Wireless Nanosensor Networks using Graphene-based Nano-Antennas

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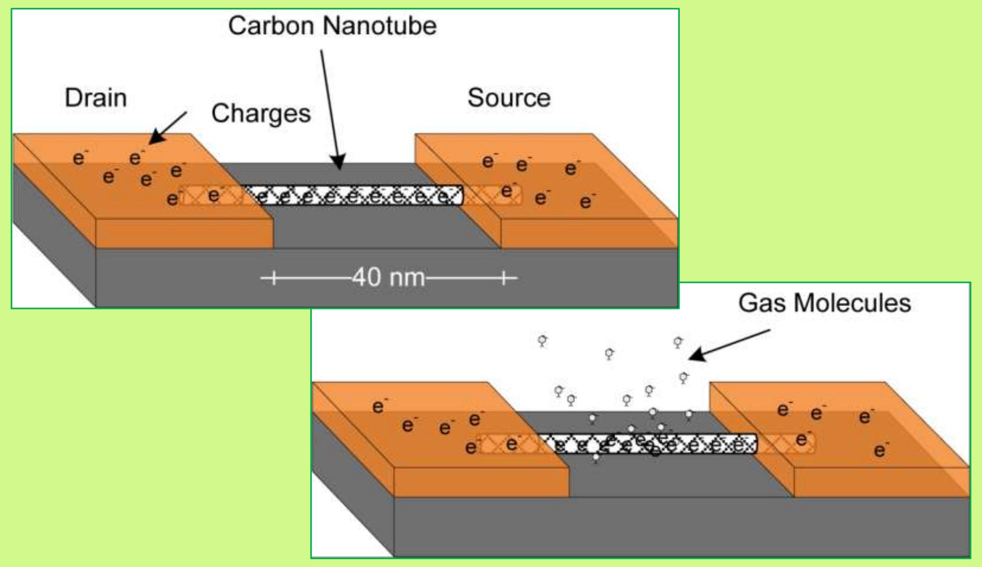
Nanotechnology and Graphene

I. F. Akyildiz and J. M. Jornet, ***"Electromagnetic Wireless Nanosensor Networks,"*** Nano Communication Networks (Elsevier) Journal, Vol. 1, no. 1, pp. 3-19, March 2010.

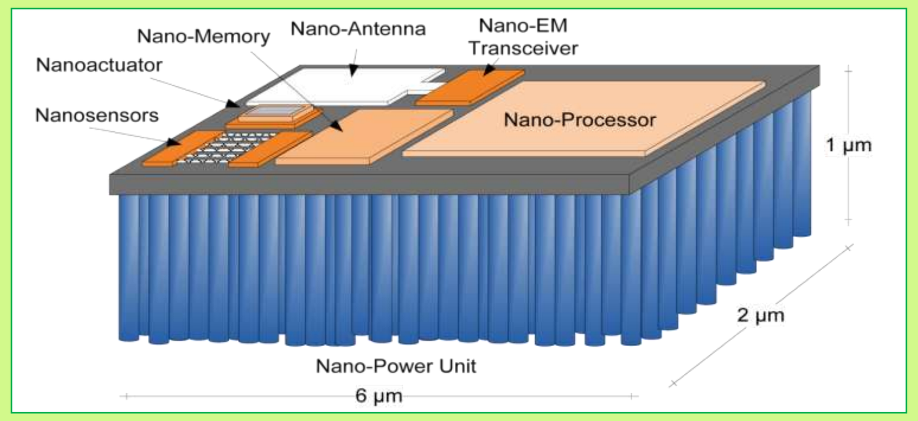
- **Nanotechnology** is a truly multidisciplinary field which has yielded numerous discoveries, such as **graphene** and its incredible properties. Indeed, graphene is considered essential for the development of electronic components in a scale ranging from one to a few hundreds of nanometers, such as:
  - Nanoscale FET transistors
  - *Nanosensors*
  - Nanoactuators
  - Nanobatteries
  - **Nano-Antennas**



Autonomous Nano-Devices

I. F. Akyildiz and J. M. Jornet, ***"Electromagnetic Wireless Nanosensor Networks,"*** Nano Communication Networks (Elsevier) Journal, Vol. 1, no. 1, pp. 3-19, March 2010.
I. F. Akyildiz and J. M. Jornet, ***"The Internet of Nano-Things,"*** IEEE Wireless Communications Magazine, Vol. 17, no. 6, pp. 58-63, December 2010.

