MOLECULAR COMMUNICATION OPTIONS FOR LONG RANGE NANONETWORKS

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Advisor: Ian F. Akyildiz

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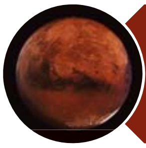
ABOUT THIS PRESENTATION…

1-Why?
Research reasons



2-How?
Looking for possibilities

3-Then…
Evaluation, future work, conclusion

2

1.- WHY?

1.1
- Nanotechnology
  - *Motivation, Overview*

1.2
- Nanocommunication
  - *Nano-machines, Approaches*

1.3
- Long Range NanoCom
  - *Advantages, Applications*

Molecular Communication Options for Long Range Nanonetworks

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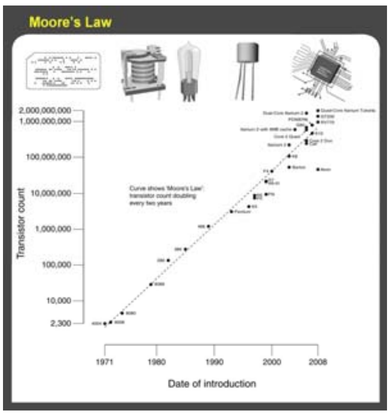
LIMITATIONS ON SILICON TECHNOLOGY



- Current evolution based on downscaling silicon transistor dimensions is not feasible.
- Additionally, the power consumption of tiny semiconductor devices is a major problem.

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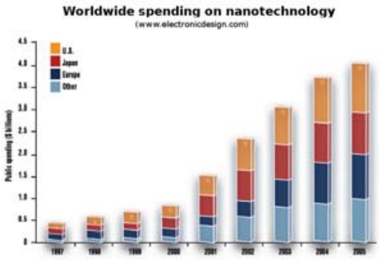
SOLUTION: NANOTECHNOLOGY



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NANOMACHINES AND NANONETWORKS

- **NanoMachine:** Nano-scale device able to perform *very specific tasks*, such as communicating, computing, data storing, sensing and/or actuation.
- **NanoNetworks:**
  - The interconnection of different nano-machines providing them a way to cooperate and share information.
  - NanoNetworks will expand the capabilities of single nano-machines.

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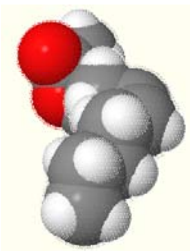
NANOCOMMUNICATION - APPROACHES

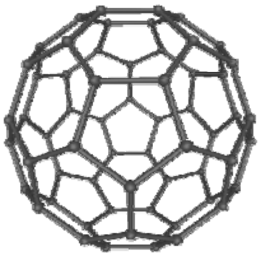
Molecular Comm

- Use biological elements as blocks or design patterns (enc. molecules)



Quantum Comm

- Use semiconductor materials at atomic scale (EM fields)



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NanoCommunication – Approach ADV

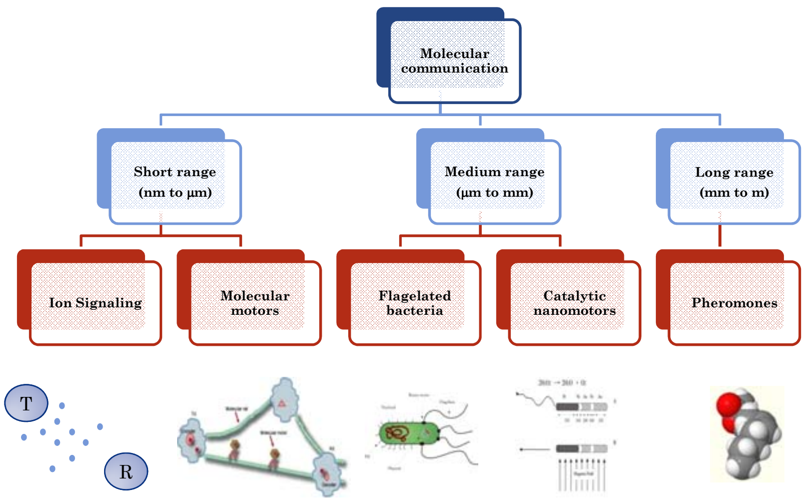
Molecular Comm

- Very efficient power consumption
- Bio-compatibility
- Already existing elements
- New approach in ICT field

