Prospects of Graphene-enabled Wireless Communications

Ignacio Llatser[1], Sergi Abadal[1], Raül Gómez Cid-Fuentes[1], Josep Miquel Jornet[1,2]
Albert Cabellos-Aparicio[1], Eduard Alarcón[1], Josep Solé-Pareta[1] and Ian F. Akyildiz[1,2]

[1]NaNoNetworking Center in Catalunya (N3Cat), UPC
[2]Broadband Wireless Networking Laboratory, Georgia Tech

Introduction

Nanotechnology and Nanosystems

- Nanotechnology is enabling the development of novel nano-components…
  - … which can individually perform specific tasks such as computation, data storing, sensing and actuation.
- The integration of several of these nano-components into a single unit will allow the development of more advanced nanosystems.
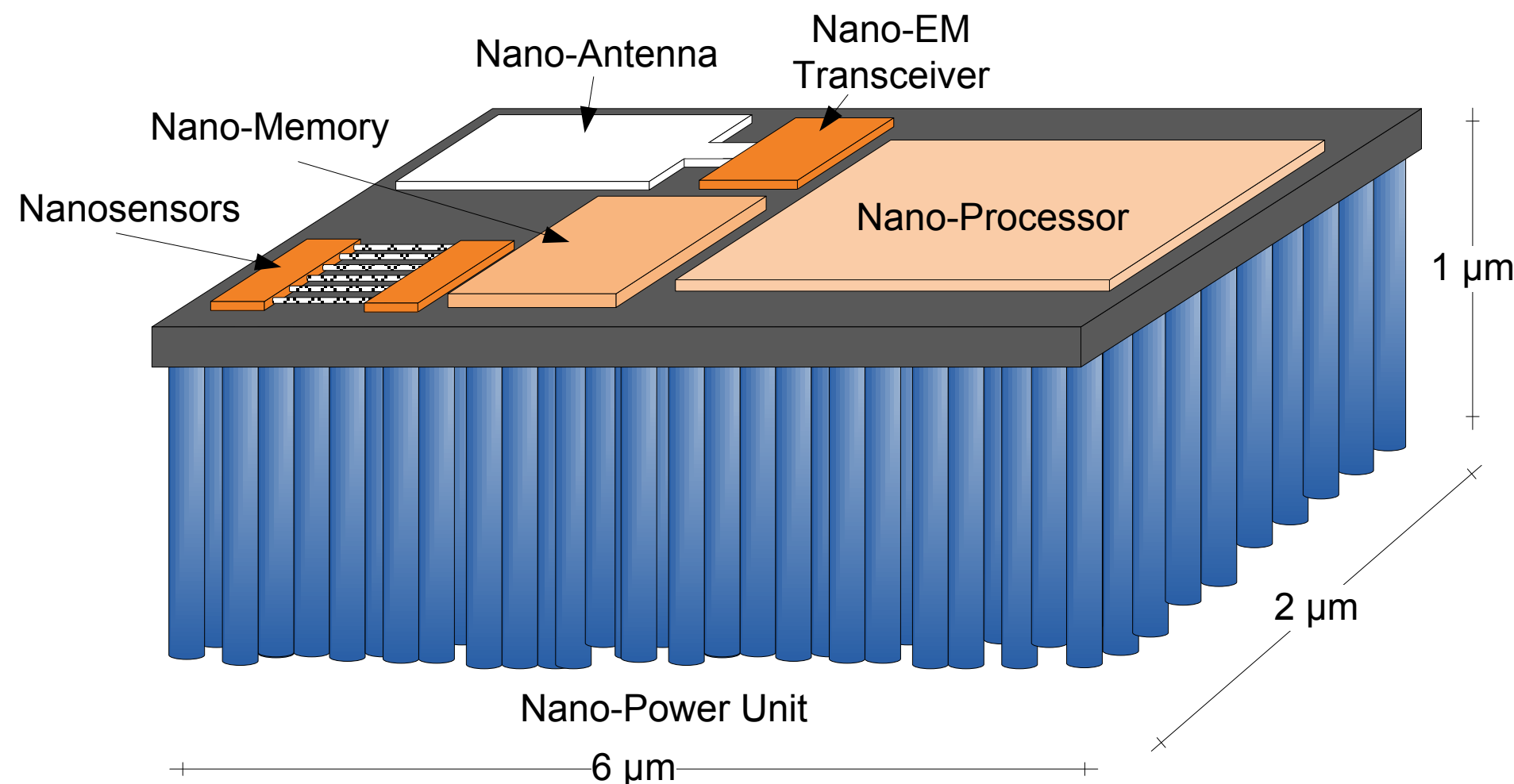
Nanoscale Communication & Networks

