The Use of Nano-machines in Molecular and Electromagnetic Communications: A Brief Survey

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***Abstract*—In recent years, we witnessed advances in biological science as well as nanotechnology which led to the design and construction of nano-scale useful devices to communicate with biological molecules and cells. Nanomachines are tiny devices at the scale of nanometer (10^{-9} meters). These devices are still in the design and development phase. However, some nanosensors have been built and tested recently. This paper provides a brief overview of nanomachines in both Molecular and Electromagnetic Communications. Firstly, the architectural design and biological engineering of components in molecular communication is presented. Then, a detailed design and architecture of an electromagnetic nanodevice is reviewed. Moreover, this paper discusses a group of available and potential applications in this promising technology. Finally, a collection ofissues, challenges and opportunities that opens the door for more research studies is listed at the end of the paper.**

***Index Terms*— Nano-Technology, Nanomachines, Molecular Communications, Electromagnetic Communication, Nano-sensors, Challenges and Opportunities.**

I. Introduction

Nanonetworks composed of a number of nanomachines connected all together. This kind of networks, which attracts the attention of countless number of researches around the world, is likely to increase the abilities of the usual micro-networks in the future. Currently, nanomachines are able to accomplish very simple tasks such as sensing and storing very small size of information. Nanonetworks support new types of applications in different fields like nanotechnology in the biomedical field, environmental research and military technology applications. For example, in medical field, nanotechnology enables the opportunity to merge nanomaterials with biological elements since these nanoscale materials are in the same size of cellular inner structures. This will help in building new medical applications such as better diagnostic devices and powerful body scanners.

There are many applications of these nanomachines in the field of nanosensors [8, 9, 10, 11]. A nanosensor is not just a tiny sensing electronic piece, but an important component that makes use of the new features of nanomaterials to pinpoint, control and may be measure different forms of actions in the nanoscale level. In general, nanosensors is able to measure chemical mixtures in concentrations as low as one part per billion [12, 13] Moreover, it can detect the occurrence of biological problems such as virus or cancer cells [14, 15, 16]. But one of the big issues with these machines is the limited sensing zone. Hence, more than one nanosensors are required to cover specific area. In addition, another microdevice is needed to communicate with these nanosensors and send data to a microcomputer.

According to [2], there are three ways of building nanomachines: Top-Down, the Bottom-up and the Bio-hybrid approaches, as shown in Fig. 1. In the top-down approach, manufacturers build nanomachines by scaling back the current microelectronic devices to nano-level [3]. In the bottom-up approach, nanomachines are built using discrete molecules as the building blocks. The bio-hybrid approach suggests the use of human biological nanomachines as models to build new nanomachines or to use them as building blocks in order to be used in developing systems that are more complex [4].

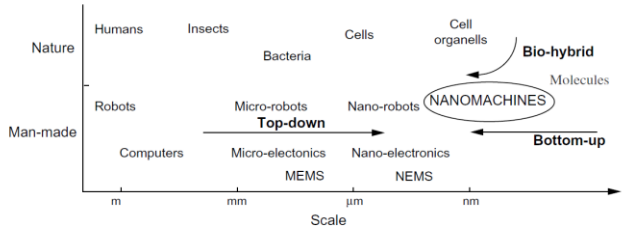

Fig. 1: Approaches for the development of nanomachines from [2]

Since it is a new concept, nanonetworks face many challenges in its design ranging from the nanomachine to the communication medium. There are two ways of communication in nanoscale: Electromagnetic and Molecular [5].

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The rest of paper is organized as follows. In section 2, the Electromagnetic Communication is introduced. In section 3, the paper presents the Molecular Communications and its components. In section 4, a group of current and possible nano applications is reviewed. In section 5, a collection of challenges and issues of both communication approaches is listed. Finally, section 6 concludes the paper.

II. ELECTROMAGNETIC COMMUNICATION

As the name implies electromagnetic communication is built on communication by means of electromagnetic technology (mainly wireless networks). In the recent years, the vast improvements in carbon electronics have led to the fabrications of new electronic nano-materials such as nano-batteries, nano-memories, and nano-antennas [7,27]. These new devices can perform new activities in the nano-dimensional scale that no micro-device could perform in the micro-dimensional scale. Therefore, the main objective of nanotechnology is to construct a nanodevice with exclusive features [17, 5].

An internal architecture of a nanosensor is presented in Fig. 2 [5]. The size of the device is around 10–100 μm^2 and able to perform some computational tasks as well as communicating with other machines. It is composed of:

1) **Sensing Unit:** This unit could be made of Graphene which is an innovative material, or its derivatives, for example: Graphene Nanoribbons (GNRs) or Carbon Nanotubes (CNTs) [18] It offers an exceptional sensing competencies and is considered to be the source for different kinds of sensors [11].

