Guest Editorial
Special Feature on Bio-Chem-ICTs: Synergies Between Bio/Nanotechnologies and Molecular Communications

I. Introduction

THE TRANSFER of 'information' via molecules is a theme that resonates across the realm of nature, underlying collective behavior, homeostasis, and many disorders and diseases, and potentially holding the answers to some of the life's most profound questions. The prospects of understanding and manipulating this natural modality of communication have attracted a significant research interest from information and communication theorists (ICT) over the past two decades. The aim is to provide novel means of understanding and engineering biological systems. These efforts have produced substantial body of literature that sets the groundwork for bio-inspired, artificial *Molecular Communication (MC)* systems. This ICT-based perspective has also contributed to the understanding of natural MC, with many of the results from these endeavors being published in this journal.

It is no wonder that this fundamental form of communication has been a topic of significant interest in many diverse research domains beyond just ICT, such as synthetic biology, systems chemistry, micro/nanorobotics, network medicine, biochemical sensing, molecular and biological computing. Despite the significant overlap in both problem and application domains, there have been only a few isolated efforts to bridge the gaps across these fields. Some of these attempts have given rise to innovative and unifying concepts, such as Bio-Chem-ICTs and the Internet of Bio-Nano Things (IoBNT), leveraging MC alongside unconventional forms of computation, networking, and micro- and nano-scale production. One potential barrier to further progress, therefore, can be identified as the lack of strong interactions among different research communities. This challenge is not solely due to the inherent diversity of research methodologies and solution approaches, but also stems from different languages embraced by these communities, which tend to remain isolated within their specific publication venues. Yet, fostering closer ties among these disciplines can stimulate invaluable synergies, and help collaboratively address more challenging research problems and create unprecedented applications.

In line with the interdisciplinary vision of IEEE TRANSACTIONS ON MOLECULAR, BIOLOGICAL, AND MULTI-SCALE COMMUNICATIONS, the goal of this special feature is to bridge these divides, by bringing together the contributions of prominent researchers from diverse fields that share a common denominator with the ICT approach to MC. Through this compilation, we aim to highlight the powerful intersections that may emerge when the disciplinary boundaries are blurred.

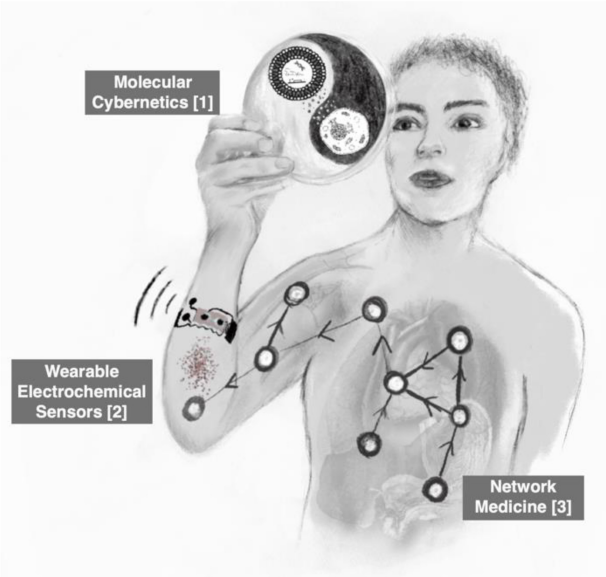

Fig. 1. Research areas highlighted in the Special Feature.

II. Overview of Accepted Articles

This Special Feature on Bio-Chem-ICTs presents three review articles from seemingly distinct fields (Fig. 1); yet, each highlights a research domain where the integration of bio/nanotechnologies with molecular communications offers substantial potential.

The first paper [A1] by Kuzuya et al. introduces the emerging paradigm of *molecular cybernetics*, where molecular robotics blends with molecular communications, culminating in the development of chemical artificial intelligence (Chemical AI). The authors provide a brief review of recent achievements concerning the realization of three

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main functions in artificial cells possessing lipid membranes: sensing, processing, and actuating, which are essential for the envisioned chemical AI systems. The authors' insights into future directions highlight the pivotal role of molecular communications in this domain.

The second paper [A2] by Mirlou and Beker presents a seamless integration of bio/nanotechnologies and ICT, providing an overview of state-of-the-art flexible and *wearable electrochemical sensors* capable of continuously and non-invasively monitoring molecular biomarkers (e.g., hormones) across various biofluids, including sweat and tear, and transmitting this information to mobile devices. As the authors articulate in their review, these technologies hold a central role in IoBNT applications as bio-cyber interfaces that can interconnect molecular networks and conventional electromagnetic networks.