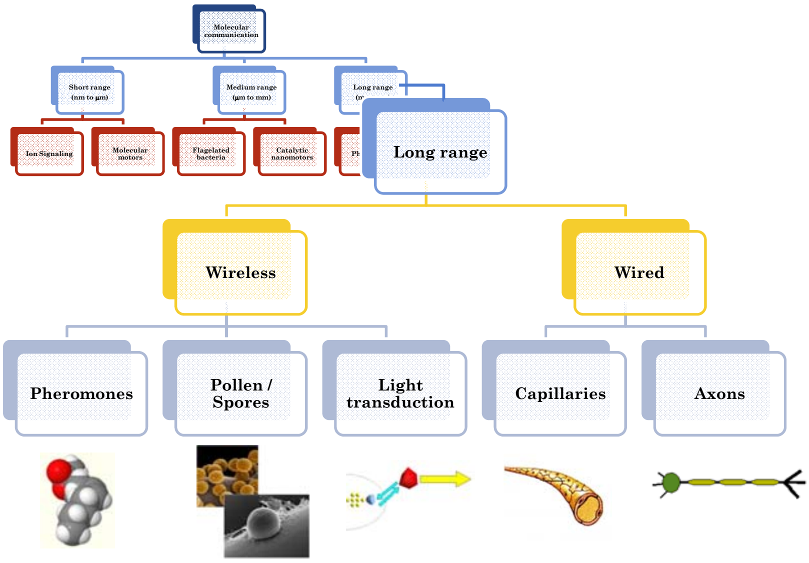
Quantum Comm

- Fast transmission speed
- Easier interface with existing SC devices

Molecular communication overview



MOLECULAR COMMUNICATION OVERVIEW



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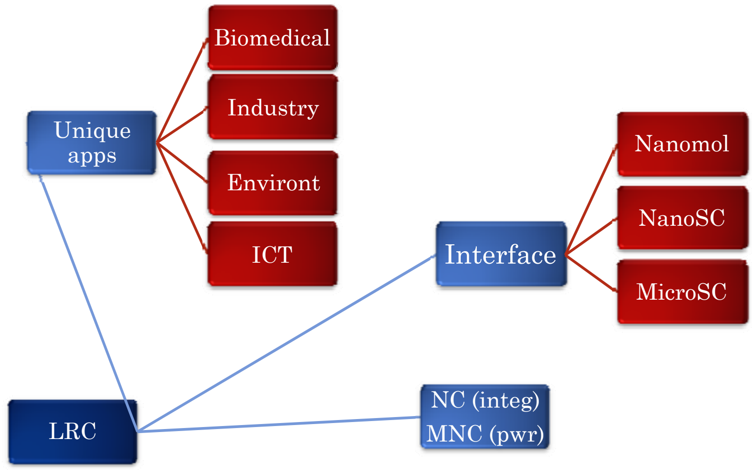
Advantages of Long Range Comm.



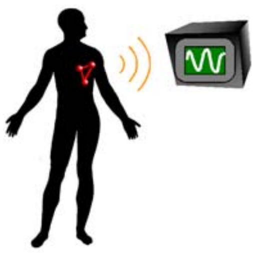
Long range applications (1/2)

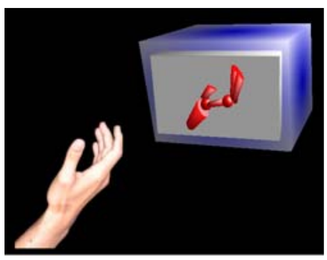
Biomedical

- Pathway between nano-networks and macro devices
- Gateway between several nanonetworks

