HORIZON 2020

CIRCLE

COORDINATING EUROPEAN RESEARCH ON MOLECULAR COMMUNICATIONS

D3.3 Knowledge Sharing and Best Practice Progress Report

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1. Introduction

This deliverable reports on the progress of the knowledge sharing activities and the identified best practice roadmap in CIRCLE after the first year of the project.

A critical perspective is presented, with the aim of both highlighting the achieved results and the identified existing issues which characterize the highly interdisciplinary field of molecular communications.

Furthermore, this document illustrates the activities and the initiatives undertaken within the first year of CIRCLE WP3 activities, the established joint research initiatives, and the strategic plans for the second year of the project.

As illustrated in the deliverable D3.1, the activities related to knowledge sharing and best practices contribute to the achievement of all the CIRCLE objectives, reported in what follows for the readers' convenience:

> **O1** Harmonize heterogeneous islands of research in Molecular Communications across Europe by providing a structured research agenda through the collaborative specification and continual refinement of a research roadmap that will be developed within CIRCLE project.
>
> **O2** Stimulate guided learning for young researchers entering the area of Molecular Communications, through improving efficiency of knowledge acquisition in key disciplines.
>
> **O3** Build a structured community across Europe of research leaders and collaborators working in the area of Molecular Communications.
>
> **O4** Accelerate the exchange of knowledge and best practice between researchers with Europe and internationally focusing on Molecular Communications.
>
> **O5** Facilitate a staff exchange program between partners within CIRCLE specifically focusing on young researchers.
>
> **O6** Reduce the barriers for entry into the area of Molecular Communications for high tech SMEs through the collaborative specification and continual refinement of an industry engagement roadmap (mainly addressed by WP4).

These objectives have been mapped in the structure of the WP3, the tasks of which are:

Task 3.1 Collect and exchange knowledge between research groups (**O1, O2, O3**)
Task 3.2 Collect and exchange simulation/modeling tools used in Molecular communications (**O4**)
Task 3.3 Collect and exchange approaches and experimental methodologies (**O4**)
Task 3.4 Collect and exchange knowledge / best practice at Member State and EU level (**O3, O5, O6**)

The knowledge and best practice sharing initiatives in CIRCLE have been organized according to the scheme shown in Figure 1. The figure shows also the relations between individual activities and their association with the CIRCLE objectives and the WP3 Tasks.

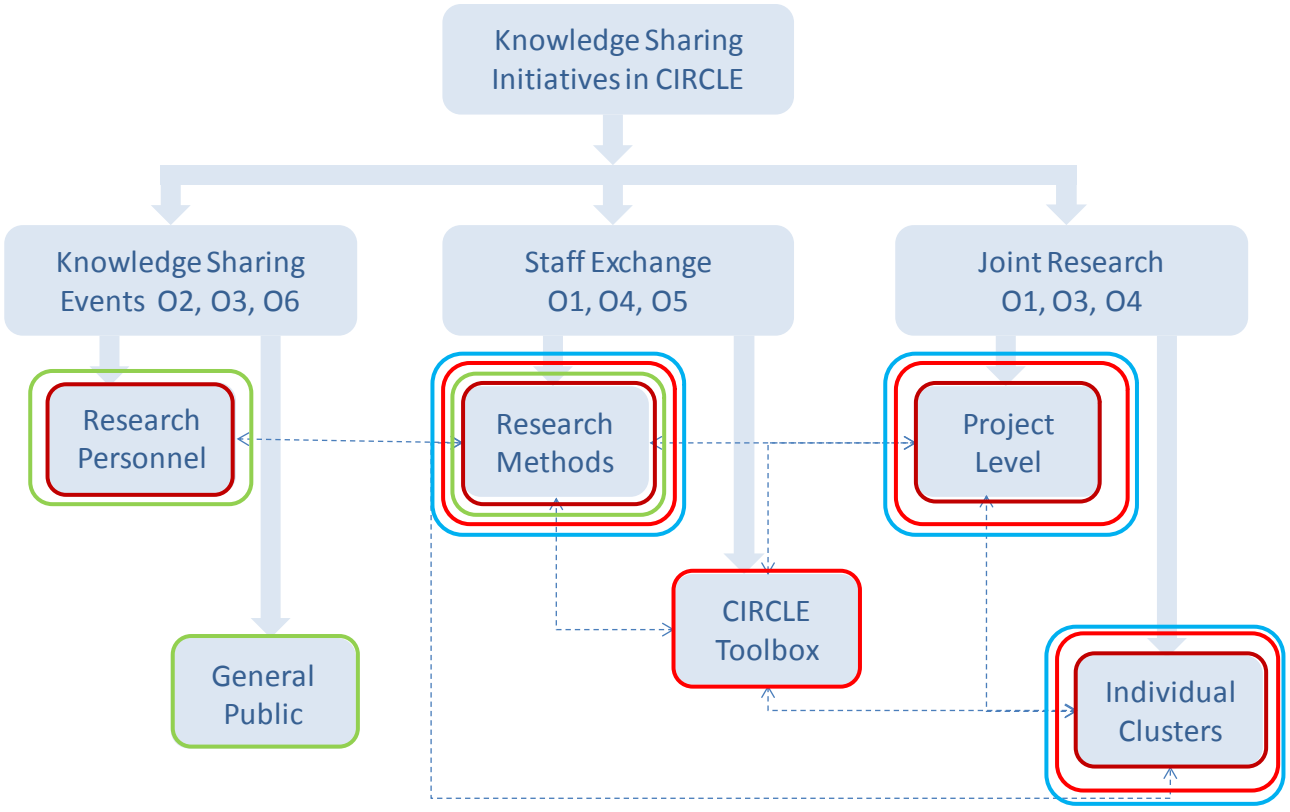

Figure 1. Knowledge sharing in CIRCLE.

Knowledge sharing in CIRCLE has been organized in three main strands of activities. They consists of the *organization of events* (**O2, O3, O6**), the *staff exchange* process (**O1, O4, O5**), and *joint research* activities (**O1, O3, O4**).

In turn, some events are dedicated to *research personnel*, intended as *PhD Students* (**O2**), *University Researchers*, (**O3**) and *Company Researchers* (**O6**). Other events have been organized for disseminating general information on molecular communications to a *generic audience*. For what concerns the staff exchanges (**O1**), they are organized for leveraging mutual expertise, by sharing research methodologies (**O1, O4, O5**), and for implementing research tools (**O4, O5**), such as the MolCom Murkup Language and the CIRCLE simulation Toolbox, that have a central role in mutual collaborations of the CIRCLE beneficiaries. In terms of *joint research*, CIRCLE stimulates the birth of novel research clusters that, for some key activities, involve all the CIRCLE beneficiaries. Some of these clusters involve partners who formally are not part of the project, but thanks to the knowledge sharing activities in CIRCLE they have established sound collaborations with the CIRCLE participants (**O1, O3, O4**).

As expected, these initiatives are interrelated. Logical and practical relations between initiatives are shown by dashed arrows. For example, the organization of a workshop including tutorials, presentation of research results, and targeted meetings for solving implementation issues and organising publication activities can contribute to many if the categories in Figure 1.

This deliverable is organized as follows. In Section 2, we report the main events which contributed to knowledge sharing objective. Section 3 reports the joint research activities and the relevant publications relevant to the first year of the project, which contributed to objective **O3** of CIRCLE. In Section 4, we report the status of the initiatives relevant to fulfilling objective **O2** of the project. Section 5 presents the report for the first year about personnel exchange, and the plans for the second year. Finally, Section 6 includes the description of the ongoing implementation of the MolCom Toolbox. Although CIRCLE aims at stimulating collaborations and knowledge sharing, and research activities fall beyond the scope of the project, the strategic importance of the MolCom Toolbox for achieving the WP3 knowledge sharing objectives induced us to report on this specific activity. Also the future plans for the second year of the project, are illustrated. Finally, performance evaluation assessment of knowledge sharing initiatives at the end of the first year is presented in Section 6.

We underline that the content of the document reflects the state of the project at the end of the first year of the project. Nevertheless, since at the time of writing an important amendment has been requested in the composition of the partnership of the project, this change will be considered as well. The achievements of WP3 at the end of the project will be shown in the follow-up deliverable D3.4 (to be delivered at month 24).

