Wireless Networks for Mobile Applications

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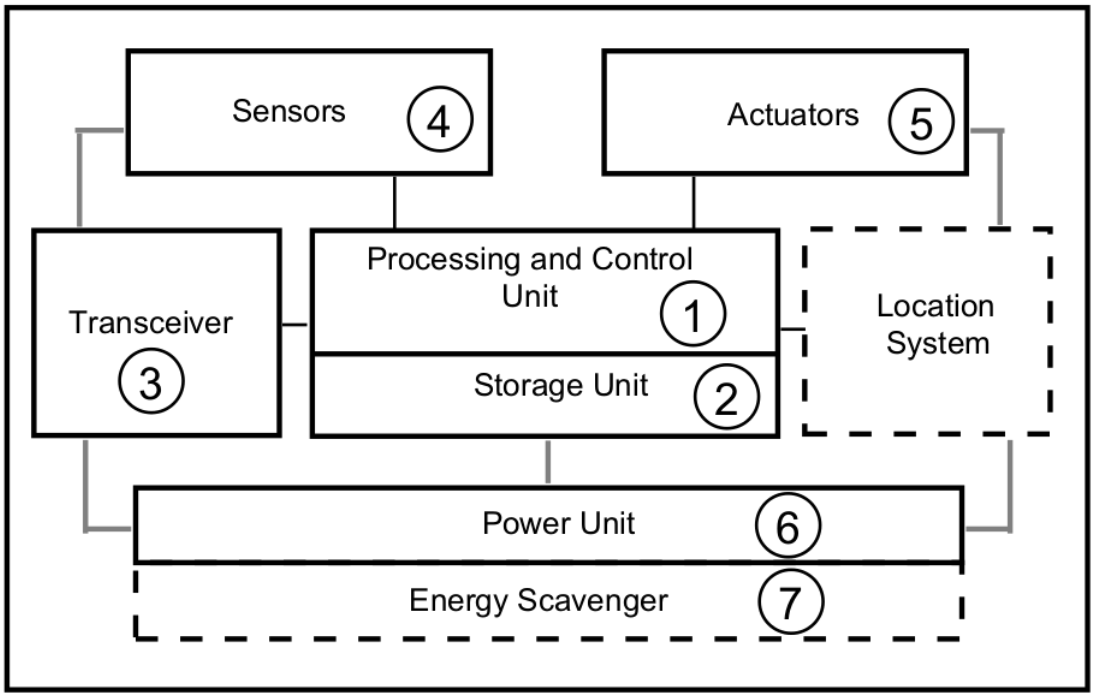
Molecular Communication

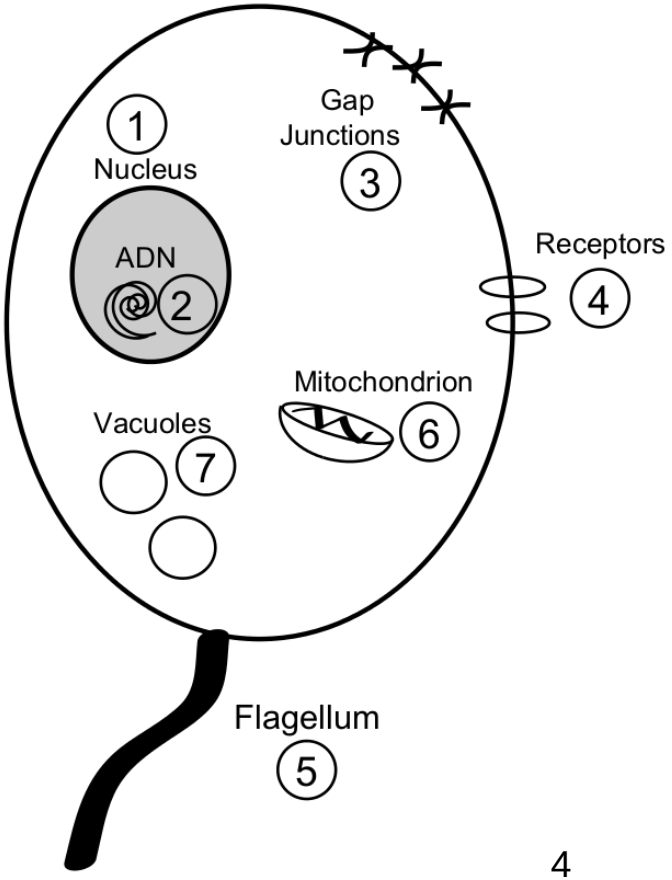
What is a Nano-machine?

