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NANO-MACHINES AND NANO-NETWORKS

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ABSTRACT

Nanotechnologies have several applications in the fields of medicine, manufacturing, ICT and military applications. At nano-scale, a nano-machine can be treated as the most basic functional unit. The nano-machines are tiny components consisting of an arranged set of molecules, which are able to perform very simple tasks. These tiny machines can be integrated together to enhance the capabilities of interconnected nano-machines. In this paper, the nano-machines and the nano-networks have been presented including the research challenges in this domain.

Keywords- *Nanotechnology, nanomachines, nanonetwork, communication.*

I. INTRODUCTION

This The concepts of nanotechnology were first brought out by the physicist Richard Feynman in December 1959 but it was first defined 15 years later by [1] as: ‘‘Nanotechnology mainly consists of the processing of, separation, consolidation, and deformation of materials by one atom or by one molecule”. This definition was further explored in depth in the 1980s by [2]. Research works on nanotechnology really began to gain momentum in the early 2000s.

High level of miniaturization and fabrication of devices in a scale ranging from 1 to 100 nanometers are possible using nanotechnology. A machine fabricated at this scale, is termed as nano-machine and can be considered as a nano-machine capable of the most basic function. Nano-machines are tiny components consisting of an arranged set of molecules which are able to perform very simple computation, sensing and/or actuation tasks [3]. Nano-machines can be integrated together for developing more complex systems such as nano-robots and computing devices such as nano-processors, nano-memory or nano-clocks.

Nano-machines can be interconnected to execute collaborative tasks in a distributed manner. Resulting nano-networks are envisaged to expand the capabilities and applications of single nano-machines in the following ways:

- Nano-machines such as chemical sensors, nano-valves, nano-switches, or molecular elevators [4], cannot execute complex tasks by themselves. The exchange of information and commands between networked nano-machines will allow them to work in a cooperative and synchronous manner to perform more complex tasks such as in-body drug delivery or disease treatments.
- The workspace of a single nano-machine is extremely limited. Nano-networks will allow dense deployments of interconnected nano-machines. Thus, larger application scenarios will be enabled, such as monitoring and control of chemical agents in ambient air.
- In some application scenarios, nano-machines will be deployed over large areas, ranging from meters to kilometers. In these scenarios, the control of a specific nano-machine is extremely difficult due to its small size. Nano-networks will enable the interaction with remote nano-machines by means of broadcasting and multihop communication mechanisms.

Communication between nano-machines can be realized through nanomechanical, acoustic, electromagnetic and chemical or molecular communication means [5].

Nanomechanical communication is defined as the transmission of information through mechanical contact between the transmitter and the receiver. In acoustic communication, the transmitted message is encoded using acoustic energy, i.e., pressure variations. Electromagnetic communication is based on the modulation of electromagnetic waves to transmit information. Molecular communication can be formally defined as the use of molecules as messages between transmitters and receivers.

Molecular communication is the most promising approach for nano-networking based on the following advantages:

- Due to the size and principles of traditional acoustic transducers and radiofrequency transceivers, their integration at molecular or nano-scale is not feasible [5]. By contrast, molecular transceivers are intrinsically conceived at nano-scale. These are nano-machines which are able to emit and receive molecules.
- In nanomechanical communication, transmitters and receivers need to be in direct contact. This is not a restriction for molecular communication over large areas, where transmitters and receivers can be remotely located as long as the transmitted molecules reach the intended receiver.

In the recent literature, the term ‘‘nano-networks” refers to electronic components and their interconnection within a single chip on a nano-scale [6]. This concept is also known as Network on Chip (NoC). This term is also referred to as the network-like interconnection of nanomaterials as well, e.g., carbon nanotubes arrays [7, 8]. In this paper, we use the term ‘‘nano-networks” strictly for the interconnection of nano-machines based on molecular communication.