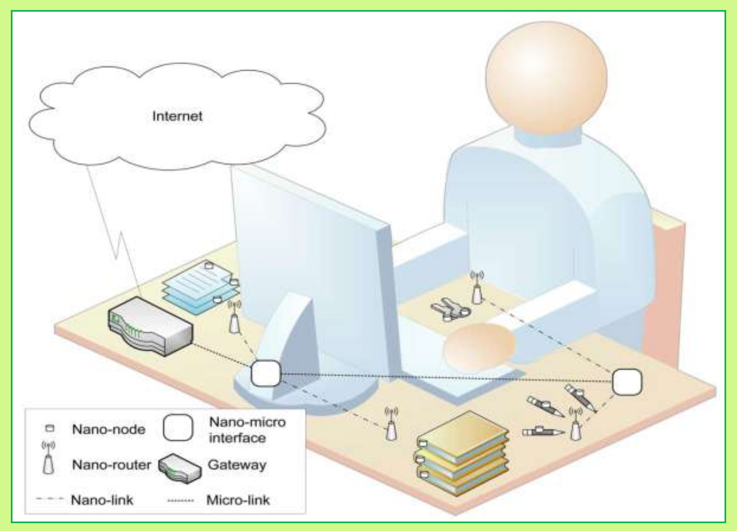
- The integration of these nano-components in a single device, just a few micrometers in size, will result in **autonomous nano-devices** able to perform specific tasks at the nano-level, such as computing, data storing, sensing or actuation.
- We propose the following conceptual architecture of a nanosensor mote with communication capabilities:



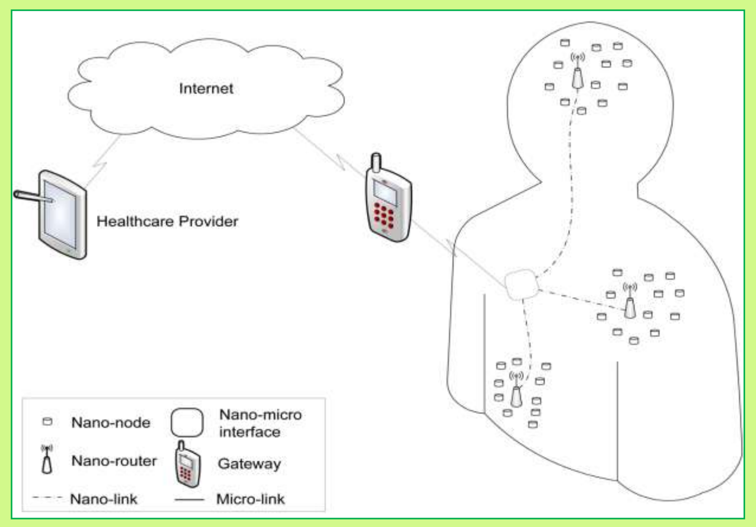
Nanonetworks: Motivation

- In order to overcome their limitations, these nano-devices can be interconnected to execute more complex tasks in a distributed manner. The resulting **nanonetworks** are envisaged to expand the capabilities and applications of single nano-machines, both in terms of complexity and range of operation.