- A nano-scale device able to perform a specific task at nano-level
  - Very simple and restricted, such as communicating, computing or data storing
- Both artificial and naturally occurring devices

Nano-machines' Structure

- Artificial vs. biological





Nano-machine Development

- Top-down approach
  - Development of nano-scale objects by downscaling current existing micro-scale level components
- Bottom-up approach
  - Nano-machines developed using individual molecules
  - Manufacturing technologies able to do that do not exist, yet
- Bio-hybrid approach
  - Biological nano-machines as models or building blocks to develop new nano-machines

What is a Nano-network?

- Generally, a Nano-network term refers to electronic components and their interconnection within a single chip on a nano-scale
  - Clearly, a network of nano-machines

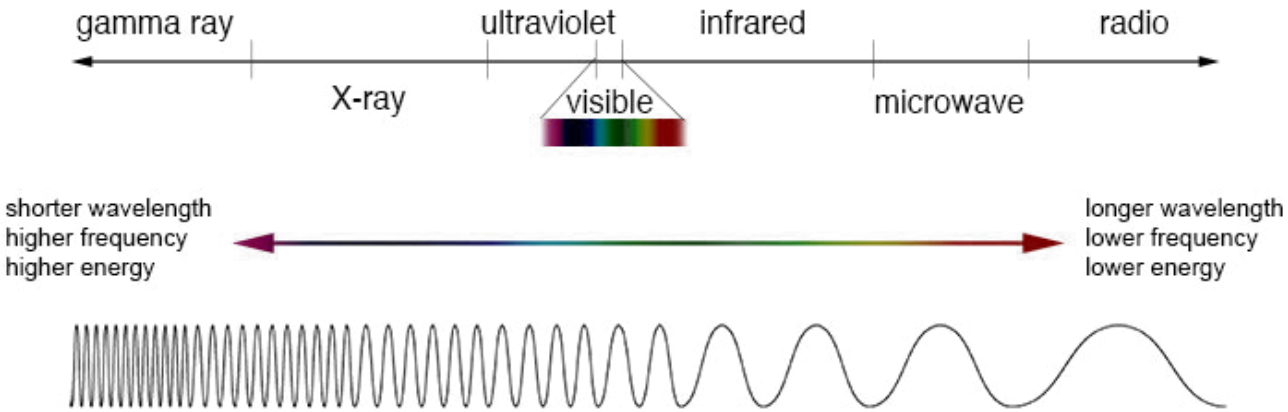
- Actually, a Nano-network is just a set of components on a nano-scale and their interconnection
  - Probably more biological than electronics

Communication Media

- Essentially we can identify three macro-categories
  - Standard Communication
  - Nano-mechanical Communication
  - Molecular Communication

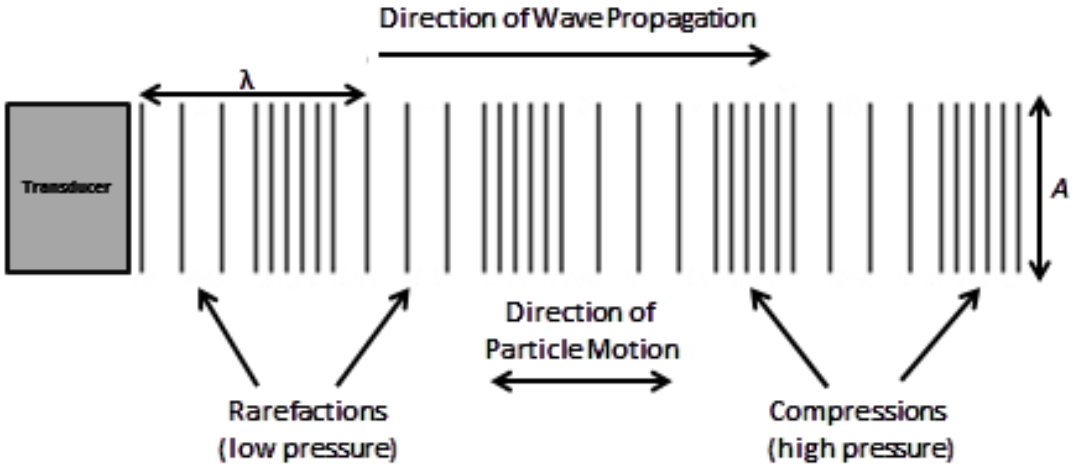
Standard Communication

- Electromagnetic waves
  - Given the size of nano-machines, wiring a large quantity of them is unfeasible
  - Wireless solutions could be used but antennas are hard to be integrated
  - Energy required to power the antenna is too high