2. Knowledge sharing events

In this section, we detail the main events through which the members of CIRCLE have actively carried out knowledge sharing activities. Basically, the main plan of the Task 3.1 is to have a constant presence in events dealing with molecular communications. This means having organizational and scientific roles in conferences and/or PhD schools having molecular communications in the set of their principal topics, such as the ACM Nanocom, and attracting the major experts in the field. The list of these events is reported below:

- Besides the organizational purposes of the project meetings, illustrated in the framework of WP1, the *Two project meetings* organised had also the purpose of harmonising research activities : the kick-off meeting in Barcelona, hosted by UPC (July 2015), and a meeting in Perugia, hosted by CNIT in January 2016. During these meetings, specific knowledge sharing initiatives have been proposed, discussed, and agreed by participants. In particular, during these meetings the CIRCLE participants have scheduled the preparation of the MolCom Toolkit. In addition, the participants have agreed the need of contributing to the IEEE TCSIM Newsletter. Most of these initiatives, which represent measurable indicators for the progress of the project, has been illustrated in the deliverable D3.1.
- The *1st CIRCLE Workshop* on Molecular Communications, organized by UCAM, held in Cambridge on 11th – 12th April 2016[1]. This workshop has been attended by a significant number of researchers, both from CIRCLE and form other research organizations, representatives of companies, that have also presented products and their ongoing initiatives, and editors (Elsevier). In particular, the session "Young Researchers in Molecular Communications", hosted by Prof. Chun Tung Chou, who is a member of the Expert Working Group, has been particularly relevant to WP3, and in particular to objective O2. This session included the talk "Paradigms and interfaces of molecular communications", by prof. Chou, "Education and Training Opportunities in Molecular Communications", by Prof. Reali, and "The state of the art in Molecular Communications: art or science? Squaring the Circle", by prof. Alarcon, followed by an open discussion on these topics. Special emphasis has been given to the initiatives for supporting young researchers, including both general wisdom indications for undertaking research activities

[1] http://fet-circle.eu/index.php/1st-circle-workshop-on-molecular-communications/

and specific suggestions about molecular communications. The latter has also included a detailed description of paradigms and interfaces of molecular communication. In addition, the MolCom Started Kit has been presented, together with a list of possible academic programs dealing with molecular communications. Finally, a survey of the state of the art, with a critical perspective, has concluded the session devoted to young researchers.

- Special session, sponsored by CIRCLE, in the *Doctoral School* "Multiscale Bioengineering: from Molecules to organs (μMBioEng)"[2]. This school will be held in Perugia on June 6-10, 2016. The special Session has been organized by CNIT and has included lecturers from CNIT, UNIPG, and UCAM.

    - Talk 1: Education and training opportunities in Molecular Communications, Gianluca Reali (CNIT): this talk has illustrated the novel opportunities in education for young researchers willing to face the challenges of molecular communications. During the session, the MolCom Starter Kit has been sketched, as well as the various opportunities in terms of PhD programs and Master schools oriented to molecular communications or including well distinguishable contents of them.

    - Talk 2: Applications Opportunities of Molecular Communications, Pietro Liò (UCAM). This talk has illustrated the novel applications that could benefit of the molecular communications paradigm as enabling technology.

    - Talk 3: Cellular Interaction Mechanisms, Antonio Macchiarulo (UNIPG). This talk has explored the research opportunity for molecular communications in chemistry and drug discovery, which is one of the most important research fields in pharmacology.

    - Talk 4: Models of Molecular Communications Systems, Mauro Femminella (CNIT). This talk has illustrated various models for molecular communication systems, focusing on the receiver models. Some models, characterized by different complexity and achievable performance have been presented and analysed, together with an applicability analysis tailored to the considered application scenario.

[2] http://mmbioeng2016.jimdo.com/

- Training session: Simulation of Molecular Communication Systems, executed in the Software Engineering Lab, by Luca Felicetti and Mauro Femminella (CNIT). During this session, the students have used the open source simulator BiNS2 to test the reliability of a receiver models illustrated during the previous session.

- Talks in *PhD schools*/international forums:
  - Pietro Liò: "Inflammatory events and cancer: a statistical Bioinformatics perspectives" and "Combining Bioinformatics and cancer survival analysis", Cancer development and complexity, May 2016.
  - Pietro Liò: invited speaker in the session "Computational Intelligence Applications in Health and Smart Cities", 2nd International Forum on Research and Technologies for Society and Industry Technologies for smarter societies, Bologna, September 2016.
- Talks in *seminars and workshops* (accomplished)
  - Prof. Ozgur Akan: "Fundamentals of Molecular Communications in Nanonetworks"), Polytechnic University of Milan, Milan-Italy, 23-29 January 2016.
  - Prof.Ozgur Akan: "Communication Theoretical Understanding of Nervous Nanonetworks", University of Naples Federico II, Naples, Italy, October 2015.
  - Prof.Ozgur Akan: "Fundamentals of Molecular Information and Communication Science", Workshop on Bio-Nano Things for Human Health, Oslo University Hospital/Rikshospitalet, Oslo, Norway, March 2016.
  - Prof.Ozgur Akan: "Fundamentals of Molecular Communications in Nanonetworks", Sapienza University of Rome, Rome, Italy, 23 – 29 January 2016
  - Pietro Liò, "Multidimensional methods to integrate biological data", Dagstuhl workshop, June 2016.
- Talks in *seminars and workshops* (scheduled)
  - Pietro Liò, "Design of Microfluidic Biochips: Connecting Algorithms and Foundations of Chip Design to Biochemistry and the Life Sciences", Dagstuhl workshop, August 2016.
  - P. Liò, "Next Generation Sequencing – Algorithms, and Software For Biomedical Applications", Dagstuhl workshop, August-September 2016.

- *Courses*: "Nanoscale and Molecular Communications", Prof Ozgur Akan, (KU-ELEC 550 Selected Topics in Electrical and Electronics Engineering), Spring 2016, Koc University.
- The CIRCLE personnel had a central role in the organization of the *ACM Nanocom 2015*, a conference focused on research activities on nanoscale communications, including molecular and terahertz communications. This conference was held in Boston, USA, on 21-22 September, 2015. In addition, CIRCLE has been a conference sponsor. Details can be found at the URL http://nanocom.acm.org/nanocom2015/index.html. In particular, some researchers in CIRCLE were included in the conference committees (http://nanocom.acm.org/nanocom2015/committees.html), as follows:
    - Sasitharan Balasubramaniam, TUT, Ozgur Baris Akan, KU, and Albert Cabellos, UPC, have been members of the steering committee;
    - Sasitharan Balasubramaniam, TUT, has been general conference co-chair;
    - Albert Cabellos, UPC, has been publication co-chair;
    - The following CIRCLE participants have been members of the TPC: Ozgur Akan (KU), Eduard Alarcon (UPC), Mauro Femminella (CNIT), Gianluca Reali (CNIT), Brendan Jennings (WIT), Pietro Liò (UCAM), Yevgeni Koucheryavy (TUT).
- Dissemination to the general public.
    - The CIRCLE Coordinator, Alan Davy, and the CIRCLE project appeared different times in the Irish press, 2015.
    - On September 25, 2015, Luca Felicetti (CNIT) presented the CIRCLE project at the event Appy Days, Todi, Italy. http://www.appydays.it/speakers/luca-felicetti/
- The CIRCLE personnel have a central role in the organization of the forthcoming *ACM Nanocom 2016*, to be held in New York on 28-30 September, 2016. More details can be found at the URL http://nanocom.acm.org/committees.php):
    - Sasitharan Balasubramaniam, TUT, and Ozgur Baris Akan, KU, are members of the steering committee;
    - Yevgeni Koucheryavy, TUT, is a general conference co-chair;
    - Alan Davy, WIT, is a sponsorship co-chair;
    - Mauro Femminella, CNIT, is a tutorial co-chair, and has organized a tutorial on molecular communications entitled "Enlisting Synthetic Biology and

Electrochemistry for Molecular Communication", to be presented by prof. W.E. Bentley and G.P. Payne, both of University of Maryland (more details at http://nanocom.acm.org/tutorials.php);

- Eduard Alarcon (UPC) is a tutorial speaker;
- The following persons participating in CIRCLE are members of the TPC: Eduard Alarcon (UPC), Albert Cabellos (UPC), Josep Solé-Pareta (UPC), Luca Felicetti (CNIT), Mauro Femminella (CNIT), Yevgeni Koucheryavy (TUT).

- Future plans: additional events will be organized by CIRCLE. In particular, the consortium has agreed to co-locate the second CIRCLE workshop with a summer school, which will be held in the spring 2017. During this joint event (training + workshop), a number of prestigious lectures, including people with both biology and ICT background, will provide talks to the workshop attendees and PhD students. The relevance of the invited scientists is expected to attract a large number of people, so as to achieve a significant visibility of CIRCLE and to promote awareness of the molecular communications research.

3. Joint research and publication activities

A considerable number of research and collaboration activities have been undertaken during the first year of the CIRCLE project. We classify these activities in two categories. The first one includes the activities that have been contributed by some CIRCLE participants and received also collaboration of external groups. The second one includes the activities that have been contributed by all CIRCLE participants. All activities contribute the objective **O3** of CIRCLE.

Joint research and consequent knowledge sharing in CIRCLE is promoted also through the establishment of the *CIRCLE Forum*, accessible in the CIRCLE portal under the Forum tab, or by means a direct link[3]. The *CIRCLE code repository* is an additional tool supporting knowledge sharing and collaborative research. These infrastructures have been implemented in the framework of WP2, but its main usage is relevant to WP3.

In addition, the CIRCLE project publishes a *CIRCLE Newsletter*, to which can be easily subscribed via the project web site. The strategic plan of the project consists of improving the amount of novel contents published in the CIRCLE web site, and in particular on the home page, in order to attract visitors. In addition, a periodic CIRCLE bulletin will be issued, with 3 or 4 hot topics, which aim to stimulate researcher to contribute to an open debate on the MolCom field.