II. OVERVIEW OF NANOMACHINES

A nano-machine can be defined as ‘‘an artificial eutectic mechanical device that relies on nanometer-scale components” [9]. The term ‘‘molecular machine” is defined as ‘‘a mechanical device that performs a useful function using components of nanometer-scale and defined molecular structure; includes both artificial nano-machines and naturally occurring devices found in biological systems”.

In general terms, a nano-machine can be defined as ‘‘a device, consisting of nano-scale components, able to perform a specific task at nano-level, such as communicating, computing, data storing, sensing and/or actuation”. The capabilities of a nano-machine are very simple and restricted to its close environment due to its low complexity and small size.

There are three different approaches for the development of nano-machines as depicted in Fig. 1. In the topdown approach, nano-machines are developed by means of downscaling current microelectronic and micro-electro-mechanical technologies without atomic level control. In the bottom-up approach, the design of nano-machines is realized from molecular components, which assemble themselves chemically by principles of molecular recognition arranging molecule by molecule. Recently, a third approach called bio-hybrid is proposed for the development of nano-machines [10]. This approach is based on the use of existing biological nano-machines, such as molecular motors, as components or models for the development of new nano-machines. In Fig. 1, different systems are mapped according to their origin, biological or man-made systems, and to their size, ranging from nanometers to meters. In the future, nano-machines will be obtained following any of these three approaches. However, the existence of successful biological nano-machines, which are highly optimized in terms of architecture, power consumption and communication, motivate their use as models or building blocks for new developments.

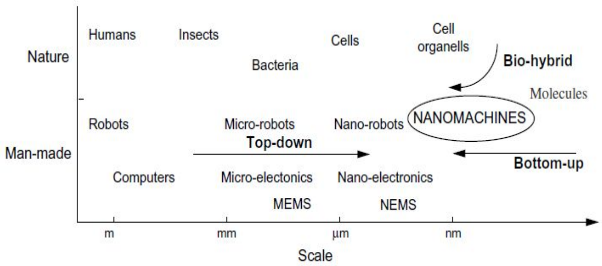

Fig. 1. Approaches for the development of nano-machines

1. Development of Nano-machines

1.1 Top-down Approech

Recently, newest manufacturing processes, such as the 45 nm lithographic process, have made the integration of nano-scale electronic components in a single device possible [11]. The top-down approach is focused on the development of nano-scale objects by downscaling current existing micro-scale level device components. To achieve this goal, advanced manufacturing techniques, such as electron beam lithography [12] and micro-contact printing [13], are used. Resulting devices keep the architecture of preexisting micro-scale components such as microelectronic devices and micro-electro-mechanical systems (MEMS). Nano-machines, such as nano-electromechanical systems (NEMS) components, are being developed using this approach [14, 15, 16]. However, the fabrication and assembly of these nano-machines is still at an early stage. So far, only simple mechanical structures, such as nano-gears [17], can be created following this approach.

1.2 Bottom-up Approech

In the bottom-up approach, nano-machines are developed using individual molecules as the building blocks. Recently, many nano-machines, such as molecular differential gears and pumps [18], have been theoretically designed using a discrete number of molecules. Manufacturing technologies able to assemble nano-machines molecule by molecule do not exist, but once they do; nanomachines could be efficiently created by the precise and controlled arrangement of molecules. This process is called molecular manufacturing [9].

Molecular manufacturing could be developed from current technologies in couple decades if adequate resources are invested. Current development of nano-machines using this bottom-up approach, such as molecular switches [19] and molecular shuttles [20], are based on self-assembly molecular properties [21].

1.3 Bio-hybrid Approech

Several biological structures found in living organisms can be considered as nano-machines. Most of these biological nano-machines can be found in cells. Biological nano-machines in cells include: nano-biosensors, nanoactuators, and biological data storing components, tools and control units [22]. Expected features of future nano-machines are already present in a living cell, which can be defined as a self-replicating collection of nano-machines [10]. Several biological nano-machines are interconnected in order to perform more complex tasks such as cell division. The resulting nano-network is based on molecular signaling. This communication technique is also used for inter-cell communication allowing multiple cells to cooperate to achieve a common objective such as the control of hormonal activities or immune system responses in humans.