Standard Communication

- Acoustic waves
  - Implies transducers in nano-machines capable to sense the waves
  - Again, the size of these transducers represents the major barrier



Nano-mechanical Communication

- Information is transmitted through hard junctions between linked devices at nano-level

- Drawback, requires physical contact between transmitter and receiver

Molecular Communication

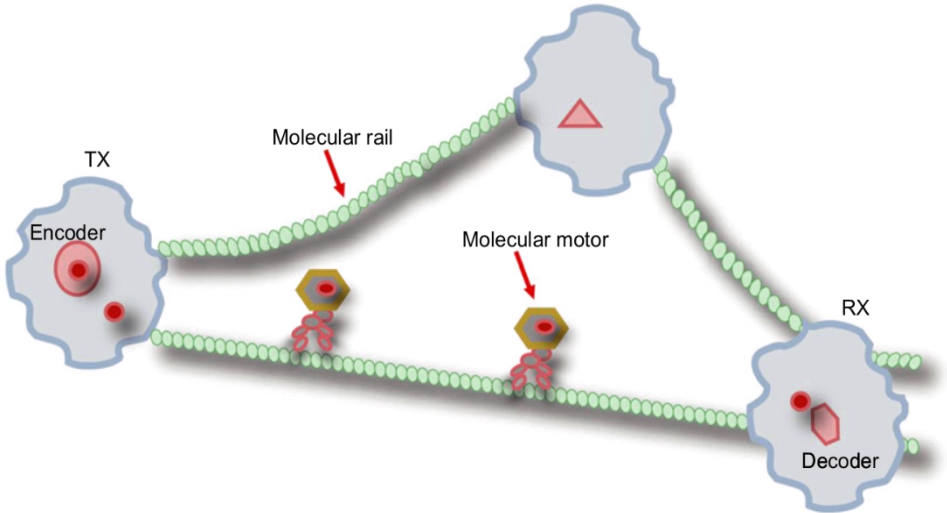
- Defined as the transmission and reception of information encoded in molecules
- Most promising approach for nano-networking
  - Molecular transceivers are already conceived at nano-scale
  - Transmitters and receivers can be remotely located as far as the transmitted molecules can go

Molecular Communication

- Short range communications (within *mm*)
  - Molecular motors
  - Calcium signalling
- Long range communications from (*mm* up to *km*)
  - Pheromones
  - Bacteria

Molecular Motors

- Molecular motors are proteins that transform chemical energy into mechanical work
- They travel along molecular rails called micro-tubules, previously deployed setting a complete railway
- Just like as standard communications, data need to be encoded, transmitted and decoded