2) **Actuation unit:** This unit allows the nanosensor to deal with its nearby environment. It could be either physical or biological. In Physical actuator, generating an electrical wave could some kind of physical deformation in a nanotube. Also in the biological nanoactuators, the cancer cells can be attacked and damaged by nano- electromagnetic particles [5,19].

3) **Power unit:** This is supposed to provide the nanosensor with power. It generates power through the piezoelectric effect seen in zinc oxide (ZnO) nanowires which can be seen at the bottom of the architecture in Fig. 2. These nanowires generate voltage when they are physically bent. Moreover, power can be also generated via some other sources such as “vibrational energy” which could be harvested via nanotubes and nanocantilevers. The collected energy then can be used immediately by the nanosensor or saved in a nanobattery to be used later on [5].

4) **Storage unit:** Storing data is one of the issues that still under research because of the limitations in size. Nano-memories can store only one bit in each atom by means of nanomaterial. The main simple idea behind some types of nano-memories is that their work is based on the presence and absence of silicon atom on a gold track i.e. presence means 1, for example, and absence means 0 or vice versa. So to do the writing process, a tool in the nano-memory removes the silicon atoms. Whereas for the reading process a tool locates the silicon atoms and compose the series on 1’s and 0’s. But here is another limitation: this nano-memory is not rewritable. Lately, IBM corp. has developed the magnetic atomic memories in which they used magnetic surface instead.

5) **Communication unit:** In the current micro-scale wireless communications, frequency between hundreds of MHz to GHz are used. In this case an antenna with few centimetres height is needed, which is impossible in the nano-scale devices due to size limitations and high attenuation [20]. To overcome this problem, graphene could be used. This graphene nano antenna is 1 μm long and it can use frequency up to 10 terahertz (THz) [27]. It is very tiny that could be built using one or a set of carbon nanotube [21].

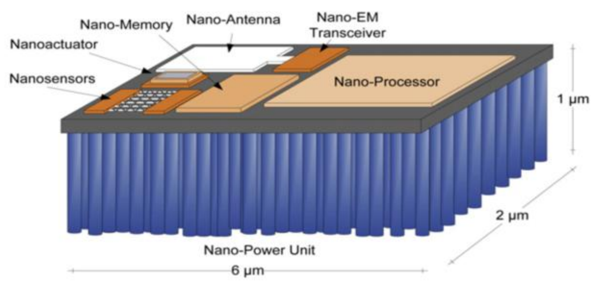

Fig. 2. Integrated Electromagnetic Nanosensor

III.MOLECULAR COMMUNICATION

Molecular communication is defined as sending and receiving information using molecules. The main purpose of molecular communication is to keep a reliable level of communication between nano devices. Due to the technological advances, the biological nano devices became a standard in the nano scale networks [6]. There are some challenging issues with this type of nano networks such as signaling. Still there is no available a device that take into consideration all the constraints of such a new technology [6]. As can be seen in Fig. 3, there are two nanomachines, the transmitter (to the left) upload molecules with encoded information and propagates them

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inside the physical medium then they find their way to the other nanomachine (to the right) [22].

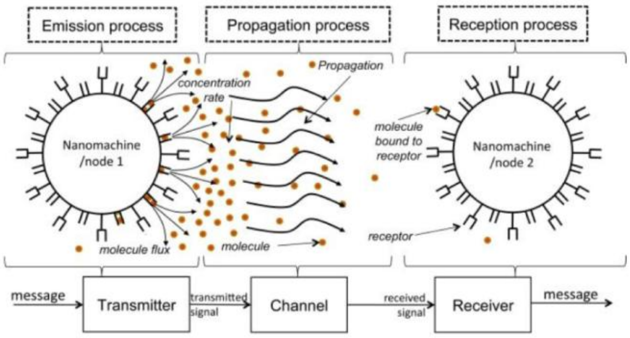

Fig. 3:Two-node Molecular Communication Network [23]

The general phases of Molecular communication are: i) information encoding, which is done by the transmitting nanomachine. ii) information propagation into the environment. iii) information receiving which is performed by the receiving nanomachine. iv) decoding of the information which is done by the receiving nanomachine. Hereafter is the description of each phase of the molecular communication:

1) **Encoding**: The sending nanomachine translates information and loads it to the molecules. This process is called Encoding. There are many methods to encode molecules, such as the use of temporal concentration of exact molecules in the environment. So the receiving nanomachines decodes information based on the number of molecules per volume. This method works exactly like data transfer via time-varying sequences in normal communications. Another method of encoding information uses physical characteristics of the molecules such as chemical structure, relative positioning of molecular elements or polarization. [24, 25].