3.1. Individual research clusters

In what follows we report a list of collaboration and knowledge sharing activities in CIRCLE.

- UCAM, CNIT, UNIPG – Knowledge sharing activities on molecular communication systems in blood vessels. A survey of medical applications of Molecular Communications has been published in the Elsevier Nano Communication Networks journal (see the publications section). In addition, a further knowledge sharing activity is pursued by this cluster, based on staff exchange, focused on Molecular Communications techniques devoted to the early detection of circulating tumour cells (CTC) in blood vessels. UNIPG has to provide values of the key parameters (e.g. vessels and cells size, bloodstream velocity, receptor expressed on the surface of endothelial cells) by analysing the state of the art literature. UCAM has to provide models about the generation and the survival of CTCs. Finally, CNIT deals with integration of models and simulations.

[3] http://conan.diei.unipg.it/lab/index.php/forum-circle

- UCAM, UPC, CNIT, WIT – Development of a mark-up language for Molecular Communications Systems (Molecular Communications Markup Language, MolComML). This markup language has a central role in the CIRCLE activities since it has been defined to univocally specify simulation configuration (simulation parameters, topology, output format), also using different simulators. This would help to make in silico analysis comparable. A co-authored paper has been accepted and presented to the conference ACM Nanocom 2016. Given the strategic importance of MolComML for CIRCLE, an extensive description of this activity is reported in section 5.
- WIT, TUT, KU – Collaboration and knowledge sharing activity in the framework of neural dust motes to stimulate neuronal circuits molecular communications within the cortex. The context consists of investigating the development of neural dust motes that can be used to stimulate neuronal circuits molecular communications within the cortex. The aim here is to provide new, long-term solutions that will allow these devices to be embedded permanently within the cortex, and stimulate the neurons at single cell level. The mechanism of stimulation is through the process known as optogenetics, where light is used to stimulate the neurons that are genetically engineered. The key challenges of this activity is the development of such a small scale device that can interface and stimulate the neuron, and mechanism of powering the devices as well. The shared expertise of each of the organization is as follows: TUT - neural dust modeling, in particular light behaviour within the tissue; WIT - calcium signaling molecular communication within the neurons; Koc University - electro-chemical signaling between neurons. The collaboration includes a prestigious external organization, the University at Buffalo, State University of New York, coordinated by Prof. Josep Miquel Jornet, who has a sound expertise in the research is electro-magnetic wireless nano sensor networks.
- KU, WIT, and UCAM – Knowledge sharing activities relevant to testing molecular + electromagnetic communications between bacteria. KU, in collaboration with WIT and UCAM, is working on an initiative external to the CIRCLE project that consists of initiating a wet-lab experiment with the objective of realizing molecular + EM communication between bacterial populations located in different university campuses. The experiments are expected to evolve towards a multi-purpose testbed, which will be used to test synthetic biology based interfacing and transceiving capabilities of engineered bacteria. This will be a first major step towards realizing synthetic bacteria based bio-transceivers

for molecular communication applications. Sharing of knowledge and best practices is in the scope of CIRCLE

- All CIRCLE participants: Review of Molecular Communications Simulators, with plans for integrating the existing simulators, developed by the CIRCLE participants, within a comprehensive *CIRCLE MolCom Toolbox*. Since this activity is a central point of the CIRCLE project, and mainly of the WP3, an extensive description is reported in section 5.1. A survey on currently available MolCom simulators has been accepted for publication in the forthcoming IEEE TCSIM (Technical Committee on Simulation) Newsletter, illustrated in the following section.

3.2. Publication Activities

Collaboration activities on Molecular Communications, carried out in clusters or individually, are accompanied by publication activities. Some papers have already been accepted and published. Other papers will be prepared and submitted for publication in the upcoming months.

For what concerns the publication activities involving the CIRCLE consortium as a whole, two ongoing initiatives have been undertaken.

- A CIRCLE contribution have been accepted for publication in the next issue of the IEEE Technical Committee on Simulation (TCSIM) newsletter. This contribution illustrates the current status of the simulation technologies in Molecular Communications and the plans for a comprehensive CIRCLE Molcom ToolBox. In addition, a paper will be submitted to a research journal illustrating the technical novelties of the CIRCLE MolCom ToolBox. Recently, the WP3 leader has joined the Editorial Board of IEEE TCSIM as Vice-Editor. He will chair a stable Section of the Newsletter dedicated to Molecular Communication systems in the forthcoming TCSIM issues. Contributions can be short papers, but also interviews to distinguished researchers, call for papers, etc.
- Special Issue in the Elsevier Nano Communication Networks journal, consisting of MolCom tutorials, organized, edited and contributed by different CIRCLE participants, to be published in Spring 2017. Given the prestige of this publication venue, it could boost the interest in MolCom, especially in young researchers, which could smoothly enter this challenging area. This would be a significant contribution, aimed to young researchers, to provide a systematic organization of all the available teaching and research material, dispersed in a number of journals, conference proceedings, and books. The strategic plan of CIRCLE is to accompany this initiative also with multimedia contents, and more in

detail with video to be published in YouTube detailing concepts illustrated in the tutorials.

For what concerns the individual publication activities, we have to distinguish between paper published or accepted for publication, and papers in preparation. Papers belonging to these two categories are listed in the two following sub-sections. Our strategic plan for the second year of the project, in addition to the tutorials on molecular communications to be published in a special issue of the Elsevier Nano Communication Networks journal, include the publication of a joint contribution on cell communications in blood, to be published possibly in a journal with a non-ICT focus, so as to enlarge the visibility of CIRCLE activities to other communities.

3.2.1. Papers published/accepted for publication

- Luca Felicetti, Mauro Femminella, and Gianluca Reali. 2015. Smart antennas for diffusion-based molecular communications. In Proceedings of the Second Annual International Conference on Nanoscale Computing and Communication (NANOCOM' 15).
- M. Femminella, G. Reali and A. V. Vasilakos*, "A Molecular Communications Model for Drug Delivery," in IEEE Transactions on NanoBioscience, vol. 14, no. 8, pp. 935-945, Dec. 2015. doi: 10.1109/TNB.2015.2489565
- L. Felicetti, M. Femminella, G. Reali, P. Liò, Applications of molecular communications to medicine: A survey, Nano Communication Networks, Volume 7, March 2016, Pages 27-45, ISSN 1878-7789, doi: 10.1016/j.nancom.2015.08.004.
- L. Felicetti, M. Femminella, G. Reali. A simple and scalable receiver model in molecular communication systems. Accepted for publication in ACM Nanocom 2016.
- E. Alarcon, R. G. Cid-Fuentes, A. Davy, L. Felicetti, M. Femminella, P. Liò, G. Reali,, J.S. Pareta. MolComML: The Molecular Communication Markup Language. Accepted for publication in ACM Nanocom 2016.
- G. Reali, M. Femminella, L. Felicetti, A. Davy, Michael Barros, R. G. Cid-Fuentes, A. Cabellos-Aparicio, J.S. Pareta, E. Alarcon, P. Liò, P. Gresele, M. Malvestiti, W. Tavernier, Y. Koucheryavy, V. Petrov, S. Balasubramaniam, Ozgur B. Akan. Simulation tools for molecular communications. Accepted for publication in the IEEE TCSIM (IEEE Computer Society Technical Committee on Simulation) Newsletter.

- S. S. Assaf, S. Salehi, R. G. Cid-Fuentes, J. Solé-Pareta and E. Alarcón. Characterizing the Physical Influence of Neighboring Absorbing Receivers in Molecular Communication. Accepted for publication in ACM Nanocom 2016.
- O. B. Akan, H. Ramezani, T. Khan, N. A. Abbasi, M. Kuscu. Fundamentals of Molecular Information and Communication Science. Accepted for publication in the Proceedings of IEEE.
- M. Kuscu, O. B. Akan. Modeling and Analysis of SiNW FET-Based Molecular Communication Receiver. Accepted for publication in IEEE Transactions on Communications.

3.2.2. Papers in preparation/submitted

- S. Salehi, S. S. Assaf, R. G. Cid-Fuentes, J. Solé-Pareta, E. Alarcón and N. S. Moayedian. Optimal Deployment of Multiple Transmitter Drug Delivery System: A Spatial Sampling Theorem Approach. Submitted for publication
- S. Salehi, S. S. Assaf, R. G. Cid-Fuentes, J. Solé-Pareta, E. Alarcón and N. S. Moayedian. Designing a Local Drug Delivery System Considering Multiple Transmitter Deployments. In preparation.
- G. Reali, M. Femminella, L. Felicetti, A. Davy, Michael Barros, R. G. Cid-Fuentes, A. Cabellos-Aparicio, J.S. Pareta, E. Alarcon, P. Liò, P. Gresele, M. Malvestiti, W. Tavernier, Y. Koucheryavy, V. Petrov, S. Balasubramaniam, Ozgur B. Akan. A survey of simulation tools for molecular communications. In preparation.
- T. Khan, B. A. Bilgin, O. B. Akan. Three-Dimensional Diffusion-based Model of a Synaptic Channel with Pre-synaptic Re-uptake. Submitted for publication in IEEE Transactions on Communications.
- B. A. Bilgin, O. B. Akan. A Deterministic Approach for Modelling Stochastic Synaptic Communication. Submitted for publication in IEEE Transactions on Nanobioscience.
- N. A. Abbasi, O. B. Akan. Nervous system based molecular communication link using Earthworms. Submitted for publication in Nature Communications.
- H. Ramezani, O. B. Akan. Modeling Spike Amplitude Variation in the Axonal Transmission. Submitted for publication in IEEE Transactions on Communications.