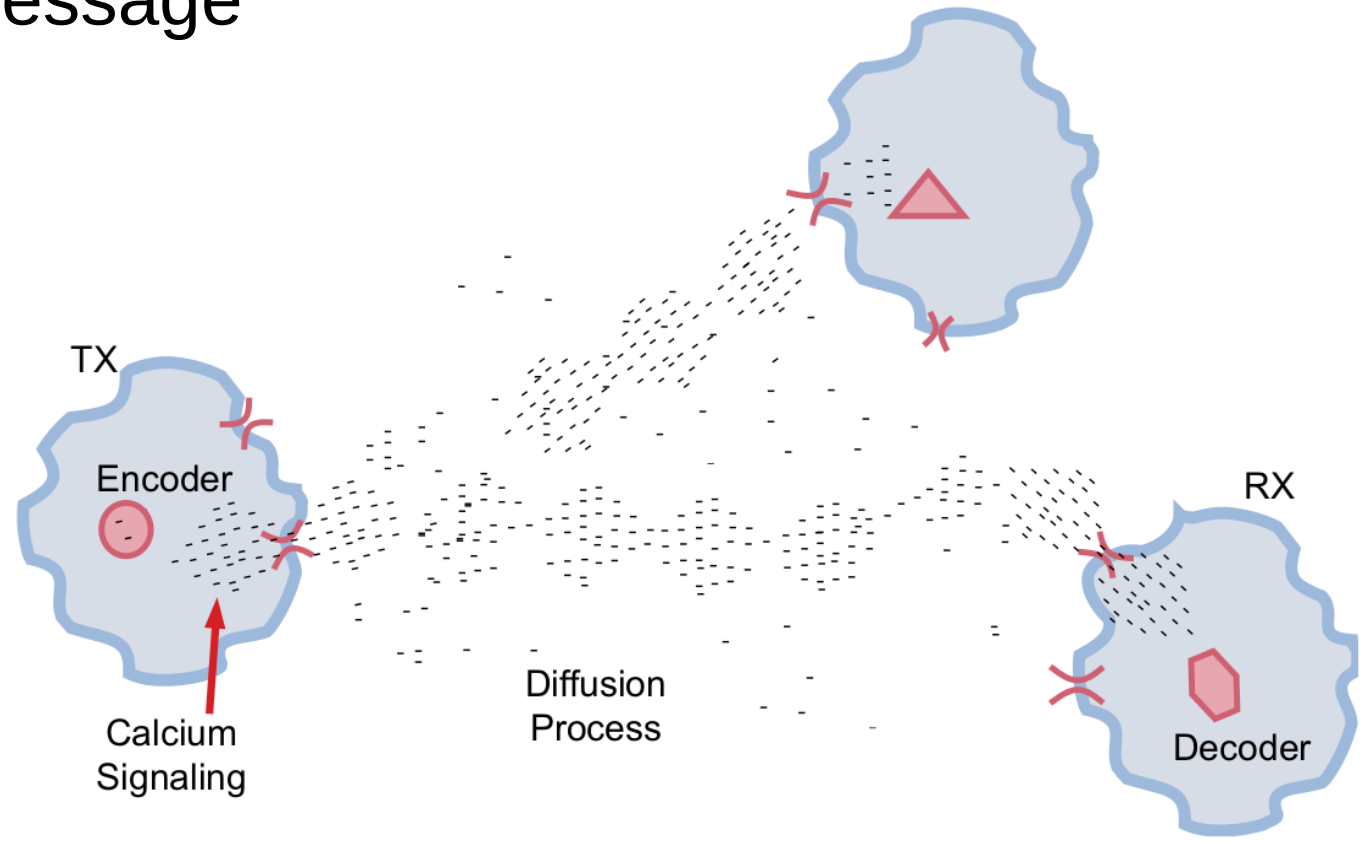


Calcium Signalling

- One of the most well-known molecular communication technique in biology
- Responsible for many coordinated cellular tasks such as fertilization, contraction and secretion
- More flexible, there is no need of railways as in molecular motors communication

