NaNoNetworking Center in Catalunya (N3Cat)

Graphene-enabled Wireless Communications

About N3Cat

Research interests

N3Cat in CATGRAPHNET

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- The initiative
  - Nanotechnology is enabling the development of devices in a scale ranging from one to a few hundred nanometers, which are able to perform simple tasks such as computing, data storing, sensing and actuation
  - By means of communication, these nano-devices will be able to achieve more complex tasks and cover larger areas
  - However, classical communication paradigms need to be revised/rethought before being used in the nanoscale
  - The NaNoNetworking Center in Catalonia (N3Cat) has been created with the main goals of carrying fundamental research on communications among nano-devices, and educating and training the new generation of students in this field

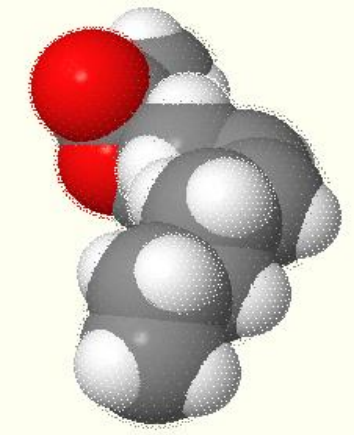
Director: Prof. Ian F. Akyildiz
Academic staffs: 6 Students: 8 - 10

- Current members
  - Broadband Wireless Networking Lab. (GeorgiaTech)
    - Ian F. Akyildiz (Honorary Professor with the UPC and Director of N3Cat)
  - Computer Architecture Dept. (UPC)
    - Josep Solé-Pareta and Albert Cabellos-Aparicio
  - Electronic Engineering Dept. (UPC)
    - Eduard Alarcón-Cot and Ramon Bragós
  - Electrical & Electronics Engineering Dept. (Koç University)
    - Özgür B. Akan

Key research topics

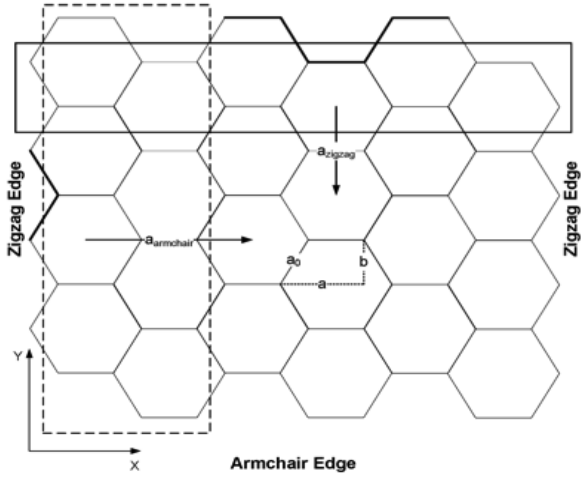
Molecular Communications

- Use biological elements as blocks or design patterns (Information encoded inside molecules)