- By means of communication, nanosystems will be able to achieve more complex tasks in a distributed manner.
  - Nanonetworks will boost the range of applications of nanotechnology in the biomedical, industrial and military fields.
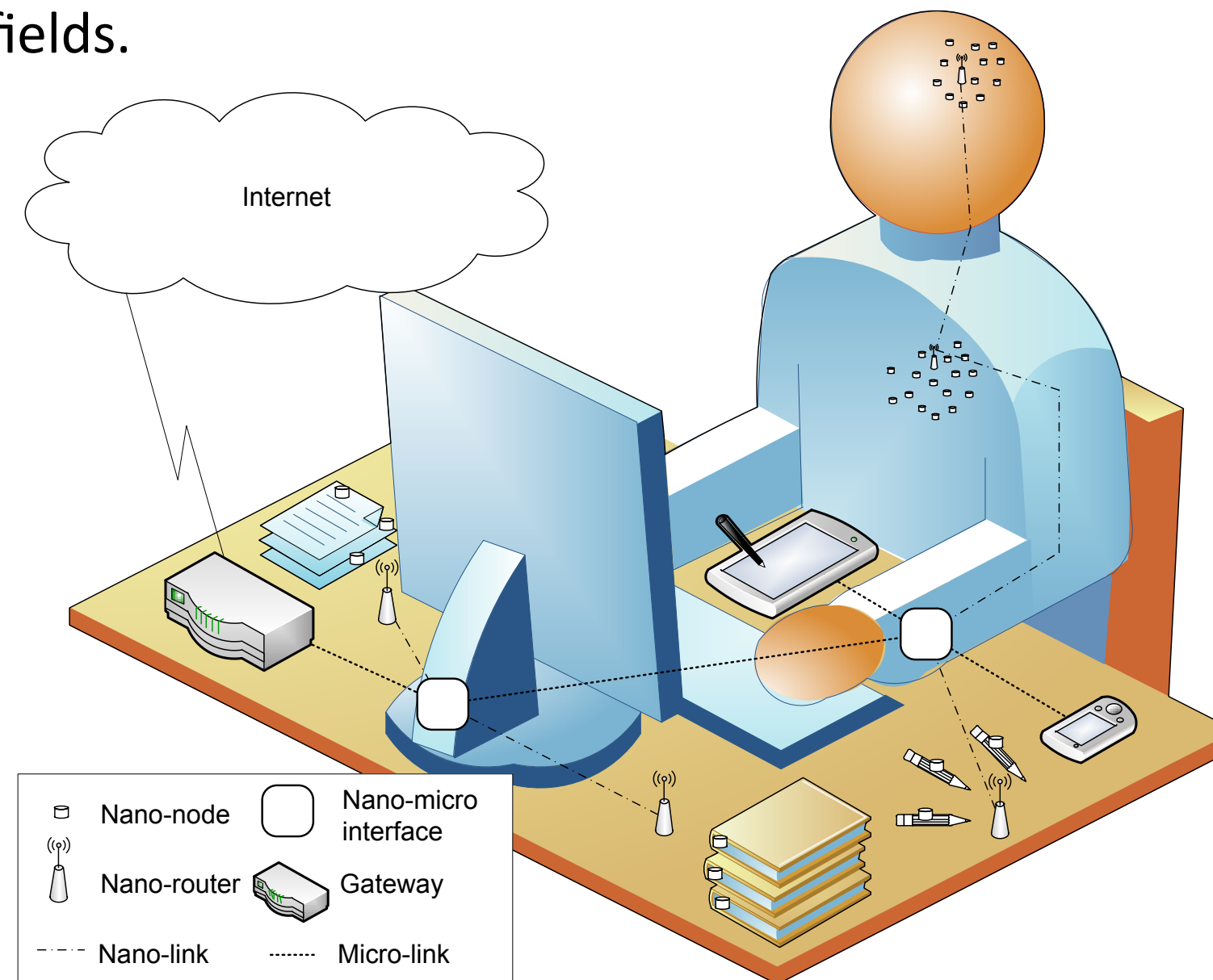
I. F. Akyildiz and J. M. Jornet, *"Electromagnetic Wireless Nanosensor Networks,"* Nano Communication Networks (Elsevier) Journal, vol. 1, no. 1, pp. 3-19, March 2010.
I. F. Akyildiz and J. M. Jornet, *"The Internet of Nano-Things,"* IEEE Wireless Communications Magazine, vol. 17, no. 6, pp. 58-63, December 2010.