Calcium Signalling

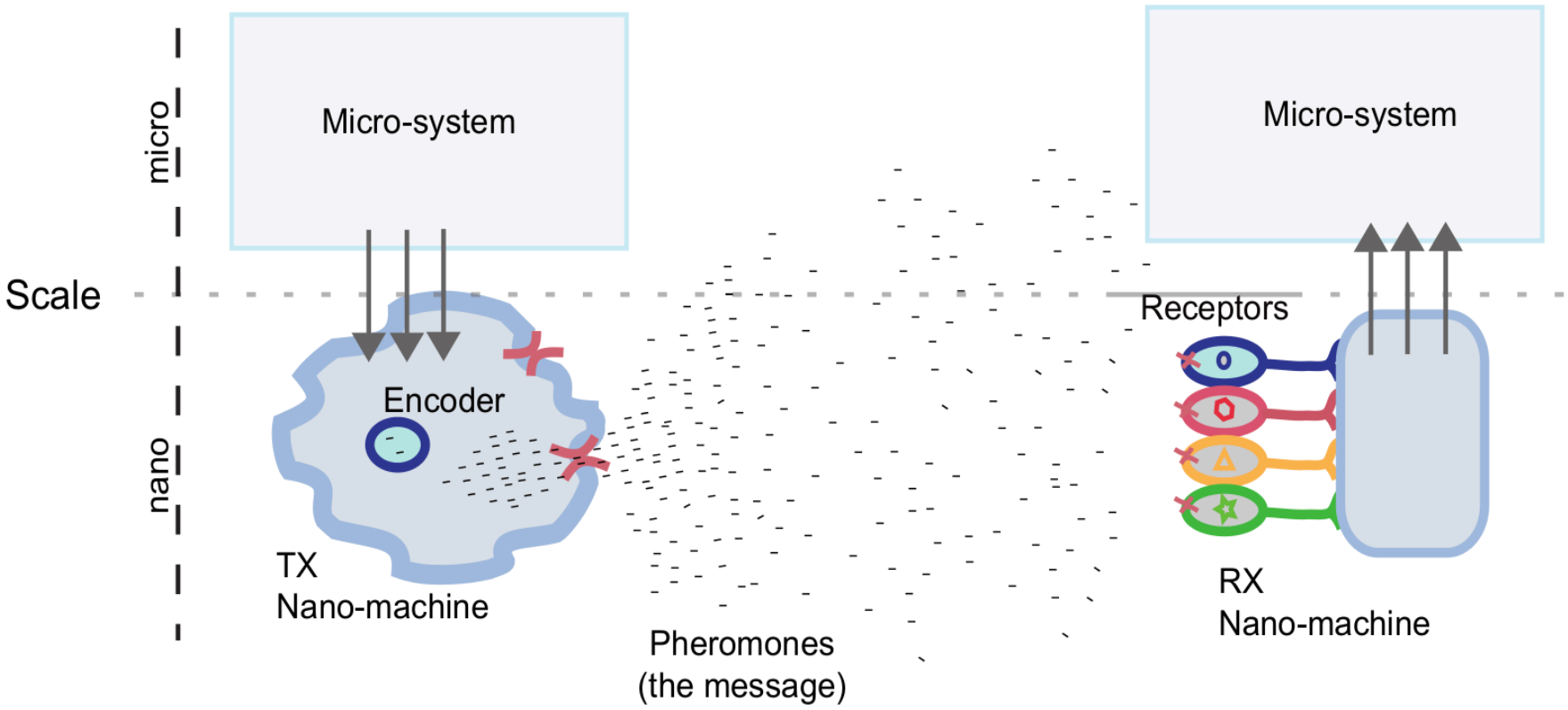
- Similar to broadcast networks, all surrounding nano-machines can receive a broadcast message



Pheromones

- Molecular compounds containing information that can only be decoded by specific receivers
- Messages consist of molecules
  - Huge quantity of possible combinations
  - In ants colony, the whole communication between members is based on pheromones

Pheromones

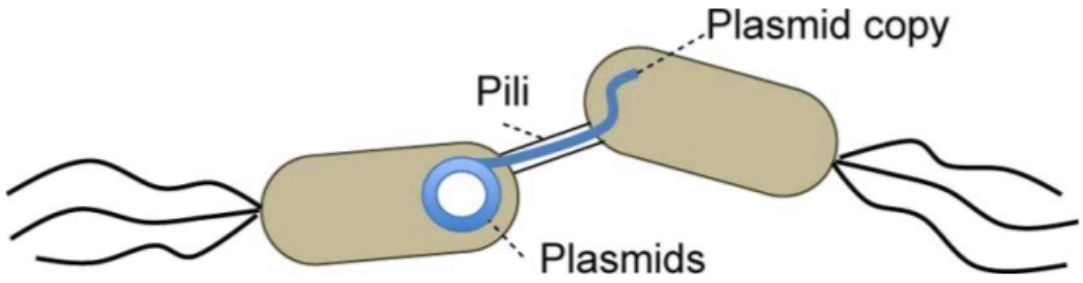

micro
nano
Scale
Micro-system
Micro-system
Encoder
Receptors
TX
Nano-machine
Pheromones
(the message)
RX
Nano-machine

Bacteria

- Bacteria have a number of interesting characteristics
  - Conjugation
  - Chemotaxis
  - Antibiotics resistance
- Ideal as medium range information carriers for nano-networks

Bacteria Conjugation

- Bacteria conjugation allows different bacteria to interconnect and pass copies of plasmids
  - Plasmids are genetic messages encoded as strings of four nucleotides



Bacterial Chemotaxis

- Chemotaxis is the movement induced into bacteria by chemical stimuli
  - Can swim towards food particles, like glucose
  - Can swim away from poisons, like salts
- Bacteria can communicate through simple emission of these chemo-components
  - Colony survival rates increase with cooperation

