Molecular communication in Nano Networks

Sidra Zafar[1],Mohsin Nazir[1], Aneeqa Sabah[2]

[1]Department of Computer Science, Lahore College for Women University ,Pakistan.
[1]Department of Physics, Lahore College for Women University ,Pakistan.
Email: sidzafar.88@gmail.com
mohsinsage@gmail.com

Abstract

This article examines the current research in nano communication networks specifically Molecular Communication (MC).Molecular Communication is an emerging communication paradigm where molecules are used to exchange information. Unlike traditional communication paradigms, molecules are transmitted as messages between biological nano machines. Key research challenges in molecular communication include design of system components and mathematical modeling of each system component as well as entire systems. Recent research in molecular communication and its propagation medium has been reviewed in this article.

Keywords: Nano machine; Nano communication networks; Nano communication networks applications; Molecular communication; Molecular Propagation Systems.

Introduction

Nanotechnology is miniaturization and fabrication of devices in a scale ranging from 1 to 100 nanometers. The prefix nano means one billionth i.e., ($1x10^{-9}$). Nanotechnology has been defined in a number of ways in literature. However according to [1] nanotechnology is "a branch of technology dealing with the manufacture of objects with dimensions of less than 100 nano-meters and the manipulation of individual molecules and atoms". Nano machines are fully functional devices and capable of performing trivial tasks like sensing, actuation, computing and data storage. Single nano machines are only capable of performing trivial tasks therefore to perform more complex tasks they must be interconnected to form a network [2], [24]. Nano-machines can be manufactured using three approaches top-down, bottom-up and bio-hybrid.

Molecular communication (MC) is the paradigm in nano communication networks that utilizes molecules for communication among nano machine [2][3][20]. Molecular communication is biologically inspired i.e., it adapts the communication mechanisms already existent in nature for communication among living organisms. Human body is composed of a large scale heterogeneous network where molecular communication takes place for intra body communication [25].There are a number of intra body applications where small scale communication is necessary e-g targeted drug delivery, BMI (Brain Imaging Interface), tissue engineering and cell repair etc [2][20][25]. Various communication and networking aspects of MC are currently being explored by research community. We have investigated the current research in propagation medium of Molecular communication, after giving brief introduction of nano communication network.

Section 2 discusses the current research in Molecular Communication. Section 3 defines the architecture of nano machines between which Molecular communication takes place. Section 4 highlights the applications of nano networks. Section 5 discusses different communication mediums used for communication between nano machines. In Section 6 detailed architecture of Molecular communication has been discussed and in Section 7 is the conclusion.

Background Study

Molecular communication is as old as the existence of nature, as communication has been taking place between living organisms since then. However with the advancement in computer networking the significance of Molecular communication has been brought to light all over. The research on molecular communication from the networking perspective is almost two decades old but still is immature. There are still a number of open issues regarding design and mathematical modeling of system components that needs to be addressed.

Molecular communication is able to take place in three ranges according to [2]. (1) Short range communication using molecular motors is the mechanism where inter cell and intra cell communication takes place using molecular motors, which are carriers of information encoded molecule. (2)Short range communication using calcium ions is another mechanism of molecular communication where communication might take place either between physically adjacent cells or distant cells using calcium ions (Ca^{2+}).(3)Long range communication using pheromones is the communication mechanism that takes place between sender and receiver nano machines that might be millimeters to kilometers apart. Application domains long range communication is military field and environmental applications [2].