The bio-hybrid approach proposes the use of these biological nano-machines as models to develop new nano-machines or to use them as building blocks integrating them into more complex systems such as nano-robots. Following this approach, the use of a biological nano-motor to power a nano-device has been reported in [23]. Another example in line with this approach is the use of bacteria as controlled propulsion mechanisms for the transport of micro-scale objects [24].

2. Expected Features of Nano-machines

The main constraint in the development of nano-machines is the lack of tools which are able to handle and assemble molecular structures in a precise way. However, given the rapid advances in manufacturing technologies, efficient fabrication of more complex nano-machines will be possible in the near future. They are expected to include most of the functionalities of existing devices at microscale. In addition, nano-machines will present novel features enabled by molecular properties of the materials that can be exploited at nano-scale. The most important and expected features of future nano-machines can be described as follows:

- Nano-machines will be intrinsically self-contained. This means that each nano-machine will contain a set of instructions or code to realize the intended task. These instructions or sequence of operations can be embedded in the molecular structure of nano-machines, or can be read from another molecular structure in which the instruction set is stored.
- Self-assembly is defined as the process in which several disordered elements form an organized structure without external intervention, as a result of local interactions between them. At nano-level, self-assembly is naturally driven by molecular affinities between two different elements. Self-assembly will leverage the development of nano-machines and will allow them to interact with external molecules in an autonomous way.
- Self-replication is defined as the process in which a device makes a copy of itself using external elements. This potential process will enable the creation of large number of nano-machines to realize macroscopic tasks in an inexpensive way [25]. Similar to the first feature, self-replication implies that the nano-machine contains the instructions to create a copy of itself.
- Locomotion is the ability to move from one place to another. Nano-machines are aimed to accomplish specific tasks, which are usually described by a spatial-temporal actuation. This means that a nano-machine should be located in the right place at the right time to accomplish the task. However, no single nano-machine is able to move towards a previously identified target. More complex systems could use embedded nano-sensors and nano-propellers to detect and follow specific traces of the target. Locomotion will enable the use of nano-machines in applications where mobile actors are needed, e.g., nano-robots for disease treatments [26].
- Communication between nano-machines is needed to allow them to realize more complex tasks in a cooperative manner. At this level, as explained in Section 1, the most promising technique is based on molecular communication. Further advances in nano-sensors and nano-actuators are expected to enable the integration of molecular transceivers into nano-machines.

3. Nano-machine Architecture

A nano-machine could consist of one or more components, resulting in different levels of complexity, which could be from simple molecular switches to nano-robots [26]. The most complete nano-machines will include the following architecture components:

(1) Control unit. It is aimed at executing the instructions to perform the intended tasks. To achieve this goal, it can control all the other components of the nano-machine. The control unit could include a storage unit, in which the information of the nano-machine is saved.

(2) Communication unit. It consists of a transceiver able to transmit and receive messages at nano-level, e.g., molecules.

(3) Reproduction unit. The function of this unit is to fabricate each component of the nano-machine using external elements, and then assemble them to replicate the nano-machine. This unit is provided with all the instructions needed to realize this task.

(4) Power unit. This unit is aimed at powering all the components of the nano-machine. The unit will be able to scavenge energy from external sources such as light, temperature and store it for a later distribution and consumption.

(5) Sensor and actuators. Similar to the communication unit, these components act as an interface between the environment and the nano-machine. Several sensors and/or actuators can be included in a nano-machine, e.g., temperature sensors, chemical sensors, clamps, pumps, motor or locomotion mechanisms.

Currently such complex nano-machines cannot be built. However, there exist systems found in the nature, such as living cells, with similar architectures. According to the bio-hybrid approach these biological models, i.e., the cells, can be used to learn and understand the principles governing the operation of nano-machines and their interactions. This knowledge is expected to contribute to the development of new bio-inspired nano-machines and systems for specific purposes. In Fig. 2, we show a component mapping between a generic architecture of a nano-machine and a living cell, including its biological nano-machines. Similar to the architecture of a nano-machine, a cell contains the following components:

(1) Control unit. The nucleus can be considered as the control unit of the cell. It contains all the instructions to realize the intended cell functions.

