A Communication Interface Using Vesicles Embedded with Channel Forming Proteins in Molecular Communication

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ABSTRACT
This paper describes design and empirically study of a communication interface in molecular communication. The communication interface hides the characteristics of the molecules during the propagation from the sender to a receiver to allow a generic transport of molecules independent of the characteristics. The authors of this paper propose a communication interface that uses a vesicle embedded with channel forming proteins. The channel forming proteins embedded with the vesicle form communication channels between the vesicle itself and a sender/receiver. The proposed molecular communication interface uses vesicle to hide the characteristics of the molecules and the communication channels to encapsulate/decapsulate the molecules into/from the vesicle. The vesicle receives the molecules from the sender through the communication channels formed between the vesicle itself and the sender. The molecules are encapsulated in the vesicle, and their characteristics are hidden by the vesicle structure during the propagation to a receiver. At the receiver, the molecules are transferred into the receiver through the communication channels formed between the vesicle itself and the receiver. The authors of this paper constructed the vesicles embedded with channel forming proteins and the molecules were successfully encapsulated into the vesicle. It was also demonstrated that molecules were transferred through the communication channels.

Keywords
Molecular Communication, Molecular Communication Interface, Vesicle, Channel Forming Proteins

1. INTRODUCTION
Molecular communication uses molecules as an information medium and allows biological and artificially-created nano- or cell-scale entities (e.g., cells) to communicate over a short distance [1]. Molecular communication is inspired by the biological communication mechanisms (e.g., cell-cell communication using hormones [2]) and artificially creates a controllable communication system using molecules as an information medium. It is a new communication paradigm and is different from the existing communication paradigm that uses electromagnetic waves as an information medium. Key research challenges in molecular communication include 1) design of a sender that generates and emits molecules, 2) design of a molecular propagation system that transports the emitted molecules from a sender to a receiver, 3) design of a receiver that receives the transported molecules and biochemically reacts to the received molecules, 4) design of a communication interface between a sender and a propagation system and also between a propagation system and a receiver to allow a generic transport of molecules independent of their characteristics. This paper focuses on a molecular communication interface that uses a vesicle to hide the characteristics of the molecules from a molecular propagation system.

In living cells such as eukaryotic cells, vesicles that encapsulate molecules are transported between endoplasmic reticulum (ER) and Golgi apparatus [2]. In this intra-cellular communication, the vesicles are used as molecular containers to hide the characteristics of the transported molecules. Thus, the authors of this paper believe that it is suitable to use vesicles for a molecular communication interface to hide the characteristics of the transported molecules.

In the intra-cellular communication described above, the molecules in ER are encapsulated into the vesicle with the fission of the vesicle from the ER. At the Golgi apparatus, the molecules are decapsulated from the vesicle with the fusion of the vesicle into the Golgi apparatus. For the fission of the vesicle, it is necessary to control the localization of lots of proteins such as coat proteins [3]. The authors of this paper believe that it is not suitable to apply this mechanism for encapsulating the molecules into the vesicle at a sender because it is difficult to control the localization of the specific molecules in the molecular communication environment.

This paper describes design and empirically study of a molecular communication interface that uses a vesicle embedded with channel forming proteins. The vesicle encapsulates molecules to hide the characteristics of the molecules from a molecular propagation system and receives/transfers the molecules from/into a sender/receiver through communication channels formed between the vesicle itself and a sender/receiver. The empirical

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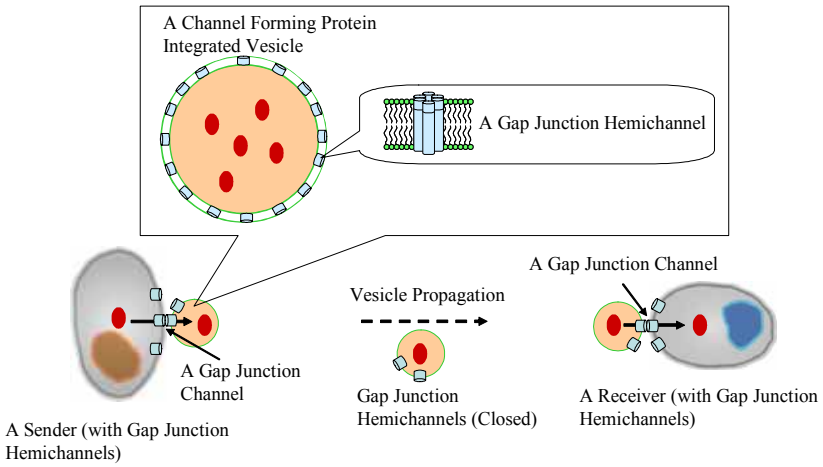