Conjugation Based Opportunistic Routing

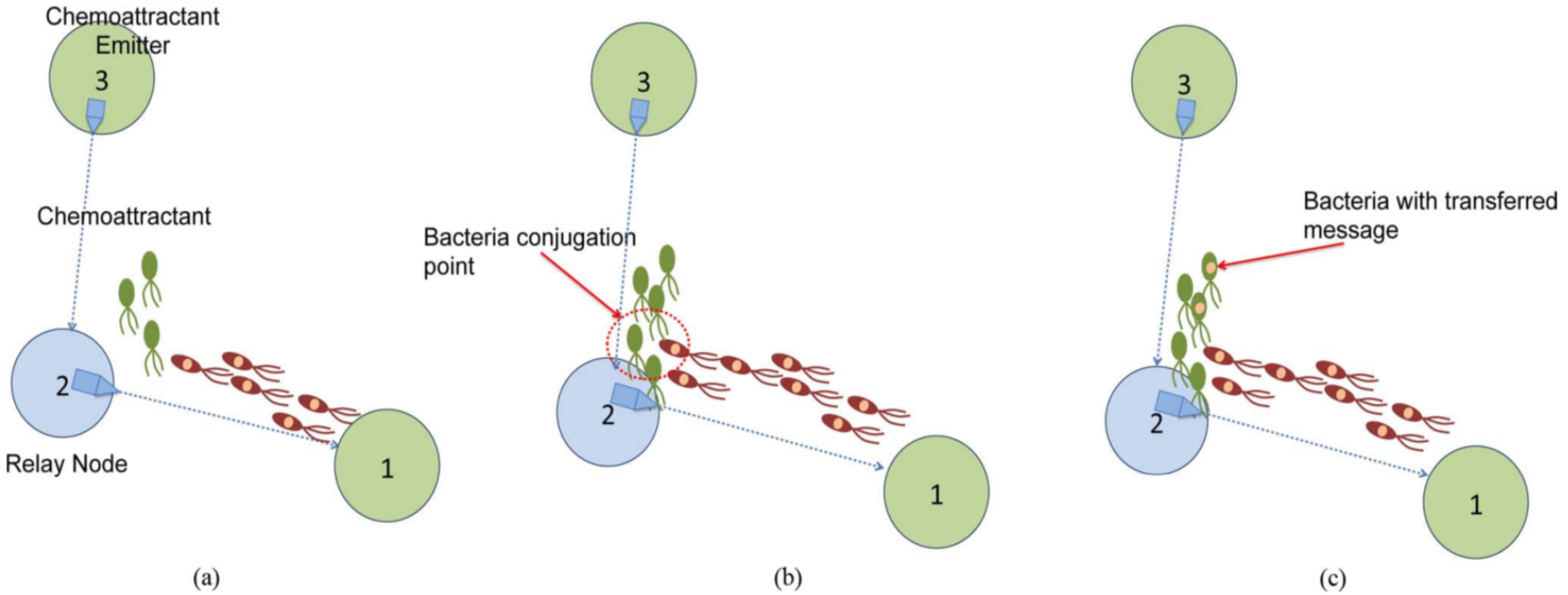
- An opportunistic network is a type of challenged network where contacts are intermittent or link performance is extremely variable

- Applicable to bacteria-based nanonetworks
  - Similarly to wireless broadcast networks, messages not intended for the recipients are simply dropped
  - Chemoattractants are spread to achieve the wanted path