(2) Communication. The gap junctions and hormonal and pheromonal receptors, located on the cell membrane, act as molecular transceivers for inter-cell communication.

(3) Reproduction. Several nano-machines are involved in the reproduction process of the cell such as the centrosome and some molecular motors. The code of the nano-machine is stored in molecular sequences, which are duplicated before the cell division. Each resulting cell will contain a copy of the original DNA sequence.

(4) Power unit. Cells can include different nano-machines for power generation. One of them is the mitochondrion that generates most of the chemical substances, which are used as energy in many cellular processes. Another interesting nano-machine is the chloroplast, which converts sunlight into chemical fuel.

(5) Sensors and actuators. Cells can include several sensors and actuators such as the Transient Receptor Potential channels for tastes and the flagellum of the bacteria for locomotion. The chloroplast of the plants can also be

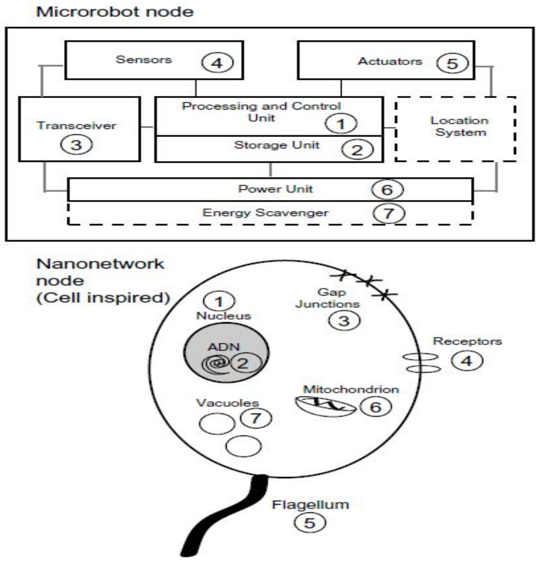

Fig. 2. Functional architecture mapping between nano-machines of a micro or nano-robot, nano-machines found in a cell

considered as an actuator since it transforms water to oxygen that is later released to the environment.

A bio-hybrid approach cannot only be used to develop novel nano-machines, but also to understand their interactions in larger systems such as cells. These interactions, exclusively enabled by molecular communication techniques, are essential since this is the only way to explore their capabilities to achieve more complex tasks in a cooperative manner.

In this paper, we expand the bio-hybrid approach beyond the models for novel nano-machines in order to study and develop molecular communication techniques for their interconnection.

III. Nanonetwork Applications

The potential applications of nano-networks are unlimited. We categorise them in four groups: biomedical, environmental, industrial and military applications. However, since nanotechnologies have a key role in the manufacturing process of several devices, nano-networks could be used extensively in many other fields such as consumer electronics, life style and home appliances among others.

1. Biomedical applications

The most direct applications of nano-machines and nano-networks are in the biomedical field. Biological models inspire and encourage the use of nanotechnologies to interact with organs and tissues. The advantages provided by nano-networks are clearly in terms of size, biocompatibility and biostability, enabled by the control of system components at molecular level. These are some of the envisaged applications:

- Immune system support. The immune system is composed by several nano-machines that protect organism against diseases. These nano-machines are a collection of nano, micro and macro systems, including sensors and actuators, acting in a coordinated way to identify and control foreign and pathogen elements. Nano-machines can be used to help the detection and elimination procedures. They could realize tasks of localization and response to malicious agents and cells, such as cancer cells [27, 28], resulting in a less aggressive and invasive treatments compared to the existing ones.
  - Bio-hybrid implants. These are aimed at supporting or replacing components such as organs, nervous tracks or lost tissues [9, 29]. Nano-networks can provide friendly interfaces between the implant and the environment. Restoration of central nervous system tracks is a possible application of bio-hybrid implants.
  - Drug delivery systems. These are another specific type of implants. For instance, these systems could help to compensate metabolism diseases such as diabetes. In this sense, nano-sensors and smart glucose reservoirs or producers can work in a cooperative manner to support regulating mechanisms [30]. Drug delivery systems

could also help to mitigate the effects of neurodegenerative diseases by delivering neurotransmitters or specific drugs [31].