2) **Sending and Propagation**: During this phase, the sending nanomachine propagates information molecules into the medium. For example, if the transmitter nanomachine is a biological cell, it propagates molecules by budding vesicles from a biological cell. The information molecules are transferred between transmitter and receiver nanomachines in three ranges of distance. They are short-range (from nm to µm), medium-range (from µm to mm) and large-range (from mm to m) [22]. The information molecule could move through the environment either passively without using chemical energy or using motor which provides motion.

3) **Receiving**: In this phase, the receiver nano-machine detach the information molecules from it. The receiver should be permeable to the information molecules so as to be able to read the information. Or in other option the surface of the receiver nano-machine could be sensitive to some chemical molecules or able to binding with them.

4) **Decoding**: After receiving the information molecules, the receiver nano-machine decodes it and then start its reaction. The reaction could be a small task such as creating signals or larger task such as sending new information molecules to different nano-machines.

IV. Current and Possible Applications in Nano Scale

This section presents a number of applications utilizing either Molecular or Electromagnetic nano-machine. Some of these application have been built while the others still under construction and need more work to be finished.

For example, a research suggestedto use the neural networks for molecular communications [17]. For signal generation, they built alink between nano-machines and neurons. Then they presented a communication scheduling to confirm that information (signals) will be delivered to the receiver. Their work is based on the Generic Algorithm (GA) which is an optimization technique.

Another application can be found in [22]. The authors designed a self-organizing microtubule network. Microtubules are a constituent of the cytoskeleton, found through the cytoplasm inside a cell. The microtubule network is able to communicate with nano-machines via molecular motors.

Moreover, a health monitoring application can be designed to measure the levels of cholesterol, glucose …etc. in blood. Many nanosensors can be spread around the body to collect information. This information then could be delivered to an external device such as microcomputer. People with diabetes will no longer have their fingers pricked to measure the level of glucose. In addition, these nanosensors could detect the existence of infections and may be cancer. Consequently, nanomachines will provide drug delivery in order to cure infected cells, or could be aggressive enough to attack cancerous cells [26].

Additionally, there are many nanomachine applications deployed in Industry such as smart office. In this applications a network of nano-sensors can be built in an office to provide an interconnection between employees and all their belongings. These nano-sensors could be connected to the Internet, so employees can communicate with everything inside their offices remotely [5].

Finally, tiny nano-sensors can be utilized to detect small cracks in civil structures. This will help to discover big problems and disasters before it really happens. The

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idea is to install a network of nanosensors over the structure and the results will be sent directly to a micro device such as computer.

V. NANOSENSOR CHALLENGES

After introducing the applications of nano machines and nap sensors in both electromagnetic and molecular networks, it is better now to present the challenges and opportunities that will help researchers to work on.

1. Challenges of Molecular Communication

In addition to the aforementioned challenges, here is a list of challenges in Molecular Communication:

a. We still need to work on the protocols such as medium access protocols.
b. If data is transferred among many nodes, we need an addressing mechanism and a routing protocol.
c. We still do not know exactly how many molecules do we need to send information. This issue is open for research.
d. Guiding information molecules within the communication medium needs more control to reduce the data loss.
e. Molecules face many obstacles within the environment. We need to find the best way to overcome such obstacles.

2. Challenges of Electromagnetic Communication

Like molecular communications, electromagnetic communications in nano scale are still facing many challenges. Here is a list of some open issues in this field:

a. Noise and Attenuation are issues need to be discussed and studied.
b. There is a lack of protocols in this kind of communications such as MAC protocols and Routing protocols.
c. The number of published papers discussing the THz band are not enough. There is a need to study this band and to decide whether it is the best medium to transfer data in this nano scale or not.
d. More studies are needed to overcome the environment obstacles facing signals while traveling from sender to receiver.
e. The power is a big issue in nano scale communication. Available battery does not provide enough power to send and receive information.
f. Strong information is another important issue. We need to find more powerful ways to store information in a small size memory or buffer.
g. Moreover, researchers are needed to perform more experiments on all other communication issues which path-loss, noise, channel capacity which are still big issues in the normal current networks.
h. Although many researchers are busy in constructing novel nano-antenna, but the outcome is still in the form of designs and models.

VI. CONCLUSIONS

This paper presented two promisingapproaches of communications in nano scale: Molecular and Electromagnetic. We discussed the main componentsof them including the nature of nanomachine in both approaches and the architecture of nanonetworks in nano-scale dimensions. According to many researchers, these nanomachine networks will dominate the future of Information and Communication Technology (ICT). However, there are many obstacles and challenges inhibit their success take off. Hence, this paper provided a long list of such issues which need engineers and researchers to focus on. For example, in Molecular Communications there are some challenges such as protocols and harsh environment. Whereas Electromagnetic Communications are facing problems such as power supply, size of battery and Routing protocols.

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