Architecture of Nano-machines

Nano-machine consists of five components in its complete form. In order to develop efficient and novel nano-machines and to understand the communication mechanism between nano-machine, study of biological cell architecture and their interactions has been proved helpful. Following architectural components are included in most complete nano-machines and their biological cell counterparts are identified by [2], [6] and compared in the table below:

Table 1. Mapping between synthesized nano-machines and nano-machines found in biological cells

Synthesized nano-machines	Biological nano-machines
Control Unit. It contains the embedded software, which aims to perform the intended task of nano machine.	**Control Unit**. Similar to software conditional expressions biological control unit encodes protein structures, data units and regulatory sequences.
Communication Unit. Communication mechanism of nano machine is realized through transceivers. Transceivers allow the embedded system to exchange information by transmitting and receiving messages at nano level.	**Communication Unit**. The inter-cellular communication is realized through the gap junctions, hormonal and pheromonal receptors placed on the membrane of cell.
Reproduction unit. It contains the instructions to fabricate the components of nano-machines and then to replicate them.	**Reproduction**. This process takes place when nano machines are replicated by saving the code of nano machine in molecular sequences .
Power Unit. Power unit supplies stored energy to all the other components of nano-machines, to maintain the electrical current in embedded software.	**Power Unit**. Mitochondrion, chloroplast and Adenosien Tri phosphate are some of the substances of cells that correspond to the external chemical reactions to produce energy. This chemical energy is stored in the cell reservoirs and supplied to regulate the other components of cell.

Sensor and Actuators. This unit provides interface between environment and nano machine.	**Sensors and Actuators**. Sensing and actuation is the ability of biological cell to distinguish external molecules or stimuli e-g chloroplast of plants and flagellum of bacteria.

The most complete nano machine consists of all the components described above. However according to application domain nano machines might be changed in shape such as nano robots in medical applications.

Nano Network Applications

Nanonetworks applications are unlimited and are used extensively in almost every field. However they are classified in following broad groups in [2].

Biomedical applications

The size of nano devices makes them feasible for a number of bio medical and health monitoring applications including diagnostics, treatment and prevention of diseases. Another advancement in the field of healthcare is the nano machine deployed inside the human body which can remotely be controlled from the nanoscale and over the internet by an external user (healthcare provider) [7].

Industrial applications

Nano devices are showing potential in a number of industrial and consumer good applications. Interconnected nano-machines are used by video gaming industry for increased thrill and realistic gaming experience. It provides the functionality of transporting molecules from one location to another, mixing different types of molecules and separating specific kind of molecules from a mixture [10][11] .

Military Applications

Nanotechnology also has several applications in the military field. Nano devices such as imperceptible nano cameras, ultrasonic nano phones, and biological nano-sensors are devices that show potential in battlefield monitoring and actuation [2][7].

Environmental Applications

The bio inspired nature of nano technology makes it feasible to detect and sense contaminated materials found in nature. The problem of handling and dumping garbage is increasing around the world; this problem can be dealt by biodegradation process that uses nano-networks [2].
Nanonetworks can also be used to monitor air, thus controlling air pollution and nano filters can be developed to improve air quality and remove harmful materials from air [12].

Communication between Nano Machines

Nano-machines are only able to perform trivial tasks on their own; therefore communication among nano-machines is very important to realize more complex tasks .Nano-machines can be interconnected to execute collaborative tasks in a distributed manner resulting in nano-networks that expand the capabilities and applications of single nano-machines [2].
Nano-machine communication technologies are divided into four groups namely:

- Electromagnetic communication
- Acoustic Communication
- Nano Mechanical Communication
- Molecular Communication.

Electromagnetic communication
This type of communication based on the transmission and reception of electromagnetic waves between novel nano materials such as carbon nanotubes and graphene based nanoribbons [2][13]. The traditional transceiver of classical wireless communication is not feasible for nano-scale communication, however novel graphene based nano-materials have shown potential to overcome this limitation [13].

Acoustic Communication
Acoustic communication is realized by the transmission of ultrasonic waves through nano machine integrated transducers .These transducers should be capable to sense the variety of pressure and then react accordingly. Currently the size of transducers is the major barrier to implement this communication mechanism at nano-scale [2].

Nano Mechanical Communication
In nano mechanical communication, the information is sent through nano machines that are linked physically. One of the major drawbacks for this communication technique in nano communication context is physical connection between devices. Therefore it is not feasible for the applications where nano-machines have to be placed at distant locations [4].

