Mobility and Controllability of Bio-nanomachines

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ABSTRACT

Externally controllable molecular communication is expected
to expand the capability of molecular communication by al-
lowing conventional devices placed in the external environ-
ment to control the location and timing of molecular commu-
nication processes taking place in the molecular communica-
tion environment. In this paper, we consider externally con-
trollable mobile bionanosensor networks where an external
device is used to control the mobility of bio-nanomachines.
We first describe a simple model to describe the mobility
of bio-nanomachines. We then show how mutual informa-
tion can be used to evaluate the controllability of mobile
bio-nanomachines.

Keywords

Molecular communication, mobile bio-nanomachine, exter-
nal control

1. INTRODUCTION

This paper applies the concept of externally controllable
molecular communication [6] to design externally control-
lable mobile bionanosensor networks. A bionanosensor net-
work considered in this paper consists of a group of mobile
bio-nanomachines that communicate molecularly in the en-
vironment [8, 9, 7] and an external device that controls the
mobility of bio-nanomachines. Promising application areas
of such networks include interactive drug delivery systems
where human physicians use external control to direct drug-
carrying bio-nanomachines to target locations in the body
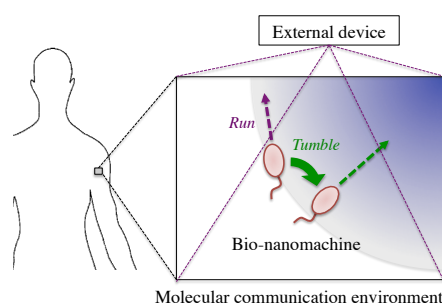[2, 3].

**Figure 1: Interaction between an external device
and a bio-nanomachine**

Fig. 1 shows an overview of externally controllable mobile
bionanosensor networks where the interaction between an
external device and a bio-nanomachine is highlighted. An
external device is a micro or larger scale conventional device
(e.g., implantable and ingestible medical devices [4]) and it
releases a type of attractant molecule to form a concentra-
tion gradient in the environment. A bio-nanomachine is a
micro-scale device composed of biomaterials and exists in
the molecular communication environment (e.g., in the hu-
man body). A bio-nanomachine has a chemotactic ability to
detect the attractant concentration gradient and changes its
moving direction based on the gradient. In the following, we
first describe a simple stochastic model to describe the mo-
bility of bio-nanomachines (Section 2). We then show how
information theory may apply to evaluate the controllability
of mobile bio-nanomachines (Section 3).

2. MOBILITY MODEL

We assume that an external device chooses a single point
in a two-dimensional environment where a group of bio-
nanomachines exist, releases a type of attractant molecule
from the single point, and forms a concentration gradient in
the environment. We also assume that each bio-nanomachine
moves in a two-dimensional environment based on the mo-
bility model of a chemotactic bacterium [1]. Briefly, each

bio-nanomachine has two mobility modes: *run* and *tumble* modes. A bio-nanomachine in the run mode keeps its moving direction while a bio-nanomachine in the tumble mode changes its moving direction. A bio-nanomachine tends to move based on the run mode when moving up the attractant concentration gradient, otherwise it tends to move based on the tumble mode.

For a given bio-nanomachine in the environment, let X be the direction of the incoming signal, representing the direction toward the point where the external device releases a type of attractant molecule (i.e., the direction of the maximum attractant concentration gradient at the location of the bio-nanomachine). For simplicity in the following, we assume that the direction X follows $\mathcal{U}(-\pi, \pi)$. We further assume that the direction of the incoming signal X is subject to noise in the environment; as a result, the bio-nanomachine receives the direction Θ that may follow Gaussian distribution $\mathcal{N}(x, \sigma)$ wrapped over a range $[x - \pi, x + \pi]$ where σ represents noise effect.

Depending on the received signal θ, a bio-nanomachine sets its mobility mode to either the run or tumble mode probabilistically based on the chemotactic index [5]. The bio-nanomachine then updates its moving direction Y; in the run mode, the bio-nanomachine retains its moving direction Y, and in the tumble mode it changes the moving direction Y by $2\pi/81$ radian per second in either a clockwise or counter clockwise direction [1].

3. PRELIMINARY RESULTS

We use mutual information between X and Y to evaluate the controllability of mobile bio-nanomachines. Mutual information between X and Y dictates the distinct number of directions that the external device can choose to which bio-nanomachines are directed. In numerical experiments, we use the model described in the previous section, determine Y after sufficiently long time elapses for a given X, and compute mutual information between X and Y.

Fig. 2 shows the distribution of the moving direction Y of a bio-nanomachine when the direction of the incoming signal X is 0 with noise effect σ varied in $\{0.1, 0.5, 1.0\}$. As shown in the figure, more bio-nanomachines are directed toward the direction X as σ decreases. Fig. 3 shows the impact of noise on mutual information between X and Y. When $\sigma = 0.1$, the mutual information is 1.79, meaning that $2^{1.79} \simeq 3.46$ distinct number of directions can be correctly communicated with the bio-nanomachine. As σ increases, the mutual information decreases to around 0.09, showing how controllability decreases as the noise effect increases.

how information theory may apply to analyze the performance of bacterium-based bio-nanomachines.

ACKNOWLEDGMENTS

4. REFERENCES

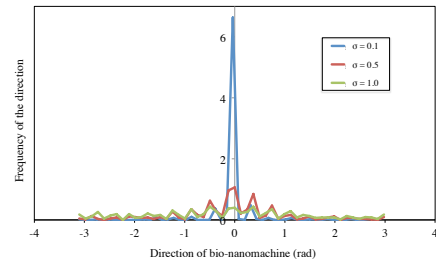[1] H. C. Berg and D. A. Brown. Chemotaxis in escherichia coli analysed by three-dimensional
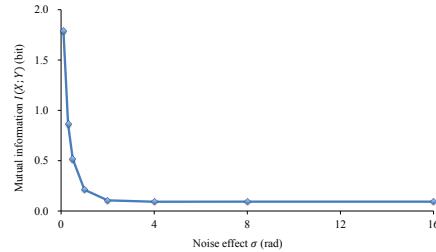
Figure 2: Impact of noise on moving directions

Figure 3: Impact of noise on mutual information

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