Graphene-enabled Wireless Communications

- EM based communications at the nano scale



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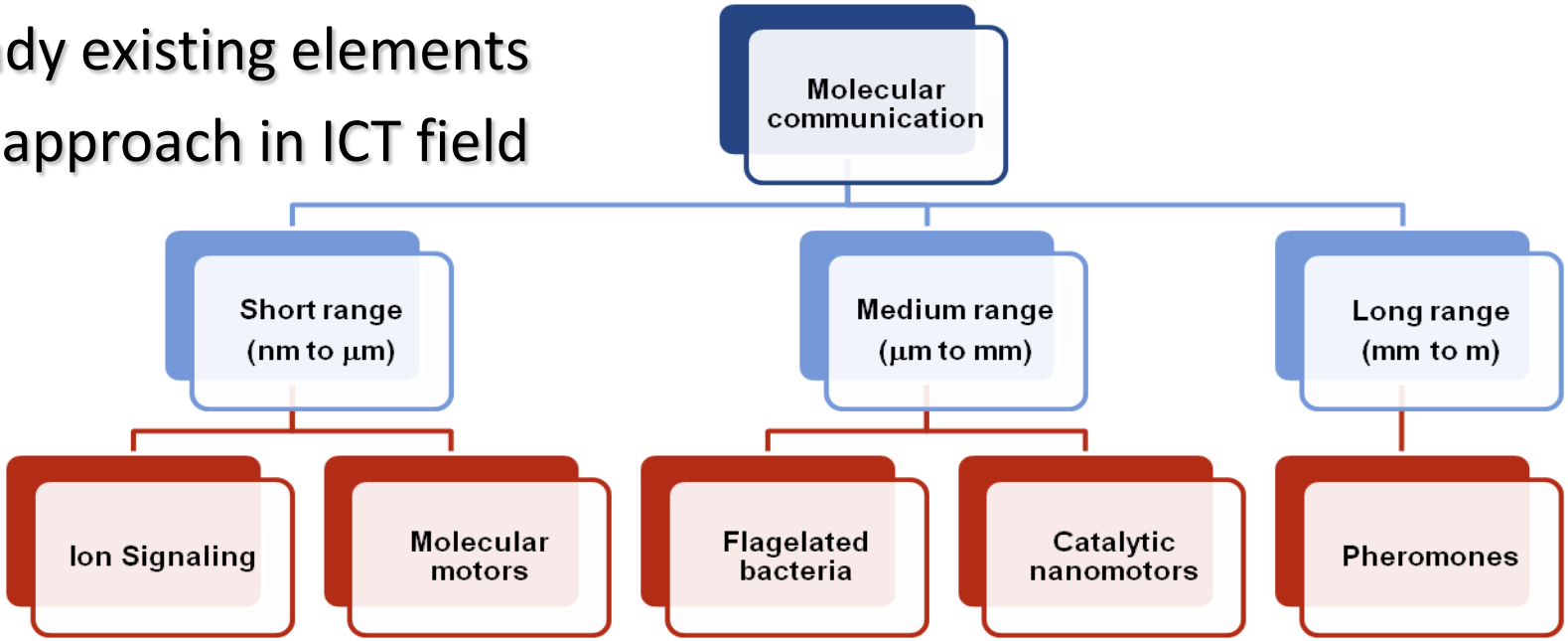
Molecular Communications

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



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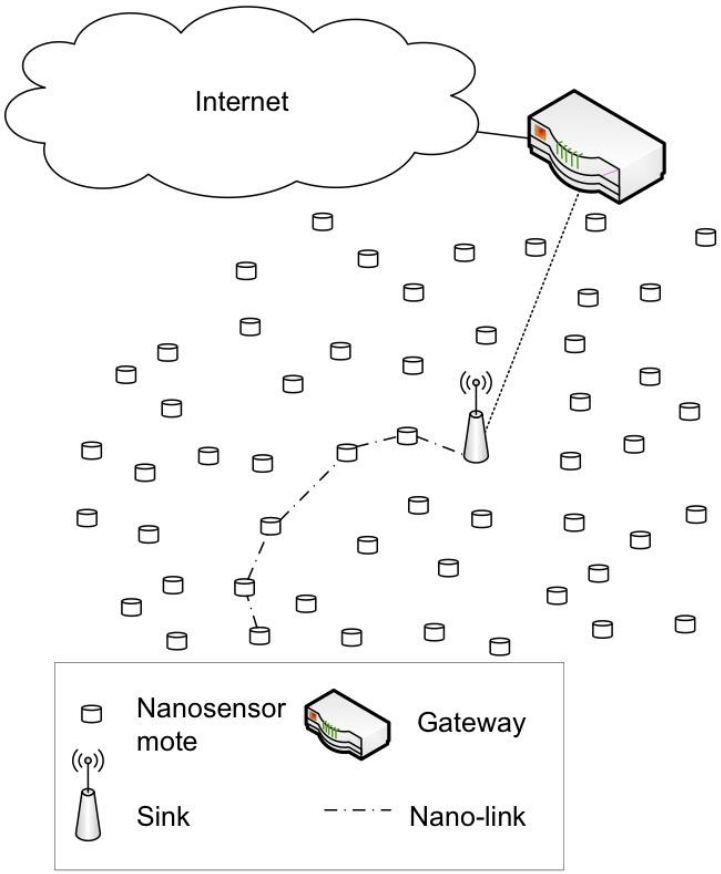
Graphene-enabled Wireless Communications

- Wireless Nanosensor Networks
- Wireless Networks-on-Chip
- etc.