WIRELESS NANOSENSOR NETWORKS



Consumer Goods

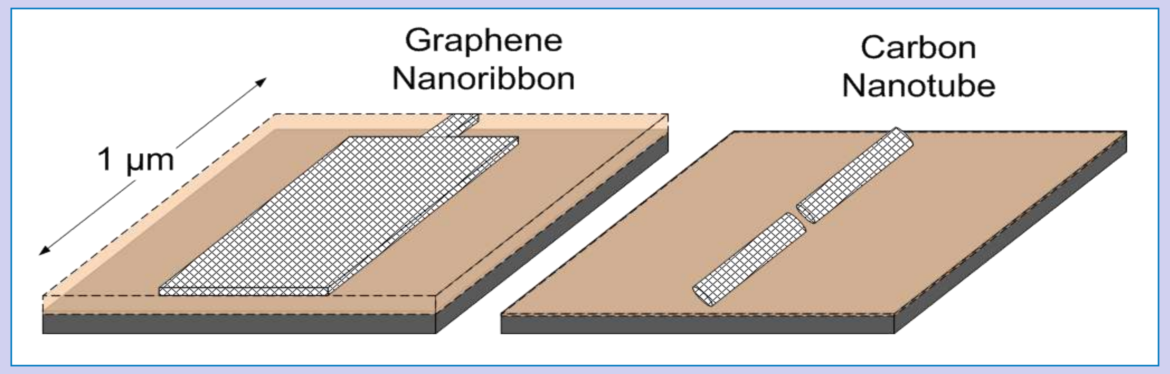


Healthcare

Graphene-Based Nano-Antennas

J. M. Jornet and I. F. Akyildiz, **"Graphene-Based Nano-Antennas for Electromagnetic Nanonetworks in the Terahertz Band,"** in Proc. of 4th European Conference on Antennas and Propagation, Barcelona, Spain, April 2010.

- Novel nanomaterials such as Carbon Nanotubes (CNTs) and Graphene Nanoribbons (GNRs) have been proposed as the building material of novel **nano-antennas**.
- Their development stems from the necessity of solutions which radiate in adequate frequencies. If we used the classical approach, antennas reduced to the nanoscale would radiate at extremely high frequencies, compromising the feasibility of the communication.

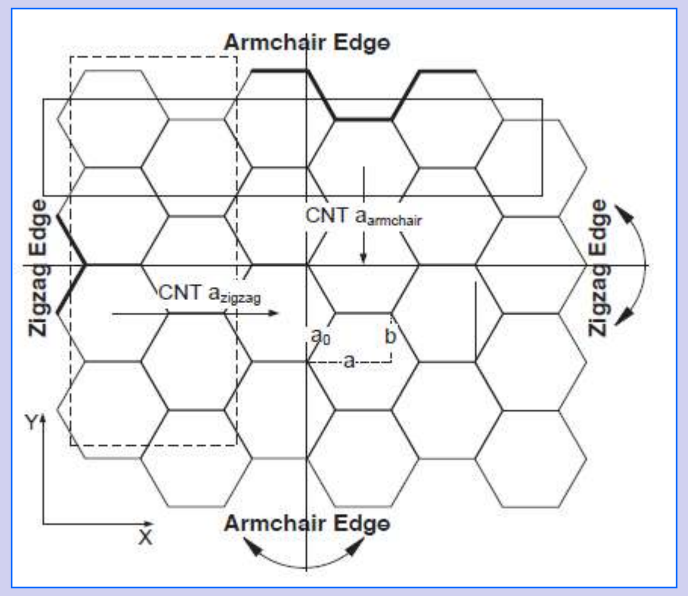


Graphene-Based Nano-Antennas (II)

- By accounting for the quantum interactions between every single atom in the graphene structure, the transmission line properties of nano-antennas can be accurately modeled, namely, kinetic inductance ($\mathcal{L}$), quantum capacitance ($\mathcal{C}$) and contact resistance *(R)*.
- These depend on the antenna dimensions, Fermi energy and the **structure of their edge**.
- The radiation frequency *(f)* can be calculated if the transmission line properties are known.

