Detection of Incoherent Signal In Molecular Communication Based on Channel Impulse Response

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Abstract. In order to solve the problem of intercode interference (ISI) and background noise caused by molecular diffusion in molecular communication, Honda analyzed and studied four methods to resist ISI signal, and analyzed the characteristics of the received signal at the moment. A reliable incoherent molecular signal detection algorithm independent of channel impulse response (CIR) is proposed, and an adaptive threshold calculation method is designed, and the theoretical value of bit error rate (BER) is given. The simulation results show that the proposed scheme BER is lower than the traditional scheme BER under the same computational complexity, so it has a wide application prospect in the nanoscale molecular communication system with limited computing power.

1. System model

1.1. MCVD system model

Figure 1 shows a typical MCVD system, combining a nano-transmitter, a nano-receiver, and the diffusion channel between them. When communication begins, TX encodes the original information into the MCVD system. The molecular information is released into the diffusion channel, and the information molecules diffuse in the medium in the form of Brownian motion. Finally, the Rx section recreates the original information according to the time-varying concentration of the information.[1-4]
MCVD systems generally take the following assumptions.

1) Communication takes place in an infinite three-dimensional fluid environment, and the collision between information molecules can be ignored.

2) The synchronization between TX and RX is perfectly realized by blind synchronization method.

3) The distance between Tx and Rx is large enough compared with the size of Tx, so Tx can be regarded as a point, which is conducive to mathematical modeling of the channel in this paper.

4) Assume that Rx is a nanoreceiver of radius R.

1.2. MCVD channel impulse response model

MCVD has a variety of CIR models depending on the channel environment.

From the perspective of RX, it can be divided into two categories: passive receiving model and active receiving model.

1) Passive reception model

In this case, the acceptor does not affect the motion of the molecule, and the acceptor can leave the radius of RX. Assuming that the molecule is emitted from Tx at the time t = 0, the average concentration of molecules in Rx at t BBB 0 can be derived as

\[
h(t) = \frac{4}{3} \frac{\pi r^3}{(4\pi Dt)^{\frac{3}{2}}} \exp\left(-\frac{(d-vt)^2}{4Dt} - \lambda t\right)
\]  

(1)

Where, D is the distance between Tx and Rx, D is the diffusion coefficient related to temperature and medium viscosity, V is the liquid flow rate in the channel (such as the blood flow rate in the blood vessel), and is the reaction attenuation index (information molecules are catalyzed by enzymes to react with other molecules and thus the number of information molecules decreases).[5-7]

2) Active receiving model

Compared with the passive receiving model, in the active receiving model, Rx is an active absorber with a large number of receptors on its surface. Once the information molecules reach RX, they will bind to the receptor and be removed from the environment, becoming a part of the received signal recognized by Rx. In this case, CIR is exported as

\[
h(t) = \frac{r}{r+d} \frac{d}{4\pi Dt^{\frac{3}{2}}} \exp\left(-\frac{(d-vt)^2}{4Dt} - \lambda t\right)
\]  

(2)

The relationship between molecular concentration and time after normalization in the above channel model is shown in Fig. 2. It should be noted that the passive receiving model and the active receiving model in Fig. 2 specifically refer to the velocity v=0 and the response attenuation exponent in the above equation respectively \(\lambda = 0\), the velocity model is \(v \neq 0\) and \(\lambda = 0\). By enzyme catalysis, enzyme catalysis model reaction rate attenuation caused by that \(\lambda \neq 0\) and v=0. In the case. As can be seen from Fig. 2, although the channel parameters and modes are different, the waveform shape of each signal is similar, following the long tail effect that increases first and then decreases. This commonality enables a new feature extraction method to demodulate and detect the received signal.
Feature extraction

In B-CSK, the essence of binary signal detection is to determine whether the current transmitted signal is 1 or 0. According to the relationship between molecular concentration and time in the molecular channel in Figure 2, this section will give four features based on the transient characteristics of molecular signals: rising edge feature, falling feature, molecular energy feature and energy difference feature. Fig. 3 shows four characteristics in the $a_k = 0$ and $a_k = 1$ in the case of the diagram.
Fig. 3 Features in $a_k = 0$ and $a_k = 1$ in the case of the diagram
3. Incoherent signal detection scheme

The conventional incoherent demodulation based on electromagnetic wave communication is different in concept from the incoherent detection for MC VD proposed in this paper. The former is a demodulation method which does not need to extract carrier information. In MCVD, the information is transmitted by molecular diffusion and there is no concept of carrier modulation. Therefore, the conventional incoherent demodulation method is not suitable for MCVD scenarios.