Problem

- Wireless communications among nanosystems cannot be achieved by simply reducing the size of metallic antennas…
  - ... since that would impose the use of very high resonant frequencies in the optical range.
- The feasibility of nanonetworks would be compromised if this approach were followed due to:
  - The very limited power of nanosystems.
  - The low mobility of electrons in metals when nanoscale structures are considered.
  - The challenges in the implementation of a nano-transceiver able to operate at such a high frequency.

How can we reduce the antenna size without drastically increasing its resonant frequency???

Graphene-based Plasmonic Nano-antennas (GRAPHENNAS)

Graphennas

- Graphene is proposed as the enabling technology to implement wireless communication among nanosystems:
  - Graphene-based plasmonic nano-antennas, or graphennas, just a few micrometers in size, can radiate electromagnetic waves in the Terahertz Band (0.1-10 THz), which is a relatively low frequency band compared to that of metallic antennas.
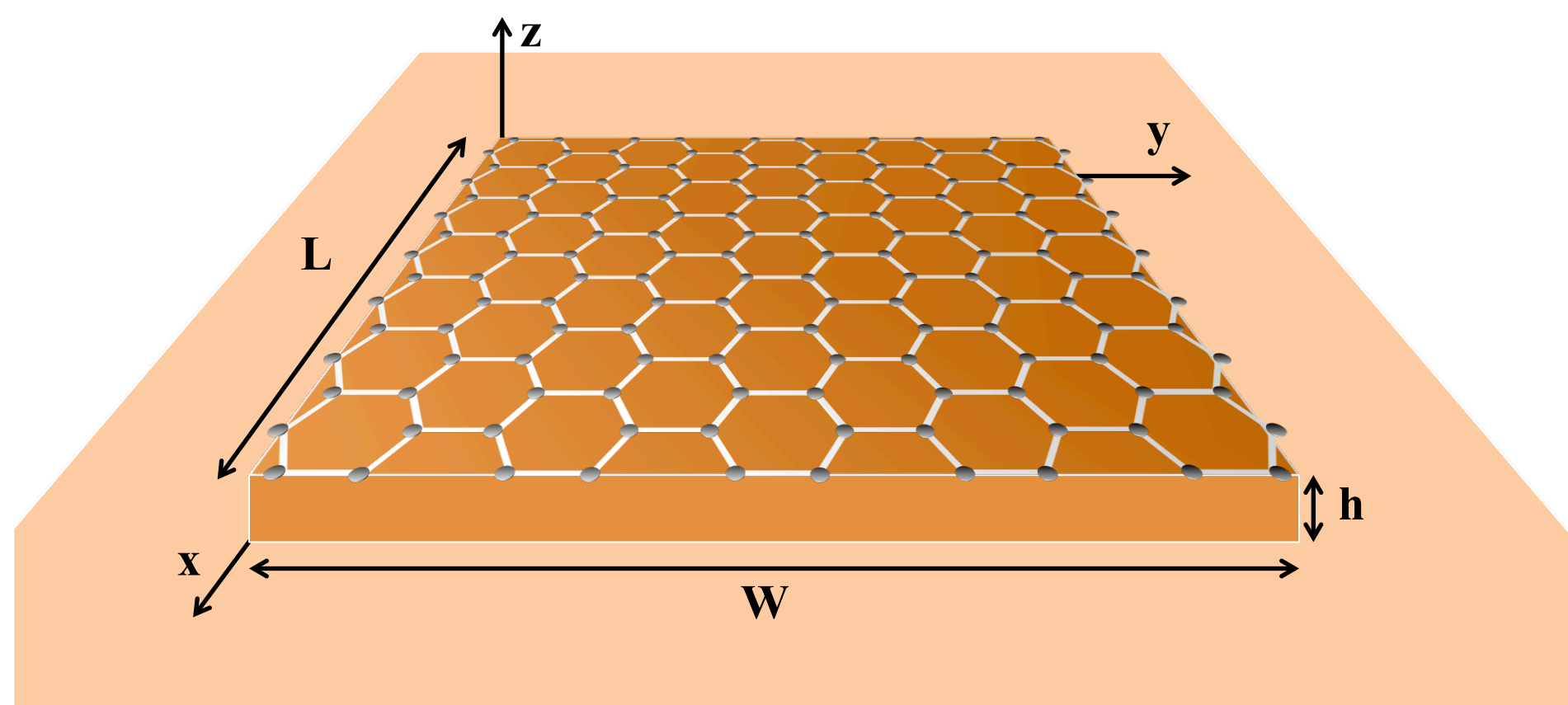
J. M. Jornet and I. F. Akyildiz, **"Graphene-Based Nano-Antennas for Electromagnetic Nanonetworks in the Terahertz Band,"** in Proc. of EUCAP, Barcelona, Spain, April 2010.
J. M. Jornet and I. F. Akyildiz, *"A Graphene-based Plasmonic Nano-Patch Antenna for Terahertz Communication in Nanonetworks,"* submitted for journal publication, 2012.