Research interests

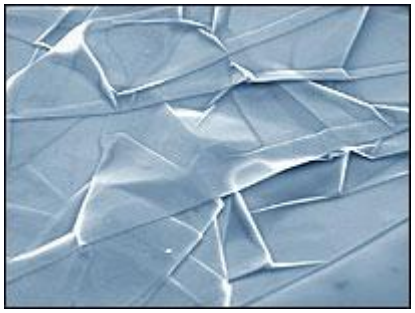
- Common problems:
  - Channel modeling
  - Scalability
  - Nano-network architectures
  - Performance evaluation by simulation

- In progress activity
  - http://www.n3cat.upc.edu/

- Potential applications of graphene

Composites

Chemistry

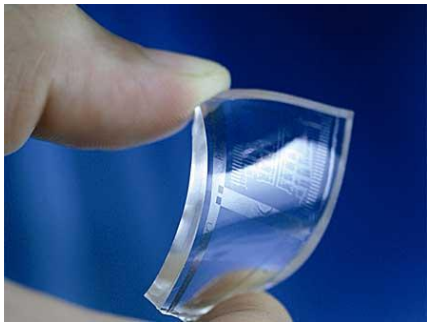


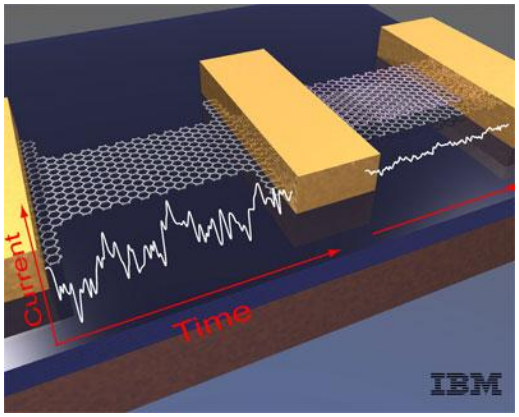
Nano-optics

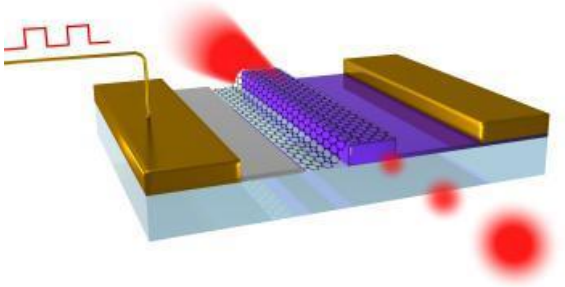
Nano-electronics

Bio-medicine

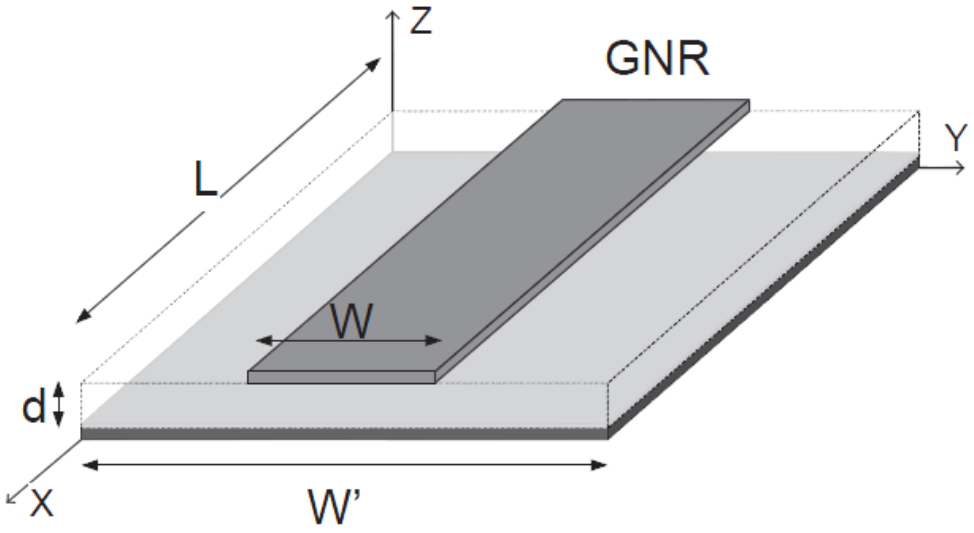
¿Wireless communications?