- D. Malak, H. Ramezani, O. B. Akan. Adaptive Weight Update in Cortical Neurons and Estimation of Channel Weights in Synaptic Interference Channel. Submitted for publication in IEEE Transactions on Nanobioscience.

4. Analysis of the strategic initiatives for training young researchers

A Catalogue of the skills and the available academic programs for Molecular Communications have been prepared and presented and the 1st CIRCLE Workshop in Cambridge. This report includes PhD programs, academic courses, and targeted academic initiatives:

- University of Tampere, Finland, ELT-53406, Special course on networking, http://www.cs.tut.fi/kurssit/ELT-53406/
- Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany, Seminar Special Topics in Communication, http://www.idc.lnt.de/en/lehre/winter-term-201516/seminar-special-topics-in-communication/
- Ss Cyril and Methodius University (SsCMU), Skopje, Macedonia, master study program in Micro and Nano Technologies, http://en.feit.ukim.edu.mk/news/new-master-study-program-in-micro-and-nano-technologies-a-t-feeit-ss-c-yril-and-methodius-university-ssc-mu
- Boğaziçi University, Turkey, CmpE 49I Sp.Tp. Nanonetworking & Molecular Communications, https://www.cmpe.boun.edu.tr/courses/cmpe49i/2015/fall
- Integrated Research Training Group "Erlangen School of Molecular Communication", Germany, http://www.sfb796-gk.forschung.uni-erlangen.de/
- Osaka University, Japan, OU-Nanoprogram, http://www.sigma.es.osaka-u.ac.jp/pub/nanokiko/html/english/index.html

The discussion following the presentation of the report has allowed to further integrate and improve the report. UPC has undertaken an initiative aiming to identify the key elements of research on Molecular Communications. Although this activity is essentially targeted to WP4, it has provided also a contribution to the WP3 in the framework of the session “Young Researchers in Molecular Communications”, hosted by Prof. Chun Tung Chou at the 1st CIRCLE workshop in Cambridge. It consist of collecting and processing information from the main research publishers regarding papers related to Molecular Communications. These data have been processed through algorithm and techniques typical of Data Science. Results have allowed identifying suitable taxonomy, which is very important since MolCom is an open field, which encompasses some other scientific disciplines. In addition, it was shown how it can take advantage of achievements

in different areas and how it can contribute to future science and technology. Hence, it emerged a considerable social impact due to the wide range of possible applications.

In addition, during the workshop and in the subsequent PhD school in Perugia, where CIRCLE hosted a dedicated session on Molecular Communication Systems, the MolCom Starter Kit has been presented.

Staff exchange status and future plans

Staff Exchange is a key activity for knowledge sharing in CIRCLE. The first year of the project has allowed the CIRCLE participants to establish sound research collaborations. Thus, although few staff exchanges have been done during the first year of the project, the framework for promoting staff exchange have been established and the CIRCLE participants are in the process of beginning exchange of personnel, in particular young researchers. From the formal perspective, the "*Staff exchange reporting process and register*" document has been prepared and made available to the CIRCLE participants in the initial phase of the project in order to put the process in motion.

The exchange of researchers will happen both between CIRCLE beneficiaries and between a beneficiary in CIRCLE and other prestigious institutions that have established research collaboration with CIRCLE since the project has started. This collaboration between CIRCLE and other external institutions, and the relevant fruitful exchange of expertise, is a further strategic objective the project.

The plans for staff exchange are detailed for each individual CIRCLE beneficiary and are illustrated according the following schema:

(a) collaborating organization, (b) topic(s) of the research collaboration, (c) the expected period of the exchange, (d) the name of the involved people, (e) the expected benefits for CIRCLE.

Waterford Institute of Technology - WIT

Staff Exchange #1

a) Collaborating organization: Federal University of Campina Grande, Brazil.

b) Topic(s): Data Coding for DNA sequences.

c) Period: 14th of September to 07th of November of 2016.

d) People: (Hosts) Michael Taynnan Barros (Visitors) Raphael Tavares de Alencar and Marcelo Sampaio de Alencar.

e) Benefits for CIRCLE: This research is bringing the collaboration with Brazilian partners, country which still has no current activities on molecular communication research.

Staff Exchange #2

a) Collaborating organization: Tampere University of Technology

b) Topic(s): Control theory and Molecular Communications

c) Period: 3rd March - 3rd April
d) People: (Visitors) Michael Taynnan Barros, (Hosts) Yevgeni Koucheryavy
e) Benefits for CIRCLE: Sharing of experimental facilities and exchange of knowledge

University of Cambridge - UCAM

Staff Exchange #1

a) Collaborating organization: CNIT
b) Topic(s): Molecular Communications Toolbox
c) Period: One week February 2017, one week March 2017
d) People: (Vistor) Pietro Liò, (Host) Gianluca Reali
e) Benefits for CIRCLE: The Molecular Communications Toolbox is a key component of the CIRCLE Simulation Toolbox, as illustrated in Section 5.

Staff Exchange #2

a) Collaborating organization: Univ. of Electronic Science and Tech. of China, Chengdu, China
b) Topic(s): Reseach on Molecular Communications, in particular on the
c) Period: One year since Fall 2016 (supported also by other initiatives)
d) People: (Vistor) He Peng, (Host @ UCAM) Pietro Liò
e) Benefits for CIRCLE: The Molecular Communications Toolbox is a key component of the CIRCLE Simulation Toolbox, as illustrated in Section 5.

i-Minds

Staff Exchange #1

a) Collaborating organization: N3CAT Barcelona
b) Topic(s): Scalable and tunable routing in diffusion. A characteristic of most diffusion-based molecular communication networks is the huge number of nodes in small areas. For instance, for a transmission range of 100 μm, the number of nodes required to cover a volume of just 1 cm2 is in the order of 10^6 . With such a high number of nodes, and given the limited capabilities of nanomachines, giving a unique address to each network node, as is done in traditional wireless networks, will become nearly impossible. Routing therefore becomes a very challenging problem as needs to cope with a highly dynamic environment where cooperative protocols are required.
c) Period: 1 month by the end of the project.
d) People: (Visitor) Ir. Pieter Stroobant, (Host) Prof. Dr. Eduard Alarcon (UPC)
e) Benefits for CIRCLE: Improve efficiency of nano-communication over larger networks. Involvement of network engineering and routing expertise in nanocommunication. This internship will investigate routing requirements in diffusion environments as well as assess existing routing schemes applicable in such challenging conditions.

Koc University - KU

Staff Exchange #1

a) Collaborating organization: University of Cambridge

b) Topic(s): robust detection methods for molecular communications inspired from bacterial signalling in collaboration with Dr. Pietro Lio from UCAM. They will analyse the performance of these detection methods for different modulation techniques and under several interference and noise conditions.

c) Period: February 2017 - March 2017.

d) People: (Vistor) Murat Kuscu, (Host) Pietro Liò

e) Benefits for CIRCLE: Strategic collaboration to initiate detection experiments using engineered bacteria towards realizing synthetic bacteria based bio-transceivers for molecular communications.

Staff Exchange #2 - Outgoing team (contributing to the same topic)

a) Collaborating organization: University of Cambridge

b) Topic(s): The team will work on the development of an artificial synapse which will mimic the molecular communications in synaptic channels as well as the electrochemical communication in neural axons, in collaboration with Dr.

c) Period: February 2017 - March 2017

d) People: (Visitors) Dr. Bilgesu Bilgin [Postdoc], N. A. Abbasi [PhD candidate], H. Ramezani [PhD candidate]; (Host) Pietro Liò.

e) Benefits for CIRCLE: strategic activity aiming at gaining expertise by the team in executing experiments with nanoscale components on microfluidic platforms.

As specified in section 3.1. KU, in collaboration with WIT and UCAM, is working on initiating a wet-lab experiment with the objective of realizing molecular + EM communication between bacterial populations located in different university campuses. Exchanges #1 and #2 will facilitate the activities of this research cluster.

Staff Exchange #3

a) Collaborating organization: Tampere University of Technology

b) Topic(s): game theoretic approach to molecular communications

c) Period: February 2017 - March 2017

d) People: Caglar Koca

e) Benefits for CIRCLE: this activity can reveal the fundamentals of cooperation in molecular nanonetworks.

In addition to the CIRCLE funds, the staff exchange will be funded also by the ERC project MINERVA and other funding sources of Dr.Ozgur Akan.