Surface Plasmon Polariton Waves

- A graphenna supports the propagation of tightly confined Surface Plasmon Polariton (SPP) waves.
- Due to their high effective mode index, the propagation speed of SPP waves can be up to two orders of magnitude below the EM wave propagation speed in vacuum:
  - First, this reduces the resonant frequency of the graphenna, enabling the use of much lower frequencies than the ones expected for such a small antenna.
  - Second, the lower radiation frequency of graphennas results in a lower channel attenuation and less strict requirements for the transceiver.
  - Third, however, the mismatch between the EM wave propagation speed in the graphenna and the free space also reduces its radiation efficiency.

I. Llatser, C. Kremers, A. Cabellos-Aparicio, J. M. Jornet, E. Alarcón, and D. N. Chigrin, *"Scattering of Terahertz Radiation on a Graphene-based Nano-antenna,"* in Proc. of the 4th International Workshop on Theoretical and Computational Nano-Photonics, TaCoNa-Photonics, Bad Honnef, Germany, October 2011.

Frequency Response

- Starting from the conductivity of finite size graphene nanoribbons, the frequency response of a graphenna can be computed:
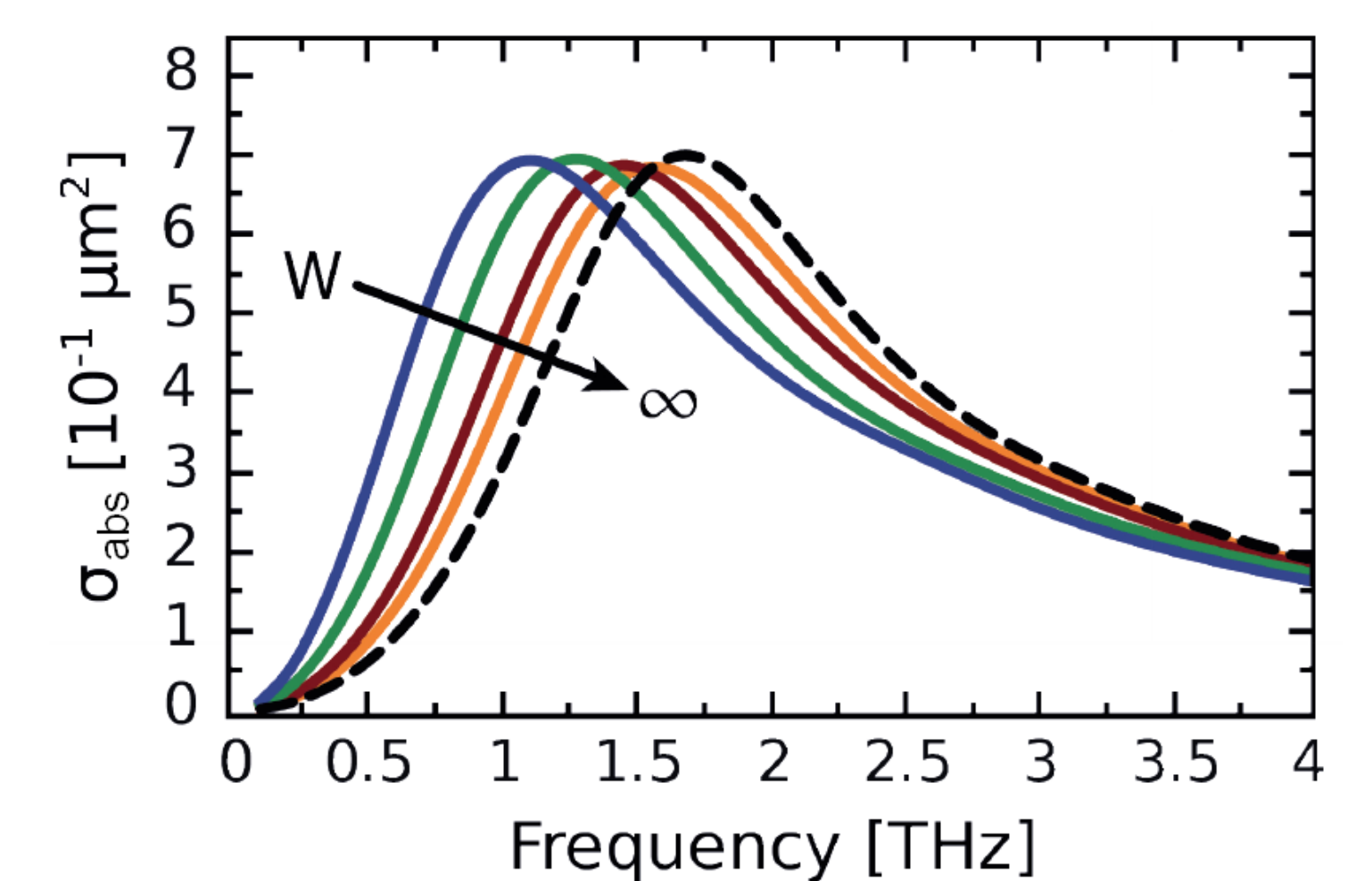
- Dependence of the absorption cross section of a graphene-based nano-patch antenna as a function of its width. The antenna length is L = 5 μm. The plots correspond to infinite, 10 μm, 5 μm, 2 μm and 1 μm wide patches (right to left).

Graphene-enabled Wireless Communications (GWC)

Truly ICT Applications

Wireless NanoSensor Networks
