Appeared in Encyclopedia, 2007

Molecular Communication: New Paradigm for Communication among Nanoscale Biological Machines

Michael Moore, Akihiro Enomoto, Tatsuya Suda, Tadashi Nakano, and Yutaka Okaie

INTRODUCTION

Biological nanomachines (or "nanomachines," for short) are nanoscale and microscale devices that either exist in the biological world or are artificially created from biological materials (i.e., molecules) and that perform simple functions such as sensing, logic, and actuation. Molecular communication is a new paradigm for communication between nanomachines over a short (nanoscale or microscale) range. It is the process of communication between nanomachines through encoding information onto molecules, rather than electrons or electromagnetic waves, and exchanging the molecules between nanomachines (Hiyama, Moritani, and Suda 2006). Using electrons or electromagnetic waves for communication is particularly limited at the nanoscale and microscale range because of power constraints and limitations in the size of communication components. Because nanomachines are too small and simple to communicate using electrons or electromagnetic waves, molecular communication provides a novel mechanism for nanomachines to communicate by propagating molecules that represent the information.

In biological systems, a nanomachine (such as a cell or a protein complex) is a basic building block of organisms, and nanomachines use various forms of molecular communication to transmit information to other nanomachines. For instance, cells communicate by Ca2ions through protein channels, or transferring DNA instructions. Some nanomachines in biological systems also have the ability to self-replicate (through, for instance, biological cell reproduction) and to self-assemble into organisms that coordinate through molecular communication. The nanomachines communicate with hormones to activate and synchronize the activity of replication and nanomachine organization. Existing research on artificially creating (or engineering) molecular communication is based on understanding the design of molecular communication in biological systems and on modifying the functionality of existing molecular communication in biological systems. Creating molecular communication, thus, represents an interdisciplinary research area that spans the areas of biology, nanotechnology, and computer science.

This chapter is organized in the following manner. The remainder of this section describes possible applications of molecular communication, the key components and phases of molecular communication, and key characteristics of molecular communication. Then we describe molecular communication that occurs in biological systems. We go on to discuss existing research in engineering molecular communication and to describe existing research to engineer a molecular communication network—that is, a system of communicating nanomachines.

Applications

Molecular communication integrates techniques from biology to interact with biological systems, from nanotechnology to perform nanoscale and microscale interactions, and from computer science to integrate into larger-scale information and communication processing.
Molecular communication has signifi cant potential, since it interacts directly with biological systems at nanoscales and microscales and may enable new applications through integrated nanomachines.

Molecular communication may impact how nanomachines interact with biological systems (Montemagno 2001). For instance, a biological system (e.g., the human body) is composed of a large number of cells (i.e., nanomachines). Each cell performs simple and specific operations such as uptake, processing, and release of molecules. Cells interact to perform various functions of the body (e.g., distributing molecules for metabolism and replication of cells). Molecular communication provides mechanisms to transport molecules between cells, and thus, it may help perform targeted delivery of drugs by providing mechanisms to transport drugs (informationencoded molecules) between drug repositories embedded in a human body (sender nanomachines) and specific cells in a human body (receiver nanomachines). Molecular communication also provides mechanisms for nanomachines to communicate, and thus, it may help drug repositories (sender nanomachines) to coordinate and control the amount and timing of drug release. Targeting delivery of drugs to specifi c cells in a human body and creating molecular communication for such applications involve understanding how molecules are transported within a biological system, how molecules are addressed to specific locations within a biological system (i.e., molecule-addressing mechanisms in a biological system), or even adding receptor molecules to a biological system to produce an addressing mechanism (Langer 2001; Peppas and Huang 2004; Allen and Cullis 2004). Molecular communication may eventually provide a mechanism to interact with the human body at the molecular level (Moritani, Hiyami, and Suda 2006, Molecular communication for health care applications).

END of the translation sample