University of Perugia - UNIPG

Staff Exchange #1

a) Collaborating organization: VU University Medical Center, Amsterdam (NL)

b) Topic(s): Nano-comunications in platelet-cancer cells. Exchange of genetic information between platelets and circulating cancer cells (CTC) for exploring the chance of reprograming cellular death of CTC.

c) Period: March-July 2017

d) People: (Visitor) Dr. Marco Malvestiti, (Host) Thomas Wurdinger

e) Benefits for CIRCLE: Improve knowledge over nano-comunications in biological applications. Involvement of new medical and biological staff in the consortium.

f) The work is purely based on theoretical modeling and simulations with no wet lab experimental work. Therefore, no issues with ethics on this research work is expected.

Tampere University of Technology - TUT

Staff Exchange #1

a) Collaborating organization: WIT, Waterford Institute of Technology.

b) Topic(s): Use of neural dust device to interface to neuronal network. This basically takes the molecular communication research to a new emerging direction where external devices can be used to stimulate and control the signaling behaviour of the molecular communication networks.

c) Period: the exchange period will be for 6 weeks for each organization by the end of the project.

d) People: (Vistors from TUT) - Stefanus Wirdatmaja, Sasitharan Balasubramaniam, Yevgeni Koucheryavy; (Host) Alan Davy, Michael Barros.

e) Benefits for CIRCLE: the expected benefits for the CIRCLE project is the new direction in the area of molecular neuronal networks. The other benefit is to develop an application for molecular communication, and in particular neuronal networks. This application will be for providing neural stimulation to people who suffer from neurodegenerative diseases.

Staff Exchange #2

a) Collaborating organization: Koc University.

b) Topic(s): Use of neural dust device to interface to neuronal network. This basically takes the molecular communication research to a new emerging direction where external devices can be used to stimulate and control the signaling behaviour of the molecular communication networks.

c) Period: the exchange period will be for 6 weeks by the end of the project.

d) People: (Vistors from TUT) - Stefanus Wirdatmaja, Sasitharan Balasubramaniam, Yevgeni Koucheryavy; (Host) Ozgur Baris Akan

e) The expected benefits for the CIRCLE project is the new direction in the area of molecular neuronal networks (see the more detailed description of the research activity in the TUT, WIT, KU research cluster). The other benefit is to develop an application for molecular communication, and in particular neuronal networks. This application will be for providing neural stimulation to people who suffer from neurodegenerative diseases.

UPC

Staff Exchange #1

a) Collaborating organization: CNIT

b) Topic(s): Inclusion of multiple transmitter multiple receiver molecular communications scenarios (MIMO) into MOLCOM simulators.

c) Period: 1 month by the end of the project.

d) People: (Visitor) Ir. Simon Assaf, (Host) Gianluca Reali and Mauro Feminnella

e) Improve MOLCOM simulator to encompass the simulation setup, performance metrics and description language required for addressing multi transmitter multi receiver cases. Given the strategic importance of the simulation activities in CIRCLE, a detailed description is reported in Section 5.

CNIT

Staff Exchange #1

a) Collaborating organization: Waterford Institute of Technology (WIT)

b) Topic(s): Simulation of Molecular Communications systems

c) Period: One week, May 2017

d) People: (Visitor) Luca Felicetti, (Host) Alan Davy.

e) Finalization of the CIRCLE Simulation Toolbox for molecular communications; Accomplishment of a CIRCLE milestone. Given the strategic importance of the simulation activities in CIRCLE, a detailed description is reported in Section 5.

Staff Exchange #2

a) Collaborating organization: University of Cambridge

b) Topic(s): Simulation of Molecular Communications systems

c) Period: One week, May 2017

d) People: (Visitor) Gianluca Reali, Luca Felicetti, or Mauro Femminella, (Host) Pietro Liò.

e) Finalization of the CIRCLE Simulation Toolbox for molecular communications; Accomplishment of a CIRCLE milestone. Given the strategic importance of the simulation activities in CIRCLE, a detailed description is reported in Section 5.

5. CIRCLE MolCom Toolbox

As an example of intense collaboration of the CIRCLE beneficiaries, and the fruitful collaboration also through staff exchange detailed in Section 5, we illustrate the development of the CIRCLE MolCom Toolbox, which is a pivotal activity in CIRCLE. The beneficiaries that have mostly contributed to this toolbox are UPC, CNIT, UCAM, and WIT. Nevertheless, *all the CIRCLE beneficiaries in CIRCLE have given a contribution for the design, implementation, experimentation, assessment, and dissemination of this toolbox*.

This activity tackles the need of harmonizing the various MolCom simulation tools in a single toolbox, able to provide users with a unified interface to interact with the simulator. This activity is strategic for the future of molecular communication research, since it is relevant to Task 3.2, with the aim of fulfilling the objective **O4**. This activity has generated, in turn, two distinct although strongly related activities: the design of an integrated MolCom toolbox, and the definition of a MolCom Markup Language (MolComML). Whilst the first activity clearly addresses the need of providing a unified simulation platform, the second has a slight different scope. In fact, the MolCom Toolbox, as illustrated in the next subsection, may need to exchange simulation and configuration data between the integrated simulators during a single simulation session. This requires a standardized way to encode data, and especially simulation configuration, in order to provide configuration information that do not strictly depend on the source/destination simulator, but are standardized. This relieves each researcher with unneeded knowledge of the internal simulation structure. In addition, the MolComML, similarly to other markup languages, such as SBML, SBOL, and CellML, has a broader scope, since may allow exchanging also simulation models in a compact yet effective way. Finally, the scope of MolComML, in principle, is not tied to simulations only. In fact, it could be used to describe, in a standardized and unique way, also web lab experiments, to ease their reproducibility in different laboratory. Clearly, this would require also the design and implementation of a software tool able to visualize, in an easy to use way, the information encoded in the XML format.

Plans for the future include the of a significant portion of the MolCom Toolbox, which is a huge software integration program, so as to integrate at least two simulators, and the complete definition and implementation of the MolComML, together with the design and implementation of input models in existing simulators to read these standardized simulation configuration data.

5.1. Strategic plan for designing an integrating the MolCom Toolbox

The CIRCLE MolCom toolbox has a modular software architecture, based on three main modules sketched in Figure 2. : the I/O module, the orchestration module and the execution module. The latter is a container including the functions and algorithms which are already available within the relevant packages.

The effectiveness and the interactions between the elements of the CIRCLE MolCom toolbox are illustrated through the following example. Assume that a body-on-chip system, aimed to analyze drug toxicity in human beings, is simulated. In this system, a microfluidic network interconnects microenvironments (transwells) enhanced with cell cultures, emulating organs. The design of such body-on-a-chip devices poses some relevant issues in terms of both characterization of the drug propagation mechanisms inside organs (diffusion, degradation, swelling, and affinity-based mechanisms) and the exchange of particles among organs using microfluidic channels (e.g. capillary transport). The simulation of these complex systems can be realized through a multi-scale simulation based on the CIRCLE MolCom toolbox. The interactions between the entities of the toolbox are sketched in Figure 3. Through the I/O module, the user can load a script, written in Java or Python, illustrating the desired simulation behavior. This script is run by the Execution Module. The first step of the simulation is to request the Orchestration Module the instantiation of the needed packages included in the CIRCLE Container. In the example shown, these packages are the microfluidic simulator, that manage the whole microfluidic propagation, some BiNS instances [2], which simulate the drug delivery to cell receptors, the pathway models, which determines the drug effects within cells, and a CalComSim instance [3], which emulates a drug-induced calcium signaling within cells. The interactions between these entities are determined by a state diagram associated with each of them. The interaction procedure involves the Orchestration Module. This module implements a messaging system based on the well-known publish-subscribe model. Hence, each package instance needs to implement only an interface to communicate with the orchestration broker, and this simplifies the integration of different simulation packages. Messages are used to trigger the execution of different packages with a number of parameters, and, when two or more packages are running, to keep them synchronized on the simulation time axis. When the Microfluidic simulator has received all the necessary molecular results, the simulation ends and the simulation results are returned to the user through the main simulation script.

Note that the CIRCLE MolCom toolbox is not aimed at introducing a new simulator, or a different simulation strategy. On the contrary, it leverages the existing simulators, by taking advantage from all their peculiarities, and achieving ambitious results though their integration.