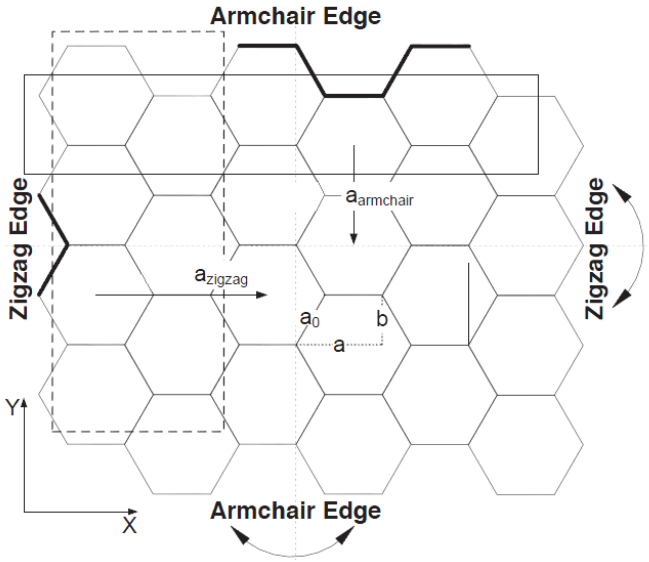






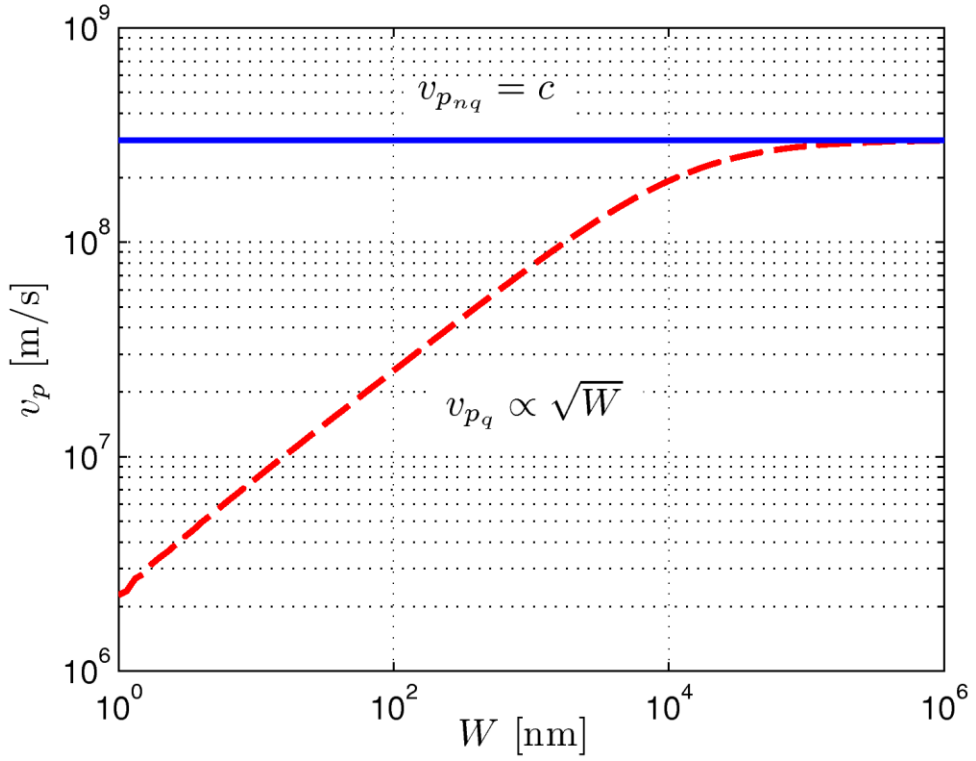
- **Graphene-based nano-patch antennas** show novel properties, different from metallic antennas
- These quantum effects are envisaged to enable wireless communications at the nanoscale





Josep Miquel Jornet, Ian F. Akyildiz, "Graphene-Based Nano-Antennas for Electromagnetic Nanocommunications in the Terahertz Band", *Proc. European Conference on Antennas and Propagation*, Barcelona, 2010 .

