

WIRELESS COMMUNICATIONS AT THE NANOSCALE



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In recent years, the importance of wireless communications is increasing thanks to the numerous types of services supported by wireless devices, which allow the realization of the *always best connected* vision. However, the dramatic boost toward miniaturization and nanoscale technologies requires rethinking of wireless communications on such a scale.

In 1998, the Alliance for Telecommunications Industry Solutions (ATIS), one of the seven world leading ICT standards development organizations, introduced a definition for “wireless” [1]. This definition states that wireless is “*descriptive of a network or terminal that uses electromagnetic waves (including RF, infrared, laser, visible light and acoustic energy) rather than wire conductors for telecommunications.*”

This definition is most relevant to the traditional vision of pure electromagnetic wireless communications that are embedded in various devices found within our environment. While the transformation from wired to wireless communication has improved connectivity for end users and spawned new research areas, the field as a whole is approaching a crossroad. The main reason for this is the emergence of miniature devices, in particular devices that are built from nano components, which has led to new challenges for the wireless communication paradigm.

The field of nano communication has been developed as a new emerging area that will aim to address these challenges. This new field can be categorized into two main areas:

- Electromagnetic nano communication (EM-nano)
- Molecular communications

EM-nano communication utilizes electromagnetic waves for communication, and requires addressing a number of new challenges not covered by current wireless communication paradigms [2]. For example, unexplored frequency bands have to be utilized due to the nanoscale size of nanomachines and, thus, their antennas; also, nanonetworks require a large set of functions to be performed including addressing, information propagation, and access control, where traditional solutions may not be applicable due to the remarkable limitations in terms of computing and communication capabilities characterizing the nanomachines. Molecular communications, on the other hand, enable communication between nanomachines taking inspiration from natural biological mechanisms and requires a multidisciplinary perspective [3–7]; this new area of research is basically a cutting edge research field that is emerging to be very promising, as witnessed by the increasing number of financed research projects [8, 9].

For this special issue, we solicited research articles addressing wireless nanoscale communications under different perspectives, including pure EM-nano as well as molecular communications. A total of 25 manuscripts were received in response to our solicitation. Each article underwent two rounds of rigorous review, and finally seven papers were accepted for publication.

Starting from a molecular perspective, the article entitled “MoNaCo: Fundamentals of Molecular Nano-Communication Networks” by Akyildiz *et al.* presents a branch of research focused on investigating the use of molecules to encode and transmit information among nanomachines as a viable solution to realize nano-communication networks.

A similar perspective is explored in “Calcium Signaling: An Overview of a Molecular Communication Paradigm” by Kurian *et al.*, where the authors focus their attention on mechanisms for molecular communications based on calcium signaling. Calcium signaling is a natural intercellular calcium wave found in biology cells that enables communication at short range between cells. Using this form of signaling can enable short-range communication that exploits a combination of biological constructs and engineered cells.

In “A New Frontier of Wireless Communications Theory: Diffusion-Based Molecular Communications” by Cheng *et al.*, the authors explore the communication theoretical analogs and differences between electromagnetic and molecular concepts in wireless communications. In particular, the authors explored the mechanisms of channel coding and intersymbol interference with a particular focus on diffusion-based molecular communications.

Also, in “Networking Challenges and Principles of Molecular Communication” by Llatser *et al.*, diffusion-based molecular communication (DMC) is addressed where information encoded into a concentration of molecules is diffused throughout the medium. In this work, again a parallelism between the physical channel of DMC and concepts taken from wireless electromagnetic communications is considered. The main challenges of DMC are discussed, and guidelines for the design of a novel network architecture for DMC networks are provided.

The article “Enabling Communication and Cooperation in Bio-Nanosensor Networks: Toward Innovative Healthcare Solutions” by Agoulmine *et al.* discusses a new class of eHealth solutions inspired by bionanosensors working at a microscopic size inside the human body. These miniaturized biosensors will be able to

communicate to exchange information about sensed molecules or chemical compound concentration and therefore draw a global response in case of anomaly. In order to realize this capability, two communication techniques are reviewed: electromagnetic wireless communications in the terahertz band and molecular communications. The characteristics of these two modes of communication are highlighted, and a general architecture for the bionanosensors is proposed along with examples of a cooperation scheme.

Moving to a pure electromagnetic perspective, the article entitled “Applications and Performance of a Nanoreceiver with Carbon Nanotube Antenna Forest” by Koksal *et al.* discusses an RF nanoreceiver based on a forest of carbon nanotube (CNT) antennas packaged together. The authors present a discussion on the robustness of CNT receivers for scenarios of both low and high signal-bandwidth at given SNR values. The relationship presented by the authors, shows that the achieved rate grows as $n(1/4)$ with the number of CNTs.

Due to the high level of spatial miniaturization achievable using this CNT technology, many millions of CNTs can be packaged together, resulting in achievable rates comparable to commercially available wireless receivers.

Finally, Matolak *et al.*, in their article entitled “Wireless Networks-on-Chips: Architecture, Wireless Channel, and Devices,” discuss hybrid wired/wireless architectures for wireless networks-on-chips (WINoCs), which hold substantial promise for enhancing multicore integrated circuit performance by augmenting conventional wired interconnects.

Use of wireless connections can help to both save power and reduce latency. In this article the iWISE architecture is designed and illustrated with the aim of a scalable wireless interconnect design. Interesting results on the integration of wireless and wired interconnects in NoCs are drawn, thus allowing the power consumption to be reduced by more than 30 percent while speeding up real applications by a factor of 2.5.

Research in wireless communications at the nanoscale is bound to increase in coming years. We have had the great pleasure of putting together this special issue, composed of new exciting research work that highlights recent advances in wireless communications at the nanoscale. We thank the numerous authors who submitted papers to this special issue, and the anonymous referees for their timely and conscientious reports. The result is a fine collection of articles we are confident will lay a strong foundation for this new emerging area, and result in exciting reading for the wireless communication audience. We also want to thank Editor-in-Chief Prof. Hsiao-Hwa Chen and former Editor-in-Chief, Prof. Y. M. Fang for their support in making this special issue a great success.

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BIOGRAPHIES

LAURA GALLUCCIO [M] (lauragalluccio@gmail.com) received her laurea degree in electrical engineering from the University of Catania, Italy, in 2001. In March 2005 she got her Ph.D. in electrical, computer, and telecommunications engineering from the same university. In 2002 she joined the Italian National Consortium of Telecommunications (CNIT), where she worked as a research fellow within the VICOM and SATNEX Projects. Since November 2010 she has been an assistant professor at the University of Catania. Her research interests include nanocommunication networks, ad hoc and sensor networks, protocols and algorithms for wireless networks, and network performance analysis. In 2005 she was a visiting scholar at the COMET Group, Columbia University, New York. She is member of Sigmobile. She has been Guest Editor for Elsevier *Ad Hoc Networks Journal*, Special Issue on Cross-Layer Design in Ad Hoc and Sensor Networks, and is Associate Editor of Wiley *Wireless Communications and Mobile Computing Journal* and Elsevier *Ad Hoc Networks Journal*. She was also Demo Chair of ACM Sigmobile MobiOpp 2010 and TPC Member of numerous prestigious ACM and IEEE conferences. She was the recipient of the Marisa Bellisario International Prize in 2002.

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