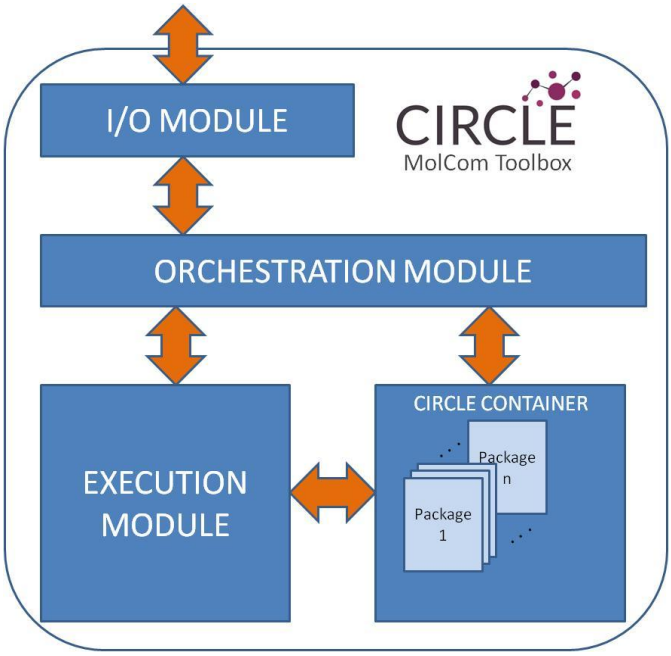

Figure 2. CIRCLE MolCom Toolbox.

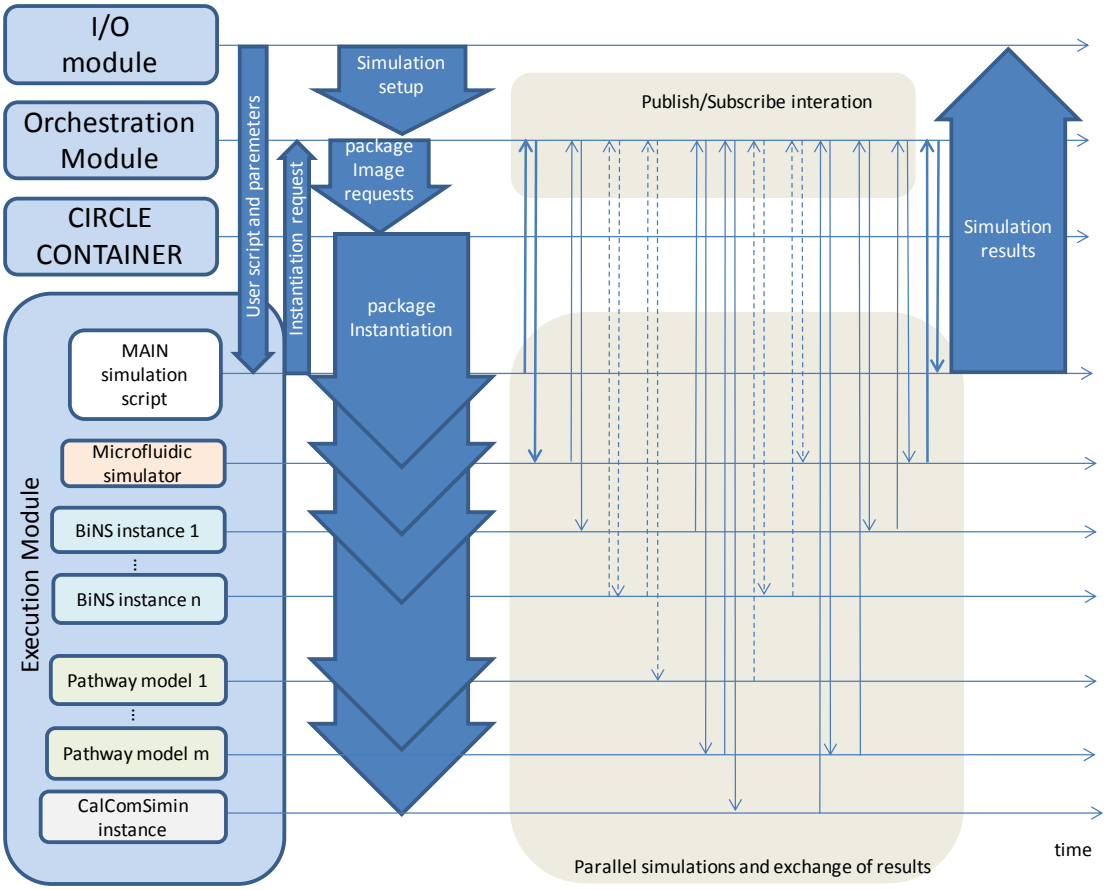

Figure 3. Interactions between the entities of the CIRCLE MolCom Toolbox.

5.2. MolCom Markup Language (MolcomML)

Consider the existing simulation tools of molecular communication systems, some of which have been mentioned in the previous section 5.1. They utilize different languages, configuration and output files, and other particular features that make cross-validation and reproducibility or results often unfeasible, especially for complex communication architectures. In order to facilitate collaboration and knowledge sharing we have pursued the development of a harmonization tool, the so called MolCom Markup Language (MolComML).

In this section, we provide some details about the initial design MolComML. It is an XML-based language that promises to reunite both numerical analysis and experimental synthesis by ensuring a flexible markup language [4]. This will allow cross-validation of experiments with the theoretical results, as well as to reduce significant researcher time in interfacing different software tools. As sketched in Figure 4. , the target of this activity can be compared with that of

XML-based languages, which allow specifying network configuration in a unified way, such as NETCONF [6], or OF-CONF [5] for Software Defined Networking devices.

We present the initial design concepts of MolComML, including the main objectives, elements and functionality of the proposed language.

The definition of the MolComML is guided through a simple example, which aids the overall understanding of the language. First, we overview existing specification languages for other disciplines, as well as the IEEE 1906.1 standard.

- The model defined by the IEEE 1906.1 Working Group stands as the first nanoscale and molecular communication standard and constitutes a recommended practice for the definition of a general framework for the nanoscale communications. The proposed markup language extends the definitions given by the IEEE 1906.1, allowing an easy description of the molecular communication networks. This standard proposes an architecture based on the following blocks: NetDevice, Communication Interface, Medium, Motion, Field, Specificity, and Perturbation.
- As for mark-up languages used in biology, one of the most important related language is SBML [8], that is nowadays the standard for representing computational models in system biology. Specifically, it allows communication and storing of computational models of biological processes. Its success is due to the possibility to represent different classes of biological phenomena, such as cell signalling pathways, regulatory networks, and many others. The main purposes of SBML are essentially model sharing on different software environments and allow these models to survive beyond the lifetime of the software packages used to create them. Given the strategic importance of these features, we have decided to introduce them also in MolComML, thus allowing also an easy integration of the SBML models.
- Another specification language used for the description of molecular biology is SBOL [9]. It was introduced for specifying and exchanging biological design information in synthetic biology. It can describe biological processes in deeper details than SBML. For example, it allow representing amino acid or nucleotide sequences. In particular, it supports the explicit and unambiguous description of biological designs through a rigorous definition of rules on how to use the provided data models with a special focus on the design details. Hence, the SBOL standard is fully qualified to represent structural components of a

biological design, such as DNA and RNA, proteins, small molecules, including also behavioural aspects.

- The CellML language is an open standard based on the XML markup language [10]. The purpose of CellML is to store and exchange computer-based mathematical models. CellML allows scientists to share models even when they use different model-building software. It also enables them to reuse components from one model to another one, thus accelerating model building. Although CellML was originally aimed to the description of biological models, it has a broader application. CellML includes information about model structure, mathematics and metadata by leveraging existing languages, including MathML and RDF. The CellML project is closely affiliated with another XML-based language project currently underway at the University of Auckland, FieldML. Combined, these languages provide a complete vocabulary for describing biological information at a range of resolutions from the subcellular to organism level.
- NeuroML is an XML-based model description language, which provides a powerful common data format for defining and exchanging models of neurons and neuronal networks [11]. The structure and behavior of ion channel, synapse, cell, and network model descriptions are based on underlying definitions provided in LEMS, a domain-independent language for expressing hierarchical mathematical models of physical entities. It includes two Application Programming Interfaces (APIs) written in Python to simplify the process of developing and modifying models expressed in NeuroML and LEMS.

In CIRCLE, a new MolCom Markup Language (MolComML) is necessary for bridging the areas of interest for molecular communications. Accordingly, this needs to be flexible and generic, such that it can be understood by *any software and simulation platforms* for molecular communications. It also needs to handle a large set of parameters, by providing all governing equations, parameter values and necessary conditions, such that it can entirely describe a MolCom environment in either a simulation or experimental test-bed.

In addition, due to the large growing rate of MolCom research and its high multi-disciplinarity, MolComML needs to be easily extensible to integrate the most recent and on-going advancements, compatible with existing languages of neighboring disciplines (e.g., SBML for systems biology and NeuronML for neurology). Finally, MolComML should be compliant with the IEEE P1906.1 recommended practice for nanoscale and molecular communication.

Its basic structure consists of several main blocks, reflecting the main components of a general molecular communication case. Each block is composed of a set of required parameters and a set of custom parameters that could be defined each time according to the molecular communication needs. A possible application scenario is illustrated in Figure 5. Part of the XML code relevant to the scenario depicted in Figure 5. is reported in Figure 6.

In order to be able to use a MolComML file, each compliant simulator needs a parser module, able to extract the information from MolComML and translate it into its specific configuration file. A further step is to design an input module, able to read directly the information contained in the MolComML file. We are implementing this input module in BiNS2 [2] as proof-of-concept; the relevant source code will be available on the simulator web site and on the CIRCLE code repository (http://gitlab.fet-circle.eu).