- Conjugation and chemotaxis are jointly used

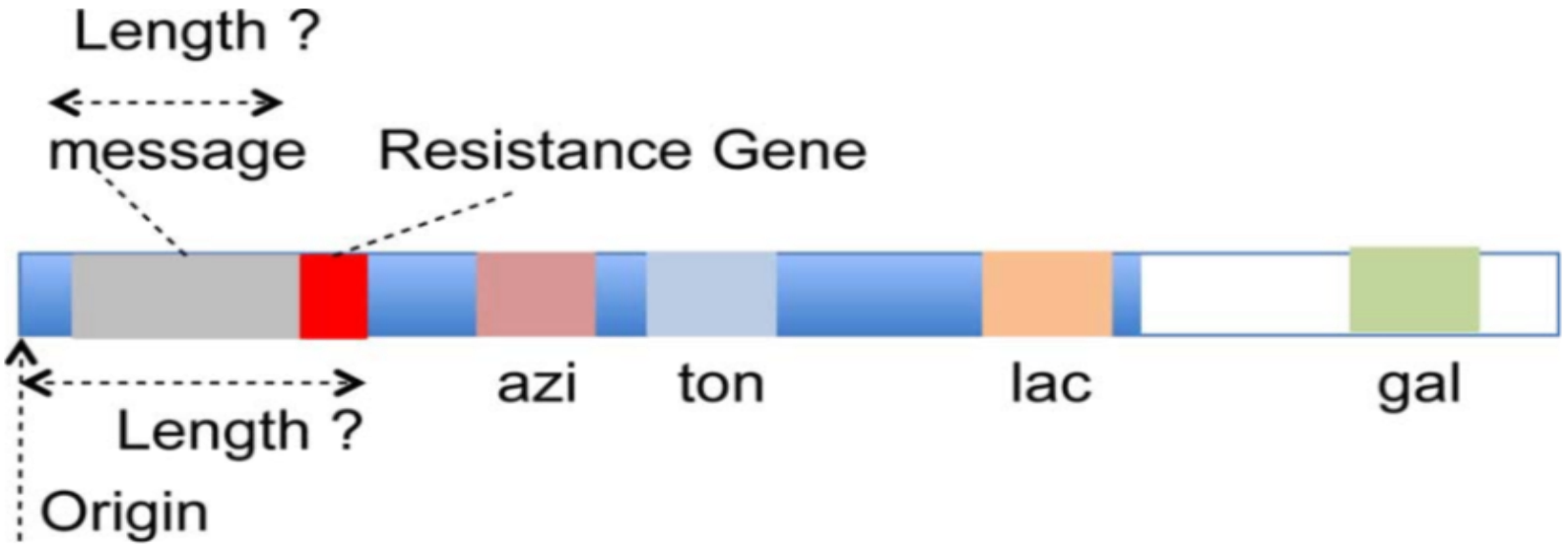
Conjugation Based Opportunistic Routing

- Chemoattractant from node 2 attracts bacteria from node 1
- Chemoattractant from node 3 attracts bacteria from node 2



Resistance to Antibiotics

- Resistance to antibiotics is a fundamental characteristic
  - Can be used to filter and kill off bacteria that do not contain legitimate and/or complete plasmids
- Plasmids only gone through partial conjugation are efficiently discarded



Some Possible Applications

- Novel healthcare and medical technologies
  - Targeted Drug Delivery [Okonkwo et al., 2016]
  - Live health monitoring
- Novel environment technologies
  - Oil spilling containment [De Lorenzo, 2001]
  - Water resources monitoring
- Counter bioterrorism applications
- Being highly critical applications, the implementations should be highly reliable and secure

Conclusions

- High multi-disciplinary context that involves numerous research fields such as computer science, engineering, biology
- Open design issues are of paramount importance
  - Further researches on the topic should be stimulated

References

- U. A. K. Chude-Okonkwo, R. Malekian and B. T. S. Maharaj, "Molecular Communication Model for Targeted Drug Delivery in Multiple Disease Sites With Diversely Expressed Enzymes," in IEEE Transactions on NanoBioscience, vol. 15, no. 3, pp. 230-245, April 2016.

- Valeria Loscrì, Cesar Marchal, Nathalie Mitton, Giancarlo Fortino, Athanasios V. Vasilakos, “Security and Privacy in Molecular Communication and Networking: Opportunities and Challenges”, IEEE Transactions on Nanobioscience, accepted, 2014

- Ian F. Akyildiz, Fernando Brunetti, Cristina Blázquez, “Nanonetworks: A new communication paradigm”, Computer Networks, 52, 2260–2279, 2008

- Sasitharan Balasubramaniam, Pietro Liò, “Multi-hop Conjugation based Bacteria Nanonetworks”, IEEE Transactions on NanoBioscience, vol. 12, no. 1, pp.47-59, March 2013

- Tadashi Nakano and Athanasios V. Vasilakos, “Guest Editorial Special Section on Molecular Communication”. IEEE Transactions on NanoBioscience, Vol. 13, no. 3, 2014