Receiver Design Considerations in Concentration-Encoded Molecular Communication Based on Sampling Rate Selection

Mohammad Upal Mahfuz
University of Wisconsin-Green Bay
2420 Nicolet Drive, Green Bay,
Wisconsin, 54311, USA
+1 (920) 465-2790
mahfuzm@uwgb.edu

ABSTRACT

In this position paper, the roles of sampling rate, i.e. alternatively, sampling time, have been investigated in the receiver design of a concentration-encoded molecular communication (CEMC) system. While several signal detection algorithms so far in CEMC are based on uniform sampling of concentration intensity at the RN, this paper presents four new sampling rate selection schemes based on both uniform and nonuniform sampling rates at the RN, which would potentially be useful in designing computationally-efficient CEMC receiver. This paper has mainly focused on reducing the total number of samples that the RN needs to sense and/or process in order to reduce the computational burden of the receiver.

Categories and Subject Descriptors

H.1.1 [**Systems and Information Theory**]: Information theory

General Terms

Theory

Keywords

Molecular communication, sampling rate, sampling time, concentration-encoding, receiver design, nanonetworks.

1. INTRODUCTION

Molecular communication (MC) is a new communication paradigm to realize communication among tiny machines known as nanomachines [1, 2]. In concentration-encoded molecular communication (CEMC), the number of transmitted *information molecules* is varied in order to send symbols 1 and 0 [3]. After a transmitting nanomachine (TN) releases information molecules in the propagation medium, the information molecules propagate through the medium (a.k.a. channel) and become available at the receiving nanomachine (RN). The RN senses the channel by sampling it at predefined temporal instants, measures the concentration of available molecules, applies detection signal processing algorithms, and finally decides on the transmitted symbol. In CEMC, examples of TN and RN are natural and/or engineered biological cells that can send and receive information molecules [2]. Information molecules are different from the solvent molecules in the propagation medium, i.e. water, air, blood plasma media.

In CEMC, signal detection becomes challenging partly because, first, the information molecules are of a *single* type that makes it difficult to differentiate between molecules originating from a desired symbol and the residual molecules causing intersymbol interference (ISI), and second, nanomachines are in general extremely limited in terms of their functional capabilities, which makes it sometimes unclear to understand whether conventional optimum signal detection algorithms would be able to satisfy the design constraints of an RN. Therefore, a computationally-efficient receiver structure at the RN is always desired.

Our previous works presented optimum signal detection algorithms of sampling-based detection (SD) [4] and strength (i.e. energy)-based detection (ED) [5] approaches for CEMC. Both SD and ED, algorithms detect the transmitted signal by processing the measured concentration intensity samples taken *uniformly* over the entire symbol duration T_{sym}. The previous works [4, 5] also provided optimum receiver structures for SD and ED approaches based on uniform temporal sampling rate. However, computational burden may sometimes be a challenging issue in implementing signal detectors in a CEMC receiver given the fact that biological nanomachines are in general extremely limited in their functionalities. As a result, computationally-efficient receiver structure is desired. This paper addresses the issue of receiver complexity from the viewpoint of temporal sampling rate selection and presents the possibilities of uniform and nonuniform temporal sampling rates for computationally-efficient receiver design in CEMC.

The rest of this paper is organized as follows: Section 2 presents a quick overview of our prior work that provided optimum SD and ED receiver structures based on uniform temporal sampling rate in CEMC. Finally, section 3 discusses how computationally-efficient receiver structures might be developed based on the observation that uniform and nonuniform sampling rates might contribute to reducing computational load of the RN.

2. CEMC SIGNAL DETECTION

In SD, the RN samples the concentration intensity at uniform, i.e. regular, temporal intervals and considers each of the sensed concentration samples as a random variable. This allows the receiver to collect N independent samples at each symbol duration. The RN then applies these N samples to signal processing block and derives the optimum receiver structure [4]. In ED, the RN senses the concentration intensity at uniform temporal intervals and computes the total number of information molecules sensed during the entire T_{sym} and processes that in signal processing block to derive the optimum receiver [5].

