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Review article

Molecular communication via microtubules and physical contact in nanonetworks: A survey

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A R T I C L E I N F O

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A B S T R A C T

Advancements in nanotechnology have promised the building of nanomachines capable of carrying out simple tasks. Final goals of using these nanomachines in applications such as monitoring body tissues, drug delivery or other complicated applications need them to do complex tasks. A feasible way to have them cooperate and do complex tasks is to interconnect them by building a nanonetwork. As nanomachines can only carry out simple tasks, nanonetworks bring up new issues in networking and communication. There have been many papers addressing solutions for communication challenges in nanonetworks and analysing their characteristics. At this stage, going towards higher goals needs a comprehensive look at the literature and state of the art in the field. In this paper, we present an inclusive look at issues introduced and analysed in nanonetworks. We focus on two methods which provide properties needed in nanonetworks efficiently, namely communication via microtubules and physical contact.

Contents

1. Introduction

The concept of manipulating materials at the molecular level was first pointed out in Richard Feynman's speech

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"There Is Plenty of Room at the Bottom" in 1959. Since then, there have been huge advancements in the field and now it is recognized as nanotechnology. Recent achievements in nanotechnology promise our ability to build functional units capable of performing simple tasks at the molecular level. At this scale, we call these units nanomachines.

Interconnection of nanomachines constitutes nanonetworks. Nanonetworks provide a means for cooperation and information sharing among nanomachines, allowing them to fulfil more complex tasks. Considering the size of nanomachines, nanonetworks could carry out complex tasks in different applications like: biomedical applications (immune system support, bio-hybrid implants, drug delivery systems, health monitoring, and genetic engineering), industrial and consumer goods applications (food and water quality control), military applications (nuclear, biological, and chemical defence, nano-functionalized equipments), and environmental applications (biodegradation, air pollution control) [1].

In order to make the cooperation between nanomachines happen, they need to communicate. Communication in a nanonetwork can be categorized with respect to the type of nodes participating in it as follows:

- Communication between nanomachines and larger systems such as electronic micro-devices.
- Communication between two or more nanomachines.

In this paper, we focus on communication between two or more nanomachines.

In classical wireless communication networks, electromagnetic waves in megahertz frequency bands are used to transmit data from a transmitter to the receiver. To establish a wireless communication with classical approaches in nanonetworks, the nanomachines should be integrated with radio frequency transceivers and nanoscale antennas. However, due to the size and complexity of the transceivers, they still cannot be easily integrated into nanomachines. In addition, if it were possible, enough power output of the transceiver would be another issue [1].

There are four major communication approaches proposed to be used in nanonetworks: terahertz electromagnetic communication, quantum communication, communication with fluorescence resonance energy transfer, and molecular communication. In terahertz electromagnetic communication, electromagnetic waves in terahertz frequency bands are used to transmit data. Using these frequency bands makes it possible to build efficient transceivers in molecular scales. Carbon nanotubes are one of the top candidate materials to be used in the transceivers, because they exhibit unique electrical and quantum properties which result in an efficient performance in terms of power consumption, robustness, etc. [2]. Quantum communication is the process of transferring quantum states from a transmitter to the receiver. The most common method to do so is quantum teleportation. Quantum teleportation is the process of sending quantum states using entangled (entanglement occurs when particles interact physically and then become separated) qubits (the basic unit of quantum information) [3]. Fluorescence resonance energy transfer is the process of energy transfer between two chromophores. This energy transfer is carried out through a dipole–dipole coupling. Communication with fluorescence resonance energy transfer uses this energy transfer to transmit data [21]. Molecular communication is the bio-inspired solution. There are already many molecular scale machines in nature, such as cells, communicating with each other. Inspired by them, molecular communication is defined as the process in which information is encoded in molecules. Transceivers are nanomachines which are capable of releasing specific types of molecules as a response to an external or internal command, or reacting appropriately upon receiving different types of molecules [1]. In this paper, we consider this bio-inspired method.

There are three types of molecular communications: free diffusion, communication via microtubules (microtubules are cylindrical polymers in the cytoskeleton, providing a platform for cargo transfer and other cellular processes), and communication via physical contact. Free diffusion is a type of molecular communication in which a transmitter releases information molecules to diffuse through the medium freely and reach the receiver. In communication via microtubules, a transmitter releases information molecules which will bind to specific molecules known as molecular motors. Molecular motors can attach to microtubules, and move along them, while carrying information molecules, to reach the receiver. For communicating via physical contact, transmitter and receiver should have a physical contact via gap junctions (gap junction is an intercellular connection) or synapses. In this type of communication, a transmitter releases information molecules which diffuse through gap junctions or synapses and reach the receiver.

Among the three types of molecular communication, free diffusion has attracted more attention [22,20,24], since communication via microtubules and physical contact are not as easy to implement as free diffusion. However, there are some drawbacks with the free diffusion. Since there is almost no control over a particle diffusing through a medium, routing is complex in this scheme of communication. However, a transmitter can control where an information molecule is heading to by picking appropriate microtubule, or controlling permeability of gap junctions. Also, for the same reason, single receiver communication is not an option in free diffusion. But it can be carried out in communication via microtubules or physical contact. Moreover, as we will see later, free diffusion will lead to low information rates. So, although implementation of nanonetworks with nodes communicating via microtubules or physical contact may not be as easy as using free diffusion, the advantages these techniques have over free diffusion would be worth it, and lead to more efficient networks in terms of routing, information rate, etc.

There have been some papers which have reported different works in the field. Akyildiz et al. [1] define the architecture of a nanonetwork. They discuss a high level engineering of a system, introduce applications for it and propose different possible communication techniques, without going into the details. Nakano et al. [31] focus on molecular communication. They present the state of the