Industrial

- Added value in manufactured products
- Haptic interfacing

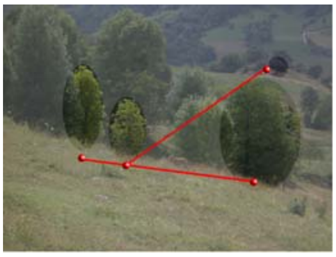




LONG RANGE APPLICATIONS (2/2)

Environmental

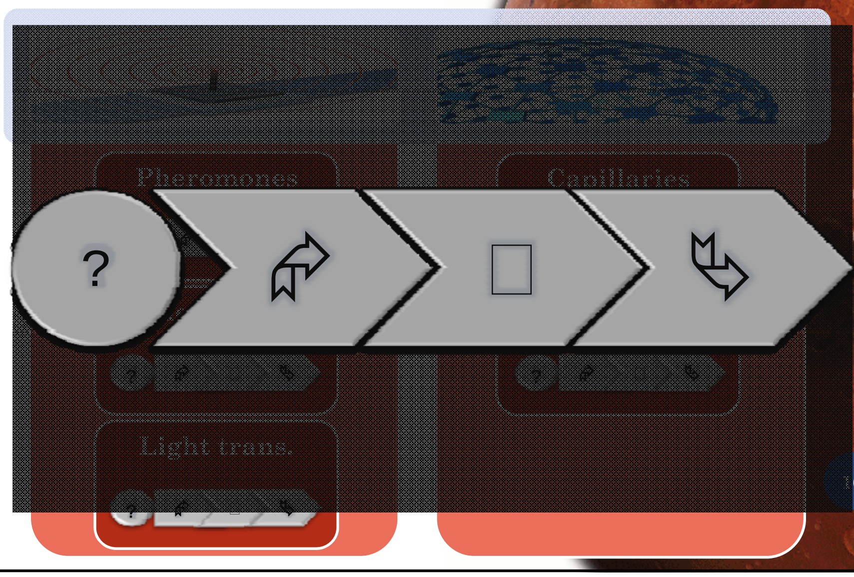
- Accurate particle detection
- Sensor Networks (toxicity in river, humidity in forest)



ICT

- Ad-hoc molecular nano-devices interconnection
- Molecular hotspot access

2.- HOW?



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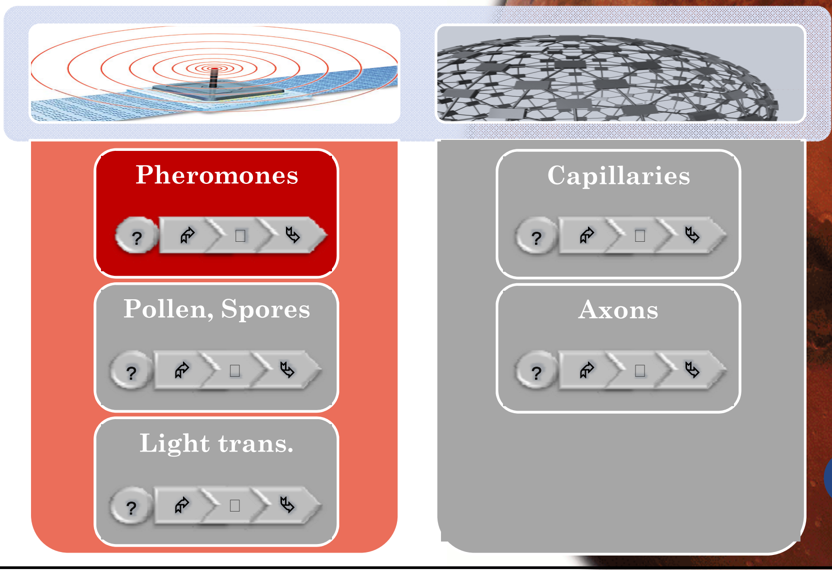