- Health monitoring. Oxygen and cholesterol level, hormonal disorders, and early diagnosis are some examples of possible applications that can take advantage of inbody nano-sensor networks [29, 32]. The information retrieved by these systems must be accessible by relevant actors. Thus, nano-networks must provide the proper level of connectivity to deliver the sensed information.
- Genetic engineering. Manipulation and modification of nano-structures such as molecular sequences and genes can be achieved by nano-machines. The use of nano-networks will allow expanding the potential applications in genetic engineering.

2. Industrial and Consumer Goods Applications

Nano-networks will be used not only the intra-body but also in industries. Nano-networks can help with the development of new materials, manufacturing processes and quality control procedures. More specifically, these applications have already been proposed:

Food and water quality control. Similar to health monitoring applications, food and fluids quality control can take advantage of nano-networks. Nano-sensor networks can help detecting small bacteria and toxic components that can affect to the product quality and cannot be detected using traditional sensing technologies [33]. Advanced self-powered nano-sensor networks can be used to detect very small amount of chemical or biological agents installed in water supplies across the country.

- Functionalized materials and fabrics. Nano-networks can be included in advanced fabrics and materials to get new and improved functionalities. Antimicrobial and stain-repeller textiles are being developed using nanofunctionalized materials [34]. For instance, nano-actuators can help to improve the airflow in smart fabrics. These nano-actuators can communicate to nano-sensors to control the proper reaction based on the external conditions.

3. Military Applications

Nanotechnologies can also have several applications in the military field. While in the applications pointed out before, the range covered by nano-networks is short, in military field the deployment range of nano-networks can be widely variable depending on the application. Battlefield monitoring and actuation demand a dense deployment of nano-networks over large areas, while systems aimed at monitoring soldier performance are deployed in smaller areas, i.e., human body. Among the military applications, we can mention:

- Nuclear, biological and chemical (NBC) defenses. This is a classic application for large area deployment. Nano-networks can be deployed over the battlefield or targeted areas to detect aggressive chemical and biological agents and coordinate the defensive response [35]. The overall system can be compounded of nano-sensors and nano-actuators, which would detect and control the hostile agents. Nano-sensor networks could also be deployed into cargo containers to detect the unauthorized entrance of chemical, biological or radiological materials.
- Nano-functionalized equipments. These applications are similar to those found in consumer goods field, but it is focused on military equipment. Advanced camouflage as well as army uniforms can take advantage of nano-networks. For instance, equipments can be manufactured using advanced materials containing nan-onetworks that self-regulate the temperature underneath soldier's clothes [36] and even detect whether the soldier has been injured.

4. Environmental Applications

Since nano-neworks are inspired in biological systems found in nature, they can also be applied in environmental fields achieving several goals that could not be solved with current technologies. Some environmental applications are:

- Biodegradation. There is an existing and growing problem with garbage handling around the world. In this line, nano-networks could help with the biodegradation process in the garbage dumps. Nano-networks can help the biodegradation process by sensing and tagging different materials that can be later located and processed by smart nano-actuators.
- Animals and biodiversity control. Nano-networks can be also used in natural environments to control several species. For instance, as seen in nature, nano-networks using pheromones as messages can trigger certain behaviors on animals. As a result it is possible to interact with those animals and also to control their presence in particular areas.

- Air pollution control. Similar to the quality control applications, air can be monitored using nano-networks. Moreover, nano-filters can be developed to improve the air quality by removing harmful substances contained in it [37].