Finally, the third paper [A3] by Ayar et al. provides an investigation into the field of *network medicine*, reviewing recent approaches from network theory to understand the human interactome and its associations with diseases and drug resistance. After outlining the challenges and presenting the standard workflows employed in the field, the authors share their perspectives on the potential intersections of network medicine with MC research.

APPENDIX: RELATED ARTICLES

[A1] A. Kuzuya, S.-I. M. Nomura, T. Toyota, T. Nakakuki, and S. Murata, "From molecular robotics to molecular cybernetics: The first step toward chemical artificial intelligence," *IEEE Trans. Mol. Biol. Multi-Scale Commun.*, vol. 9, no. 3, pp. 354–363, Sep. 2023.

[A2] F. Mirlou and L. Beker, "Wearable electrochemical sensors for healthcare monitoring: A review of current developments and future prospects," *IEEE Trans. Mol. Biol. Multi-Scale Commun.*, vol. 9, no. 3, pp. 364–373, Sep. 2023.

[A3] E. Ayar, S. Dadmand, and N. Tuncbag, "Network medicine: From conceptual frameworks to applications and future trends," *IEEE Trans. Mol. Biol. Multi-Scale Commun.*, vol. 9, no. 3, pp. 374–381, Sep. 2023.

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Murat Kuscu (Member, IEEE) received the first Ph.D. degree in electrical and electronics engineering from Koç University, Turkey, in 2017, and the second Ph.D. degree in engineering from the University of Cambridge, U.K., in 2020. He is currently an Assistant Professor and a Marie Skłodowska-Curie Fellow with the Department of Electrical and Electronics Engineering, Koç University, where he is also acting as the Director of Nano/Bio/Physical Information and Communications Laboratory and the Assistant Director of Nanofabrication and Nanocharacterization Center. His research interests include the Internet of Bio-Nano Things, molecular information and communication technologies, graphene and related 2-D nanomaterials, biosensors, bio-cyber interfaces, ligand-receptor interactions, and microfluidics.

Pasquale Stano received the M.S. degree in chemistry from the University of Pisa, Italy. Then he moved to ETH Zürich, Switzerland, to join the Supramolecular Chemistry Group of Pier Luigi Luisi for a Liposome-Based Drug Delivery Project. Next, he was awarded by a Research Grant with Enrico Fermi Research Center, Rome, Italy, and worked as an Assistant Professor with Roma Tre University, Rome. Taking parts to international projects on the construction of chemical cell-like systems (EU-FP6 SynthCells and HFSP Minimal Cell), he has gained expertise on reactions in micro-compartments. He is currently an Associate Professor of Organic Chemistry with the University of Salento, Lecce, Italy. His interests are in the fields of synthetic biology, origins of life, systems chemistry, artificial life, bio-organic chemistry, organocatalysis, autopoiesis-and-cognition, and philosophy of science. He is currently involved in editorial roles for several journals.

Malcolm Egan received the Ph.D. degree in electrical engineering from The University of Sydney, Australia, in 2014. Previously he was an Assistant Professor with INSA Lyon and a Postdoctoral Researcher with the Laboratoire de Mathématiques, Université Blaise Pascal, France, and the Department of Computer Science, Czech Technical University, Prague, Czech Republic. He is currently a Chargé de Recherche (Permanent Research Staff) with INRIA hosted by CITI, a joint Laboratory between INRIA, INSA Lyon, and Université de Lyon, France. His research interests include information theory and statistical signal processing with applications in wireless and molecular communications. He is currently an Associate Editor of IEEE COMMUNICATIONS LETTERS and previously a Guest Editor of IEEE ACCESS.

Michael T. Barros (Member, IEEE) received the Ph.D. degree in computer science from South East Technological University, Ireland, in 2016. He has been an Assistant Professor (Lecturer) with the School of Computer Science and Electronic Engineering, University of Essex, U.K., since June 2020. He is the Head of Unconventional Communications and Computing Laboratory, which is part of the Communications and Networks Research Group. He has over 80 research peer-reviewed scientific publications in top journals and conferences, such as *Scientific Reports* (Nature), IEEE TRANSACTIONS ON COMMUNICATIONS, and IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, and in the areas of molecular and unconventional communications, biomedical engineering, bionano science, and Beyond 5G. He received the CONNECT Prof. Tom Brazil Excellence in Research Award in 2020. Since 2020, he has been a Review Editor of the *Frontiers in Communications and Networks* in the area of unconventional communications. He also served as a Guest Editor for the IEEE TRANSACTIONS ON MOLECULAR, BIOLOGICAL AND MULTI-SCALE COMMUNICATIONS.

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