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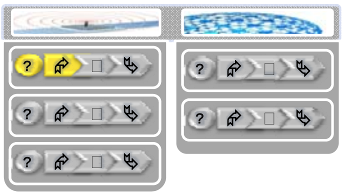
PHEROMONES.
DEF. AND EMISSION



- Pheromones
  - Pheromones are chemical compounds released by insects, plants and animals that trigger different behaviors in the receptor member of the same species.
- Pheromones – Encoding and Emitting
  - When a cell or a nano-machine has to transmit some information (usually to trigger a remote reaction) it releases a specific type of pheromones, into either an aqueous or a gaseous medium. At that moment, the concentration of molecules around the cell increases abruptly.

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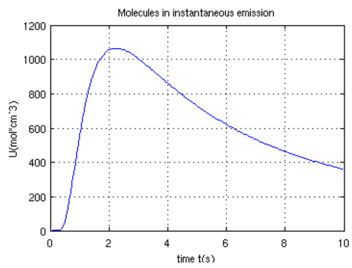
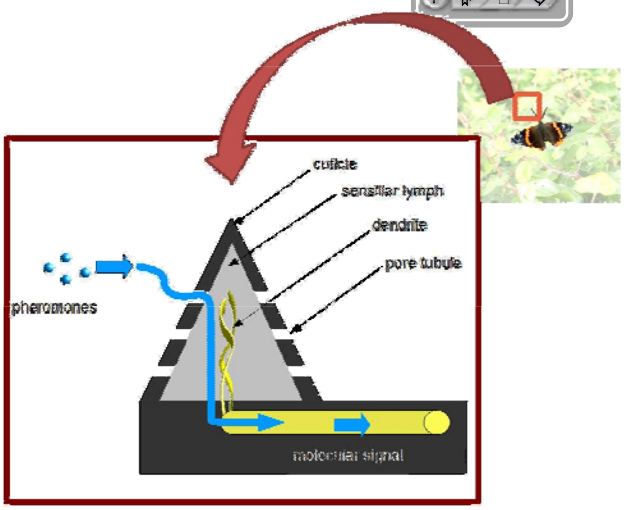
Pheromones. Propagation

- Due to molecular diffusion, pheromones will travel through the medium dispersing themselves randomly.
- Particles in the medium following Brownian dynamics can collide, or even block the movement. Physical obstacles should be also taken into account.



Pheromones. Reception



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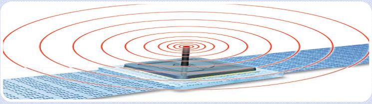
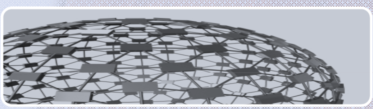
2.- HOW?





Pheromones

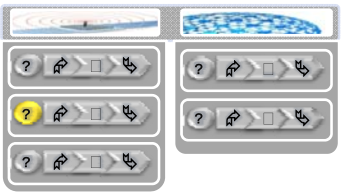
Pollen, Spores

Light trans.

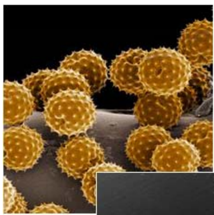
Capillaries

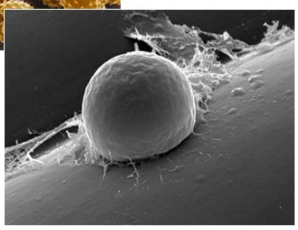
Axons

Pollen and Spores Definition



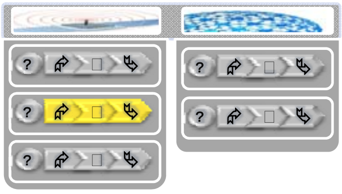
- Reproductive particles released by plants and fungi
- Smallest pollen grain (Myosotis): 6 µm
- Spore Aspergillus: 2 to 10 µm
- Particle air diffusion model, as pheromones

