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

Murat Kuscü, Pasquale Stano, Malcolm Egan, Michael Barros, Bige Deniz
Unluturk, Gregory Payne

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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 TMBMC, 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.

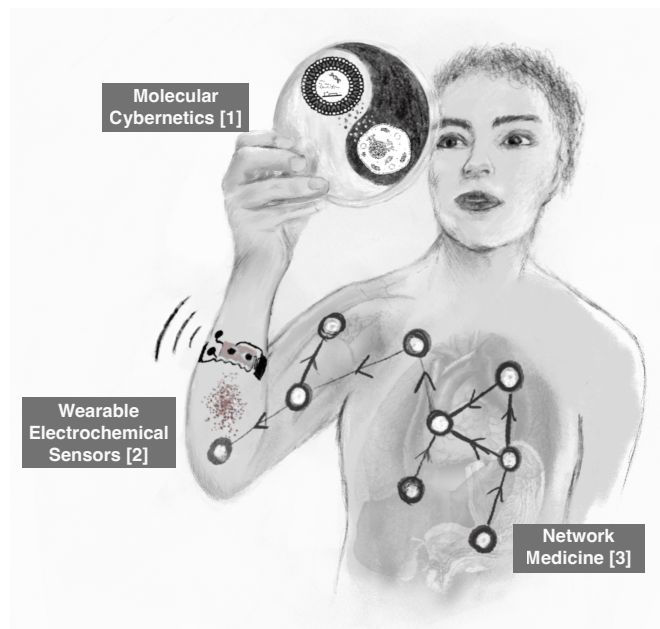


Fig. 1. Research areas highlighted in the Special Feature.

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 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.

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Murat Kescu (Member, IEEE) received his PhD degrees in engineering from University of Cambridge, UK, in 2020, and in electrical and electronics engineering from Koç University, Turkey, in 2017. He is currently an Assistant Professor and a Marie Skłodowska-Curie Fellow at the Department of Electrical and Electronics Engineering, Koç University, Turkey, where he is also acting as the Director of Nano/Bio/Physical Information and Communications Laboratory (CALICO Lab), and the Assistant Director of the Nanofabrication

and Nanocharacterization Center (n2STAR). His research interests include the Internet of Bio-Nano Things, molecular information and communication technologies, graphene and related 2D 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 Switzerland, to the ETH Zürich, 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 at the Enrico Fermi Research Center (Rome, Italy), and worked as assistant professor at the Roma Tre University (Rome, Italy). Taking parts to international projects on the construction of chemical cell-like systems (EU-FP6 SynthCells, HFSP Minimal Cell), he has

gained expertise on reactions in micro-compartments. Currently he is associate professor of Organic Chemistry at the University of Salento (Lecce, Italy), and involved in editorial roles for several journals. His interests are in the fields of synthetic biology, origins of life, systems chemistry, artificial life, bio-organic chemistry, organocatalysis, autopoiesis-and-cognition, philosophy of science.



Malcolm Egan received the Ph.D. degree in electrical engineering from the University of Sydney, Australia, in 2014. Previously he was an Assistant Professor at INSA Lyon, and a Postdoctoral Researcher at the Laboratoire de Mathématiques, Université Blaise Pascal, France, and the Department of Computer Science, Czech Technical University in Prague, Czech Republic. He is currently a Chargé de Recherche (Permanent Research Staff) at 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 for IEEE Communications Letters and previously a Guest Editor of IEEE Access.



Michael T. Barros (Member, IEEE) (M'16) Dr Barros is an Assistant Professor (Lecturer) since June 2020 in the School of Computer Science and Electronic Engineering at the University of Essex, UK. He received the PhD in Computer Science at the South East Technological University, Ireland, in 2016. He is the head of the 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 Nature Scientific Reports, IEEE Transactions on Communications, IEEE Transactions on Vehicular Technology, in the areas of molecular and unconventional communications, biomedical engineering, bionano science and Beyond 5G. Since 2020, he is a review editor for the Frontiers in Communications and Networks journal in the area of unconventional communications. He also served as guest editor for the IEEE Transactions on Molecular, Biological and Multi-Scale Communications. He received the CONNECT Prof. Tom Brazil Excellence in Research Award in 2020.



Bige Deniz Unluturk (Member, IEEE) received the graduation degree in electrical and electronics engineering from Middle East Technical University, Ankara, Turkey, in 2011, the M.Sc. degree from Koç University, Istanbul, Turkey, in 2013, and the Ph.D. degree in electrical and computer engineering from the Georgia Institute of Technology, Atlanta, GA, USA, in August 2020, under the guidance of Prof. Dr. Ian F. Akyildiz. She is currently an Assistant Professor with the Department of Electrical & Computer Engineering and Biomedical Engineering,

Michigan State University, East Lansing, MI, USA, since 2021. Between August 2020 and August 2021, she was a Postdoctoral Research Associate with Dr. Chris Contag's Lab, Institute for Quantitative Health Science and Engineering, MSU. Her research interests include wireless communication and networking, more specifically molecular communications and internet of bio nanothings and their applications to healthcare.



Gregory F. Payne received the B.S. and M.S. degrees from Cornell University, Ithaca, NY, USA, and the Ph.D. degree from the University of Michigan Ann Arbor, Ann Arbor, MI, USA. He is currently a Professor with the University of Maryland at College Park. He is also the guest or chair professor at several universities around the world. His group does research at the intersection of material science, biology, and information sciences. His work is internationally recognized by invitations to be a keynote speaker at several scientific conferences. He is currently a Principal Investigator of the prestigious Materials Genome Initiative Project of the National Science Foundation with the aim of understanding

how to integrate biology and electronics.