DIPARTIMENTO DI INGEGNERIA
CORSO DI DOTTORATO IN INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE -
PHD COURSE IN INDUSTRIAL AND INFORMATION ENGINEERING - 37TH CYCLE

Title of the research activity:	**Molecular communications for interfacing and modeling living systems**
State of the Art:	The Molecular Communications (MolCom) field is an emerging research area that promises significant breakthroughs in some strategic socio-economic fields. MolCom encompasses multi-disciplinary research that brings together information and communication technologies, molecular biology, physics, chemistry, biotechnology, as well as technologies that will realize the vision of transferring information within biological environments at extremely small scales, down to a size comparable to that of molecules. MolCom consists of transmission of information by means of exchange of molecules, carried out by either natural or artificial nanomachines. The physical mechanisms that allow transferring information at such small scales are typically inspired by the biological mechanisms that exist in living bodies to exchange many types of signaling molecules, such as proteins, pheromones, and immune system activation signals, both within and between different cells. To draw a general picture of the subject, these communication mechanisms can be broadly classified as follows: (i) Diffusion-based molecular communications are implemented through molecules, typically referred to as carriers that propagate through a fluidic medium. Molecule propagation is modeled by the laws of diffusion, sometimes integrated by other motion components such as the drag present in blood vessels. A specialized form of diffusion is found in the human cellular tissues, where molecules propagation (e.g. calcium) is mediated through cell-cell communication. Cells are connected via gap junction channels, which allow the flow of molecules from one cell to another. The information is usually encoded in either the timing or the amplitude of the concentration of molecules. (ii) Flow-based molecular communications consists of a guided motion of molecules that propagate through a microfluidic device or natural pipe, such as a blood vessel. (iii) Active-based molecular communication is a further classification that encompasses a motor-based carrier for transporting information molecules. An example is molecular motors that walk along the act in filament rails found inside the cells. Another example is the use of flagellated bacteria that swim and carry information encoded into DNA molecules. The unconventional nature of MolCom needs the contribution of competences coming from multi-disciplinary fields, as described earlier. This multidisciplinary nature characterizes also the tools that are used to design and analyze such systems. In addition to the analytical tools that have been developed, the complexity of the problem usually requires the use of simulators tailored to the specific biological environment, to be validated by wet lab experiments. In fact, for a simulator to be useful for investigating the detailed interactions that occur at extremely small scales, it must implement at the desired level of abstraction the elementary interaction mechanisms that characterize the analyzed

	environment. The combined usage of solid and established analytical model, simulations, and wet lab experiments represent the instruments by which a researcher can approach the novel field of MolCom.
Short description and objectives of the research activity:	MolCom has established as one of the novel interdisciplinary research themes with strongest impact of the last five years. While most of the relevant research is devoted to investigate techniques to model and/or design artificial molecular communications systems, focusing on reliability, bit rate, range extensions, and so on, mimicking and inspiring to classic wireless communication paradigms, a lot of research MolCom can span in different and novel areas. In particular, MolCom research offers new possibilities to model communications within living systems. For instance, they can be used to measure and model noise, information tranfer rate, and interference between protein networks. In addition to modeling living systems, another almost unexplored research area consists of using MolCom to enable the establishment of a communication control interface between the living system itself and external technologies, opening uncountable applications and research opportunities. For instance, during the ongoing COVID-19 pandemic has been realized that within the prognostic factors to consider, there are not only registry (advanced age and sex), clinical (presence of comorbidities - e.g. hypertension, cerebro- and cardio-vascular diseases, diabetes), but also laboratory factors. This includes lymphopenia, high red blood cell and neutrophil counts, high levels of d-dimer, C-reactive protein, LDH, AST, ALT, CK, and some cytokines/chemokines such as IL2, IL6, IL7, IL10, GSCF, IP10, MCP1, MIP1A, TNFα. Thus, MolCom can leverage its specificity and be used to monitor specific conditions that favour the resistance to the COVID-19 or other future similar diseases, or to control the activation/deactivation of these biological agents. Thus, the main research topics will be the design of new tools for modelling/controlling living system exploiting the potentials of MolCom, as well as new methods and technologies to interface with living systems, including forthcoming 6G networks coupled with MolCom technologies.
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