Molecular Communication
Molecular Communication (MC) is a molecule based communication paradigm that enables transmission of bio-chemical information (e.g. status of living organisms), which is not feasible using traditional communication [14]. Molecules encoded with information to be transmitted, are called information molecules. The information molecules activate bio-chemical reaction at receiver and may recreate phenomena and/or chemical status, which sender then transmits [9][14] Molecular communication (MC) is considered the most promising nano networking mechanism due to its nano-sized transceivers that can easily integrate into nano machine [2][15].

Molecular Communication Architecture
Molecular communication architecture consists of information molecules that contain information to be transmitted, sender bio-nano machines that send information molecules, and receiver bio-nano machines that receive information molecules. Other types of molecules might be included in the system such as transport molecules which move information molecules, guide molecules which guides the movement of transport molecules, interface molecules for selective transport of information molecules [17].MC communication architecture is presented in the figure below. Different phases of molecular communication are described below [2][17]:

- **Encoding** in this phase sender nano machine encodes the information into the information molecules in various forms.
- **Sending:** In this phase sender bio nano machine releases information molecules in the environment.
- **Propagation:** It is the phase in which molecules travel from sender nano machine towards receiver nano machine. This transport can be either passive or active. Passive transport is the through diffusion of molecules in the environment without chemical energy, where as in active transport information molecules bind to molecular motors.
- **Receiving:** Transmitted molecules are received from the aqueous medium in this phase usually with the help of chemical receptors [38].
- **Decoding:** In this phase the captured molecules are decoded by receiver nano-machines into the form of chemical energy.

Conclusion

Molecular Communication is a novel communication paradigm which uses molecules for information transmission. Unlike traditional communication MC is capable to transmit information over short distances [22]. As MC is inspired from the communication among living cells and other biological materials it provides a number of biomedical and environmental applications. Nano Communication inside human body can poses a number of health applications e.g., targeted drug delivery, tissue engineering, BMI (Brain Machine Interface) and enhanced immune system [22].Interdisciplinary research is needed to develop theoretical and mathematical models for end-to-end communication between bio-nano machines. However authors in [18][24] have done wonderful work to explain layered and TCP like molecular communication.

References

[1] Nanotechnology. (n.d.).*Collins English Dictionary-Complete & Unabridged 10th Edition*.Retreived January 04, 2016 from Dictionary.com website http://dictionary.refference.com/browse/nanotechnology

[2] Akyildiz, I., Brunetti, F., & Blázquez, C. (2008). Nanonetworks: A new communication paradigm. *Computer Networks*, *52*(12), 2260-2279. http://dx.doi.org/10.1016/j.comnet.2008.04.001

[3] Minoli, D. (2006). *Nanotechnology applications to telecommunications and networking*. Hoboken, N.J.: Wiley-Interscience.

[4] Akyildiz, I., Jornet, J., & Pierobon, M. (2011). Nanonetworks:A New Frontier in Communications. *Communications Of The ACM*, *54*(11), 84. http://dx.doi.org/10.1145/2018396.2018417.

[5] Lim, H. (2004). Nanotechnology in diagnostics and drug delivery. *Medicinal Chemistry Research*, *13*(6-7), 401-413. http://dx.doi.org/10.1007/s00044-004-0044-4

[6] Liu, G. R., Zhang, G. Y., Dai, K. Y., Wang, Y. Y., Zhong, Z. H., Li, G. Y. and Han, X. (2005) A linearly conforming point interpolation method (LC-PIM) for 2D mechanics problems, *International Journal for Computational Methods* **2**, 645–665.