It should be emphasized that the incoherent signal detection of MCVD refers to the detection scheme that does not need to estimate the molecular CIR. Corresponding to this is the molecular coherence detection scheme which relies on CIR estimation. The incoherent molecular signal detection algorithm designed in this paper aims to eliminate ISI and realize signal detection through the above four features that are insensitive to CIR, so as to avoid complex channel estimation and a posterior probability calculation and meet the resource-constrained scenarios of nanoscale molecular communication.[8-10]

4. Numerical results

In this section, experiments are carried out on the features mentioned in this paper and the feature-based non-coherent detection algorithm. The experimental parameters are as follows. The molecular concentration signal is generated by a Brownian motion model based on Monte Carlo simulation. Where, diffusion coefficient $D = 5 \times 10^{-9} \text{m}^2 / \text{s}$, the distance between the molecular nano transmitter and the molecular nano receiver $d = 2 \times 10^{-6} \text{m}$. In this paper, detection errors caused by ISI and noise are mainly considered and solved, while BER introduced by insufficient number of receiving molecules is ignored. In order to ensure that the receiver receives sufficient number of molecules when sending signal 1, the number of molecules released when sending signal 1 is set as $Q = 10^5$. Nano receiver, receiver radius $r = 0.225 \times 10^{-6} \text{m}$. With no loss of regularity, the ratio of sampling rate and transmission interval $M = 30$ is maintained.

Comparison of BER of coherence detection algorithm in the same computational complexity. Here, different ISI intensities are represented by the change of the transmission interval $T$, that is, with the increase of the transmission interval, the influence between signals gradually becomes weak and the ISI gradually decreases. As can be seen from Fig. 4, under different transmission intervals, the four-feature noncoherent detection algorithm proposed in this paper has a lower BER. Compared with the coherent MAP sequential detection algorithm, the advantages of the four-feature non-coherent detection algorithm proposed in this paper come from the extraction of four features that are independent of the specific CIR expression. These features can reflect the characteristics of molecular signals even in the presence of ISI. Therefore, the four-feature incoherent detection algorithm proposed in this paper can still achieve reliable communication performance without the need of channel estimation. As can be seen from Figure 4, compared with the three-feature incoherent detection algorithm, the four-feature incoherent detection algorithm proposed in this paper has a better effect under strong ISI. This is because in the case of strong ISI, the characteristics of rising edge and molecular energy quantum characteristics considered in this paper can still keep roughly the same shape as those in the case of low intensity ISI, and they are more insensitive to CIR. Therefore, the four-feature incoherent detection algorithm based on these sub-features can still effectively distinguish different binary messages in the strong ISI region, and has a more accurate signal detection performance.
Fig. 4 Comparison of bit error rates of different algorithms under different ISI intensities

5. Conclusion
In complex MCVD scenarios, how to counter challenges such as ISI and channel noise caused by molecular diffusion and accurately and reliably detect the information loaded by molecular signals is of great significance to scientific research and engineering practice. In addition, the limited resources of nanoscale MCVD devices make it difficult to implement coherent signal detection schemes that rely on accurate channel estimation and probability analysis. However, the existing incoherent detection algorithms cannot provide reliable detection performance of molecular signals. To solve these problems, an incoherent signal detection algorithm which does not rely on channel estimation is proposed to fill the gap. Based on the transient characteristics of the received signal, four CIR-independent signal characteristics are presented. These characteristics can offset the ISI caused by molecular diffusion characteristics without estimating the CIR. On this basis, this paper designs an adaptive threshold calculation method, which provides the possibility for the realization of real-time signal detection.

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