3. DISCUSSION: RECEIVER DESIGN

Figure 1 shows the concentration intensity at time instant t, denoted as $U(r,t)$ at the RN located at a distance r from the TN. The TN

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transmits a signal $Q(t)$ where transmitted bits 1 and 0 are represented by sending 10000 and 5000 molecules respectively and the sampling interval $t_s = 5\ s$. If t_s at the RN were equal to τ_{step}, i.e. the time taken by an individual molecule to make one single step, the available concentration of molecules $U(r,t)$ would have been the continuous time function as found by the solutions to Fick's laws [6]. In practical sense, $\tau_{step} < t_s < T_{sym}$ and, therefore, temporal sampling rate plays a significant role in the performance of the CEMC system and the design of the RN. In order to have uncorrelated and statistically independent concentration samples, it is necessary to have a sampling time greater than the waiting time of a molecule [5], which emphasizes that t_s should be reasonably greater than τ_{step}. Regardless of whether sampling is performed uniformly or nonuniformly, a reduced number of samples would generally result in a computationally-efficient receiver design in CEMC. In the following, based on both uniform and nonuniform sampling rates, four receiver design schemes have been proposed for CEMC, which could be considered useful in providing computational efficiency of the RN.

3.1 Uniform Sampling

3.1.1 *Truncated Signals*

As seen from Fig. 1, at longer temporal instants, the concentration of diffused molecules drops significantly, which allows for a truncated channel impulse response signal beyond a certain temporal instant t_{Tr} such that the RN won't be sampling the concentration beyond t_{Tr}. It is up to the CEMC system designer to choose an appropriate t_{Tr} to meet design goals. Not having to sample the channel beyond t_{Tr} would yield a reduced number of samples in each symbol, which would provide less computational load on the RN.

3.1.2 *Multiple Uniform Sampling Rates*

In this scheme, the RN first samples the concentration intensity at a uniform rate for some time, preferably up to the time t_p when the concentration reaches its peak, and then it reduces the sampling rate to a lower rate in one or more steps and continues to sample at this rate until the end of T_{sym}. Reducing the sampling rate to one or more lower uniform rates yields a lower number of samples that the RN handles for the detection circuit compared to pure uniform sampling rate, which reduces the computational load of the RN.

3.2 Nonuniform Sampling

The idea of nonuniform temporal sampling in CEMC should be considered important because of the following two reasons.

First, noting that in diffusion-based CEMC the peak concentration of molecules occurs at the time instant $t_p = r^2/6D$ where D is the diffusion coefficient of information molecules in the propagation medium, using uniform sampling only the RN might miss the peak concentration intensity at time t_p. Since MC is a low rate communication system, it is found that for most cases $t_p \ll T_{sym}$ and thus applying uniform sampling yields a large number of samples at the later part of the symbol compared to the earlier part of the symbol. For example, when transmission data rate is 0.01 bps, $T_{sym} = 100\ s$, with $D = 10^{-6}\ cm^2/s$, for $r = 800\ nm, 10\ \mu m,$ and $100\ \mu m$, the peak of concentration occurs at $t_p = 1\ ms, 166\ ms,$ and $16.67\ s$ respectively. Therefore, starting at $t = 0$, uniform sampling with interval $t_s = 1\ s$ would miss the peak concentration in the first two cases.

Second, as seen from Fig. 1, in the later part of each symbol, the RN samples uniformly almost the same level of concentration each time, where the concentration does not vary remarkably. This may provide opportunities not to sample uniformly in the later part of each symbol but to consider a reduced number of samples in order to reduce the computational load of the RN as shown in the two schemes below.

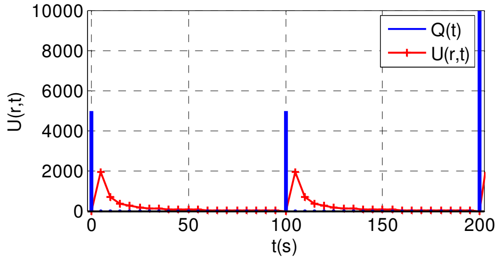

Fig. 1. Uniform temporal sampling in CEMC

3.2.1 *Pure nonuniform sampling*

In the pure nonuniform sampling, the sampling intervals are not fixed, rather based on other parameters of the system, e.g. the TN-RN distance *r*. When *r* is known to the RN, it can choose when to sample at higher or lower rate than the uniform sampling rate.

3.2.2 *Truncated Signals*

In this scheme, the RN truncates the signal beyond t_{Tr} where the appropriate t_{Tr} is chosen by the system designer. Truncated signal yields a reduced number of samples that the RN handles and so reduces the computational load of the RN.

Existing research in the field of MC aims at improving the performance of an MC system while at the same time providing an efficient design of the receiver. Sampling rate is an important factor that not only affects the molecular signal as sensed by the receiver but also impacts the design complexity of the receiver. Our on-going research is focusing on sampling rate selection with the goal to offer computationally-efficient design for CEMC receivers.

4. REFERENCES

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