[7] Jornet, J. & Akyildiz, I. (2012). The Internet of Multimedia Nano-Things. *Nano Communication Networks*, *3*(4), 242-251. http://dx.doi.org/10.1016/j.nancom.2012.10.001

[8] Moritani, Y., Hiyama, S., & Suda, T. (2006, May). Molecular communication among nanomachines using vesicles. In *Proceedings of NSTI nanotechnology conference*

[9] Moritani, Y., Hiyama, S., & Suda, T. (2006, March). Molecular communication for health care applications. In *Pervasive computing and communications workshops, 2006. PerCom Workshops 2006. Fourth Annual IEEE International Conference on* (pp. 5-pp). IEEE

[10] Yager, P., Edwards, T., Fu, E., Helton, K., Nelson, K., Tam, M., & Weigl, B. (2006). Microfluidic diagnostic technologies for global public health. *Nature*, *442*(7101), 412-418. http://dx.doi.org/10.1038/nature05064

[11] Dittrich, P. & Manz, A. (2006). Lab-on-a-chip: microfluidics in drug discovery. *Nature Reviews Drug Discovery*, *5*(3), 210-218. http://dx.doi.org/10.1038/nrd1985

[12] Han, J., Fu, J., & Schoch, R. (2008). Molecular sieving using nanofilters: Past, present and future. *Lab Chip*, *8*(1), 23-33. http://dx.doi.org/10.1039/b714128a.

[13] Akyildiz, I. F., Jornet, J. M., & Pierobon, M. (2010, April). Propagation models for nanocommunication networks. In *Antennas and Propagation (EuCAP), 2010 Proceedings of the Fourth European Conference on* (pp. 1-5). IEEE.

[14] Hiyama, S. & Moritani, Y. (2010). Molecular communication: Harnessing biochemical materials to engineer biomimetic communication systems. *Nano Communication Networks*, *1*(1), 20-30. http://dx.doi.org/10.1016/j.nancom.2010.04.003

[15] Akyildiz, I. & Jornet, J. (2010). The Internet of nano-things. *IEEE Wireless Commun.*, *17*(6), 58-63. http://dx.doi.org/10.1109/mwc.2010.5675779

[16] Loscri, V., Marchal, C., Mitton, N., Fortino, G., & Vasilakos, A. (2014). Security and Privacy in Molecular Communication and Networking: Opportunities and Challenges. *IEEE Transactions On Nanobioscience*, *13*(3), 198-207. http://dx.doi.org/10.1109/tnb.2014.2349111

[17] Nakano, T., Moore, M., Fang Wei, Vasilakos, A., & Jianwei Shuai,. (2012). Molecular Communication and Networking: Opportunities and Challenges. *IEEE Transactions On Nanobioscience*, *11*(2), 135-148. http://dx.doi.org/10.1109/tnb.2012.2191570

[18] Davis, S. (2000). Giant Vesicles. *Journal Of Controlled Release*, *68*(1), 135-136. http://dx.doi.org/10.1016/s0168-3659(00)00254-6

[19] Jesorka, A. & Orwar, O. (2008). Liposomes: Technologies and Analytical Applications. *Annual Review Of Analytical Chemistry*, *1*(1), 801-832. http://dx.doi.org/10.1146/annurev.anchem.1.031207.112747