- Networks of nanoscale sensors that can **cooperatively measure novel nanoscale magnitudes with unprecedented accuracy.**

Wireless Networks-on-Chip
- Wireless communication in **multicore processors,** which enable **radically new computing architectures.**

Programmable Matter
- Very high density networks of nanosystems which communicate **to dynamically form tangible 3D objects.**

Ubiquitous Computing
- Networks of nanosystems that **fit the human environment instead of forcing humans to enter theirs.**

Challenges and Ongoing Work

Nano-antenna Design
- To develop a new **nano-antenna theory**.
- To build the first **graphenna prototype**.

Nano-transceiver Design
- To develop a systematic methodology for **characterization, modeling and design of graphene-based circuits**.

Terahertz Channel Modeling
- To develop a Terahertz Band **channel model**.
- To **experimentally validate** the model.

Protocols and Architecture
- To design low complexity modulations, coding schemes, and Medium Access Control, addressing and routing solutions.

NaNoNetworking Summit 2012

Barcelona, June 21-22, 2012

- The N[3]Summit aims to become the main discussion forum for researchers of the different scientific areas related to nanoscale communication networks.
- With this objective in mind, the N[3]Summit 2012 will bring together international researchers to exchange ideas and results related to the theoretical and practical aspects of nanodevices, communications among nanodevices, nano-computing and applications of nanonetworks.
- For more details, please visit: http://www.n3cat.upc.edu/n3summit2012/scope_of_papers.php