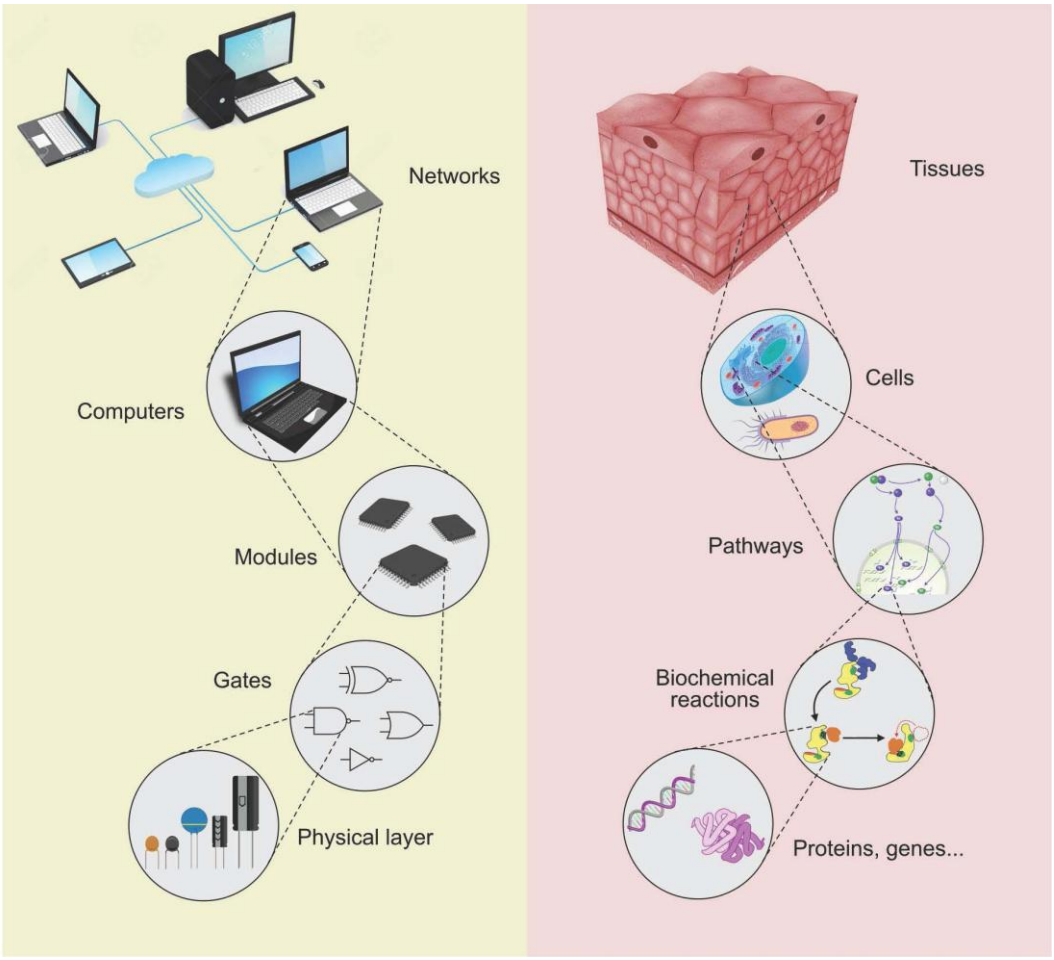

Figure 4. Top-bottom comparison between a computer network and a Biological System

List of objectives

The main objectives of the MolComML format are listed in what follows:

- Representation of different classes of molecular communication scenarios, at all levels of abstraction.
- Enable the use of multiple software tools without having to rewrite models to conform to different file formats.
- Guarantee the survival of models beyond the lifetime of the software used to create them.
- Usage of a single language both to analyze the considered scenarios through software tools, as well as to synthesize actual experiments. This ensures repeatability and cross-validation.
- Enable models to be shared and published in a form that any researcher can use even by making use of different software environments.
- Enable future expandability of the markup language. Due to the rapid knowledge growth in this field, this language needs to be constantly updated. MolComML will be versioned to structure the integration of novel definitions and models.

Elements and Functionality

Network Elements

Network elements are regarded as the building blocks by users. They are created and interconnected to define the simulation or experimental set-up. Each element may be defined by different levels of abstraction. For instance, it can be an entirely conceptual entity, it can have some real physical interpretation, or both. Each network element has a set of standard attributes that could be extended by the introduction of custom ones.

The most important attributes describe the shape and size of the element, its mass and time to live properties, the accepted and transmitted signals and, finally, the motion rules, if such element is equipped by autonomous propulsion system.

The main network elements are as follows:

- Transmitter: These elements are in charge of encoding information in the form of a molecular communication. They need to include all the relevant parameters. Among

others, rate of creation of molecules, rate of emission, and the molecule release mechanism.

- Receiver: These elements are in charge of decoding the information by detecting the induced fluctuations in the molecular channel. They need to consider multiple configurations and types of receivers, such as absorbing receiver and receiver with absorbing receptors.
- Signal: The transmitted signal carries the information towards the receiver. This can be based on DNA, proteins, ions, and others.

Derivations of these elements, as well as other elements (active or passive) in the communication channel that may affect the communication process can also be part of this list.

Communication Interface

Network Elements can be connected with other elements by using the *Communication Interface* element, that describes the external interfaces of each network element. Such interfaces have several properties that describe also the type of transmitted and received signals, their affinity and the direction of communication. Again, a subset of custom parameters can be defined in order to describe more in details the properties of each interface, as described in what follows.

Properties and parameters

It is often allowed the definition of a list of custom attributes. This approach allows a high customization capabilities, extending the predefined attributes or introducing completely new ones. This approach allows specifying both properties and attributes of each element described in the MolComML configuration file.

Compartment Elements

The compartments are intended as a kind of well-stirred container of a particular type and finite size where species (e.g. chemical substances) may be located. A model may contain multiple compartments even of the same compartment type, and they can also be located inside each another, hierarchically. Connections between different compartments are handled by Gates, that define the rules for crossing. Note that each species (i.e. Network Element) in a model must be located within a compartment.

Gates

It is possible to define a list of Interconnection gates between a couple of adjacent compartments. Each gate is identified by a unique name, a position, size, shape and orientation, in order to create a sort of passing hole on the surface of both compartments.

Interaction Rules

A set of rules need to be defined. They restrict or specify the operation of the network elements and their connections. The collision behaviour is a typical example: upon impact, molecules can join, merge, or absorb each other, or they can bounce away from each other.

Each rule could either be a global rule valid everywhere or be more specific, describing only a part of the communication environment, or be valid only for a subset of network elements. In general, rules are described by mathematical expressions imported from an external model (e.g. MathML). It is also possible to initialize constants and variables of the imported equations.

Communication Channels

The transmitted signals are transferred to receivers through communication channels. There exist several channel types. Junction-based, diffusion, and diffusion-with-drift are examples of existing channel types. A channel element has to be defined and connected to each compartment placed in the communication environment. This ensures the description, with a high degree of accuracy, of the local environmental conditions, by means of specific mathematical rules defined in one or more external MathML files. It is also possible to initialize a set of the parameters used in the imported equations. Each channel definition could be shared between two or more Compartments. The association channel-compartment is defined in the compartment section.

Network Topology

Each Network Element defines only the main properties of such element. The Network Topology section is used to place the required elements in the proper Compartment. The Topology of the molecular communication network is described by defining the position and orientation of each element and also the communication protocol at the basis of the end-to-end communication. The initialization of any node parameters are declared here.

Protocol Stack

In this section we define the protocol stack that could be used for the communication needs. It is possible to define any number of protocol stacks and each one could have a custom structure

composed of different depth and identification name. Each layer could map the well known protocol stacks of the traditional telecommunication field or define completely new layers.

The layers are defined by a set of rules and each one is composed of two signals, the first is for the forward communication and the second is for the backward communication. For each signal, the type of carrier that will be transmitted and the modulation type are defined. It is also allowed the definition of a set of custom parameters in the standard XML format in order to initialize all the required parameters for that layer. By considering the scenario in Figure 5. , it is necessary, for the link layer, to specify the format of the transmitted messages, along with the algorithms that manage the communication, such as the synchronization and the rate control algorithms for each signal type defined above.

Event Scheduler

The Event Scheduler tag allows the definition of both the initial state for each Network Element and specific events that cause a state transition on a target node, upon the occurrence of an event or at scheduled times.

Unit Definition

Each numerical attribute defined in the MolComML files is associated with a unit of measure declared in a specific section. It is possible to define the most common units, and their multiples, in the International System. The definition of custom units is based on the combination of the previous ones, by setting their values, scales and exponents. The name selected for each custom unit can be used in the other sections of the file, i.e. for the definition of the numerical value of the considered attribute.

