Prospects of Graphene-enabled Wireless Communications

Ignacio Llatser[1], Sergi Abadal[1], Raúl 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)
Universitat Politècnica de Catalunya
Barcelona, Spain
E-mail: {llatser,abadal,rgomez,jmjornet,acabello,pareta,ian}@ac.upc.edu, eduard.alarcon@upc.edu

[2]Broadband Wireless Networking Laboratory
School of Electrical and Computer Engineering
Georgia Institute of Technology, Atlanta, Georgia 30332, USA
E-mail: {jmjornet,ian}@ece.gatech.edu

Graphene has recently attracted the attention of the research community due to its novel mechanical, thermal, chemical, electronic and optical properties. Due to its unique characteristics, graphene has given rise to a plethora of potential applications in many diverse fields, ranging from ultra high-speed transistors to transparent solar cells.

Among these, a particularly promising emerging field is graphene-enabled wireless communications. Wireless communications among nanosystems cannot be achieved by simply reducing the size of classical metallic antennas, since that would impose the use of very high resonant frequencies in the optical range. Due to the expectedly very limited power of nanosystems, the low mobility of electrons in metals when nanometer scale structures are considered, and the challenges in implementing a nano-transceiver able to operate at this extremely high frequency, the feasibility of wireless communications at the nanoscale would be compromised if this approach were followed. Moreover, scaling down metallic antennas to a size of just a few micrometers would make them non-resonant and hence dramatically reduce their antenna efficiency.

However, due to its groundbreaking properties, graphene is seen as the enabling technology to implement wireless communications among nanosystems. Indeed, graphene-based nano-antennas, or ***graphennas***, just a few micrometers in size are envisaged to radiate electromagnetic waves in the terahertz band [1], at a dramatically lower frequency and with a higher radiation efficiency with respect to their metallic counterparts. Moreover, the progress in the development of graphene-based components shows that the high electron mobility of graphene makes it an excellent candidate for ultra-high-frequency applications [2]. Recently-published work demonstrates the great potential of graphene-based ambipolar devices for analogue and RF circuits, such as LNAs, mixers and frequency multipliers [3,4].

Indeed, a graphenna supports the propagation of tightly confined Surface Plasmon Polariton (SPP) waves [5]. 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. The consequences of this effect are twofold. On the one hand, it reduces the resonant frequency of the graphenna, enabling the use of much lower frequencies than the ones expected for such a small antenna. For instance, a graphenna with a size of a few micrometers is expected to resonate in the terahertz band (see Figure 2). The lower radiation frequency of graphennas results in a lower channel attenuation and less strict requirements for the transceiver. On the other hand, however, the mismatch between the EM wave propagation speed in the graphenna and the free space also reduces their radiation efficiency. Despite these challenges, graphene is seen as the enabling technology to implement wireless communications at the nanoscale.

In consequence, graphennas have the potential to enable wireless communications among nanosystems. Communication and information sharing among nanosystems, in its turn, will allow the implementation of nanonetworks [6], i.e., networks of interconnected nanosystems, which are envisaged to create new applications in diverse fields. Therefore, nanonetworks will enhance the capabilities of individual nanosystems both in terms of complexity and range of operation, leading to the development of a novel networking paradigm.

Figure 1 shows a conceptual diagram of a nanonetwork, consisting of a group of nanosystems communicating wirelessly with each other and with the Internet. Similarly to the way in which communication among computers enabled revolutionary applications such as the Internet, nanonetworks are envisaged to enable a large amount of long-awaited applications that will change the way in which society interacts and understands technology. These include, amongst others:

- ***Ubiquitous Computing***, which has been defined as "*machines that fit the human environment instead of forcing humans to enter theirs*". In this context, nanosystems will be integrated into everyday objects and activities, and humans will communicate and interact with them. As an example, environmental sensors (such as light or temperature) could be interconnected with biometric monitors woven into clothing in such a way that the environment automatically adapts to the user needs.
- ***Programmable Matter***, where many nanosystems will communicate among them to form tangible 3D objects that a user can interact with. This programmable matter will have the ability to change its physical properties, such as its shape, density and color, based on user input or autonomous sensing. For instance, programmable matter can provide tangible, interactive forms to information, so that a user can experience virtual objects and environments as if they were real.
- ***Wireless NanoSensor Networks*** *(WNSNs)* [7], i.e., networks of small sensors that can cooperatively measure magnitudes with unprecedented nanoscale accuracy and transmit this information to a central hub. For example, researchers have already built nanosensors able to measure physical characteristics of structures just a few nanometers in size, chemical compounds in concentrations as low as one part per billion, or the presence of biological agents such as virus, bacteria or cancerous cells. However, a single nanosensor is not enough to implement applications such as novel countermeasures against biological and chemical attacks at the nanoscale or advanced intra-body health monitoring and drug delivery systems. In order to enable these applications, collaboration among a swarm of these nanosensors by means of a WNSN will be needed.