[20] Walsh, F., Balasubramaniam, S., Botvich, D., Suda, T., Nakano, T., Bush, S. F., & Foghlú, M. Ó. (2008). Hybrid DNA and enzyme based computing for address encoding, link switching and error correction in molecular communication. In *Nano-Net* (pp. 28-38). Springer Berlin Heidelberg.
[21] Nakano, T., Suda, T., Okaie, Y., Moore, M., & Vasilakos, A. (2014). Molecular Communication Among Biological Nanomachines: A Layered Architecture and Research Issues. *IEEE Transactions On Nanobioscience*, *13*(3), 169-197. http://dx.doi.org/10.1109/tnb.2014.2316674
[22] Freitas, R. A. (1999). *Nanomedicine, volume I: basic capabilities* (pp. 17-8). Georgetown, TX: Landes Bioscience.'
[23] Ladd, A., Gang, H., Zhu, J., & Weitz, D. (1995). Time-Dependent Collective Diffusion of Colloidal Particles. *Phys. Rev. Lett.*, *74*(2), 318-321. http://dx.doi.org/10.1103/physrevlett.74.318
[24] ShahMohammadian, H., Messier, G., & Magierowski, S. (2012). Optimum receiver for molecule shift keying modulation in diffusion-based molecular communication channels. *Nano Communication Networks*, *3*(3), 183-195. http://dx.doi.org/10.1016/j.nancom.2012.09.006.
[25] Felicetti, L., Femminella, M., Reali, G., Nakano, T., & Vasilakos, A. (2014). TCP-Like Molecular Communications. *IEEE J. Select. Areas Commun.*, *32*(12), 2354-2367. http://dx.doi.org/10.1109/jsac.2014.2367653
[26] Malak, D. & Akan, O. (2012). Molecular communication nanonetworks inside human body. *Nano Communication Networks*, *3*(1), 19-35. http://dx.doi.org/10.1016/j.nancom.2011.10.002
[27] Felicetti, L., Femminella, M., Reali, G., & Liò, P. (2016). Applications of molecular communications to medicine: A survey. *Nano Communication Networks*, *7*, 27-45. http://dx.doi.org/10.1016/j.nancom.2015.08.004.
[28] Dressler, F. & Kargl, F. (2012). Towards security in nano-communication: Challenges and opportunities. *Nano Communication Networks*, *3*(3), 151-160. http://dx.doi.org/10.1016/j.nancom.2012.08.00
[29] Dressler, F. & Fischer, S. (2015). Connecting in-body nano communication with body area networks: Challenges and opportunities of the Internet of Nano Things. *Nano Communication Networks*, *6*(2), 29-38. http://dx.doi.org/10.1016/j.nancom.2015.01.006
[30] Dressler, F., & Kargl, F. (2012, June). Security in nano communication: Challenges and open research issues. In *Communications (ICC), 2012 IEEE International Conference on* (pp. 6183-6187). IEEE.
[31] L u, P., & Wu, Z. (2016). Continuous Molecular Communication in one dimensional situation. *arXiv preprint arXiv:1603.03495*.
[32] Neri, I., Travasso, F., Vocca, H., & Gammaitoni, L. (2011). Nonlinear noise harvesters for nanosensors. *Nano Communication Networks*, *2*(4), 230-234. http://dx.doi.org/10.1016/j.nancom.2011.09.001.
[33] Chou, C. (2013). Noise properties of linear molecular communication networks. *Nano Communication Networks*, *4*(3), 87-97. http://dx.doi.org/10.1016/j.nancom.2013.06.001.
[34] Jabbari, A. & Balasingham, I. (2013). Noise characterization in a stochastic neural communication network. *Nano Communication Networks*, *4*(2), 65-72. http://dx.doi.org/10.1016/j.nancom.2013.04.002.
[35] Gul, E., Atakan, B., & Akan, O. (2010). NanoNS: A nanoscale network simulator framework for molecular communications. *Nano Communication Networks*, *1*(2), 138-156. http://dx.doi.org/10.1016/j.nancom.2010.08.003.
[36] Llatser, I., Demiray, D., Cabellos-Aparicio, A., Altilar, D., & Alarcón, E. (2014). N3Sim: Simulation framework for diffusion-based molecular communication nanonetworks. *Simulation Modelling Practice And Theory*, *42*, 210-222. http://dx.doi.org/10.1016/j.simpat.2013.11.004.
[37] Chahibi, Y., Akyildiz, I., Balasubramaniam, S., & Koucheryavy, Y. (2015). Molecular Communication Modeling of Antibody-Mediated Drug Delivery Systems. *IEEE Transactions On Biomedical Engineering*, *62*(7), 1683-1695. http://dx.doi.org/10.1109/tbme.2015.2400631.
[38] Chou, C. (2015). Impact of Receiver Reaction Mechanisms on the Performance of Molecular Communication Networks. *IEEE Transactions On Nanotechnology*, *14*(2), 304-317. http://dx.doi.org/10.1109/tnano.2015.2393866.