IV. COMMUNICATION AMONG NANO-MACHINES

Among all of the expected features of future nano-machines, the communication capabilities are also very important. This is the only feature that enables them to work in a synchronous, supervised and cooperative manner to pursuit a common objective.

Nano-machines communication can include the two following bidirectional scenarios:

(1) Communication between a nano-machine and a larger system such as electronic micro-devices, and

(2) Communication between two or more nano-machines.

Different communication technologies, such as electromagnetic, acoustic, nanomechanical or molecular; have been proposed for each scenario in [5].

Communication based on electromagnetic waves is the most common technique to interconnect microelectronic devices. These waves can propagate with minimal losses along wires or through air. However, given the size of nano-machines, wiring a large quantity of them is unfeasible. As an alternative, wireless solutions could be used. To establish a bidirectional wireless communication, a radiofrequency transceiver should be integrated in the nano-machine. Nano-scale antennas could be developed for very high frequency communication. However, due to the size and current complexity of the transceivers, they still cannot be easily integrated into nano-machines. In addition, if the integration were possible, the output power of the nano-transceiver would not be enough to establish a bidirectional communication channel [5]. As a consequence, electromagnetic communication could be used to transmit information from a micro-device to a nano-machine, but not from nano-machines to micro-devices, nor among nano-machines.

At nano-level, acoustic communication is mainly based on the transmission of ultrasonic waves. Similar to the communication based on electromagnetic waves, the acoustic communication implies the integration of ultrasonic transducers in the nano-machines. These transducers should be capable to sense the rapid variations of pressure produced by ultrasonic waves and to emit acoustic signals accordingly. Again, the size of these transducers represents the major barrier in their integration in the nano-machines.

In nanomechanical communication, the information is transmitted through hard junctions between linked devices at nano-level. The main drawback of this type of communication is that a physical contact between the transmitter and the receiver is required. Moreover, this coupling should be precise enough to guarantee that the desired mechanical transceivers are aligned correctly. This communication technique is not suitable in many application scenarios where nano-machines are deployed over large areas without any direct contact between them. In addition, without precise navigation systems in nano-machines, their positioning for a correct nanomechanical communication is a major barrier.

Molecular communication is defined as the transmission and reception of information encoded in molecules. Molecular communication is a new and interdisciplinary field that spans nano, bio and communication technologies [38]. Unlike previous communication techniques, the integration process of molecular transceivers in nano-machines is more feasible due to the size and natural domain of molecular transceivers, i.e., nano-scale framework. These transceivers are nano-machines which are able to react to specific molecules, and to release others as a response to an internal command.

Molecular communication can be used to interconnect multiple nano-machines, resulting in nano-networks as defined earlier. Nano-networks expand the capabilities of single nano-machines in the following terms:

- More complex objectives can be achieved if multiple nano-machines cooperate. Nano-networks enable this cooperation by providing mechanisms to exchange information between different nano-machines such as molecular motors or nano-switches.
- Single nano-machines can only perform tasks at nanolevel, and therefore their workspace is very limited. However, if a large number of nano-machines are interconnected, they can pursuit macro-scale objectives, and work over larger areas, such as treatment of cancer tumors or air pollution monitoring.
- If multiple nano-machines are deployed over large areas, the interaction with a specific nano-machine is extremely difficult due to its small size. This interaction includes procedures such as nano-machines activation/deactivation, configuration of parameters, data acquisition or actuation commands. Nano-networks will enable this interaction by

providing the infrastructure and mechanism to broadcast the information over these areas. In addition, two nano-machines could interact indirectly by using other nano-machines as repeaters.