$$v_p = \frac{1}{\sqrt{\mathcal{L}\mathcal{C}}}$$

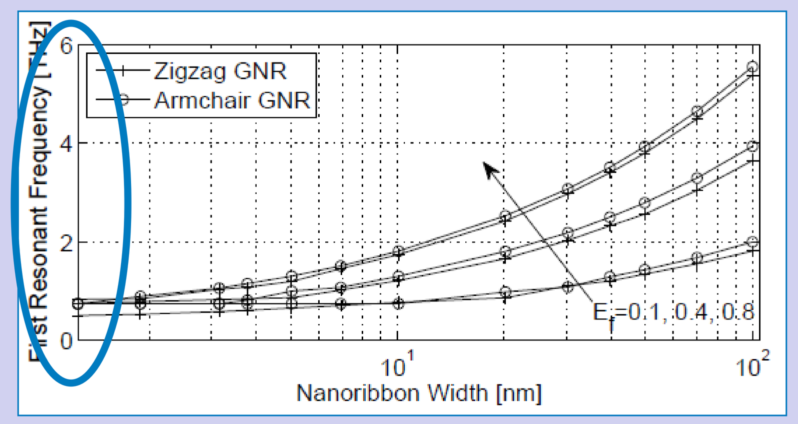
$$f = \frac{v_p}{2L}$$



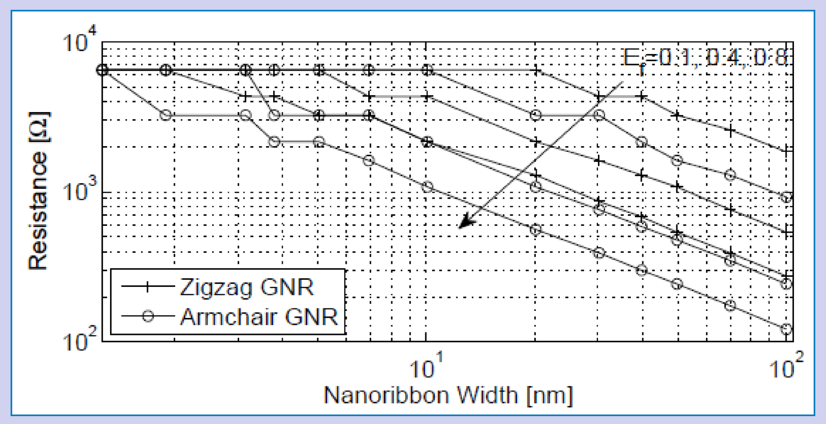
Graphene-Based Nano-Antennas (III)

- The numerical results show that the EM wave propagation speed can be up to 100 times below that of speed of light in vacuum, for CNT and GNR in both edge configurations.
- For all this, a 1 µm long antenna radiates in the **Terahertz Band** (0.1 – 10.0 THz).
- Feasible input resistances are achieved with higher voltage or larger antenna dimensions.

First Resonant Frequency



Input Resistance



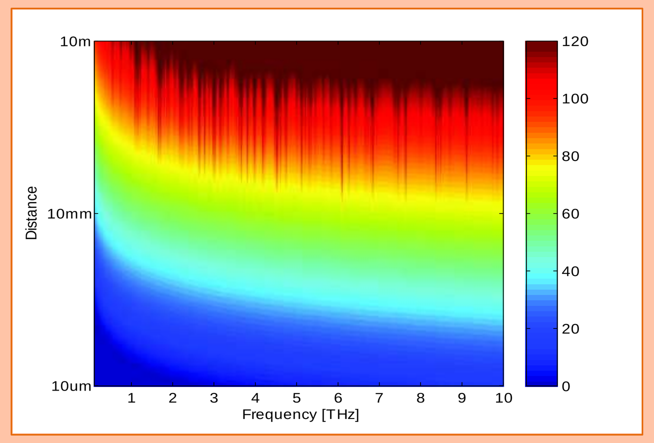
GNR-based nano-patch (L=1 µm)