- EM waves propagating in graphene-based nano-antennas have a lower propagation speed than in metallic antennas



$$v_p = \frac{1}{\sqrt{LC}}$$

v_p: wave propagation speed
c: speed of light
W: antenna width
L: distributed inductance
C: distributed capacitance

- Why do we need a low propagation speed?
  - Let's consider a 1 µm-long nano-antenna
    - Metallic antenna

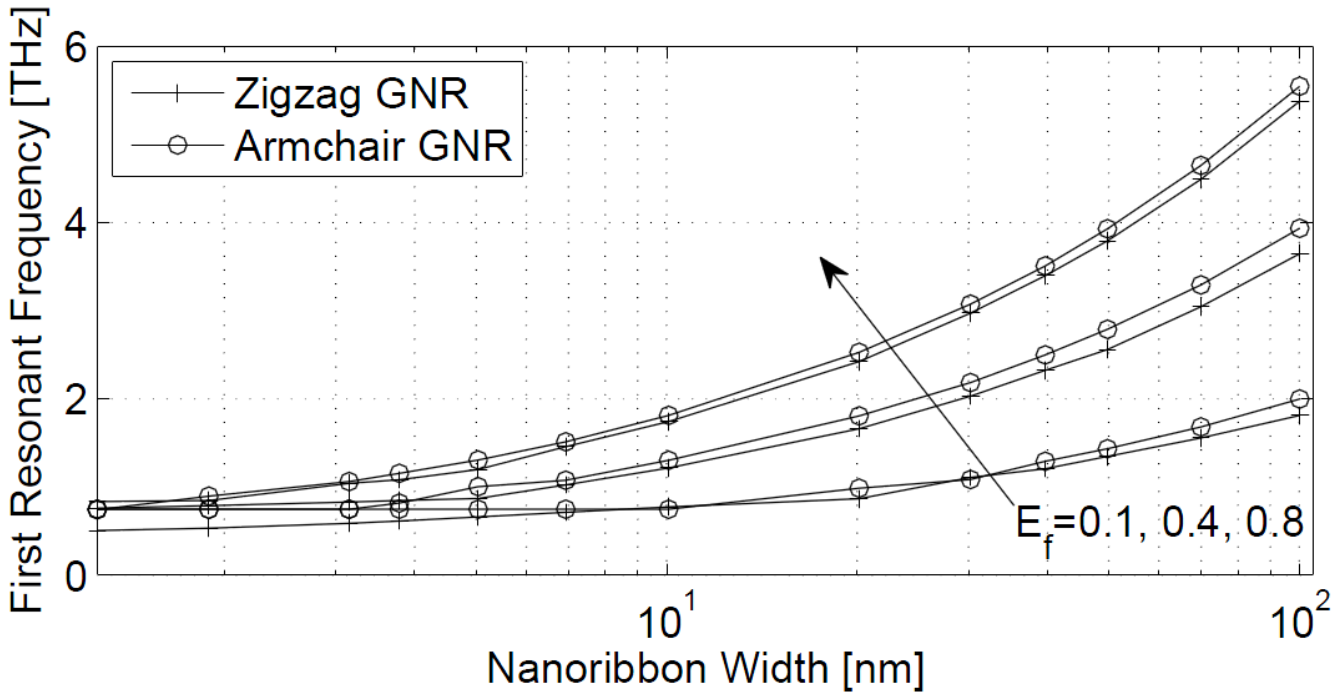
$$v_p \approx 2{\cdot}10^8\ \text{m/s} \longrightarrow f = \frac{v_p}{2l} \approx 100\ \text{THz} \longrightarrow \text{optical domain}$$

    - Graphene-based antenna

$$v_p \approx 2{\cdot}10^6\ \text{m/s} \longrightarrow f = \frac{v_p}{2l} \approx 1\ \text{THz} \longrightarrow \text{electromagnetic domain, THz band}$$