External Sources

MolCom systems is expected to interact with elements modeled in the neighboring disciplines. In order to allow interoperability, it is necessary to translate the configuration parameters and results from the other languages, such as SBML or SBOL, providing a flexible adaptation layer that will help integrating and extending the usability of MolComML. For this reason, in the MolComML files it is possible to define the elements to be imported from each external source. For each one, the list of imported elements is defined by specifying the coupling between the original name in the external source with the name used in the MolComML file. For each pairing, also the importing rule is specified; it could be either a comprehensive or a partial import. For the latter case, it is necessary to define each parameter that has to been imported, by specifying its identification name on the external source.

Output

The output data format is fixed for all simulations and numerical results. The defined output scheme allows it to specify which elements have to be exported. In more detail, it is possible to define the list of Network Elements, of the Compartments and of their attributes, by specifying also the time interval for their monitoring. The definition of the monitored attributes is completely custom, so you can define a rule for each attribute of interest.

If the software performs additional post-processing steps applied on the raw numerical results of simulation steps, these have to be described in detail. This includes the identification of data to process, the order in which changes were applied, and also the nature of changes.

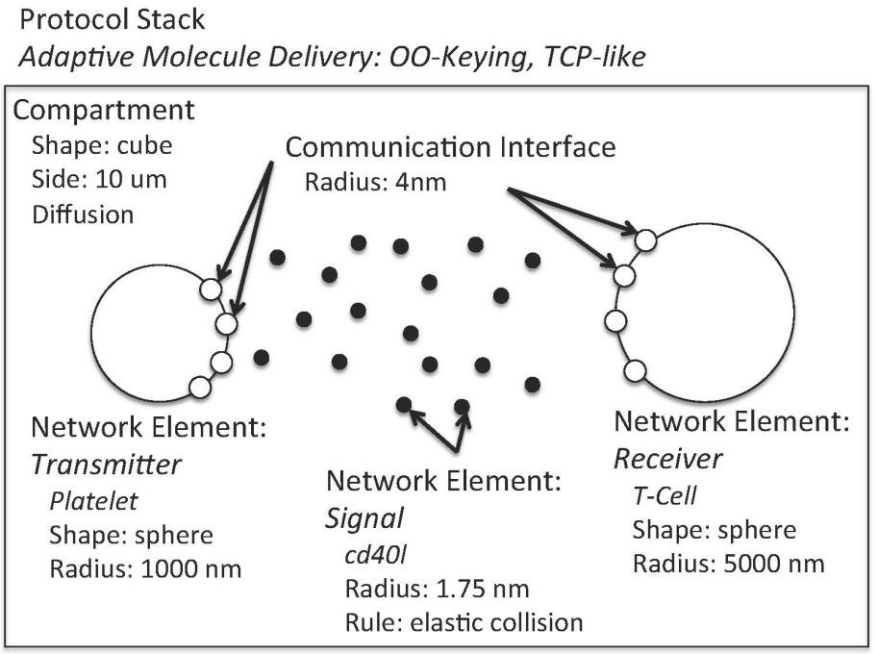

Figure 5. Objectives Graphical description of the MolComML to illustrate the framework in [7].

```
<?xml version="1.0" encoding="UTF-8"?>
<molcomml version="1.0">
  <model name="Platelet_TCell_Communication" description="...">
    <listOfConfigurationParameters>
      <param name="T" value="310" unit="K" description="temp" />
    </listOfConfigurationParameters>
    <listOfUnits>
      <unit name="nm" scale="-9" />
    </listOfUnits>

    <listOfNetworkElements>
      <NetworkElement name="platelet" type="transmitter/receiver">
        <size name="radius" unit="nm" value="1000" />
        <signal type="cd40l" direction="out" />
        <signal type="trombin" direction="in" />
        <motion type="none" />
      </NetworkElement>
    </listOfNetworkElements>

    <listOfCommunicationInterface>
      <CommunicationInterface name="platR" type="element">
        <status type="enabled" />
        <direction input="no" output="yes" />
        <signal type="cd40l" direction="out" time="4" unit="s"
         affinity="none" />
        </CommunicationInterface>
    </listOfCommunicationInterface>

    <listOfProtocolStacks>
      <protocolStack name="Adaptive_Mol_Delivery" maxLevel="5">
        <layer level="1" type="Physical">
          <rule>
            <signal type="cd40l" direction="forward"></signal>
            <signal type="IL-4" direction="feedback"></signal>
          </rule>
        </layer>
        <layer level="2" type="Link">
          <rule>
            <signal type="cd40l" direction="forward">
              <controlMessage name="start" format="1011" />
              <synchronization name="syncAlgorithm" />
            </signal>
            <signal type="IL-4" direction="feedback">
              <dataMessage name="upload" format="burst"
               payload="none"/>
              <rateControl name="TCP_Like_Algorithm" />
            </signal>
          </rule>
        </layer>
     </protocolStack>
    </listOfProtocolStacks>

  <listOfCompartments>
    <externalChannel name="diffusion">
      <Compartment name="box" parent="none">
          <shape type="cube" />
        <gate name="gate1" />
        <channel name="diffusion" />
      </Compartment>
    </externalChannel>
  </listOfCompartments>

  <listOfChannels>
    <channel name="diffusion" >
      <mathRule name="diffusion" path="./mathEquations">
      </mathRule>
        </channel>
  </listOfChannels>

  <networkTopology>
    <disposedNetworkElement name="tx1" type="platelet" >
      <compartment name="tube" />
      <position name="coords" x="100" y="200" z="100" unit="um" />
      <protocolStack type="Adaptive_Mol_Delivery" />
    </disposedNetworkElement>
  </networkTopology>
  </model>
</molcomml>
```

Figure 6. MolComML Configuration file of the framework presented in[7] and Figure 5.

6. Performance assessment of the knowledge sharing initiatives.

This section includes a midway evaluation of the WP3 project activities (knowledge sharing), on the basis of the criteria introduced in the deliverable D3.1. This assessment consists of the joint verification of the milestones having a deadline within the first year of the project and other performance metrics. For what concerns the project milestones, MS3 and MS5 are formally in charge to WP3, and have been accomplished within the first year of the project. In addition, even the other project milestones, which are necessary for a correct execution of the WP3 activities, have been successfully accomplished. Thus, the necessary conditions identified in D3.1 are met. For what concerns the other performance metrics, which are relevant to the objectives of the project, that are reported in what follows for convenience along with their assessment.

- **O1:** Submission of consortium wide papers on molecular communications. At least a research paper, demonstrating the contribution of different research groups in CIRCLE, must be submitted by the end of the first year of the project. It is expected, for very positive assessment, multiple papers to be published. Largely Accomplished. See section 3.2.1.
- **O2:** At least a tutorial paper must be published. This tutorial paper should include the expertise of different disciplines and demonstrate the suitable integration of the biomedical expertise and the ICT expertise. Partially accomplished. In Section 3.2. we have illustrated that a Special Issue in the Elsevier Nano Communication Networks journal, consisting of MolCom tutorials, organized and written by the CIRCLE participants, will be published. They will allow to totally accomplish this requirement during the second year of the project.
- **O3:** The performance assessment relevant to this objective can be done well beyond the end of the project. A qualitative positive assessment consists of the presence of published papers co-authored by at least five young researchers, demonstrating original and innovative thinking. Accomplished. See section 3.2.1.
- **O4:** Performance assessment of knowledge sharing relevant to this objective consists of fulfilling the following four requirements:

O4.1: Presence of at least one follow-on initiative oriented to support research in molecular communications. Accomplished. See D5.2 Section 2.1.

O4.2: Presence of a research initiative compliant with the existing standardization activities. Accomplished. MolComML is compliant with IEEE 1906.1. See Section 6.2.

04.3: Accomplishment of a comprehensive analysis on the current opportunities for undertaking studies at master and PhD levels in molecular communications.

Accomplished. See Section 4.

O4.4: CIRCLE sponsorship to a specialized conference on molecular communication and contribution to a doctoral school. Accomplished. See Section 2, CIRCLE is a sponsor of ACM Nanocom Conference 2015 and 2016.

- **O5:** The performance assessment of this objective is purely quantitative. Full assessment of it consists of the realization of the personnel exchanges illustrated. These exchanges are expected to happen essentially the second year of the project. Not Accomplished. Plans for accomplishing during the second year of the project are ready.
- **O6:** The performance assessment relevant to this objective can be done well beyond the end of the project. A qualitative positive assessment consists of the attendance of representatives of companies to the dissemination events organized by the project CIRCLE. Partially Accomplished during the 1st CIRCLE workshop in Cambridge. See Section 2 and D2.3. It will be fully accomplished during the second year of the project.

List of acronyms and abbreviations

MolCom	Molecular Communications
IEEE	Institute of Electrical and Electronic Engineers
TCSIM	Technical Commettee on Simulation

Circle Participants

WIT	Waterford Institute of Technology
UNIPG	Università degli Studi di Perugia
UPC	Universitat Politècnica de Catalunya
UMC	University Medical Center
KU	Koc University
TUT	Tampere University of Technology
UCAM	The Chancellor, Masters and Scholars of the University of Cambridge
iMINDS	iMINDS
CNIT	Consorzio Nazionale Interuniversitario per le Telecomunicazioni

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