Terahertz Propagation Model

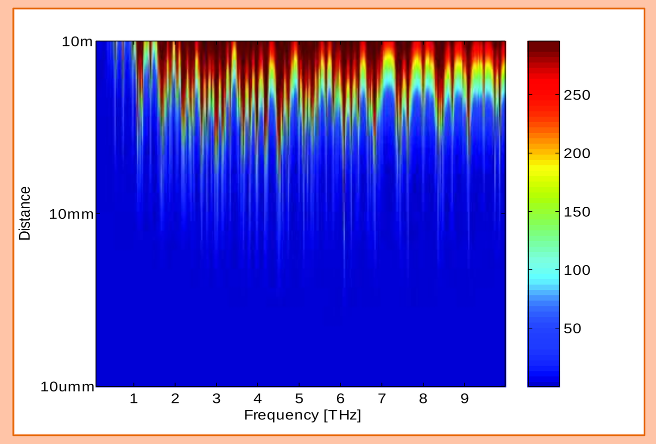
J. M. Jornet and I. F. Akyildiz, **"Channel Capacity of Electromagnetic Nanonetworks in the Terahertz Band,"** in Proc. of International Conference on Communications, ICC, Cape Town, South Africa, May 2010.
J. M. Jornet and I. F. Akyildiz, **"Channel Modeling and Capacity Analysis of Electromagnetic Nanonetworks in the Terahertz Band,"** to appear in IEEE Transactions on Wireless Communications, Fall 2011.

- The terahertz band is an **unlicensed frequency range** between 100 GHz and 10 THz.
- The terahertz channel is mainly determined by **molecular absorption**, i.e. the conversion of the wave energy into kinetic energy in several gas molecules. It determines **path-loss** and **molecular noise,** which lead to the conclusion that the channel is **highly frequency selective.**

Path-Loss



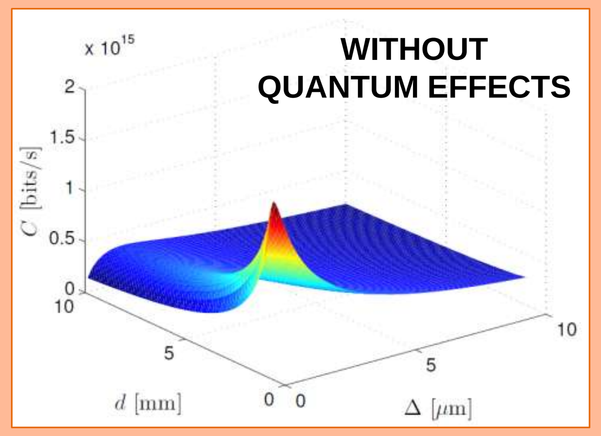
Molecular Noise

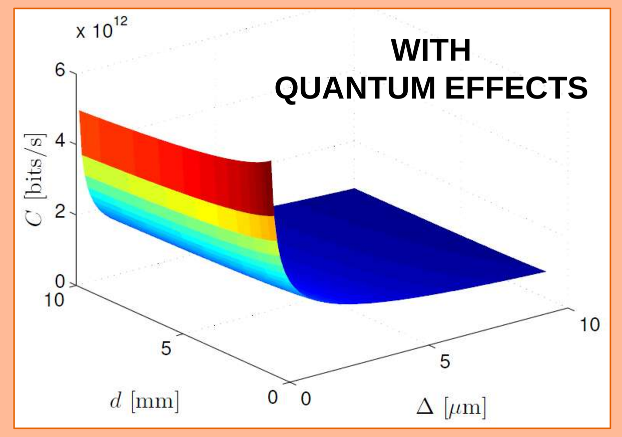


Theory of Scalability of Nanonetworks

I. Llatser, A. Cabellos-Aparicio, E. Alarcón, J. M. Jornet, I. F. Akyildiz, "**Scalability of the Channel Capacity of Graphene-enabled Wireless Networks at the Nanoscale**", submitted for Journal Publication.

- As the elements in nanonetworks inherently lie in the nanoscale, it is interesting to study how networks scale when its size is reduced.
- The dependences among **performance metrics** are analyzed:
  - Device Size
  - Transmission Distance
  - ***Channel Capacity***





Future Work on Graphene-enabled Nanonetworks

Our current projects include:

- To design, simulate and develop **experimental prototypes** of novel **graphene-based nano-antennas**.
- To provide a **channel model for THz-band** communications at the nanoscale.
- To develop a **network architecture** for Wireless Nanosensor Networks(WNSN) based on the antennas here presented.

Third NaNoNetworking Summit

June 22-23, 2011 – Barcelona

Graphene 2011, ImagineNano, Bilbao, Spain, April 11-14, 2011.