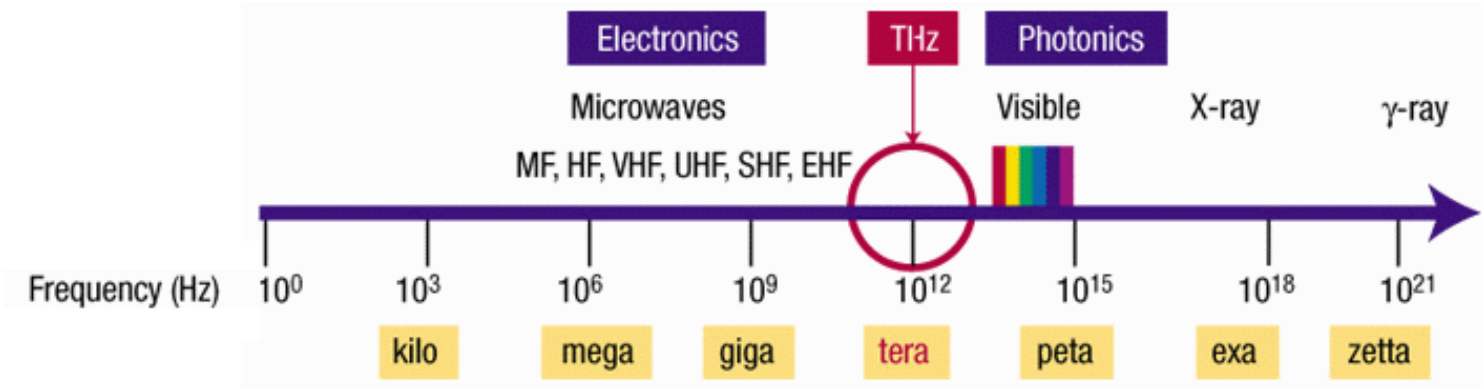
v_p: wave propagation speed
f: antenna resonant frequency
l: antenna length

- First resonant frequency of a graphene-based nano-patch antenna as a function of the nanoribbon width



Josep Miquel Jornet, Ian F. Akyildiz, "Graphene-Based Nano-Antennas for Electromagnetic Nanocommunications in the Terahertz Band", *Proc. European Conference on Antennas and Propagation*, Barcelona, 2010 .

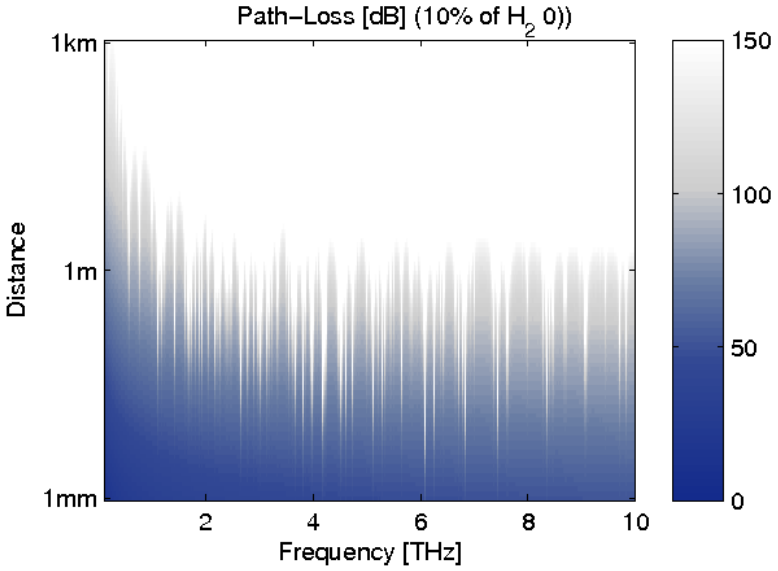
- Graphene-based nano-antennas radiate EM waves in the **terahertz band**



- We need to study the properties of the terahertz channel at the nanoscale
  - Path loss
  - Noise