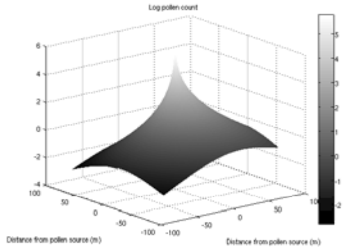




POLLEN AND SPORES VS PHEROMONES

- Advantages
  - **Message codification in DNA mutations**
  - **More robust to particle noise**
- Drawbacks
  - **Slower propagation**
  - **Turbulence has bigger effects**





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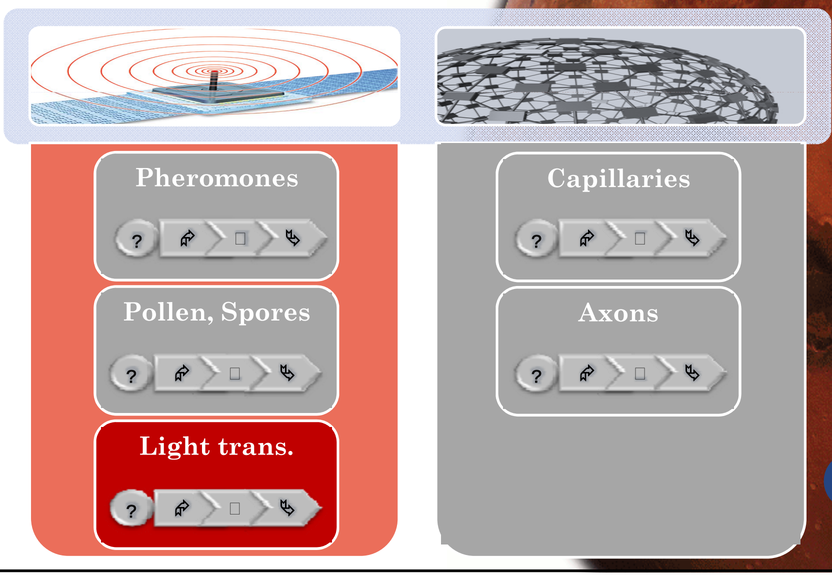
2.- HOW?



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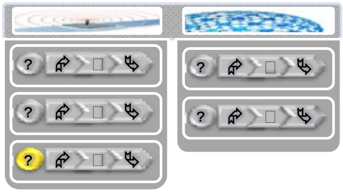
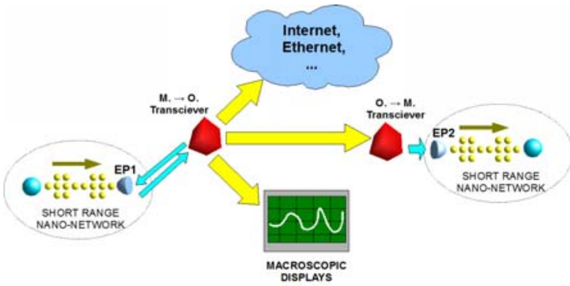
Light transduction
Definition



- For light transduction we refer to the conversion between molecular and optical signals.
- It is envisaged to provide high speed propagation (light) and known signal processing (thus allowing semiconductor components when molecular information is converted)



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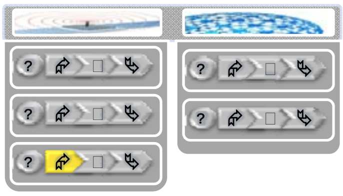
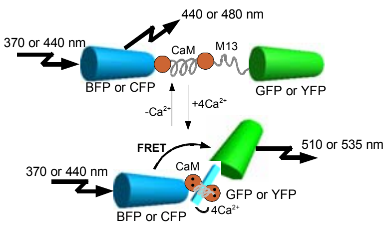
Light transduction
Emission



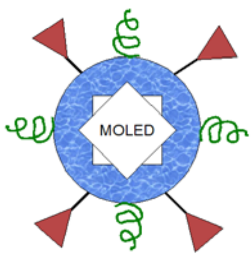
Fluorescent proteins

- Biological molecules composed of aminoacids that fluoresces at certain wavelength when exposed to different wavelength.