We envisage that graphene-enabled wireless communications, and nanonetworks in general, will have a great impact in almost every field of our society, ranging from healthcare to industrial or environmental protection, and many research efforts are required for the development of this novel networking paradigm.

References

[1] J. M. Jornet, I. F. Akyildiz, Proc. European Conference on Antennas and Propagation (2010).
[2] M. C. Lemme, Solid State Phenomena **156-158** (2010), pp. 499–509.
[3] H. Wang, A. Hsu, J. Wu, J. Kong, T. Palacios, IEEE Electron Device Letters **31** (2010), pp. 906–908.
[4] S. Koswatta, A. Valdes-Garcia, M. Steiner, Y. Lin, P. Avouris, IEEE Transactions on Microwave Theory and Techniques **59** (2011), pp. 2739–2750.
[5] I. Llatser, C. Kremers, D. N. Chigrin, J. M. Jornet, M. C. Lemme, A. Cabellos-Aparicio, E. Alarcón, Proc. European Conference on Antennas and Propagation (2012).
[6] I. F. Akyildiz, F. Brunetti, C. Blázquez, Computer Networks **52** (2008), pp. 2260–2279.
[7] I. F. Akyildiz, J. M. Jornet, Nano Communication Networks **1**, (2010), pp. 3–19.

Figures

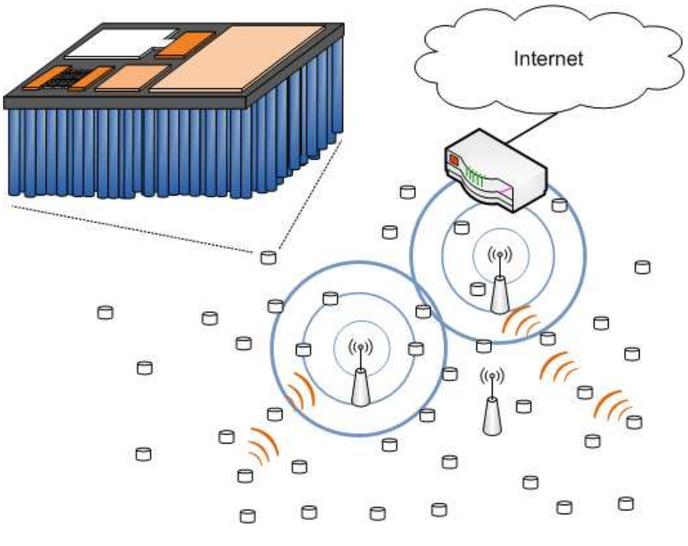

Figure 1: Conceptual diagram of a nanonetwork. The upper left corner shows a magnified individual nanosystem.

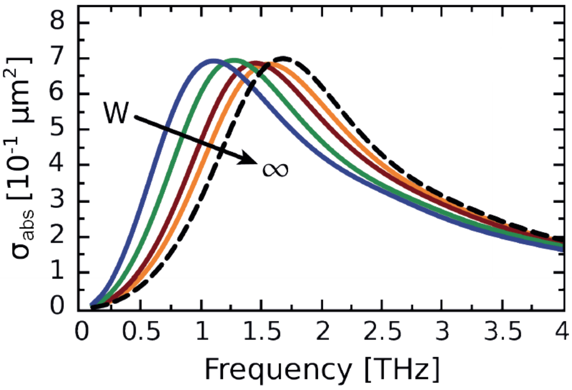

Figure 2: Dependence of the absorption cross section of a graphene-based nano-patch antenna as a function of its width. The antenna length is L = 5 μm. The plots correspond to infinite, 10 μm, 5 μm, 2 μm and 1 μm wide patches (right to left).