Figure 1: A schematic diagram of a molecular communication interface

investigation shows that vesicles embedded with channel forming protein integrated vesicle can encapsulate molecules and receive/transfer the molecules from/into a sender/receiver.

2. SYSTEM DESIGN

The molecular communication interface described in this paper hides the characteristics of transported molecules during the propagation through encapsulating the molecules in the vesicles. The vesicle receives the molecules from a sender and transfers the molecules to a receiver through a gap junction channel formed between the vesicle itself and the sender/receiver (See Figure 1). A gap junction is an inter-cellular communication channel formed between neighboring two cells, and it consists of two docked hemichannels (connexons) constructed from self-assembled six gap junction proteins (connexins) [4]. Molecules whose molecular masses are less than 1.8kDa can directly propagate through a gap junction channel connecting two cells according to the molecular concentration gradient. In addition, the gap junction hemichannel is closed unless two hemichannels are docked.

A sender generates molecules for molecular communication and stores the generated molecules inside itself. A sender has gap junction hemichannels. When a vesicle with gap junction hemichannels physically contacts the sender, gap junction channels are formed between the sender and the vesicle, and the molecules are transferred from the sender to the vesicle according to the molecular concentration gradient. When the vesicle detaches from the sender, the gap junction hemichannels at the sender and at the vesicle close, and the molecules transferred from the sender to the vesicle are encapsulated into the vesicle. A molecular propagation system transports the vesicle from the sender to a receiver independent of the characteristics of the molecules encapsulated in the vesicle. In addition, the molecules encapsulated in the vesicles are protected from denaturization caused by the noise in the propagation environment during the propagation from the sender to a receiver. A receiver also has gap junction hemichannels, and when the vesicle from the sender physically contacts the receiver, a gap junction channel is formed between the vesicle and the receiver, and the molecules in the vesicle are transferred into the receiver according to the molecular concentration gradient.

3. RESULTS

In order to construct a molecular communication system using the molecular communication interface shown in Figure 1, the authors of this paper successfully created connexin-43 reconstituted liposomes. Connexin-43 is one of the gap junction forming proteins and liposome is a phospholipid vesicle. The reconstitution of connexin-43 into liposomes was observed through a confocal microscopy by using Green Fluorescence Protein (GFP)-tagged connexin-43.

It was also observed through a confocal microscopy that molecules were transferred between a vesicle and a sender/receiver and the transferred molecules were encapsulated into the vesicles. In this experiment, calcein (a hydrophilic dye) were used as the transferred molecule and connexin-43 reconstituted Texas Red-labeled liposome was used as a sender (or a receiver). The transfer of calcein from connexin-43 reconstituted Texas Red-labeled liposomes (senders) to connexin-43 reconstituted liposomes (vesicles) and from connexin-43 reconstituted liposomes (vesicles) to connexin-43 reconstituted Texas Red-labeled liposomes (receivers) were observed. The transferred calcein were encapsulated in the connexin-43 reconstituted liposomes (vesicles). In addition, the transfer of calcein from the connexin-43 reconstituted liposomes (vesicles) to the cells with connexin-43 (receivers) was observed. These results indicate that the created connexin-43 reconstituted liposome (a vesicle) can receive/transfer molecules from/into a sender/receiver.

4. CONCLUSIONS

This paper describes a design and the initial empirical results of a molecular communication interface that uses vesicles embedded with channel forming proteins. The authors of this paper are currently examining how molecules are transferred from the cells with connexin-43 (senders) to the connexin-43 reconstituted liposomes (vesicles). In addition, the authors of this paper are

currently investigating how the molecular communication interface described in this paper work with other components of molecular communication (such as a molecular propagation system [5] and a receiver [6]).

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