MOLED's

- Semi-conductor structures in nanoscale dimensions, embedded in biological shield for molecular compatibility.



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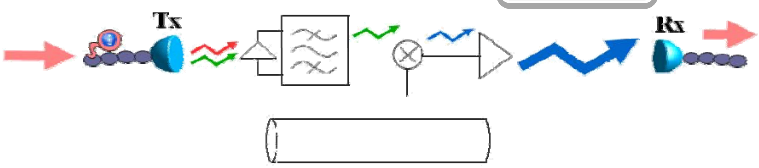
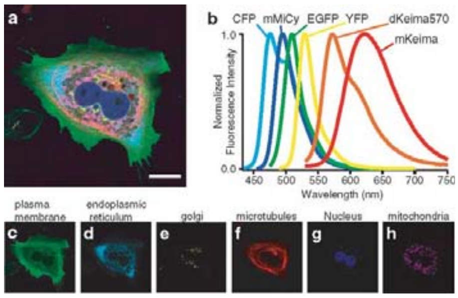
Light transduction
Propagation



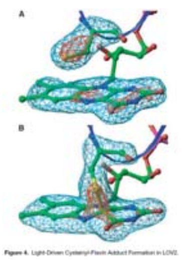


Light transduction
Reception

Molecular Communication Options for Long Range Nanonetworks

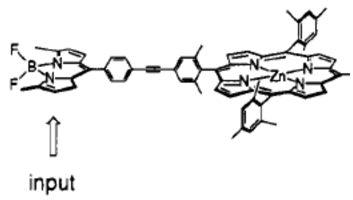
Molecular switch

- A molecule that can be reversibly shifted between two or more stable states.
- A subset of molecular switches actuates in response of light variation.



Molecular wire

- Specific dyes (e.g., boron-dipyrromethene) to capture incoming optical signal
- Convert photons to electrons in ZnO nano-wires



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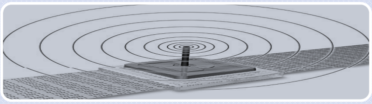
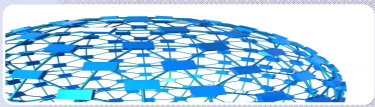

Pheromones

Pollen, Spores

Light trans.

Capillaries

Axons

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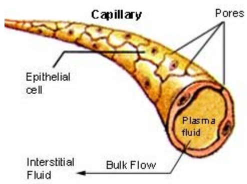
CAPILLARIES
DEFINITION

- Capillaries are the smallest of blood vessels, measuring from 5μm to 10μm in diameter. They connect arterioles and venules and their main function is to interchange chemicals and nutrients between blood and surrounding tissues.



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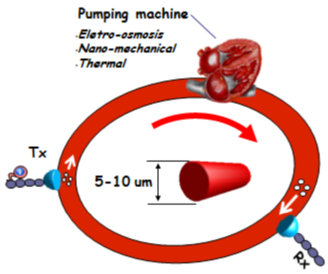
CAPILLARIES
EMISSION

- The emulation of capillaries for long-range wired architectures enables the usage of most of communication particles that are already used in animal blood.

- Hormones are the most suitable particles to be used. Endocrine hormones, which travel in blood stream, serve the body as chemical messenger to communicate cells

CAPILLARIES
PROPAGATION

- The hardware required to use capillary pipes as guided propagation is complex and has to be carefully monitored (integrity, flow).
- Pumping system:
  - Electro-osmosis (requires high voltage)
  - Mechanical Nano-valvules (requires high precission)
  - Thermal circuit (requires temperature gradient)



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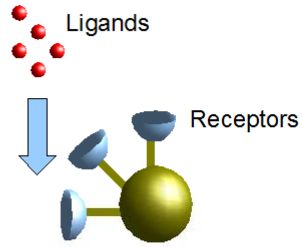
Capillaries
Reception

- Detection probability: receptor/ligand binding theory.
  - A ligand is a substance that is able to bind to and form a complex with a biomolecule to serve a biological purpose.
  - A receptor is a protein molecule, embedded in either the plasma membrane or the cytoplasm of a cell, to which a molecule used for signalling may attach.



