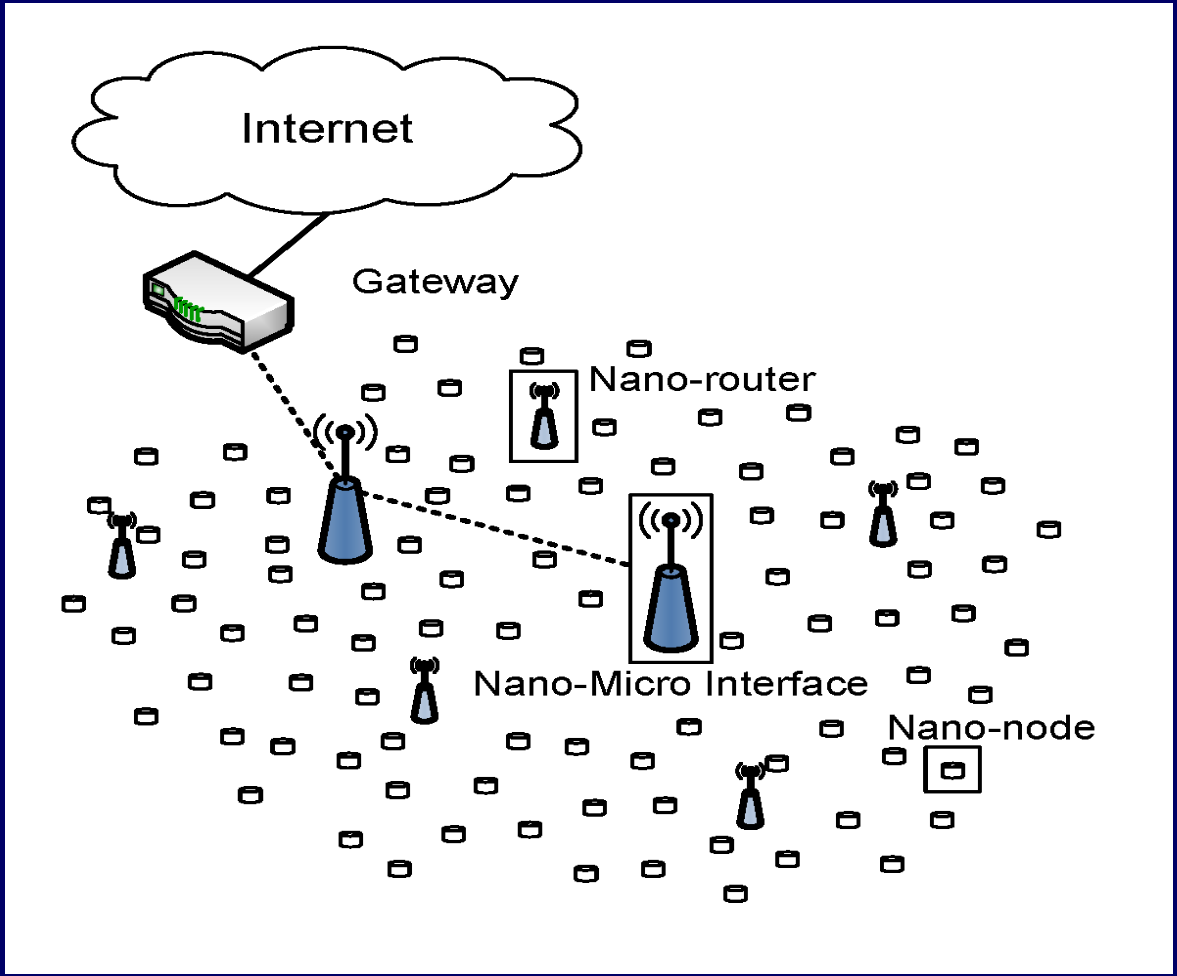
M. Pierobon, and I. F. Akyildiz, ``A Physical Communication Model for Molecular Communication in Nanonetworks,'' *submitted for journal publication*, March 2009.

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)



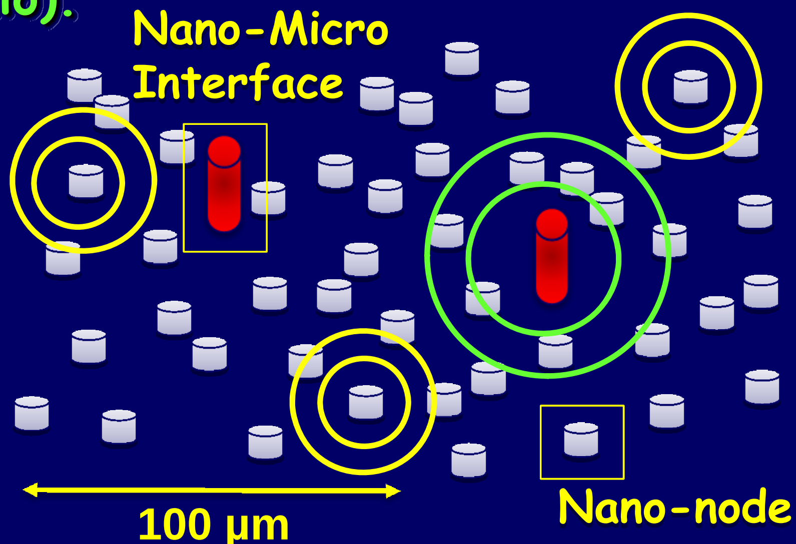
Nano-Electromagnetic Communications

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.