Besides expanding capabilities of single nano-machines, nano-networks represent a potential solution for some applications where available communication networks and micro-devices are not suitable. Compared to current communication network technologies, nano-networks have

the following advantages:

- The reduced size of nano-machines and the resulting nano-network components can be an advantage in many applications where the dimension of the involved systems is critic. For instance, in the biomedical field, nano-machines can be used for intra-body applications allowing nano-networks to lead to nano-invasive and more selective treatments.
- Biocompatibility is defined as the quality of a device to operate accordingly in biological environments without affecting them negatively. In some biomedical applications, many electronic devices have to cope with hostile environments as well as many organisms reject implants and drugs. Nanotechnologies can be used to enhance the compatibility between nano-machines and natural organs or tissues by means of more friendly materials and interfaces. For instance, bio-hybrid nano-machines compound by biological elements can interact with natural processes without any side effect. In addition, nano-machines and molecular messages may also be programmed to deactivate after completing the nano-network task preventing removal procedures. Nanotechnologies, allow the control of materials at molecular level. Using these materials, we can design nano-networks nodes according to specific environmental conditions improving the biocompatibility of the system.
  - Chemical reactions are highly efficient in terms of energy consumption [39]. These reactions will power the nano-networks nodes and processes. Chemical reactions can also represent complex computation and decision processes, which in traditional communication could mean multiple operations.

1. Nanonetwork Components

The first models of nano-networks are based on those used in Information and Communication Technologies (ICT) for telecommunication networks. We have shown the general concepts of nano-networks versus existing telecommunication systems. Nano-networks components are functionally similar to those found in traditional networks.

In nano-networks, we can identify five different components: the transmitter node, the receiver node, the messages, the carrier, and the medium. Each of these components affects the overall communication process, which includes the following steps:

(1) The transmitter encodes the message onto molecules.

(2) The transmitter inserts the message into the medium by releasing the molecules to the environment or attaching them to molecular carriers.

(3) The message propagates from the transmitter to the receiver.

(4) The receiver detects the message.

(5) The receiver decodes the molecular message into useful information such as reaction, data storing, actuation commands, etc.

V. RESEARCH CHALLENGES IN NANO-NETOWROKS

The interest in nanotechnologies is growing while more applications are being proposed. The potential impact of these technologies leverages the continuous development of new tools, such as simulators [26], scanning probe microscopes [40], or lithography machines able to pattern nano-metric structures.

Over the last years, novel molecular manufacturing techniques are enabling the development of more advanced nano-machines. Using nano-networks, these nano-machines can be interconnected to realize more complex tasks in a coordinated and complementary manner. First, developments in nano-networks are inspired by biological systems based on molecular communication.

Recently, two molecular communication schemes have been proposed based on natural models. These schemes are based on inter and intra-cell molecular communication techniques [3]. Additionally, in this paper we propose a third communication scheme based on pheromones. These three communication schemes are examples for short or long-range molecular communication observed in nature. They are proposed as basic models for the development of future nano-networks.

Nano-networks are not only related to the molecular communication techniques, but also to nano-machines, which are able to communicate at this level. The nano-networks development roadmap includes several stages, in which an interdisciplinary scientific approach is needed to address all the posted research challenges.

VI. CONCLUSION

The development of nanotechnologies will continue and will have a great impact in almost every field. The use and control of these technologies will be a major advantage in economics, homeland security, sustainable growth and healthcare. Intrinsic technological burdens will limit the use of more advanced and smart materials, sensors, actuators and devices at nano-scale, if they are not able to communicate to cooperate to perform more complex tasks. This need for a communication network will be more plausible with the increased complexity of developed nano-devices.

Molecular communication seems to provide efficient mechanisms for networking of nano-machines. It represents a complete new communication paradigm in which the information is encoded into molecules. In this paper the term ‘‘nano-network” was defined as the interconnection of multiple nano-machines using molecular communication. Nano-networks demand innovative solutions to create reliable molecular communication channels among nano-machines. First developments are bio-inspired by existing biological nano-networks. At nano-level, many components and communication process has been studied from a biological or chemical point of view.

Despite being a novel communication paradigm that requires an interdisciplinary approach, information and communication technologies (ICT) are called to be a key contributor for the evolution of the nano-networks. Network architectures, channel models, nano-machines and transceivers architectures, medium access control and routing protocols are some of the contributions that are expected from the ICT field.

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