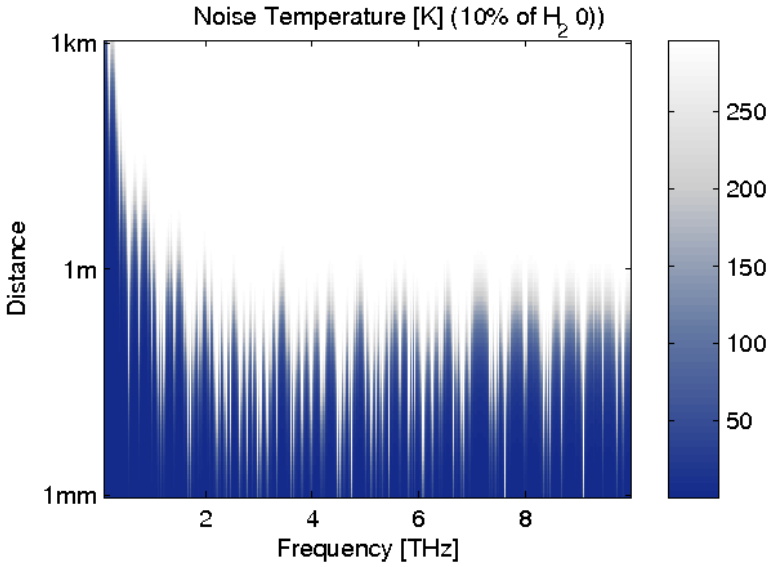
Terahertz channel

- Molecular absorption



$$A_{abs} = \frac{1}{\tau} = e^{k(f)d}$$

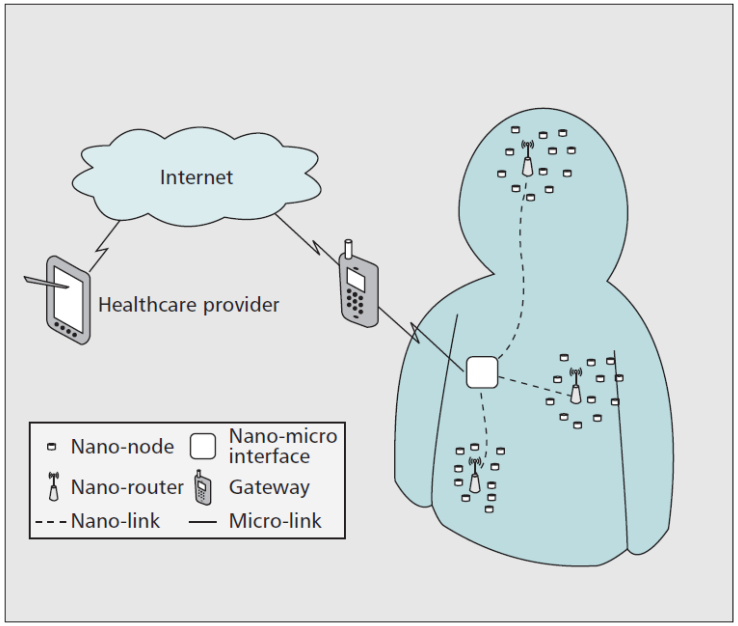
- Molecular Noise



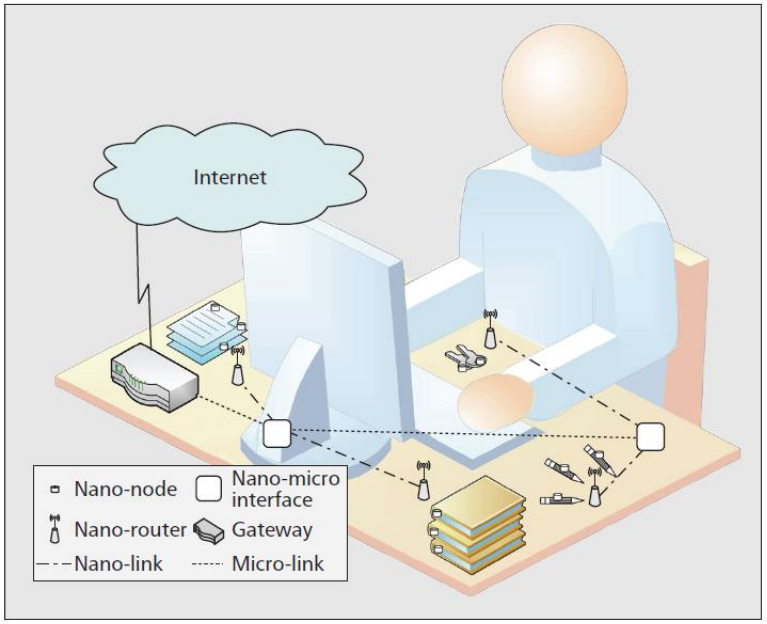
$$T_{mol} = T_0(1-\tau) = T_0\left(1-e^{-k(f)d}\right)$$

J. M. Jornet and I. F. Akyildiz, “Channel Capacity of Electromagnetic Nanonetworks in the Terahertz Band,” in *Proc. IEEE International Conference in Communications, Cape Town, 2010.*

- Applications
  - Wireless Sensor Networks at the nanoscale: Wireless Nanosensor Networks



- Health monitoring



- Internet of nano-things

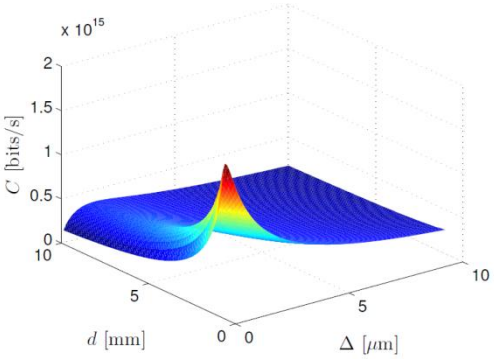
Ian F. Akyildiz, Josep Miquel Jornet, "The Internet of Nano-Things", *IEEE Wireless Communications*, 2010.

