Biochemically-Engineered Molecular Communication Interface and Propagation System

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ABSTRACT
The authors of this paper have proposed the concept of "molecular communication". The molecular communication uses molecules (i.e., chemical signals) as an information medium and allows biological and artificially-created nano- or cell-scale devices to communicate over a short distance. It is a new and biologically inspired communication paradigm and is different from the existing communication paradigm that uses electromagnetic waves (i.e., electronic and optical signals) as an information medium. This paper focuses on designs of a molecular communication interface and a molecular propagation system and their preliminary experiments to show the feasibilities.

Keywords
Molecular communication, Biochemical engineering, Molecular communication interface, Molecular propagation system

1. INTRODUCTION
Molecular communication uses molecules (i.e., chemical signals) as an information medium and allows biological and artificially-created nano- or cell-scale devices to communicate over a short distance [1, 2]. It is a new and biologically inspired communication paradigm based on the biochemical reactions caused by received molecules. Molecular communication aims to transmit biochemical information such as phenomena and status of living organisms that is not feasible to transmit with the existing communication that uses electromagnetic waves (i.e., electronic and optical signals) as an information medium.

In molecular communication, a molecular sender encodes information onto molecules (called information molecules) and emits the information molecules to the molecular propagation environment. The emitted information molecules then directionally propagate to a molecular receiver. The molecular receiver, upon receiving the information molecules, decodes the information and reacts biochemically to the received information molecules. Molecular communication artificially creates a controllable communication system using biological materials (e.g., proteins and DNAs) and biological signal transduction systems (e.g., inter- and intra-cellular communication).

Key research challenges in molecular communication include 1) design of a molecular sender that generates molecules, encodes information onto the generated molecules (information molecules), and emits the information molecules, 2) design of a molecular propagation system that directionally transports the emitted information molecules from a molecular sender to a molecular receiver, 3) design of a molecular receiver that receives the transported information molecules, decodes the information encoded onto the received information molecules, and biochemically reacts to the received information molecules, 4) design of a molecular communication interface between a molecular sender and a molecular propagation system and also between a molecular propagation system and a molecular receiver to allow a generic transport of information molecules independent of the biochemical/physical characteristics, and 5) mathematical modeling and simulation of molecular communication components and systems.

This paper focuses on designs of a molecular communication interface and a molecular propagation system and their preliminary experiments to show the feasibilities.

2. MOLECULAR COMMUNICATION INTERFACE
The molecular communication interface proposed by the authors of this paper uses a liposome with gap junction proteins [3, 4]. A liposome acts as a container of information molecules. Information molecules propagate through gap junctions from a molecular sender to a liposome (at a molecular sender) and also from a liposome to a molecular receiver (at a molecular receiver). The proposed liposome-based molecular communication interface provides a mechanism to transport different types of information molecules in diverse propagation environments. This is because the liposome structure provides a generic architecture that compartmentalizes and transports diverse types of information molecules independent of their biochemical/physical characteristics. The liposome structure also protects information molecules from denaturation in the propagation environment.

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In order to investigate the feasibility of the designed molecular communication interface, the authors of this paper created connexin-43 (one of the gap junction proteins) embedded liposomes. Microscopic observations confirmed that calceins (hydrophilic dyes used as model information molecules) were transferred between connexin-43 embedded liposomes and the transferred calceins were encapsulated into the liposomes. This result indicates that the created connexin-43 embedded liposome (a molecular communication interface) may encapsulate information molecules and receive/transfer information molecules from/into a molecular sender/receiver through gap junctions.

3. MOLECULAR PROPAGATION SYSTEM

The molecular propagation system proposed by the authors of this paper is based on a novel scheme of selectively delivering cargo-beads (acting as liposomes encapsulating information molecules) to a designated molecular receiver using DNA labeled microtubules (acting as cargo transporters) gliding on motor protein-coated surfaces [5, 6, 7]. The loading (at a molecular sender) and unloading (at a molecular receiver) of cargo-beads are realized through the DNA hybridization and strand exchange among single-stranded DNAs (ssDNAs) attached to microtubules (MTs), cargo-beads, and unloading sites at molecular receivers.

In order to investigate the feasibility of the designed molecular propagation system, the authors labeled MTs with ssDNAs using a chemical linkage that cross-links thiolated ssDNAs and amino groups of MTs, while maintaining smooth gliding of labeled MTs on motor proteins (kinesins). Microscopic observations confirmed that 23-base ssDNAs labeled cargo-beads were selectively loaded onto gliding MTs labeled with complementary 15-base ssDNAs. Microscopic observations also confirmed that loaded cargo-beads were selectively unloaded from the gliding MTs at a micro-patterned unloading site where complementary 23-base ssDNAs were immobilized. These results indicate that gliding MTs may load/unload cargo-liposomes at a molecular sender/receiver through the DNA hybridization/strand exchange.

4. CONCLUSION

This paper discussed system designs of a molecular communication interface that uses a liposome embedded with gap junction proteins and a molecular propagation system that uses MT motility on kinesins and DNA hybridization/strand exchange. The feasibilities of the designed system components were confirmed through the biochemical experiments.

5. ACKNOWLEDGMENTS

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