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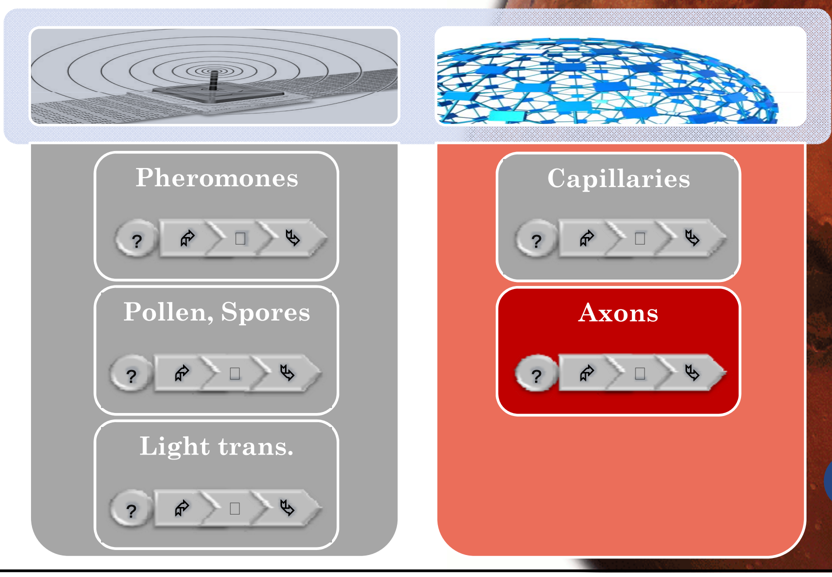

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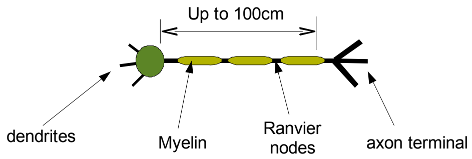
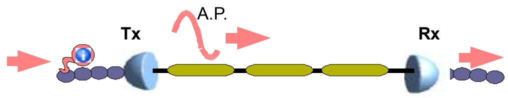
Axons
Definition

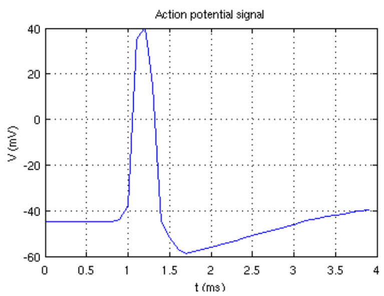
- Nerve fibers that animal brain uses to order muscle movements or receive external stimulus, is the underlying idea to be developed. Axons, the slender projection of the neuron, offer promising features for nano-communication.





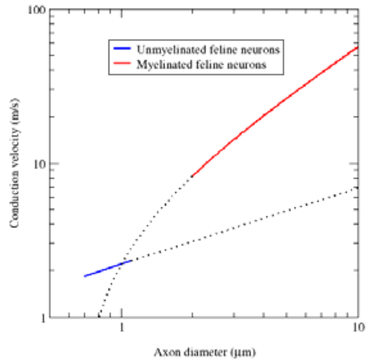
Axons
Emission

- The signal travelling along an axon (only in one direction) is the action potential.
- Electric signal => semiconductor receivers and transmitters could be attached to axon, constituting an interconnection path between different nanonetworking techniques. Ranvier nodes => plug interface?