- Enabling Electromagnetic Communication among Nanosensor Devices (ELCONA)
  - To design, simulate, manufacture and measure novel **graphene-based nano-antennas**
  - To provide a physical channel model for **THz-band communications** at the nanoscale and validate it experimentally
  - To develop a network architecture for **Wireless Nanosensor Networks** based on these antennas

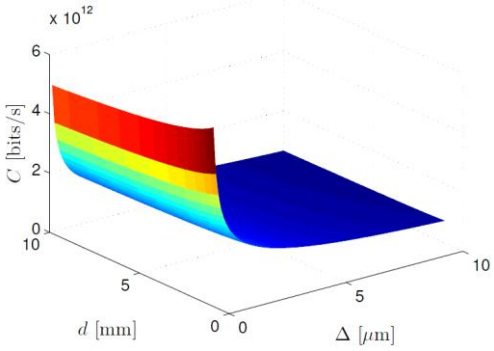
Sergi Abadal, Josep Miquel Jornet, Ignacio Llatser, Albert Cabellos-Aparicio, Eduard Alarcon, Ian F. Akyildiz, "Wireless Nanosensor Networks using Graphene-based Nano-Antennas", *in Graphene 2011, Bilbao.*

- Enabling Electromagnetic Communication among Nanosensor Devices (ELCONA)
  - Project submitted to the ICT FET-Open call
  - Currently in the second stage (full proposal just submitted)
  - Consortium partners
    - **Nanonetworking Center in Catalunya – UPC (Spain)**
    - Sineurop Nanotech GmbH (Germany)
    - University of Wuppertal (Germany)
    - Royal Institute of Technology – KTH (Sweden)
    - Koc University (Turkey)
    - Phantoms Foundation (Spain)

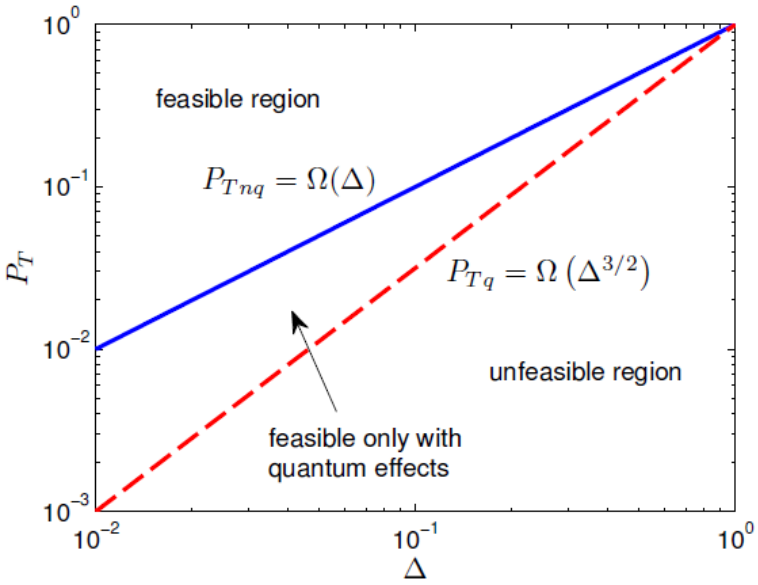
- Theory of scalability for Graphene-based Wireless Communications at the nanoscale
  - Study how metrics scale
    - Channel capacity
    - Transmitted power



without quantum effects (metal)



with quantum effects (graphene)



Ignacio Llatser, Albert Cabellos-Aparicio, Eduard Alarcón, Josep Miquel Jornet, Ian F. Akyildiz, "Scalability of the Channel Capacity of Electromagnetic Nanonetworks in the Terahertz Band", *submitted to IEEE Transactions on Wireless Communications.*

Summary

- Graphene-based nano-antennas enable wireless communications at the nanoscale
  - Antenna size in the order of 1 µm
  - Radiation at the THz band
- Graphene-enabled wireless communications will be radically different from current ones
  - Classical communication paradigms and techniques need to be revised
- Countless applications
  - Wireless Nanosensor Networks

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