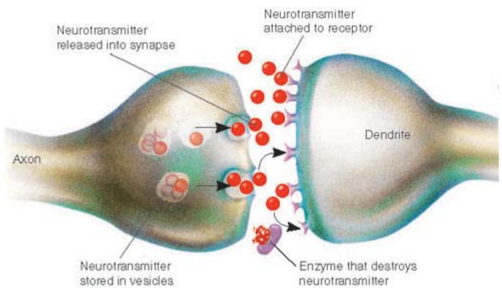
Axons
Propagation

- high speed (90 m/s in big myelinated ones)
- long length (up to 1m, plus joining possibilites)
- interference free (coaxial wire)



Axons
Reception

- The AP can be conformed back to molecular info by **synapse processes**.
- This process is used between neurons, and in nerve fibers.



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3.- THEN…

- 3.1 • Evaluation
- 3.2 • Future work
- 3.3 • Conclusions

QUALITATIVE EVALUATION

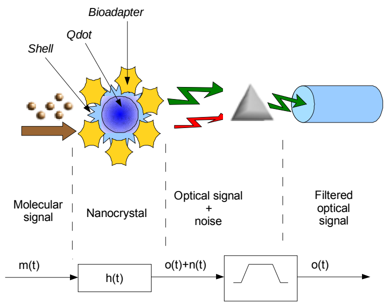
	phero	pollen spores	light	axons	capillary
Hw complex	Easy (9)	Easy (9)	Complex (3)	Easy (7)	[illegible]
Diversity	Huge (10)	Huge (10)	Freqs (7)	Act. Pot. [illegible]	H[illegible]
Range	10's cms (5)	Low (3)	Optical (10)	M[illegible]	[illegible]
S. Speed	Diffusion (4)	Diffusion (3)	Intrf.+EM (7)	90m/s [illegible]	[illegible]
Exp. Results	Entomlgy (5)	Mycology (4)	Current (8)	Neuroc. [illegible]	[illegible]
Reliability	Medium (5)	Medium (6)	Good (7)	V. Good (8)	Good (7)
Noise	Particles (4)	Structure (5)	EM (8)	Shielded (9)	Tubes (8)

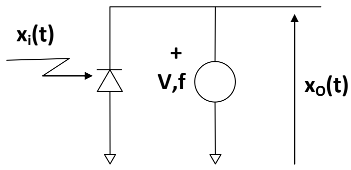
Plus: Interface with Si world through optical waves

LIGHT TRANSDUCTION MODELING

M→O Transceiver

O→M Transceiver





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3.- THEN…

- 3.1 • Evaluation
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- 3.3 • Conclusions

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Future work

Theoretical

- Physical channel characterization
- Simulation of complete comm. process.
- Identify noise sources
- Define molecular communication protocols

Future work

Practical

- Develop testbeds, from diff. expertise
- Laboratory results in bio-communication
- Test validity of molecular comm. vs quantum comm.
- Find concrete apps and targets

3.- THEN…

- 3.1 • Evaluation
- 3.2 • Future work
- 3.3 • Conclusions

CONCLUSIONS – ASPECTS TACKLED

- ✓ Overview of nanotechnology and current nano-communication research.
- ✓ Definition of possible applications using molecular long range communication (MLRC).
- ✓ Proposal of 4 new communication options to expand MLRC techniques (2 wireless, 2 wired), added to pheromones.
- ✓ Exploration of the 5 MLRC proposed techniques, in emission, propagation and reception stages.
- ✓ Qualitative evaluation under several performance and communication parameters.
- ✓ Identification of critical parts and its mathematical modeling.

Conclusions – Final Statement

- Molecular nano-comunication techniques and its principles are envisaged to **greatly influence** the development of **nanotechnology**.
- Long range techniques covers an unexplored and promising research area. A wide range of **applications will be feasible** with the proposed techniques.
- Among all the techniques, **light transduction** offer the **best features** for molecular long range communication.

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Thank you for your attention

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